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**DUCT INJECTION TECHNOLOGY PROTOTYPE DEVELOPMENT
Scale-Up Methodology and Engineering Design Criteria
Topical Report No. 4**

April 1991

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**For
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Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania**

**By
United Engineers & Constructors Inc.
Englewood, Colorado**

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PROTOTYPE DEVELOPMENT

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SCALE-UP METHODOLOGY AND
ENGINEERING DESIGN CRITERIA

TOPICAL REPORT NO. 4

April 1991

Prepared For

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SUMMARY

One of the final work products to be developed under the Department of Energy's Duct Injection Technology Development Program is a design handbook that will provide the practical process, equipment, and economic information required to evaluate, design, and retrofit a full-scale duct injection system. As one step leading to the publication of the design handbook, United Engineers & Constructors Inc. (UE&C) has developed scale-up methodology and engineering design criteria relevant to duct injection technology. This Topical Report No. 4 presents UE&C's preliminary scale-up methodology and design criteria for a full-scale duct injection system retrofit.

The scale-up methodology and engineering design criteria are divided into five major areas:

- ° Design criteria
- ° Engineering drawings
- ° Equipment sizing and design requirements
- ° Plant and equipment arrangement considerations
- ° Equipment bid specifications

The design criteria section provides the information necessary to determine the primary process design of the system. Formulas, curves, and other information are included to enable the user to predict required calcium to sulfur ratio, sorbent utilization, humidification water requirements, duct residence time, quantities of waste produced, etc.

The engineering drawings presented in this report include process flow diagrams (PFDs) for dry sorbent injection (DSI) with either off-site or on-site hydration of the hydrated lime sorbent and for duct spray drying (USD). Each PFD shows the major process streams and contains a blank table listing all of the streams and their characteristics (flow rate, temperature, pressure, etc.) for completion by the user. Also presented in this section are detailed piping and instrumentation diagrams (P&IDs) for both DSI and USD. Equipment lists accompany these drawings.

The equipment sizing and design section provides detailed, specific design requirements for the major equipment shown on the PFDs and P&IDs. This section also provides a step-by-step method for designing each subsystem in the process. Mechanical design criteria are presented which allow the user to determine sorbent storage requirements, compressed air requirements, tank capacities, etc. The requirements in this section give the user sufficient information to size the equipment and fill out detailed specification data sheets for equipment bidding.

The section treating plant and equipment arrangements provides general considerations regarding equipment configurations such as real estate requirements and equipment layout. Specific retrofit considerations such as conveying distance limitations, utility interfaces, and multi-unit considerations are also provided in this section. In addition, several special cases such as two electrostatic precipitators in series are discussed.

Finally, pro forma bid specifications have been completed for all of the major equipment associated with a DSI or DSD system with the exception of specifications for the sorbent injectors (DSI only) and spray nozzles. These specifications have not been included in an appendix to this report because of their bulk. They will be included in the design handbook. The final section of this report gives guidelines to the user regarding the use of these specifications.

INTRODUCTION

The objective of the Duct Injection Technology Prototype Development project is to develop a sound design basis for applying duct injection technology as a post-combustion SO₂ emissions control method to existing, pre-NSPS, coal-fired power plants. The project is being executed by United Engineers & Constructors Inc. (UE&C) for the U.S. Department of Energy - Pittsburgh Energy Technology Center (DOE-PETC). UE&C will develop the necessary engineering design and scale-up criteria for the commercialization of duct injection technology for the control of SO₂ emissions from coal-fired boilers in the utility industry.

Task 2 of the UE&C project is dedicated to the development of engineering design criteria. Under Task 2, Subtask 2.3 involves the development of scale-up methodology and engineering design criteria. This Topical Report No. 4 presents UE&C's preliminary scale-up methodology and design criteria for a duct injection system retrofit.

In the UE&C Work Plan, Subtask 2.3 was broken into five major areas. Topical Report No. 4 is similarly divided as follows:

<u>Task</u>	<u>Topical Report No. 4 Section No.</u>
Design Criteria	3.0
Engineering Drawings	5.0
Equipment Sizing and Design	6.0
Plant and Equipment Arrangement	7.0
Considerations	
Equipment Bid Specification Guidelines	10.0

Each of the five sections in this topical report will become a section of the final design handbook. To facilitate the transition of these sections from this report into the design handbook, the text contained herein has been given section and subsection numbers which correspond to those in the table of contents for the design handbook. For example, Section 3.0 of this topical report, Design Criteria, will be Section 3.0 in the design handbook. Five sections in this topical report, Sections 1.0, 2.0, 4.0, 8.0, and 9.0, do not contain any text and are not used; they are marked accordingly in the Table of Contents and in each section itself.

1.0 NOT USED

2.0 NOT USED

3.0 DESIGN CRITERIA

3.1 Specific Plant Information

Table 3-1 lists the plant design and operating data required for the conceptual design of a retrofit duct injection system. The following sections will guide the user in obtaining these data. The subsections in this Section 3.1 are numbered in the same order as the items are listed in Table 3-1. For instance, the text which suggests how the fly ash/bottom ash split may be obtained (Item 8 in Table 3-1) is given in Section 3.1.8. Some data will simply come from design manuals and operating logs, while other values must be calculated or obtained from field tests or measurements. The abbreviations for each item given in Table 3-1 will be used in the equations presented throughout this section.

TABLE 3-1

DATA REQUIREMENTS FOR THE CONCEPTUAL DESIGN
OF A RETROFIT DUCT INJECTION SYSTEM

<u>ITEM</u>	<u>DESCRIPTION</u>	<u>ABBREV.</u>	<u>UNITS</u>
1	Flue Gas Velocity	Vg	Ft/S
2	Flue Gas Volumetric Flow Rate	Qg	ACFM
3	Flue Gas Mass Flow Rate	Mg	Lbs/hr
4	Flue Gas Temperature	Tg	°F
5	Flue Gas Saturation Temperature (Wet Bulb)	Twb	°F
6	Coal Firing Rate	MCoal	Lbs/hr
7	Coal Ash Content	%Ash	%
8	Fly Ash/Bottom Ash Split	N/A	Ratio
9	Fly Ash Mass Loading	Mfa	Lbs/hr
10	Coal Sulfur Content	%S	%
11	SO ₂ Mass Flow Rate	MSO ₂	Lbs/hr
12	Reagent Purity	Pur	%
13	Desired SO ₂ Removal Efficiency	N/A	%
14	Particulate Emissions Limit	N/A	Lbs/hr
15	Existing ESP SCA	SCA	Ft ² /KACFM
16	Existing ESP Face Velocity	Vesp	Ft/S
17	ESP Design Type (WW or RDE)	N/A	N/A
18	Longest Straight Run of Ductwork Between APH & ESP	LSR	Ft
19	Dimensions of LSR	WxH	FtxFt
20	Residence Time in LSR	REZ	Sec
21	Ash Removal System Type	N/A	N/A
22	Ash Removal System Capacity (Actual)	ARC	Tons/hr
23	Ash Storage Capacity	ASC	Ft ³ or Tons
24	Stack or Chimney Liner Type	N/A	N/A

As values are determined for each of the above items, the user should enter the values on Form 3-1, which is located at the end of this Section 3.1. This form should be photocopied and used as a worksheet.

3.1.1-3 Flue Gas Velocity, Volumetric Flow Rate, and Mass Flow Rate (Vg, Qg, Mg)

The flue gas flow rate exiting the air preheater must be determined. This should include all in-leakage across the air preheater. If possible, this gas flow should be measured using EPA Reference Methods 1 through 4 or similar procedures. These EPA Reference Methods 1 through 4 are located in 40 CFR Part 60, Appendix A. For the user's convenience, they have been included in Appendix B of this design handbook.

It is not advisable to use design flow rates (such as from original boiler specs) or dated test results since these data may not be representative of the actual current operating conditions. Boiler performance or particulate collector efficiency test data normally include flue gas flow rate measurements, and these results can be used provided they are recent (less than two years old) and the boiler operating conditions were representative. Full load test data are necessary for design purposes, but it is advisable to have gas flow measurements across a range of boiler operating conditions (boiler load, excess air, etc.). Minimum boiler load conditions, typically yield the low end of the flue gas flow rate range, and these data are important to consider for atomizer placement, as well as solids and droplet settling tendencies.

The user should consider the condition of the unit when making measurements or reviewing historical data. Many plant/operating modifications can potentially affect flue gas flow rate. Among the most significant are fuel quality, combustion modifications, burner management, excess air, and air preheater in-leakage (conditions of seals).

EPA Method 1 should be used to determine traverse points for pitot tube measurements in the ductwork downstream of the air preheater. EPA Method 2 or equivalent should be used to determine flue gas velocity and volumetric flowrate. EPA Methods 3 and 4 should be used to determine flue gas molecular weight and moisture content, respectively. From these data, the mass flow rate (Mg) can be calculated:

$$M_g \text{ (lbs/hr)} = Q_g \text{ (ACFM)} \times \frac{P_g}{T_g} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{\text{MWW}}{10.73} \quad (3-1)$$

Where: P_g = Flue gas pressure (psia)
 T_g = Flue gas temperature ($^{\circ}\text{R}$ which is $^{\circ}\text{F} + 460$)
MWW = Molecular weight of wet flue gas (lb/lb mole)

After the maximum flue gas flow rate has been determined, the user may wish to add an additional safety margin, but no more than 10% is advised.

3.1.4 Flue Gas Temperature (Tg)

The flue gas temperature downstream of the air preheater must be determined. Temperature measurements are made as part of the EPA Method 2 velocity determination test procedure. These measurements will provide a flue gas temperature profile across the duct at the measurement point(s). The average flue gas temperature can then be calculated from the traverse data.

3.1.5 Flue Gas Saturation Temperature (Twb)

Typically, a duct injection process is controlled so that the treated flue gas is cooled to a certain temperature above the saturation or wet bulb temperature of the gas. This difference between operating temperature and saturation temperature is called the "approach" temperature, i.e., it indicates how close the operation approaches the saturation temperature. In order to determine the approach temperature, it is necessary to measure the flue gas saturation temperature (Twb). The most common method to measure saturation temperature is with a wet bulb thermocouple. The measurement should be made in the flue gas ductwork between the air preheater and the particulate collector, at a representative full load condition. A simultaneous dry bulb temperature measurement should be made at the same location.

3.1.6 Coal Firing Rate (MCoal)

If no fuel change is planned, nor any major operational changes that would affect the plant heat rate, the coal firing rate can be obtained from representative full load historical operating data. If a coal change is planned, the firing rate must be estimated based on heating value, volatiles, combustion characteristics, etc.

3.1.7 Coal Ash Content (%ASH)

Coal ash content data can be found in the as-received proximate analyses. If the records indicate a range, the user should select the high side of the range. If a coal change is planned, it is advisable to add a margin of safety to the ash content indicated in the proximate analysis of the prospective coal.

3.1.8 Fly Ash/Bottom Ash Split (Fly ash fraction)

Of the total ash in the coal fired in a boiler, a portion forms slag and heavy bottom ash, and the remaining portion is carried with the flue gas as fly ash. The ratio of fly ash to bottom ash varies with boiler type, operation, and, to some extent, fuel quality. The fly ash fraction is used to calculate fly ash mass

loading. These data can typically be found in plant records. If these data cannot be found, 80% fly ash/20% bottom ash can be used for PC boilers.

3.1.9 Fly Ash Mass Loading (Mfa)

Fly ash mass loading is measured upstream of the particulate collector during particulate collector efficiency tests. EPA Reference Method 5 or 17 (reference Appendix B, EPA Reference Methods) is typically used. If these data are dated or unavailable, it is advisable to conduct new tests or calculate the value as follows

$$Mfa \text{ (lbs/hr)} = M_{\text{Coal}} \times (\% \text{Ash}/100) \times \text{Fly ash fraction} \quad (3-2)$$

3.1.10 Coal Sulfur Content (%S)

This value is found in the as-received coal proximate analyses. As with fly ash, it is advisable to use the high end of the range found in the representative coal analysis records. In the case of a coal switch, an additional margin of safety should be added to the prospective coal sulfur content for the design value.

3.1.11 SO₂ Mass Flow Rate (MSO₂)

For the purpose of this design effort, all fuel sulfur will be assumed to form SO₂. In part for simplicity, but more for design conservatism, SO₃ and pyritic sulfur will be included in the SO₂ value. Therefore, SO₂ mass flow rate (lbs/hr) can be calculated as follows:

$$MSO_2 = M_{\text{Coal}} \times (\%S/100) \times \frac{2 \text{ lbs SO}_2}{1 \text{ lb S}} \quad (3-3)$$

3.1.12 Reagent Purity (Pur)

This information is found in the chemical and physical data sheets from the reagent supplier. All quicklime (CaO) and hydrated lime [Ca(OH)₂] contain a certain amount of grits and impurities.

3.1.13 Desired SO₂ Removal Efficiency

This value must be determined in order to proceed with the design effort. If a specified stack SO₂ emission rate is desired, it is advisable to base the required removal efficiency on the design, untreated SO₂ mass flow rate determined in Eq. 3-3 (Section 3.1.11).

3.1.14 Particulate Emissions Limit

The particulate emissions limit is ultimately set by the regulatory agency with jurisdiction. In most cases, this is set on a lbs of

particulate per MMBTU basis. For duct injection design purposes, it will be necessary to convert this to lbs/hr at maximum load. The user should take into consideration any pending regulatory changes which could subject a given unit to more restrictive emission limits. Also, the user should determine if increases in emissions above current emission levels, but below the compliance limit, are acceptable. In some cases, increases over a proven emission rate have been considered violations.

3.1.15 Existing ESP SCA (SCA)

The specific collection area of an ESP is an indicator of ESP size. SCA is measured as collection surface (ft²) per 1,000 ACFM of flue gas flow rate. It is, therefore, a function of flue gas flow rate. In many cases, the actual SCA will be significantly different from the original design SCA as specified by the ESP manufacturer. The ESP Design Manual should list the total collection area (ft²). If there have been modifications to the ESP which altered the original collection area, these must be included. The SCA can be calculated by:

$$SCA = \text{Total Collection Area (ft}^2\text{)} / (Q_g / 1,000) \quad (3-4)$$

3.1.16 Existing ESP Face Velocity (Vesp)

The same considerations affecting SCA pertain to ESP face velocity. The ESP Design Manual lists the total cross - sectional area available for gas flow (ft²). To determine actual ESP face velocity:

$$V_{esp} \text{ (ft/s)} = \frac{Q_g}{\text{Total gas flow area (ft}^2\text{)}} \times \frac{1 \text{ min}}{60 \text{ sec}} \quad (3-5)$$

3.1.17 ESP Design Type

The user should indicate if the ESP is of weighted wire (WW) design or rigid discharge electrode (RDE) design. This information is found in the ESP Design Manual.

3.1.18 Longest Straight Run of Ductwork Between Air Preheater and ESP (LSR)

The user needs to determine the length (ft) of the longest straight run of flue gas ductwork between the air preheater and ESP. This will be the most likely location for duct injection and humidification. This length may be found from plant drawings or actual measurements.

3.1.19 Dimensions of LSR (WxH)

From plant drawing or actual measurements, the user will need to

determine the inside dimensions of the LSR: Width (ft) x Height (ft).

3.1.20 Residence Time in LSR (REZ)

The residence time of the flue gas within the LSR is critical to the duct injection processes. The water or slurry droplets which are sprayed into the duct need adequate time to dry before impacting duct walls or downstream bends, etc. The residence time, in seconds, is calculated as follows:

$$\text{REZ} = \text{LSR (ft)} \times (\text{W} \times \text{H}) / \text{Qg} \times \frac{60 \text{ sec}}{\text{min}} \quad (3-6)$$

3.1.21 Ash Removal System Type

Indicate type of ash removal system: vacuum pneumatic, pressure pneumatic, mechanical, sluice, or other.

3.1.22 Ash Removal Capacity (ARC)

Indicate capacity of existing fly ash removal system. Actual test data should be used if available. It is recommended that tests be conducted to determine the maximum rate achievable, because design capacities (such as from original specs or design manuals) are usually not achievable.

3.1.23 Ash Storage Capacity (ASC)

Indicate the capacity of the existing fly ash storage silo(s). Please provide both storage area (ft²) and maximum load rating (tons).

3.1.24 Stack of Chimney Liner Type

Indicate existing stack of chimney liner material: steel, concrete, acid resistant brick, FRP, or other.

FORM 3-1
DUCT INJECTION DATA REQUIREMENTS
WORKSHEET

1. Flue Gas Velocity (Full Load)	Vg	_____ Ft/S
2. Flue Gas Volume Flow (Full Load)	Qg	_____ ACFM
3. Flue Gas Mass Flow (Full Load)	Mg	_____ Lbs/hr
4. Flue Gas Temp (Full Load)	Tg	_____ °F
5. Saturation Temp (Wet Bulb)	Twb	_____ °F
6. Coal Firing Rate (Full Load)	MCoal	_____ Lbs/hr
7. Coal Ash Content (Design)	%Ash	_____ %
8. Fly Ash/Bottom Ash Split	N/A	_____ Ratio
9. Fly Ash Mass Loading (Full Load)	Mfa	_____ Lbs/hr
10. Coal Sulfur (Design)	%S	_____ %
11. SO ₂ Mass Flow Rate	MSO ₂	_____ Lbs/hr
12. Reagent, Purity	Pur	_____ %
13. Desired SO ₂ Removal		
Efficiency (Max)	N/A	_____ %
14. Particulate Emissions Limit	N/A	_____ Lbs/hr
15. Existing ESP SCA	SCA	_____ Ft ² / KACFM
16. Existing ESP Face Velocity	Vesp	_____ Ft/S
17. ESP Design Type (WW or RDE)	N/A	_____ N/A
18. Longest Straight Run of		
Ductwork Between APH & ESP	LSR	_____ Ft
19. Dimensions of LSR	WxH	_____ FtxFt
20. Residence Time in LSR	REZ	_____ Sec
21. Ash Removal System Type	N/A	_____ N/A
22. Ash Removal System Capacity		
(Actual)	ARC	_____ Tons/ hr
23. Ash Storage Capacity	ASC	_____ Ft ³ or Tons
24. Stack or Chimney Liner Type	N/A	_____ N/A

3.2 Process Design Criteria

In order to determine reagent requirements, the size and design of duct injection process equipment, and the required modifications to existing plant equipment, it is necessary to perform some process material balance calculations. Sections 3.2.1 and 3.2.2 provide material balance calculation guidelines for the DSI and DSD processes, respectively. If the user has selected a duct injection process, then it should proceed to the appropriate section. It may be necessary to run through both cases in order to select the best process.

There are several critical duct injection process streams for which flow rates must be determined. For many parameters, design values will vary from the operating values to ensure that the duct injection process is conservatively sized and designed to operate at full load conditions and to be capable of being turned down over the full range of operating conditions.

Results from these calculations will also provide the necessary information to assess the impact of duct injection on existing major plant equipment. Section 3.2.3 describes the criteria used to determine the modifications and/or upgrades required for existing plant equipment. The major plant equipment discussed in Section 3.2.3 includes the ductwork downstream of sorbent injection, the particulate collection device, and the waste handling system equipment.

3.2.1 Dry Sorbent Injection

The major DSI process stream flow rates to be determined are:

1. Humidification water flow requirements
2. Atomizer air flow requirements
3. Fresh sorbent requirements
4. Hydration water requirements
5. Fresh sorbent conveying air requirements
6. Recycle material requirements
7. Recycle material conveying air requirements
8. Solid waste handling, storage, and disposal requirements

The following sections will guide the user in determining flow rates for each of these streams.

Form 3-2, which is located at the end of this Section 3.2.1, is a simplified DSI Process Flow Diagram with the major process streams indicated. This form should be photocopied and used as a worksheet.

3.2.1.1 Humidification Water Flow Requirements

Among the most critical factors to be determined is the approach to

saturation temperature at which the duct injection process should be operated. SO₂ removal and calcium utilization increase with decreasing approach to saturation; however, so does the potential for operational problems such as wall wetting and solids deposition. For design purposes, it is recommended that equipment (pumps, etc.) be sized to allow operation at a 20°F approach even though it may not be practical to operate at this low approach temperature. The humidification water requirements can be calculated as follows:

$$\text{Humidification H}_2\text{O (lbs/hr)} = \frac{M_g \times C_p \times (T_g - T_d)}{H_{\text{vap}}} \quad (3-5)$$

Where: C_p = Specific heat of flue gas (BTU/lb-°F)
 T_g = Flue gas temperature downstream of air preheater (°F)
 T_d = Flue gas temperature downstream of duct injection (°F)
 = T_{wb} + target approach to saturation temperature
 H_{vap} = Heat of vaporization (Btu/lb)

For design purposes, the user can use a C_p value of 0.25 Btu/lb-°F which is appropriate for typical flue gas compositions and temperatures. A value of 1048 Btu/lb can be used for the heat of vaporization and is based on 80°F water from the steam tables.

3.2.1.2 Atomizer Air Flow Requirements

The air flow requirements for atomizing the humidification water in the spray nozzles will vary considerably among the available commercial atomizers. The air-to-liquid ratio required to generate the droplet size distribution necessary for adequate evaporation must be obtained from the nozzle supplier. A conservative estimate for preliminary design purposes is 0.5 lbs air/lb H₂O. Required air pressure at the atomizer also varies depending on the atomizer chosen, but it usually varies from 60 psig to 125 psig. These data are necessary to properly size and design air compressors and compressed air piping systems.

3.2.1.3 Fresh Sorbent Requirements

In DSI, hydrated lime [Ca(OH)₂] is the sorbent utilized. The first step in determining fresh sorbent (reagent) requirements is to estimate the necessary calcium to sulfur molar ratio (Ca/S) to achieve the desired SO₂ removal efficiency determined in Section 3.1.13. Figure 3-1 is a nomograph of SO₂ removal as a function of calcium to sulfur ratio for DSI. Curves are shown for four approach to saturation temperatures which may be selected. Since it is possible that operation at a 20°F approach to saturation may not be practical at many plants, it is advisable to size equipment based on calcium requirements at the 30°F or 40°F approach temperature curves.

SO₂ Removal vs Ca/S Dry Sorbent Injection (DSI)

Figure 3-1

Correction for Recycle

The use of recycle can reduce fresh sorbent requirements. Figure 3-2 can be used to estimate the percent reduction in the required Ca/S ratio, as a function of recycle ratio (lbs recycle/lbs fresh sorbent). Curves are given for four SO₂ removal rates. For purposes of conservatism, the data in Figure 3-2 are based on a 40°F approach to saturation. The lbs of reagent required to achieve the desired SO₂ removal can now be calculated.

$$\frac{\text{Lbs Ca(OH)}_2}{\text{Hr}} = \text{MSO}_2 \times \text{Ca/S} \times \frac{74}{64} \quad (3-8)$$

If the purity of the hydrated lime reagent is known, the total reagent flow (including impurities) can be calculated by dividing the Ca(OH)₂ flow rate from Eq. 3-8 by the fractional purity.

3.2.1.4 Hydration Water Requirements

If the user is planning to hydrate quicklime on-site, the hydration water flow must be calculated. This is the water necessary for stoichiometric hydration, plus evaporation and other process losses.

$$\frac{\text{Lbs CaO Required}}{\text{Hr}} = \frac{\text{Lbs Ca(OH)}_2}{\text{Hr}} \times \frac{56}{74} \quad (3-9a)$$

If the purity of the quicklime reagent is known, the total reagent flow (including impurities) can be calculated by dividing the CaO flow rate from Eq. 3-9a by the fractional purity.

$$\text{Hydration Water Flow Rate (lbs/hr)} = \text{Lbs CaO/Hr} \times 0.4 \quad (3-9b)$$

3.2.1.5 Fresh Sorbent Conveying Air Requirements

A dilute phase pressure pneumatic conveying system to inject hydrated lime will require about 0.10 lbs of dry conveying air per lb of solids.

3.2.1.6 Recycle Material Requirements

Spent sorbent and fly ash collected in the particulate collection device can be re-injected into the flue gas to reduce fresh reagent requirements. Since the reagent is poorly utilized in duct injection processes, there is a considerable amount of unreacted reagent collected in the particulate collector. In the DSI process, recycle is injected into the duct on a mass ratio based on the fresh reagent injection rate. This ratio can be estimated from Figure 3-2. Data indicate the marginal effectiveness of recycle drops dramatically above recycle ratios of 4:1. For a first cut, a recycle ratio of 2:1 is suggested.

Reduction in Sorbent Requirements with Recycle in DSI

Figure 3-2

Recycle Rate (lbs/hr) = Recycle Ratio x Fresh Reagent Rate (3-10)

3.2.1.7 Recycle Material Conveying Air Requirements

A dilute phase pressure pneumatic conveying system to inject recycle material will require about 0.20 lbs of dry conveying air per lb of solids.

3.2.1.8 Solid Waste Handling, Storage, and Disposal Requirements

The DSI process will cause a drastic increase in solid waste generation over the baseline fly ash only operation. The new waste will consist of fly ash, calcium-sulfur reaction products, unreacted reagent, other calcium compounds (CaCO_3) and reagent inerts. The amounts of each of these components will vary with operation, SO_2 removal, load, etc.

3.2.2 Duct Spray Drying

The major DSD process stream flow rates to be determined are:

1. Humidification water flow requirements
2. Slurry injection requirements
3. Atomizer air flow requirements
4. Fresh sorbent requirements
5. Lime slurry requirements
6. Recycle material requirements
7. Recycle slurry requirements
8. Dilution water requirements
9. Solid waste handling, storage, and disposal requirements

The following sections will guide the user in determining flow rates for each of these streams.

Form 3-3, which is located at the end of this Section 3.2.2, is a simplified DSD Process Flow Diagram with the major process streams indicated. This form should be photocopied and used as a worksheet.

3.2.2.1 Humidification Water Flow Requirements

The humidification water requirements include the combination of three separate water streams:

1. Free Water in the Lime Slurry
2. Water to the Recycle Slurry Tank
3. Dilution Water to the Atomizer Feed Tank

These three streams combine to make up the total free water in the atomizer feed slurry, which evaporates to cool the gas to the desired approach to saturation temperature.

Among the most critical factors to be determined is the approach to saturation temperature at which the duct injection process should be operated. SO_2 removal and calcium utilization increase with decreasing approach to saturation; however, so does the potential for operational problems such as wall wetting and solids deposition. For design purposes, it is recommended that equipment (pumps, etc.) be sized to allow operation at a 20°F approach, even though it may not be practical to operate at this low approach temperature. The humidification water requirements can be calculated as follows:

$$\text{Humidification H}_2\text{O (lbs/hr)} = \frac{M_g \times C_p \times (T_g - T_d)}{H_{\text{vap}}} \quad (3-13)$$

Where: C_p = Specific heat of flue gas (BTU/lb- $^\circ\text{F}$)
 T_g = Flue gas temperature downstream of air preheater ($^\circ\text{F}$)

T_d = Flue gas temperature downstream of duct injection ($^{\circ}\text{F}$)
 $= T_{wb} + \text{target approach to saturation temperature}$
 H_{vap} = Heat of vaporization (Btu/lb)

For design purposes, the user can use a C_p value of 0.25 Btu/lb- $^{\circ}\text{F}$ which is appropriate for typical flue gas compositions and temperatures. A value of 1048 Btu/lb can be used for the heat of vaporization and is based on 80 $^{\circ}\text{F}$ water from the steam tables.

3.2.2.2 Slurry Injection Requirements

In spray drying processes, it is beneficial to operate the atomizer at the highest feasible slurry solids content. The maximum slurry solids content is limited by atomizer design. Dual-fluid atomizers, as used in DSD, may vary widely in maximum slurry solids limits. It is important to obtain this performance data from the atomize manufacturer. With these data, the slurry mass flow rate to the atomizer can be determined.

$$\frac{\text{Lbs Slurry to Atomizer}}{\text{Hr}} = \frac{\text{Lbs Humidification H}_2\text{O}}{\text{Hr}} \times \frac{100}{100 - \% \text{ Max Slurry Solids}} \quad (3-14)$$

The total solids to the atomizer can then be calculated:

$$\frac{\text{Lbs Total Solids to Atomizer}}{\text{Hr}} = \frac{\text{Lbs Slurry to Atomizer}}{\text{Hr}} \times \frac{\text{Humidification H}_2\text{O}}{\text{Hr}} \quad (3-15)$$

3.2.2.3 Atomizer Air Flow Requirements

The air flow requirements for atomizing the slurry in the spray nozzles will vary considerably among the available commercial atomizers. The air-to-liquid ratio required to generate the droplet size distribution necessary for adequate evaporation must be obtained from the nozzle supplier. A conservative estimate for preliminary design purposes is 0.5 lbs air/lb slurry. Required air pressure at the atomizer also varies depending on the atomizer chosen, but it usually varies from 60 psig to 125 psig. These data are necessary to properly size and design air compressors and compressed air piping systems.

3.2.2.4 Fresh Sorbent Requirements

In DSD, quicklime (CaO) is the sorbent utilized. The first step in determining fresh sorbent requirements is to estimate the necessary calcium to sulfur molar ratio (Ca/S) to achieve the desired SO_2 removal efficiency determined in Section 3.1.13. Figure 3-3 is a nomograph of SO_2 removal as a function of calcium to sulfur ratio for DSD. Curves are shown for four approach to saturation temperatures which may be selected. Since it is possible that operation at 20 $^{\circ}\text{F}$ approach to saturation may not be practical at

SO₂ Removal vs Ca/S

Duct Spray Drying (DSD)

Figure 3-3

many plants, it is advisable to size equipment based on calcium requirements at the 30°F or 40°F approach temperature curves. The curves in Figure 3-3 are based on the use of recycle. Recycle operation is considered the baseline configuration for DSD. Using the Ca/S from Figure 3-3, the CaO requirements can be calculated as follows:

$$\frac{\text{Lbs CaO}}{\text{Hr}} = \text{MSO}_2 \times \text{Ca/S} \times \frac{56}{64} \quad (3-16)$$

If the purity of the quicklime reagent is known, the total reagent flow (including impurities) can be calculated by dividing the CaO flow rate from Eq. 3-16 by the fractional purity.

3.2.2.5 Lime Slurry Requirements

Water requirements and resulting lime slurry concentration are a function of slaker type. A ball mill slaker, for example, may produce a lime slurry which contains 25% solids. Paste slakers and detention slakers may produce more dilute slurries. To calculate the slurry mass flow rate out of the slaker, determine the product slurry solids content specified by the slaker manufacturer.

(3-17)

$$\text{Fresh Lime Slurry (lbs/hr)} = \frac{\text{Lbs CaO}}{\text{Hr}} \times \frac{74 \text{ lbs Ca(OH)}_2}{56 \text{ lbs CaO}} \times \frac{100}{\% \text{ Solids in Slurry}}$$

Note that the lime slurry solids are in the form of slaked lime: Ca(OH)₂. The water requirements for slaking can then be calculated:

(3-18)

$$\frac{\text{Lbs H}_2\text{O to Slaker}}{\text{Hr}} = \frac{\text{Lbs Fresh Lime Slurry}}{\text{Hr}} - \frac{\text{Lbs CaO to Slaker}}{\text{Hr}}$$

3.2.2.6 Recycle Material Requirements

To determine the amount of dry solids to be recycled from the particulate collector back to the DSD process, subtract the solids in the lime slurry from the total solids in the slurry to the atomizer (Eq. 3-15):

$$\frac{\text{Lbs Recycle Solids}}{\text{Hr}} = \frac{\text{Lbs Total Solids to Atomizer}}{\text{Hr}} - \quad (3-19)$$

$$\frac{\text{Lbs Fresh CaO}}{\text{Hr}} \times \frac{74 \text{ lbs Ca(OH)}_2}{56 \text{ Lbs CaO}}$$

3.2.2.7 Recycle Slurry Requirements

To determine the water requirements for the recycle slurry, assume 45% recycle solids in the recycle slurry:

$$\frac{\text{Lbs Recycle Slurry H}_2\text{O}}{\text{Hr}} = \frac{\text{Lbs Recycle Solids}}{\text{Hr}} \times \frac{0.55}{0.45} \quad (3-20)$$

3.2.2.8 Dilution Water Requirements

The dilution water stream is used to make up the required water for flue gas humidification when the combined water flow rates in the lime slurry and recycle slurry are insufficient. This can occur during unusual operational conditions (e.g. unusual combinations of approach temperature and Ca/S) or when there are equipment problems with the fresh lime or recycle systems. It is advised to size the dilution water process equipment for the same flow rates as the recycle water equipment.

3.2.2.9 Solid Waste Handling, Storage, and Disposal Requirements

The DSD process will cause a drastic increase in solid waste generation over the baseline fly ash only operation. The new waste will consist of fly ash, calcium-sulfur reaction products, unreacted reagent, other calcium compounds (CaCO_3) and reagent inerts. The amounts of each of these components will vary with operation, SO_2 removal, load, etc.

FORM 3-3 Process Flow Worksheet Duct Spray Drying (DSD)

1. FLUE GAS DOWNSTREAM OF AIR HEATER Flue Gas _____ lbs/hr Fly Ash _____ lbs/hr SO ₂ _____ lbs/hr Temperature _____ °F Wet bulb _____ °F		8. DILUTION WATER H ₂ O _____ lbs/hr		11. COLLECTED SOLIDS Total Solids _____ lbs/hr	
2. LIME TO SLAKER CaO _____ lbs/hr		9. SLURRY INJECTION Solids _____ lbs/hr H ₂ O _____ lbs/hr Atomizing Air _____ lbs/hr		12. DISPOSABLE WASTE Solids _____ lbs/hr H ₂ O _____ lbs/hr Total _____ lbs/hr	
3. WATER TO SLAKER H ₂ O _____ lbs/hr		10. ESP INLET Flue Gas _____ lbs/hr Solids _____ lbs/hr Temperature _____ °F Δ T App _____ °F		13. EMISSIONS SO ₂ _____ lbs/hr Particulate _____ lbs/hr	

3.2.3 Criteria for Existing Plant Equipment Upgrades

3.2.3.1 Duct Residence Time Requirements For Droplet Evaporation

Residence time for adequate evaporation of humidification water or slurry droplets is a critical parameter for atomizer placement and atomizer selection. Figure 3-4 presents a simplified relationship between droplet size and drying time. The user must use care in interpreting droplet size data. The Sauter mean diameter is a good representation of average droplet size; however, the large fraction of the distribution is of the most concern for evaporation. The information in Figure 3-4 can be compared to the residence time in the longest straight run (LSR) as determined in Section 3.1.18.

If residence time in the longest straight run is inadequate, duct injection should not be retrofit.

