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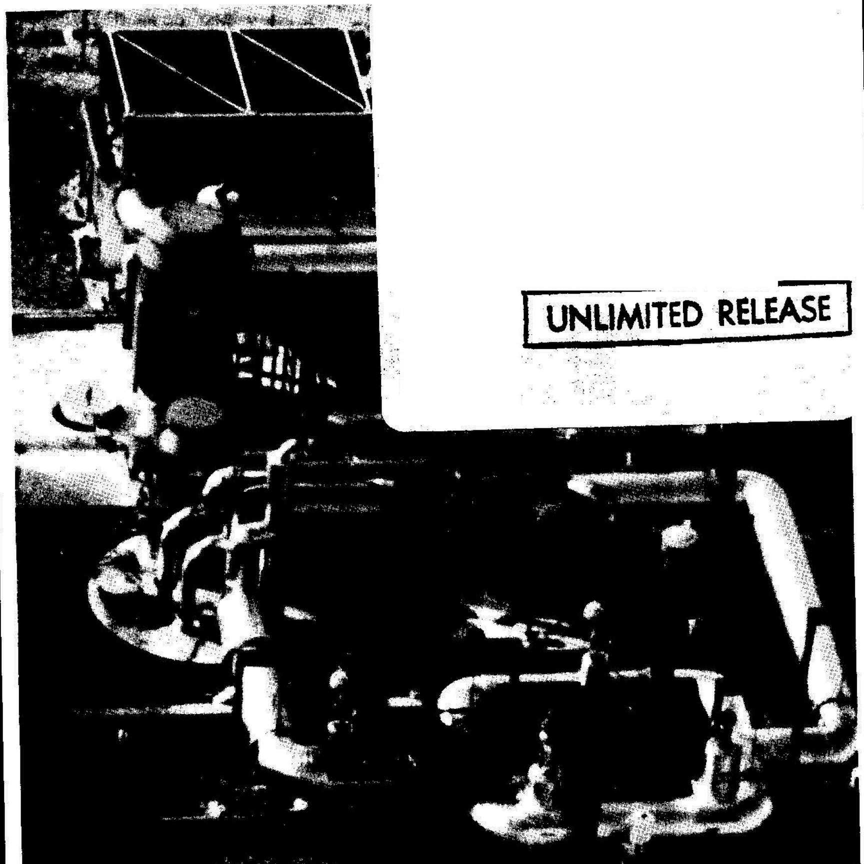
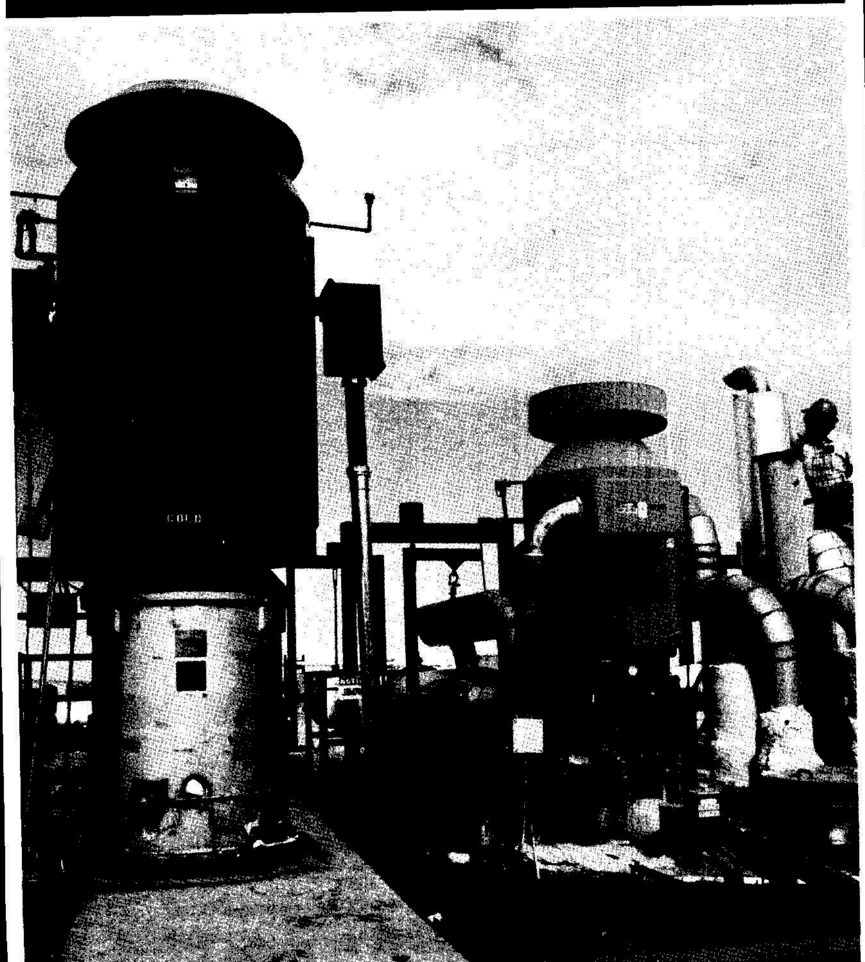


REPORT ON THE TEST OF THE MOLTEN-SALT PUMP AND VALVE LOOPS



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ABSTRACT

The purpose of the molten-salt pump and valve loop test is to demonstrate the performance, reliability, and service life of full-scale hot- and cold-salt pumps and valves for use in commercial central receiver solar power plants. This test was in operation at Sandia National Laboratories National Solar Thermal Test Facility from January 1988 to September 1990. The test hardware consists of two pumped loops; the "hot-salt loop" to simulate the piping and components on the hot (565°C) side of the receiver and the "cold-salt loop" to simulate piping and components on the receiver's cold (285°C) side. Each loop contains a pump and five valves sized to be representative of a conceptual 60-MW_e commercial solar power plant design. The hot-salt loop accumulated over 6700 hours of operation and the cold-salt loop over 2500 hours during the test period. This project has demonstrated the performance and reliability required for commercial-scale molten-salt pumps and valves.

ACKNOWLEDGMENT

The authors of the paper would like to acknowledge the contributions of the Department Of Energy, Sandia National Laboratories, the National Solar Thermal Test Facility team members (specifically, Milt Stomp, Sam Dunkin, Jim Imboden, J. J. Kelton, Walt Einhorn, Fred Webb, and Jim Grossman), and component suppliers for their contributions to the successful test program.

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1.0 INTRODUCTION

The success of a molten nitrate salt solar power plant will depend not only on the development of new components, but also on the application of common components to the new service conditions dictated by molten salt. In particular, large plants will require the application of large pumps and large valves that have not been used in molten salt service.

1.1 Background

There is a limited amount of experience with pump and valve performance in molten nitrate salt (60% sodium nitrate, 40% potassium nitrate by weight) service. This experience is based on several experiments conducted at the National Solar Thermal Test Facility (NSTTF). These include: a 5-MW_t receiver experiment,[1] a 7-MW_t-h energy storage experiment,[2] an integrated electric system experiment,[3-6] and an advanced 5-MW_t receiver experiment.[7] In addition, a limited amount of data from other applications in chemical process plants is available.[8] The pumps and valves used in the experiments at NSTTF performed satisfactorily; however, the proposed size of the components for utility-scale commercial plants is significantly larger than that used in the experiments. Additional experience on pumps and valves is available from the operation of the 2.5-MW_e Themis power plant.[9] Themis used a different salt with a lower operating temperature. Also, the component sizes are smaller than those to be used in a commercial plant. The Themis pump is a vertical-cantilever design, and is not representative of those that would be used in a commercial plant. However, the packed valves used in the plant, although smaller than those needed in a commercial system, provide information on packed valves in molten salt service.

The larger components needed for a commercial plant compel fundamental changes in design that go beyond simple scale-up. In particular, the vertical-cantilever design employed in the NSTTF and Themis experiments for both hot- and cold-salt pumps is impractical for commercial-scale cold-salt pumps. Also, the increase in valve size makes bellows stem seals (employed almost exclusively in the experiments) less practical, and so motivates the search for an effective valve packing material. The packing material used in the Themis valves was tested in this experiment.

The molten-salt pump and valve (P&V) loop test, shown in Figure 1, was conducted as part of the Molten Salt Subsystem/Component Test Experiment (MSS/CTE)[10] to test utility-scale pumps and valves. This test was designed to draw from "off-the-shelf" commercial pump and valve technologies for design of pumps and valves typical of those required for utility-scale plants such as the Saguaro and Solar 100 molten salt solar power plants (conceptual design studies conducted in the early 1980s).[10-11] The Saguaro plant was sized to supply 60 MW_e of solar-generated power to the Arizona Public Service power grid. The design employed three half-capacity cold-salt pumps to supply flow to a 190-MW_t receiver from a cold-salt storage tank and three half-capacity hot-salt pumps to supply flow to a 173-MW_t steam generator from a hot-salt storage tank. This arrangement allowed for a level of redundancy in the pumping system. The P&V loop test was sized to simulate the heat-transfer system at the Saguaro Plant.

