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IMPROVED LIQUID/SOLIDS HANDLING MODULE

Final Report for Period September 1, 1979—October 31, 1980

By
L. K. West

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Aerojet Energy Conversion Company
Sacramento, California

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IMPROVED LIQUID/SOLIDS
HANDLING MODULE

Final Report 2321:01
1 September 1979 to 31 October 1980
Contract DE-AC03-79ET27193

Prepared for:

U.S. Department of Energy
Division of Geothermal Energy
San Francisco Operations Office

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NOTICE

Your copy of Report No. DOE/ET/27193-T1, "Improved Liquid/Solids Handling Module," may be missing the attached pages. If so, please insert them in your copy.

LIQUID/SOLIDS HANDLING MODULE

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1.0 INTRODUCTION, SUMMARY AND CONCLUSIONS

1.1 Introduction

The Improved Liquid/Solids Handling System (L/S) is an integral part of an Advanced Geothermal Primary Heat Exchanger (APEX)(1) development program conducted for the Department of Energy. The program is designed to provide a low cost self-cleaning binary heat exchanger for utilization with medium temperature, high total dissolved solids laden brines.

Fouling of heat exchangers is the major unresolved problem in heat transfer apparatus. The problem appears in all facets of the heat exchanger industry but is particularly troublesome in geothermal and oil field applications. Typically, the heat exchanger designer will use a so-called fouling "factor" to size the equipment. The most popular source for this factor is the TEMA standards. Unfortunately, these published factors are given as a constant undocumented number. The net result is that heat exchangers are generally oversize for a given application in order to provide the extra surface area needed to accomodate the fouling. In the case of geothermal applications, this can be by as much a factor of two. Since the heat exchangers in a geothermal application (such as a binary cycle) represent a sizable portion of the plant costs, it is important that all possibilities of scale control and/or prevention be explored.

Fouling depositions inside a heat exchanger assume many forms, dependent upon the mineral and biological content of the flowstream. In geothermal applications, the scale formed can range from a soft spongy-type deposition, which occurs in calcium carbonate wells, to a hard rock-like substance composed of silicate and/or heavy metal sulfides.

Very little research has been done on scale or fouling prevention. In practice, prevention is limited to techniques of water quality control, flow velocity control, and tubewall temperature control. Scale cleanup has been limited to mechanical methods, such as reaming the tubes inside which scale has formed and in some cases, chemical treatment.

1.1, Introduction (cont.)

More recently, attempts have been made to either prevent scale formation or clean it up once it has formed by the circulation of a slurry of abrasive compounds and water. One technique used in the refinery industry⁽²⁾ is to circulate a slurry of air, sand, and water through the tubes of a condenser. This has proven quite effective in this application. Another similar technique⁽³⁾ is used to prevent calcium sulfate scale buildup on heat exchanger surfaces during flash-evaporation desalting of sea water. In this application, calcium is fluidized within or outside the vertical heat exchanger tubes as salt water goes through the bed of particles. The mild scouring action of the fluidized particles does double duty, helping keep tubewalls, as well as their own surfaces, free of calcium sulfate buildup.

The most recent application of a sand slurry for scale control is the Aerojet APEX⁽¹⁾ concept. The APEX self-cleaning heat exchanger concept, briefly, is one of recirculating solids (such as sand) through the heat exchangers with the washing geothermal fluid. The solids are collected at the exchanger exit and are re-introduced at the inlet. The APEX principle has been demonstrated to be an effective method of controlling scale⁽¹⁾. A critical feature of this system is that it is necessary to minimize the carryover of solids on downstream reinjection cleanup systems. Also, it is essential that wear on pumps and other system components be minimal. These two items, the carryover and system life, are the key to a successful Liquid/Solids Handling System.

The objectives of the Improved Liquid/Solids Handling System (L/S) Program is to develop a system which will meet the stringent requirements of geothermal injection systems. Specifically:

- (1) Develop a solids handling dispersant and control system;
- (2) Maximize recovery efficiencies;
- (3) Develop monitoring and measurement system;

1.1, Introduction (cont.)

- (4) Demonstrate system durability; and
- (5) Design system for integration into present APEX test equipment for future well site testing.

The program was divided into three major technical tasks.

Task 1, Design, included two subtasks of Preliminary and Detailed Design.

The Preliminary Design subtask included both the evaluation of L/S test equipment and that of potential downstream injection cleanup equipment. This was necessary to insure system compatibility and to provide a sense of what an overall system might require. It was concluded that hydro-cyclone separation and injection pumping which displaces solids with brine under pressure was the optimal design approach. The following Detailed Design subtask simply focused on the developing of the system design and specifications.

Task 2, System Fabrication, included procurement of commercially available components refurbishing salvaged APEX equipment and fabrication of special components, as well as assembly.

The third major task (Task 3) was the testing of the system at the Aerojet test facility in Sacramento, California. This included equipment set up, checkout tests, followed by verification testing and data analysis.

The detailed conclusions reached as a result of L/S testing are discussed in the body of this report. It was concluded that the L/S system operated within design limits and provided collection efficiencies in excess of 99%.

This report, a continuation of the APEX program, covers the work performed under Contract No. DE-AC03-79ET27193 from 31 August 1979 to 31 October 1980, and focuses on the development and laboratory testing of a mobile liquid/solids handling unit (L/S). The work described herein was conducted for the Geothermal Energy Division, San Francisco Operations Office, Department of Energy. John Gonzales is the DOE Program Coordinator. The

1.1, Introduction (cont.)

program was conducted at the Aerojet Energy Conversion Company facility at Sacramento, California.

The project activity at Aerojet included contributions from the following personnel:

J. P. Nesewich	- Program Manager
L. K. West	- Project Engineer
F. H. Miller	- Supervisory Engineer
C. M. Gracey	- Field Test Operations Engineer
C. S. Mah	- Staff Specialist
Dr. E.M. VanderWall	- Field Test Operations Manager

1.2 Summary

An equipment investigation was conducted to establish types of equipment available for the L/S application and their separation capability and costs. The information gained was used to define a possible total L/S system, define the scope of complexity for this contract, and then formulate the L/S design specification.

A total L/S system was conceived using hydrocyclones for the recirculation separators and mixed media bed filters for reinjection clean-up. The resources of this contract limit the scope of work to the injection-separation-recirculation cycle, leaving the effluent polishing to future work. The design specification established design requirements for the L/S system operating under geothermal conditions, although system performance was to be evaluated at cold flow conditions on plant for this contract.