3.2.3.2 Effects On Particulate Collection Device

To determine the suitability of the existing particulate collection device, the user must determine the required particulate removal efficiency when operating under duct injection flue gas conditions. The particulate emissions rate limit was determined in Section 3.1.14. The user may wish to reduce this rate further as a safety measure, to compensate for particulate collection device operational problems such as ESP fields out of service. The solids loading to the ESP was calculated in Section 3.2.1.8 for DSI or 3.2.2.9 in the case of DSD. The required ESP efficiency is calculated as follows:

$$\text{Required ESP Efficiency (\%)} = \frac{\text{Total Solids Entering ESP-Particulate Emissions Limit}}{\text{Total Solids Entering ESP}} \quad (3-21)$$

ESP performance is a very complex issue and difficult to predict. Figure 3-5 shows a very generic relationship of ESP efficiency as a function of specific collection area (SCA) at duct injection flue gas conditions. This figure should be used only for rough approximations. It is intended to guide the user in assessing the adequacy of an existing ESP size for a duct injection retrofit. For a more accurate prediction, it is recommended that the user use the duct injection model which contains a submodel of ESP performance.

If Figure 3-5 indicates an ESP is undersized, there are a variety of ESP upgrade strategies to consider:

1. Increasing the size/treatment time of the ESP
2. Additives to improve efficiency
3. Improving flue gas velocity distribution
4. Improving voltage and/or rapping controls

Drying Time vs Droplet Size

Duct Injection Processes

Figure 3-4

ESP Efficiency Versus SCA **Duct Injection Flue Gas Conditions** **CONCEPTUAL MOCK-UP** **FOR ILLUSTRATION ONLY**

FIGURE 3-5

A more complete discussion of the application of these ESP upgrade strategies will be completed at a LATER time when more information becomes available. The complete discussion will be included in the design handbook.

If a fabric filter is used as the particulate collector, the concern is not so much with removal efficiency as it is with operation. The increase in solids loading will likely require more frequent cleaning; however, the dust cake properties on the filter bags will likely be very different, which directly affects pressure drop across the filter. More data regarding fabric filters will be added LATER when test results from side stream fabric filter experiments at Beverly have been completed.

3.2.3.3 Effects On Existing Ash Handling and Storage Systems

Duct injection results in a substantial increase in solids collected in the particulate collection device. The solids collected in the particulate collector are equal to the total solids entering (Section 3.2.1.8 or 3.2.2.9, as applicable) multiplied by the ESP removal efficiency (Eq. 3-21). This value should be compared to the ash removal system capacity as determined in Section 3.1.22. Undersized systems may have to be upgraded or replaced to accommodate the solids increase. In addition to capacity concerns, the physical and chemical properties of the duct injection waste solids may require other upgrades to the ash handling system. These properties include increased moisture, increased cohesivity, low temperature, and increased alkalinity. The most significant potential problems are a general decrease in flowability, and moisture/condensation which can lead to plugging.

3.2.3.4 Effects On Stack/Chimney Liner

Criteria will be developed LATER to assess the need for chimney liner upgrades or replacements and/or the use of reheat systems.

3.2.4 Sorbent Selection

The selection of a sorbent for a duct injection process will likely be based on economics. Although differences in sorbent characteristics have shown significant effects on SO₂ removal and sorbent utilization in laboratory tests, these effects have not been realized in pilot-scale test projects. The effects of scavenging appear to override particle size, surface area and porosity when the sorbent is injected upstream of humidification. These physical characteristics have shown a much greater effect in furnace sorbent injection, economizer sorbent injection, and in dry sorbent injection in non-scavenging configurations. However, the scavenging mode of DSI has shown the capacity for much higher SO₂ removal. These data recommend selecting the least expensive sorbent based on available calcium content.

3.2.4.1 On-Site vs. Off-Site Hydration for DSI

In the dry sorbent injection process, dry hydrated lime [$\text{Ca}(\text{OH})_2$] is injected to remove SO_2 . A major economic and process design issue will be whether to purchase hydrated lime or purchase quicklime (CaO) and hydrate it at the plant site. Although quicklime and hydrated lime are offered at similar prices, one lb of quicklime produces 1.32 lbs of $\text{Ca}(\text{OH})_2$ when hydrated on-site. There are a number of factors involved in making this decision. These include overall sorbent requirements, price and availability of each sorbent, transportation costs and distances, available plant space for a lime hydrator, etc. A lime hydrator will likely require additional manpower and add a level of complexity to the DSI process. Preliminary economic evaluations conducted by UE&C using very generic criteria resulted in a break point of approximately 100 MW plant size. At plants larger than 100 MW, on-site lime hydration is less expensive on a levelized control cost basis. This is a site specific determination, and is discussed in more detail in Section 3.3, Economic Evaluation Criteria.

3.2.4.2 Truck vs. Rail Unloading

Another very important economic and process design issue concerns reagent receiving. Lime reagent can be delivered by truck, rail or barge. This discussion will focus primarily on truck and rail receiving. Lime reagent suppliers and transportation companies should be contacted to determine the price and availability of both truck and rail delivery. The delivered price/ton may vary considerably among the various suppliers. The user should consider the following in making its decision:

1. Maximum lime usage rate - This will determine the maximum amount of trucks/day. Self unloading trucks typically require 1 to 2 hours to unload. Six trucks per shift are a realistic maximum unloading rate per silo fill tube.
2. The number of shifts the plant will permit sorbent truck traffic and unloading.
3. Access space for multiple truck unloading. These trucks are quite large; adequate space to park the truck(s), turn around, waiting, etc. must be considered.
4. Operator(s) for rail unloading. A plant operator will be required to operate and monitor the unloading system, position rail cars, etc.
5. Rail access and clearance - Rail unloading systems require considerable space, and pose many potential access and retrofit difficulties in older plants.

Table 3-2 summarizes other considerations.

TABLE 3-2
TRUCK VS. RAIL UNLOADING

	<u>Truck</u>	<u>Rail</u>
Capital cost for unloading equipment	Minimal-trucks are self-unloading pneumatic type	Expensive-site specific- usually involves rail spur, pit area beneath tracks, pneu- matic system
Manpower requirements	Little or none-truck operator usually	Manpower re- quired for rail car management, unloading system operation
Unloading rate	Much slower (15-20 tons/ hr) than rail system - 6 trucks/shift/system - could potentially have logistics problems	Have greater capacity-can typically be unloaded faster (30-40 tons/hr). Easier to manage logistically

This information indicates that plants requiring over 300 tons/day of sorbent (12 trucks @ 25 ton/truck) should select rail unloading. Those plants requiring less than 300 tons/day should base their decision on the criteria discussed above.

3.3 Economic Evaluation Criteria

LATER

4.0 NOT USED

5.0 ENGINEERING DRAWINGS

Typical drawings have been prepared for a DSI and DSD duct injection system. These drawings are based on two ducts and two separate ESPs downstream of the boiler air preheaters. The user will need to modify the drawings to account for the site-specific aspects of its plant.

Detailed electrical and instrumentation drawings were not part of the scope of this project, and, therefore, they have not been developed. General control loop philosophy for controlling a DSI or DSD system is contained in Section 8.1. No general arrangement, mechanical equipment, or structural drawings have been prepared due to the site-specific nature of these drawings. Ideas on general equipment configurations and retrofit considerations are given in Section 7.0.

5.1 Process Flow Diagrams

The following process flow diagrams (PFDs) have been developed and are attached:

Sheet 01 Dry Sorbent Injection, Off-Site Hydration PFD
Sheet 02 Dry Sorbent Injection, On-Site Hydration PFD
Sheet 03 Duct Spray Drying PFD

Each PFD has a material balance outline built into the drawing which can be used to develop the material balance for a specific application. The prefix "K" denotes "thousands"; e.g., KLB/HR indicates thousands of pounds per hour. Sample material balances have been developed for a specific plant using these PFDs in the DSI and DSD Case Studies, Sections 13.0 and 14.0, respectively. Suggestions to the user for developing the material balances and stream conditions are given in Section 5.2.

The PFDs are all based on two ducts/ESPs for injection because (from the Duct Configuration Survey) that is most typical of candidate plants, but they can be readily modified to reflect one or three ducts/ESPs. This is true because streams representing the overall quantities of reagent, compressed air, etc. are included before they split and branch out to the duct(s).

A positive pressure rail car unloading system is shown in the PFDs. This is only one type of rail car unloading system available, and it is shown for simplicity only - not as a recommendation.

The PFDs show an existing vacuum ash handling system. If a positive pressure or mechanical system will be used, the recycle material may be conveyed directly to the recycle bin, and modifications to the existing ash silo may not be required.

The PFDs do not reflect equipment details or redundancy. These are shown on the P&IDs in Section 5.3.

5.1.1 Dry Sorbent Injection

On the two DSI PFDs, the hydrated lime and recycle material injectors are shown upstream of the dual-fluid humidification nozzles. Although sorbent injection upstream of humidification (scavenging mode) is generally considered to result in superior SO₂ removal, it can cause material deposition. Locating the injectors and the humidification nozzles in the same vertical plane (for horizontal ducts) may give better operability. In that case, there would be no separate gas Stream No. 3 on the DSI PFD.

For DSI, the decision to use on-site or off-site hydration has a significant effect on the PFD. That is why a PFD has been developed for both options. The criteria to make this decision are given in Section 3.0.

For off-site hydration (PFD 01), the hydrate silo may be located either right next to the injection point(s) or remote from it as space and unloading constraints permit. However, the most reliable and economical feed rate control of the hydrated lime will be achieved if the silo is located close to the injection point(s). If the silo cannot be located near the injection point(s), the user may want to consider pneumatically transferring the lime from the remote silo to a hydrate day bin located close to the injection points. This case is not shown on the PFD.

For the on-site hydration option (PFD 02), the pebble lime silo, hydrators, and hydrate bin may be located either right next to the injection point(s) or remote from it as space and unloading constraints permit. However, to achieve the most reliable feed rate control of the hydrated lime, the hydrate bin should be located as close to the injection point(s) as possible, even if the silo and hydrators are located remotely.

5.1.2 Duct Spray Drying

For the DSD PFD, both a pebble lime silo and day bin are shown. This equipment arrangement reflects a conservative configuration in which the silo has to be located relatively far away from the injection ductwork due to rail car unloading or other site-specific constraints. For this equipment arrangement, it is considered more feasible to pneumatically convey lime from the silo to a small day bin located near the injection point (and have the slurry preparation accomplished close to the injection point) than to prepare the slurry near the remote silo and pump it a long distance to the injection point. This is especially true because a slurry return line to the atomizer feed tank is normally required to keep

slurry pipeline velocities high. If the silo can be located close to the duct injection point, a separate lime day bin is not required.

A ball mill slaker is shown on the DSD PFD. A detention-type or paste-type slaker could also be used. These options are included in the detailed P&IDs in Section 5.3.

5.2 Material Balances

LATER

5.3 Piping and Instrumentation Diagrams

Piping and instrumentation diagrams (P&IDs) have been developed for both the DSI and DSD duct injection systems. For each set of diagrams, a cover sheet is included which identifies the various symbols used in the drawings and describes the equipment numbering system utilized. These P&IDs were developed from three sources: 1) a review of the design of duct injection pilot plants/demonstration units, 2) existing lime spray dryer installations, and 3) good engineering practice for water, air, slurry, and flue gas systems.

The major components in each system have been assigned equipment numbers, and these numbers are listed at the top of the P&ID in which the equipment appears. An equipment list has been developed for each system which summarizes all of the major equipment and their corresponding numbers, and which identifies the sheet of the P&IDs that that equipment appears. These equipment lists are included in Section 5.4.

Similar to the PFDs in Section 5.1, the P&IDs for both systems are based on two ducts/ESPs for injection. They will need to be modified if the plant being modified has a different number of injection points.

The P&IDs are also based on a positive pressure rail car unloading system. This was used for reference only. A vacuum unloading system or combination vacuum-pressure system could be used as noted in the rail car unloading system bid specification (reference Appendix E). The P&IDs will need to be modified to reflect the unloading system selected for service.

The P&IDs for both systems give two options for recycling material collected in the ESP: 1) vacuum conveying from the ESP to the existing ash silo and, from there, positive pressure conveying to a recycle bin, or 2) positive pressure or mechanical conveying from the ESP directly to a recycle bin utilizing a diverter valve. The unused arrangement should be deleted from the production set of P&IDs.

For both the DSI and DSD system P&IDs, inlet SO_2/O_2 analyzers are shown in the ductwork upstream of the sorbent injection point. These are normally only required for two reasons: 1) if the SO_2 percent removal across the system is required to be reported (not just the outlet emission), or 2) if a feed-forward SO_2 signal is utilized in the process control. If neither of these two requirements exist, the inlet SO_2/O_2 analyzers may be deleted.

In the design presented in the miscellaneous utilities P&ID for both DSI and DSD, service and instrument air are assumed to be available

from the existing plant compressors; new service and/or instrument air compressors are not shown.

5.3.1 Dry Sorbent Injection

The following P&IDs have been developed for the DSI system and are attached:

Sheet A	Legend & Symbols
Sheet 1	Flue Gas Duct Controls
Sheet 2	Flue Gas Duct Controls
Sheet 3A	Hydrate Unloading & Storage
Sheet 3B	Pebble Lime Unloading & Storage
Sheet 4	Pebble Lime Hydration & Hydrate Storage
Sheet 5A	Used Sorbent Recycle from Fly Ash Silo
Sheet 5B	Used Sorbent Recycle from Pressure Pneumatic or Mechanical Conveyor
Sheet 6	Miscellaneous Utilities

In addition, the DSI equipment list is included in Section 5.4.

Sheet 1 of the DSI P&IDs indicates that the sorbent is injected upstream of the humidification water. Although sorbent injection upstream of humidification (scavenging mode) is generally considered to result in superior SO₂ removal, it can cause material deposition. Locating the injectors and the humidification nozzles in the same vertical plane (for horizontal ducts) may give better operability. In that case, the P&ID would need to be modified to show coplanar injection.

If off-site hydration is chosen for DSI, hydrated lime will be unloaded and stored at the plant, and only Sheet 3A will be required. Sheets 3B and 4 should be deleted from the production set of P&IDs. Conversely, if on-site hydration is chosen, Sheet 3A should be deleted, and Sheets 3B and 4 included in the production set.

Sheet 3A of the DSI P&IDs reflects one silo for both hydrated lime storage and feeding of the duct injection points. As mentioned in Section 5.1.1, if this silo cannot be located near the injection points, the user may want to consider pneumatically transferring the lime from the remote silo to a hydrate day bin located close to the injection points. In this case, the P&IDs would have to be revised accordingly.

On Sheet 5A, waste material is shown to be transferred from the existing plant ash silo to a recycle bin. From the recycle bin, the waste material is recycled back through two separate feeders to the injection points. This was done because it is difficult to split pneumatically conveyed material evenly between two ducts. If only

one duct exists at the plant site, a variable speed rotary feeder can be installed upstream of the fly ash silo rotary air lock (F401), and the recycle material injected directly from the ash silo to the injection point. In this case, the recycle bin may be deleted.

5.3.2 Duct Spray Drying

The following P&IDs have been developed for the DSD system and are attached:

Sheet A	Legend & Symbols
Sheet 1A	Flue Gas Duct Controls - Dual-Fluid Atomizer
Sheet 1B	Flue Gas Duct Controls - Rotary Atomizer
Sheet 2	Flue Gas Duct Controls
Sheet 3	Pebble Lime Unloading & Storage
Sheet 4A	Ball Mill Slaker
Sheet 4B	Detention Slaker
Sheet 4C	Paste Slaker
Sheet 5	Reagent Dilution & Storage
Sheet 6A	Used Sorbent Recycle from Fly Ash Silo
Sheet 6B	Used Sorbent Recycle from Pressure Pneumatic or Mechanical Conveyor
Sheet 7	Miscellaneous Utilities

In addition, the DSD equipment list is included in Section 5.4.

Depending on which type of atomizers are chosen for slurry injection, either Sheet 1A or 1B will be deleted from the production set of P&IDs. At the time of publication of this handbook, dual-fluid nozzles have been developed for DSD more extensively than rotary atomizers. Therefore, only dual-fluid nozzles are discussed in detail in this handbook. The P&ID for rotary atomizers (Sheet 1B) is based on lime spray dryer FGD applications.

Both a pebble lime silo and day bin are shown in the DSD P&IDs (Sheet 3). This equipment arrangement reflects a conservative configuration in which the silo has to be located relatively far away from the injection ductwork due to rail car unloading or other site-specific constraints. For this equipment arrangement, it is considered more feasible to pneumatically convey lime from the silo to a small day bin located near the injection point (and have the slurry preparation accomplished close to the injection point) than to prepare the slurry near the remote silo and pump it a long distance to the injection point. This is especially true because a slurry return line to the atomizer feed tank is normally required to keep slurry pipeline velocities high. If the silo can be located close to the duct injection point, a separate lime day bin is not required.

Three options are given in the P&IDs for slaking the pebble lime: 1) ball mill (Sheet 4A), 2) detention slaker (Sheet 4B), or 3) paste slaker (Sheet 4C). The P&ID sheets corresponding to the two methods not chosen for inclusion need to be deleted from the production set.

In the slurry lines, no flush or drain connections are shown so as to simplify the P&IDs. However, flush and drain connections are required for each slaker and slurry pump and for flushing all long runs of slurry lines. Also, atomizer flushing is required periodically. The flush system may be "hard piped" or manual using flexible hoses and pipe stub connections.

All slurry pumps show recirculation lines back to the tank from which they take suction. This helps to keep slurry velocities high and minimize line pluggage. A back pressure valve is shown in each recirculation line. These are typically manual pinch valves; restriction orifices are not recommended for slurry service. Valves in slurry service are specified in the slurry valve bid specification (Appendix E).

5.4 Equipment Lists

The following documents are attached to this section:

Equipment Numbering System

Dry Sorbent Injection Equipment List

Duct Spray Drying Equipment List

EQUIPMENT NUMBERING SYSTEM

The first part of the equipment letter-number designation is a letter describing the type of equipment:

- A - Agitator
- B - Blower, Fan
- C - Conveyor, Compressor
- D - Dust Collector, Dryer
- F - Feeder, Air Lock, Diverter Valve
- H - Heat Exchanger
- M - Bin Activator, Slaker, Hydrator
- P - Pump
- S - Strainer, Screen, Scrubber
- T - Tank
- V - Bin, Silo, Miscellaneous Vessel
- W - Weighing Device
- X - Injector Assembly/Atomizer

The next part of the letter-number designates in what area the equipment is located and the sequence. For example, A101 designates an agitator in Area 100 and is the number one agitator in that area. The area codes are as follows:

<u>AREA CODE</u>	<u>AREA NAME</u>
100	Sorbent Storage and Preparation System
200	Humidification/Sorbent Injection System
300	Flue Gas System
400	Recycle System
500	Waste Handling System
600	General Support Equipment
700	Miscellaneous

If there is more than one item in the same service, they are identified by suffix alphabetically. For example, if there are redundant pumps in parallel, the pumps may be identified as P201A and P201B.

DRY SORBENT INJECTION EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
-----------------------------	---------------------------	--------------------------------------

AREA 100 - SORBENT STORAGE AND PREPARATION SYSTEM

Hydrate Unloading & Storage

B101	Rail Car Unloading Blower	3A
B102	Hydrate Silo Aeration Blower	3A
B103A,B,C	Hydrate Injection Blower	3A
C101A,B	Hydrate Screw Feeder	3A
D101	Hydrate Silo Dust Collector	3A
D104	Aeration Air Dryer	3A
F101	Rail Car Unloading Feeders	3A
F102A,B	Hydrate Rotary Air Lock	3A
V101	Hydrate Silo	3A

Pebble Lime Unloading & Storage/Hydration & Hydrate Storage

B104	Rail Car Unloading Blower	3B
B105A,B	Hydrate Transfer Blower	4
B106	Hydrate Bin Aeration Blower	4
B107A,B,C	Hydrate Injection Blower	4
B108A,B	Hydrator Scrubber Fan	4
C102A,B	Hydrate Screw Feeder	4
D102	Pebble Lime Silo Dust Collector	3B
D103	Hydrate Bin Dust Collector	4
D105	Aeration Air Dryer	4
F103	Rail Car Unloading Feeders	3B
F104	Lime Diverter Valve	3B
F105A,B	Lime Weigh Belt Feeder	3B
F106A,B	Hydrator Discharge Rotary Air Lock	4
F107A,B	Hydrate Rotary Air Lock	4

DRY SORBENT INJECTION EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
M101	Pebble Lime Silo Bin Activator	3B
M102A,B	Hydrator	4
S101A,B	Hydrator Scrubber	4
V102	Pebble Lime Silo	3B
V103	Hydrate Bin	4

AREA 200 - HUMIDIFICATION/SORBENT INJECTION SYSTEM

X201A,B	Fresh Reagent Injection Manifold	1
X202A,B	Recycle Reagent Injection Manifold	1
X203A,B	Dual-Fluid Atomizing Nozzle Assembly	1

AREA 400 - RECYCLE SYSTEM

Used Sorbent Recycle from Fly Ash Silo

B401	Recycle Transfer Blower	5A
F401	Fly Ash Silo Rotary Air Lock	5A

Common to Both Sorbent Recycle Systems

B402	Recycle Bin Aeration Blower	5A&B
B403A,B	Recycle Injection Blower	5A&B
D401	Recycle Bin Dust Collector	5A&B
F402A,B	Recycle Bin Rotary Feeder	5A&B
F403A,B	Recycle Bin Rotary Air Lock	5A&B
V401	Recycle Bin	5A&B

DRY SORBENT INJECTION EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
<u>AREA 600 - GENERAL SUPPORT EQUIPMENT</u>		
C601A,B,C	Atomizing Air Compressor	6
P601A,B	Hydration Water Pump	6
P602A,B	Humidification Water Pump	6
P603A,B	Waste Conditioning Water Pump	6
S601	Humidification Water Filter (Coarse)	6
S602	Humidification Water Filter (Fine)	6
T601	Raw Water Tank	6
T602	Blowdown Water Tank	6
V601	Atomizing Air Receiver	6

DUCT SPRAY DRYING EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
-----------------------------	---------------------------	--------------------------------------

AREA 100 - SORBENT STORAGE AND PREPARATION SYSTEM

Pebble Lime Unloading & Storage

B101	Rail Car Unloading Blower	3
B102	Pebble Lime Transfer Blower	3
D101	Pebble Lime Silo Dust Collector	3
D102	Pebble Lime Day Bin Dust Collector	3
F101	Rail Car Unloading Feeders	3
F102	Pebble Lime Rotary Air Lock	3
F103	Lime Diverter Valve	3
F104A,B	Lime Weigh Belt Feeder	3
M101	Pebble Lime Silo Bin Activator	3
M102	Pebble Lime Day Bin Activator	3
V101	Pebble Lime Silo	3
V102	Pebble Lime Day Bin	3

Ball Mill Slaker

A101A,B	Ball Mill Sump Agitator	4A
F105A,B	Diverter Valve	4A
H101A,B	Slaking Water Heater	4A
M103A,B	Ball Mill Slaker	4A
P101A,B,C,D	Ball Mill Sump Pump	4A
S101A,B	Lime Grit Screen	4A
T101A,B	Ball Mill Sump	4A

DUCT SPRAY DRYING EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
----------------------	--------------------	-------------------------------

Detention Slaker

H102A,B	Slaking Water Heater	4B
M104A,B	Detention Slaker	4B
S102A,B	Lime Grit Screen	4B
V103A,B	Grit Bin	4B

Paste Slaker

H103A,B	Slaking Water Heater	4C
M105A,B	Paste Slaker	4C
S103A,B	Lime Grit Screen	4C
V104A,B	Grit Bin	4C

Reagent Dilution & Storage

A102	Lime Slurry Storage Tank Agitator	5
A103	Atomizer Feed Tank Agitator	5
P102A,B	Lime Slurry Pump	5
P103A,B	Atomizer Feed Pump	5
T102	Lime Slurry Storage Tank	5
T103	Atomizer Feed Tank	5

AREA 200 - HUMIDIFICATION/SORBENT INJECTION SYSTEM

Dual-Fluid Atomization

X201A,B	Dual-Fluid Atomizing Nozzle Assembly	1A
---------	--------------------------------------	----

Rotary Atomization

H201A,B	Atomizer Oil Filter/Cooler	1B
P201A,B	Atomizer Lube Oil Pump	1B
V201A,B	Head Tank	1B
X202A,B	Rotary Atomizer	1B

DUCT SPRAY DRYING EQUIPMENT LIST

<u>Equipment No.</u>	<u>Description</u>	<u>P&ID Sheet No.</u>
<u>AREA 400 - RECYCLE SYSTEM</u>		
<u>Used Sorbent Recycle from Fly Ash Silo</u>		
B401	Recycle Transfer Blower	6A
F401	Fly Ash Silo Rotary Air Lock	6A
<u>Common to Both Sorbent Recycle Systems</u>		
A401	Recycle Slurry Tank Agitator	6A&B
B402	Recycle Bin Aeration Blower	6A&B
D401	Recycle Bin Dust Collector	6A&B
F402	Recycle Bin Rotary Feeder	6A&B
P401A,B	Recycle Slurry Pump	6A&B
S401	Recycle Grit Screen	5
T401	Recycle Slurry Tank	6A&B
V401	Recycle Oversize Bin	5
V402	Recycle Bin	6A&B
<u>AREA 600 - GENERAL SUPPORT EQUIPMENT</u>		
C601A,B,C	Atomizing Air Compressor	7
P601A,B	Slaking Water Pump	7
P602A,B	Dilution Water Pump	7
P603A,B	Recycle Ash Water Pump	7
P604A,B	Waste Conditioning Water Pump	7
T601	Raw Water Tank	7
T602	Blowdown Water Tank	7
V601	Atomizing Air Receiver	7

A
B
C
D
E
F
G
H
I

1 2 3 4 5 6 7 8 9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
FLUE GAS DOWNSTREAM OF ECONOMIZER																											
FLUE GAS DOWNSTREAM OF AIR HEATER PER DUCT																											
FLUE GAS AFTER SLURRY INJECTION PER DUCT																											
FLUE GAS DOWNSTREAM OF ESP PER DUCT																											
FLUE GAS DOWNSTREAM OF LB PER DUCT																											
STACK GAS																											
LINE TO BALL MILL																											
SLAKING WATER TO BALL MILL																											
LINE SLURRY TO ATOMIZER FEED TANK																											
WATER TO RECYCLE SLURRY TANK																											
WATER TO BALL MILL SUMP																											
SOLIDS FROM ESP TO AS-1 SILO																											
RECYCLE SOLIDS TO RECYCLE SLURRY TANK																											
WATER TO ATOMIZER FEED TANK																											
RECYCLE SLURRY TO ATOMIZER FEED TANK																											
SLURRY FROM ATOMIZER FEED TANK																											
SLURRY TO ATOMIZERS PER DUCT																											
WASTE SOLIDS TO PUG MILL																											
WASTE CONDITIONING WATER																											
WASTE TO DISPOSAL																											
ATOMIZING AIR TO ATOMIZERS PER DUCT																											
RAW WATER																											
STEAM TO SLAKING WATER HEATER																											
CONDENSATE TO CONDENSER																											
AIR COMPRESSOR COOLING WATER IN																											
AIR COMPRESSOR COOLING WATER OUT																											
COOLING TOWER																											

MASS FLOW	KL B/HR
TEMPERATURE	°F
PRESSURE	PSIG IN. H ₂ O
VOLUMETRIC FLOW	GPM KAL/H
SO ₂	KL B/HR
H ₂ O	KL B/HR
SOLIDS	KL B/HR

LINES

INSTRUMENTS

INSTRUMENT SYMBOLS

TYPE OF —
EQUIPMENT

A - AGITATOR
 B - BLOWER
 C - CONVEYER
 D - DUST COLLECTOR
 F - FEEDER
 H - HEAT EXCHANGER
 M - BIN ACTUATOR
 P - PUMP
 S - STRAINER
 T - TANK
 V - BIN, SILENCE
 W - WEIGH
 X - INJECTOR

VALVES

INSTRUMENT IDENTIFICATION INDEX

	FIRST LETTER	SECOND LETTER	THIRD LETTER
A	ANALYSIS	ALARM	ALARM
B			
C		CONTROL	CONTROLLER
D	DENSITY	DIFFERENTIAL	
E		ELEMENT	
F	FLOW		
G			
H	HAND		HIGH
I	CURRENT	INDICATOR	INDICATOR
J		SCAN	
K			
L	LEVEL		LOW
M	MOISTURE		
N			
O		ORIFICE	
P	PRESSURE		
Q			
R	RESTRICTION	RECORD	RECORD
S	SPEED	SAFETY/SWITCH	SWITCH
T	TEMPERATURE	TRANSMITTER	TRANSMITTER
U			
V	VIBRATION	VALVE	VALVE
W	WEIGHT		
X		TEST CONNECTION	
Y		RELAY/COMPUTE	
Z	POSITION	POSITION	

EQUIPMENT NUMBERING SYSTEM

X 201 A

TYPE OF
EQUIPMENT

DUCT DESIGNATOR
OR REDUNDANT EQUIPMENT INDICATOR

AREA CODE

AREA NAME

- A - AGITATOR
- B - BLOWER, FAN
- C - CONVEYOR, COMPRESSOR
- D - DUST COLLECTOR, DRYER
- F - FEEDER, AIR LOCK, DIVERter VALVE
- H - HEAT EXCHANGER
- M - BIN ACTIVATOR, HYDRATOR
- P - PUMP
- S - STRAINER, SCREEN, SCRUBBER
- T - TANK
- V - BIN, SILO, MISCELLANEOUS VESSEL
- W - WEIGHING DEVICE
- X - INJECTOR ASSEMBLY/ATOMIZER

- 100
- 200
- 300
- 400
- 500
- 600
- 700

- SORBENT STORAGE AND PREPARATION SYSTEM
- HUMIDIFICATION/SORBENT INJECTION SYSTEM
- FLUE GAS SYSTEM
- RECYCLE SYSTEM
- WASTE HANDLING SYSTEM
- GENERAL SUPPORT EQUIPMENT
- MISCELLANEOUS

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9330.001

DRY SORBENT INJECTION
LEGEND
&
SYMBOLS

SHEET A

SCALE
NONE

X201A,B
FRESH REAGENT
INJECTION MANIFOLD

X202A,B
RECYCLE REAGENT
INJECTION MANIFOLD

X203A,B
DUAL-FLUID
ATOMIZING NOZZLE
ASSEMBLY

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DRY SORBENT INJECTION
FLUE GAS DUCT CONTROLS

SHEET 1

SCALE
NONE

5-20

CAD NO. A90P0001 DATE 02/11/91 DRW

ELECTROSTATIC
PRECIPITATOR
(EXISTING)

CONTINUED
FROM
SHEET 1

INDUCED
DRAFT FAN
(EXISTING)

-TO HYDRATE FLOW
CONTROLLERS
A & B DUCTS
SHEET 3A OR 4

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9330.001

DRY SORBENT INJECTION
FLUE GAS DUCT CONTROLS

5-21

SHEET 2

SCALE
NONE

CAD NO. A90P0002 DATE 12/07/90 DRW

F102A,B
HYDRATE
ROTARY AIR LOCK

B103A,B,C
HYDRATE
INJECTION BLOWER

V101
HYDRATE SILO

D101
HYDRATE
DUST COL

DEPARTMENT OF ENERGY 9330.001	
DRY SORBENT INJECTION HYDRATE UNLOADING & STORAGE	
SHEET 3A	SCALE NONE

F103
RAIL CAR
UNLOADING FEEDERS
B104
RAIL CAR
UNLOADING BLOWER

INSTRUMENT
AIR

FROM HYDRATE BIN
HIGH LEVEL SWITCH

SHEET 4

B107A,B,C
HYDRATE
INJECTION BLOWER

F107A,B
HYDRATE
ROTARY AIR LOCK

V103
HYDRATE BIN

B106
HYDRATE BIN
AERATION BLOWER

D103
HYDRATE BIN
DUST COLLECTOR
C102A,B
HYDRATE
SCREW FEEDER

M102A,B
HYDRATOR
S101A,B
HYDRATOR
SCRUBBER

B105
HYDR
TRAN
BLOW

NOTES:
1. HYDRATOR A SHOWN -
TYPICAL FOR B

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9330.001

DRY SORBENT INJECTION
PEBBLE LIME
HYDRATION & HYDRATE STORAGE

SHEET 4

SCALE
NONE

B401
RECYCLE TRANSFER
BLOWER

F401
FLY ASH SILO
ROTARY AIR LOCK

V401
RECYCLE BIN
D401
RECYCLE BIN
DUST COLLECTOR

F402A,B
RECYCLE BIN
ROTARY FEEDER

F403A,B
RECYCLE BIN
ROTARY AIR LOCK

B403A,B
RECYCLE
INJECTION BLOWER

B402
RECYCLE BIN
AERATION BLOWER

FROM A DUCT HYDRATE
FLOW CONTROLLER
SHEET 3A OR 4

FROM B DUCT HYDRATE
FLOW CONTROLLER
SHEET 3A OR 4

RECYCLE REAGENT
TO B DUCT SHEET 1

RECYCLE REAGENT
TO A DUCT SHEET 1

DEPARTMENT OF ENERGY
9330.001

DRY SORBENT INJECTION
USED SORBENT
RECYCLE
FROM FLY ASH SILO

SHEET 5A

SCALE
NONE

V401
RECYCLE BIND401
RECYCLE BIN
DUST COLLECTOR

BIN
COLLECTOR

F402A,B
RECYCLE BIN
ROTARY FEEDER

F403A,B
RECYCLE BIN
ROTARY AIR LOCK

B403A,B
RECYCLE
INJECTION BLOWER

B402
RECYCLE BIN
AERATION BLOWER

DEPARTMENT OF ENERGY
9330.001

DRY SORBENT INJECTION
USED SORBENT RECYCLE
FROM PRESSURE PNEUMATIC OR
MECHANICAL CONVEYOR

SHEET 5B

SCALE
NONE

SHEET 6

T601

C601A,B,C

RAW
WATER TANK

ATOMIZING AIR
COMPRESSOR

DEPARTMENT OF ENERGY 9330.001	
DRY SORBENT INJECTION MISCELLANEOUS UTILITIES	
SHEET 6	SCALE NONE

LINES INSTRUMENTS INSTRUMENT SYMBOLS VALVES

TYPE OF EQUIPMENT

A - AGITATOR
 B - BLOWER, FAN
 C - CONVEYOR, CD
 D - DUST COLLEC
 F - FEEDER, AIR I
 H - HEAT EXCHANI
 M - BIN ACTIVATE
 P - PUMP
 S - STRAINER, SCI
 T - TANK
 V - BIN, SILO, MI
 W - WEIGHING DE
 X - INJECTOR ASS