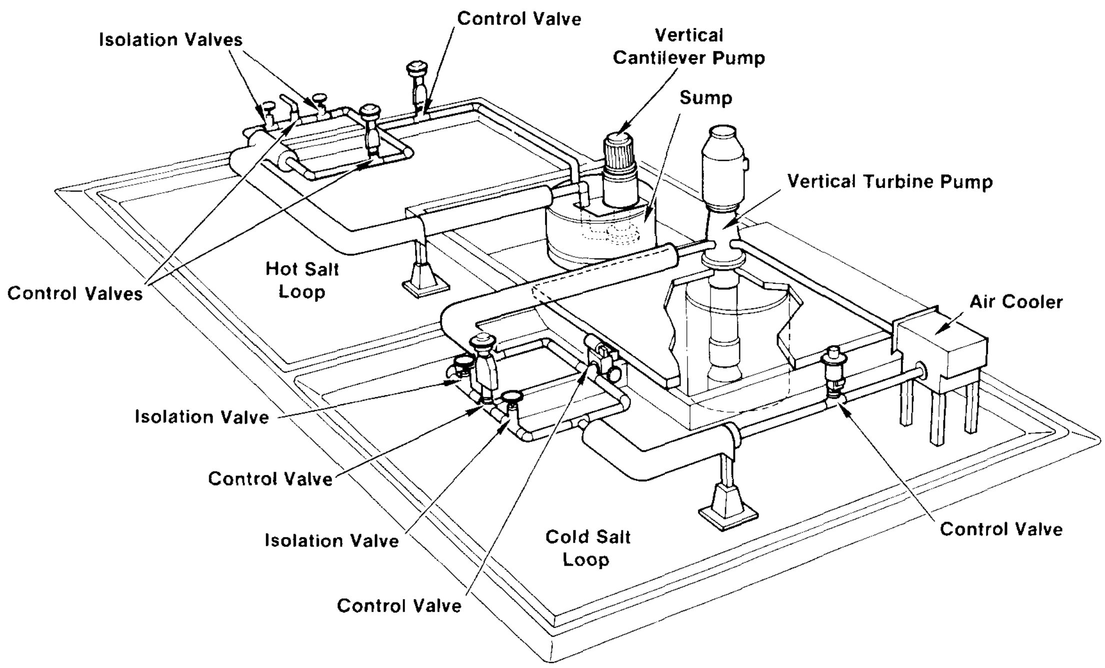

Figure 1. The Molten-Salt Pump and Valve Test Facility

The molten-salt pump and valve test was supported by a team managed by Sandia National Laboratories (SNL) with Babcock & Wilcox (B&W) as the prime contractor. The team members were Arizona Public Service, Black & Veatch, McDonnell Douglas, Olin Chemical, and Southern California Edison.

1.2 Objectives

The objective of the molten-salt pump and valve test was to test commercial-scale pumps and valves with molten salt in order to verify their use in a solar central receiver power plant.

For the pumps, the objectives for this series of tests were to test the two pumps over the range of plant operating conditions to:

- Verify pump performance,
- Check for vibration and wear,
- Check pump seals and bearings,
- Evaluate pump maintainability, and
- Identify operating procedures that yield the best performance.

For valves, the current objective was to test a variety of valve configurations typical of those a plant designer would use for various control and isolation applications in order to:

- Evaluate/compare valve seals at plant operating conditions,
- Test valves for long-term cycling,
- Verify valve seat/trim design and materials at conditions for control and shutoff,
- Check for evidence of valve erosion, corrosion, and wear,
- Determine the drainability of the valve bodies, and
- Confirm the stability of the packing materials screened during the bench test in a dynamic environment.

A goal of this test was to demonstrate to the utility power community that current pump and valve designs are available to support construction of large-scale solar plants similar to the Solar 100 or Saguaro designs.

2.0 DESCRIPTION OF THE TEST FACILITY

The two adjacent loops, designated the hot-salt loop and the cold-salt loop, are located in an environment typical of a commercial solar power plant that uses molten salt. Each consists of one pump and five control and isolation valves. The salt pumps are set in sump tanks, which hold an inventory of molten nitrate salt. Each loop incorporates an air-cooled heat exchanger for rejection of heat generated as a result of pumping power. In both loops, the flow of molten salt is regulated alternatively by one of two valves arranged in parallel paths. A control valve downstream maintains a back pressure on the flow control valves. General service isolation valves are located on either side of one flow control valve in each loop. A schematic of the hot loop is presented in Figure 2, and the cold loop schematic is shown in Figure 3. The pumps and valves are described in Table I. The design conditions for the pumps are given in Table II. Details on the design construction, and specifics on the components are provided in the report "Construction of the Molten Salt Pump and Valve Loops" by P. Bator and R. Dowling.[13] An interim report on the P&V loop test[14] provides details on the initial testing phase. Details on the operational experience of individual components are provided in Appendix A.

2.1 Description of the Cold-Salt Pump

The cold-salt pump is a seven-stage vertical-turbine pump manufactured by the Bryon-Jackson Pump Division of Borg-Warner (B-J). The pump is powered by a 1.7-MW-output (2250-horsepower) 4160-volt, 3-phase motor manufactured by Siemens-Allis. The pump is illustrated in Figure 4. This pump is of a standard design offered by B-J. Custom features are incorporated into the pump design as required to make it compatible with the molten salt. Pump components are made of carbon steel. A multi-stage pump is required for this application because of the pressure requirement and need for high efficiencies to limit plant parasitics. The multi-stage design introduces bearings into the molten-salt environment. Each pump stage incorporates a journal bearing lubricated by the pumped fluid. The presence of a journal bearing lubricated by molten salt was a new feature that had not been tested previously. Cast iron bearings were selected for the design. The vertical-turbine

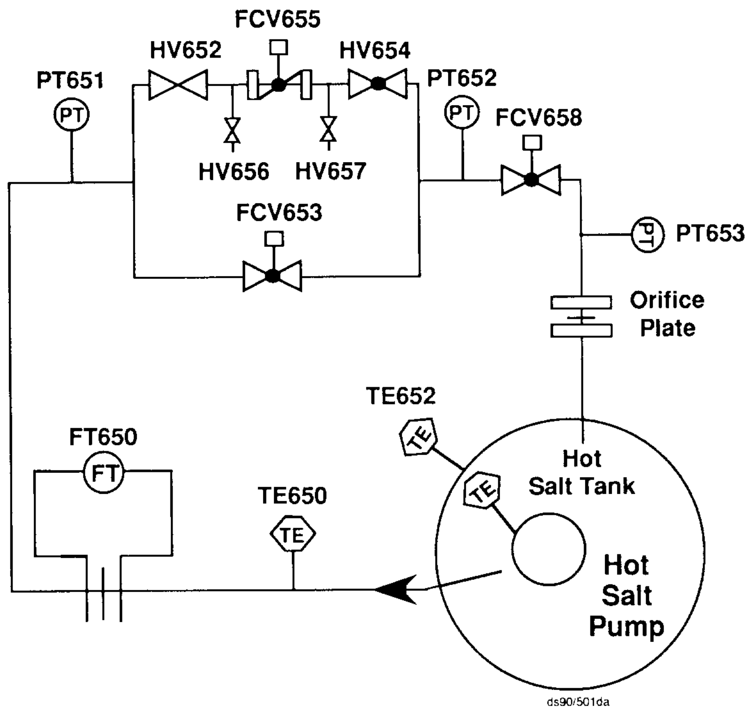

Figure 2. Hot-Salt Loop Schematic

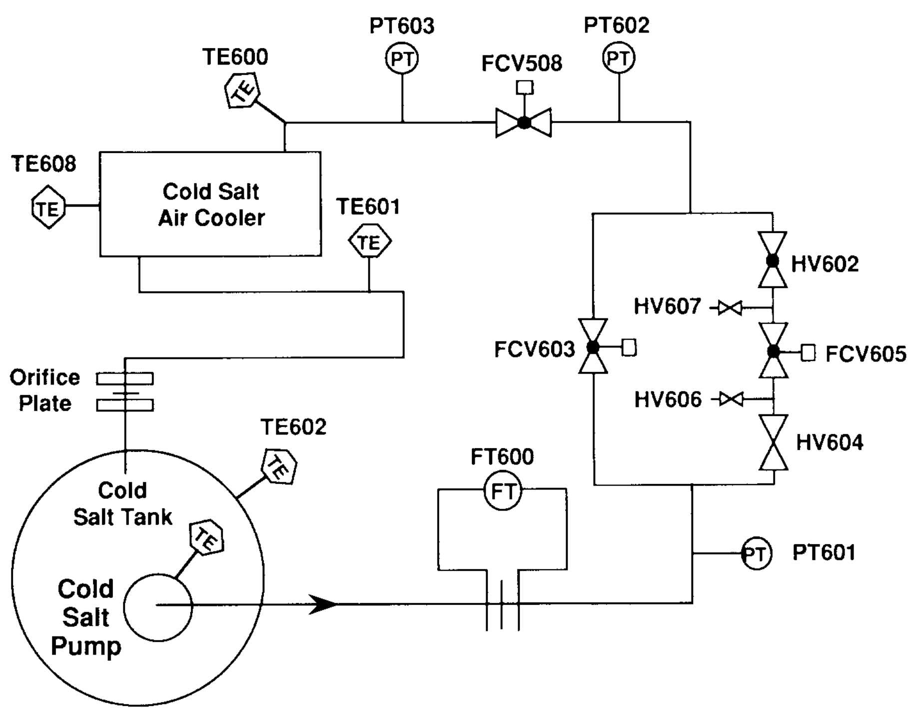

Figure 3. Cold-Salt Loop Schematic

Table I

Pump and Valve Experiment Components

Component	Description	Manufacturer
Cold-Salt Loop		
Cold-Salt Pump	Multi-stage 2250 HP vertical-turbine pump	Bryon-Jackson
FCV-603	Cam-Flex™ control valve with rotary packing seal	Masonelian
FCV-605	Globe control valve with packing stem seal	Copes-Vulcan
FCV-608	Globe control valve with bellows stem seal	Copes-Vulcan
HV-602	Globe isolation valve with packing stem seal	Atwood & Morrill
HV-604	Gate isolation valve with packing stem seal	Crane
Hot-Salt Loop		
Hot-Salt Pump	Single-stage 350-HP vertical-cantilever pump	Lawrence Pump and Engine
FCV-653	Glove control valve with packing stem seal	Fisher Controls
FCV-655	Disk control valve with rotary packing stem seal	Valtek
FCV-658	Globe control valve with bellows stem seal	Fisher Controls
HV-652	Gate isolation valve with packing stem seal	Crane
HV-654	Globe isolation valve with packing stem seal	Crane

Table II

Pump Design Conditions

	Hot-Salt Loop	Cold-Salt Loop
Flow: m^3/sec (GPM)	0.115 (1850)	0.130 (2050)
Head: m (ft)	64 (210)	459 (1505)
Temperature: °C (°F)	565 (1050)	315 (600)

