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MODELLING AND ASSESSMENT OF ADVANCED PROCESSES
FOR INTEGRATED ENVIRONMENTAL CONTROL OF
COAL-FIRED POWER PLANTS

Technical Progress Report

By
J. G. Barrett
C. N. Bloyd
F. C. McMichael
E. S. Rubin

July 1984

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Carnegie-Mellon University
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**MODELLING AND ASSESSMENT OF
ADVANCED PROCESSES FOR
INTEGRATED ENVIRONMENTAL CONTROL
OF COAL-FIRED POWER PLANTS**

Technical Progress Report

To

**Pittsburgh Energy Technology Center
U.S. Department of Energy
Pittsburgh, Pennsylvania 15236**

From

**Center for Energy and Environmental Studies
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213**

**J.G. Barrett
C.N. Bloyd
F.C. McMichael
E.S. Rubin**

July 1984

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SUMMARY

The key objective of this research is the development of a computer based model for the assessment of integrated environmental control (IEC) systems for conventional and advanced coal fired power plant designs. Efforts during the period April 1 - June 30, 1984 focused on, (1) testing of a preliminary integrated model linking pre-combustion and post-combustion control options for conventional plants; (2) documentation of the analytical models of existing control technology options; (3) development and preliminary testing of a second model design for the propagation and analysis of uncertainty; and (4) development of new analytical models needed for IEC assessments. Activities and accomplishments in each of these areas are described.

1. INTRODUCTION

The key objective of this research is the development of a computer based model for the assessment of integrated environmental control (IEC) systems for conventional and advanced coal fired power plant designs. Efforts during the April 1 - June 30, 1984 focused on, (1) testing of a preliminary integrated model linking pre-combustion and post-combustion control options for conventional plants; (2) documentation of the analytical models of existing control technology options; (3) development and preliminary testing of a second model design for the propagation and analysis of uncertainty; and (4) development of new analytical models needed for IEC assessments. Activities and accomplishments in each of these areas are described below.

2. TESTING OF PRELIMINARY INTEGRATED MODEL

A preliminary FORTRAN program has been developed to model a coal-fired power plant employing arbitrarily specified combinations of air pollution control systems employed before, during or after combustion. Options currently implemented in the model are listed in Table 1. These components have been developed in previous studies [1,2], but have been revised and linked in a new modelling framework developed for this project. During the past calendar quarter we have focused on testing of the coal cleaning plant model in a stand-alone fashion, and on the integration of the coal cleaning plant model with a model of a conventional power plant employing wet or dry flue gas desulfurization (FGD).

2.1. Coal Cleaning Plant Model

Our last progress report [3] described a new computer model of physical coal cleaning (PCC) plants recently developed at CMU. This model simulates the performance and cost of four "levels" of coal cleaning, corresponding to four nominal flowsheet designs of increasing complexity that reflect currently available technology. The model also determines the optimum (least-cost) partitioning of crushed coal sizes to achieve a desired product coal quality.

Table 1. Current Components of the IEC Model

System Area	Technology
Pre-Combustion	Physical Coal Cleaning (Levels 1, 2, 3, 4)
Combustion	Low-NO _x Burners Limestone Injection Multi-Stage Burners (LIMB)
Post-Combustion	Electrostatic Precipitator Fabric Filter Collector Wet Limestone FGD Dry Lime FGD Solid Waste Ponding Solid Waste Landfill

Preliminary testing of the model included the development of computer graphic techniques to display the results of model calculations in response to parameter variations.

Figures 1 to 5 illustrate results of model calculations for one particular coal. This is a very high sulfur coal (4.6% sulfur) Lower Kittanning coal (Indiana County, PA) with extremely good washability characteristics. Figure 1 shows the predicted capital cost for cleaning plant levels 2, 3 and 4 for different levels of plant size (expressed in units of tons of cleaned coal per hour at full capacity). Here, capital cost is shown on an annualized basis, and expressed as 1983\$/ton of clean coal output. On this normalized basis capital costs are seen to be relatively insensitive to plant size and capacity. Figure 2 shows the combined costs of capital and annual operating expenses on the same normalized basis. Now, significant economies of scale are seen for plant capacities in excess of about 300 tons per hour; also the higher costs of more complex plant designs become more pronounced. For these cases, it is assumed that all plant levels accomplish a 30% reduction in coal sulfur content when expressed in terms of mass of sulfur per unit of coal energy.