INSTRUMENT IDENTIFICATION INDEX

	FIRST LETTER	SECOND LETTER	THIRD LETTER
A	ANALYSIS	ALARM	ALARM
B			
C		CONTROL	CONTROLLER
D	DENSITY	DIFFERENTIAL	
E		ELEMENT	
F	FLOW		
G			
H	HAND		HIGH
I	CURRENT	INDICATOR	INDICATOR
J		SCAN	
K			
L	LEVEL		LOW
M	MOISTURE		
N			
O		ORIFICE	
P	PRESSURE		
Q			
R	RESTRICTION	RECORD	RECORD
S	SPEED	SAFETY/SWITCH	SWITCH
T	TEMPERATURE	TRANSMITTER	TRANSMITTER
U			
V	VIBRATION	VALVE	VALVE
W	WEIGHT		
X		TEST CONNECTION	
Y		RELAY/COMPUTE	
Z	POSITION	POSITION	

EQUIPMENT NUMBERING SYSTEM

- AGITATOR - BLOWER, FAN - CONVEYOR, COMPRESSOR - DUST COLLECTOR - FEEDER, AIR LOCK, DIVERter VALVE - HEAT EXCHANGER - BIN ACTIVATOR, SLAKER - PUMP - STRAINER, SCREEN, SCRUBBER - TANK - BIN, SILO, MISCELLANEOUS VESSEL - WEIGHING DEVICE - INJECTOR ASSEMBLY/ATOMIZER	100
200
300
400
500
600
700 | SORBENT STORAGE AND PREPARATION SYSTEM
HUMIDIFICATION/SORBENT INJECTION SYSTEM
FLUE GAS SYSTEM
RECYCLE SYSTEM
WASTE HANDLING SYSTEM
GENERAL SUPPORT EQUIPMENT
MISCELLANEOUS |
|--|---|---|

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9330.001

DUCT SPRAY DRYING
LEGEND
&
SYMBOLS

SHEET A

SCALE
NONE

5-29

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
FLUE GAS DUCT CONTROLS
DUAL-FLUID ATOMIZER

SHEET 1A

SCALE
NONE

CAD NO. A90P101A DATE 02/22/91 DRW

AIR
PREHEATERS
(EXISTING)

B DUCT

TO MASS RATIO
CONTROLLER
SHEET 5

FROM B DUCT

A DUCT

TEST
PORTS

CONTINUED
ON SHEET 2

DEPARTMENT OF ENERGY 9330.001	
DUCT SPRAY DRYING FLUE GAS DUCT CONTROLS ROTARY ATOMIZER	
SHEET 1B	SCALE NONE

ELECTROSTATIC
PRECIPITATOR
(EXIST)

INDUCED
DRAFT FAN
(EXIST)

TO MASS
RATIO CONTROLLER
SHEET 5

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
FLUE GAS DUCT CONTROLS

SHEET 2

SCALE
NONE

5-31

CAD NO. A90P1002 DATE 11/28/90 DRW

F101
RAIL CAR
UNLOADING
FEEDERS

B101
RAIL CAR
UNLOADING BLOWER

D101
PEBBLE LIME SILO
DUST COLLECTOR

V101
PEBBLE LIME SILO

M101
PEBBLE LIME SILD
BIN ACTIVATOR

F102
PEBBLE LIME
ROTARY AIR LOCK

B102
PEBBLE LIME
TRANSFER BLOWER

D102
PEBBLE LIME DAY BIN
DUST COLLECTOR
V102
PEBBLE LIME DAY BIN
M102
PEBBLE LIME DAY BIN
ACTIVATOR

F103
LIME DIVERTER VALVE
F104A,B
LIME WEIGH
BELT FEEDER

K

ER

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
PEBBLE LIME UNLOADING
& STORAGE

FROM LIME WEIGH BELT
FEEDER A SHEET 3

FROM SLAKING WATER
PUMP SHEET 7

TO BALL MILL
SLAKER B

FROM LIME WEIGH BELT
FEEDER A SHEET 3

FROM SLAKING WATER
PUMP SHEET 7

INSTRUMENT AIR

TO COND.
RETURN

BALL MILL
BEARING
LUBE OIL
SYSTEM

TO BALL MILL
SUMP B

H101A,B
SLAKING
WATER
HEATER

M103A,B
BALL
MILL SLAKER

S101A,B
LIME GRIT
SCREEN
F105A,B
DIVERTER
VALVE

T101A,B
BALL MILL
SUMP

P101A,B,C,D
BALL MILL
SUMP PUMP

A101A,B
BALL MILL
SUMP AGITATOR

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
BALL MILL SLAKER

SHEET 4A

SCALE
NONE

FROM LIME WEIGH
FEEDER A SHEET 3

4
JG
R

M104A,B
DETENTION
SLAKER

V103A,B
GRIT
BIN

S102A,B
LIME GRIT
SCREEN

NOTES:

1. SLAKER A SHOWN -
TYPICAL FOR B
2. FLUSH/DRAIN CONNECTIONS
NOT SHOWN FOR CLARITY

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING,
DETENTION SLAKER

SHEET 4B

SCALE
1:1

5-34

CAD NO. A90P104B DATE 02/22/91 DRW

H103A,B
SLAKING
WATER
HEATER

M105A,B
PASTE
SLAKER

V104A,B
GRIT
BIN

S103A,B
LIME GRIT
SCREEN

NOTES:

1. SLAKER A SHOWN -
TYPICAL FOR B
2. FLUSH/DRAIN CONNECTIONS
NOT SHOWN FOR CLARITY

TO LIME SLURRY
STORAGE TANK SHT. 5

FROM LIME GRIT SCREEN B

TO MASS RATIO
CONTROLLER
SHEET 5

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
PASTE SLAKER

SHEET 4C

SCALE
NONE

5-35

CAD NO. A90P104C DATE 02/08/91 DRW

SHEET 5

P102A,B
LIME SLURRY
PUMP

P103A,B
ATOMIZER
FEED PUMP

T102
LIME SLURRY
STORAGE TANK

A102
LIME SLURRY STORAGE
TANK AGITATOR

T103
ATOMIZER
FEED TANK

A103
ATOMIZER FEED
TANK AGITATOR

S401
RECYCLE
GRIT SCREEN

V401
RECYCLE
OVERSIZE
BIN

NOTES:
1. FLUSH/DRAIN CONNECTIONS
NOT SHOWN FOR CLARITY

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
REAGENT DILUTION
& STORAGE

SHEET 5

SCALE
NONE

5-36

CAD NO. A90P1005 DATE 02/08/91 DRW

SHEET 6A

B402
RECYCLE BIN
AERATION BLOWER

B401
RECYCLE TRANSFER
BLOWER

D401
RECYCLE BIN
DUST COLLECTOR

F401
FLY ASH SILO
ROTARY AIR LOCK

F402
RECYCLE BIN
ROTARY FEEDER

P401A,B
RECYCLE SLURRY
PUMP

A401
RECYCLE SLURRY
TANK AGITATOR

EXISTING BAG FILTER

EXISTING MECHANICAL COLLECTOR

FROM EXISTING ESP

EXISTING DUST COLLECTOR

VENT

MAIN PLANT FLY ASH SILO (EXIST.)

HV

INSTRUMENT AIR

FI

M F401

PAH

PSH

PAL

PSL

PI

PSV

TAH

TSS

PI

SILENCER (TYPICAL)

B401

EXISTING VACUUM PRODUCER

LAHH

LAH

LAL

LSHH

LSH

LSL

LT

FI

INST. AIR

SC

M

SET

FIR

FY

TO DRAIN

REC CON

PI

PDAH

P

HV

TO DRAIN

REC CON

RECYCLE BIN
AERATION BLOWER

RECYCLE TRANSFER
BLOWER

RECYCLE BIN
DUST COLLECTOR

FLY ASH SILO
ROTARY AIR LOCK

RECYCLE BIN
ROTARY FEEDER

RECYCLE SLURRY
PUMP

RECYCLE SLURRY TANK AGITATOR

INSTRUMENT
AIR S

EXISTING
VACUUM
PRODUCER

EXISTING
MECHANICAL
COLLECTOR

FROM
EXISTING ESP

EXISTING
BAG -
FILTER

EXISTING
DUST
COLLECTOR

VENT

MAIN PLANT
FLY ASH
SILO (EXIST.)

HV

INSTRUMENT
AIR 2

FI

Ⓜ F 401

РАИ

PSH

PAL

PSL

PI

PSV

ТАН

(TSS

57

SILENCER (TYPICAL)

B401

PI

PDAH

LAH

LAH

(LAL

LSHH

LSH

(LSL

INST. AIR

FI

SC

Q

(SET

FIR

FY

TO
DRAIN

REC
CON

NOTES:
1. FLUSH/DRAIN CONNECTIONS
NOT SHOWN FOR CLARITY

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
USED SORBENT RECYCLE
FROM FLY ASH SILO

SHEET 6A

SCALE
NONE

5-37

CAD NO. A90P106A DATE 02/22/91 DRW

DI
DAH

RECYCLE
BIN

RECYCLE BIN
ROTARY FEEDER

RECYCLE BIN
DUST COLLECTOR

RECYCLE SLURRY
PUMP

T401
RECYCLE
SLURRY TANK

B402
RECYCLE BIN
AERATION BLOWER

NOTES:
1. FLUSH/DRAIN CONNECTIONS
NOT SHOWN FOR CLARITY

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
USED SORBENT RECYCLE FROM
PRESSURE PNEUMATIC OR
MECHANICAL CONVEYOR

SHEET 6B

SCALE
NONE

T601
RAW WATER TANK

T602
BLOWDOWN
WATER TANK

P603
RECY
WATI
P602
DILU
WATI

P601A,B
SLAKING WATER
PUMP

P604A,B
WASTE CONDITIONING
WATER PUMP

TO SLAKERS
SHEET 4A, 4B OR 4C

TO BALL MILL SUMPS
SHEET 4A OR
SLAKERS
SHEET 4B OR 4C

P603A,B
RECYCLE ASH
WATER PUMP
P602A,B
DILUTION
WATER PUMP

C601A,B,C
ATOMIZING
AIR COMPRESSOR

V601
ATOMIZING
AIR RECEIVER

DEPARTMENT OF ENERGY
9330.001

DUCT SPRAY DRYING
MISCELLANEOUS
UTILITIES

SHEET 7

SCALE
NONE

5-39

CAD NO. A90P1007 DATE 02/22/91 DRW

6.0 EQUIPMENT SIZING AND DESIGN

This sections gives sizing and design criteria for specific equipment. Once the material balances have been developed per the discussions in Sections 3.0 and 5.2, individual pieces of equipment and other components of the duct injection system retrofit may be sized and designed.

6.1 Sorbent Storage and Preparation

6.1.1 Dry Sorbent Injection

One of the first steps in designing the equipment in a DSI duct injection system is determining whether the hydrated lime will be produced off-site or on-site. The criteria to make this decision are given in Section 3.0. If off-site hydration is selected, commercial grade hydrated lime will be received at the plant site, and Section 6.1.1.1 below is applicable. If on-site hydration is selected, 1/4 in. minus pebble lime (quicklime) will be received and hydrated at the plant, and Section 6.1.1.2 below is applicable.

6.1.1.1 Off-Site Hydration (Ref. DSI P&ID Sheet 3A)

Rail Car Unloading

Each rail car will hold about 50 tons of hydrated lime. Each rail car will have two to four compartments/hoppers, each with a bottom discharge gate. The options for pneumatically unloading the car, and the corresponding equipment required, are discussed in detail in the rail car unloading system specification (Spec. No. M101) in Appendix E.

The unloading system capacity should be determined with two primary factors in mind: 1) the unloading rate should be high enough to unload the rail cars quickly, thereby minimizing demurrage on the rail cars and minimizing the operating labor required to "keep an eye" on the unloading, and 2) the unloading rate should be high enough such that, optimally, unloading may be accomplished Monday through Friday during the day shift.

Using the second criterion above, the design lime consumption [injected into the duct(s)] in ton/hr, multiplied by 168 hours in a week, gives the maximum tons for a week's supply of lime. These maximum tons divided by 40 hours (8 hours unloading per day Monday through Friday) gives a good estimate of the required lime unloading rate.

Typical capacities for a rail car unloading system range from 30 - 40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30 - 40 ton/hr, one or more of the following will have to be considered: 1) unloading during evening and/or graveyard shifts,

2) increasing the capacity of the rail car unloading system above 40 ton/hr (through discussions with system suppliers), and 3) the use of two unloading systems to allow unloading two cars at a time.

Typical pneumatic unloading conveying velocities range from 2,500 to 3,000 ft/min for hydrated lime. The air required for conveying the lime is somewhat dependent on conveying distance. For an unloading conveying distance of 100 ft, about 0.05 lb air per lb lime is required compared to 0.075 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the rail car unloading system specification.

Redundant blowers for either positive or negative pressure systems are typically not required; only one blower per service is suggested as shown on DSI P&ID Sheet 3A in Section 5.3. This is true because 1) the blowers should only operate 30-40% of the time allowing time for routine maintenance, and 2) as discussed below, provisions for truck unloading should be included in the storage silo - this will allow lime to be unloaded directly into the silo by truck-mounted blowers if one of the rail car unloading blowers is unavailable.

Truck Unloading

Even if rail is to be the principal mode of lime delivery, truck shipments will probably be needed from time to time to compensate for railroad strikes, problems with the rail car unloading system, etc. The storage silo should be fitted with a truck fill pipe as noted in DSI P&ID Sheet 3A. If lime delivery by truck is the only mode utilized, two truck fill pipes per silo are recommended. Material, size, and fittings for this pipe are given in the silo/day bin specification (Spec. No. M102) in Appendix E.

If a rail car and truck fill line are connected to a silo, they each will require some way of being isolated. Otherwise, conveying air/lime will discharge from the truck fill pipe when the rail car unloading conveyor is used, and/or the rail car unloading line could become plugged with lime dust when the truck fill pipe is used. The truck fill pipe can be isolated simply by using a cap at the quick coupling at grade. When the truck fill pipe is used, the rail car unloading line should be blanked off to prevent lime dust from possibly filling up and plugging this line. If the truck fill pipe is to be sparingly used, a manual gate in the rail car unloading line is adequate. If the truck fill line is to be used frequently, a pneumatically operated isolation gate in the rail car unloading line would be more appropriate. Regardless of the type of operator, the gate in the rail car unloading line should be located as close as possible to the silo inlet connection. If two truck unloading lines are the only means of filling the silo, each should be furnished with a cap at the quick coupling at grade.

A pneumatic lime truck will hold about 20 tons of hydrated lime. Because of the truck-mounted blower, the truck is essentially self-unloading, requiring only that the storage silo be equipped with a bin vent filter and pressure relief device. Hydrated lime can be blown up to 200 ft vertically and 300 ft combined vertical and horizontal run with the truck-mounted blower. The intake end of the fill pipe should be mounted vertically, with the bottom about 4 ft above ground. The truck fill pipe should run vertically first, then horizontally. Normally, a truck can be unloaded in about 1 hour.

Hydrate Silo

Minimum lime storage capacity for a continuously operating facility is generally considered to be either 150% of the normal delivery quantity (e.g., enough capacity to hold 12 rail cars worth of lime if 8 rail cars is the normal delivery) or 10 days of storage at the design lime consumption [injected into the duct(s)], whichever is greater. A bulk density of 30 lb per cu ft may be used for capacity of hydrated lime.

Whether to use one or more hydrate silos depends on the design lime consumption, silo construction economy, and also on silo height. Since hydrated lime can be unloaded 200 ft vertically using a truck-mounted blower, the silo straight wall height is limited to about 155 ft (considering the cone height and process equipment located underneath the silo). At a straight wall height to diameter ratio of 2.5, the corresponding diameter is 62 ft, and the storage capacity (at a bulk density of 30 lb per cu ft) is about 7,000 tons. This is a huge silo and is the largest that should be considered. Construction economy will likely limit silo diameter to 30 - 40 ft (800 - 1900 tons of hydrated lime storage at a 2.5 aspect ratio). These calculations assume that the silo freeboard volume is approximately equal to the silo cone volume. Therefore, the approximate silo capacity can be calculated using the total straight wall height and ignoring the cone volume.

Hydrated lime tends to form rat holes and craters which can cause arching or bridging in storage. The silo cone angle for hydrated lime should be 70 degrees from the horizontal if no flow aid is utilized, or 60 degrees if fluidizing pads are installed. A bin activator or vibrator is not recommended on hydrated lime silos as they tend to pack the material rather than enhance the flow. Fluidizing pads are recommended in conjunction with a dedicated hydrate silo aeration blower. As noted in DSI P&ID Sheet 3A, a spare aeration blower is not recommended. However, a tie-in from a plant service air line (with pressure reducing station) should be used as a back-up when the aeration blower is not available. If an air dryer is not installed downstream of the service air tie-in, instrument air should be used instead.

A minimum of four fluidizing pads should be installed starting at about 1-2 ft above the hopper outlet. The pads should be mounted directly to the hopper wall. The pads should be 8 in. to 12 in. wide and about 8 ft long depending on the silo size. The fluidizing pads should be porous stone or polyester fabric with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. Although not shown on the P&IDs, a manually operated butterfly or ball valve should be installed in the line to each fluidizing pad for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing pad area. The aeration (fluidizing) blower should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air pads.

In areas of high humidity, an air dryer (desiccant type) is recommended for the fluidizing air as shown in DSI P&ID Sheet 3A. Hydrated lime is quite hygroscopic, and moisture in the fluidizing air could cause agglomeration and flowability problems within the silo. The air dryer should be sized for the full fluidizing blower discharge flow.

An alternative to fluidizing pads is aeration flow cones. These devices are mounted directly to the hopper walls and use compressed air to aerate along the inside of hopper walls. The compressed air is released in a circular pattern, and the aeration results in undercutting and flowability of the lime. Such aeration flow cones are the Vibra-Jet Bin Aerator manufactured by Dynamic Air Conveying Systems of St. Paul, MN

The hopper flow design for the hydrate silo should be mass flow, i.e., first in - first out. This eliminates an annular portion of the lime that remains in the silo until the level is drawn down very low. Any stagnant areas will likely form hard deposits over time due to the affinity of water to hydrated lime. An exception to mass flow design may be required if the silo location limits the available head room; mass flow design requires a relatively tall silo. In this case, expanded flow - with minimal dead areas in the silo - should be used.

The pressure relief device on top of the hydrate silo may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification.

The hydrate silo dust collector must be sized to filter the transport air from a positive pressure rail car unloading system and/or a truck-mounted blower. Normally, the rail car unloading system will not operate concurrent with the unloading of a truck, so the collector should be sized for the larger flow of the two which is usually the rail car unloading system. If truck unloading is the only means of filling the silo, and two truck fill pipes are installed, the dust

collector should be sized for two trucks unloading concurrently (2 @ 800 cfm per truck gives 1,600 cfm). If a vacuum rail car unloading system is employed with the filter receiver located on top of the silo, a dust collector is still required, but it may be much smaller as it only needs to filter the air displaced from the silo as it fills with lime and/or filter the conveying air from a truck-mounted blower. In this case, the air from a truck-mounted blower (about 800 cfm) is used to size the dust collector.

The use of an exhaustor fan on the dust collector is optional. However, the slight negative pressure in the silo air space, created by the exhaustor, will result in air in-leakage through any small openings in the silo roof instead of lime dust out-leakage, and it will minimize the possibility of lime dust filling and plugging an idle silo fill line. For silos/bins located indoors, an exhaustor fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification (Spec. No. M103) in Appendix E.

If more than one silo is required for the required storage capacity, a rotary vane feeder would be attached to each silo cone. The feeders would discharge to a common screw conveyor. The flow from each silo would be controlled either by blending the flows together or by total flow from each silo in sequence. The common screw conveyor would feed a hopper or bin (probably requiring a bucket elevator); the hopper or bin would discharge to the downstream process equipment. If only one silo is used (as shown in DSI P&ID Sheet 3A), the silo would discharge directly to the downstream process equipment.

Sheet 3A of the DSI P&IDs reflects one silo for both hydrated lime storage and feeding of the duct injection points. As noted in Section 5.3.1, if this silo cannot be located near the injection points, due to space and/or unloading constraints, the user may want to consider pneumatically transferring the lime from the remote silo to a hydrate day bin located close to the injection points. In this case, the design criteria for both the pneumatic transfer conveyor and the day bin will be essentially the same as those given in Section 6.1.1.2. Whether the hydrated lime, which is injected into the duct(s), is fed from a silo or a day bin, the hydrated lime injection equipment, as described below, would be the same.

Hydrated Lime Injection Equipment

Although there are a number of ways of metering the injected lime, the P&IDs show the lime being discharged from the silo through a variable speed screw feeder and into a dilute phase, positive pressure pneumatic conveying system through a constant speed air lock valve. The screw speed is controlled to maintain a specified SO_2 emission based on SO_2 monitor signal or coal sulfur and boiler load. Controls are discussed in Section 8.0.

The injection conveyor should be a dilute phase pressure conveying system to provide a constant flow at the required pressure to the injectors. A single pipe would convey the lime to a distribution bottle near the flue gas duct where it is split into smaller, balanced loss pipes to each injector. Injector design is discussed in Section 6.2.1.

The conveyor piping should be routed either vertically or horizontally with no more than a 15 degree deviation from vertical or horizontal to minimize particle drop out in the pipe.

One hydrate screw feeder/rotary air lock should be provided per duct. Each hydrate screw feeder and hydrate rotary air lock should be sized for at least 100% of the design hydrated lime usage rate for that duct as adjusted for the lowest available calcium in the hydrated lime received. For example, if the suppliers of hydrated lime closest to the plant indicate that the range of $\text{Ca}(\text{OH})_2$ in their hydrate is 95-98%, the screw feeders and air locks should be sized for the design $\text{Ca}(\text{OH})_2$ required (reference Eq. 3-8 in Section 3.2.1) divided by 0.95 to account for the inerts.

Variable speed rotary feeders can be purchased, but they are typically not as accurate as screw feeders. For good lime feed control, screw feeders in series with constant speed rotary air locks are recommended. The additional advantage of this arrangement is that any blowback of pressurized conveying air which leaks through the air lock will not prevent the lime from flowing out of the silo - it will dissipate through the screw feeder casing. A vent should be installed from the rotary air lock to the top of the silo to vent off this pressurized air (reference the P&IDs), but this vent line is prone to pluggage.

The hydrate injection pneumatic conveying system capacity for each duct should be at least 100% of the design hydrated lime usage rate for that duct as adjusted for the lowest available calcium in the hydrated lime received. The hydrate injection blowers should be sized for conveying velocities ranging from 2,500 to 3,000 ft/min. The air required for conveying the lime is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.05 lb air per lb lime is required compared to 0.075 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification and the screw feeders specification (Spec. Nos. M105 and M107, respectively) in Appendix E.

A spare injection blower should be available when an in-service machine requires maintenance. For the two duct case shown in the P&IDs, a total of three blowers would be required - one dedicated to each duct with a common spare. A spare set of screw feeder/rotary air lock is not shown in the P&IDs. A third set is not recommended because of the complexity of tying in a common spare to the other two sets. In addition, with three chutes from the lime silo, it is more uncertain that lime will fill each chute properly compared to two chutes. Instead of a "hard piped" spare set of feeders, it is recommended that spares be available to replace the in-line screw feeder and/or rotary air lock in a minimum amount of time.

If only one duct requires lime injection, two 100% systems would be recommended.

6.1.1.2 On-Site Hydration (Ref. DSI P&ID Sheets 3B & 4)

Rail Car Unloading

Each rail car will hold about 100 tons of pebble quicklime. Each rail car will have two to four compartments/hoppers, each with a bottom discharge gate. The options for pneumatically unloading the car, and the corresponding equipment required, are discussed in detail in the rail car unloading system specification (Spec. No. M101) in Appendix E.

The unloading system capacity should be determined with two primary factors in mind: 1) the unloading rate should be high enough to unload the rail cars quickly, thereby minimizing demurrage on the rail cars and minimizing the operating labor required to "keep an eye" on the unloading, and 2) the unloading rate should be high enough such that, optimally, unloading may be accomplished Monday through Friday during the day shift.

Using the second criterion above, the design lime consumption [injected into the duct(s)] in ton/hr, multiplied by 168 hours in a week, gives the maximum tons for a week's supply of lime. These maximum tons divided by 40 hours (8 hours unloading per day Monday through Friday) gives a good estimate of the required lime unloading rate. Note: The design lime consumption injected into the duct(s) will be based on hydrated lime; the lime unloading capacity will be based on pebble lime; a conversion will have to be made between the two.

Typical capacities for a rail car unloading system range from 30 - 40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30 - 40 ton/hr, one or more of the following will have to be considered: 1) unloading during evening and/or graveyard shifts, 2) increasing the capacity of the rail car unloading system above 40 ton/hr (through discussions with system suppliers), and 3) the use of two unloading systems to allow unloading two cars at a time.

Typical pneumatic unloading conveying velocities range from 4,000 to 5,000 ft/min for pebble quicklime. The air required for conveying the lime is somewhat dependent on conveying distance. For an unloading conveying distance of 100 ft, about 0.11 lb air per lb lime is required compared to 0.16 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the rail car unloading system specification.

Redundant blowers for either positive or negative pressure systems are typically not required; only one blower per service is suggested as shown on DSI P&ID Sheet 3B in Section 5.3. This is true because 1) the blowers should only operate 30 - 40% of the time allowing time for routine maintenance, and 2) as discussed below, provisions for truck unloading should be included in the storage silo - this will allow lime to be unloaded directly into the silo by truck-mounted blowers if one of the rail car unloading blowers is unavailable.

Truck Unloading

Even if rail is to be the principal mode of lime delivery, truck shipments will probably be needed from time to time to compensate for railroad strikes, problems with the rail car unloading system, etc. The storage silo should be fitted with a truck fill pipe as noted in DSI P&ID Sheet 3B. If lime delivery by truck is the only mode utilized, two truck fill pipes per silo are recommended. Material, size, and fittings for this pipe are given in the silo/day bin specification (Spec. No. M102) in Appendix E.

If a rail car and truck fill line are connected to a silo, they each will require some way of being isolated. Otherwise, conveying air/lime will discharge from the truck fill pipe when the rail car unloading conveyor is used, and/or the rail car unloading line could become plugged with lime dust when the truck fill pipe is used. The truck fill pipe can be isolated simply by using a cap at the quick coupling at grade. When the truck fill pipe is used, the rail car unloading line should be blanked off to prevent lime dust from possibly filling up and plugging this line. If the truck fill pipe is to be sparingly used, a manual gate in the rail car unloading line is adequate. If the truck fill line is to be used frequently, a pneumatically operated isolation gate in the rail car unloading line would be more appropriate. Regardless of the type of operator, the gate in the rail car unloading line should be located as close as possible to the silo inlet connection. If two truck unloading lines are the only means of filling the silo, each should be furnished with a cap at the quick coupling at grade.

A pneumatic lime truck will hold about 25 tons of pebble quicklime. Because of the truck-mounted blower, the truck is essentially self-unloading, requiring only that the storage silo be equipped with a bin vent filter and pressure relief device. Pebble lime can be blown up to 100 ft vertically and 150 ft combined vertical and horizontal run with the truck-mounted blower. The intake end of the fill pipe should be mounted vertically, with the bottom about 4 ft above ground. The truck fill pipe should run vertically first, then horizontally. Normally, a truck can be unloaded in about 1 hour.

Pebble Lime Silo

Minimum lime storage capacity for a continuously operating facility is generally considered to be either 150% of the normal delivery quantity (e.g., enough capacity to hold 12 rail cars worth of lime if 8 rail cars is the normal delivery) or 10 days of storage at the design lime consumption [injected into the duct(s)], whichever is greater. A bulk density of 55 lb per cu ft may be used for capacity of pebble lime.

Whether to use one or more pebble lime silos depends on the design lime consumption, silo construction economy, and also on silo height. Since pebble lime can be unloaded 100 ft vertically using a truck-mounted blower, the silo straight wall height is limited to about 55 ft (considering the cone height and process equipment located underneath the silo). At a straight wall height to diameter ratio of 2.5, the corresponding diameter is 22 ft, and the storage capacity (at a bulk density of 55 lb per cu ft) is about 575 tons. These calculations assume that the silo freeboard volume is approximately equal to the silo cone volume. Therefore, the approximate silo capacity can be calculated using the total straight wall height and ignoring the cone volume.

Pebble lime tends to form rat holes and craters which can cause arching or bridging in storage. The silo cone angle for pebble lime should be 60 degrees from the horizontal. A bin activator or vibrator is recommended on pebble lime silos to promote flow.

The hopper flow design for the pebble lime silo can be mass flow, expanded flow, or funnel flow as long as the hopper angle is 60 degrees. The pressure relief device on top of the pebble lime silo may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification and bin activator specification (Spec. No. M104) in Appendix E.

The pebble lime silo dust collector must be sized to filter the transport air from a positive pressure rail car unloading system and/or a truck-mounted blower. Normally, the rail car unloading system will not operate concurrent with the unloading of a truck, so the collector should be sized for the larger flow of the two which is usually the rail car unloading system. If truck unloading is the only means of

filling the silo, and two truck fill pipes are installed, the dust collector should be sized for two trucks unloading concurrently (2 @ 800 cfm per truck gives 1,600 cfm). If a vacuum rail car unloading system is employed with the filter receiver located on top of the silo, a dust collector is still required, but it may be much smaller as it only needs to filter the air displaced from the silo as it fills with lime and/or filter the conveying air from a truck-mounted blower. In this case, the air from a truck-mounted blower (about 800 cfm) is used to size the dust collector.

The use of an exhaustor fan on the dust collector is optional. However, the slight negative pressure in the silo air space, created by the exhaustor, will result in air in-leakage through any small openings in the silo roof instead of lime dust out-leakage, and it will minimize the possibility of lime dust filling and plugging an idle silo fill line. For silos/bins located indoors, an exhaustor fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification (Spec. No. M103) in Appendix E.

If more than one silo is required for the required storage capacity, a rotary vane feeder would be attached to each silo cone. The feeders would discharge to a common screw conveyor. The flow from each silo would be controlled either by blending the flows together or by total flow from each silo in sequence. The common screw conveyor would feed a hopper or bin (probably requiring a bucket elevator); the hopper or bin would discharge to the downstream process equipment. If only one silo is used (as shown in DSI P&ID Sheet 3B), the silo would discharge directly to the downstream process equipment.

Hydration Equipment

Although there are a number of ways of metering pebble lime into the hydrators, the P&IDs show the lime being discharged from the silo to two, redundant weigh belt feeders. Each 100% capacity weigh belt feeder feeds a 100% capacity lime hydrator. Redundancy is recommended in this equipment due to its historically high maintenance; therefore, two 100% capacity trains are suggested.

The weigh belt feeder is a short belt conveyor equipped with a weigh deck which measures the weight of lime carried on a section of the belt. Instrumentation adjusts a vertical gate and the speed of the belt so that only a set weight of material is allowed out of the pebble lime silo and into the hydration chamber of the hydrator. Weigh belt feeders are suggested in lieu of screw feeders because they are generally more accurate. Good control of the pebble lime and water feed rates to the hydrator is required to produce a product with the proper characteristics.

The hydrator consists of a hydration chamber followed by a seasoning chamber. The premixer introduces just enough water into the pebble lime to cause the formation of a dry hydrate. No further grinding would be required for this process. The commercial hydrators available range in size from 2 to 45 ton/hr of hydrated product at 30 lb per cu ft.

The capacity of the hydrators should be at least 100% of the design hydrated lime usage [injected into the duct(s)] as adjusted for the lowest available calcium in the hydrated lime produced. The minimum available Ca(OH)_2 in the hydrated lime product should be about 95% if a high calcium quicklime is used. Therefore, the hydrators should be sized for the design Ca(OH)_2 required (reference Eq. 3-8 in Section 3.2.1) divided by 0.95 to account for the inerts. Note: The design lime consumption injected into the duct(s) will be based on hydrated lime; the lime feeding capacity of the weigh belt feeders will be based on pebble lime; a conversion will have to be made between the two. For example, if the suppliers of pebble lime closest to the plant indicate that the range of CaO in their lime is 88-93%, the weigh belt feeders should be sized for the design CaO required (reference Eq. 3-9a in Section 3.2.1) divided by 0.88 to account for the inerts.

The hydrators can be operated either continuously, or on a batch basis, depending on plant operating philosophy. If the plant chooses to operate the hydrators continuously, or at least several hours each shift, then the capacity of the weigh belts and hydrators only needs to be based on the design hydrated lime usage in the duct(s) as suggested above. If the plant prefers that all of the hydrated lime for 24 hours of operation be generated on the day shift and stored in the hydrate bin, the capacity of the weigh belts/hydrators needs to be based on three times the design hydrated lime usage.

Grit which enters the hydrators with the pebble lime typically builds up in the seasoning chamber and must be cleaned out periodically by an operator. Since most of the grit remains in the hydrator, the hydrated lime product should contain 1% of grit or less. Other requirements of the hydrate produced are given in Appendix C.

Other design criteria for the weigh belt feeders and hydrators are contained in Spec. Nos. M106 and M108, respectively, in Appendix E.

The hydrator discharges into a surge chamber feeding a pneumatic conveyor that transfers the hydrate to a day bin (hydrate bin) located near the injection points. The rotary feeder which feeds the hydrate into the hydrate transfer conveyor and the pneumatic transfer conveyor itself would be sized to handle the design capacity of the hydrator. One dedicated rotary feeder and pneumatic transfer conveyor should be provided for each hydrator.

The hydrate transfer blowers should be sized for conveying velocities ranging from 2,500 to 3,000 ft/min. The air required for conveying the lime is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.05 lb air per lb lime is required compared to 0.075 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification (Spec. No. M105) in Appendix E.

Hydrate Bin

The hydrate bin should be fitted with a truck fill pipe as noted in DSI P&ID Sheet 4. This will allow truck delivery of hydrated lime to the plant in the event interruptions in the pebble lime supply are experienced, both hydrators are out of service, etc. Material, size, and fittings for this pipe are given in the silo/day bin specification in Appendix E.

Since there will be three fill lines to the hydrate bin (from the two hydrators and the emergency truck fill pipe), they each will require some way of being isolated. Otherwise, conveying air/lime will discharge from the truck fill pipe when either of the hydrate transfer conveyers is used, and/or one or both of the hydrate transfer lines could become plugged with lime dust when the truck fill pipe is used. Since the truck fill pipe will likely be used only sparingly, it can be isolated simply by using a cap at the quick coupling at grade. Each of the hydrate transfer conveying lines, however, should be fitted with a pneumatically operated isolation gate located as close as possible to the bin inlet connection.