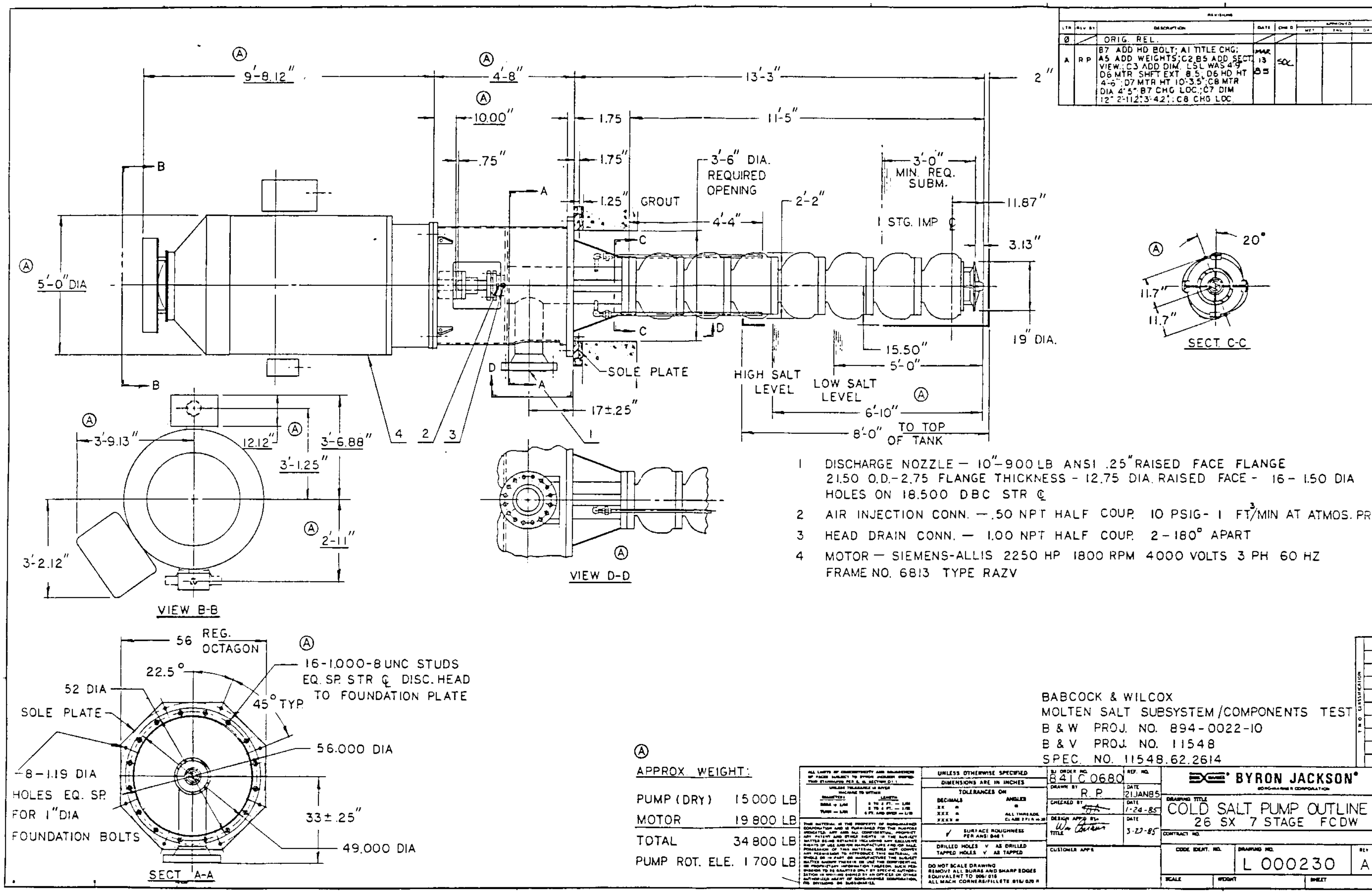

Figure 4. Schematic of the Cold-Loop Pump

pump design also offers the advantage of high efficiency. The pump has a design-point efficiency of 82%, at $0.13 m^3/sec$, based on the manufacturer's specification. A plot of the pump curve is shown in Figure 5; its efficiency is an important advantage because this pump represents a significant parasitic loss in the operation of a commercial power plant.

An alternative configuration for multiple vertical-cantiliver pumps connected in series was considered. Such a configuration could meet the pressure requirement. A similar series of two pumps had been used to supply the MSEE and MSS/CTE receivers tested at the NSTTF,[3,7] and multiple pumps had been considered in commercial power plant designs. The advantage of such a configuration is that no bearings are placed in the aggressive molten-salt environment. The disadvantage, however, is that such trains of pumps have low efficiencies. The decision to test the multi-stage vertical-turbine pump was based upon the cost advantage of lower parasitic losses for commercial plants, and the specification of such a pump in the Saguaro Repowering study.[11]

2.2 <u>Description of the Hot-Salt Pump</u>

The hot-salt pump is a single-stage vertical-cantilever pump manufactured by Lawrence Pump & Engine Company. The pump is powered by a 260-kW-output (350-horsepower) 4160-volt, 3-phase motor manufactured by Siemens-Allis. The pump is illustrated in Figure 6, and is of standard design. Components exposed to the molten salt are made of stainless steel to make it compatible with molten salt. The cantilever design employs no bearings in the molten salt i.e., the bearings are located above the salt. This advantage is important since hot molten salt is an aggressive oxidizer (much more so than the cold salt). The design conditions of pressure and flow are within the capability of a single-stage pump.

The design-point efficiency for this pump is 69% (at $0.115 m^3/sec$); the lower efficiency relative to the cold-salt pump is a by-product of the cantilever design. A plot of the efficiency and curve for the hot-salt pump is shown in Figure 7. The pump impeller is mounted on a shaft that has no bearings in the vicinity of the impeller.

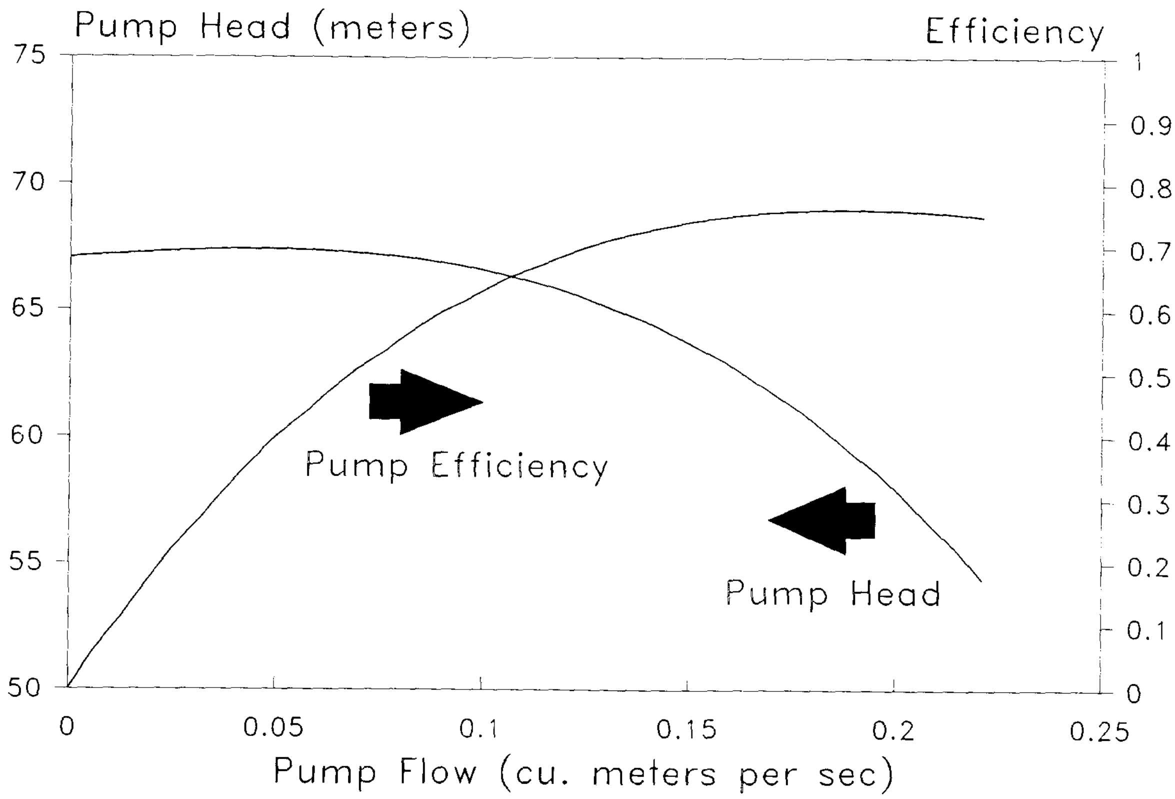

Figure 5. Plot of Efficiency and Pump Curve for the Cold-Salt Pump

The shaft is supported by anti-friction bearings mounted approximately 1.5 meters above the impeller in the body of the pump. The impeller is cantilevered on the end of the shaft within the pump volute below the level of the salt being pumped. Salt that leaks past the clearance between the impeller and the volute returns to the pool of salt; thus, no pump seals are required. This design requires somewhat larger clearances and thus greater leakage, resulting in the lower efficiency. Relative to the cold-salt pump, however, this pump draws little power because of its lower outlet pressure. Thus, it represents a less significant parasitic loss to a commercial power plant. The decision to test a vertical-cantilever pump instead of a possibly more efficient vertical-turbine pump in the hot loop was based upon the relatively modest efficiency reduction in this lower pressure application, and the more aggressive nature of the hot molten salt.