Figures 3, 4 and 5 show the cost implications of achieving different levels of sulfur removal for a fixed plant capacity of 500 tons per hour. Annualized capital and operating costs are seen to increase with increasing sulfur removal and increasing levels of plant complexity (Figure 3). The same is true for the cost of coal lost as solid waste refuse from the plant (Figure 4). In Figure 5, the combined costs of cleaning plant construction, operation and coal refuse loss are added to the base coal price to show the overall variation in total coal price (expressed in terms of cents/million Btu) as a function of sulfur removal. Because of the unusually good washing characteristics of this particular coal, sulfur removal levels as high as 70% (on an energy basis) are technically achievable, though this is not characteristic of most high sulfur coals. For example, Figure 6 shows how washing costs vary with sulfur removal for a 2.1% sulfur eastern coal (Bedford County, PA). In comparison

**Figure 1. Coal Cleaning Plant Capital Cost Versus Size
(4.6% S)**

**Figure 2. Total Cleaning Plant Cost Versus Size
(4.6% S)**

Figure 3. Coal Cleaning Cost as a Function of Sulfur Reduction
(4.6% S; 500 tph)

Figure 4. Refuse Coal Cost (Yield) Versus %S Reduction
(500 tph; 4.6% S)

Figure 5. Effects of Coal Cleaning on Coal Cost
(4.6% S Coal)

Figure 6. Coal Cleaning Cost as a Function of Sulfur Reduction
(2.1% S; 500 tph)

with Figure 3, significantly higher costs and lower levels of overall removal are seen. As part of future studies, additional sensitivity analyses, are anticipated which will include variations of economic and financial parameters as well as plant operating and design parameters.

2.2. Integrated Model Results

Figure 7 illustrates results from the current design of the integrated power plant model for the case of a 500 MW unit complying with current new source performance standards using a cold-side ESP for flyash removal and a wet limestone FGD system for sulfur removal. The increase in levelized electricity cost due to pollution control systems is shown for a hypothetical case in which coal sulfur content varies while all other parameters remain fixed (except that coal heating value is adjusted to account for the change in sulfur level). The cost components due to flyash collection, solid waste disposal, and sulfur removal are shown separately, along with the combined cost of control. FGD costs dominate the total cost and increase significantly within increasing sulfur content. The change in slope of FGD costs at a little more than 2% sulfur (seen also in total cost) occurs at the point where partial bypass of the FGD system can no longer be employed to reduce costs while still complying with emission requirements. In this example, nitrogen oxide control costs are assumed to be included with the boiler costs, so that the purchased unit meets NSPS requirements with no additional control needs.

In Figure 8 we show how the total levelized cost of pollution control for the power plant just presented would vary in response to a reduction in coal sulfur content, assuming as a base case the same 4.6% sulfur coal used to illustrate the performance and cost of the coal cleaning plant model. Control costs are seen to continually decrease with increasing sulfur reduction as FGD systems costs and solid waste disposal costs decline. Results for the integrated model, which combines coal cleaning and power plant operation, are shown in Figure 9 for the case of the 4.6% sulfur coal. This figure shows the net effect of increasing coal costs (Figure 5) and

Figure 7. Effects of Coal Sulfur on Wet FGD Emission Control Costs

Figure 8. Air Emission Control Cost in Wet FGD-Coal Cleaning System (4.6% S Coal)