The main components of the L/S system are two hydrocyclones, two accumulator tanks, and an injection pump. The pump pressurizes (with fresh brine) one of the two accumulator tank-hydrocyclone combinations which forces a thick slurry into the main flowstream. The resultant thin slurry of approximately 6 Wt/Wt% solids concentration (used for APEX) then flows to the hydrocyclone influent of the second tank; there the sand is separated and falls into the accumulator tank. While one accumulator tank is emptying, the other fills. After the transfer of sand, the roles are reversed. The

1.2, Summary (cont.)

second one empties and the first one fills with sand. The process continues alternating throughout an experimental run.

The L/S equipment was assembled on an 8 ft. by 16 ft. flatbed trailer which will facilitate future moves to specific sites for geothermal well testing. The system was designed for 300 psig, 400°F maximum operating conditions and nominal operating parameters of 30 gpm, 6 Wt/Wt% solids and 90 mesh sand. Controls of the system allow intermittent to continuous operation depending on well operation needs.

The objectives of the test program were to evaluate L/S's capability to perform as the solids control system for APEX and to ascertain its impact on reinjection cleanup. Its capability was determined primarily by separation efficiency, effluent solids concentration, and to a lesser degree, by injection consistency, pressure drops, and hydrocyclone wear. The separation efficiency and impact on reinjection were evaluated at varying system flowrates of 20, 30, and 40 gpm; solids concentrations of 2, 6, and 10 Wt/Wt% solids; and sand mesh sizes of 30, 50, 90, and 140 mesh.

1.3 Conclusions

The entire L/S system functioned as designed: expulsion of sand from the accumulator tank, mixing at the injection point, separation by the hydrocyclone, and accumulation of sand for recirculation all occurred as expected.

Test results confirmed anticipated L/S performance trends; over the ranges of the variables tested, higher hydrocyclone flowrates, lower solids concentrations, and larger particle sizes increase separation efficiencies and decrease L/S impact on reinjection. Requirements of the design specification for working fluid cleanup were surpassed; particles greater than 88 μ were collected for recirculation at efficiencies greater than 99%. Of the three parameters, separation is most sensitive to changes in particle size. If flowrate and solids concentration were left at 30 gpm and 6 Wt/Wt% respectively, and if 50 mesh sand (nominal 300 μ) that contained

1.3, Conclusions (cont.)

no particles smaller than 125μ were used, test results showed that greater than 99.9% separation efficiency would be achieved. For L/S impact on reinjection cleanup, this greater than 99.9% would equate to less than 66 ppm solids concentration in the L/S effluent. The impact on reinjection could be further reduced to less than 30 ppm if the solids concentration were set at 4 Wt/Wt% with the above conditions.

Qualitative examination reveals that the injection consistency (concentration) achieved is adequate for the L/S system. Accumulator tank expulsion times and concentration profiles vs. time were repeatable. In addition, hydrocyclone effluent concentration was very steady, meaning that influent concentration was consistent enough not to cause separation perturbations. Nominal condition pressure drops at a 30 gpm flowrate for the hydrocyclone and L/S system are 8 psi and 38 psi respectively. From hydrocyclone erosion data and given assumptions, it is projected that the hydrocyclone life will be about 15,000 hours.

Overall, it is concluded that L/S is capable of performing as the solids control system for an APEX test unit since each L/S function (injection, separation, and recirculation) operated as desired. The optimum set of operating conditions for L/S where it impacts reinjection with as little as 30 ppm effluent concentration are 30 gpm flowrate, 4 Wt/Wt% solids, and 50 mesh sand. The performance results indicate 40 gpm, 2 Wt/Wt%, and 30 mesh would be superior but these numbers are tempered by engineering judgment which indicates that 40 gpm might give too high of a pressure drop, 2 Wt/Wt% might not be effective for scale prevention, and 30 mesh sand might stratify.

2.0 EQUIPMENT DESIGN

2.1 Preliminary Design

An equipment investigation conducted at the program outset established the types of equipment available for the L/S application and their

2.1, Preliminary Design (cont.)

separation capability and costs. The information gained was used to define a possible total L/S system, determine the scope of complexity compatible with the program resources, and finally, formulate the L/S design specification.

The APEX heat exchanger concept (of which the L/S is part) is designed for use in a binary power plant where flashing doesn't occur and brine pressure remains high. The only pressure losses are friction losses associated with flow through the system. It is advantageous to keep the brine pressurized for two reasons. Firstly, certain dissolved solids can be kept from precipitating by retention of CO₂ in the brine⁽⁴⁾. Changing CO₂ levels changes the brine pH which in turn changes the chemical equilibrium. Secondly, retaining as much wellhead pressure as possible reduces the pumping requirements of reinjection which increases the overall efficiency of the power plant. For these reasons, only pressurized continuous operating equipment was considered.

A total binary geothermal brine handling system was devised that would incorporate L/S-APEX and brine reinjection cleanup equipment. Experience borrowed from the mining, chemical and water treatment industries⁽⁵⁾ for the use of hydrocyclones, mixed media bed filters⁽⁶⁾, filter presses, and continuous solid bowl centrifuges⁽⁷⁾. Settling ponds such as those in use at most geothermal well sites were not considered for the primary L/S flow, but are viable for secondary flows. Figure 1 shows the process schematic of one possible total brine handling system. It consists of the L/S injection-separation-recirculation unit with the APEX heat exchanger shown on the left side, and a mixed media bed filter with backwash scheme for reinjection cleanup on the right. The hydrocyclones make the first cut separation of injected sand particles mixed with some scale particles removed from APEX. This initial separation should remove at least 99%⁽⁸⁾ of the particle mass entering the hydrocyclones which minimizes the L/S's carryover impact on the bed filter. The bed filter can then polish the hydrocyclone effluent

Figure 1. A Total Geothermal Brine Handling System for an L/S-APEX Binary Heat Exchanger

2.1, Preliminary Design (cont.)

with a minimum number of backwash cycles. The backwash slurry which is a minute flow compared to the main brine flow could go to a small settling pond or a continuous solid bowl centrifuge.

2.2 Process Design and Description

The main components of the L/S system (Figure 2) are two hydrocyclones, two accumulator tanks, and an injection pump. Two sets of hydrocyclone-accumulator tank combinations are required so they can alternate operation. While one accumulator is filling with sand removed from the spent brine, the other is discharging sand into incoming brine; they then reverse operations.