The hydrate bin storage capacity should be either 8 or 24 hours worth of hydrate at the design hydrated lime usage. The decision to select 8 or 24 hours of capacity is based on whether the hydrators will be operated only one shift or all day as discussed above. A bulk density of 30 lb per cu ft may be used for capacity of hydrated lime.

Hydrated lime tends to form rat holes and craters which can cause arching or bridging in storage. The hydrate bin cone angle should be 70 degrees from the horizontal if no flow aid is utilized, or 60 degrees if fluidizing pads are installed. A bin activator or vibrator is not recommended on hydrated lime bins as they tend to pack the material rather than enhance the flow. Fluidizing pads are recommended in conjunction with a dedicated hydrate bin aeration blower. As noted in DSI P&ID Sheet 4, a spare aeration blower is not recommended. However, a tie-in from a plant service air line (with pressure reducing station) should be used as a back-up when the aeration blower is not available. If an air dryer is not installed downstream of the service air tie-in, instrument air should be used instead.

A minimum of four fluidizing pads should be installed starting at about 1-2 ft above the hopper outlet. The pads should be mounted directly to the hopper wall. The pads should be 8 in. to 12 in. wide and about 8 ft long depending on bin size. The fluidizing pads should be porous stone or polyester fabric with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. Although not shown on the P&IDs, a manually operated butterfly or ball valve should be installed in the line to each fluidizing pad for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing pad area. The aeration (fluidizing) blower should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air pads.

In areas of high humidity, an air dryer (desiccant type) is recommended for the fluidizing air as shown in DSI P&ID Sheet 4. Hydrated lime is quite hygroscopic, and moisture in the fluidizing air could cause agglomeration and flowability problems within the silo. The air dryer should be sized for the full fluidizing blower discharge flow.

An alternative to fluidizing pads is aeration flow cones. These devices are mounted directly to the hopper walls and use compressed air to aerate along the inside of hopper walls. The compressed air is released in a circular pattern, and the aeration results in undercutting and flowability of the lime. Such aeration flow cones are the Vibra-Jet Bin Aerator manufactured by Dynamic Air Conveying Systems of St. Paul, MN.

The hopper flow design for the hydrate bin should be mass flow, i.e., first in - first out. This eliminates an annular portion of the lime that remains in the bin until the level is drawn down very low. Any stagnant areas will likely form hard deposits over time due to the affinity of water to hydrated lime. An exception to mass flow design may be required if the bin location limits the available head room; mass flow design requires a relatively tall bin. In this case, expanded flow - with minimal dead areas in the bin - should be used.

The pressure relief device on top of the hydrate bin may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification.

The hydrate bin dust collector must be sized to filter the transport air when both positive pressure hydrate transfer conveyors are in operation simultaneously, in case the plant needs to operate both hydrators concurrently.

The use of an exhauster fan on the dust collector is optional. However, the slight negative pressure in the bin air space, created by the exhauster, will result in air in-leakage through any small openings in the bin roof instead of lime dust out-leakage, and it will minimize the possibility of lime dust filling and plugging an idle bin fill line. For silos/bins located indoors, an exhauster fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification.

Hydrated Lime Injection Equipment

Although there are a number of ways of metering the injected lime, the P&IDs show the lime being discharged from the bin through a variable speed screw feeder and into a dilute phase, positive pressure pneumatic conveying system through a constant speed air lock valve. The screw speed is controlled to maintain a specified SO_2 emission based on SO_2 monitor signal or coal sulfur and boiler load. Controls are discussed in Section 8.0

The injection conveyor should be a dilute phase pressure conveying system to provide a constant flow at the required pressure to the injectors. A single pipe would convey the lime to a distribution bottle near the flue gas duct where it is split into smaller, balanced loss pipes to each injector. Injector design is discussed in Section 6.2.1.

The conveyor piping should be routed either vertically or horizontally with no more than a 15 degree deviation from vertical or horizontal to minimize particle drop out in the pipe.

One hydrate screw feeder/rotary air lock should be provided per duct. Each hydrate screw feeder and hydrate rotary air lock should be sized for at least 100% of the design hydrated lime usage for that duct as adjusted for the lowest available calcium in the hydrated lime produced. For example, if the suppliers of hydrators indicate that the range of $\text{Ca}(\text{OH})_2$ in the hydrate produced from the pebble lime is 95-98%, the screw feeders and air locks should be sized for the design $\text{Ca}(\text{OH})_2$ required (reference Eq. 3-8 in Section 3.2.1) divided by 0.95 to account for the inerts.

Variable speed rotary feeders can be purchased, but they are typically not as accurate as screw feeders. For good lime feed control, screw feeders in series with constant speed rotary air locks are recommended. The additional advantage of this arrangement is that any blowback of

pressurized conveying air which leaks through the air lock will not prevent the lime from flowing out of the hydrate bin - it will dissipate through the screw feeder casing. A vent should be installed from the rotary air lock to the top of the bin to vent off this pressurized air (reference the P&IDs), but this vent line is prone to pluggage.

The hydrate injection pneumatic conveying system capacity for each duct should be at least 100% of the design hydrated lime usage rate for that duct as adjusted for the lowest available calcium in the hydrated lime produced. The hydrate injection blowers should be sized for conveying velocities ranging from 2,500 to 3,000 ft/min. The air required for conveying the lime is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.05 lb air per lb lime is required compared to 0.075 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification and the screw feeders specification (Spec. Nos. M105 and M107, respectively) in Appendix E.

A spare injection blower should be available when an in-service machine requires maintenance. For the two duct case shown in the P&IDs, a total of three blowers would be required - one dedicated to each duct with a common spare. A spare set of screw feeder/rotary air lock is not shown in the P&IDs. A third set is not recommended because of the complexity of tying in a common spare to the other two sets. In addition, with three chutes from the hydrate bin, it is more uncertain that lime will fill each chute properly compared to two chutes. Instead of a "hard piped" spare set of feeders, it is recommended that spares be available to replace the in-line screw feeder and/or rotary air lock in a minimum amount of time.

If only one duct requires lime injection, two 100% systems would be recommended.

6.1.2 Duct Spray Drying (Ref. DSD P&ID Sheets 3-5)

In DSD, 3/4 in. minus pebble lime (quicklime) will be received at the plant and stored in a pebble lime silo(s). From the silo(s), the lime will be fed to a slaking system which converts the pebble lime to a lime slurry; the lime slurry will then be pumped to dual-fluid or rotary atomizers in the flue gas duct. The equipment required would be essentially the same as that used in existing utility spray dryer installations except that no spray dryer vessels would be required.

Rail Car Unloading

Each rail car will hold about 100 tons of pebble quicklime. Each rail car will have two to four compartments/hoppers, each with a bottom discharge gate. The options for pneumatically unloading the car, and the corresponding equipment required, are discussed in detail in the rail car unloading system specification (Spec. No. M101) in Appendix E.

The unloading system capacity should be determined with two primary factors in mind: 1) the unloading rate should be high enough to unload the rail cars quickly, thereby minimizing demurrage on the rail cars and minimizing the operating labor required to "keep an eye" on the unloading, and 2) the unloading rate should be high enough such that, optimally, unloading may be accomplished Monday through Friday during the day shift.

Using the second criterion above, the design lime consumption [injected into the duct(s)] in ton/hr, multiplied by 168 hours in a week, gives the maximum tons for a week's supply of lime. These maximum tons divided by 40 hours (8 hours unloading per day Monday through Friday) gives a good estimate of the required lime unloading rate.

Typical capacities for a rail car unloading system range from 30-40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30-40 ton/hr, one or more of the following will have to be considered: 1) unloading during evening and/or graveyard shifts, 2) increasing the capacity of the rail car unloading system above 40 ton/hr (through discussions with system suppliers), and 3) the use of two unloading systems to allow unloading two cars at a time.

Typical pneumatic unloading conveying velocities range from 4,000 to 5,000 ft/min for pebble quicklime. The air required for conveying the lime is somewhat dependent on conveying distance. For an unloading conveying distance of 100 ft, about 0.11 lb air per lb lime is required compared to 0.16 lb air per lb lime for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the rail car unloading system specification.

Redundant blowers for either positive or negative pressure systems are typically not required; only one blower per service is suggested as shown on DSD P&ID Sheet 3 in Section 5.3. This is true because 1) the blowers should only operate 30-40% of the time allowing time for routine maintenance, and 2) as discussed below, provisions for truck unloading should be included in the storage silo - this will allow lime to be unloaded directly into the silo by truck-mounted blowers if one of the rail car unloading blowers is unavailable.

Truck Unloading

Even if rail is to be the principal mode of lime delivery, truck shipments will probably be needed from time to time to compensate for railroad strikes, problems with the rail car unloading system, etc. The storage silo should be fitted with a truck fill pipe as noted in DSD P&ID Sheet 3. If lime delivery by truck is the only mode utilized, two truck fill pipes per silo are recommended. Material, size, and fittings for this pipe are given in the silo/day bin specification (Spec. No. M102) in Appendix E.

If a rail car and truck fill line are connected to a silo, they each will require some way of being isolated. Otherwise, conveying air/lime will discharge from the truck fill pipe when the rail car unloading conveyor is used, and/or the rail car unloading line could become plugged with lime dust when the truck fill pipe is used. The truck fill pipe can be isolated simply by using a cap at the quick coupling at grade. When the truck fill pipe is used, the rail car unloading line should be blanked off to prevent lime dust from possibly filling up and plugging this line. If the truck fill pipe is to be sparingly used, a manual gate in the rail car unloading line is adequate. If the truck fill line is to be used frequently, a pneumatically operated isolation gate in the rail car unloading line would be more appropriate. Regardless of the type of operator, the gate in the rail car unloading line should be located as close as possible to the silo inlet connection. If two truck unloading lines are the only means of filling the silo, each should be furnished with a cap at the quick coupling at grade.

A pneumatic lime truck will hold about 25 tons of pebble quicklime. Because of the truck-mounted blower, the truck is essentially self-unloading, requiring only that the storage silo be equipped with a bin vent filter and pressure relief device. Pebble lime can be blown up to 100 ft vertically and 150 ft combined vertical and horizontal run with the truck-mounted blower. The intake end of the fill pipe should be mounted vertically, with the bottom about 4 ft above ground. The truck fill pipe should run vertically first, then horizontally. Normally, a truck can be unloaded in about 1 hour.

Pebble Lime Silo

Minimum lime storage capacity for a continuously operating facility is generally considered to be either 150% of the normal delivery quantity (e.g., enough capacity to hold 12 rail cars worth of lime if 8 rail cars is the normal delivery) or 10 days of storage at the design lime consumption (injected into the duct(s)), whichever is greater. A bulk density of 55 lb per cu ft may be used for capacity of pebble lime.

Whether to use one or more pebble lime silos depends on the design lime consumption, silo construction economy, and also on silo height. Since pebble lime can be unloaded 100 ft vertically using a truck-mounted blower, the silo straight wall height is limited to about 55 ft (considering the cone height and process equipment located underneath the silo). At a straight wall height to diameter ratio of 2.5, the

corresponding diameter is 22 ft, and the storage capacity (at a bulk density of 55 lb per cu ft) is about 575 tons. These calculations assume that the silo freeboard volume is approximately equal to the silo cone volume. Therefore, the approximate silo capacity can be calculated using the total straight wall height and ignoring the cone volume.

Pebble lime tends to form rat holes and craters which can cause arching or bridging in storage. The silo cone angle for pebble lime should be 60 degrees from the horizontal. A bin activator or vibrator is recommended on pebble lime silos to promote flow.

The hopper flow design for the pebble lime silo can be mass flow, expanded flow, or funnel flow as long as the hopper angle is 60 degrees. The pressure relief device on top of the pebble lime silo may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification and bin activator specification (Spec. No. M104) in Appendix E.

The pebble lime silo dust collector must be sized to filter the transport air from a positive pressure rail car unloading system and/or a truck-mounted blower. Normally, the rail car unloading system will not operate concurrent with the unloading of a truck, so the collector should be sized for the larger flow of the two which is usually the rail car unloading system. If truck unloading is the only means of filling the silo, and two truck fill pipes are installed, the dust collector should be sized for two trucks unloading concurrently (2 @ 800 cfm per truck gives 1,600 cfm). If a vacuum rail car unloading system is employed with the filter receiver located on top of the silo, a dust collector is still required, but it may be much smaller as it only needs to filter the air displaced from the silo as it fills with lime and/or filter the conveying air from a truck-mounted blower. In this case, the air from a truck-mounted blower (about 800 cfm) is used to size the dust collector.

The use of an exhaustor fan on the dust collector is optional. However, the slight negative pressure in the silo air space, created by the exhaustor, will result in air in-leakage through any small openings in the silo roof instead of lime dust out-leakage, and it will minimize the possibility of lime dust filling and plugging an idle silo fill line. For silos/bins located indoors, an exhaustor fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification (Spec. No. M103) in Appendix E.

If more than one silo is required for the required storage capacity, a rotary vane feeder would be attached to each silo cone. The feeders would discharge to a common screw conveyor. The flow from each silo would be controlled either by blending the flows together or by total flow from each silo in sequence. The common screw conveyor would feed a hopper or bin (probably requiring a bucket elevator); the hopper or bin would discharge to the downstream process equipment. If only one silo is used (as shown in DSD P&ID Sheet 3), the silo would discharge directly to the downstream process equipment.

Both a pebble lime silo and day bin are shown in the DSD P&IDs (Sheet 3). This equipment arrangement reflects a conservative configuration in which the silo has to be located relatively far away from the injection ductwork due to rail car unloading or other site-specific constraints. For this equipment arrangement, it is considered more feasible to pneumatically convey lime from the silo to a small day bin located near the injection point (and have the slurry preparation accomplished close to the injection point) than to prepare the slurry near the remote silo and pump it a long distance to the injection point. This is especially true because a slurry return line to the atomizer feed tank is normally required to keep slurry pipeline velocities high. From a practical standpoint, slurry should be prepared within 200 ft of the point of use. If the silo can be located close to the duct injection point, a separate lime day bin is not required.

If a separate pebble lime day bin is required, a positive pressure transfer conveyor will be required to pneumatically convey the lime from the silo to the day bin. A rotary air lock is attached to the silo cone to feed the lime into the transfer conveyor. The capacity of the rotary air lock/transfer conveyor should be three times the design lime consumption in the duct injection process. That way, a 24 hour capacity day bin can be filled in one shift (likely the day shift), or an 8 hour capacity day bin can be filled in a couple of hours.

Typical capacities for a pneumatic transfer conveyor range from 30-40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30-40 ton/hr, one or more of the following will have to be considered: 1) conveying for longer periods of time such as during the evening and/or graveyard shifts, 2) increasing the capacity of the transfer conveying system above 40 ton/hr (through discussions with conveyor suppliers), and 3) the use of two conveying systems to increase total conveying rate.

Typical pneumatic conveying velocities range from 4,000 to 5,000 ft/min for transfer of pebble lime. The air required for conveying the lime is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.11 lb air per lb lime is required compared to 0.16 lb air per lb lime for 400 ft. of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification (Spec. No. M105) in Appendix E.

A spare blower for the transfer conveyor is typically not required; only one blower is suggested as shown on DSD P&ID Sheet 3. This is true because 1) the blower should only operate 30-40% of the time allowing time for routine maintenance, and 2) as discussed below, provisions for emergency truck unloading should be included in the day bin - this will allow lime to be unloaded directly into the day bin by truck-mounted blowers if the transfer blower is unavailable.

Pebble Lime Day Bin

The pebble lime day bin should be fitted with a truck fill pipe as noted in DSD P&ID Sheet 3. This will allow truck delivery of pebble lime to the plant in the event there are problems with the silo unloading system, the silo itself, and/or the transfer conveyor from the silo to the day bin. Material, size, and fittings for this pipe are given in the silo/day bin specification in Appendix E.

Since there will be two fill lines to the day bin (from the transfer conveyor and the emergency truck fill pipe), they each will require some way of being isolated. Otherwise, conveying air/lime will discharge from the truck fill pipe when the transfer conveyor is used, and/or the transfer conveying line could become plugged with lime dust when the truck fill pipe is used. Since the truck fill pipe will likely be used only sparingly, it can be isolated simply by using a cap at the quick coupling at grade. Similarly, a manual gate in the transfer conveying line is adequate; this gate should be located as close as possible to the day bin inlet connection.

The pebble lime day bin storage capacity should be either 8 or 24 hours worth of pebble lime at the design lime usage. The decision to select 8 or 24 hours of capacity is based on whether the slakers will be operated only one shift or all day as discussed below. A bulk density of 55 lb per cu ft may be used for capacity of pebble lime.

Pebble lime tends to form rat holes and craters which can cause arching or bridging in storage. The day bin cone angle for pebble lime should be 60 degrees from the horizontal. A bin activator or vibrator is recommended on pebble lime day bins to promote flow.

The hopper flow design for the pebble lime day bin can be mass flow, expanded flow, or funnel flow as long as the hopper angle is 60 degrees. The pressure relief device on top of the pebble lime day bin may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification and bin activator specification in Appendix E.

The pebble lime day bin dust collector must be sized to filter the transport air from the positive pressure transfer conveyor and/or a truck-mounted blower. Normally, the transfer conveyor will not operate concurrent with the unloading of a truck, so the collector should be sized for the larger flow of the two which is usually the transfer conveyor.

The use of an exhaustor fan on the dust collector is optional. However, the slight negative pressure in the bin air space, created by the exhaustor, will result in air in-leakage through any small openings in the bin roof instead of lime dust out-leakage, and it will minimize the possibility of lime dust filling and plugging an idle bin fill line. For silos/bins located indoors, an exhaustor fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification.

Slaking Equipment

Although there are a number of ways of metering pebble lime into the slakers, the P&IDs show the lime being discharged from the day bin to two, redundant weigh belt feeders. Each 100% capacity weigh belt feeder feeds a 100% capacity lime slaker. Redundancy is recommended in this equipment due to its historically high maintenance; therefore, two 100% capacity trains are suggested.

The weight belt feeder is a short belt conveyor equipped with a weigh deck which measures the weight of lime carried on a section of the belt. Instrumentation adjusts a vertical gate and the speed of the belt so that only a set weight of material is allowed out of the pebble lime day bin and into the slaker. Weigh belt feeders are suggested in lieu of screw feeders because they are generally more accurate. Good control of the pebble lime and water feed rates to the slaker is required to produce a slurry with the proper characteristics.

The capacity of the weigh belt feeders and slakers should be at least 100% of the design pebble lime usage as adjusted for the lowest available calcium in the pebble lime received. For example, if the suppliers of pebble lime closest to the plant indicate that the range of CaO in their lime is 88-93%, the weigh belt feeders and slakers should be sized for the design CaO required (reference Eq. 3-16 in Section 3.2.2) divided by 0.88 to account for the inerts.

The slakers can be operated either continuously, or on a batch basis, depending on plant operating philosophy. If the plant chooses to operate the slakers continuously, or at least several hours each shift, then the capacity of the weigh belts and slakers only needs to equal the design pebble lime usage as suggested above. If the plant prefers

that all of the lime slurry for 24 hours of operation be generated on the day shift and stored in the lime slurry storage tank, the capacity of the weigh belts/slakers needs to be three times the design pebble lime usage.

Other design criteria for the weigh belt feeders are contained in the gravimetric feeder specification (Spec. No. M106) in Appendix E.

Three options are given in the P&IDs for slaking the pebble lime: 1) ball mills (Sheet 4A), 2) detention slakers (Sheet 4B), or 3) paste slakers (Sheet 4C).

Ball Mill Slakers

Ball mill slakers operate on the principle of a grinding ball mill (ref. DSD P&ID Sheet 4A). The ball mill slaker consists of a ball mill, an agitated ball mill sump, sump pumps, and a recycle cyclone or screen. Any core or grit which may be in the lime is effectively ground up and its lime value recovered. A separate grit removal system is not required. The lime and water are fed into the ball mill where they are mixed. Iron balls in the mill pulverize the larger particles and produce a finer particle size slurry. The slurry overflows the ball mill discharge into a sump tank that is agitated to keep the slurry in suspension. The slurry is pumped to either a cyclone separator or a vibrating screen where the larger particles are removed and recycled to the ball mill for further grinding. The undersize portion flows to an agitated lime slurry storage tank and then to the process. Because extremely fine grinding is not the primary function of the mill, fewer balls are added to the drum than in a typical grinding application. Only enough balls are added to ensure removal of the layers of unreactive scale which may form on the lime particles and to grind the grit material. The mill drum is sized to provide adequate retention time for the slaking reaction, usually 5-10 minutes. Typically, the solids content of the lime slurry from a ball mill slaker is 25-30% (specific gravity of 1.17-1.22).

The design solids content of the lime slurry from the ball mill slakers should range from 20-35% (specific gravity of 1.14 - 1.26). A 35% lime slurry is very viscous and is physically the upper limit. All of the non-inert solids in the slurry will be assumed to be in the form of Ca(OH)_2 if a high calcium pebble lime is used. The lime slurry should have 99% passing through 200 mesh and 90% passing through 400 mesh. It is anticipated that grit particles as large as 1/4 in. in size will occasionally discharge from the ball mill. Depending on the percent solids in the discharged lime slurry and on the temperature of the inlet slaking water, the temperature of the lime slurry which will discharge from the ball mill will range from 170-190°F. The pH of the lime slurry will be 12 plus. The chloride range will be the same range as in the slaking water as diluted due to the lime addition.

It is recommended that good quality raw water (less than 500 mg/l of sulfite, sulfate, or bisulfate ions, less than 100 mg/l of chlorides, and less than 1,000 mg/l of total dissolved solids) be used for dilution in the sump as well as for slaking.

The lime slurry which exits the ball mill discharges to a small ball mill sump. This tank gives time for slurry stabilization - for completion of all chemical reactions - before the slurry passes through pumps, small-bore piping, and valves. The storage capacity of this tank should be 5-10 minutes at the design lime consumption. The slurry from the ball mill is typically diluted in the ball mill sump. Typically, the solids content of the lime slurry will vary from 20-25% solids (specific gravity of 1.14-1.17).

It is recommended that ball mill slakers be mounted on concrete pedestals at grade - not on elevated floors. The ball mill sump height must be short enough such that the slurry can discharge from the ball mill to the sump by gravity. This requirement adds another criterion for the design and size of the ball mill sumps.

Ball mill sumps should have a minimum of 1-1/2 ft of freeboard (non-wetted wall height). These tanks should be designed such that their wetted wall height is approximately equal to the tank diameter. These tanks are vented to atmosphere, so the design pressure is atmospheric pressure plus the fluid static height. A design temperature at 250°F is adequate. These tanks will likely require personnel protection insulation or other means of protecting personnel because the tank walls will likely exceed 140°F at times. A coating or lining is not required.

The agitator in each sump will be required to keep the lime and grit solids in suspension as well as blend the dilution water with the lime slurry from the ball mill discharge. The agitator will be required to achieve complete off-bottom suspension. The agitator must be capable of handling slurries ranging from 20-30% solids.

Two 100%, redundant ball mill sump pumps should be provided per ball mill sump to transfer lime slurry to the lime slurry storage tank. These pumps should be designed to accommodate the 1/4 in. inerts that will be in the lime slurry from the ball mill. The capacity (in gpm) of each pump should be at least 110% of the lime slurry produced by the ball mill slaker, diluted to 20% solids, when the ball mill slaker is operating at its design capacity. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the ball mill sump even at design capacity. The pumps must be capable of handling slurries ranging from 20-30% solids. The design head and available NPSH for these pumps will depend on equipment layout.

Lime slurry piping may be unlined schedule 80 carbon steel. The piping should be designed as a loop system with recirculation back to the sump. The piping would be periodically flushed with water to remove any build-up that occurred.

The lime grit screen should have a 20 mesh screen. All slurry solids greater than 20 mesh will be recycled back to the ball mill inlet. The capacity (in gpm) of the lime grit screen should be equal to the capacity of each ball mill sump pump. The grit screen must be capable of handling slurries ranging from 20-30% solids. The slurry should

have 99% of the slurry particles passing through 200 mesh. A cyclone classifier with the same design criteria listed above could be used instead of the vibrating screen.

Other design criteria for the ball mill slakers, ball mill sumps, agitators, sump pumps, and lime grit screens are contained in Spec. Nos. M109, M113, M114, M115, and M112, respectively, in Appendix E.

A slaking water heater is recommended to preheat the slaking water during one or more of the following situations: 1) slaker start-up, 2) when the slaking water is very cold resulting in a lime slurry temperature out of the ball mill of less than 170°F, and/or 3) when the lime quality is poor resulting in a lime slurry temperature out of the ball mill of less than 170°F. The slaking water heater will typically be rated for 150 psig saturated auxiliary steam on the shell side. The exchanger should be rated to heat up 100% of the required slaking water flow from 35°F to 135°F when the ball mill slaker is operating at its design capacity.

Detention Slaker

The detention slaker is probably the simplest of the three slakers. It consists of a slaking compartment and a classifier compartment (ref. DSD P&ID Sheet 4B). The slaking section is comprised of a steel tank and an impeller type mixer(s) supported by tank spanning beams. It is designed to promote rapid, intimate contact. The flared tank classifier compartment is connected to the slaker by submerged slurry passage ports. It consists of heavy duty reciprocating rakes or a classifying screw, and a washed grit discharge section. Lime and slaking water are fed into the slaker through openings in the cover. After slaking, the slurry passes into the classifier where it is diluted and grit is settled. The classifier moves the grit up an inclined deck for a final water spray and then to the discharge container. The degritted milk of lime flows into a launder, which spans the classifier, and then to a vibrating grit screen. Slurry is retained in a detention slaker for 10-30 minutes. Quicklime and water are fed to the slaker in specific proportions. Typically, the ratio is adjusted in order to produce a slurry containing 20-25% solids (specific gravity of 1.14-1.17).

The design solids content of the lime slurry from the detention slakers should range from 20-30% (specific gravity of 1.14-1.22). The optimum water to lime ratio and resulting solids content varies somewhat among vendors' designs. All of the non-inert solids in the slurry will be assumed to be in the form of Ca(OH)_2 if a high calcium pebble lime is used. The lime slurry should have 99% passing through 200 mesh and 90% passing through 400 mesh. It is anticipated that grit particles as large as 1/4 in. in size will occasionally discharge from the detention slaker. Depending on the percent solids in the discharged lime slurry and on the temperature of the inlet slaking water, the temperature of the lime slurry which will discharge from the detention slaker will range from 170-190°F. The pH of the lime slurry will be 12 plus. The chloride range will be the same range as in the slaking water as diluted due to the lime addition.

It is recommended that good quality raw water (less than 500 mg/l of sulfite, sulfate, or bisulfate ions, less than 100 mg/l of chlorides, and less than 1,000 mg/l of total dissolved solids) be used for dilution in the classifier as well as for slaking.

The detention slakers should optimally be located on an elevated floor. In this arrangement, the slurry which overflows from the slaker flows by gravity through the lime grit screen and into the lime slurry storage tank. No pumping would be required.

The lime grit screen should have a 20 mesh screen. All slurry solids greater than 20 mesh will discharge into the same grit bin as the grit removed in the slaker classifier. The grit bin should be a dumpster capable of being removed through a roll-up door using existing plant equipment. The capacity (in gpm) of the lime grit screen should be equal to the lime slurry produced by the detention slaker, diluted to 20% solids, when the detention slaker is operating at its design capacity. The grit screen must be capable of handling slurries ranging from 20-30% solids. The slurry should have 99% of the slurry particles passing through 200 mesh.

Other design criteria for the detention slakers and lime grit screens are contained in Spec. Nos. M110 and M112, respectively, in Appendix E.

A slaking water heater is recommended to preheat the slaking water during one or more of the following situations: 1) slaker start-up, 2) when the slaking water is very cold resulting in a lime slurry temperature out of the slaker of less than 170°F, and/or 3) when the lime quality is poor resulting in a lime slurry temperature out of the slaker of less than 170°F. The slaking water heater will typically be rated for 150 psig saturated auxiliary steam on the shell side. The exchanger should be rated to heat up 100% of the required slaking water flow from 35°F to 135°F when the slaker is operating at its design capacity.

Paste Slaker

The paste slaker consists of a slaking compartment with two sets of counter-rotating paddles acting as a pug mill for mixing. Water and quicklime are fed continuously and automatically by a torque-actuated water inlet valve (ref. DSD P&ID Sheet 4C). Increasing torque indicates that the lime paste is too thick so additional water is added to reduce the viscosity of the paste to the desired level. As the paste is discharged over a weir into a dilution compartment, a continuous water spray dilutes the paste to a slurry. The grit settles and moving rakes on the same shaft as the mixing paddles maintain proper agitation of the lime suspension to remove the grit to a classifier for discharge into an external enclosed elevator. The slurry then flows over a weir and out the discharge port. The grit is washed free of lime in the elevator, and the recovered lime water is returned to the dilution chamber. The washed grit exits the elevator into the discharge container. Slurry is retained in a paste slaker for about 5 to 10 minutes. Quicklime and water are fed to the slaker at

a 2:1 ratio resulting in about a 44% solids paste. In the dilution compartment, the paste is typically diluted to 20-25% solids (specific gravity of 1.14-1.17).

The design solids content of the lime slurry from the paste slakers should range from 20-30% (specific gravity of 1.14-1.22). The optimum water to lime ratio and resulting solids content varies somewhat among vendors' designs. All of the non-inert solids in the slurry will be assumed to be in the form of $\text{Ca}(\text{OH})_2$ if a high calcium pebble lime is used. The lime slurry should have 99% passing through 200 mesh and 90% passing through 400 mesh. It is anticipated that grit particles as large as 1/4 in. in size will occasionally discharge from the paste slaker. Depending on the percent solids in the discharged lime slurry and on the temperature of the inlet slaking water, the temperature of the lime slurry which will discharge from the paste slaker will range from 170-190°F. The pH of the lime slurry will be 12 plus. The chloride range will be the same range as in the slaking water as diluted due to the lime addition.

It is recommended that good quality raw water (less than 500 mg/l of sulfite, sulfate, or bisulfate, less than 100 mg/l of chlorides, and less than 1,000 mg/l of total dissolved solids) be used for dilution in the dilution compartment as well as for slaking.

The paste slakers should optimally be located on an elevated floor. In this arrangement, the slurry which overflows from the slaker flows by gravity through the lime grit screen and into the lime slurry storage tank. No pumping would be required.

The lime grit screen should have a 20 mesh screen. All slurry solids greater than 20 mesh will discharge into the same grit bin as the grit removed in the slaker classifier. The grit bin should be a dumpster capable of being removed through a roll-up door using existing plant equipment. The capacity (in gpm) of the lime grit screen should be equal to the lime slurry produced by the paste slaker, diluted to 20% solids, when the paste slaker is operating at its design capacity. The grit screen must be capable of handling slurries ranging from 20-30% solids. The slurry should have 99% of the slurry particles passing through 200 mesh.

Other design criteria for the paste slakers and lime grit screens are contained in Spec. Nos. M111 and M112, respectively, in Appendix E.

A slaking water heater is recommended to preheat the slaking water during one or more of the following situations: 1) slaker start-up, 2) when the slaking water is very cold resulting in a lime slurry temperature out of the slaker of less than 170°F, and/or 3) when the lime quality is poor resulting in a lime slurry temperature out of the slaker of less than 170°F. The slaking water heater will typically be rated for 150 psig saturated auxiliary steam on the shell side. The exchanger should be rated to heat up 100% of the required slaking water flow from 35°F to 135°F when the slaker is operating at its design capacity.

Choosing a Slaker

All three slakers described above have advantages and disadvantages. The discussion which follows will give the user some basis for choosing the slaker type to be used in a specific application. The best basis for making such a decision is on previous plant experience with one or more of the slaker types. Barring that, the discussion below (paraphrased from EPRI's Lime FGD Systems Data Book, 2nd ed., EPRI CS-2781, January 1983) may be useful.

The range of slaking conditions is limited in any type of slaker by the occurrence of drowning or burning conditions that produce low-quality slurry. Drowning is caused by the presence of too much water in proportion to lime and is indicated by a sharp drop in slaking temperature when the flow of water is increased slightly. The result is that the calcium hydroxide being produced adheres to the quicklime particles. Each quicklime particle is surrounded by a layer of relatively impervious and unreactive calcium hydroxide. Because of its grinding action, ball mill slakers are less susceptible to this type of problem than detention or paste slakers. At the other extreme, burning also produces particles of unreacted quicklime surrounded by a hard impervious layer of hydrate. In burning, insufficient water causes localized overheating at the surface of the quicklime particles. The very high temperatures that develop cause formation of unreactive oxide and hydrate crystals. Burning usually produces steam, which removes water from the mixture and causes a further increase in temperature when the flow of slaking water is decreased slightly. If not controlled, it will cause serious overheating that may damage the equipment.

A detention or paste slaker must include provisions for removing grit from the slurry. Grit consists of sand and similar impurities, plus the carbonate cores of quicklime pebbles that were not calcined during lime manufacture. Good-quality quicklime contains 1 to 2% grit; poor grades may contain up to 5%. The grit is usually discarded in a sludge pond or land fill. Grit particles that remain in the slurry cause abrasive damage to slurry handling equipment. Properly slaked slurry of pure hydrated lime can be considered nonabrasive, since the lime particles are soft, lightweight solids that do not scratch or erode metals. Ball mill slakers grind the grit to a fine size and do not produce a separate grit stream. The finely ground grit particles are included in the slaked lime slurry. The lime slurry from a ball mill may be somewhat abrasive.

None of these slaker types have proved superior for all applications. Each type offers certain advantages. Characteristics of these slakers are listed in Table 6-1.

Table 6-1
SLAKER CHARACTERISTICS

<u>Characteristic</u>	<u>Ball Mill Slaker</u>	<u>Detention Slaker</u>	<u>Paste Slaker</u>
Size of equipment for equal capacity	Smallest for large capacity	Large equipment	Intermediate equipment
Capacity of available equipment	Can be built in any capacity	Can be built in any capacity	Available only in standard capacities, limited to about 8000 lb quicklime/hr
Quality of quicklime	High quality or poor quality quicklime	High quality or medium quality quicklime	High quality quicklime
Lime size range	Can handle any size which can be handled by feeder	Can handle any size up to 2 in. lumps	Should be limited to particles smaller than 3/4 in.
Mechanical complexity	Moderately complex	Very simple	Moderately complex
Water-to-lime-ratio	Needs less slaking water	Needs more slaking water	Needs less slaking water
Slurry quality	Smaller particles	Larger particles	Usually slightly smaller particles
Initial cost of equipment of equal capacity	Intermediate cost	Least cost	Highest cost

The lime slurry storage tank should have a minimum of 3 ft of freeboard (non-wetted wall height).