**Figure 9. Wet FGD/Coal Cleanign Based System:
Net Electricity Cost (4.6% S Coal)**

**Figure 10. Electricity Cost, as a Function of the Level of
Sulfur Reduction from coal Cleaning (2.1% S Coal)**

decreasing plant operating costs (Figure 8) as additional sulfur is removed from raw coal through physical cleaning. Results here are given in terms of the total electricity cost (including base plant capital, operating and maintenance costs) in 1983 mill/kWh. Initially, electricity costs rise in response to the higher cost of coal with relatively little benefit from low levels of sulfur reduction. Subsequently, however, net costs gradually decline as additional sulfur is removed, leading to savings in plant costs which outweigh the increased cost of fuel. At an overall sulfur reduction of about 62 percent costs begin to rise as the increase in coal cost again dominates. For this case, combining the use of pre-combustion (washed coal) and post-combustion (FGD) control systems reduces the overall cost of electricity when the raw coal is washed to achieve sulfur removal levels in excess of about 35 percent. For lower levels of sulfur removal, use of the unwashed coal (zero percent removal in Figure 9) leads to a lower electricity cost. In these examples a coal transportation cost of \$10/ton was assumed in addition to the mine-mouth coal prices shown in Figure 5.

As has been found in other studies, the combination of pre-combustion and post-combustion sulfur controls does not always lead to reduced electricity cost compared to the case of FGD alone. Figure 10, for example, shows electricity cost variations as a function of sulfur reduction for the 2.1% sulfur coal described in Figure 6. Here, the higher delivered costs of cleaned coal are not sufficiently offset by the benefits of reduced gas cleaning costs, with the result that electricity costs remain higher for all levels of coal cleaning than for the case of no coal cleaning at all. This is true both for the case of a wet limestone FGD system, as well as for the case of a dry lime spray tower system combined with a fabric filter device for particulate collection (also shown in Figure 10). These results also show the dry FGD system to be lower in costs than the wet system for the case illustrated here. Additional case studies and sensitivity analysis are planned in future phases of this project.

3. MODEL DOCUMENTATION ACTIVITIES

During the past quarter, work was initiated on detailed documentation of the analytical models being used and developed as part of this research. Earlier draft documentation has been revised and updated to reflect changes made during the course of this study. Additional documentation of the coal cleaning plant model also was developed. A set of detailed sample calculations to illustrate the quantitative aspects of the model and computer code also are being prepared.

We believe that early efforts to provide written documentation of the analytical basis for these models, together with sample numerical examples showing details of calculation procedures, will be especially beneficial to the overall project and its subsequent use to others. A detail description of model designs will accompany the final report of this project.

4. PROPAGATION AND ANALYSIS OF UNCERTAINTY

In our last progress report we indicated that efforts had been initiated to develop a new model design especially suited for analyzing effects of uncertainty. This was to utilize the DEMOS software system recently developed by Henrion and Morgan [4,5].

4.1. Model Implementation in DEMOS

DEMOS (for Decision Modeling System) is an interactive modeling environment for structuring, analyzing and communicating probabilistic models. It allows the user to input modeling relationships and data in an arbitrary fashion, leaving DEMOS to solve the resulting system of equations.

A particularly powerful feature is that DEMOS allows the insertion of probability distributions about most modeling variables. DEMOS is then capable of generating both a probability density function (PDF) and a cumulative distribution function (CDF) for any or all dependent parameters. This can be especially important in characterizing the uncertainty associated with advanced technologies, whose

performance and cost characteristics are not likely to be well defined. The variable being considered can depend on many uncertain variables. The resulting functions are displayed on a computer terminal using character graphics.

The method used to generate probability functions is a series of Monte Carlo (random choice) simulations. The variable whose probability function is to be determined is calculated and stored a number of times. Each time it is calculated a value for each uncertain variable is selected according to the probability distribution specified for each uncertain parameter. After a repeated number of simulations (perhaps up to several hundred or more), DEMOS has built up a data base of possible values for the variable being considered. This allows the calculation of an "experimental" CDF and PDF for this variable. This approaches the "true" distribution as the number of simulations increases.

Once the CDF is generated it is possible to determine the range of values which apply for any given degree of confidence. Thus, estimates of variable values (such as cost) can be reported as lying within a given range with an X% confidence. In this fashion, the effect of individual uncertainties may be studied in a more realistic manner with DEMOS than with conventional sensitivity analysis, in which only a single parameter or two are varied over discrete ranges to produce deterministic (rather than probabilistic) results. This ability to examine the effect of uncertainty in light of other uncertainties is a very significant one.