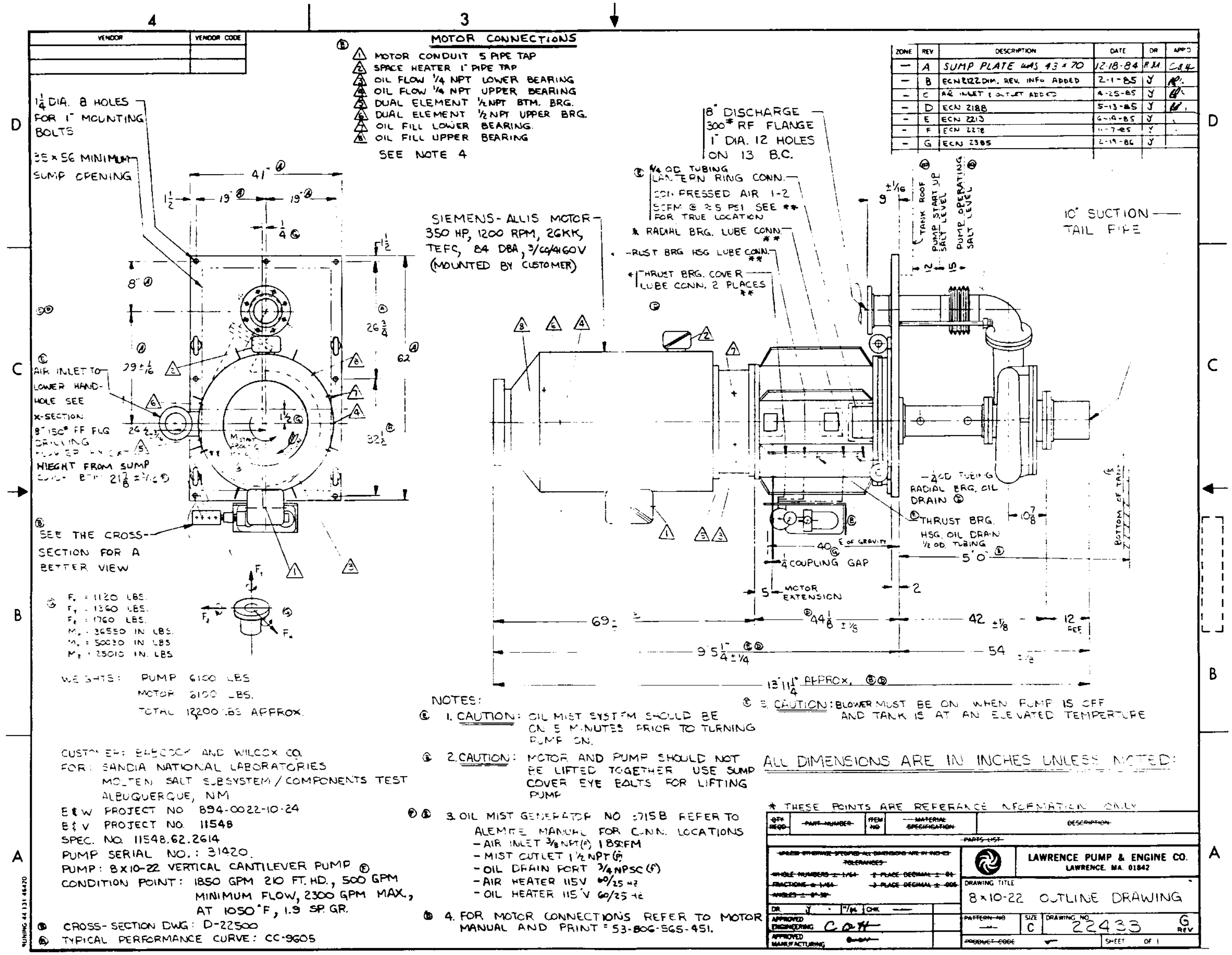

Figure 6. Schematic of the Hot-Salt Loop Pump

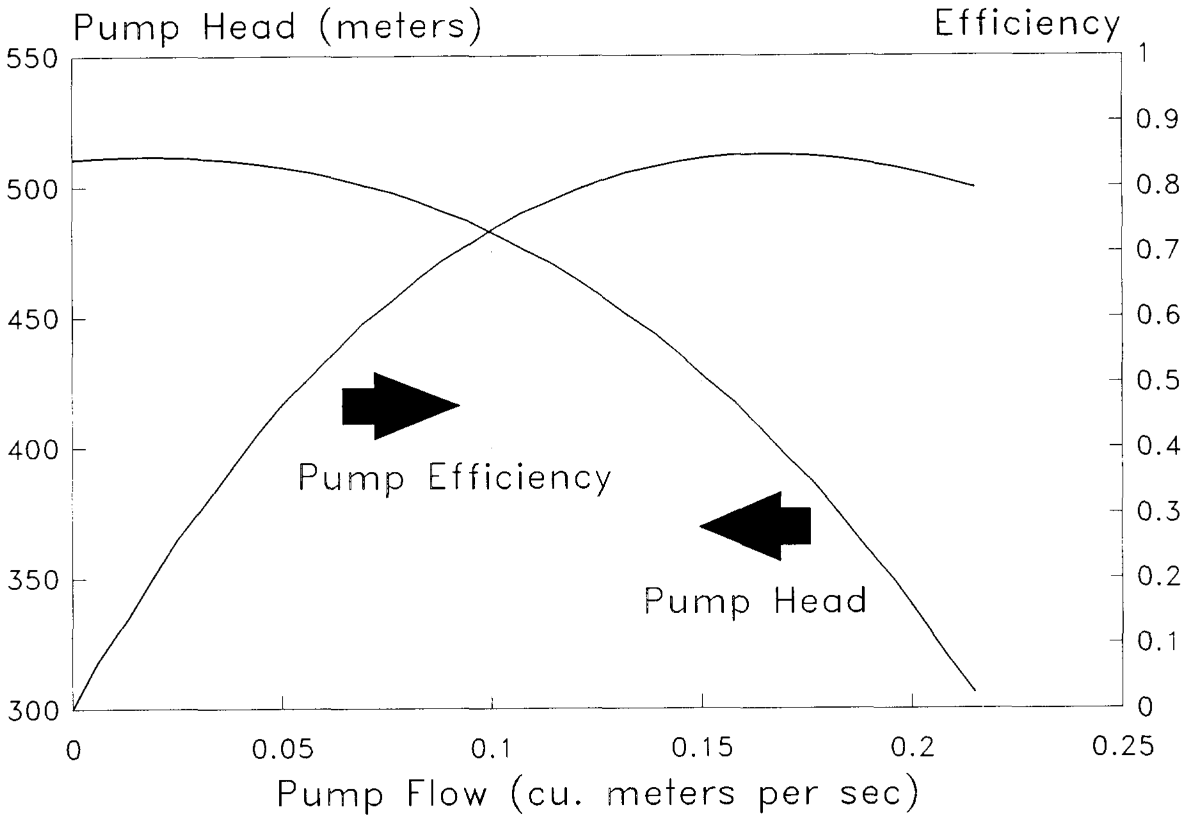

Figure 7. Plot of the Efficiency and Pump Curve for the Hot-Salt Pump

2.3 Description of the Valves

The valves installed in the test loops are divided into two general categories. These are:

1) Flow Control Valves, and
2) Isolation Valves.

Typical molten salt solar central receiver power plants employ valves of both types in both hot and cold salt service. The valves selected for the test cover a range of different types that might be employed in a large commercial power plant. These include: linearly actuated globe type flow control valves, rotary type flow control valves, linearly actuated globe isolation valves, and linearly actuated gate isolation valves.

Flow control valves are intended for use in applications where salt flow must be throttled in order to control a process in a molten salt solar power plant. Flow control valves are used, for example, to control cold salt flow to the receiver to regulate its outlet temperature, control the salt flow to the steam generator thereby regulating steam flow, throttle hot salt flow descending the downcomer from the receiver, and regulate the salt level in the pump sumps. To accomplish their role, the valves have specially engineered mechanisms to vary the valve opening as a function of the position of the valve stem. This mechanism, called a valve trim, allows for even control of a process over a range of conditions. The valve trims in the globe-type flow control valves were replaceable. This allows for maintenance, and allows the valve characteristics to be changed if conditions warrant.

Isolation valves, on the other hand, are applied in situations where a flow path must be open at some times and closed at others. Throttling should not be done with isolation valves. Isolation valves are designed to produce minimum restriction to flow when they are opened, and to seat tightly when closed. Isolation valves are employed in a plant, for example, to isolate pumps for maintenance, and as drain valves. Globe-type isolation valves are similar to globe flow control valves, except that they are generally simpler. They employ only a valve seat to shut-off flow, but no trim for throttling. Gate type isolation valves employ a sliding gate that retracts from the flow path. This mechanism generally requires more motion of the valve stem to open the valve, but offers the advantage that the full pipe area is opened, offering minimum flow resistance.

The valves in both the hot and cold loop are of standard design, purchased according to specifications detailing the intended service. Both hot- and cold-salt valves utilize bolted bonnet flanges and standard packing gland arrangements. One cold-salt valve and one hot-salt valve employ a primary bellows seal, with a secondary packing seal to prevent blowout in the event of a bellows failure. Each valve was initially packed with an arrangement of alternating braided graphite packing[2] and glass-reinforced Teflon™ washers.[3] These packing material arrangements were based on a previous bench-test[15] conducted as part of this project. The hot-salt valves use extended bonnets to remove the packing from the high-temperature salt flow through the valve. The packing glands in all valves are insulated and heated electrically to maintain their temperature near the salt melting point of 260°C. The control valves are actuated pneumatically, and the isolation valves have handwheels.

2.4 Description of Instrumentation and Control Equipment

The salt-loop instrumentation consists primarily of a number of thermocouples, pressure sensors, and a few specialized instruments. Pressure instrumentation used remote seals with an intermediate fill fluid to isolate the transmitter from the molten salt. Flow in the loops was measured using a venturi mounted in the piping and remote-seal differential pressure transmitters. The intermediate fill fluid was sodium-potassium (NaK) liquid metal in all transmitters except the flow transmitter in the cold loop, where a silicone oil was used. The molten-salt level in the pump sumps was measured with a "bubbler" gauge. Current transformers were used to measure pump current, and vibration sensors were installed on both pumps. All instruments produced electrical signals that were connected as inputs to the control system.

2.5 Description of Piping and Heat Trace

Corrosion limitations dictated the use of stainless steel for the hot loop piping, pumps and valves, and carbon steel for the cold loop. Flanged connections were minimized because of the potential for leaks, but were used in some locations such as the pump outlets. All flanged connections are subject to leaks and the thermal cycling in a salt loop would exacerbate the problem. The piping was heated by seamless mineral-insulated heater cable manufactured by Pyrotenax.[4] Band heaters and strip heaters were used to heat smaller components such as instrument diaphragms and valve bodies.

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[2] Crane 1625 Gf, John Crane-Houdaille, Inc., Morton Grove, IL
[3] Supplied by RM Industrial Products, North Charleston, SC
[4] Pyrotenax of Canada, Limited, Trenton, Ontario.

The heaters were divided into multiple control zones and were actively controlled by a simple on/off control system to maintain pipe temperature. The heaters were oversized for the estimated heat loss to allow for variabilities in the insulation and in environmental conditions. Immersion heaters were installed in the hot sump. All components were insulated with a 1-inch-thick layer of ceramic fiber insulation, then 20.3 cm (8 inches) of calcium-silicate block insulation. The pipes were supported by insulated pipe supports. The total heat trace load (including the immersion heaters) for the hot and cold loops was 72 kW each. During operation, the duty cycle of the heat trace was approximately 80% off and 20% on.