Both high temperature and long retention time are required to slake some poor quality grades of quicklime. It is uneconomical to slake poor quality quicklime with paste slakers if it is necessary to operate several slakers at reduced capacity in order to provide adequate retention time. In a detention slaker, poor quality quicklime can be processed by heating the feed water, thereby providing both high temperature and longer retention time. Preheated water can also be used with a paste slaker, but the technique is less effective since the lower water-to-lime ratio limits the amount of preheat that can be used without causing burning. Ball mill slakers can economically slake poor quality quicklime by proper sizing of the reaction time. Preheating the slaking water would be beneficial but is not required.

Slakers must be ventilated to prevent condensation of vapor inside the weigh belt feeder. If the vapor is not allowed to escape, it condenses and reacts with lime dust to form hard deposits on the feeder surface. A slaker ventilation system must remove the hot, humid air. However, it should also be designed to prevent discharge of lime dust into the atmosphere. A ventilation system is shown for all of the slakers in the DSD P&IDs. A water operated eductor is shown that uses a portion of the dilution water to exhaust a small amount of air from the slaking chamber.

When quicklime is slaked in either a detention or a paste slaker, the quality of the resulting lime slurry is affected by the slaking water used. Impurities reduce the slaking rate and cause the production of large, dense particles of partially hydrated lime. The slurry may be more abrasive, thereby increasing the maintenance requirement for the system. As discussed earlier, ball mill slakers are less sensitive to water quality because the grinding action removes the coatings on the lime particles.

Reagent Storage and Injection Equipment

Regardless of which slaking method is employed, the lime slurry is stored in an agitated lime slurry storage tank (reference DSD P&ID Sheet 5). Only one tank is recommended to keep capital costs low and because of the historically high availability of such tanks. Two tanks would be recommended for increased reliability if adequate space and capital are available. The pump cross-ties and control system for two, redundant tanks, however, is complex.

This tank gives time for slurry stabilization - for completion of all chemical reactions - before the slurry passes through pumps, small-bore piping, and valves. The storage capacity of this tank should be either 8 or 24 hours worth of lime slurry at the design lime usage. The decision to select 8 or 24 hours of capacity is based on whether the slakers will be operated only one shift or all day as discussed above. Typically, the solids content of the lime slurry will vary from 20-25% (specific gravity of 1.14 - 1.17).

The lime slurry storage tank should have a minimum of 3 ft of freeboard (non-wetted wall height). This tank should be designed such that its wetted wall height is approximately equal to the tank diameter. This tank is vented to atmosphere, so the design pressure is atmospheric pressure plus the fluid static height. A design temperature of 250°F is adequate. This tank will likely require personnel protection insulation or other means of protecting personnel because the tank walls will likely exceed 140°F at times. A coating or lining is not required.

The lime slurry storage tank agitator will be required to keep the lime solids (and ground grit if a ball mill slaker is used) in suspension. The agitator will be required to achieve complete off-bottom suspension. The agitator must be capable of handling slurries ranging from 20-30% solids.

Two 100%, redundant lime slurry pumps should be provided to transfer lime slurry to the atomizer feed tank. These pumps should pump only screened slurry with a maximum particle size of 20 mesh. The capacity (in gpm) of each pump should be at least 110% of the design lime consumption required for injection into the duct(s), diluted to 20% solids. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the lime slurry storage tank even at design capacity. The pumps must be capable of handling slurries ranging from 20-30% solids. The design head and available NPSH for these pumps will depend on equipment layout.

Lime slurry piping may be unlined schedule 80 carbon steel. The piping should be designed as a loop system with recirculation back to the storage tank so that flow to the atomizer feed tank can vary from minimum to maximum flow and still maintain enough velocity in the piping to minimize lime build-up inside the pipes. The piping would be periodically flushed with water to remove any build-up that occurred.

The lime slurry is pumped to an agitated atomizer feed tank. Only one tank is recommended to keep capital costs low and because of the historically high availability of such tanks. Two tanks would be recommended for increased reliability if adequate space and capital are available. The pump cross-ties and control system for two, redundant tanks, however, is complex.

This tank mixes the lime slurry, recycle slurry, and (possibly) dilution water before injection into the ductwork. The storage capacity of this tank must be small in order to allow rapid changes in slurry concentration as fluctuations in sulfur dioxide occur. A capacity of 15 minutes at the design lime consumption plus normal recycle ratio plus design water required for cooling the flue gas is recommended. Typically, the solids content of the feed slurry will vary from 30-40% (specific gravity of 1.22 - 1.30). However, the solids content could be as low as 20% (specific gravity of 1.14) with lime slurry only when the recycle system is unavailable.

The atomizer feed tank should have a minimum of 1-1/2 ft of freeboard (non-wetted wall height). This tank should be designed such that its wetted wall height is approximately equal to the tank diameter. This tank is vented to atmosphere, so the design pressure is atmospheric pressure plus the fluid static height. A design temperature of 200°F is adequate. No personnel protection is necessary on this tank. A coating or lining is not required.

The atomizer feed tank agitator will be required to keep the solids in suspension as well as blend the lime slurry, recycle slurry, and dilution water. The agitator will be required to achieve complete off-bottom suspension. The agitator must be capable of handling slurries ranging from 20% (lime slurry only) to 40% (lime plus recycle slurry) solids.

Two 100%, redundant atomizer feed pumps should be provided to pump the feed slurry from the feed tank to the atomizers at the required pressure. These pumps should pump only screened slurry with a maximum particle size of 20 mesh. The capacity (in gpm) of each pump should be at least 110% of the design lime consumption plus normal recycle ratio plus design water required for cooling the flue gas. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the atomizer feed tank even at design capacity. The pumps must be capable of handling slurries ranging from 20% (lime slurry only) to 40% solids. The design head and available NPSH for these pumps will depend on equipment layout and required slurry pressure at the atomizers.

Feed slurry piping may be unlined schedule 80 carbon steel. The piping should be designed as a loop system with recirculation back to the feed tank so that flow to the atomizers can vary from minimum to maximum flow and still maintain enough velocity in the piping to minimize build up inside the pipes. The piping would be periodically flushed with water to remove any build-up that occurred.

Other design criteria for the lime slurry and atomizer feed tanks, agitators, slurry pumps, and slurry valves are contained in Spec. Nos. M113, M114, M115, and M116, respectively, in Appendix E.

6.2 Duct Sorbent Injection/Flue Gas Humidification

6.2.1 Dry Sorbent Injection

In DSI, separate injection of the dry hydrated lime sorbent and humidification water are required. The humidification water is sprayed into the ductwork utilizing some kind of atomizer. At the time of publication of this handbook, dual-fluid nozzles have been developed for spraying the humidification water in DSI processes more extensively than rotary atomizers. Therefore, only dual-fluid nozzles are discussed in detail in this handbook. The hydrated lime sorbent is injected into the ductwork via injector pipes. The design and placement of both the humidification nozzles and sorbent injectors are discussed below.

6.2.1.1 Humidification Nozzle Design

Nozzles used for humidifying the flue gas are among the most critical components in a DSI process. Poor performance of the nozzles can lead to wall wetting, wet solids deposition, and frequent and costly equipment maintenance and downtime. Atomizer capacity, performance, and arrangement are critical in eliminating material deposition while maximizing SO_2 capture.

Nozzle Droplet Size

For successful duct injection of humidification water, the nozzles must be capable of providing a spray in which the largest droplets formed in the atomization process are sufficiently small to completely evaporate in the available residence time. The droplet size of the atomized sprays is recognized as a key parameter for achieving success.

For in-duct atomization of water, spray Sauter Mean Diameters of 20 to 40 microns are required. Additionally, the amount of spray mass above 100 microns must be small (1% or less) so that complete dryout of the droplets is attained. In all cases, the required Sauter Mean Diameter and largest acceptable drop size can be estimated based on the available gas residence time and the approach to saturation temperature.

Commercially available nozzles are capable of providing the required water droplet sizes, but the liquid capacities of these nozzles are small (0.08 to 2.0 GPM) and the air-to-water ratios are high (0.3 to 0.8 lb air per lb water).

Nozzle Liquid Capacity

The liquid capacity required for any specific duct injection application is determined based on the flue gas flow rate and temperature and on the desired approach to saturation temperature. However, the optimum number of nozzles to provide the total liquid flow rate is not well understood at this time.

The results of past and on-going projects indicate that multiple small nozzles perform better than a single larger nozzle even when the droplet size distribution is the same for both cases. This appears to be the result of small nozzles causing less disturbance to the gas flow. However, all of the projects have used a trial and error approach. At this time, there is no methodology for specifying either the nozzle capacity or the geometry of a nozzle array.

Droplet Trajectory/Spray Angle

Nozzles of different designs provide sprays with widely varying droplet trajectory. Droplet trajectory influences nozzle performance because the initial direction of the high velocity spray can result in direct impingement of liquid on internal surfaces. In contrast, it is imperative that the spray adequately mix with the surrounding flue gas so that complete drying of the droplets can occur in the limited time available. Better performance has been achieved in tests with nozzles that provide a spray trajectory with a smaller included angle. Nozzles with a single discharge hole or with multiple holes oriented with a small included angle have achieved the highest success.

As with liquid capacity, there is no proven technique for specifying the spray angle of nozzles. A lower limit in spray angle is probably about 12 to 14 degrees which represents the expansion of a free jet. The upper limit on spray angle has not been defined, but correlations exist in the literature for relating droplet momentum and angle to droplet trajectory when injected into co-flowing gas of a known velocity. A 25 degree spray angle is a likely maximum.

Nozzle Hydraulic Characteristics

For successful DSI, uniform profiles of temperature and velocity across the duct cross section have been shown to be important. Likewise, the mass flux of injected water must be uniform across the duct cross section. A poor distribution of gas temperature, gas velocity, and/or liquid mass flux (as droplets) will result in localized regions of saturated gas that can lead to wetting and deposition.

Additionally, the droplet size performance of each of the nozzles on an array should be identical. In small-scale applications which involve 1 to 10 nozzles, it is feasible to monitor the flows of air and water to each individual nozzle. However, with larger arrays of nozzles, this approach is no longer practicable. Rather, multiple nozzles are manifolded into a parallel array and controlled by a single source of air and water. With this geometry, it is imperative that each of the nozzles in a group perform identically. Otherwise, for each nozzle supplied with a common water pressure, the water flow to each could be substantially different.

Arrays of nozzles for DSI will require very good part-to-part repeatability and consistency in hydraulic characteristics and atomization performance. Also, the sensitivity of the nozzles

(i.e., variation in flow rate with pressure) must be sufficiently low so that normal process variation does not result in water flow maldistribution across the duct.

Materials of Construction

For humidification water nozzles, the material of construction is typically 316 stainless steel. Hastelloy is recommended if the chloride level in the water is above LATER ppm.

If water quality is questionable (containing suspended solids above LATER ppm), a two-stage filtering system should be provided (reference section 6.7.1) and/or ceramic inserts for the spray nozzles are suggested.

6.2.1.2 Humidification Nozzle Placement

The humidification nozzle headers should be in the form of an airfoil to reduce build-up on the upstream edge of surfaces.

The most successful duct injection projects have utilized arrays (totaling 10 to 100 nozzles) of small capacity nozzles to achieve atomization with acceptable amounts of deposition. The geometry of nozzle arrays that provides good performance without deposition is difficult to determine without detailed modeling. Suggested clearances are 1 ft between nozzles (both horizontally and vertically) and 2 ft between the outer-most nozzles and the duct walls and ceiling. For horizontal ducts, the spacing between the lower-most nozzles and duct floor should be about 3 ft.

6.2.1.3 Sorbent Injector Design

The dry sorbent injector designs fall in two basic categories:

1. Cross Duct Lances
2. Parallel Flow Injectors

Cross Duct Lances

The cross duct lances consist of several pipes that extend the full width (or height) of the flue duct. There are holes in the pipes that disperse the sorbent parallel to the gas stream (reference Figure 6-1).

Cross duct lances typically consist of 6 in. pipes connected to a header. Each pipe is drilled with 2-3 in. diameter injection nozzles (holes) spaced every 3 ft along the pipe. The nozzles point downstream, concurrent with the direction of flue gas flow.

Due to the geometry of the injection system, vertical pipes tend to fill from the bottom with settled reagent. As the level increases, the lower injection nozzles along the pipe would become obscured and rendered inoperative. Therefore, horizontally-oriented pipes are recommended.

Cross duct lances give good dispersion with low conveying pressure. The main concerns with this type of injector are that the lances cause a significant obstruction to the gas flow and that pluggage of the holes is possible.

Parallel Flow Injectors

An alternative to the cross duct lances is a series of single point parallel flow injectors. Each injector would consist of a 1 1/2 - 2 in. diameter pipe installed across the duct cross section. The pipes would enter from the top of the duct (for horizontal ducts) and are of varying length. Each pipe ends in an elbow that turns the sorbent stream so that it is injected parallel to the gas flow (Figure 6-2). The pipes would be spaced about 3 ft apart horizontally and would be of varying lengths so that the vertical spacing (for horizontal ducts) is also about 3 ft. The pneumatic blower system used to transport the fresh sorbent (and recycle material) should be designed to produce velocities of 40-80 ft/sec at the injector outlet.

Recycle material injection may be used to reduce fresh lime consumption (reference section 6.5.2.1). Although combining the recycle material with the fresh sorbent would likely result in the best distribution within the duct, this is not recommended so as to preserve operation if the recycle system is not available.

6.2.1.4 Sorbent Injector Placement

In DSI, the hydrated lime must be dispersed in such a manner as to obtain rapid mixing, uniform distribution, and maximum utilization of the sorbent. The location of the sorbent injectors within the existing ductwork is critical for two major reasons. First, adequate retention time is required for SO_2 removal by the hydrate before the gas enters the ESP. Second, proper mixing and distribution of the sorbent across the duct cross section is required to promote optimum SO_2 removal and minimize wall deposition. The sorbent injection point should be in a straight duct section for proper mixing and distribution, and it should be upstream of the ESP as far as possible to maximize retention time.

Operation with sorbent injection downstream of humidification may result in significant build-up of fly ash on duct walls just downstream of the humidification nozzle array. In addition, severe corrosion to the sorbent and ductwork immediately downstream of the water nozzles may result due to high levels of SO_3 in the humidified flue gas.

In upstream sorbent injection, sorbent particles come in direct contact with, and are encapsulated by, water droplets sprayed into the duct downstream of the sorbent injection point (scavenging), and the sorbent utilization is significantly higher. It is believed that wall wetting deposition problems will not be severe in the full-scale duct since the humidification nozzles can be adequately spaced. In addition, corrosion potential is reduced because, with upstream sorbent injection, the alkaline sorbent will remove most of the SO_3 before it contacts the humidification section.

Upstream hydrate injection is decidedly more beneficial from an SO₂ removal standpoint than downstream injection. Therefore, sorbents should be injected upstream of, or in the same plane as, the humidification water. Injection of the sorbent in the coplanar configuration minimizes the build-up of sorbent on the upstream edge of the nozzle array. Therefore, it is recommended that the sorbent injection system be located in the same plane as the humidification system.

If used, each recycle injector would be located about 6 in. to 1 ft away from its corresponding fresh sorbent injector.

6.2.2 Duct Spray Drying

For DSD, the lime reagent, humidification water, and recycle material (if used) are mixed together before injection into the duct. The resulting slurry is sprayed into the ductwork utilizing some kind of atomizer. At the time of publication of this handbook, dual-fluid nozzles have been developed for spraying the slurry in DSD processes more extensively than rotary atomizers. Therefore, only dual-fluid nozzles are discussed in detail in this handbook. The design and placement of the slurry nozzles are discussed below.

6.2.2.1 Slurry Nozzle Design

Nozzles used for spraying slurry are among the most critical components in a DSD process. Poor performance of the nozzles can lead to wall wetting, wet solids deposition, and frequent and costly equipment maintenance and downtime. Atomizer capacity, performance, and arrangement are critical in eliminating material deposition while maximizing SO₂ capture.

Nozzle Droplet Size

For successful duct injection of slurry, the nozzles must be capable of providing a spray in which the largest droplets formed in the atomization process are sufficiently small to almost completely dry in the available residence time. The droplet size of the atomized sprays is recognized as a key parameter for achieving success.

For in-duct atomization of slurry, spray Sauter Mean Diameters of 20 to 40 microns are required. Additionally, the amount of spray mass above 100 microns must be small (1% or less) so that near complete dryout of the droplets is attained. In all cases, the required Sauter Mean Diameter and largest acceptable drop size can be estimated based on the available gas residence time and the approach to saturation temperature.

Commercially available nozzles are capable of providing the required slurry droplet sizes, but the liquid capacities of these nozzles are small (0.08 to 2.0 GPM) and the air-to-slurry ratios are high (0.3 to 0.8 lb air per lb slurry).

Nozzle Liquid Capacity

The liquid capacity required for any specific duct injection application is determined based on the flue gas flow rate and temperature and on the desired approach to saturation temperature. However, the optimum number of nozzles to provide the total liquid flow rate is not well understood at this time.

The results of past and on-going projects indicate that multiple small nozzles perform better than a single larger nozzle even when the droplet size distribution is the same for both cases. This appears to be the result of small nozzles causing less disturbance to the gas flow. However, all of the projects have used a trial and error approach. At this time, there is no methodology for specifying either the nozzle capacity or the geometry of a nozzle array.

Droplet Trajectory/Spray Angle

Nozzles of different designs provide sprays with widely varying droplet trajectory. Droplet trajectory influences nozzle performance because the initial direction of the high velocity spray can result in direct impingement of liquid on internal surfaces. In contrast, it is imperative that the spray adequately mix with the surrounding flue gas so that near complete drying of the droplets can occur in the limited time available. Better performance has been achieved in tests with nozzles that provide a spray trajectory with a smaller included angle. Nozzles with a single discharge hole or with multiple holes oriented with a small included angle have achieved the highest success.

As with liquid capacity, there is no proven technique for specifying the spray angle of nozzles. A lower limit in spray angle is probably about 12 to 14 degrees which represents the expansion of a free jet. The upper limit on spray angle has not been defined, but correlations exist in the literature for relating droplet momentum and angle to droplet trajectory when injected into co-flowing gas of a known velocity. A 25 degree spray angle is a likely maximum.

Nozzle Hydraulic Characteristics

For successful DSD, uniform profiles of temperature and velocity across the duct cross section have been shown to be important. Likewise, the mass flux of injected slurry must be uniform across the duct cross section. A poor distribution of gas temperature, gas velocity, and/or liquid mass flux (as droplets) will result in localized regions of saturated gas that can lead to wetting and deposition.

Additionally, the droplet size performance of each of the nozzles on an array should be identical. In small-scale applications which involve 1 to 10 nozzles, it is feasible to monitor the flows of air and slurry to each individual nozzle. However, with larger arrays of nozzles, this approach is no longer practicable. Rather, multiple nozzles are manifolded into a parallel array and controlled by a single

source of air and slurry. With this geometry, it is imperative that each of the nozzles in a group perform identically. Otherwise, for each nozzle supplied with a common slurry pressure, the slurry flow to each could be substantially different.

Arrays of nozzles for DSD will require very good part-to-part repeatability and consistency in hydraulic characteristics and atomization performance. Also, the sensitivity of the nozzles (i.e., variation in flow rate with pressure) must be sufficiently low so that normal process variation does not result in slurry flow maldistribution across the duct.

Materials of Construction

For slurry nozzles, the material of construction is typically 316 stainless steel with ceramic or silicon carbide inserts for erosion resistance.

6.2.2.2. Slurry Nozzle Placement

The slurry nozzle headers should be in the form of an airfoil to reduce build-up on the upstream edge of surfaces.

The most successful duct injection projects have utilized arrays (totaling 10 to 100 nozzles) of small capacity nozzles to achieve atomization with acceptable amounts of deposition. The geometry of nozzle arrays that provides good performance without deposition is difficult to determine without detailed modeling. Suggested clearances are 1 ft between nozzles (both horizontally and vertically) and 2 ft between the outer-most nozzles and the duct walls and ceiling. For horizontal ducts, the spacing between the lower-most nozzles and duct floor should be about 3 ft.

6.3 Ductwork Modifications

6.3.1 Ductwork Internals

This section provides suggestions for modifications to existing ductwork internals to facilitate the retrofit and operation of a duct injection system. These discussions and resulting modifications will hopefully minimize material build-up. Section 6.3.3 deals with specific design considerations that will likely be required to accommodate material deposition if it occurs.

6.3.1.1 Gas Velocity and Temperature Profile to the Injection Point

Since this project involves scrubbing the flue gas by injecting sorbent into existing ducts, it is necessary to know the flue gas velocity and temperature profiles inside the duct upstream and downstream of the injection location. Knowledge of the velocity profiles is necessary because a proper profile can stop the sorbent from directly impacting the wall, maintain sorbent entrainment, ensure proper residence time for chemical reaction and drying, and maximize sorbent and flue gas mixing to promote maximum contact with SO_2 . The temperature profiles must be known so that it can be determined whether the flue gas temperature will remain above the water dew point and the acid dew point to prevent condensation on, and corrosion of, the duct walls; in addition to corrosion, wet walls will result in material deposition and wall build-up. Also, knowing the temperature profile facilitates control of the amount of humidification necessary to hold the desired approach temperature for chemical reaction.

The velocity profile at the exit of the air heater heat transfer surface is generally considered to be uniform. There is usually sufficient pressure drop in the air heater heat transfer surface to dampen out most flow nonuniformities that may have been present upstream of the air heater. However, at the air heater outlet, the temperature profile can be nonuniform and independent of the velocity profile. As the flue gas flows from the air heater outlet to the injection location, either profile can become more or less uniform depending upon the duct configuration. It is in this section of the ductwork that distribution devices may be necessary to correct the velocity and/or temperature profiles to provide the required distribution prior to the injection location.

Turning vanes used to correct a velocity profile will not necessarily correct a temperature profile. When using turning vanes, if there is a maldistribution in temperature upstream of the vanes, the same temperature maldistribution will exist downstream because the vanes do not increase gas mixing. Only gas mixing can correct an uneven temperature distribution, which would require additional pressure drop that may not be available in a retrofit application. Therefore, it is imperative that criteria be established for acceptable velocity and temperature profiles at the injection location.

The Industrial Gas Cleaning Institute (IGCI) has set criteria for the velocity profile entering an electrostatic precipitator. The IGCI standards state that a fixed percentage of the velocity data points at a given location cannot be greater than the average value by a fixed amount:

- ° 85% of the measured velocities less than 1.15 times the average velocity
- ° 99% of the measured velocities less than 1.40 times the average velocity

This type of criteria ensures that there are no local velocity high spots in the velocity profile.

The Air Movement and Control Association (AMCA) has set up standards for the velocity profile entering a fan. Their criteria ensure that the velocity profile is uniform for both high and low values of local velocity by forcing the standard deviation of the velocity data to be within a specified limit. These AMCA conditions are slightly more strict than those of the IGCI, but either set of criteria can be used as a guideline for duct injection.

The velocity and temperature profiles at the injection point need to be measured to determine if corrective devices are needed. The recommended minimum number of traverse points for rectangular ducts is indicated in Figure LATER. For rectangular ducts with cross-sectional areas of 24 sq ft and less, the recommended minimum number is 24. For cross-sectional areas greater than 24 sq ft, the minimum number of points increases as indicated in Figure LATER. The points are to be located in the centers of equal areas with the areas as nearly square as practical. Fewer points may be used if the flow is very uniform; however, the maximum area covered per point should not exceed 3 sq ft.

Once the velocity profile at the injection point is determined, it must be compared to the IGCI or AMCA criteria noted above. If the existing velocity profile is poorer than these criteria, turning vanes and/or distribution plates must be installed upstream to achieve these minimum criteria. These modifications should be implemented per ASHRAE or AMCA 210 recommendations.

If the existing temperature profile is poorer than the criteria given above, devices must be installed upstream to increase gas mixing.

A scale flow model can be used to determine the internal corrective devices in the duct to provide the required velocity and temperature profiles upstream of the injection location before installing these devices in the full size unit. The flow model can also be used to minimize the system pressure drop for the retrofit application.

6.3.1.2 Modifications to Duct Internals Downstream of the Injection Point

The physical layout of the ductwork downstream of the injection point is important in minimizing material deposition. The ideal arrangement would be a straight duct without any internals such as stiffeners, bracing, turning vanes, etc. This is rarely the case.

It is recommended that all internal bracing and/or stiffeners be removed and replaced with external stiffeners. This is typically an expensive and involved changeout because it requires removal and reinstallation of duct insulation. It is considered necessary, however, to eliminate potential sites for material deposition.

Thermocouples located downstream of water or slurry injection but upstream of the particulate control device should be shielded from the wet solids and/or water droplets. Unshielded thermocouples may be used downstream of the humidification zone if they are located far enough downstream that evaporation is complete. Thermocouple number, location, and design are discussed in more detail in Section 8.0 and are shown in the P&IDs, Section 5.3.

If turning vanes are located in the ductwork downstream of water or slurry injection, build-up will occur on them unless evaporation is complete before the solids reach the vanes. Typically, this build-up will necessitate shutdown and manual cleaning. Therefore, duct injection retrofit is not recommended in a section of ductwork containing turning vanes unless sufficient residence time exists to completely dry all droplets. Even then, coating the vanes with a non-stick surface coating, such as Teflon, and installing rappers on the vanes is recommended.

6.3.2 Ductwork Externals

This section provides suggestions for modifications to existing ductwork externals to facilitate the retrofit and operation of a duct injection system.

6.3.2.1 Support Steel

The design of the existing ductwork support structural steel must be evaluated to determine if it can accommodate normal levels of solids build-up and large amounts of material deposition in an upset condition. In an upset condition, material @ 100 lb per cu ft could fill the duct half full before it is noticed.

6.3.2.2 Access Doors/Viewports

Access doors (24 in. x 30 in. high) should be added in the duct to allow access to the duct injection equipment and to facilitate cleanout. Two access doors should be available on each side of the duct - one at the spray injection equipment, and one about 20 ft downstream. To aid in visual inspection and troubleshooting, viewports should be provided at the water nozzle grid and at the sorbent

injection location for DSI or at the slurry nozzle grid for DSD. A minimum of the two such viewports should be provided on each side of the duct.

6.3.2.3 Test Ports

Test ports are recommended upstream and downstream of the duct injection location to facilitate performance testing and troubleshooting/diagnostics. The number and location of the test ports should be determined per 40 CFR Part 60, Appendix A, Reference Method 1.

6.3.2.4 Access Platforms

Permanent access platforms with toeplate and handrail should be provided to the new access doors, viewports and test ports. For the access platforms at the test ports, the handrail should be removable to facilitate test probe handling.

6.3.2.5 Load Cells/Strain Sensors

Detecting the start of material build-up is important in order to take immediate corrective action. Duct skin thermocouples are not considered as reliable as external load cells or strain sensors (such as Kistler-Morse Microcell Sensors). These devices should be mounted on each main vertical support member for the ductwork between the injection point and ESP. The output signals can be sent to stand-alone displays or can be tied into the duct injection control system. The control room indication should be alarms as a minimum.

6.3.2.6 Insulation

Ductwork insulation is important to minimize corrosion of internal duct surfaces downstream of humidification. A minimum of 3 in. of insulation should be installed on all duct services, and 4 in. would be even better. This applies to the ductwork between the ESP and chimney as well.

6.3.3 Deposition Control Modifications

Some level of material deposition is likely inevitable, under certain operating conditions, no matter how well the duct injection system is designed. Poor nozzle performance, nozzle erosion, load swings, and unsatisfactory ductwork geometry and/or unsatisfactory gas velocity or temperature profiles can be major causes of material deposition.

Most power plant ductwork is rectangular, contains several turns, and may lack flow straightening devices. Rarely does it contain the long, square, straight sections needed to eliminate material deposition. Therefore, the sorbent and water injection scheme will be heavily dependent on the particular ductwork layout and geometry.

Deposition occurs by several mechanisms, depending on the specific technology being applied. The two main mechanisms are direct impingement of slurry or water sprays on duct surfaces, and incomplete evaporation of droplets that impact with duct walls or other internals. Deposition may range from a thin coating to thick layers that choke off almost the entire cross section of the duct. Material deposition can lead to boiler downtime and increased maintenance costs. Therefore, any successful commercial application of duct injection technology must limit material deposition to manageable levels.

Material deposition is typically progressive, i.e., wall deposits lead to greater impingement and accelerated growth. Methods need to be employed to remove the deposits quickly after they form. Research has shown that material deposition is usually confined to a small area within the duct. Installation of appropriate solids handling equipment is recommended in this "affected zone" where deposition can be expected. One or more of the following suggestions should be implemented to minimize solids build-up.

6.3.3.1 Sootblowers

Sootblowers are effective at removing wall and floor deposits in a localized area. They are usually used in conjunction with a hopper(s) to collect the material which is dislodged from the walls. The sootblowers should be rated at about 100 scfm each and use 100 psig air. They should be mounted on 10 ft centers in the walls and ceiling of the affected zone. The sootblowers should be mounted flush with the duct wall or recessed a fraction of an inch so as not to create any projection into the gas stream.

6.3.3.2 Droplet Impingement Devices

Droplet impingement devices (DIDs) consist of two staggered rows of heated pipes installed just before a duct bend, the perforated plate at the ESP inlet, or other location which cannot tolerate unevaporated droplets. Water or slurry droplets which are not evaporated are forced to impact the DIDs. The deposits that form on the pipes are removed by periodic rapping and fall into a hopper installed underneath. DIDs are normally not required unless a residence time of less than 10 seconds is available to the bend, perforated plate, or other flow disturbance.

Each row of pipes should be 10 in. diameter on 10 in. centers (50% open area for each row). The two rows should be 10 ft apart (reference Figure 10). The pipes may be heated by 10.

6.3.3.3 Sonic Horns

Sonic horns have been tested in duct injection systems, but it is not clear how effective they are at minimizing duct wall deposition. When used, they have been mounted upstream of the nozzles/injectors with the bell pointing downstream. This arrangement minimizes solids building up in the bell.

6.3.3.4 Air Lances

The humidification nozzles in DSI or slurry nozzles in DSD are relatively cold during operation as they have "cold" water or slurry flowing through them. It is likely that fly ash will build up on their upstream surfaces. In addition, if sorbent injection is located upstream of the humidification nozzles in the DSI process, significant build-up of sorbent will occur on the upstream surfaces of the humidification nozzles.

Air lances may be installed, either fixed or moving type to blow compressed air on upstream surfaces of the nozzles and support structure. Nominal air pressure should be 100 psig.

6.3.3.5 Rappers

Rappers are recommended to dislodge solids build-up on nozzles and the nozzle support structure. The vertical support beams of the nozzle array may be extended through the top of the duct roof plate (or through the side of vertical ducts). Rappers may be installed to rap the protruding support beams.

6.3.3.6 Hoppers

As noted in several previous sections, installation of a hopper(s) is recommended to collect dislodged materials in the affected zone in horizontal ducts. In vertical ducts, installation of a hopper is recommended at the bottom of the vertical run.

For hoppers located in horizontal ducts, material tends to build up at the point where the downstream side of the hopper is attached to the duct floor. Therefore, it is recommended that a sootblower be installed near the duct floor just downstream of the hopper. This sootblower would consist of a 2 to 2-1/2 in. pipe with LATER in. holes drilled in it on LATER in. centers. The holes are located so that the sootblowing air is injected upstream (into the on-coming flue gas) to blow any material build-up into the hopper.

The hopper should have a minimum of 24 in. diameter (if round) or 24 in. by 24 in. opening at the bottom. It should be fitted with a crusher or lump breaker of some kind to grind the lumps before the material enters the ash handling system. The hopper valley angle should be at least 60 degrees with the horizontal.

The hopper should be provided with hopper heaters on at least the bottom third of the vertical height of the hopper, including the hopper outlet throat. The entire hopper should be insulated. Each hopper shall be provided with one solid steel strike bar that shall protrude through the insulation to be used as a striking anvil to relieve hopper plugging. Two 4 in. pipe nipples fitted with pipe caps (or equivalent removable cover), extending 4 in. beyond all adjacent insulation and lagging, shall be located near each hopper outlet flange to permit emergency rodding.

Each hopper shall be equipped with a high dust level alarm device, consisting of a nuclear level sensor. This device shall include one source and detector attachment per hopper and two normally closed contacts.

6.3.3.7 Non-stick Coatings

The duct walls and ceiling (for horizontal ducts) may be lined with a non-stick coating to minimize material deposition. The coating would require a temperature rating of the normal air heater outlet temperature plus at least 50°F to account for upsets. These types of coatings have not been tested in duct injection applications, and their usefulness has not been verified.

6.4 Particulate Collection Device Modifications

6.4.1 Electrostatic Precipitators

One of the most important issues to be addressed in the retrofit of a duct injection system is the ability of an existing electrostatic precipitator (ESP) to maintain emission levels after the retrofit. Depending on the desired SO_2 removal and coal sulfur content, duct injection will increase the mass loading to an ESP by 5-15 gr/acf; this corresponds to an increase in loading to the ESP by a factor of 3-12. An ESP basically operates on an efficiency basis which means that, at any set operating condition, an increase in inlet mass loading will result in an increase in outlet emissions. Therefore, in order to maintain particulate outlet loading and opacity levels while the inlet loading increases, ESP efficiency must increase.

6.4.1.1 Effects of Duct Injection on ESP Performance

Flue Gas Effects

The retrofit of a DSI or DSD process causes the following changes to the flue gas entering the ESP:

- Increase in particulate loading
- Decrease in temperature
- Increase in density
- Decrease in gas volume with corresponding decrease in velocity
- Increase in humidity
- Decrease in SO_2/SO_3 content

The decrease in flue gas volume flow rate results in a higher net ESP specific collection area (SCA) and a lower velocity. The increase in gas density allows the ESP to operate at higher power levels without back corona (sparking). These effects may allow better performance to offset the increase in particulate loading.

Low-Resistivity Dust

Humidification also results in a decrease in particulate resistivity. Tests indicate that, although calcium-based sorbents have very high (10^{13} to 10^{14} ohm-cm) resistivities at 300°F, the surface conditioning due to humidification and cooling reduces the resistivities of the ash/sorbent wastes from duct injection processes to extremely low (10^1 to 10^8 ohm-cm) values. This is primarily due to the low temperature, high humidity conditions in ESPs downstream of these processes.

Although reduced resistivity allows the particulate to be collected more easily, ESPs operating on low-resistivity dusts can experience rapping and scouring re-entrainment of the collected solids due to reduced holding forces. When re-entrainment is a problem, the emissions can increase by a factor of 10 or more. Scouring re-entrainment is strongly influenced by velocity.