Operation of the system begins by filling tank A1 with sand. Most of the working fluid (water or brine) is then pumped through the main flowstream (indicated by heavy lines) of the system. Approximately 2 gpm of the working fluid is branched for accumulator pressurization and replaced by an equal 2 gpm injection slurry which keeps the total flow at 30 gpm. The injection pump brine (~2 gpm) is pumped to a higher pressure and piped to the top of sand filled A1. The lines entering and leaving hydrocyclone H1 are closed, so that the incoming injection pump brine forces the dense settled sand slurry out of the tank to mix with the main flowstream forming an approximate 6 Wt/Wt% slurry. The diluted slurry then flows through APEX (not used in this program) scouring the tubewalls, and then flows on to hydrocyclone H2. H2 separates the sand from the incoming flow. The fluid is forced out the top towards the system exit while the sand is forced into the accumulator. This flow path remains unchanged while sand in tank A1 empties and tank A2 fills. When tank A1 becomes empty, valves V21 and V10 close and bypass V33 opens; after this sequence, action is delayed to allow the sand slurry to flow to and be separated by H2. Valves V23 and V24 then switch to divert flow from H2 to H1. There are no perturbations of the separation process while valves 23 and 24 switch since there is no sand flowing in the mainstream flow at that time. With flow diverted and stabilized to H1, the

Figure 2. Liquid/Solids Process Schematic

2.2, Process Design and Description (cont.)

step is taken to start emptying A2 and filling A1; valves V20 and V12 are opened while V33 is closed. The injection pump is now pressurizing tank A2 and H1 becomes the on-line separator. When A2 becomes empty and A1 is full of sand again, the valve sequence is reversed and tank A1 is pressurized and H2 goes on-line.

Operation of the system can continue indefinitely by simply alternating accumulator tanks and hydrocyclones. The system can also be operated intermittently; slurry operation is described above, but to operate without the slurry, valves V10, V12, V20, V21, V33 are closed and the injection pump is turned off. In a full scale system, the hydrocyclones would be bypassed to save pumping energy. To begin slurry operation again, the appropriate valves are opened to empty the tank with the most sand. It is important to mention that bypass valve V33 allows continuous flow through the injection pump while valves V20 and V21 are closed during tank switching. Without V33, the pump would temporarily be deadheaded and the control valve would fully open, causing a tremendous surge when V20 or V21 were reopened. This surge would in turn cause a surge in slurry concentration which would effect separation efficiency.

The L/S incorporates a special hydrocyclone setup in order to highly concentrate the separated sand. As Figure 3 shows, in a typical hydrocyclone setup⁽⁶⁾, the underflow volumetric rate is approximately 20% of the incoming flow. Since it is imperative to keep to a minimum the enthalpy reduction caused by injection of sand into the hot brine upstream of APEX, it is advantageous to inject a slurry as concentrated as possible. In view of this requirement, the hydrocyclone accumulator concept shown on the right provides the best operation and is used for the L/S system.

This concept involves two distinct particle actions occurring sequentially; the sand is centrifugally separated by the hydrocyclone and then settles to the bottom of the accumulator by gravity. When the operation begins, the accumulator tank is full of water at system pressure. As sand

TYPICAL HYDROCYCLONE SETUP -
EXIT TO ATMOSPHERE

SPECIAL HYDROCYCLONE SETUP -
SOLIDS DELIVERY TO CLOSED VESSEL

Figure 3. Hydrocyclone Operation

2.2, Process Design and Description (cont.)

is separated, it is forced into the accumulator tank as a concentrated water-sand slurry; the water displaced by this slurry must exit the accumulator somehow. If there is no path for the displaced water to take, the accumulator will appear to have a static pressure higher than the hydrocyclone APEX which would prevent the slurry from entering the accumulator. Therefore, a "bleedline" or "pressure equalization line" was attached from the tank to the effluent of the hydrocyclone to assure a path for the displaced volume water. The displaced volume exits either up through the low pressure central core of the hydrocyclone or out the bleedline to the effluent, or a combination of both flow paths.

Equally as important as the separation-accumulation is the expulsion of the sand from the tank. The settled concentrated slurry is pressurized by the injection pump as shown in Figure 4. It is not simply a pressurization but a pressurized flowrate that causes the expulsion. If it were simply a pressurization phenomenon, one would expect that the slurry exiting the tank would have the same voidance factor or concentration as the settled sand. Instead, the settled sand has a 38% voidance factor (81 Wt/Wt% sand) versus the exit slurry's voidance factor of 50% (73 Wt/Wt% sand). These facts demonstrate that the expulsion is a combination of fluid pressure on the sand top boundary and entrainment of the particles by viscous drag effects as the pressure fluid passes by the particles at the tank outlet.

To insure that the sand wouldn't bridge at the tank APEX when injection was taking place, slurry tests were made with water and sand in a one gallon can. As shown in Figures 5 and 6, bridging did not occur for either a 1-inch diameter or a 0.25-inch diameter hole, giving the system designer ample latitude in deciding tank outlet size. Also, during these tests the 38% static voidance and 50% dynamic voidance were determined.

The Liquid/Solids Handling System Process and Instrumentation Diagram (P&ID) shown in Figure 7 shows the system in detail. It is the same basic schematic as Figure 3 but added are the filter and sampling circuits (B1 to D1), the provision for a sand bed loader (B5), the sand disposal

Figure 4. Accumulator Tank Expulsion

1 GALLON CAN WITH
1.0 INCH OUTLET

Figure 5. Expulsion Experiment (1 gallon with 1.0 inch outlet)

1 GALLON CAN WITH
0.25 INCH OUTLET

Figure 6. Expulsion Experiment (1 gallon can with 0.25 inch outlet)

2.2, Process Design and Description (cont.)

circuits (B6, B4), pipe sizes, valving, pressures, instrumentation, system controls, and data output.

It was determined during the APEX program that 10 ft/sec slurry velocity was necessary to avoid stratification in the pipes⁽¹⁾. The L/S system piping is 1" schedule 40 which yields 11 ft/sec velocity at 30 gpm. The system pressure drop at a 30 gpm flowrate was calculated to be 65 psi. The Aerojet facility water pressure of 90-100 psig would be sufficient for the 30 gpm flowrate but a pump P-1 was necessary to overcome the predicted 120 psi pressure drop at a 40 gpm flowrate.

The bag filters (F1 and F2) and sampling circuits (YE17, 26 and NE17, 26) were designed for maximum data flexibility. It was intended that filter samples constitute the major data bank but the sampling circuits are important for spot checks and instrumentation calibration.