3.0 TEST PLAN DESCRIPTION

The overall goal of the hot- and cold-salt P&V tests is to demonstrate to the DOE, system integrators, investors, and the utility power community that pump and valve designs are available to support construction of large-scale molten-salt solar plants. Specific objectives of the P&V testing are to verify the performance of the components, and evaluate their service life and maintenance requirements.

The testing is designed to provide accelerated testing of the pumps and valves. In addition, each test loop is designed to exercise the pumps and valves in a manner similar to operation in a commercial plant. In each test sequence, six hours for the cold-salt loop and three hours for the hot-salt loop, the pump is cycled through a range of flows. While cycling through the various flow rates the valves are cycling to control flow and pressures. The test sequence is designed to optimize the number of cycles on the pumps and valves. However, the sequence time is controlled by the number of starts allowed per day for each pump motor, six for the cold-salt pump and fifteen for the hot-salt pump. The delay period allows the pump-motor to cool-down before it is restarted. The key test parameters are shown in Table III. The specific test parameters are described in detail by Bator and Dowling[13] and Rush, et al.[14]

Table III

Loop Test Parameters

	Cold Loop	Hot Loop
Maximum Pump Flow (l/sec)	140	140
Minimum Pump Flow (l/sec)	90	60
Test Sequence Time (hr)	6	3
Delay Period (min)	10	24

4.0 TEST RESULTS

Operation of the hot-salt loop began in January 1988, and operation of the cold-salt loop in March 1988. A picture of the entire pump and valve test loop is shown in Figure 8a, and a picture of the cold and hot pumps/motors are shown in Figure 8b. Cumulative hours of operation for both loops are shown in Figure 9. Quantitative data from the test was collected by the control system and transferred to a minicomputer network and stored on disk. This data was archived to magnetic tape monthly. In addition, a test log was maintained that includes a description of all component failures, maintenance operations, and significant observations regarding the operation of the test.

The hot-salt loop operated for 6711 hours and accumulated 2160 cycles on the pump. The number of control valve cycles are approximately twelve times the pump cycles because of the manner in which the valves are cycled. Operation of the cold-salt loop resulted in an accumulation of 2542 hours and 583 cycles. Control valve cycles are approximately 24 times the number of pump cycles. Problems with the cold-salt pump early in the test program and limited hours of operation resulted in the reduced test time for the cold-salt loop compared to the hot-salt loop.