Re-entrainment may also occur when low-resistivity particles on the ESP collecting plates reverse their polarity and are repelled from the plates. ESPs with large SCAs may have enough excess collecting area to compensate for re-entrainment problems.

Space Charge Quenching

Another potential effect of a duct injection retrofit upstream of an ESP is space charge quenching due to high concentrations of fine particles in the ESP inlet field. This current density reduction may be sufficient to reduce the charge on the particles resulting in reduced ESP collection efficiency. Because DSD results in larger particles, it may not result in such severe quenching effects.

Electrode Design

One retrofit concern is the cleanability of deposits from weighted wire type discharge electrodes when operating under duct injection conditions. Increased quantities, as well as physical properties of the ash/sorbent waste solids, may lead to increased wire deposits. If wire deposits increase with duct injection, they could lead to potential degradation of precipitator electrical conditions if the deposits cannot be easily removed by the existing rapper system. Increased rapping intensity can lead to more wire failures which result in reduced collection efficiency and higher maintenance cost.

6.4.1.2 Potential Options for Upgrading ESP Performance

As noted in Section 6.4.1.1, the retrofit of a duct injection system will cause both positive and negative effects on ESP performance. The net change in performance for a particular ESP is site specific and very difficult to determine in advance.

Several methods exist for increasing the efficiency of an existing ESP. Unfortunately, not all of these methods are applicable after the retrofit of duct injection technology. Many of these techniques for improving precipitator performance were developed to overcome problems associated with difficult to collect, high resistivity (10^1 to 10^3 ohm-cm) fly ash. As previously mentioned, the particulate resistivity will decrease with the application of a duct injection system.

Among the upgrade options not considered to be effective for duct injection retrofits are: SO_3 conditioning, cooled electrode precharging, wide plate spacing, pulsed energization, and intermittent energization. There are a number of strategies that have the potential to improve ESP performance in a duct injection system application.

1. Correcting gas velocity distribution
2. Increasing SCA
3. Collection plate modifications
4. Flue gas conditioning with ammonia
5. Increasing ESP operating voltage
6. Special discharge electrodes

These options may have to be implemented individually or in combination. Application criteria are site specific.

Correcting Gas Velocity Distribution

Industrial Gas Cleaning Institute (IGCI) guidelines for ESP gas distribution recommend that 85% of velocity readings fall within 25% of the average velocity and no readings be more than 40% from the average value. The velocity distribution at the ESP inlet should be measured. It may be necessary to modify the inlet section by adding turning vanes or perforated plates to create an even gas flow per IGCI guidelines and by adding baffles to prevent sneakage.

Increasing Specific Collection Area (SCA)

Some ESPs may need to be enlarged to meet the required emission levels. Although expensive, 20% additional SCA can be created by increasing only the ESP height of many ESPs. Larger SCA increases would require additional precipitator fields which add to the space occupied by the ESP and would involve a significant capital cost. Nevertheless, increasing the SCA of an existing ESP is an option that should be evaluated if the duct injection process results in increased emissions.

The addition of a second ESP in parallel with the existing ESP to increase SCA has some special advantages. Re-entrainment due to low resistivity is a strong function of velocity. In these cases, a small decrease in velocity can cause a large decrease in emissions. A second ESP in parallel with the existing ESP will allow both ESPs to operate at lower gas velocities while providing an increase in SCA. An additional advantage of adding a parallel ESP is that the boiler does not have to be taken off-line during construction; only a short outage is necessary for tie-in.

Collection Plate Modifications

Although many ESPs have some type of baffle arrangement on the collection plates to minimize gas velocity near the dust layer surface, this may be inadequate for the low-resistivity conditions associated with duct injection systems. It may be possible, depending on existing wire-plate arrangement, to provide additional baffles or shields on the collection plates to minimize scouring and rapping re-entrainment. Examples of such baffles include: V-plate type shielding, zig-zag plates, and offset plates. Depending on the specific design of the existing ESP, such collection plate modifications may not be technically feasible or may require substantial capital expense.

Flue Gas Conditioning with Ammonia

The injection of a small amount (10 to 30 ppm) of ammonia (NH_3) has been successfully demonstrated to reduce emissions due to re-entrainment by increasing the cohesiveness of precipitated fly ash.

By forming agglomerates and/or sheets, the ash will fall into the collection hopper instead of being carried out of the ESP as fine particles. This results in reduced emissions due to particle re-entrainment caused by rapping, high gas velocities (scouring), or hopper sweepage.

NH₃ combines with SO₃ in the flue gas to form ammonium bisulfate and ammonium sulfate which condense on the surface of the particle. Since the ammonia requires the presence of SO₃ to increase cohesion, it would have to be injected upstream of where the sorbent is added. Therefore, it would only be effective for increasing the cohesion of the fly ash particles. However, from analysis of the particle size data, it appears that fly ash particles may represent a significant portion of the outlet emissions. This indicates that ammonia addition may provide some improvement in ESP performance in conjunction with a duct injection system.

Increasing ESP Operating Voltage

Flue gas density will increase downstream of duct injection due to lower duct temperature. The voltage at which an ESP will operate is nearly proportional to the gas density. This means that an ESP operating at 45 KV at 300°F should be able to operate at 57 KV at 145°F. Theoretically, the performance of an ESP should be proportional to the square of the operating voltage. Therefore, neglecting non-ideal effects, if lower operating temperatures allow a 28% increase in operating voltage, then performance would increase by 64%.

However, non-ideal effects may cause unexpected results. Under current density conditions typical of an ESP, low-resistivity duct injection ash/sorbent waste may acquire an induced charge that is the same charge as that existing on the ESP plates. This could cause collected material to be repelled from the plates and re-entrained in the gas stream.

It is unlikely that an older ESP operating in conjunction with the retrofit of a duct injection system could achieve the full benefit from the increased gas density because the existing power supplies will probably not be rated to deliver the increased voltage. Replacement of the existing T-R sets with higher voltage units would therefore be necessary to operate at the higher levels that can be obtained at the reduced flue gas temperature. This would result in a significant capital expenditure.

Special Discharge Electrodes

Space charge quenching is often found in high dust loading applications such as cement kilns or applications with large amounts of submicron particles such as smelters. For these applications, ESP vendors recommend corona electrodes designed with barbs to produce more current at a given voltage. If corona quenching in the first ESP section is found to be a limiting factor, a discharge electrode designed for increased current may be installed in the first section.

High current discharge electrodes may have another advantage. As previously mentioned, low-resistivity material may be repelled from the ESP plates induced by the high potential gradient in the ESP. Increasing the voltage would aggravate this problem, but increasing the current density would help to hold particles to the plates.

6.4.1.3 ESP Operating and Maintenance Considerations

Rapping Cycle Modifications

Optimizing rapping intensity and frequency can improve ESP performance. A portion of the emissions from all ESPs is the result of rapping re-entrainment. The rapping frequency and intensity should be adjusted for the fly ash and flue gas conditions specific to each ESP application. When these conditions are altered, as in the case of a duct injection retrofit, the rappers must be readjusted. In many cases, optimizing rapping frequency and intensity can significantly improve the performance of an ESP.

For ESPs operating with low-resistivity ash, rapper adjustments can generally minimize opacity spiking, but they may not result in significant reductions in overall mass emissions. In these cases, mass emissions from velocity scouring far outweigh the contribution of rapper related re-entrainment. Since opacity is generally the day to day indicator of ESP emissions compliance, however, rapper optimization is a very necessary task.

Power-Off Rapping

Extended operation of sorbent injection may result in a long-term residual build-up of particulate on the ESP collecting plates. This would result in severe ESP power degradations and increased opacity. Intermittent power-off rapping should be generally successful in removing these long-term plate build-ups and in restoring stack opacity to acceptable levels. This is typically accomplished by de-energizing the electrical field and manually initiating the rapping. However, this sometimes results in high opacity excursions. While this practice in its crude form may not be suitable for normal power plant operations, it may be possible to automate the procedure. Several manufacturers offer microprocessor based programmable rapper controllers and automatic precipitator power controllers. By initiating power-off rapping field by field at carefully timed intervals, opacity excursions may be avoided. This option is considered feasible in conjunction with the retrofit of a duct injection system.

6.4.1.4 Miscellaneous ESP Modifications

A complete review and inspection of the electrical and mechanical conditions of the ESP should be performed. The following items are recommended:

Access Doors

Many existing access doors will be corroded and/or their gaskets shot. All doors, including hot and cold roof access doors, side access doors, access doors at high voltage rapper insulator compartments, and hopper access doors, should be inspected.

If the gasket is shot, replace it. If the door is corroded, replace it and then add an insulated door cover. Corrosion will be worse after the duct injection retrofit.

Insulation

If not already in place, install an insulator compartment heating and ventilation system. Install insulation in the insulator compartment area.

If not already in place, install throat heaters on the hopper outlets.

If not already in place, insulate the high voltage rapper compartments.

Blow in additional insulation on each outside wall of the ESP. This will fill all of the voids caused by the stiffeners. Add insulation to the outlet nozzle of the ESP.

Fluidizing Air Provisions

It is recommended that two fluidizing stones per hopper be added to the first two rows of the ESP.

The fluidizing pads should be porous stone with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. A manually operated butterfly or ball valve should be installed in the line to each fluidizing pad for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing pad area. The fluidizing blower(s) should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air pads.

Installation of hopper fluidizing stones will require removal and reinstallation of existing insulation and lagging. It will also likely require removal of existing hopper heaters and possibly replacing certain sections in the affected area with new heaters due to the mounting collars required. As a minimum, the new hopper heaters should have a heating capability equal to or greater than the existing hopper heaters.

6.5 Waste Handling System Modifications

6.5.1 Waste Handling System

The physical, chemical, and mineralogical properties of the waste generated from a duct injection system will be different from fly ash. Several of these properties can affect the conveyance and storage of this material. To some extent, ash/sorbent waste from duct injection processes is similar to that from spray dryer scrubbers although there is considerably more unreacted Ca(OH)_2 in the duct injection waste because of its inherently lower sorbent utilization.

In addition to a change in waste properties, the quantity of waste generated is the other most important factor in evaluating the effects of a duct injection retrofit on an existing waste handling system. Depending on the desired SO_2 removal, coal ash and sulfur content, and recycle rate, duct injection will increase the particulate loading to the particulate collection device by a factor of 2-12.

A waste handling system consists of three principle subsystems: conveying, storage, and conditioning. The conveying, storage, and conditioning of wastes produced by the DSI and DSD processes are addressed in this Section 6.5; the disposal of these wastes is covered separately in Section 6.6.

6.5.1.1 Conveying System

After the fly ash/sorbent waste is collected in the particulate collection device [usually an electrostatic precipitator (ESP)], a waste conveying system removes the waste from the collection hoppers and conveys it to a temporary storage area (bin or silo). The conveying equipment may consist of both feeders and conveyors.

There are several types of waste conveying systems:

- a. Vacuum Pneumatic
- b. Pressure Pneumatic
- c. Mechanical
- d. Wet Sluicing

Vacuum Pneumatic Conveying

The dilute phase, vacuum pneumatic system is probably the most widely used in the utility industry. However, after retrofit of DSI or DSD, this conveying system can potentially experience one or more of the following problems:

- a. Plugging in ash intake valves.
- b. Build-up of material in conveying lines.
- c. Insufficient conveying capacity.

Plugging in ash intake valves is the result of damp solids from the duct injection process and/or condensation caused by the reduced operating temperature in the ESP. Heat tracing and insulating these intake valves should solve this problem. Fluidizing pads may be required in ESP hoppers to get DSI or DSD waste to flow into the conveying system. Two fluidizing stones per hopper are recommended.

Build-up and subsequent plugging in the conveying system is a result of the relatively poor flowability and hygroscopic nature of these wastes. Compared to fly ash only, a significant amount of waste may settle out of the air stream in vacuum conveying lines; most of these deposits will consist of calcium products. This is of special concern in areas of high ambient humidity. Such problems can be minimized by using dry, heated air for transporting the solids and/or heat tracing/insulating of the conveying lines. Extending the air inlets into heated enclosures may also be used. Retrofitting wide-angle elbows can reduce the plugging problems at bends. A regular inspection and maintenance program is recommended to minimize plugging of lines and elbows.

Insufficient conveying capacity is the result of increased solids loading to the ESP, especially in cases where recycle is used. A revision of the ash pulling schedule is the most straightforward and cost-effective solution. In cases where this is insufficient or impossible, increasing conveying air capacity and/or system component size may be necessary (conveying lines, blowers, bin receivers, etc.). Discussions with the supplier of the existing ash conveying system are the best way to evaluate increases in capacity.

If the existing system is currently at or near operational capacity, the best solution may be to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. If adequate clearance exists, a pressure pneumatic ash handling system should be considered as the replacement if recycle of the collected waste will be utilized. This is discussed further in the pressure pneumatic subsection.

One method of increasing the conveying capacity, while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

When installing a new system, the waste conveying rate should include approximately a 100% margin over the maximum expected rate to account for lost time due to system warm-up, interruptions in ash flow to the pipeline, gate changeover time, dump time of separating equipment, purging of conveyor line prior to shutdown, and downtime for maintenance.

In vacuum systems, the waste must first be transferred to the existing plant ash silo. If recycle of a portion of these solids is required, the recycle waste would then be conveyed from the ash silo directly to the duct or to a recycle bin as shown in DSI P&ID Sheet 5A and DSD P&ID Sheet 6A (this is discussed more in Section 6.5.2). In some cases, it will not be possible to modify the existing ash silo to convey material from it back to the process. In these cases, either recycle would not be possible, or a new ash silo would have to be constructed. The new silo would be capable of receiving waste from the ESP, and allowing it to be pneumatically conveyed back to the process as well as discharged to trucks, etc. This is discussed more in the storage discussion below (Section 6.5.1.2).

Pressure Pneumatic Conveying

Pressure pneumatic conveying systems are subject to the same potential operating problems and limitations (plugging/build-up in ash intakes and conveying lines) as vacuum pneumatic systems. The same solutions as discussed above apply to pressure pneumatic systems as well.

As with vacuum ash conveying systems, a revision of the ash pulling schedule is the most straightforward and cost-effective solution to insufficient conveying capacity after a duct injection retrofit. In cases where this is insufficient or impossible, increasing conveying air capacity and/or system component size may be necessary (conveying lines, blowers, pressure tanks, etc.). Discussions with the supplier of the existing ash conveying system are the best way to evaluate increases in capacity.

If the existing system is currently at or near operational capacity, the best solution may be to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. One method of increasing the conveying capacity, while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

When installing a new system, the waste conveying rate should include approximately a 100% margin over the maximum expected rate to account for lost time due to system warm-up, interruptions in ash flow to the pipeline, gate changeover time, purging of conveyor line prior to shutdown, and downtime for maintenance.

Pressure pneumatic ash handling systems allow recycle solids to be periodically diverted directly into a recycle bin for subsequent injection into the duct (reference DSI P&ID Sheet 5B and DSD P&ID Sheet 6B).

Mechanical Conveying

When considering the retrofit of DSI or DSD to plants that use a mechanical ash conveying system, the primary concern is conveying capacity. Since many mechanical conveying systems are designed to operate continuously, increasing cycle frequency may not apply. It may be possible to increase this capacity by increasing feeder or conveyor speed, increasing motor size, gearing changes, increasing screw flight diameters, etc. Discussions with the supplier of the existing ash conveying system are the best way to evaluate increases in capacity.

If the existing system cannot be modified to meet the expected increase in solids from duct injection, it may be necessary to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. One method of increasing the conveying capacity while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

When installing a new system, the waste conveying rate should include approximately a 100% margin over the maximum expected rate to account for lost time due to interruptions in ash flow to the conveyor, gate changeover time, and downtime for maintenance.

Mechanical ash handling systems allow recycle solids to be diverted directly into a recycle bin for subsequent injection into the duct - similar to a pressure pneumatic conveyor (reference DSI P&ID Sheet 5B and DSD P&ID Sheet 6B). However, the modifications required to achieve this would likely be extensive. It would likely be more cost-effective to continue to convey mechanically to the existing plant ash silo, and then convey the solids pneumatically from the ash silo back to the process (similar to vacuum ash conveying systems). In some cases, it will not be possible to modify the existing ash silo to convey material from it back to the process. In these cases, either recycle would not be possible, or a new ash silo would have to be constructed. The new silo would be capable of receiving waste from the ESP, and allowing it to be pneumatically conveyed back to the process as well as discharged to trucks, etc. This discussed more in the storage discussion below (Section 6.5.1.2).

In addition to capacity limitations, the physical properties of the ash/sorbent waste material may cause operational problems. As previously mentioned, these wastes are hygroscopic and exhibit poor flowability characteristics. They tend to be sticky and bridge over easily. In addition, the material will likely be easily aerated (similar to spray dryer waste), and this limits the speed at which it can be conveyed using mechanical conveyors without being wetted or enclosed.

The following discussion, paraphrased from EPRI's Calcium Spray Dryer Waste Management Design Guidelines, EPRI CS-5312, September 1987, describes potential modifications to mechanical conveying equipment after the retrofit of a duct injection system.

Belt Conveyors - The material to be transported may have to be wetted on the belt conveyor to minimize dusting problems. However, if the material is wetted, it may become sticky and special belt cleaners or scrapers may have to be installed to prevent material from accumulating on the belt. Wetting duct injection wastes also increases their potential to cause corrosion; therefore, special corrosion resistant materials of construction should be used.

Screw Conveyors - The typical screw conveyor consists primarily of a standard pitch helix (pitch equal to its outside diameter) supported within a U-shaped trough. These standard components may be modified, however, to improve operations and thereby broaden the range of useful applications.

The flight configuration (shape and/or pitch) can be varied to promote mixing, improve feed control or to improve the conveyability of sticky, lumpy or very free flowing materials. Almost any degree of mixing can be achieved with screw-conveyor flights which have been cut, cut and folded or replaced by a series of paddles. The use of ribbon flights allows sticky materials to be handled. Variable-pitch, tapered-flight, or stepped-flight units can provide precise control of the transport rate. Short-pitch screws retard flushing.

As stated previously, the conveyor screw is supported within a trough that typically is U-shaped. Alternate trough shapes also are available to improve conveyor operation. Rectangular troughs (with or without a detachable bottom) are frequently used for handling hot or abrasive materials. During transfer in this type of trough, the material forms a layer on the bottom and partially up the side forcing the material in transit to travel on itself. Thus, abrasion is reduced and internal insulation is provided by the material itself. Tubular troughs are used for outdoor applications and for loading full cross-sections.

Standard materials of construction for screw fighting, flight mounting, troughs, trough ends, covers, hanger straps, feed/discharge spouts, gates, and shafting are generally satisfactory for most screw conveyor applications. However, when any of the following conditions are encountered, special construction materials are required.

- a. Solids pack and build on the trough.
- b. Corrosive or abrasive materials are to be conveyed.
- c. The material to be conveyed is very wet.

For conveyor applications involving duct injection waste, abrasion and possibly corrosion of the conveyor components should be considered. Solids may tend to build up on the trough if moisture is encountered; consequently, the first item listed above also may require consideration. The last item is not expected to be a concern with duct injection wastes.

Stainless steel or mild steel coated with epoxy resin, plastic, rubber ceramic or galvanizing is recommended for trough construction if solids build-up is expected to occur. Constructing most remaining conveyor components with coated mild steel will minimize the effects of abrasive and slightly to mildly corrosive materials during transfer.

Chain Conveyors - The primary component of all chain conveyors is the chain. Selection of the appropriate construction material for a given application generally is dependent on the required strength, expected travel speed and needed attachments (if any). To minimize excessive wear, chain material hardness (based on the Brinell Scale) also must be compatible with the abrasive and corrosive properties of the material to be conveyed (based on the Mohs Index). When severely abrasive materials are handled, special localized hardening can be applied to the areas subjected to wear. The resulting Brinell hardness generally is 180 to 200. Tables and/or graphs presenting acceptable Mohs Index values for materials of specified hardnesses are available to provide guidance during chain material selection.

Drag chain conveyors frequently are equipped with a Type "H" or "C" chain. These chain types are relatively wide, have broad, flat sliding surfaces, and range in pitch (length of one complete unit of chain) from 5 to 8 in. One of the primary differences between the two chains is working strength. Type "C" drag chains are available with working strengths of 7,000 to 9,300 pounds whereas Type "H" chains have lower strengths ranging from 3,500 to 6,500 pounds. Type "C" chains also have a greater wearing surface for sliding on both carrying and return runs. The welded steel chain is a relatively new development. This chain type is available as a drag chain and has a working strength that generally ranges from 10,000 to 15,000 pounds. A fourth type of drag chain, the "SD" chain, is often used when abrasive materials such as cement clinkers, slag and ashes are handled. This type of chain is similar to the first two types ("H" and "C") except it is fabricated from heavy, heat-treated cast alloy steel and has wide, flat Z-section sidebars. "SD" chains are available with a 6- or 9-in. pitch and working strengths of 16,700 to 23,400 pounds.

A standard en-masse conveyor is provided with straight flights. When some materials are conveyed vertically or even up a steep incline with a chain having this configuration, particles may tend to fall through the chain rather than travel with it. Consequently, the straight flights are replaced with "U"- or "O"-shaped flights to increase the chain surface area in contact with the material and thereby enhance the ability of material particles to interlock with each other. These "U"- or "O"-shaped flights are covered with solid plates at calculated intervals when fine powdery materials are conveyed.

Bucket Conveyors - The primary components of a bucket elevator consist of:

- a. Buckets
- b. Carrying medium
- c. Terminals
- d. Casing

Presented below is a brief discussion of design considerations associated with each of these components.

Buckets - When relatively abrasive materials are handled and extra protection of the digging lip is required, style AA buckets are provided. Styles SC and C buckets are used to convey sticky materials that tend to pack in the bottom of the bucket. The style AC bucket, originally developed for cement plants, is primarily used for fine solids with fluid-like characteristics where large capacities are required or for highly abrasive free-flowing materials. This type of bucket is provided with a high front lip to increase capacity.

Carrying Medium - Two types of conveying medium are available for bucket elevators -- chain and belt. Belts generally are limited to centrifugal discharge type elevators. Belt and bucket elevators are well adapted to handling abrasive materials that would produce excessive wear on chains. They also are more suitable for high speed applications. However, belt type elevators are sensitive to elevated temperatures. Consequently, when temperatures in excess of 300°F are anticipated, chain elevators are used. Chain and bucket elevators also are equipped frequently with perforated buckets when handling wet materials, to drain surplus water.

Terminals - Chain elevators operate over head sprockets or traction wheels. Using traction wheels at the head-end of an elevator greatly increases both chain and wheel life. The traction wheel can be used on all centrifugal elevators except when handling materials of a lubricating nature. To operate successfully, the traction wheel requires a high coefficient of friction between the chain bushing and wheel surface. Properly applied, a traction wheel operates without slip, thereby eliminating the relative angular movement or scrubbing action between the chain and steel surface, which is typical of a sprocket and chain combination. The benefit derived from using a traction wheel in lieu of a head sprocket (increased chain and wheel life) is not as significant with continuous elevators because of the lower speeds. However, when used, care must be taken in the selection to eliminate the possibility of slip. Sprockets rather than traction wheels generally are used at the foot-end of an elevator. Engagement between the wheel and chain tends to be loose, resulting in poor guiding of the chain and buckets through the loading zone. Pulleys are used with belts. Elevator pulleys are either cast iron or welded steel with a nominal crown face for tracking. Head pulleys sometimes are covered with rubber belting, vulcanized rubber or non-skid fabric to provide a higher coefficient of friction between the belt and pulley.

Casing - Elevator casing usually is sectional, dust-tight and is fabricated with structural steel, sheet steel or aluminum. The boot section typically is of heavier gauge. Doors are provided for accessing elevator machinery.

Wet Sluicing Conveying

Very little is known about the potential effects of DSI or DSD wastes on a wet sluicing ash removal system. There are concerns regarding the cementitious properties of calcium-based materials that can potentially lead to plugging and scaling of venturries and conveying lines. The calcium in DSI and DSD wastes, however, has been hydrated prior to entering the process; the potential for any additional hydration in the sluice line is minimal. It is possible that periodic pigging of these lines or cleaning with high pressure water lances may be required to remove scale and deposits. Water addition to the waste material may increase environmental concerns by requiring wet disposal (the unreacted lime in the waste will likely raise the pH of the sluice to as high as 12).

As with vacuum ash conveying systems, a revision of the ash pulling schedule is the most straightforward and cost-effective solution to insufficient conveying capacity after a duct injection retrofit. In cases where this is insufficient or impossible, increasing conveying capacity and/or system component size may be necessary (conveying lines, venturries, tanks, etc.). Discussions with the supplier of the existing ash conveying system are the best way to evaluate increases in capacity.

If the existing system is currently at or near operational capacity, the best solution may be to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. One method of increasing the conveying capacity, while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

When installing a new system, the waste conveying rate should include approximately a 100% margin over the maximum expected rate to account for lost time due to system warm-up, interruptions in ash flow to the pipeline, gate changeover time, purging of conveyor line prior to shutdown, and downtime for maintenance.

Ash sluicing systems wet the ash to a dilute slurry. Therefore, this type of ash handling system is not conducive to recycling the material back to the process. In DSI, the recycle material needs to be dry, so wet sluicing will not allow recycle operation. For DSD, the waste material is slurried with water, but usually to a 40-45% solids slurry - not 20% solids typical of a wet sluicing system. Therefore, wet sluicing will generally not be compatible with recycle of material back into the duct.

Recommended Testing

The waste properties are expected to vary with different plant designs and operating conditions. Therefore, tests to assess accurate waste characteristics should be performed for each DSI or DSD installation as part of the selection and equipment design process. If testing is performed at laboratory-scale, field conditions must be duplicated to give as-conveyed conditions (e.g., ambient conditions at the plant must be considered).

6.5.1.2 Storage

An ash silo or bin is usually in place to provide surge capacity between ash production and transport to disposal. The increased volume of waste solids resulting from a duct injection retrofit will reduce the surge capacity. To compensate for this reduction:

- a. the frequency of discharging the waste solids for disposal must be increased; expanding the ash hauling schedule over a longer period, or increasing the number of trips (or trucks) may be necessary, and/or
- b. additional storage capacity may be required; additional waste solids silos may be added to maintain the number of hours or days of storage.

A new storage silo may be desired for two reasons: 1) to increase surge capacity, and 2) to allow waste to be recycled back to the process - the existing ash silo may not be physically capable of being modified to allow material to be recycled.

If another silo(s) is desired, it should be large enough so that, between the existing and new silo(s), 3 days (72 hours) of surge capacity is provided. This provides surge capacity over a three-day weekend. The new silo(s) should be fitted with a dry unloading spout to accommodate the recycle system rotary feeders, etc., as shown in DSI P&ID Sheet 5A and DSD P&ID Sheet 6A, as well as the traditional rotary unloader or pug mill for unloading into trucks, etc. A bulk density of 50 lb per cu ft may be used for capacity of waste material.

If a new, dedicated ash handling system is installed on the first field(s) of the ESP, the waste conveyed from these fields should empty into the new silo fitted with recycle system provisions. This should be done because the material in the first field(s) would likely have the largest percentage of unreacted lime; therefore, this would be the material of choice to be recycled.

Discharge of waste from an ash silo after DSI or DSD retrofit can be different from that with fly ash only. Due to the physical properties mentioned above, the potential for bridging and rat-holing is much greater. Existing ash silos can likely be utilized after duct injection retrofit, but fluidization (if not already existing) will likely be required to effect material discharge. A bin activator or vibrator is not recommended on ash silos as they tend to pack the

material rather than enhance the flow. Fluidizing is recommended in conjunction with a dedicated ash silo aeration blower. A spare aeration blower is not recommended; however, a tie-in from a plant service air line could be used as a back-up when the aeration blower is not available as was recommended for the hydrate lime silos and bins in Section 6.1.1

Experience has shown that uniform surface coverage (fluidized bottoms) is better than concentrated local fluidization (fluidizing pads). Fluidizing bottoms should be porous stone with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. A manually operated butterfly or ball valve should be installed in the line to each section of the fluidized bottom for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing stone area. The aeration (fluidizing) blower should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air stones.

In addition to fluidizing, hopper modifications such as air cannons, poke holes, or strike plates may be required when using existing silos for storage.

New ash silos may utilize either 60 degree conical hoppers or flat-bottoms, but fluidizing air is required for either design. The flat-bottom design generally is recommended because of its lower cost and its traditional acceptance for conventional fly ash applications.

New ash silos should be designed similarly to the requirements given above for modifications to existing silos with regard to fluidizing system, air cannons, poke holes, strike plates, etc.

The hopper flow design for new ash silos should be funnel flow. The pressure relief device on top of new ash silos may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification (Spec. No. M102) in Appendix E.

Recommended Testing

To predict flow from storage vessels, flow properties should be determined by conducting special direct shear, controlled strain tests. The flow properties obtained from these tests are bulk density, effective internal angle of friction during flow, internal angle of friction in incipient flow, kinematic angle of wall friction, and unconfined yield strength. To obtain an accurate assessment of these flow properties, test procedures must reflect the conditions expected to occur within a storage vessel such as compaction pressure and moisture content.

6.5.1.3 Conditioning

Conditioning can be used to make DSI or DSD wastes more amenable for transport and disposal. The alternatives are:

- a. Conditioning the waste with water.
- b. Blending the waste with sludge.
- c. Pelletizing or sintering the waste.

The technique of pelletizing or sintering the waste is used primarily for utilizing the waste product instead of disposing of it. But pelletizing or sintering also may be useful prior to disposal. This process reduces and controls the waste volume, prevents dusting problems, and reduces leaching potential in the landfill. However, the costs associated with these processes are typically very high.

Blending the dry waste with dewatered FGD sludge is another alternative for waste conditioning. The advantages of this method over separate disposal of these wastes are easier handling and stabilizing of the sludge.

The most common method of conditioning dry waste is the addition of water prior to disposal. The proper amount of water must be added to control dust generation during truck loading and transport without causing the waste to harden or set up. Generally this will require about 15-25% water, by weight, but this value should be verified by appropriate testing for specific applications.

As with conveying and storage systems, additional equipment may be required to handle the increased waste solids volume. Ready access of conditioning equipment is important for daily wash-down.

As an alternative to water, specialty chemicals including surfactants and foam are commonly used to suppress dust from solids handling systems. The advantages of these specialty chemicals are that they reduce water requirements.

6.5.2 Recycle System

Recycle in a duct injection system consists of returning a portion of the waste solids (fly ash, calcium-sulfur salts, and unreacted lime) to the flue gas stream. By providing multiple exposures of sorbent to the flue gas, recycling increases the opportunity for a given sorbent particle to react with SO_2 . For a given level of SO_2 removal, increased utilization of the reagent will result in less unreacted sorbent in the waste product. Thus, recycle of ash/sorbent waste material will reduce the total quantity of waste which must be disposed.

If the user chooses to utilize the recycle of ash/sorbent waste material collected in the particulate collection device [usually an electrostatic precipitator (ESP)], the equipment configuration to accomplish this is fairly site specific. The type of existing ash handling system, the ease at which an existing ash silo may be modified

to incorporate recycle provisions, and the number of ducts for injection of the recycle material are all considerations.

6.5.2.1 Dry Sorbent Injection Recycle

In DSI, the recycle material is maintained dry, and the important design considerations are the same as for the waste material: dry conveying and storage. After storage, the recycle material is injected into the duct utilizing injectors separate from, but near, the fresh lime injectors.

Vacuum Pneumatic Ash Handling System

It is expected that many candidate plants for DSI retrofit will employ an existing vacuum pneumatic system to convey ash from the ESP to an existing ash silo. Because of the nature of vacuum ash handling systems, the ash has to be conveyed to the ash silo first before it can be recycled. It may be possible to modify the discharge equipment underneath the existing ash silo to allow a portion of the ash to either be blown directly back into the duct or conveyed to a recycle storage bin for subsequent injection into the duct (see DSI P&ID Sheet 5A).

For units where injection will occur in a single duct, the ash may be metered and then dilute-phase conveyed (using a variable speed rotary feeder and constant speed rotary air lock underneath the ash silo) directly back to the duct distribution header. For this design, the need for a separate recycle storage bin is eliminated. For larger units, especially units with more than one duct/ESP, ash will normally be dilute-phase or dense-phase conveyed from the existing ash silo to a recycle bin; from the recycle bin, it will be metered and dilute-phase conveyed using rotary feeders/rotary air locks to the various injection points - one dedicated set of rotary valves and blower per duct.

If a separate recycle bin is required (as shown in the P&IDs), a positive pressure transfer conveyor will be required to pneumatically convey the waste from the ash silo to the recycle bin. A rotary air lock is attached to the silo discharge to feed the waste material into the transfer conveyor. The capacity of the rotary air lock/transfer conveyor should be three times the design recycle material consumption in the duct injection process as calculated by the criteria in Section 3.0. That way, a 24 hour capacity recycle bin can be filled in one shift (likely the day shift), or an 8 hour capacity recycle bin can be filled in a couple of hours.

Typical capacities for a pneumatic transfer conveyor range from 30-40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30-40 ton/hr, one or more of the following will have to be considered: 1) conveying for longer periods of time such as during the evening and/or graveyard shifts, 2) increasing the capacity of the transfer conveying system above 40 ton/hr (through discussions with conveyor suppliers), and 3) the use of two conveying systems to increase total conveying rate.

Typical pneumatic conveying velocities range from 4,000 to 6,000 ft/min for transfer of waste material. The air required for conveying the waste is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.10 lb air per lb waste is required compared to 0.20 lb air per lb waste for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification (Spec. No. M105) in Appendix E.

A spare blower for the transfer conveyor is typically not required; only one blower is suggested as shown on DSI P&ID Sheet 5A. This is true because 1) the blower should only operate 30-40% of the time allowing time for routine maintenance, and 2) the recycle system is not critical to the operation of the duct injection system, i.e., the required SO₂ removal can be achieved without recycle solids.

Pressure Pneumatic/Mechanical Ash Handling System

If a positive pressure or mechanical ash handling system exists at the plant, a diverter gate may be installed in the ash line(s) to the existing ash silo to direct the ash/sorbent waste to a recycle bin for a portion of the time (reference DSI P&ID Sheet 5B). This design eliminates the need to convey the recycle solids out to the ash silo and then back to the process. In addition, no modifications to the existing ash silo discharge equipment would be necessary. It may be possible to direct ash from only the hoppers nearest the ESP inlet to the recycle bin. Inlet fields collect the majority of the solids, including most of the unreacted lime.

Wet Sluicing Ash Handling System

As noted in Section 6.5.1.1, wet sluicing of waste from the ESP will not allow recycle operation.