The L/S equipment was assembled on an 8 ft x 16 ft flatbed steel deck trailer according to detail design drawings (Figure A1). The two major system components, accumulators and hydrocyclones, were further depicted in their own detail drawings (Figures A2 and A3 respectively). The accumulator tanks have many special design features necessary for this application. They are ASME coded pressure vessels rated at the L/S 400°F, 300 psig specification. Standard pipe parts were used wherever possible to minimize cost; the shell is 18-inch diameter pipe and the top head is an 18-inch diameter blind flange. The blind flange head offered two advantages over typical ellipsoidal welded heads; first, the removable flange allows access to the vessel interior for tank modifications; second, it simplified the geometric positioning of six different attachments to the head. The quick-opening closure located on the head streamlines the sand loading process. After loosening two lightly tightened bolts, the closure swings open, revealing a 3-inch diameter porthole. In addition, it has a pressure warning device to warn a user if the tank is pressurized when opening is attempted. The conical head on the tank bottom eliminates any dead space which could hold

2.2, Process Design and Description (cont.)

sand over from test to test, possibly affecting the particle size distribution. Glass view ports were installed in the tank shell to make it possible to visually observe filling and emptying of sand.

The hydrocyclone (Figure A3) fits onto the tank at the open 3-inch diameter drilled and tapped flange. Special machining of the hydrocyclone allows it to protrude through the tank head flange so that it is in direct contact with the vessel reservoir. The lower half of the hydrocyclone started as a solid mass of steel; internally, it is machined to a conical section, and the outside is machined to the tank's attachment requirements. The flexibility gained by this machining allows as large as a 6-inch diameter hydrocyclone to be fitted to these tanks if needed for future development work. A cyclone is sized based on the flowrate, pressure drop allowed, and particle size separation cut required. The L/S flowrate is 30 gpm, the separation cut desired is as low in particle size as possible (30 μ range), and the acceptable pressure drop is 15 psi. These specifications are best fitted by the 3-inch diameter hydrocyclones purchased.

Figures 8 and 9 show the L/S equipment ready for testing at the AECC Engineering Laboratories. Items appearing in the Major Equipment List (Table 2) are identified on the pictures with captions.

The L/S equipment was designed for future geothermal well testing. However, a few changes will be required before hot high pressure brine testing can commence. Two instruments not rated to 300 psig would be removed. One pump and two bag filters, rated at 300 psig, 400°F, would be purchased. The piping would be revised to accommodate the above changes.

2.3 Design Specification

A design specification was formulated based on the needs of the APEX and the Total Brine Handling concepts required by a geothermal well-head operation. The L/S system was designed to satisfy the requirements of the specification shown in Table 1. Maximum temperature and pressure of 400°F and 300 psi, respectively, were specifications used for APEX and the

Figure 8. Equipment Trailer

Figure 9. Equipment Trailer

TABLE 1
LIQUID/SOLIDS DESIGN SPECIFICATION

1.	Max Pressure:	300 Psia
2.	Max Temperature:	400 °F
3.	Flowrate:	Nominal 30 GPM, 20 to 40
4.	Slurry Concentration:	0% to 20% Solids by Weight
5.	Sand Size Range:	Mean Particle Diameter from 50 to 140 Mesh (300 μ to 105 μ)
6.	Operation Cycle:	Intermittent to Continuous
7.	Working Fluid Cleanup:	Minimize Carryover - Separate for Recirculation Greater than 99% of Particles 170 Mesh (88 μ) and Larger

TABLE 2
MAJOR EQUIPMENT LIST

<u>Items</u>	<u>Comments</u>
1. Equipment Trailer	Jacobson Flatbed, 8 Ft x 16 Ft, 9,000 GWB
2. Instrumentation Trailer	Apex Furnished
3. Two Accumulator Tanks	Conical Bottom, 5.0 Ft ³ Capacity, 300 Psig, 400°F
4. Two Hydrocyclone Separators	KREBBS, 30 GPM, 15 Psid, 300 Psig, 400°F
5. Injection Pump	Labour, Centrifugal, 5 GPM, 1750/3500 RPM, 20/80 Psid, 300 Psig, 400°F
6. Mainstream Pump	WEMCO, Centrifugal, 40 GPM, 45 Psid, 150 Psig, 300°F, Apex Furnished
7. Two Bag Filters	Carborundum, 10-50 GPM, 5 Bag, 150 Psig, AECC Furnished
8. Pyrex View Pipes	Corning, 1" Dia, 24" Long, 100 Psig @ 450°F, 200°F Thermal Shock

2.3, Design Specification (cont.)

current Hydroscale program. APEX nominal operating conditions were 30 gpm 6 Wt/Wt% solids and 90 mesh sand; these specifications were also used for L/S. Each parameter was expanded to a range of values to give maximum flexibility to the system so that a thorough evaluation could be made of the effects of changing conditions. The operation cycle was designed to be intermittent to continuous since each wellsite was expected to have different chemistry conditions and require varying times of on-line L/S operation. The final specification, working fluid cleanup, was most difficult to quantify. Since prior APEX experiments showed that 90 mesh nominal size particles were effective for descaling⁽¹⁾, it was speculated that particles less than half the nominal size would be increasingly ineffective as particle size decreased. Therefore, an arbitrary number was selected for the specification which would grade the system performance against the project objective of minimizing carry-over.

The high temperature and pressure specifications are required for system operation in geothermal well-testing. However, in this program all testing was conducted at Aerojet with service water used as the working fluid. This mode of operation proves the concept without the added cost and complications of wellsite testing.

2.4 Controls and Instrumentation

The operating parameters of L/S requiring automatic controls are system flowrate and solids concentration. The system flowrate control loop encompasses the injection flow circuit (solids concentration) and its control loop (see Figure 7) so that the control loops are independent of each other. Changes in injection flowrate will not significantly impact the system flowrate since the injection flow branches off downstream of the main control valve (FCV-6) and returns (via accumulator tank) upstream of the main flowmeter (FE-6). Both control loops consist of a magnetic flowtube, I/P converter, pneumatic indicating controller, and pneumatic actuated flow control valve.

2.4, Controls and Instrumentation (cont.)

Control for the solids concentration is accomplished with flow-rate control of the injection circuit, as mentioned above. This arrangement is used because of the uncertainty surrounding the use of the solids monitor and the new pressure injection concept. The flowrate is automatically controlled at a given set point and the corresponding solids concentration is monitored over each test cycle.

L/S utilizes the familiar 3-15 psi output pneumatic instruments for pressure transmitters, recorders, controls, etc., and 4-20 mA signal for electrical devices such as the magnetic flowtubes and solids monitors. Electrical to pneumatic (I/P) converters are used to convert the above mentioned 4-20 mA outputs to 3-15 psi. Figures 10 and 11 are views showing instrumentation mounted on equipment trailer. Figure 12 is a view of the control panel, and Table 3 is the system Instrumentation and Control List.