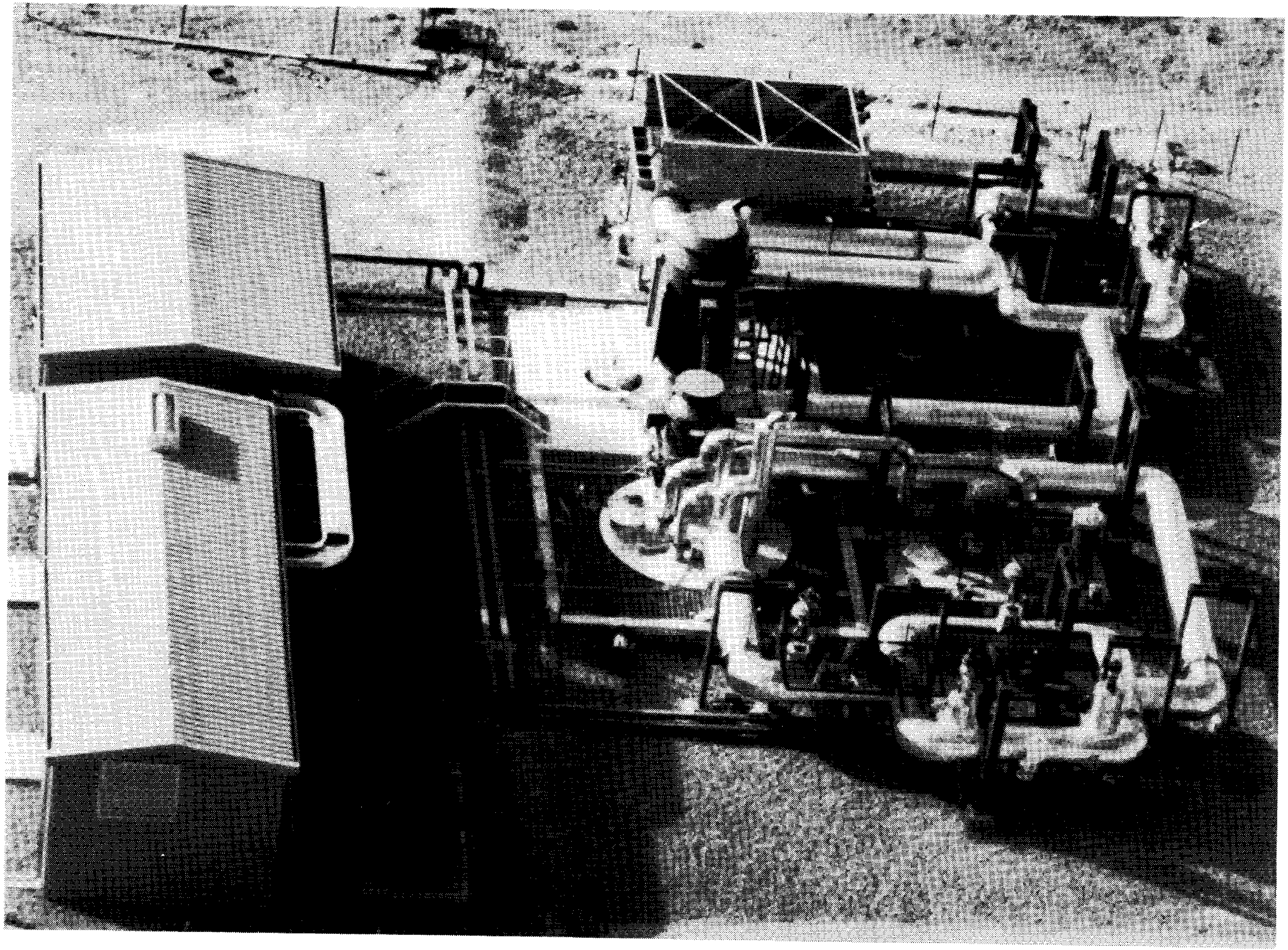

Figure 8a. Photograph of the Pump and Valve Test Loops

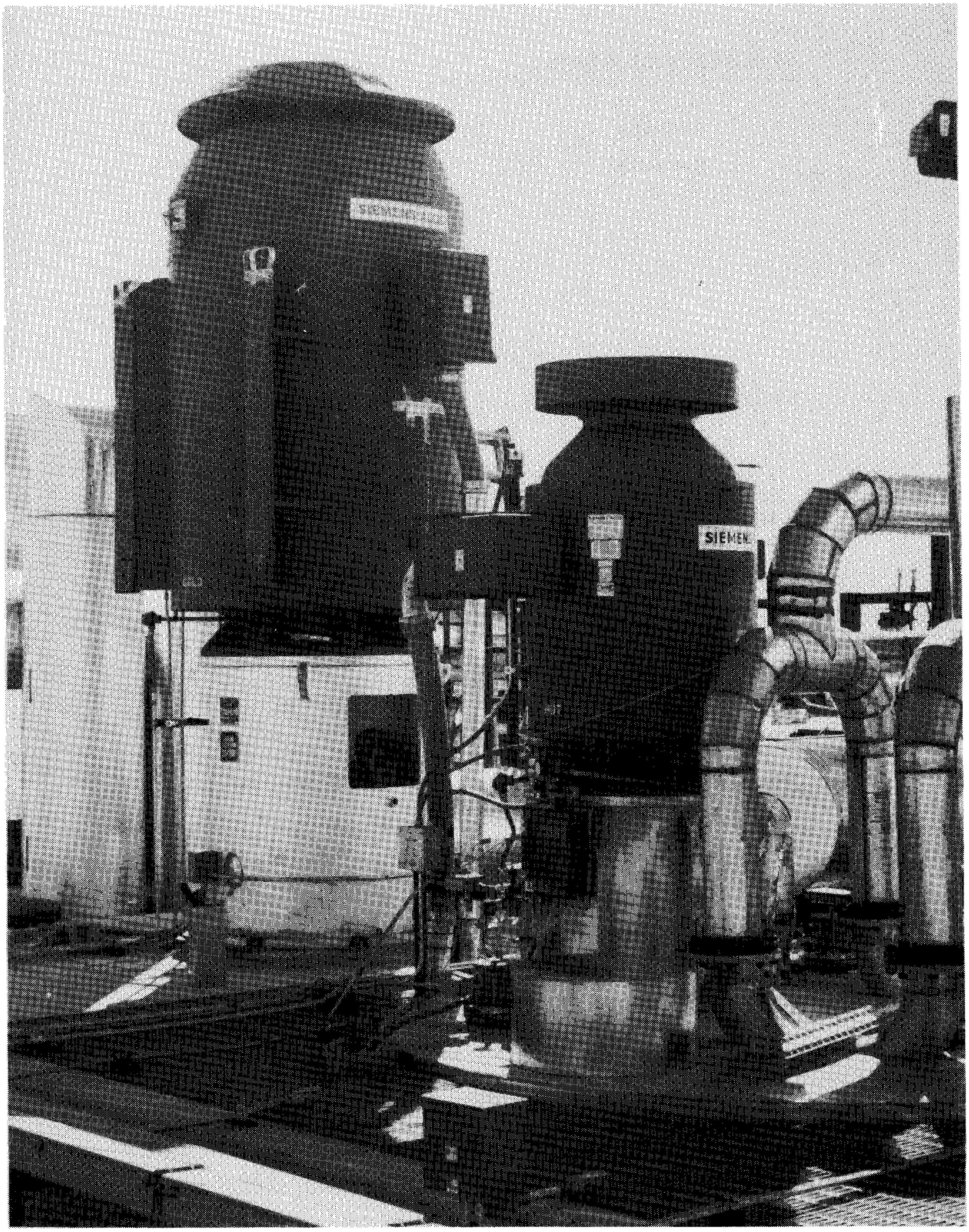

Figure 8b. Photograph of the Hot-Salt and Cold-Salt Pumps/Motors

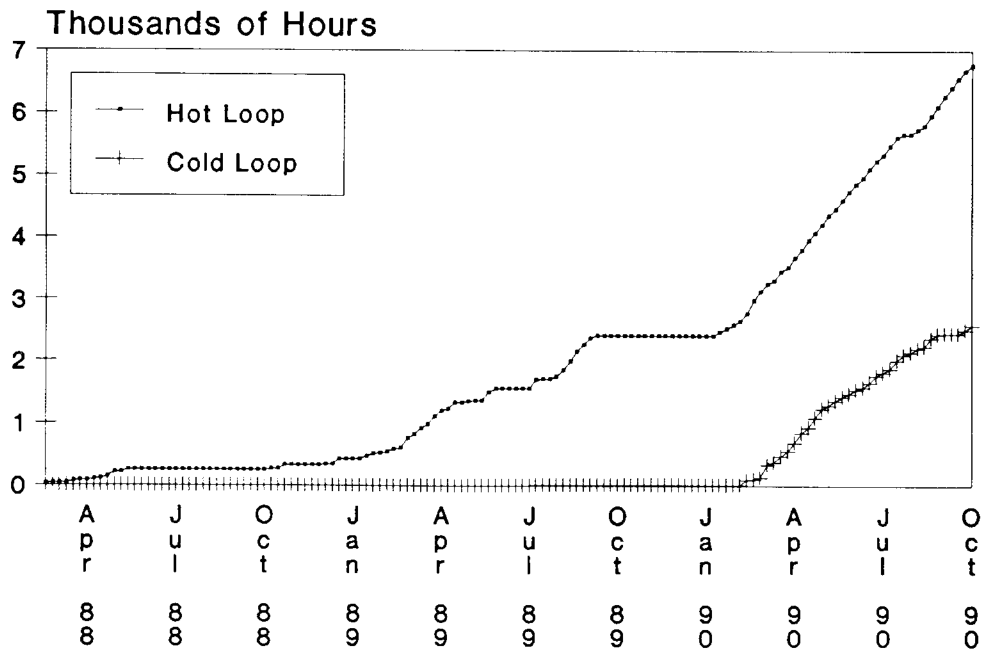

Figure 9. Test Loop Operation Time

4.1 Hot-Salt Loop

The hot loop operated for more than 6700 hours. During this time, a number of pump and valve problems were resolved, allowing the test loop to operate unattended 24 hours a day, 7 days a week. This level of performance is comparable to conventional power plant performance. Occasionally, the system tripped off-line—the reasons are described in the sections below.

4.1.1 Operation of the Hot-Salt Pump

The hot-salt pump loop was initially run with water to test its performance. It performed well, and the loop was drained, and filled with molten salt. The pump was then operated for a period of over 2000 hours, without significant problem. The measured performance of the pump during this time was slightly above the manufacturer's specification. Soon after this milestone was reached, however, a drop

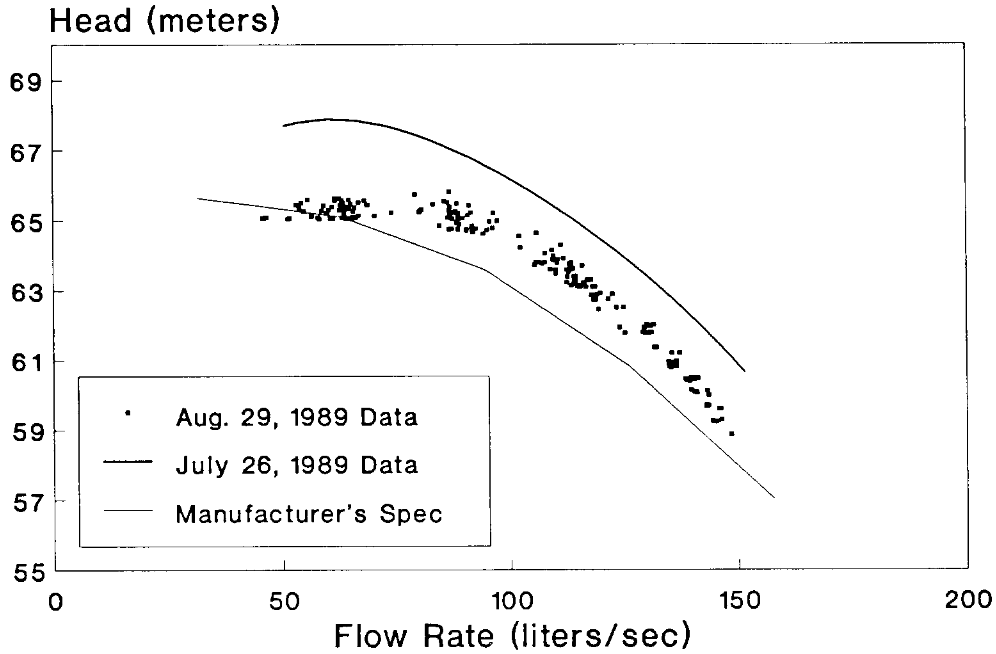

Figure 10. Hot-Salt Pump Curve Prior to the Pump Failure

in pump performance was noted, associated with increased pump vibration. Eventually, the vibration reached the trip limit. Performance curves taken approximately one week, and one month before the failure are shown in Figure 10.

Subsequent to the failure, the pump was removed from the loop, disassembled, and inspected. It was found that the shaft had a permanent deflection of 1.52 mm (0.060 inches) and that excessive wear had occurred in the close-tolerance rotating pump seal. The suspected cause of the shaft deflection is stress relief at high temperatures. The shaft of this pump experienced some temperatures marginally higher (10°C-40°C higher) than the normal 565°C in the weeks prior to the failure. At these temperatures, stresses built in during fabrication can relieve themselves by creep, distorting the shaft. A replacement shaft for the pump was procured, with specifications that the shaft be factory stress-relieved before final machining. This shaft was installed, and the pump returned to service. With the new shaft, the pump performance returned to its original level. The pump operated 4700 hours with the new shaft.

4.1.2 Operation of the Hot-Salt Control Valve

The test control valves operate in automatic control, as they would in a solar power plant. The downstream control valve (FCV-658) operates in pressure control, while the parallel valves (FCV-653 and FCV-655) alternate roles, with one valve controlling total loop flow and the other acting as a variable bypass. The variable bypass creates a perturbation in the loop to which the control valves must respond. As a result all valves are in nearly constant motion, as would be the case in a power plant. The test focused on the valve stem seals, with additional concern for the general operability of the valves. A number of problems were encountered with the operation of the control valves during the test. In all cases the problems were solved, or options were identified to avoid the problems.

Three types of valve seals were included in the test: linear packing seal, rotary packing seal, and bellows seal. The performance of each of them is discussed below:

> *Linear Packing Seal*: The original packing arrangement employed a braided graphite fiber packing,[5] with Teflon™ washers separating each of the graphite packing rings. In the hot-salt valves, the packing can be maintained at a lower temperature by using an extended valve bonnet to isolate it from the hot salt in the valve body. During operation in the loop, this arrangement suffered several complete packing failures. Although it was possible to maintain a low temperature in the packing gland if no leakage occurred, a small amount of leakage allowed the intrusion of hot salt into the packing gland, where the oxidizing nature of the salt caused further damage to the packing. This process would rapidly carry itself to complete packing failure. This behavior was judged to be unacceptable for power plant operation and led to a search for alternate materials.
>
> Alternative packing materials that were investigated included aluminum tinsel, fiberglass, and PBI.[6] The fiberglass[7] and PBI packing have shown acceptable performance when used with Teflon™ washers. Small leaks that develop grow slowly and can be arrested or slowed by tightening the packing gland.

Leakage of some salt from packed valves appears to be unavoidable. Small amounts of leakage (on the order of 1/4 liter per day) have been found to be manageable, however. The salt is relatively nontoxic, and if the leakage rate is small, the biggest problem is damage to auxiliary equipment such as heaters, instrumentation, or insulation. The salt will readily wick through the insulation along any hot surface. To prevent salt wicking, metal pans have been installed on the valves just below the packing gland to catch leaking salt. These have been effective in minimizing the impact of small salt leaks. Salt caught in these pans can ideally be filtered to remove insulation and dirt and returned to the test loop.

Another possible solution to this problem has been suggested. This is to mount the valves so that the valve stem is oriented at an angle below horizontal. Salt would then tend to fall by gravity off of the valve. This approach was not tested in this loop, however, and may create problems with support of the valve and its actuator.

Rotary Packing Seal: A rotary packing seal was installed in FCV-655. The valve was operated in the loop for approximately 3300 hours. During this time, the rotary seal performed well. The graphite/Teflon™ packing in this valve was never replaced, and leakage from the stem seal was not a problem.

The butterfly control valve, FCV-655, also demonstrated adequate ability to control flow in the loop. However, very early in the test program, this valve developed problems with leaks at its flanged connections into the piping. This is a wafer-style valve that is installed by clamping it between two flanges (the other hot-salt loop valves are welded in place). Many attempts were made to correct this leakage; however none were successful. Flanges are typically

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[5] Crane 1625 GF, John Crane-Houdaille, Inc., Morton Grove, IL

[6] Garlock 1200 BPI, Garlock, Mechanical Packing Div., Sodus, NY; A Celanese trade name

[7] Crane 287I, John Crane-Houdaille, Inc., Morton Grove, IL

trouble spots in systems that cycle thermally. In the case of this wafer-type valve, the combination of pipe loads and valve activity combined to result in a constant leak that could not be arrested. The loop was operated despite this leakage, but when maintenance problems developed with the valve actuator, the decision was made to remove this valve from the test and replace it with an orifice plate. Wafer-type valves are not recommended because of these flange leaking problems. The wafer-type valve was included in the loop test to evaluate its performance, because of its potentially lower cost.