DEMOS allows all variables not used as subscripts in tables or in the definition of uncertainty to be defined by probability distributions. This allows most variables to take on a range of values representing their uncertain nature. The five types of distributions accepted by DEMOS are:

Normal	The standard normal distribution, defined by two parameters: the mean and the standard deviation. This is the well known <i>bell curve</i> with approximately 68% of the values lying within one standard deviation of the mean, and 98% of the values with two standard deviations.
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Lognormal	The standard lognormal distribution, defined by two parameters: the median and the geometric standard deviation. This distribution has zero probability of a negative value, a peak at a low positive value, and a long thin tail into large positive values.
Uniform	A uniform distribution between two input values is defined such that the probability of any value within the range is the same.
Fractiles	A type of distribution where the percentage of results between each pair of values specified is given. The likelihood of any specific value within a subrange is uniform. The likelihood of any any subrange is determined by the percentage of values specified as coming from that subrange.
Chance	A discrete distribution which defines the probability of any specific value explicitly. This is the only discrete distribution available to DEMOS.

4.2. Illustrative Results

As an illustrative example, an analysis of the effect of several uncertain factors has been performed using the newly developed DEMOS version of the IEC model for a conventional power plant system. The parameters of the plant are given in Table 2 along with the mean values assumed in all calculations. A spray dryer FGD system and fabric filter particulate collector are assumed for this example (as in the case shown earlier in Figure 10).

The parameters selected for uncertainty analysis were chosen for the purpose of this illustration only. The uncertainty ranges, while not completely arbitrary, are not intended to reflect actual data. Similarly, the inclusion of a particular variable as certain or uncertain should not be considered to be significant at this time.

Two types of variables were selected for study. They have been loosely labeled as:

- Raw Materials Cost
- Economic Parameters

All of the parameter uncertainties were assume to be normally distributed (though other types of distributing also could have been assumed). The results presented all

Table 2. Assumed System Parameters

<u>Power Plant Characteristics</u>		Size	500 MWe (gross)
		Heat Rate:	9500 Btu/kWh
		Capacity Factor:	0.65
		Ash Sulfur Retention:	0.025
		Fraction Flyash to Overhead:	0.50
		Excess Air:	0.35
<u>Coal Properties</u>		Sulfur	2.00%
		Ash	15.14%
		HHV	11700 Btu/lb
<u>Emission Standards</u>		SO ₂	RNSPS
		TSP	0.03 lb/10 ⁶ Btu
		NO _x	0.6 lb/10 ⁶ Btu
<u>Economic Parameters</u>		Coal	\$20/ton
		Land	\$5000/Acre
		Lime	\$65/ton
		<u>Indirect Cost Factors</u>	
		Dry Lime FGD	0.80
		Waste Disposal	0.75
		TSP control	0.50
		Base Plant	0.50
		<u>Fixed Charge Factors</u>	
		Pollution Control	0.15
		Base Plant	0.20
		Variable Cost	
		Levelization Factor	1.886

deal with the cost of pollution control only.

Figure 11 shows the result of making only the cost of lime uncertain. The uncertainty was defined so that one standard deviation was \$7.50/ton (12.5% of the mean value of \$65/ton). Thus, given a normal distribution, 68% of the time the lime cost will fall between \$57.50 and \$72.50/ton and 98% of the time it will be between \$50 and \$80/ton. Under these circumstances, the CDF in Figure 11 may be used to conclude that there is a 90% probability that the cost of power produced will be below 15.05 mills/kWh, and that there is a 10% chance that it will be below 13.45 mills/kWh. It can also be stated that the cost of power is 80% certain, in the face of these uncertainties, to be 14.25 ± 0.8 mills/kWh.

The economic parameters assumed to have uncertain values in this example are the pollution control cost fixed charge factor (assumed $\sigma=0.025$), the variable cost levelization factor ($\sigma=0.20$) and the indirect cost factor for particulate control ($\sigma=0.025$). The cumulative effect of these uncertainties are shown in Figure 12. The first uncertainty produces an 80% confidence range of 13.5 to 15.7 mills/kWh, or 14.5 ± 1.1 . Adding a second uncertainty changes the 80% confidence range to 14.5 ± 1.7 , an increase of 0.6 in the range size. The third uncertainty, indirect charge factor for flyash control, alters the confidence range to 14.5 ± 1.9 , an increase of 0.2.