Valves that are sequenced for alternation of accumulator tanks and hydrocyclones are air-actuated plug-port valves; they incorporate remotely operated solenoid pilot valves and 80 psi air for operation. Air used for these valves and the 3-15 psi instrument air is filtered and refrigeration-dried prior to use.

3.0 TEST PROGRAM

3.1 Evaluation Basis

The test program evaluates the system's capability to perform as the solids control system for APEX and to measure its impact on downstream reinjection cleanup systems. It is important to determine the effects of changes in flowrate, solids concentration, and particle size. The nominal flowrate for a mobile binary heat exchanger test module (APEX) which would operate in conjunction with the L/S module is approximately in the range of 20 to 50 gpm. This is based upon equipment size and costs of a mobile closed cycle mechanical heat rejection system. Solids concentration and particle sizes, however, were selected on an empirical basis. The values of the independent parameters are as follows:

Figure 10. Equipment Trailer - Right Side Instrumentation

Figure 11. Equipment Trailer - Left Side Instrumentation

Figure 12. Control Panel

TABLE 3

INSTRUMENTATION AND CONTROL LIST

1. Control Panel	Apex Furnished
2. 2-Magnetic Flowtubes	Foxboro, 1 in., 50 GPM Apex Furnished, 1/2 in., 5 GPM, New, $\pm 1\%$ ACC. 300 Psig, 400°F
3. 2-Solids Monitors	Monitek, 1-1/2 in., 0-20 W/W% Solids $\pm 1\%$ of Range ACC., 0.01 W/W%, Solids Sensitivity, 150 Psig, 450°F
4. 6-Pressure Transmitters with Chemical Seals	Moore Products, 0-500 Psig, Apex Furnished
5. 2-Flow Control Valves	Fisher, 300 Psig, 400°F 1 @ 2 in., 1 @ 1 in., Apex Furnished
6. 5-I/P Converters	Foxboro, 4-20 MA Input, 3-15 Psi Output, $\pm 0.5\%$ of Range ACC., Two Apex Furnished
7. 2-Indicating Controllers	Foxboro, 3-15 Psi, $\pm 2\%$ of Range ACC., Apex Furnished
8. 3-Pneumatic 4 Pen Recorders	Foxboro, 3-15 Psi, $\pm 0.5\%$ of Range ACC., Apex Furnished
9. 5-Pressure Gauges	US Gauge, 0-200 Psig

3.1, Evaluation Basis (cont.)

1. System flowrate: 20, 30, 40 gpm
2. Solids concentration: 2, 6, 10 Wt/Wt%
solids
3. Nominal particle size: 30, 50, 90, 140
mesh silica sand

L/S's capability systems evaluation is determined primarily by the separation efficiency and effluent solids carryover and, to a lesser degree, by injection concentration consistency, pressure drops, and hydrocyclone wear. Separation efficiency is calculated by comparing solids concentration and particle size distributions leaving vs. entering the hydrocyclone. More specifically, efficiency is found by comparing the mass escaping in the effluent with the total mass of sand entering the cyclone.

$$\eta = \frac{\text{total mass circulated} - \text{mass escaped}}{\text{total mass circulated}}$$

Separation efficiency is a function of particle size; there is a different efficiency for each particle size in the distribution. Since it is impractical to have many efficiencies, particle size ranges were set up based on their projected applicability to the APEX concept. Four size ranges result:

1. Coarser: 0-30 mesh, $\infty\mu$ -595 μ
2. Coarse: 31-80 mesh, 594 μ -177 μ
3. Nominal: 81-170 mesh, 176 μ -88 μ (used
in previous APEX studies)
4. Fine: 171-325 mesh, 87 μ -44 μ

At the beginning of a test, the total mass of the loaded sand and the particle size distribution are known (see Figure 13). After each L/S half-cycle (one tank emptied and one filled), the mass escaping the hydrocyclone and caught by the 5 μ filter bag is dried, weighed, and run through a sieve analysis. With this information, efficiencies are calculated

Figure 13. Sand Particle Size Distributions

3.1, Evaluation Basis (cont.)

for the total distribution and for each sand size range. The escaped mass and particle size distribution is then subtracted from total mass, making a new total mass and distribution for the next half-cycle. This procedure is followed for each half-cycle to insure accurate results.

The above separation evaluation essentially averages the separation efficiency over the half-cycle of operation. These numbers would be misrepresentative if distinct fluctuations occurred in the influent concentration. The two solids monitors installed on L/S monitor and record the solids concentration of the influent and effluent continuously to warn of any such perturbations.

Reinjection cleanup is impacted by the hydrocyclone effluent concentration (carryover). This impact will be calculated by comparing sand mass escaping the hydrocyclone to the water mass leaving the system. Results will be in parts per million (ppm) units:

$$\text{ppm} = \frac{\text{mass, sand escaped}}{\text{mass, water leaving system}} \times 10^6$$

Injection consistency can only be evaluated by qualitative examination of concentration-vs-time charts taken downstream of injection, and by comparing those to the time-averaged concentration of the L/S cycle.

System pressure drops aid the designer in system scale-up and so are included. The two pressure drops of importance are the hydrocyclone drop and the drop across the total system minus the control valve.

3.2 Test Plan

A test plan to evaluate system performance was implemented to acquire data at the specified operating conditions. The system nominal conditions were set as follows: flowrate 30 gpm (flowrate), 90 mesh (sand size), and 6% solids concentration. One variation from the selected nominal condition was made at a time in order to isolate the effect of that change. For

3.2, Test Plan (cont.)

instance, to determine effect of flowrate change, the Wt/Wt% solids and particle size remained at their nominal 6 Wt/Wt% and 90 mesh, respectively, while the system flowrate was changed to 20 gpm for one test and 40 gpm for another test. The test matrix (Table 4) shows the eight data test runs and the changes to be investigated in each test.

3.3 Test Results

The L/S test program ran for approximately one month's time. After checkout tests and the usual calibration associated with a new system, all eight tests of the test plan were completed. Each test started with a fresh 300 lb. load of sand and ran one complete cycle; the effluent filter bag was changed for each half-cycle. The L/S system functioned within design limits: expulsion of sand from the tank, mixing at the injection point, separation by the hydrocyclone, and accumulation of sand for recirculation all occurred as predicted. Herein, test results are presented for the five areas of investigation: separation efficiency, reinjection, impact, injection consistency, system pressure drops, and hydrocyclone wear. As mentioned before, one test parameter was changed at a time while the two others remained at nominal conditions; the results presented indicate the performance difference caused by that particular change.