Bellows Seal: The bellows in FCV-658 failed after 700 hours of operation, causing a failure of the secondary graphite packing. This valve was repacked with fiberglass packing and returned to operation as a conventional packed valve. The precise reason for the bellows failure is not known. The failure of the bellows underscores the primary drawbacks of bellows seals; they are fragile. Once exposed to molten salt, they cannot be flexed if they are not above the salt melting temperature. This is because salt freezes within the convolutes of the bellows and immobilizes them. If the bellows is flexed, the relative motion is concentrated at a single convolute, and the bellows ruptures. In this test, the bellows temperature was monitored, and an interlock was implemented to prevent actuation of the valve by the control system if the bellows temperature was too low. The system is relatively complex, however, and inadvertent actuation of the valve is still possible by such things as loss of air pressure to the valve actuator. Bellows replacement requires major valve disassembly, and the bellows assembly is expensive as well. In general, the conclusion regarding bellows is that it can be made to work in large valves, but the complexity and expense is unwarranted, given the performance of conventional packed valves.

Generally, the globe control valves performed their functions well. Flow and pressure control were achieved with reasonable accuracy, and no degradation of the valve trims or seats has been detected. The measured flow coefficient for FCV-658 is shown in Figure 11. The figure includes the manufacturer's specified curve, the baseline curve from the original water flow test, and recent data taken during operation of the test. No degradation in performance is apparent. This is typical of the performance of FCV-653 as well.

4.1.3 Operation of the Hot-Salt Isolation Valve

The isolation valves in the hot loop have only been used on a few occasions, and their operation has been adequate. For most of the loop operating time, the valves were "backseated." Backseating refers to a second valve seat that isolates the packing region from the process fluid when the valve is fully opened. This saves the valve packing from exposure to the molten-salt fluid over most of the valve lifetime. This design feature is recommended in salt systems, where packing leaks are a problem.

4.2 Cold-Salt Loop

The cold loop operated for more than 2500 hours. Although the cold loop started at roughly the same time as the hot loop, a significant pump problem held up its operation for a year and a half. The test loop is capable of unattended operation 24 hours a day, 7 days a week. Although it could operate 24 hours a day, the cold-salt pump was not operated during times of peak electrical demand in order to minimize the electricity costs. The level of performance of the cold-salt loop as with the hot-salt loop, is comparable to conventional power plant performance.

4.2.1 Operation of the Cold-Salt Pump

The initial check of the cold-salt loop was performed with water. The pump performed well throughout this period of the test. Subsequently, the water was drained from the loop and salt was melted in the pump sump. Upon start-up using molten salt, the pump operated for approximately 45 seconds. Then high shaft deflection was sensed and the control system tripped it off automatically. Upon inspection, it was found that the motor shaft had welded itself to the upper motor cover. This was the first indication of a problem with the pump, and it would eventually be diagnosed as excessive upthrust generated in the pump shaft. This thrust, while certainly present when pumping water, was multiplied when pumping

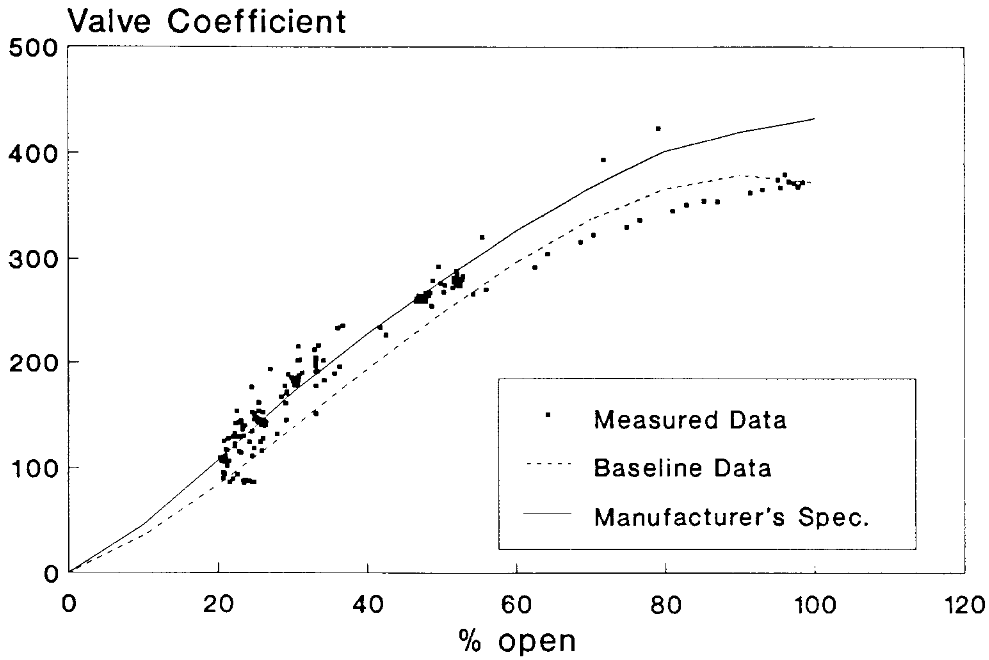

Figure 11. Valve Coefficient for FCV-658, July 18, 1990

the higher density salt. Such a thrust was not anticipated by the pump manufacturer, and no provisions were made for resistance. With water, the weight of the shaft was sufficient to counteract this thrust load. When pumping the denser salt, however, the thrust caused the pump shaft to lift the motor shaft out of the bearing housing and contact the upper motor cover.

The fix for this problem was a relatively minor redesign of the pump impeller stages. The implementation of this design fix on a pump that was already built and installed in the field was a major undertaking, however. Correcting the problem took over a year. It was necessary to remove the pump, ship it to the manufacturer, diagnose the problem, design a fix, modify the pump, return it to the test site, and reinstall it. Subsequent attempts to run the pump resulted in several motor failures. It appears that the initial damage to the motor, caused by the upward thrust of the pump, had residual effects on motor operation. After three motor repairs, and six months, the loop was started successfully. After these problems were solved the pump operated for 2400 hours before additional problems were experienced.

After 2400 hours of operation, the lower motor bearing failed. All motor bearings were replaced and the loop was restarted. Upon restart, the new upper bearing generated borderline temperatures. Apparently, the new bearing had a defect, but the condition was acceptable for the balance of the test program.

The pump curve shown in Figure 12 was derived from the test data. The measured curve lies very close to the manufacturer's specification.

A post-test inspection of the cold-salt pump was conducted by the manufacturer. The inspection revealed no evidence of bearing corrosion or wear, all the bearings were within manufacturer's specification. The impeller wear rings did show some signs of wear, i.e., they were out of specification. The wear appears to be caused by salt erosion. In order to resolve this minor issue the manufacturer recommends using a harder material for the wear rings. The inspection did not reveal any other signs of vibration, wear, or corrosion.

As a result of the shaft upthrust issue which caused so many problems at the beginning of this test, the manufacturer recommended that the motor be designed to accomodate any excessive upthrust. The additional bearings required will have very little effect on the cost or performance of the motor.

4.2.2 Operation of the Cold-Salt Control Valve

The cold-salt loop control valves act to automatically control of flow and pressure like the hot-salt loop valves. FCV-608 operates in pressure control, while FCV-603 and FCV-605 were intended to alternate roles as flow control and variable bypass valves. Early in the check-out phase, it became apparent that FCV-603 operated too slowly to use as a flow control valve. Therefore, the role of flow control was permanently assigned to FCV-605. Few other problems have been encountered with these valves.

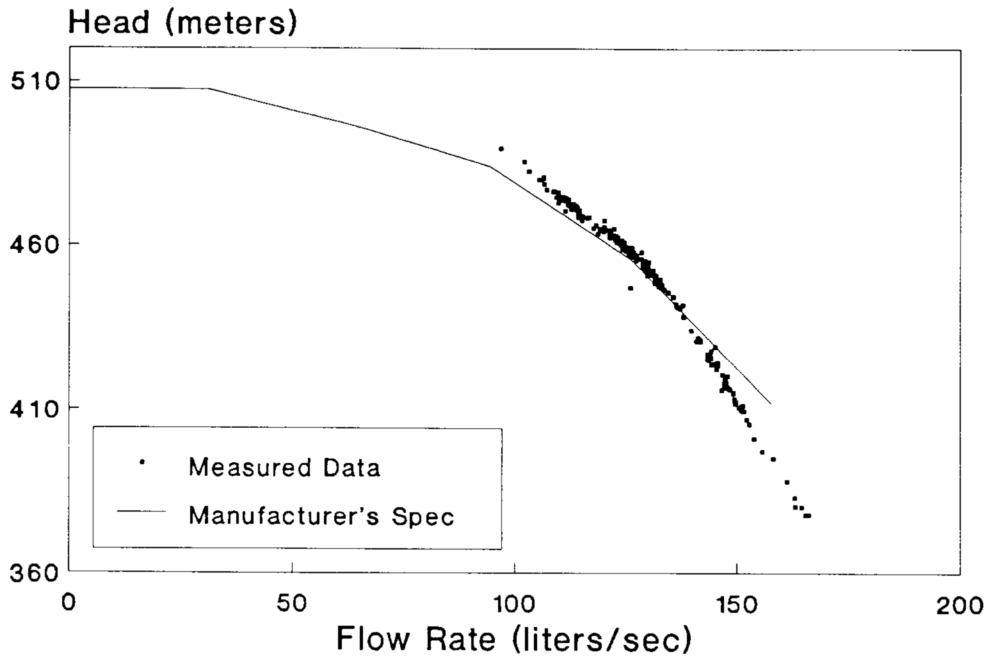

Figure 12. Cold-Salt Pump Curve, September 20, 1990

As in the hot-salt loop, three types of valve seals were included in the test: linear packing seal, rotary packing seal, and bellows seal. The performance of each is discussed below:

Linear Packing Seal: The original braided graphite fiber packing with Teflon™ washers performed adequately in the cold loop. Packing leakage was minimal. The PBI packing was installed in one of the cold loop valves for the final 100 hours of the test program. It performed adequately as well.

Rotary Packing Seal: The rotary packing seal in FCV-603 performed well with the graphite fiber packing. This also supports the expectation that rotary packing glands place less severe demands on the packing.

Bellows Seal: The bellows seal in FCV-608 has performed well and shows no sign of leakage.

4.2.3 Operation of the Cold-Salt Isolation Valve

The isolation valves in the cold-salt loop have been operated on only a few occasions. In general they are open and backseated during testing. Upon start-up, the packing in HV-604 failed completely. Only traces of the original packing material were recovered. It is suspected that the original packing was of the incorrect material, or was installed improperly. This valve was repacked and returned to service. During the test, some leakage was observed from the packing gland of this valve when the backseat pressure relaxed as a result of vibration. The leakage was stopped by tightening against the backseat. After 2000 hours of testing, the packing in this valve was removed. The Teflon™ rings were still intact, but most of the graphite fiber was gone. The reason for such behavior is not understood, in light of the fact that similar problems have not occurred with the other cold-salt valves.