Figure 13 plots the effect of the economic and raw materials uncertainties on a common scale. This figure shows the greater importance of the economic factors as compared to raw material costs in this example. Again, this effect is a result of the magnitude of uncertainties selected for both sets of variables. The values used here were arbitrarily selected simply to illustrate the type of capabilities achieved with the DEMOS software system. More rigorous testing is expected later in this project.

Figure 11. Effect of Uncertainty on Pollution Control Costs
(Raw Material Cost)

Figure 12. Effect of Uncertainty on Pollution Control Costs
(Economic Parameters)

Figure 13. Effect of Uncertainty on Pollution Control Costs
(All Parameters)

5. NEW COMPONENT MODELS

The final activity undertaken during the past quarter involved initiation of work on several new model components needed to complete the fully integrated set of baseline technologies against which advanced technologies will be compared in the second year of effort.

5.1. Selective Catalytic Reductions Systems

The baseline technology identified by DOE as the reference case for nitrogen oxide control is a selective catalytic reduction (SCR) process removing 90% of nitrogen oxide emissions from coal-fired power plants. While such systems have not yet been used commercial in the United States, several are now operating in Japan. Accordingly, efforts were initiated to develop an appropriate analytical model of SCR processes to include in the integrated model design. Efforts to date have included acquisition and review of several design and economic studies performed by the Tennessee Valley Authority (TVA) and the Electric Power Research Institute (EPRI). These studies will form the basis for the more simplified model to be developed as part of this study. A detailed report of that development is expected as part of the next quarterly progress report.

5.2. Water Pollution Control Systems

While the principal emphasis of this research project is on the air pollution control aspects of integrated environmental control systems designs, careful consideration of wastewater treatment aspects of power plant designs also is important since air pollution control systems may interact closely with solid waste and water pollution control technologies. Thus, as part of this effort, we hope to include appropriate models of two types of water pollution control systems - cooling towers for the control of thermal effluents, and centralized treatment systems for the control of chemical wastes. In this report we outline the plan that will be followed to develop engineering cost equations for the supply of water and disposal (including recycle and reuse) of wastewaters for coal-fired power plants, in compliance with

federal regulations such as the Clean Air Act (CAA), the Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA).

5.2.1. Water Requirements

Water is required for several unit operations in a power plant. There are a range of water quality requirements as well as quantity requirements for different unit operations. Boiler water for steam production has the highest requirements for quality in terms of dissolved solids, and approaches distilled water in composition. Water used for ash transport or for cooling can satisfactorily be used even with a dissolved solids composition exceeding the salinity of sea water. Hence, it is reasonable to define a hierarchy of water requirements. This is common practice today and the concepts of water reuse and recycle are exploited in both retrofit and new power plant designs. Some water is consumed through evaporation and moisture in solid waste disposal so that make-up water is required for all power plants. In certain geographical areas, zero discharge of wastewater to surface or ground water is possible through the use of evaporating ponds. It is important to note that zero discharge of wastewater does not eliminate the need for new or make-up water. The trend of current practice is to reduce the quantity of water per unit of power that is needed (withdrawn) or discharged for any utility design. We will quantify the water requirements for all unit operations subject to mass and energy balance restrictions.

5.2.2. Wastewater Disposal

Table 3 lists the current Federal new source performance standards (NSPS) for the steam electric power industry. These standards are the basis for securing a wastewater discharge permit (NPDES). Specific wastewater categories are defined. No discharge of pollutants is specified for the flyash transport category. Also no detectable amount of 126 priority pollutants may be present in cooling tower blowdown. It is important to note that the wastewater effluent guidelines are prescribed differently from the air emission guidelines. Namely, the wastewater guidelines identify chemical concentrations in the allowable discharge and do not

limit the mass rate of discharge of a chemical. There are benefits from a design that can achieve zero discharge of pollutants to a particular media. EPRI has identified about 30 operating power plants who are attempting to operate with zero wastewater discharge. However, the daily reliability of such systems is still being examined. Such systems require more careful management and maintenance than systems with some wastewater discharge.