Recycle Bin

The recycle bin storage capacity should be either 8 or 24 hours worth of waste material at the design recycle material usage. The decision to select 8 or 24 hours of capacity is based on whether the plant wants to fill the bin once per day (24 hr) or once per shift (8 hr) as discussed above. A bulk density of 50 lb per cu ft may be used for capacity of waste material.

Ash/sorbent waste tends to form rat holes and craters which can cause arching or bridging in storage. Either a 60 degree conical hopper or flat-bottom bin may be used, but fluidizing air is required for either design. The flat-bottom design generally is recommended because of its lower cost and its traditional acceptance for conventional fly ash applications. A bin activator or vibrator is not recommended on recycle bins as they tend to pack the material rather than enhance the

flow. Fluidizing is recommended in conjunction with a dedicated recycle bin aeration blower. As noted in DSI P&ID Sheets 5A and 5B, a spare aeration blower is not recommended since the recycle system is not critical to the operation of the duct injection system. However, a tie-in from a plant service air line could be used as a back-up when the aeration blower is not available as was recommended for the hydrate lime silos and bins in Section 6.1.1.

Experience has shown that uniform surface coverage (fluidized bottoms) is better than concentrated local fluidization (fluidizing pads). Fluidized bottoms should be porous stone with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. Although not shown on the P&IDs, a manually operated butterfly or ball valve should be installed in the line to each section of the fluidized bottom for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing stone area. The aeration (fluidizing) blower should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air stones.

The hopper flow design for the recycle bin should be funnel flow. The pressure relief device on top of the recycle bin may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification (Spec. No. M102) in Appendix E.

The recycle bin dust collector must be sized to filter the transport air from the positive pressure recycle transfer conveyor.

The use of an exhaust fan on the dust collector is optional. However, the slight negative pressure in the bin air space, created by the exhaust fan, will result in air in-leakage through any small openings in the bin roof instead of waste dust out-leakage, and it will minimize the possibility of waste dust filling and plugging the vent lines from the rotary feeders. For silos/bins located indoors, an exhaust fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification (Spec. No. M103) in Appendix E.

Recycle Injection Equipment

Although there are a number of ways of metering the injected recycle material, the P&IDs show the material being discharged from the bin through a variable speed rotary feeder and into a dilute phase, positive pressure pneumatic conveying system through a constant speed air lock valve. The rotary feeder speed is controlled to maintain a specified recycle ratio. Controls are discussed in Section 8.0.

The injection conveyor should be a dilute phase pressure conveying system to provide a constant flow at the required pressure to the recycle injectors. A single pipe would convey the material to a distribution bottle near the flue gas duct where it is split into smaller, balanced loss pipes to each injector. Injector design is discussed in Section 6.2.1. From a flexibility and reliability standpoint, fresh sorbent and recycle material should be injected separately. This would allow the recycle system to be shut down without interrupting the fresh sorbent system.

The conveyor piping should be routed either vertically or horizontally with no more than a 15 degree deviation from vertical or horizontal to minimize particle drop out in the pipe.

One recycle rotary feeder/rotary air lock should be provided per duct. Each rotary feeder and rotary air lock should be sized for at least 100% of the design recycle material consumption for that duct based on the design Ca(OH)_2 consumption and recycle ratio. Recycle ratio is defined as lb recycle material per lb Ca(OH)_2 (excluding inerts) injected into the duct.

For good recycle feed control, rotary feeders in series with constant speed rotary air locks are recommended. The additional advantage of this arrangement is that any blowback of pressurized conveying air which leaks through the air lock will not prevent the material from flowing out of the recycle bin. A vent should be installed from the rotary air lock to the top of the bin to vent off this pressurized air (reference the P&IDs).

The recycle injection pneumatic conveying system capacity for each duct should be at least 100% of the design recycle material consumption for that duct. The recycle injection blowers should be sized for conveying velocities ranging from 4,000 to 6,000 ft/min. The air required for conveying the material is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.10 lb air per lb material is required compared to 0.20 lb air per lb material for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification in Appendix E.

A spare injection blower is not recommended to keep capital costs low and because the recycle system is not critical to the operation of the duct injection system. A spare set of rotary feeder/rotary air lock is also not shown in the P&IDs for the same reasons.

6.5.2.2 Duct Spray Drying Recycle

For the DSD process, the recycle material is conveyed and stored dry as in the DSI system, but then it is slurried with water and combined with the fresh lime slurry before injection into the duct.

Vacuum Pneumatic Ash Handling System

It is expected that many candidate plants for DSD retrofit will employ an existing vacuum pneumatic system to convey ash from the ESP to an existing ash silo. Because of the nature of vacuum ash handling systems, the ash has to be conveyed to the ash silo first before it can be recycled. It may be possible to modify the discharge equipment underneath the existing ash silo to allow a portion of the ash to be conveyed to a recycle storage bin for subsequent reslurrying and injection into the duct (see DSD P&ID Sheet 6A).

A positive pressure transfer conveyor will be required to pneumatically convey the waste from the ash silo to the recycle bin. A rotary air lock is attached to the silo discharge to feed the waste material into the transfer conveyor. The capacity of the rotary air lock/transfer conveyor should be three times the design recycle material consumption in the duct injection process as calculated by the criteria in Section 3.0. That way, a 24 hour capacity recycle bin can be filled in one shift (likely the day shift), or an 8 hour capacity recycle bin can be filled in a couple of hours.

Typical capacities for a pneumatic transfer conveyor range from 30-40 ton/hr. If the required capacity, as estimated above, is significantly greater than 30-40 ton/hr, one or more of the following will have to be considered: 1) conveying for longer periods of time such as during the evening and/or graveyard shifts, 2) increasing the capacity of the transfer conveying system above 40 ton/hr (through discussions with conveyor suppliers), and 3) the use of two conveying systems to increase total conveying rate.

Typical pneumatic conveying velocities range from 4,000 to 6,000 ft/min for transfer of waste material. The air required for conveying the waste is somewhat dependent on conveying distance. For a conveying distance of 100 ft, about 0.10 lb air per lb waste is required compared to 0.20 lb air per lb waste for 400 ft of conveying distance. Blowers are normally rated at just less than 15 psig discharge pressure to stay below the ASME pressure code requirements.

Additional design criteria are contained in the pneumatic transfer/injection conveyors specification (Spec. No. M105) in Appendix E.

A spare blower for the transfer conveyor is typically not required; only one blower is suggested as shown on DSD P&ID Sheet 6A. This is true because 1) the blower should only operate 30-40% of the time allowing time for routine maintenance, and 2) the recycle system is not critical to the operation of the duct injection system, i.e., the required SO₂ removal can be achieved without recycle solids.

Pressure Pneumatic/Mechanical Ash Handling System

If a positive pressure or mechanical ash handling system exists at the plant, a diverter gate may be installed in the ash line(s) to the existing ash silo to direct the ash/sorbent waste to a recycle bin for a portion of the time (reference DSD P&ID Sheet 6B). This design eliminates the need to convey the recycle solids out to the ash silo and then back to the process. In addition, no modifications to the existing ash silo discharge equipment would be necessary. It may be possible to direct ash from only the hoppers nearest the ESP inlet to the recycle bin. Inlet fields collect the majority of the solids, including most of the unreacted lime.

Wet Sluicing Ash Handling System

As noted in Section 6.5.1.1, wet sluicing of waste from the ESP will not allow recycle operation.

Recycle Bin

The recycle bin storage capacity should be either 8 or 24 hours worth of waste material at the design recycle material usage. The decision to select 8 or 24 hours of capacity is based on whether the plant wants to fill the bin once per day (24 hr) or once per shift (8 hr) as discussed above. A bulk density of 50 lb per cu ft may be used for capacity of waste material.

Ash/sorbent waste tends to form rat holes and craters which can cause arching or bridging in storage. Either a 60 degree conical hopper or flat-bottom bin may be used, but fluidizing air is required for either design. The flat-bottom design generally is recommended because of its lower cost and its traditional acceptance for conventional fly ash applications. A bin activator or vibrator is not recommended on recycle bins as they tend to pack the material rather than enhance the flow. Fluidizing is recommended in conjunction with a dedicated recycle bin aeration blower. As noted in DSD P&ID Sheets 6A and 6B, a spare aeration blower is not recommended since the recycle system is not critical to the operation of the duct injection system. However, a tie-in from a plant service air line could be used as a back-up when the aeration blower is not available as was recommended for the hydrate lime silos and bins in Section 6.1.1.

Experience has shown that uniform surface coverage (fluidized bottoms) is better than concentrated local fluidization (fluidizing pads). Fluidized bottoms should be porous stone with a permeability rating of about 10 cfm per sq ft at 2 in. H₂O differential pressure. Although not shown on the P&IDs, a manually operated butterfly or ball valve

should be installed in the line to each section of the fluidized bottom for trimming air flow.

Fluidizing air pressure should be 3-5 psig, and the air flow should be 10 scfm per sq ft of fluidizing stone area. The aeration (fluidizing) blower should be sized at 10 scfm per sq ft and enough discharge pressure to overcome losses and still maintain 3-5 psig at the fluidizing air stones.

The hopper flow design for the recycle bin should be funnel flow. The pressure relief device on top of the recycle bin may be simply a hinged manhole cover or a device designed specifically to relieve pressure at a certain setpoint.

Additional design criteria are contained in the silo/day bin specification (Spec. No. M102) in Appendix E.

The recycle bin dust collector must be sized to filter the transport air from the positive pressure recycle transfer conveyor.

The use of an exhaust fan on the dust collector is optional. However, the slight negative pressure in the bin air space, created by the exhauster, will result in air in-leakage through any small openings in the bin roof instead of waste dust out-leakage, and it will minimize the possibility of waste dust filling and plugging the vent lines from the rotary feeders. For silos/bins located indoors, an exhaust fan is normally used to blow the air exiting the dust collector outside of the building.

The outlet dust loading from the dust collector is often specified by the State or local regulatory agency with jurisdiction. With no other guidance, a removal efficiency of 99.9% should be specified.

Other design criteria for the dust collector are contained in the bin vent dust collector specification (Spec. No. M103) in Appendix E.

Recycle Injection Equipment

A rotary feeder is located below the recycle bin to meter the recycle material into a recycle slurry tank (reference DSD P&ID Sheets 6A and 6B). The capacity of the rotary feeder should be at least 100% of the design recycle material consumption. Generally, the design recycle consumption for DSD will occur when a 45% solids feed slurry is being injected into the duct(s), at maximum gas flow, at the minimum expected lime consumption. The design recycle consumption may be limited from the above calculated value due to the maximum solids loading the ESP is capable of treating while still being in compliance.

The dry recycle material is wetted in an agitated recycle slurry tank. Only one tank is recommended to keep capital costs low and because the recycle system is not critical to the operation of the duct injection system. The storage capacity of this tank should be either 8 or 24 hours worth of recycle slurry at the design recycle usage. The decision to select 8 or 24 hours of capacity is based on whether

recycle slurry will be generated only one shift or all day. Typically, the solids content of the recycle slurry will vary from 40-45% (specific gravity of 1.32-1.37), but the design of the tank should be based on a range of 30-50% solids (specific gravity of 1.24-1.41).

The recycle slurry tank should have a minimum of 3 ft of freeboard (non-wetted wall height). This tank should be designed such that its wetted wall height is approximately equal to the tank diameter. This tank should be supplied with a venturi scrubber to pull a slight negative at the top of the tank. The design pressure should be atmospheric plus the fluid static height. A design temperature of 200°F is adequate. No personnel protection is necessary on this tank. A coating is not required, but a 3/8 in. carbon steel blast plate on the tank floor (in addition to the 1/4 in. floor plate) is recommended to resist erosion due to agitation of the abrasive ash. To be conservative, the 3/8 in. carbon steel liner should be extended 4 ft up the walls of the tank.

The recycle slurry tank agitator will be required to blend the recycle material with dilution water as well as keep the solids in suspension. The agitator will be required to achieve complete off-bottom suspension. The agitator must be capable of handling slurries ranging from 30-50% solids. This agitator should have two levels of blading.

Two 100%, redundant recycle slurry pumps should be provided to transfer recycle slurry to the atomizer feed tank. These pumps must be designed to accommodate the "clumps" from the recycle slurry tank. Box screens should be provided in the recycle slurry tanks over the pump suctions, but it is expected that 3/4-1 in. clumps will occasionally enter the pumps. The capacity (in gpm) of each pump should be at least 110% of the design recycle material consumption required for injection into the duct(s), diluted to 30% solids. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the recycle slurry tank even at design capacity. The pumps must be capable of handling slurries ranging from 30-50% solids. The design head and available NPSH for these pumps will depend on equipment layout.

Recycle slurry piping may be unlined schedule 80 carbon steel. The piping should be designed as a loop system with recirculation back to the recycle slurry tank so that flow to the atomizer feed tank can vary from minimum to maximum flow and still maintain enough velocity in the piping to minimize build-up inside the pipes. The piping would be periodically flushed with water to remove any build-up that occurred.

A recycle grit screen should be located above the atomizer feed tank to screen the recycle slurry (reference DSD P&ID Sheet 5). The recycle grit screen should have a 20 mesh screen. All slurry solids greater than 20 mesh will be rejected to a recycle oversize bin. The oversize bin should be a dumpster capable of being removed through a roll-up door using existing plant equipment. The capacity (in gpm) of the recycle grit screen should be equal to the capacity of each recycle slurry pump. The grit screen must be capable of handling slurries ranging from 30-50% solids.

Other design criteria for the rotary feeder, recycle slurry tank, agitator, slurry pumps, grit screen, and slurry valves are contained in Spec. Nos. M105, M113, M114, M115, M112, and M116, respectively, in Appendix E.

6.6 Waste Disposal

The physical, chemical, and mineralogical properties of the waste generated from a duct injection system will be different from fly ash. Several of these properties can affect the transportation and final disposal of this material. To some extent, ash/sorbent waste from duct injection processes is similar to that from lime spray dryer scrubbers although there is considerably more unreacted $\text{Ca}(\text{OH})_2$ in the duct injection waste because of its inherently lower sorbent utilization.

The most significant areas of potential concern for calcium-based duct sorbent injection processes have been identified as:

- a. Possible human health and operating effects associated with handling very powdery, alkaline materials.
- b. The corrosive nature of very alkaline solutions.
- c. The tendency of the waste to flash set or solidify when exposed to moisture.
- d. The possibility of highly alkaline discharges (pH greater than 12) from storage areas.

In addition to a change in waste properties, the quantity of waste generated is the other most important factor in evaluating the effects of a duct injection retrofit on an existing waste disposal system. Depending on the desired SO_2 removal and coal ash and sulfur content, duct injection will increase the disposal waste quantity by a factor of 1.8 to 5.0.

6.6.1 Transportation Methods

After the fly ash/sorbent waste has been transferred from the ESP to the ash storage silo and conditioned, the transportation subsystem transports the waste material from the plant area to the disposal site. Likely existing transport systems include:

- a. Trucks
- b. Belt Conveyors
- c. Pneumatic Conveyors
- d. Wet Sluicing
- e. Rail Cars
- f. Barges

Trucks

The primary advantages of truck transport are flexibility and reliability. The capacity of the system can be increased by simply increasing the number of trucks and/or operating shifts. They are typically the most flexible and practical alternative when considering the nature of landfill operations. Also, they often are the most practical alternative when considering surface mine disposal at mine mouth stations.

After new waste production rates have been determined, the number of trucks and operating shifts which must be provided in order to transport the increased material quantity can be estimated. Different truck sizes and numbers of shifts should be investigated in order to satisfy the increased demand on the waste transport subsystem.

The potential corrosivity (high pH) and dust problems associated with duct injection wastes should be considered when an existing truck transport system is being utilized. Corrosion may cause deterioration of truck bodies faster than for fly ash only. Special liners or materials of truck construction may be used and/or trucks can be cleaned regularly to minimize this problem. Dust problems can be minimized by either wetting the material, covering open trucks with tarps, or using enclosed truck trailers.

Belt Conveyors

The speed of the existing belt conveyor(s) may have to be increased to accommodate the greater throughput after the duct injection retrofit. However, this may not be practical because, since DSI and DSD wastes are easily aerated, this limits the speed at which they can be conveyed using belt conveyors without being wetted or enclosed. The material to be transported may have to be wetted on the belt conveyor to minimize dusting problems. However, if the material is wetted, it may become sticky and special belt cleaners or scrapers may have to be installed to prevent material from accumulating on the belt. Wetting duct injection wastes also increases their potential to cause corrosion; therefore, special corrosion resistant materials of construction may be required.

Pneumatic Conveyors

Pneumatic conveying has seen only limited applications in the transport of utility wastes. Pneumatic conveying systems are not economically efficient at distances greater than approximately 7,500 ft.

After retrofit of a DSI or DSD system, a pneumatic conveying system can potentially experience one or more of the following problems:

- a. Plugging in ash intake valves.
- b. Build-up of material in conveying lines.
- c. Insufficient conveying capacity.

Plugging in ash intake valves is the result of damp solids from the duct injection process and/or conditioning. Heat tracing and insulating these intake valves should solve this problem.

Build-up and subsequent plugging in the conveying system is a result of the relatively poor flowability and hygroscopic nature of these wastes. Compared to fly ash only, a significant amount of waste may settle out of the air stream in vacuum conveying lines; most of these deposits will consist of calcium products. This is of special concern in areas of high ambient humidity. Such problems can be minimized by using dry, heated air for transporting the solids and/or heat

tracing/insulating of the conveying lines. Extending the air inlets into heated enclosures may also be used. Retrofitting wide-angle elbows can reduce the plugging problems at bends. A regular inspection and maintenance program is recommended to minimize plugging of lines and elbows.

Insufficient conveying capacity is the result of increased waste production rate. A revision in the waste conveying schedule is the most straightforward and cost-effective solution. In cases where this is insufficient or impossible, increasing conveying air capacity and/or system component size may be necessary (conveying lines, blowers, etc.). Discussions with the supplier of the existing conveying system are the best way to evaluate increases in capacity. If the existing system is currently at or near operational capacity, the best solution may be to replace the entire system with a new system designed to accommodate the full duct injection waste disposal rate.

Wet Sluicing

Very little is known about the potential effects of DSI or DSD wastes on a wet sluicing transport system. There are concerns regarding the cementitious properties of calcium-based materials that can potentially lead to plugging and scaling of ventureries and conveying lines. The calcium in DSI and DSD wastes, however, has been hydrated prior to entering the process; the potential for any additional hydration in the sluice line is minimal. It is possible that periodic pigging of these lines or cleaning with high pressure water lances may be required to remove scale and deposits.

Water addition to the waste material may increase environmental concerns by requiring wet disposal (the unreacted lime in the waste will likely raise the pH of the sluice to as high as 12). A liquid separation and reclaim water system or other special modifications may be required at the disposal area similar to mineral tailings systems.

Rail Cars

The same comments regarding increase in waste quantity, dustiness, and corrosivity apply to a railroad transport system as were discussed above for a truck system.

Barges

If analyses of the DSI or DSD waste indicate no major problems with corrosivity and dusting, standard barges can be used. More frequent hauling will be required due to the increase in waste to disposal.

6.6.2 Final Disposal Methods

Waste disposal is the final placement of the waste in a permanent location. The three most common disposal methods in use for fly ash are landfill, mine disposal, and wet impoundment (pond).

Water conditioning to control dusting during transport and to achieve the optimum moisture content for disposal is a critical factor in the handling characteristics of DSI and DSD waste material. Too much water causes the material to become sticky and hard to handle and to possibly set up in the transport equipment. Not enough water results in ineffective dust control. Optimum moisture appears to be 20-30% by weight. A properly mixed fly ash/sorbent waste product will, in most cases, enhance the landfill operation due to the pozzolanic action of the lime portion. This will tend to decrease the permeability of the waste and form a cementitious crust that will deter erosion of the exposed surface. In addition, it can significantly reduce the leachability of potentially problematic elements (As, Ba, Cd, Pb, Se, etc.).

In general, the potential environmental risks posed by DSI/DSD wastes appear to be minimal. The moisture content, dry density, strength, and permeability of these wastes are such that landfill without a liner should be generally adequate. The leachability of the RCRA-regulated elements are below current RCRA standards. However, certain State and/or local regulations may pose restrictions on the disposal of the waste from these processes. These regulations need to be considered when applying this technology.

If additives are used in the duct injection process, testing will be required to determine their effect on disposal properties such as strength, permeability, and leachate properties.

6.6.2.1 Modification of Existing Disposal Areas

If there is capacity remaining in the existing disposal area which is currently accepting coal combustion wastes, it should be considered for duct injection wastes. Because the site already is being used for waste disposal, information should be available for the site including geotechnical data and permitting information. This information will provide a basis upon which to begin analyses of any required disposal area modifications. Disposal modification may require only modifying existing permits as opposed to repeating the entire permitting process.

Any modifications to existing disposal areas should consider embankment stability and possible contamination of surface water and ground water. The following discussion, paraphrased from EPRI's Calcium Spray Dryer Waste Management Design Guidelines, EPRI CS-5312, September 1987, describes the evaluations required after the retrofit of a duct injection system.

Embankment Stability - Physical instability is a potential problem for all coal combustion by-product disposal areas. Stability is influenced by: physical waste properties such as waste density, strength, degree of saturation, effective cohesion, effective angle of shearing resistance, and behavior during shearing (dilatant versus densifying); site conditions including geotechnical characteristics of the in-place foundation material; and geometric factors such as the heights and outslopes (or slope angles) of embankments. In general, for a given

material, the maximum safe embankment height decreases with increasing slope angle. The effective slope angle of the embankment may be flattened by either lowering the slope angle (outslope) itself or by constructing benches. Benches also aid in the control of surface runoff and in providing access to all areas of the landfill face. In fact, many State regulations require benches on embankments and dictate minimum spacing and sizes. Benches are usually placed every 20 to 50 ft in vertical height and typically vary in width from 10 to 30 ft. However, flattening the outslope and/or constructing benches reduces the capacity of a landfill. Foundation material also should be analyzed; weak underlying material can lead to instability and slope failure. Design measures should be taken to minimize any potential problems with weak foundation material. Surface water and ground water controls influence the amount of moisture in the waste material and, therefore, effect the stability of embankments.

Surface Water - The potential for surface water contamination depends upon the amount of water that passes through, or is in contact with, the waste material. Therefore, in order to reduce contamination, the amount of surface water entering the landfill should be minimized. This is usually done by constructing diversion channels at the perimeter of the landfill to divert runoff from adjacent areas away from the site. Diversion of this water will reduce the amount of leachate generated, reduce erosion of the landfill, and decrease the amount of runoff from the site that must be controlled, collected or treated. All surface runoff from the active area of the site should be collected. At a minimum, this water should be passed through a sedimentation pond. In addition, it should be tested for possible contamination and treated if necessary. The site should be staged so that only runoff from the disturbed, uncovered area is collected. Limiting the drainage area to only the disturbed area reduces the amount of runoff entering the pond and reduces its size and associated cost. Therefore, landfill staging is important in sizing sedimentation ponds.

Ground Water - The potential for ground water contamination is related to the amount of water passing through the waste material, the quality of the leachate produced, and existing geologic and ground water conditions. Measures can be taken to reduce the potential for degradation of ground water aquifers. These measures are instituted because of specific site conditions, waste material characteristics and regulatory requirements. The amount of water passing through the waste material and subsequent leachate generation can be reduced by constructing diversion channels at the perimeter of the landfill and grading the waste material to drain both during construction and after reclamation. The quality of leachate varies with different DSI or DSD wastes depending on many process factors. Whether or not the leachate is a potential problem is also a function of both site location and regulatory requirements (i.e., more control measures probably will be required if a landfill is located over an area with a shallow, high-quality aquifer than if it is located in an isolated area). If the leachate contains contaminants exceeding the EPA drinking water standards, hazardous waste criteria, or other appropriate limitations,

measures may be required to reduce potential adverse ground water impacts. These measures could include: installing a liner under the disposal area to minimize leachate entering the ground water aquifer, constructing a leachate collection system to collect leachate, installing an under-drain for the landfill to collect springs and seeps thereby preventing this water from contacting the wastes, constructing diversion channels and grading the landfill to minimize surface water which can enter the landfill and generate leachate, and constructing a leachate treatment facility to treat this leachate before discharging it to the environment. Existing geologic conditions also can affect the ground water at the site. The site should ideally be located over an area with a deep, low-quality, ground water aquifer containing low permeability soils. However, most sites do not involve ideal conditions and require at least some limited measures to minimize leachate.

Design conditions will vary depending on whether the existing disposal area is a landfill, surface mine, or wet impoundment.

Modifying Existing Landfill Disposal Areas

Conventional landfill disposal areas currently receiving other combustion wastes may be able to receive duct injection wastes without significant modifications to the landfill. Because of the additional waste quantities generated with duct injection, however, the storage capacity of the disposal area will be expended over a shorter time period, shortening the life of the disposal site in general. Expansion of the landfill may extend its life; expansion can be accomplished by either horizontally or vertically enlarging the landfill.

In designing modifications for an existing landfill disposal area, the first step is to compare properties of DSI or DSD wastes with the properties of those wastes currently placed in the disposal area. The new waste properties should be used to verify the original design and develop new designs if required.

As discussed above, DSI and DSD wastes should be placeable in landfills with few potential impacts due largely to their inherently cementitious properties which reduce permeabilities and leachate quantities as well as constituent leachability. These properties also increase the strength of the wastes generally as compared to conventional fly and bottom ash, thereby improving their engineering performance.

Waste disposal at a landfill site will be subjected to numerous passes of earth-moving equipment and trucks. Because of this, the structural integrity of the waste is very important. Permeability is greatly affected by the amount of landfill compaction. It is therefore recommended that all DSI and DSD waste material landfill operations incorporate a layered compaction procedure.

Modifying Existing Mine Disposal Areas

Existing mine disposal areas currently receiving other coal combustion wastes may be able to receive duct injection wastes without major modifications to disposal operations. However, the final grades of the reclaimed mine have to be raised to allow for increased waste quantities.

Leachate and strength properties of DSI and DSD wastes should be compared to like properties for wastes currently being placed in the mine. In many cases, the new wastes will have greater strength and, therefore, will not affect mine disposal adversely. If questionable, stability and leachate analyses for mine disposal of the wastes should be performed.

Modifying Existing Wet Disposal Areas

There are two basic approaches to utilizing existing wet impoundments for disposal of duct injection wastes. The first is to continue impoundment disposing of the wastes in slurry form. The second is to drain the impoundment, stabilize the existing wastes, and landfill dry DSI or DSD wastes upon the drained impoundment wastes.

If the impoundment will continue to be used for wet disposal, duct injection wastes can be pumped to the impoundment in slurry form. However, due to the increased quantities of wastes, the slurry line to the impoundment may have to be increased in size, and the remaining life of the impoundment will be shortened. Also, due to the high pH of the slurry and the tendency of these wastes to "set-up", steps must be taken to prevent associated problems with the waste transport system (e.g., sufficiently dilute slurry, line maintenance, etc.).

6.6.2.2 New Disposal Areas

If it becomes necessary to build a new landfill, State and/or local permitting requirements may be much more stringent than Federal regulations. Site selection will be based upon transportation and economic considerations as well as technical and environmental criteria.

Because the landfill disposal option is so common, state-of-the-art environmental protection techniques have been developed and are becoming commonplace in the industry. Clay liners, impermeable synthetic liners, leachate collection/detection, ground water monitoring, and runoff/leachate collection, settling, and treatment systems are examples of this technology which are being used to meet today's stringent environmental protection requirements.

6.7 Miscellaneous Utilities

6.7.1 Dry Sorbent Injection (Ref. DSI P&ID Sheet 6)

Atomizing Air Compressors/Receiver

In the design presented in the P&IDs, service and instrument air are assumed to be available from the existing plant compressors; new service and/or instrument air compressors are not shown.

Centrifugal air compressors are suggested to provide atomizing air to the humidification nozzles. Three, 50% capacity compressors are recommended to supply the total air required. A spare compressor is recommended because of the high maintenance historically required for these machines.

The discharge pressure and total air capacity required will depend on the specific nozzles utilized; however, as a conservative approximation, a 125 psig discharge pressure and an air-to-water ratio of 0.5 lb air per lb humidification water are appropriate. This 0.5 design air-to-water ratio should be applied to the design humidification water requirement as calculated in Section 3.0.

If an aftercooler is included in the compressor package (which is how the air compressor specification in Appendix E is written), the discharge temperature of the compressed air should be 20-25°F above the cooling water inlet temperature. Normally, compressor capacity is rated in SCFM and/or ICFM. The total air in lb/hr, as calculated using the suggested air-to-water ratio given above, has to be converted to SCFM and/or ICFM. In the compressor industry, SCFM is based on 14.7 psia, 60°F, and 0% relative humidity; ICFM is typically based on intake pressure (barometric pressure minus 0.3 psi for inlet air filter losses), 60°F, and 60% relative humidity (corresponding to about 0.0065 lb water per lb dry air).

The air requirement in lb/hr may be converted to SCFM as follows:

$$\text{SCFM} = (\text{X lb/hr}) (520^\circ\text{R}) [10.73 \text{ psia-ft}^3 / (^\circ\text{R-lb mole})] / (29 \text{ lb/lb mole}) / (14.7 \text{ psia}) / (60 \text{ min/hr})$$

The air requirement in lb/hr may be converted to ICFM as follows:

$$\text{ICFM} = (\text{X lb/hr}) (1.0065) (520^\circ\text{R}) [10.73 \text{ psia-ft}^3 / (^\circ\text{R-lb mole})] / (28.886 \text{ lb/lb mole}) / (P_b - 0.3 \text{ psia}) / (60 \text{ min/hr})$$

Where: P_b = Barometric pressure in psia

Each of the 50% capacity compressors should be sized for 1/2 of the total air required for all of the duct injection points.

All of the air compressors should discharge to a common air receiver. This vessel would provide a small amount of surge capacity and would provide air to the nozzles for a short time in case of an emergency shutdown or power loss to the air compressors. The air receiver should have a design pressure of 150 psig in accordance with Section VIII, Div. 1 of the ASME Boiler and Pressure Vessel Code. The capacity of the receiver should be about 10 seconds of reserve air consumption based on the total design air requirement. The 10 second capacity should be based on actual air volume at the compressor discharge (ACFM @ 125 psig and 100-115°F).

ACFM
(at compressor discharge) = $(Y \text{ SCFM}) (14.7) (T_p + 460^\circ\text{R}) / (125 + P_g) / (520^\circ\text{R})$
Where: T_p = Compressor discharge temperature in °F
 P_g = Barometric pressure in psia

Other design criteria for the atomizing air compressors and air receiver are contained in the air compressor specification (Spec. No. M601) in Appendix E.

Water Tanks

A raw water tank and blowdown water tank should be provided for surge capacity and to facilitate water pump suction. Only one tank is needed for each service to keep capital costs low and because there are few problems with water tanks. The raw water tank would hold the "good" quality water to be used for hydrating, etc. The blowdown water tank would hold the poorer quality water to be used for flue gas humidification, waste conditioning, etc. Typically, this water is comprised largely of cooling tower blowdown, ash pond return water, etc. If ash pond return water is used, a duplex strainer should be located in the water inlet line to the blowdown water tank.

The storage capacity of these tanks should be about 1 hour at their respective design water consumptions. The raw water and blowdown water tanks should have a minimum of 3 ft of freeboard (non-wetted wall height). These tanks are vented to atmosphere, so the design pressure should be atmospheric plus the fluid static height. A design temperature of 200°F is adequate. No personnel protection is necessary on these tanks unless the source water is very hot for some reason. A coating or lining is not required. Other design criteria for the water tanks are contained in the tank specification (Spec. No. M113) in Appendix E.

Water Pumps

Two 100%, redundant water pumps should be provided for each water service noted on the P&IDs. The capacity (in gpm) of each pump should be at least 110% of the design water consumption for each service. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the respective water tank even at design capacity. The design head and available NPSH for these pumps will depend on equipment layout. Water piping may be schedule 40 carbon steel.

A coarse and fine humidification water filter are recommended (reference DSI P&ID Sheet 6). These filters keep the humidification water which is sprayed into the duct, relatively clean to minimize nozzle wear. The coarse filter should have a 40 micron filter, and the fine filter should be 10 micron. The capacity of the filters should be equal to the capacity of each humidification water pump.

6.7.2 Duct Spray Drying (Ref. DSD P&ID Sheet 7)

Atomizing Air Compressors/Receiver

In the design presented in the P&IDs, service and instrument air are assumed to be available from the existing plant compressors; new service and/or instrument air compressors are not shown.

Centrifugal air compressors are suggested to provide atomizing air to the slurry nozzles. Three, 50% capacity compressors are recommended to supply the total air required. A spare compressor is recommended because of the high maintenance historically required for these machines.

The discharge pressure and total air capacity required will depend on the specific nozzles utilized; however, as a conservative approximation, a 125 psig discharge pressure and an air-to-slurry ratio of 0.5 lb air per lb slurry are appropriate. This 0.5 design air-to-slurry ratio should be applied to the design slurry flow requirement as calculated in Section 3.0.

If an aftercooler is included in the compressor package (which is how the air compressor specification in Appendix E is written), the discharge temperature of the compressed air should be 20-25°F above the cooling water inlet temperature. Normally, compressor capacity is rated in SCFM and/or ICFM. The total air in lb/hr, as calculated using the suggested air-to-slurry ratio given above, has to be converted to SCFM and/or ICFM. In the compressor industry, SCFM is based on 14.7 psia, 60°F, and 0% relative humidity; ICFM is typically based on intake pressure (barometric pressure minus 0.3 psi for inlet air filter losses), 60°F, and 60% relative humidity (corresponding to about 0.0065 lb water per lb dry air).

The air requirement in lb/hr may be converted to SCFM as follows:

$$\text{SCFM} = (\text{X lb/hr}) (520^\circ\text{R}) [10.73 \text{ psia-ft}^3/(\text{°R-lb mole})] / (29 \text{ lb/lb mole}) / (14.7 \text{ psia}) / (60 \text{ min/hr})$$

The air requirement in lb/hr may be converted to ICFM as follows:

$$\text{ICFM} = (\text{X lb/hr}) (1.0065) (520^\circ\text{R}) [10.73 \text{ psia-ft}^3/(\text{°R-lb mole})] / (28.886 \text{ lb/lb mole}) / (P_B - 0.3 \text{ psia}) / (60 \text{ min/hr})$$

Where: P_B = Barometric pressure in psia

Each of the 50% capacity compressors should be sized for 1/2 of the total air required for all of the duct injection points.

All of the air compressors should discharge to a common air receiver. This vessel would provide a small amount of surge capacity and would provide air to the nozzles for a short time in case of an emergency shutdown or power loss to the air compressors. The air receiver should have a design pressure of 150 psig in accordance with Section VIII, Div. 1 of the ASME Boiler and Pressure Vessel Code. The capacity of the receiver should be about 10 seconds of reserve air consumption based on the total design air requirement. The 10 second capacity should be based on actual air volume at the compressor discharge (ACFM @ 125 psig and 100-115°F).