Requirements of the design specification for working fluid clean-up (Figure 2) were surpassed; under all conditions, particles greater than 88μ were collected for recirculation at efficiencies greater than 99%. Of equal importance, anticipated performance trends were confirmed by the data: higher flowrates through the hydrocyclones, lower solids concentrations, and larger particle sizes all increase separation efficiencies. Figure 14 isolates the effect of flowrate change; the drop in efficiency when decreasing flowrate to 20 gpm is greater than the improvement gained by the change to 40 gpm. At 20 gpm, the pressure drop across the cyclone is approaching the minimum allowable at 3 psi; as a result, the larger decay in efficiency occurs.

TABLE 4
DATA TEST MATRIX

<u>Test No.</u>	<u>Flowrate</u>	<u>Particle Size (Mesh, μ)</u>	<u>W/W% Solids Concentration</u>	<u>Comments</u>
1	30	90	6	Establish Nominal Performance
2	30	50	6	Tests 2, 3, and 4 Investigate Effect of Sand Size Change
3	30	25	6	
4	30	140	6	
5	30	90	2	Tests 5 and 6 will determine the effect of W/W% solids concentration change
6	30	90	10	
7	40	90	6	Tests 7 and 8 will determine the effect of flowrate change
8	20	90	6

Figure 14. Effect of Flowrate Change on Separation

3.3, Test Results (cont.)

There appears to be no significant difference when operating at 2 or 6 Wt/Wt% solids, but Figure 15 shows a large dropoff in efficiency when operating at 10 Wt/Wt%. One of the purposes of this experiment was to find favorable operating conditions; experiments indicate that the concentration should not exceed 6 Wt/Wt%.

The largest differences in separation occurred, as expected, when testing for changing particle size. When running at nominal flowrate and concentration, the separation efficiency improved tremendously as particle size increased. This trend can be seen in two different graphic representations on Figures 16 and 17. Figure 16 displays the different particle distributions plotted against efficiency, whereas Figure 17 displays actual particle size against efficiency (disregarding size distribution from which the particle came). Although tested here with great success, 30 mesh is possibly too large a particle size to avoid stratification in a long pipe section. Figure 17 shows that all particles greater than 125μ were collected at greater than 99.9%. If a 50 mesh (nominally 300μ) sand were used, that contained no particles smaller than 125μ , the separation capability would exceed 99.9% for the entire distribution. This efficiency would equate to lower than 60 ppm in the effluent (carryover) at nominal operating conditions.

The particles escaping the hydrocyclone separation (carryover) constitute L/S's impact on reinjection cleanup. This effluent concentration (carryover) is expressed in units of parts per million by weight (ppm). In the three following graphic results (Figures 18, 19, 20), the effluent concentration is given as a total effluent concentration and is also broken down into concentrations for each of the previously mentioned sand size ranges. Figure 18 shows that an increase in flowrate through the hydrocyclone improves the effluent concentrations (carryover) of the total distribution as well for the various sand size ranges.

Influent effects are displayed in Figure 19; 2 Wt/Wt% has a deceptively low effluent concentration (carryover) even though its separation

Figure 15. Effect of Solids Concentration Change on Separation

Figure 16. Effect of Sand Distribution Size Change on Separation

Figure 17. Effect of Particle Size Change on Separation

Figure 18. Effect of Flowrate Change on Effluent Concentration (Carryover)

Figure 19. Effect of Influent Solids Concentration Change on Liquid/Solids Impact

3.3, Test Results (cont.)

efficiency is approximately equal to that of 6 Wt/Wt% (Figure 16). At 2 Wt/Wt%, the influent concentration (carryover) is lower than that at 6 or 10 Wt/Wt% (see Table 5), so the same given efficiency yields a different effluent concentration (carryover). It should be noted that even though 2 Wt/Wt% yields a lower effluent concentration (carryover), it may be required to stay on-line for the APEX descaling function for a proportionally longer time. Nevertheless, the low effluent concentration (carryover) at longer operating periods may be attractive for some reinjection cleanup systems.

Increasing the particle size reduces L/S's impact on reinjection cleanup systems. In Figure 20, the effluent concentration (carryover) decreases as the particle size distribution becomes larger.

Even though these effluent concentration (carryover) graphs show the same general trends as the separation efficiency curves, they represent very important data reflecting what the L/S system can accomplish at varying modes of operation. Further, it can be surmised that if a realistically favorable operating condition were chosen (such as 4 Wt/Wt% solids, 50 mesh sand with no particles smaller than 88μ , and at a 30 gpm flowrate), an effluent concentration (carryover) as low as 30 ppm could be achieved.

Injection consistency of the L/S system is difficult to evaluate in numerical terms. For each test condition, the expulsion of the tank always took the same time, and the concentration profile vs. time was always similar. These observations indicate that the injection process was repeatable. When viewing the mixed slurry downstream of injection, some slugging was apparent in the pyrex pipe sections. This was confirmed by fluctuations of the influent solids monitor output. These fluctuations and the time required to reach and decay from the prescribed steady-state concentration are displayed in the concentration profile of Figure 21. The uncertainty associated with calibration of the fluctuating concentration and the changing profile make it impossible for the average concentration for the test to

TABLE 5

LIQUID/SOLIDS PERFORMANCE DATA

TEST NO.	FLOW RATE GPM	SOLIDS CONC W/W%	SAND SIZE MESH	AVERAGE INFLUENT CONCENTRATION, PPM					AVERAGE COLLECTION EFFICIENCY, %					AVERAGE EFFLUENT CONCENTRATION, PPM				
				I_{TOTAL}	$I_{595\mu}$	$I_{177\mu}$	$I_{88\mu}$	$I_{44\mu}$	η_{TOTAL}	η_{595}	η_{177}	η_{88}	η_{44}	E_{TOTAL}	E_{595}	E_{177}	E_{88}	E_{44}
1	30	6	90	45,200	—	28,000	13,800	3,400	99.51	—	99.96	99.46	99.92	222	—	10	75	137
2	30	6	50	45,400	—	33,200	19,300	1,900	99.69	—	99.96	99.42	96.65	139	—	15	60	64
3	30	6	30	47,700	33,900	13,800	—	—	99.997	99.998	99.995	—	—	2	1	1	—	—
4	30	6	140	47,200	—	2,900	39,300	5,000	99.24	—	99.98	99.71	95.08	356	—	1	114	241
AVERAGE η FROM DIFF. SANDS FOR 595, 177, 88, 44										99.998	99.97	99.52	95.88					
5	30	2	90	16,500	—	19,200	5,000	1,300	99.48	—	99.96	99.37	96.00	85	—	4	32	49
6	30	10	90	68,600	—	42,500	20,000	5,200	99.20	—	99.96	99.01	93.55	548	—	18	205	325
7	40	6	90	41,400	—	25,700	12,600	3,100	99.56	—	99.96	99.43	96.85	180	—	11	72	97
8	20	6	90	44,700	—	27,700	13,600	3,400	99.34	—	99.93	99.16	95.19	291	—	19	113	159

Figure 20. Effect of Sand Distribution Size Change on Liquid/Solids Effluent Concentration (Carryover)

Figure 21. Typical Concentration Profile

3.3, Test Results (cont.)

match the set point (Figure 22). The fluctuations in concentration are apparently benign, and therefore the injection consistency adequate, since the hydrocyclone performed well in all instances. Examples of the L/S slurry downstream of injection and the subsequent clear hydrocyclone effluent can be seen in the pyrex pipes of Figure 23.