5.2.3. Water System Design Concepts

Design, operation and management of a power plant utility water system must address several environmental objectives. Presently, all three media - air, water, and land - are receptors of waste discharges. Federal regulations are the principal basis for selecting the appropriate medium for the disposal of particular chemical and physical pollutants. Heat was identified in the CWA as a wastewater pollutant subject to a zero discharge requirement. Therefore, modern power plants are designed with cooling systems that mostly reject heat to the atmosphere rather than to surface or ground waters. It is possible to operate cooling towers with tight recycle to reduce the blowdown rate to a few percent of the circulating cooling tower flow rate. Chemicals that are the basis for limiting the blowdown are not typically the chemicals that are listed as the specific pollutants that must be monitored and controlled under the federal effluent guidelines.

Table 4 lists the EPRI recommended limiting concentrations of several chemicals for reliable operation of the recirculating cooling water. The basis for these operating guidelines is the management of corrosion, plugging, and reduction of heat transfer efficiency of the cooling water system. We will develop our cost equations for cooling water systems which use recycle. We anticipate that impact on system cost will be mainly on operating costs and reliability and will not substantially change the capital costs. This is because the major capital cost items depend on the total water volume and water volume circulating flow rate more than any other parameters. The quantity of water circulating in a water recycle system is not significantly

Table 3. EPA Effluent Limitations for Steam Electric Generating Plants

	Existing sources				New sources	
	BPT (To be achieved by July 1, 1977)		BAT (To be achieved by July 1, 1984)		NSPS	
	6-9 No discharge		No discharge		6.0-9.0 No discharge	
All discharges pH PCBs	Max. 1 Day	Avg. of 30	Max. 1 Day	Avg. of 30	Max. 1 Day	Avg. of 30
Low volume wastes						
TSS	100 (mg/l)	30 (mg/l)	- (mg/l)	- (mg/l)	100 (mg/l)	30 (mg/l)
Oil and grease	20	15	-	-	20	15
Flyash transport water						
TSS	100	30	-	-	No discharge of pollutants from flyash transport water	
Oil and grease	20	15	-	-		
Bottom ash						
TSS	100	30	-	-	100	30
Oil and grease	20	15	-	-	20	15
Metal cleaning wastes						
TSS	100	30	Divided into chemical and non-chemical metal cleaning wastes		Divided into chemical and non-chemical metal cleaning wastes	
Oil and grease	20	15				
Copper, total	1	1				
Iron, total	1	1				
Once-through cooling water						
Free available chlorine	0.5	0.2	0.5	0.2 (<25 MW)	0.5	0.2 (<25 MW)
Total residual chlorine	-	-	0.2	(>25 MW)	0.2	(>25 MW)
Cooling tower blowdown						
Free available chlorine	0.5	0.2	0.5	0.2	0.5	0.2
126 Priority pollutants contained in chemicals added for cooling tower maint. except:	-	-	No detectable amount		No detectable amount	
Chromium, total	-	-	0.2	0.2	0.2	0.2
Zinc, total	-	-	1.0	1.0	1.0	1.0
Coal pile runoff						
TSS	50	-	-	-	50	-
Chemical metal cleaning waste						
Copper, total	-	-	1.0	1.0	1.0	1.0
Iron, total	-	-	1.0	1.0	1.0	1.0
TSS	-	-	-	-	100	30
Oil and grease	-	-	-	-	20	15

BPT = Best practicable control technology currently available.
 BAT = Best available technology economically achievable.
 NSPS = New source performance standards.
 TSS = Total suspended solids.

Table 4. Operating Guidelines for Cooling Tower Systems in Electric Power Plants

<u>Constituent</u>	<u>Limits</u>	
	<u>Without Scale Inhibitors</u>	<u>With Scale Inhibitors</u>
pH (pH units)	6.8 - 7.2	7.8 - 8.4
Total Alkalinity (mg/l as CaCO_3)	30 - 50	200 - 250
Calcium Sulfate (mg/l of Ca as CaCO_3)	Maintain $\text{Ca} < 900$	Maintain $\text{Ca} < 900$
Silica (mg/l as SiO_2)	150	150
Magnesium Silicate (mg/l of Mg as CaCO_3 and mg/l of silica as SiO_2)	$\text{Mg} \times \text{SiO}_2 < 35,000$	$\text{Mg} \times \text{SiO}_2 < 75,000$
Suspended Solids (mg/l)	150	150
Total Dissolved Solids (mg/l)	60,000	60,000
Calcium Phosphate (mg/l as PO_4)	Maintain Orthophosphate < 5	Insufficient data
Scale Inhibitor (mg/l)	Zero	As required on an individual basis per supplier's recommendation