ACFM

(at compressor discharge) = $(Y \text{ SCFM}) (14.7) (T_0 + 460^\circ\text{R}) / ((125 + P_b) (520^\circ\text{R}))$

Where: T_0 = Compressor discharge temperature in °F

P_b = Barometric pressure in psia

Other design criteria for the atomizing air compressors and air receiver are contained in the air compressor specification (Spec. No. M601) in Appendix E.

Water Tanks

A raw water tank and blowdown water tank should be provided for surge capacity and to facilitate water pump suction. Only one tank is needed for each service to keep capital costs low and because there are few problems with water tanks. The raw water tank would hold the "good" quality water to be used for slaking, etc. The blowdown water tank would hold the poorer quality water to be used for flue gas humidification and waste conditioning, etc. Typically, this water is comprised largely of cooling tower blowdown, ash pond return water, etc. If ash pond return water is used, a duplex strainer should be located in the water inlet line to the blowdown water tank.

The storage capacity of these tanks should be about 1 hour at their respective design water consumptions. The raw water and blowdown water tanks should have a minimum of 3 ft of freeboard (non-wetted wall height). These tanks are vented to atmosphere, so the design pressure should be atmospheric plus the fluid static height. A design temperature of 200°F is adequate. No personnel protection is necessary on these tanks unless the source water is very hot for some reason. A coating or lining is not required. Other design criteria for the water tanks are contained in the tank specification (Spec. No. M113) in Appendix E.

Water Pumps

Two 100%, redundant water pumps should be provided for each water service noted on the P&IDs. The capacity (in gpm) of each pump should be at least 110% of the design water consumption for each service. The additional 10% capacity is recommended for pump wear and also to provide a minimum recirculation back to the respective water tank even at design capacity. The design head and available NPSH for these pumps will depend on equipment layout. Water piping may be schedule 40 carbon steel.

7.0 PLANT AND EQUIPMENT ARRANGEMENT CONSIDERATIONS

7.1 Equipment Configurations

Individual pieces of new equipment should be sized and designed in accordance with the suggestions of Section 6.0. This section gives suggestions and ideas to consider when selecting a duct injection equipment configuration and while laying out the new equipment.

7.1.1 Lime Unloading Arrangement and Silo Location

Normally, lime shipments (whether hydrated lime or pebble lime) will be by enclosed truck or rail car. Lime shipments by covered barge are also a possibility, but barge shipment is not covered in this handbook.

For off-site hydration in the DSI process, the hydrate silo may be located either right next to the injection point(s) or remote from it as space and unloading constraints permit. However, the most reliable and economical feed rate control of the hydrated lime will be achieved if the silo is located close to the injection point(s). If the silo cannot be located near the injection point(s), the user may want to consider pneumatically transferring the lime from the remote silo to a hydrate day bin located close to the injection point(s). This case is not shown on the PFDs or P&IDs in Section 5.0.

For the on-site hydration option in DSI, the pebble lime silo, hydrators, and hydrate bin may be located either right next to the injection point(s) or remote from it as space and unloading constraints permit. However, to achieve the most reliable feed rate control of the hydrated lime, the hydrate bin should be located as close to the injection point(s) as possible, even if the silo and hydrators are located remotely.

For the DSD process, the pebble lime silo may be located either right next to the injection point(s) or remote from it as space and unloading constraints permit. Locating the silo close to the injection point(s) is preferable; however, if the silo cannot be located near them, it is considered more feasible to pneumatically convey lime from the silo to a small day bin located near the injection point(s) [and have the slurry preparation accomplished close to the injection point(s)] than to prepare the slurry near the remote silo and pump it a long distance to the injection point(s). This is especially true because a slurry return line to the atomizer feed tank is normally required to keep slurry pipeline velocities high. From a practical standpoint, slurry should be prepared within 200 ft of the point of use. If the silo can be located close to the duct injection point(s), a separate lime day bin is not required.

7.1.1.1 Truck Delivery

For truck delivery, the lime is typically unloaded by the driver using the truck-mounted blower. No additional equipment is required. If lime delivery by truck is the only mode utilized, two truck fill pipes per silo are recommended. They should be located far enough apart to allow spotting of two trucks concurrently. On the other hand, two lines located close together will facilitate installation and reduce costs, and this arrangement may be used if space around the silo will allow two trucks to back up to the silo side-by-side. A concrete slab (or pavement as a minimum) in the area around the lime silo(s) is recommended to aid in vacuuming/washdown and general housekeeping.

7.1.1.2 Rail Car Delivery

For rail car delivery, a separate rail spur is necessary to store the cars while waiting to be unloaded or picked up. An insulated unloading shed should be located over the spur which is long enough to completely enclose at least one rail car so that the doors at each end may be closed. This allows the shed to be heated in the winter and controls the dusting. At least 12 ft of clearance is required above the car. Permanent building heat should be provided. A dust collector with suction fan should be installed on the shed to control the dusting. A concrete floor (or pavement as a minimum) should be provided within the shed to aid in vacuuming/washdown and general housekeeping. All blowers, local electrical equipment, and local controls associated with the unloading equipment should be located within the unloading shed.

The rail car unloading equipment may be vacuum only, combined vacuum-pressure, or positive pressure only (reference Spec. No. M101 in Appendix E). If vacuum unloading is utilized, the vacuum hose needs to be long enough and oriented in such a way as to reach all of the hoppers on the rail car without moving the car once it is spotted within the shed. If vacuum unloading is used, the elevation of the finished floor between the tracks should be lower than the top of the tracks by about 2 in. to aid in locating the rail car connectors which clamp to the rail car hopper outlets. In a vacuum-only rail car unloading system, the filter receiver(s) is located on top of the lime storage silo(s) and the silo(s) must be located near the rail car unloading point (typically within 100-250 ft). Vacuum blowers (depending on site elevation and corresponding barometric pressure) can convey lime only a few hundred feet.

If a combined vacuum-pressure or positive pressure-only unloading system is selected, the silo(s) may be located remote from the unloading point. This is true because pressure blowers can convey the lime up to 1500 ft. Longer distances than 1500 ft are possible, but the conveying horsepower required becomes very high. In a combined vacuum-pressure system, the filter receiver is typically located inside the unloading shed.

7.1.2 Sorbent Injector Placement in DSI

As discussed in Section 6.2.1.4, sorbent injection in the DSI process should be upstream of, or in the same plane as, humidification water injection.

7.1.3 Slaking/Slurry Handling in DSD

If ball mill-type slakers are selected, they need to be supported on concrete pedestals at grade. The resulting slurry flows by gravity into the relatively small ball mill sump tanks and is then pumped to the lime slurry storage tank. Detention and paste slakers are typically mounted on the second floor of the process equipment building, and they overflow through screens to the lime slurry storage tank mounted below at grade.

The atomizer feed tank should be located as close as practical to the injection point(s) to minimize the slurry pumping distance. This distance should be no more than 200 ft.

7.1.4 General Equipment Arrangement Considerations

A general statement can be made that most of the equipment associated with a duct injection system is fairly maintenance intensive. Therefore, the entire system should be designed and layed out to allow ready access for operation and maintenance of all components. **Sufficient area around all equipment including tanks, slakers, hydrators, feeders, vibrating screens, compressors, blowers, and pumps should be provided for operation and maintenance laydown: 3ft-6in. clear as a minimum.**

Silo/bin hoppers and all process equipment including blowers, feeders, and conveyors should be located inside insulated buildings with heating and ventilation. This is recommended for freeze protection, to minimize weather contamination of the sorbent, and to make it more convenient and comfortable for operations and maintenance personnel to perform their duties. Whether a DSI or DSD process is selected, the sorbent will quickly be everywhere; containing it to a building is aesthetically useful.

Hydrated lime can be particularly fine and lime slurry particularly messy; housekeeping will be a major effort. Fine lime particles have been known to penetrate sealed NEMA 4 electrical cabinets. All electrical cabinets and controls should be centralized in pressurized "clean" rooms. Due to excessive dusting in DSI systems with on-site hydration, it is recommended that the hydrators be located in their own "room" within the process equipment building.

Sloping floor trenches (18 in. wide, 6-18 in. deep) and a 7 ft cube (minimum) sump should be located in the process equipment building to facilitate washdown and general housekeeping. The sump should be accessible for muck-out by vacuum truck. Equipment, process, and other contaminated drainage should be hard-piped to the sump

(or trench). Floor drains in elevated floors where washdown will occur should include permanently installed piping from the drains to the sump (or trench). A sump agitator and sump pump should be provided to pump the collected drainage to an ash pond or other drain system.

All instruments, lighting, local electrical equipment, and internal building siding panels must be of a sealed design such that periodic washdown will not damage them.

A weather enclosure should be constructed next to the duct where the nozzle array manifolds and distribution headers extend from the duct. This enclosure will make it more convenient and comfortable to monitor air and liquid pressures, temperatures, and flow rates to each nozzle array and sorbent injector array (for DSI only). The enclosure will also facilitate change-out of nozzle arrays, strainer maintenance, etc.

7.2 Retrofit Considerations

Existing plant equipment modifications should be accomplished in accordance with the suggestions of Section 6.0. This section gives suggestions and ideas to consider when interfacing the duct injection equipment into the existing plant. Interface with existing plant controls are discussed separately in Section 8.0.

7.2.1 Space Constraints

LATER

7.2.2 Plant Utility Interfaces

A single point of supply for the following utilities will normally be required to be furnished by the user from the plant.

- Make-up water
- Raw water
- Cooling water
- Potable water
- Fire protection water
- Auxiliary steam
- Condensate return
- Service air (except atomizing air)
- Instrument air

Make-up water is used for flue gas humidification, slurry dilution (if applicable), hose down, and flushing. It is typically cooling water blowdown/clarifier underflow. Make-up water should be used to the greatest extent possible. A complete washdown water distribution system including piping, valves, pressure reliefs, and connections with hoses should be installed in the retrofit buildings/areas at a maximum of 100 ft intervals.

Raw water should be used only where absolutely necessary. It may be used for slaking, hydration, cooling water, and slurry pump seals. If raw water is not suitable for cooling water purposes (such as compressor cooling), a separate source of plant cooling water should be provided. Potable water should be used for emergency eye wash, shower facilities, and domestic uses only. If replaceable, non-piped emergency shower and eye wash stations are provided, potable water may not be required. Fire protection water is required depending on the design and insurance requirements of the fire protection system within the retrofit buildings/areas.

Auxiliary steam required for use in slaking water preheat and building heating is typically 150 psig saturated.

Service air will be required for pneumatic tools, maintenance, etc. Separate, new compressors would normally be required to supply the compressed air for the operation of the humidification or slurry nozzles, whichever are applicable. A complete service air

distribution system including piping, valves, pressure reliefs, and connections with hoses should be installed in the retrofit buildings/areas at a maximum of 100 ft intervals.

Instrument quality air (-40°F dewpoint) would normally be required from the plant for the control valves, etc.

7.2.3 Waste Handling and Recycle System

7.2.3.1 Existing Vacuum Pneumatic System

If the existing vacuum system is currently at or near operational capacity, it may be necessary to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. If adequate clearance exists, a pressure pneumatic ash handling system should be considered as the replacement if recycle of the collected waste will be utilized.

One method of increasing the conveying capacity, while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

In vacuum systems, the waste must first be transferred to the existing plant ash silo. If recycle of a portion of these solids is required, it may be possible to modify the discharge equipment underneath the existing ash silo to allow a portion of the waste to be conveyed from the ash silo directly to the duct, or to a recycle bin for subsequent injection into the duct. One possibility is to tie in to an existing dry unloading spout. In some cases, it will not be possible to modify the existing ash silo to convey material from it back to the process. In these cases, either recycle would not be possible, or a new ash silo would have to be constructed. The new silo would be capable of receiving waste from the ESP, and allowing it to be pneumatically conveyed back to the process as well as discharged to trucks, etc.

For units where injection will occur in a single duct, the recycle solids may be metered and then dilute-phase conveyed (using a variable speed rotary feeder and constant speed rotary air lock underneath the ash silo) directly back to the duct distribution header. For this design, the need for a separate recycle storage bin is eliminated. For larger units, especially units with more than one duct/ESP, ash will normally be dilute-phase or dense-phase conveyed from the existing or new ash silo to a recycle bin; from the recycle bin, it will be metered and dilute-phase conveyed using

rotary feeders/rotary air locks to the various injection points. The recycle bin, if used, should be located near the injection points.

7.2.3.2 Existing Pressure Pneumatic System

If the existing pressure system is currently at or near operational capacity, it may be necessary to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. One method of increasing the conveying capacity, while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

Pressure pneumatic ash handling systems allow recycle solids to be periodically diverted directly into a recycle bin for subsequent injection into the duct. A diverter gate may be installed in the ash line(s) to the existing ash silo to direct the ash/sorbent waste to a recycle bin for a portion of the time. This design would eliminate the need to convey the recycle solids out to the ash silo and then back to the process. In addition, no modifications to the existing ash silo discharge equipment would be necessary. The recycle bin should be located near the injection point(s).

7.2.3.3 Existing Mechanical System

If the existing mechanical system is currently at or near operational capacity, it may be necessary to replace a portion of, or the entire system with a new system designed to accommodate the full duct injection solids capacity. One method of increasing the conveying capacity while continuing to utilize much of the existing equipment, is to replace the conveying system for the first field or first two fields of the ESP with a new, dedicated system while continuing to utilize the existing system for the last two fields. As a rule of thumb, it is suggested that only the first field ash handling system could be replaced for a two or three field ESP; for four fields or more, the ash handling system in the first two fields could be replaced by a new system.

Mechanical ash handling systems allow recycle solids to be periodically diverted directly into a recycle bin for subsequent injection into the duct - similar to a pressure pneumatic conveyor. However, the modifications required to achieve this would likely be extensive. It would likely be more cost-effective to continue to convey mechanically to the existing plant ash silo, and then convey the solids pneumatically from the ash silo back to the process (similar to vacuum ash conveying systems). It may be possible to

modify the discharge equipment underneath the existing ash silo to allow a portion of the waste to be recycled. One possibility is to tie in to an existing dry unloading spout. In some cases, it will not be possible to modify the existing ash silo to convey material from it back to the process. In these cases, either recycle would not be possible, or a new ash silo would have to be constructed. The new silo would be capable of receiving waste from the ESP, and allowing it to be pneumatically conveyed back to the process as well as discharged to trucks, etc.

If a diverter gate can be installed in the ash line(s) to the existing ash silo, a new conveyor could direct the ash/sorbent waste to a recycle bin for a portion of the time. This design would eliminate the need to convey the recycle solids out to the ash silo and then back to the process. In addition, no modifications to the existing ash silo discharge equipment would be necessary. The recycle bin should be located near the injection point(s).

7.2.4 Special Cases

Numerous site-specific duct designs and plant arrangements will be encountered when retrofitting a duct injection process. Specific examples of special design considerations for retrofitting this technology are presented below.

7.2.4.1 Two Existing ESPs in Series

Two ESPs in series often result due to a retrofit of a second ESP to improve overall particulate collection efficiency. Two ESPs in series introduce options with regards to the point at which humidification water and sorbent may be injected. These options affect the potential for downstream material deposition and ductwork corrosion.

Since current data indicate lime injection upstream of, or in the same plane as, humidification water spray provides superior sorbent utilization for the DSI process, injecting the lime and water in this manner into the duct just downstream of the first ESP may be the most effective configuration. This arrangement is similar to the HYPAS process developed by EPRI. Adding a portion of the humidification water upstream of the first ESP would be attractive since it would improve the performance of that ESP; however, the potential for corrosion from SO_3 makes this option unacceptable. In addition, modeling suggests that the fraction of water unevaporated at the inlet of the second ESP is not improved significantly by introducing some of the humidification water upstream of the first ESP.

Injecting the sorbent just upstream of, or in the same plane as, the humidification array is expected to protect the downstream ductwork from SO_3 corrosion. The two ESPs in series may allow for operating at higher net utilization since most of the fly ash is removed by the first ESP.

7.2.4.2 Two Existing ESPs in Parallel

Two ESPs in parallel often result due to a retrofit of a second ESP to improve overall particulate collection efficiency. In many instances, the original ESP will have been "close coupled" to the boiler air preheater allowing almost no residence time for a duct injection retrofit. The ductwork to the second ESP may be more amenable to retrofit of duct injection. However, three issues must be considered if nozzles are installed upstream of one ESP, but not the other: 1) entrainment of flue gas causing maldistribution, 2) corrosion of downstream ductwork, and 3) low overall SO_2 removal.

The very high velocity of the spray exiting the nozzle causes the flue gas to become entrained - significantly altering the flue gas velocity profile. Much higher flue gas velocities would result in the vicinity of the nozzles. Depending on where the nozzles are located, this may disrupt the distribution of flue gas between the two ESPs.

If duct injection is retrofitted to one of the ESP trains, but not the other, the mixing of the humidified, cool gas from one ESP with the hot, SO_2/SO_3 laden gas from the other could cause the combined gas temperature to fall below the acid dew point of the mixed stream. This could result in severe corrosion to ductwork and the stack liner downstream of the mix point.

The third issue to consider if duct injection is applied to only one train is that 50-60% SO_2 removal across one train may result in only 20-35% overall SO_2 removal for the unit as a whole (depending on the gas flow rate split between the two ESPs).

7.2.4.3 Possibility of Stack Lean

Recent experience in the FGD industry has shown that mixing of a hot, dry gas with a cool, saturated gas in a stack may result in differential expansion and the ultimate leaning of a brick and mortar stack liner. A similar condition could exist with a retrofit project wherein duct injection is applied to only one of two duct trains which discharge to a common stack. At power stations where two or more units feed into a common flue, this situation could also occur.

In all observed cases of liner lean, the liners have been constructed of brick and mortar. In several of the stack lean cases observed, a scrubbed gas breeching has been located above the hot bypass gas breeching. This gradient has caused the

differential expansion experienced. In cases where two flue streams of different temperature enter a common chimney, the cool and hot gas breechings should be located opposite of each other at the same elevation. There should be no turning vanes located inside the stack so that the mixing of these two gas streams will occur quite rapidly and violently. The opposite breeching arrangement is believed to present a lower risk of stack lean. For retrofits of duct injection at existing plants, this potential problem would require careful analysis.

7.2.4.4 Excessive Length of ESP outlet ductwork

If the outlet ductwork from the ESP to stack is exceptionally long (greater than 300 ft), the heat loss through this ductwork would limit the humidification approach temperature because of concerns that downstream condensation might cause ductwork corrosion. The approach temperature which would minimize the potential for corrosion would depend on the length of the outlet duct run. The primary design criterion is to achieve a minimum 20°F approach temperature at the stack inlet. For a 300 ft ESP outlet duct run, the required approach temperature at the ESP inlet is estimated to be about 50°F. However, this high of an approach temperature at the ESP inlet would limit SO₂ removal. To operate at closer approach temperatures may require the application of protective coatings or linings to the outlet duct and stack, or adding a reheat system. All of these modifications will have significant capital cost impacts.

7.2.4.5 Effect of Sloped Ducts/Duct Bends

Some units may have adequate duct residence time only if two duct sections with an inclusive bend are considered. These units would be considered marginal from a humidification viewpoint. Similarly, sloped duct runs are present at some plants. With no field experience to draw upon, it should be assumed that bends in ducts and sloped ducts could present some special concerns for the placement of sorbent injectors and atomizer arrays. Flow models should be used to determine the need for additional turning vanes or gas flow distribution devices. Any wall deposition in sloped ducts could pose special problems. Deposited solids could slide down the duct and create large localized build-ups. This could, however, simplify an on-line solids removal system if a single hopper could be installed at the point of build-up.

7.2.4.6 Ash Silo Common to Several Units

It is quite possible that a duct injection system will be retrofit onto a unit which shares a common ash silo with one or more other units at the station. This would not be a major concern (other than the fact that the silo will fill more quickly than before the retrofit), but the effectiveness of any waste material recycled

back to the duct from the ash silo would be diminished. This would be due to the "dilution effect" of the non-calcium containing fly ash from the unaffected unit(s).

As noted previously in Sections 6.5.2 and 7.2.3, if an existing pressure pneumatic or mechanical system is used to convey ash/sorbent waste from the unit being retrofitted to the ash silo, the system should be modified to convey solids directly to a recycle bin for a portion of the time. This design would eliminate the need to convey the recycled solids out to the ash silo and then convey "diluted" solids back to the process. The recycle bin would then contain undiluted material which would be recycled back to the duct injection point(s).

If an existing or modified vacuum pneumatic system is used, all of the solids must first be transferred to the ash silo, and then conveyed back to the process. For the DSI process, recycle of diluted solids with a large percentage of fly ash will not increase utilization significantly. Therefore, if the DSI process is selected for a unit which would utilize a vacuum pneumatic waste handling system and which shares an ash silo with an unmodified unit, recycle of the collected waste material is not suggested. The one exception to this recommendation is if a new ash silo will be built. Then, waste handling systems could be designed such that all or most of the material entering the new silo would be duct injection ash/sorbent waste. In that case, recycle of this material directly back to the duct, or to a recycle bin for subsequent injection into the duct, would increase utilization and SO₂ removal.

If the DSD process is selected for a unit which would utilize a vacuum pneumatic waste handling system and which shares an ash silo with an unmodified unit, recycle of the collected waste material is recommended whether or not a new ash silo is erected. This recommendation is based on the fact that recycle material is needed to keep the feed slurry solids content high for drying purposes. If the recycle solids contain significant unreacted calcium, so much the better; but, whether or not recycle solids contain significant calcium, they are necessary. Slurries with 30-40% solids dry much easier than 10-20% solids slurries. The recycle material is needed to add to the lime slurry to increase the feed slurry solids content.

7.2.4.7 Positive Pressure Electrostatic Precipitator

If the ESP(s) is located downstream of the ID fans, there would be a greater potential for dust leakage into the penthouse with the increased solids loading resulting from a duct injection system. This would increase the possibility of shorting out a field. If not already pressurized, the penthouse would require a pressurization system to minimize this potential problem.

8.0 NOT USED

9.0 NOT USED

10.0 EQUIPMENT BID SPECIFICATION GUIDELINES

Bid specifications have been prepared for the major equipment required in a duct injection system retrofit. The list of specifications prepared is contained in Table 10-1. The specifications themselves are included in Appendix E. This section provides guidelines and suggestions to the user for customizing the specifications for a site-specific application.

Bid specifications are included for the major process components. Specifications for equipment which is "typical" to a power plant, such as heat exchangers, water pumps, etc., have not been included. The bid specifications are "furnish and deliver"; field erection specifications for mechanical, structural, electrical, or controls have not been included.

The specifications detail the performance and technical requirements for the equipment, but they are generic enough to allow customizing for a specific plant application.

All of the equipment specifications have the same format and section numbering system. There are several standard sections in all of the specifications which contain requirements applicable to equipment in general; these requirements may require modification for procurement of specific equipment as noted below.

The equipment specification numbering system follows the Area Codes established in Section 5.4; e.g., Spec. No. M101 refers to a mechanical equipment specification (from the prefix "M") and is applicable to Area 100, Sorbent Storage and Preparation System. Since Spec. No. M101 is the rail car unloading bid specification, this equipment fits into Area 100. Similarly, Spec. No. M601 is a mechanical equipment specification applicable to Area 600, General Support Equipment. This is the air compressor bid specification, and compressors are considered general support equipment.

Three of the documents in Appendix E have a different format than the equipment specifications. These three documents were developed to be supplements to the equipment specifications - not stand-alone documents - and they are so referenced in Section 2 of each equipment specification. These three documents are:

Spec. No. E001	NEMA Frame Induction Motors		
Spec. No. E002	Electrical Requirements	for	Packaged
	Mechanical Equipment		
Spec. No. C001	Instrumentation and Controls	for	Packaged
	Mechanical Equipment		

Specific comments and suggestions for customizing each section of the equipment specifications are given below:

Section 1 - This section briefly outlines the scope of the specification. A blank line or lines followed by a set of parentheses are included in the first paragraph for the user to specify the total number of items of that equipment to be purchased. For example, one (1) welded steel silo and two (2) day bins could be filled in in Spec. No. M102, and three (3) bin vent dust collectors in Spec. No. M103.

As noted in this section, all of the equipment specifications were written to be furnish and deliver only, with the Owner providing unloading, storage, and erection.

Throughout all of the specifications, the term "Seller" is used for the vendor, and the term "Owner" is used for the buyer and/or owner and/or operator of the plant. The term "Bidder" is not used anywhere in any specification; this was done to make it easier to convert a bid specification into a purchase specification. Similarly, the words "bid" and "proposal" are not used anywhere in any specification. If the user has specific requirements for bidders, they can be included as an attachment.

Section 2 - This section lists any drawings or documents which supplement the specification. For most of the equipment specifications, the motor specification (E001), electrical requirements specification (E002), and instrumentation and controls specification (C001) are the only referenced supplements. For those specifications where the above supplemental equipment is not applicable - such as for bins or tanks - the above supplements are not referenced. The user should add any other "standard" specifications or documents that are normally used for equipment purchase.

Section 3 - This section lists the codes, standards, and regulations which apply for the design and fabrication of the subject equipment. The codes listed have been tailored for each specific piece of equipment, but the user may want to make deletions or additions based on its experience.

Section 4 - Paragraph A of this section provides a fairly detailed listing of what specific equipment the Seller is to provide. Blank lines are provided next to each piece of equipment and major auxiliary for the user to indicate the number of items to be furnished or just to indicate that that item should be included. Continuing the example used above, the following could be entered for Spec. No. M102:

a.	<u>1</u>	silos
b.	<u>2</u>	day bins
c.	<u>2</u>	emergency truck fill pipes (for day bins only)
d.	<u>incl. for each</u>	roof hatches and shell manholes

- e. incl. for each level indicator mountings
- f. incl. for each ladders and platforms

And, for Spec. No. M103:

- a. 3 enclosures
- b. 3 sets filter bags/bag cleaning system
- c. 2 exhausters fans ~~(if required)~~ (for day bins only)
- d. incl. for each controls

The other paragraphs in this section are fairly general in nature and will not normally require input or modification by the user. However, the user may want to delete certain requirements such as O&M manuals or a training program, depending on the complexity and nature of the equipment.

Section 5 - This section provides a fairly complete listing of related equipment, materials, and/or services that the Owner will provide. This section should be reviewed carefully by the user. Although it has been tailored for each specific piece of equipment, the user may need to make site-specific modifications or additions to this section.

This section also includes a release for fabrication requirement. This statement gives the Owner some assurance that fabrication will not start until the Owner is satisfied with the Seller's design and fabrication procedures. This statement may be deleted by the user under certain circumstances, e.g., standard equipment to be supplied, etc.

Section 6 - Paragraph A should be completed by the user to reflect the environmental conditions of the plant site. Some of the items may not be applicable to all of the equipment, e.g., ambient temperature, snow load, and wind load for equipment to be located indoors. However, this paragraph gives a good checklist for the user to specify the applicable plant conditions.

Paragraph B.a(2) also needs to be completed by the user to indicate whether the equipment will be located indoors or outdoors, and to give an approximate service or capacity factor for the equipment. Specific conditions of service for the equipment will be given by the user in the Design Data Sheet Completed by Owner (reference the write-up on Technical Data below).

Paragraph C.a gives general equipment design requirements. The user will need to complete Paragraph C.a(2) as appropriate for the expected life of the retrofit. Again, specific design parameters will be given by the user in the Design Data Sheet Completed by Owner.

Section 7 - This is a general section with regard to guarantees. It does, however, reference the Technical Data sheets to be completed by the Seller wherein items to be guaranteed are denoted by asterisks. If the user has other standard requirements regarding guarantees, these may be added to this section or added as a supplement to the specification.

Section 8 - This is the section which gives the details of design and construction for each piece of equipment. These requirements have been either taken from specifications which were used to buy similar equipment on actual projects, or they were generated based on the developmental work performed as part of this DOE program.

The user may have plant and/or system design requirements which conflict with, or supplement, the requirements given in this section; these will need to be included.

Section 9 - A standard welding requirements section has been included in every specification. For most standard, shop-fabricated equipment, the Seller has its own shop welding procedures in place, and these specification requirements are not necessary. These requirements may "scare" the vendors into putting more money into their bids and/or result in numerous exceptions. In these cases, these welding requirements may be deleted at the user's discretion. The specified requirements will be useful and applicable to large weldments such as tanks and silos.

Section 10 - A standard, conservative section on shop cleaning and painting has been included in each specification. Again, some of these requirements may cause the equipment price to increase unnecessarily and/or result in numerous exceptions. In these cases, the appropriate requirements may be deleted at the discretion of the user.

Section 11 - Standard identification requirements are included in each equipment specification. These requirements are fairly typical and general in nature; however, the user may need to modify the requirements as appropriate.

Section 12 - In specifications for rotating and other equipment which produces noise emissions, requirements are given for maximum sound levels. The requirements in the appropriate specifications are for 85 dBA at 3ft. If different levels apply to the specific plant site, the user should modify this section. A data sheet for noise emissions is included in each applicable specification for the Seller to document the noise levels. If the subject equipment does not cause noise emissions, this section has been deleted.

For applicable equipment, vibration requirements are also included in this section. The design requirement is for a vibration

velocity of 0.2 in./sec. instead of a range of amplitudes. Again, if different levels apply to the specific plant, the user should modify this section. Since vibration monitoring for most process equipment of this size is seldom pursued, the Seller's scope is limited in the specifications to providing provisions for mounting the vibration monitoring equipment; the equipment itself would be supplied by the Owner.

Section 13 - A standard section giving requirements for packing and shipping is included in each specification. Some of the requirements may require modification or deletion by the user.

Section 14 - Paragraph A of this section gives general requirements for testing and inspections. This section is standard in all of the specifications. Paragraph B delineates the Seller's responsibilities and the Owner's rights for inspections of the equipment. In some of the specifications, mandatory hold points are specified beyond which the Seller may not proceed without the Owner's inspection or waiver.

Paragraph C provides the general and specific shop test requirements for the subject equipment. The general requirements are standard for all equipment. The user may have plant and/or system requirements which conflict with, or supplement, the specific requirements given in this section; these will need to be included.

Paragraph D is a standard subsection for all equipment which gives the Seller's and Owner's responsibilities with regard to field testing.

Section 15 - This is a standard section - almost identical in every specification - which lists the Seller's responsibilities for generating, filing, and/or submitting applicable documents during the design, fabrication, and testing of the equipment. The requirements given in this section are fairly extensive and detailed, but the user will need to add any site-specific requirements.

In Paragraph D, the user will need to fill in several blanks to identify the number of originals and copies of the documents to be submitted by the Seller.

Paragraph E is a listing of data and drawings to be submitted during the Seller's design phase. This list should be supplemented by the user as required. Paragraph E.f determines the Seller's requirements for O&M manuals. The user will need to specify the quantity of O&M manuals required in Paragraph E.f(1)(a).

Paragraph F.c(1) requires input from the user to specify the turnaround time required by the Owner for review of Seller's submittals. In Paragraph F.c(3), the user will specify the subsequent turnaround time allowed the Seller for submittal of revised documents after the Owner's comments are received. Finally, Paragraph F.c(5) requires the user to fill in the turnaround time required of the Seller for final certified drawings.

Section 16 - A schedule for receipt of documents and the equipment itself is included in each specification. A first review date is given in terms of days or weeks after award of purchase order for the documentation. These dates are subject to change based on the user's requirements and negotiations with the Seller. The delivery date of the equipment is left blank for the user to specify. A final issue date for applicable documentation is left open for the user to specify.

Technical Data - As mentioned above, a noise level data sheet is included in each applicable specification for the Seller to document the sound levels of its equipment both with and without sound attenuation.

Each specification contains a Design Data Sheet Completed by Owner and a Design Data Sheet Completed by Seller. The Owner's data sheets allow the user to specify the number and type of components, the specific service conditions under which the equipment will operate (e.g., slurry or solids composition, temperature, density, etc.), and the design parameters required (e.g., flow rate, capacity, design temperature and pressure, etc.).

The Design Data Sheet Completed by Seller provides the vendors (and ultimately, the Seller) with space to describe their equipment; blanks are included so the Seller can confirm its design and guaranteed performance (guaranteed items are denoted by asterisks).

Instructions at the top of the data sheet suggest that the user can reproduce the Design Data Sheet Completed by Owner so that a data sheet can be completed for each different application. Referring again to the silo/day bin example above, the Welded Steel Silos/Day Bins Design Data Sheet Completed by Owner can be reproduced so that one data sheet can be completed by the user to describe the silo and one to describe the two day bins (if the two day bins are identical - otherwise, a separate data sheet should be used for each day bin).

Similarly, instructions at the top of the data sheet suggest that the vendors (and ultimately, the Seller) should complete a separate Design Data Sheet Completed by Seller for each distinct application.

TABLE 10-1

EQUIPMENT BID SPECIFICATIONS

<u>Spec. No.</u>	<u>Title</u>
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Mechanical Equipment Specifications

M101	Rail Car Unloading System
M102	Welded Steel Silos/Day Bins
M103	Bin Vent Dust Collectors
M104	Bin Activators
M105	Pneumatic Transfer/Injection Conveyors
M106	Gravimetric Feeders
M107	Screw Feeders
M108	Atmospheric Lime Hydrators
M109	Ball Mill Lime Slakers
M110	Detention-Type Lime Slakers
M111	Paste-Type Lime Slakers
M112	Vibrating Grit Screens
M113	Water and Slurry Tanks
M114	Agitators
M115	Horizontal Centrifugal Slurry Pumps
M116	Slurry Valves
M201	Humidification Water Nozzles/Slurry Nozzles
M202	Dry Sorbent Injectors
M301	Steam Coil Flue Gas Reheaters
M601	Centrifugal Air Compressors

Controls and Instrumentation Equipment Specifications

C002	Continuous Emissions Monitoring System
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Supplements

E001	NEMA Frame Induction Motors
E002	Electrical Requirements for Packaged Mechanical Equipment
C001	Instrumentation and Controls for Packaged Mechanical Equipment

APPENDIX A

BID SPECIFICATIONS

Twenty two of the twenty four bid specifications (reference Table 10-1 in Section 5.0 of this report) have been completed. They are not attached to this Topical Report No. 4 because of their bulk. They will be included in the design handbook.

The two specifications which have not been developed, Humidification Water Nozzles/Slurry Nozzles and Dry Sorbent Injectors, will be completed after the nozzle development subtask is complete (scheduled to be complete by June 28, 1991).

END

**DATE
FILMED
5/20/92**