The 8 psi pressure drop across the hydrocyclone was lower than the expected 15 psi at a 30 gpm flowrate. Consultation with the hydrocyclone vendor revealed that he enlarged the apex and vortex finder of the cyclone to accommodate a given amount of geothermal scaling. The change didn't effect hydrocyclone performance significantly, and further, proved that a lower pressure drop (beneficial to avoid flashing) is sufficient. Figures 24 and 25 show pressure drops across the hydrocyclone and across the entire system respectively, as flowrate changes. Changing the solids concentration didn't change the pressure drops at 30 gpm as evidenced by Figures 26 and 27, so the slight viscosity and density changes of different concentrations were not significant enough to cause pressure drop changes in the L/S.

Erosion wear at the hydrocyclone apex was minimal; after 60 hours on-line, the machining ridges on the internal surface of the apex had not eroded. The diameter of the apex apparently eroded from 0.998 inches to 1.003 inches. If a more realistic erosion rate were chosen (correcting for the machining ridges) of 0.002 inches per 60 hours, and an assumption made that the hydrocyclone would perform adequately with as large as a 1.50 inch apex, the hydrocyclone would have a life expectancy of 15,000 hours.

Figure 22. Influent Concentration - Actual Average vs. Steady-State

Figure 23. Pyrex Pipe Viewing

Figure 24. Effect of Flowrate Change on Hydrocyclone Pressure Drop

Figure 25. Effect of Flowrate Change on System Pressure Drop

Figure 26. Effect of Solids Concentration Change on Hydrocyclone Pressure Drop

Figure 27. Effect of Solids Concentration Change on System Pressure Drop

FOOTNOTES

1. Addoms, J. F., and Gracey, C. M., "Wellsite Verification Testing of an Advanced Geothermal Primary Heat Exchanger (APEX)," Final Report 2146:02-F for Department of Energy, Geothermal Division, 13 November 1977.
2. Oil and Gas Journal, January 9, 1961, pp 70-71.
3. Chemical and Engineering News, March 29, 1965, pp 42-43.
4. Ellis, A. J. and Mahon, W. A. J., "Chemistry and Geothermal Systems," Academic Press, 1977.
5. Bradley, D., "The Hydrocyclone," Pergamon Press, 1965.
6. Baumann, R. E., and Cleasby, J. L., "Wastewater Filtration," Environmental Protection Agency Technology Transfer, 1976.
7. Svarovsky, Ladislav, "Sedimentation, Centrifugation, and Flotation," Chemical Engineering, 16 July 1979.
8. Krebbs Engineers, "The Sizing of Hydrocyclones."

APPENDIX

Accessory Figures

A1. Liquid/Solids Handling System Equipment Trailer Assembly
(Sheet 2 of 3)

NOTE: ALL LINES 1¢ UNLESS OTHERWISE NOTED

Equipment 2000 1000 1000 1000	
THE LIQUID/SOLIDS HANDLING SYSTEM EQUIPMENT TRAILER	
UNIT E	PLANT NO. 119223
SERIAL 101-01	PLANT DATE 11-5-9

A1. Liquid/Solids Handling System Equipment Trailer Assembly
 (Sheet 3 of 3)

VIEW G-G
 SCALE: 1/2" = 1'-0"