"Design and Operating Guidelines Manual for Cooling-Water Treatment," EPRL CS-2276, First Edition, March, 1982.

different from the water circulated in a once-through system.

Reuse of water between different unit operations in a power plant is an important design concept. In particular, the identification of sinks where water is used consumptively (evaporated) creates an opportunity for disposal of some wastewaters, and hence, is a step towards zero discharge. Both the cooling water systems and the non-regenerative flue gas scrubber systems consume (evaporate) water and generate blowdown. The interchange of water between these systems will be examined to determine its effect on water withdrawal, chemical treatment requirements, and costs.

5.2.4. Water System Operation Alternatives

Operation of water and wastewater flows in a power plant is based on the identification of which operations require once-through water use, which can operate under recycle, and which can reuse water from another power plant operation. Some recycle systems may be controlled by simply balancing blowdown and make-up water quantities and quality. Other systems are based on the concept of isolating a side or split stream from the circulating water and using some form of physical, chemical, or biochemical treatment to alter the quality of the water. Again, these split stream flow rates are typically a small fraction of the total circulating flow rate so that costs which are based on volume flow rates are also going to be a fraction of the total system cost.

5.2.5. Impact of Environmental Regulations

By several different measures, the cost of compliance with the CWA for electric power plants is smaller than cost of compliance with the CAA and RCRA. However, attention to compliance with the effluent guidelines of the CWA is not a small matter for power plants. One may by-pass the need for treatment and monitoring of a process stream if there is no wastewater discharge. However, if system reliability results in an occasional water discharge there is no circumventing the need for an NPDES permit. Reduced requirements for water withdrawal may aid in siting of a

power plant in an area with limited water resources. Similarly, a clearer definition of water quality requirements may permit the use of water discharged from another industry (such as the use of treated municipal wastewaters) for power plant supplies.

The handling of power plant solid wastes is strongly coupled to the water system. Presently, the federal regulations (RCRA) explicitly list power plant solid wastes in a non-hazardous category. Some states, however, may choose to force power plants to demonstrate that particular solid wastes will pass a buffered water extraction test. Should a solid waste fail such a test and consequently be classified as a hazardous waste, there will be a substantial (as much as 50 times) increase in the direct disposal costs, as well as new requirements for site monitoring beyond the lifetime of a disposal facility, and other extended liabilities relative to possible ground water contamination. Solid wastes which are non-hazardous often require a minimum water content for ease of handling and dust control. This moisture content requirement has been one of the traditional sinks for water. Requirements for leachate collection and treatment are additional requirements that result from the classification of solid wastes as hazardous.

5.2.6. Emphasis of Cost Models

Cost models for water use depend on the establishment of a hierarchical flow plan for air, water, and solids handling systems. The principal capital costs are associated with the cooling water and FGD systems. Costs associated with system reliability, such as discharge from processes originally described as self-contained or producing zero discharge, may be described by scenarios. Reclassification of solid wastes as hazardous rather than non-hazardous may also greatly change the water and energy balances of the system. Our models will identify the assumptions that are most critical to mass/energy balance factors and compliance with alternative regulations.

6. PLANS FOR THE NEXT REPORTING PERIOD

During the next calendar quarter research efforts will concentrate primarily on the development and implementation of new process performance and cost models needed to complete the design of a fully integrated model for baseline systems. Further development of the DEMOS model design will focus on developing simplified representations of the coal cleaning plant optimization model so that the combined effects of uncertainties in pre-combustion and post-combustion process parameters can be easily analyzed. Efforts on model testing and documentation also will continue in the next project period. Finally, efforts will be initiated to begin modelling several of the advanced technologies selected for study in this project.

7. REFERENCES

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