LIQUID/SOLIDS HANDLING SYSTEM EQUIPMENT TRAILER	
E	1192251
1	1

A3. Hydrocyclone Sketch
KREBBS M/N W3V-5339

8		7		6		5		4		3		2		1						
INSTRUMENTATION LETTERS OF IDENTIFICATION LIST <table border="0" style="width: 100%;"> <tr> <td style="vertical-align: top;"> FIRST LETTER A - ANALYSIS B - BURNER FLAME C - CONDUCTIVITY (ELECTRICAL) D - DENSITY (MASS) OR SPEC. GRAV. E - VOLTAGE (EMF) F - FLOW RATE G - GAGING (DIMENSIONAL) H - HAND (MANUAL OPERATION) I - CURRENT (ELECTRICAL) J - POWER K - TIME OR SCHEDULE L - LEVEL M - MOISTURE OR HUMIDITY N - USER'S CHOICE O - USER'S CHOICE P - PRESSURE OR VACUUM Q - QUANTITY OR EVENT R - RADIOACTIVITY S - SPEED OR FREQUENCY T - TEMPERATURE U - MULTIVARIABLE V - VISCOSITY W - WEIGHT OR FORCE X - UNCLASSIFIED Y - USER'S CHOICE Z - POSITION </td> <td style="vertical-align: top;"> SECOND LETTER NAME USER'S CHOICE CONTROL DIFFERENTIAL PRIMARY ELEMENT -- GLASS -- INDICATE CONTROL STATION LIGHT (PILOT) -- USER'S CHOICE OFFICE (RESTRICTING) POINT TEST CONNECTION INTEGRATE OR TOTALIZE RECORD OR PRINT TRANSMIT MULTIFUNCTION -- UNCLASSIFIED DELAY OR COMPUTE DRIVE ACTUATE OR UNCLASSIFIED FINAL CONTROL ELEMENT </td> <td style="vertical-align: top;"> THIRD LETTER ALARM USER'S CHOICE CONTROL -- -- -- HIGH -- -- LOW -- -- USER'S CHOICE -- -- RECORD OR PRINT SAFETY -- MULTIFUNCTION VALVE, DAMPER OR LOWER -- UNCLASSIFIED -- </td> </tr> </table>						FIRST LETTER A - ANALYSIS B - BURNER FLAME C - CONDUCTIVITY (ELECTRICAL) D - DENSITY (MASS) OR SPEC. GRAV. E - VOLTAGE (EMF) F - FLOW RATE G - GAGING (DIMENSIONAL) H - HAND (MANUAL OPERATION) I - CURRENT (ELECTRICAL) J - POWER K - TIME OR SCHEDULE L - LEVEL M - MOISTURE OR HUMIDITY N - USER'S CHOICE O - USER'S CHOICE P - PRESSURE OR VACUUM Q - QUANTITY OR EVENT R - RADIOACTIVITY S - SPEED OR FREQUENCY T - TEMPERATURE U - MULTIVARIABLE V - VISCOSITY W - WEIGHT OR FORCE X - UNCLASSIFIED Y - USER'S CHOICE Z - POSITION	SECOND LETTER NAME USER'S CHOICE CONTROL DIFFERENTIAL PRIMARY ELEMENT -- GLASS -- INDICATE CONTROL STATION LIGHT (PILOT) -- USER'S CHOICE OFFICE (RESTRICTING) POINT TEST CONNECTION INTEGRATE OR TOTALIZE RECORD OR PRINT TRANSMIT MULTIFUNCTION -- UNCLASSIFIED DELAY OR COMPUTE DRIVE ACTUATE OR UNCLASSIFIED FINAL CONTROL ELEMENT	THIRD LETTER ALARM USER'S CHOICE CONTROL -- -- -- HIGH -- -- LOW -- -- USER'S CHOICE -- -- RECORD OR PRINT SAFETY -- MULTIFUNCTION VALVE, DAMPER OR LOWER -- UNCLASSIFIED --	SUMMARY OF SPECIAL ABBREVIATIONS FOR ABBREVIATIONS OTHER THAN INSTRUMENT ABBREVIATION A ANALOG SIGNAL ADAPT. ADAPTIVE CONTROL MODE AS AIR SUPPLY AVE. AVERAGE C PATCHBOARD OR MATRIX BOARD CONNECTION C DERIVATIVE CONTROL MODE D DIGITAL SIGNAL DIFF. DIFFERENTIAL DIR. DIRECT-ACTING E VOLTAGE SIGNAL ES ELECTRIC SUPPLY FC FAIL CLOSED FI FAIL INDETERMINATE FL FAIL LOCKED FO FAIL OPEN GS GAS SUPPLY H HYDRAULIC SIGNAL HS HYDRAULIC SUPPLY I (CURRENT (ELECTRICAL) SIGNAL INTERLOCK MOTOR ACTUATOR MAX. MAXIMIZING CONTROL MODE MIN. MINIMIZING CONTROL MODE NS NITROGEN SUPPLY O ELECTROMAGNETIC OR SONIC SIGNAL OPT OPTIMIZING CONTROL MODE P PNEUMATIC SIGNAL P PROPORTIONAL CONTROL MODE PURGE OR FLUSHING DEVICE R AUTOMATIC-RESET CONTROL MODE RESET OF FAIL-LOCKED DEVICE RESISTANCE (SIGNAL) REVERSE-ACTING REV. RESISTANCE (TYPE) TEMPERATURE RTD DETECTOR S SOLENOID ACTUATOR S.P. SET-POINT SQ. RT SQUARE ROOT SS STEAM SUPPLY T TRAP WS WATER SUPPLY X MULTIPLY UNCLASSIFIED ACTUATOR						PLANT EQUIPMENT CATEGORIES A - EXCHANGERS, CONDENSERS, COOLING TOWERS B - BOILERS, STEAM GENERATORS, AUXILIARY BOILERS C - COMPRESSORS, BLOWERS, VACUUM PUMPS, FANS, REFRIGERATION UNITS, INCLUDING DRIVERS D - DEMINERALIZERS, ADSORBERS, ADSORBERS, CLARIFIERS, AIR DRYERS E - ELECTRICAL EQUIPMENT, SWITCH GEAR, MOTOR CONTROL CENTERS, TRANSFORMERS, ETC. F - FILTERS, STRAINERS, TRAVELLING SCREENS, RAKES G - FUEL HANDLING EQUIPMENT INCLUDING NUCLEAR AND COAL FUELS, CRANES, HOISTS, BALERS INCLUDING DRIVERS H - HOPPERS, BINS, CONTAINERS, ETC. I - INSTRUMENT AND CONTROL BOARDS, PANELS AND CABINETS J - TURBINES, TURBINE GENERATORS, DIESEL GENERATOR, DIESEL ENGINES, FLUID DRIVES AND GEAR REDUCERS K - PIPING SPECIALTIES, TRAPS, HOSES, EXPANSION JOINTS, RESTRICTION DEVICES, ETC. L - PUMPS INCLUDING DRIVERS M - REACTOR AND REACTOR CONTROL DEVICES N - SPECIAL PACK-AGED ITEMS OR SYSTEMS O - TANKS P - MISCELLANEOUS AIR HANDLING DEVICES					
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EXCEPTIONS FR - FLOW RATIO MLS - MANUAL LOADING STATION PH - SELF DEFINING HYDROGEN-ION CONCENTRATION PM - PULSE METER WHEN "USER'S CHOICE" IS USED, IT MUST BE DEFINED WHERE USED.						MISCELLANEOUS SYMBOLS <table border="0" style="width: 100%;"> <tr> <td style="vertical-align: top;"> PILOT LIGHT RESET FOR LATCH TYPE ACTUATOR GENERALIZED FOR UNDEFINED OR COMPANY INTERLOCK LOGIC CHEMICAL SEAL INTERLOCK IS EFFECTIVE ONLY IF ALL INPUTS EXIST INTERLOCK IS EFFECTIVE IF ANY ONE OR MORE INPUTS EXIST AIR PURGE SEAL WATER SEAL AIR </td> <td style="vertical-align: top;"> FLOW ORIFICE TURNING OR REDUCER TYPE FLOW ELEMENT PIPE REDUCER PILOT TUBE OR VENTURI FLOW ELEMENT EXPANSION JOINT EDUCTOR OR VENTURI </td> </tr> </table>						PILOT LIGHT RESET FOR LATCH TYPE ACTUATOR GENERALIZED FOR UNDEFINED OR COMPANY INTERLOCK LOGIC CHEMICAL SEAL INTERLOCK IS EFFECTIVE ONLY IF ALL INPUTS EXIST INTERLOCK IS EFFECTIVE IF ANY ONE OR MORE INPUTS EXIST AIR PURGE SEAL WATER SEAL AIR	FLOW ORIFICE TURNING OR REDUCER TYPE FLOW ELEMENT PIPE REDUCER PILOT TUBE OR VENTURI FLOW ELEMENT EXPANSION JOINT EDUCTOR OR VENTURI							
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STANDARD P&ID Equipment and Instrumentation Symbols

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