4.3 Instrumentation and Control

The instrumentation for the loop performed relatively well. A few problems were solved, but flow measurement in the cold-salt loop remains a problem. The flow transmitter in question is one with silicone-oil-filled remote diaphragms for isolation from the hot molten salt. This type has not worked well in other experiments.[7] The problem seems to be related to the fact that the oil vapor pressure is high at the operating temperatures of the loop. This causes the transmitters to be sensitive to over-temperatures. When this transmitter was purchased, no equivalent NaK-filled transmitter was available. The successful operation of the higher temperature (but lower pressure) NaK-filled flow transmitter in the hot-salt loop indicates that the problem can be solved. The NaK-filled pressure instruments have worked well. A few failures have occurred in the diaphragms separating the fill fluid from the molten salt. An orifice snubber, installed to reduce pressure pulse generated when the pump starts, seems to have eliminated the maintenance problem. There is insufficient instrumentation on the pumps to clearly evaluate pump efficiency. This should be considered in future tests or in the next plans.

The distributed digital automatic control system, a Bailey Network 90 system, has proven to be quite capable and reliable. The programming flexibility has allowed complex test sequences to be implemented in an automatic sequence. It has also facilitated programming of a comprehensive set of automatic shutdown sequences and trip signals. This has allowed 24-hour and weekend unattended operation with confidence that significant problems will be detected and the loop will shut down safely without major damage. Communication with the data acquisition system worked well and allowed easy data analysis.

4.4 Piping and Heat Trace

Pipe flanges leaked on several occasions. These leaks could usually, but not always, be stopped by retorqueing the flange bolts with the system at operating temperature. Flange leaks were more prevalent and persistent in the hot-salt loop. This may be because the hot-salt loop experienced more thermal cycling, or because the cold-salt loop components were rated to higher pressures. Flanges should be avoided where practical. If flanges must be used, they can be expected to leak at some time. They should, therefore, be located in horizontal piping lines if possible. Leaks in horizontal lines will drip salt and allow detection of the leak before a large amount of insulation becomes saturated. Welded connections in the piping to valve bodies, venturis, orifices, and other in-line components are recommended.

The low-wattage mineral-insulated heat trace cable performed well at both the hot-salt loop and cold-salt loop temperatures. In addition, it proved to be resistant to contact with the salt that leaked from the system. Band and strip heaters were very vulnerable to shorting out upon contact with salt, and maintenance of these heaters remains a problem. Mineral-insulated cable is usually installed in long sections, and replacement of these heaters is difficult. The pipe insulation must be removed to replace the cable, and in the case of calcium-silicate block, the insulation is usually not reusable. A trade-off between the economics of long heaters and the cost of labor and downtime for cable replacement should be considered when trace heat systems are designed. Redundant cables installed during construction, but not placed in service, are a partial solution. Replacement of at least some of the cables over the life of the plant can be expected. Start-up of the hot loop was delayed significantly by defects in the installation of a long heater cable, detected in the check-out phase after the insulation was installed.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The general conclusion from the test was that pumps and valves based on existing technology have demonstrated the ability to operate successfully at conditions typical of large commercial plants. The test has uncovered no reason related to pumps and valves to indicate that a large molten-salt power plant could not be built and operated reliably. Several salt-specific problems were discovered that led to difficulties with start-up of the test loops. All of these problems related to the high temperature, oxidizing nature, or density of molten nitrate salt and were found to be solvable or avoidable. Operation of the test eventually settled down to a routine affair, requiring a reasonable amount of maintenance. Specific conclusions and recommendations are presented below:

Pumps: The cantilever pump design is adequate for hot-salt, and the multi-stage turbine pump is suitable in cold salt. Attention to the details of pump design is very important, however, as small problems with pumps can cause long delays. Actual service in pumping molten salt is probably the only way to ensure that subtle design considerations have been made.

Valves: Commercially available packing materials have been found that work in both cold and hot molten salt valves. Extended bonnets are needed in hot salt to keep the packing temperature within an acceptable range, but rapid blowout failures can be avoided in the event of overheating the packing. Some packing gland leakage should be considered acceptable, and methods are available to mitigate damage from leaks. The cost and complexity of large bellows seal valves are not warranted, given that acceptable packings are available. Throttling service in hot or cold salt is not a problem with conventional control valves. Flange-connected valves and wafer-type valves in particular are not recommended because of flange leak problems. Flange-connected valve bonnet designs seem to work acceptably, however. Some leaking can be expected at bonnet flanges, but careful torqueing of the bolts at operating temperature will usually stop the leaks. Non-drainable valve designs have not been a problem.

Instrumentation and control: The only persistent instrument problem was with the flow meter in the cold-salt loop. This was a silicone-oil-filled remote differential pressure transmitter. NaK-filled transmitters worked satisfactorily in the hot-salt loop, however, and should be used in future applications if possible. The control system worked well for both process control, and for the safety/shutdown system. This made 24-hour unattended operation of the test possible.

Piping and heat trace: Flanges in the piping system should be minimized. Flanges can be made to work in high-maintenance areas such as pump connections, transmitters, and valve bonnet flanges, but leaks can be expected at some point in any flanged connection. Necessary flanges should be arranged so that salt leakage is directed away from insulation. Flanges should be located in horizontal legs with metal barriers or pans to retard salt migration. Flanges rated for higher pressure seem to be more leak-resistant. Weld-in valves, venturis, and orifices are recommended.

Low-wattage mineral-insulated cable works well for preheating piping systems. A salt-resistant sheath material for the cable is important, however. Band and strip heaters are vulnerable to damage from salt leakage, and should not be located in areas where salt leaks are probable. Replaceability of heaters is an important consideration. Thermal insulation methods are also important from this standpoint.

In conclusion, large pumps and valves for molten salt are ready for application in harnessing the vast solar energy resources available in this country through central receiver power plants. The technology to support the design and construction of a large solar thermal central receiver power plant using molten salt as a heat transport and storage medium is developed and demonstrated.

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Appendix A

OPERATIONAL EXPERIENCE WITH THE MAJOR COMPONENTS OF MOLTEN-SALT SYSTEMS*

* This Appendix is a compilation of responses from engineers and technicians involved in this test program to the questions asked about each system component.

COLD-SALT LOOP PUMP
BYRON-JACKSON PUMP & MOTOR

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Original motor-pump had a design problem. There was an upthrust on the motor when pumping salt (the problem did not occur when check-out tests were being conducted with water).

2. The capacity in the motor-pump design fix that was implemented may be marginal.

3. The lower radial bearing on the motor failed after 2000 hours of operation. The upper thrust bearing showed some possible failure also.

What would you do differently on this pump if you had to build a plant?

1. Analyze the motor-pump design to ensure that the motor bearings are adequate for the loads imposed by the pump.

2. Increase the thrust capacity of the motor.

Did the Byron-Jackson Pump do its job?

1. Yes--after the pump was modified for the upthrust problem, the pump worked fine.

2. The motor continued to experience problems (oil leaks, stator burnout, bearing failures).

Does Byron-Jackson Pump require more testing? How?

1. It would be beneficial to continue to test this pump; however, it would be even better if a <u>new</u> pump/motor could be tested. It wouldn't have the design revision and problems of the existing pump.

2. The pump performance needs verification (with better instrumentation).

HOT-SALT LOOP PUMP
LAWRENCE PUMP AND ENGINE PUMP & MOTOR

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. The pump shaft developed a .060 inch bow, at 2400 hours of operation, causing the wear ring to fail. The new shaft was stress-relieved prior to installation.

2. The discharge flange leaked--causing salt to leak into the sump insulation. The flange should have been installed in the horizontal position.

What would you do differently on this pump if you had to build a plant?

1. Specify that the shaft be stress-relieved before final machining.

2. Elbow the pump discharge to the horizontal before the discharge flange. This will aid in maintenance and removal and minimize migration of salt if the joint leaks.

3. Evaluate alternatives to oil mist for bearing lube. The oil mist is very messy. This may be a safety problem.

Did the Lawrence Pump and Engine Pump do its job?

1. Yes, the pump and motor worked well for the 7200 hours operated.

Does Lawrence Pump and Engine Pump require more testing? How?

1. No, it has demonstrated the reliability and performance of cantilever pumps.

FLOW AND PRESSURE TRANSMITTERS
ROSEMOUNT AND TAYLOR

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. There were three NaK filled-pressure transmitters (made by Taylor) in the cold-salt loop, which experienced minor problems. The transmitters could not be removed for calibration because the threaded stainless steel connection galled.

2. The oil-filled flow transmitters in the cold-salt loop (ΔP) (made by Rosemount) had problems possibly because the vapor pressure of the oil was too high. On two occasions the diaphram developed small pinhole leaks. The leaks could be the result of loop dynamics or material incompatibility.

3. All three transmitters in the hot-salt loop, which are NaK filled, had leakage problems at the flanges. These leaks caused the heat trace to short out.

4. All transmitters had problems with calibration.

What would you do differently on this Flow and Pressure transmitters - Rosemount and Taylor, if you had to build a plant?

1. Calibrate the flow meters at temperature to eliminate the offset.

2. Use NaK-filled ΔP flow transmitters for cold salt applications or try some other flow meter (vortex shedding, etc.).

3. Use heavier flanges to reduce leaks, or weld the transmitters in on the hot-salt loop.

Did the Flow and Pressure transmitters - Rosemount and Taylor - do their job?

1. Rosemount oil-filled -- No

2. Taylor NaK transmitters -- Yes

Do Flow and Pressure transmitters - Rosemount and Taylor - require more testing? How?

1. Need to test different mounting techniques with or without flanges on hot loop.

2. Oil filled ΔP transmitter needs more detailed bench testing to determine exactly what the problem is so that it may be avoided or corrected. As an alternative, high absolute pressure ΔP NaK transmitters from a commercial vendor must be found.

HEAT TRACE
MI CABLE AND ACUREX CONTROLLER
OTHER HEATERS

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. The MI cable runs are too long. For example, prior to starting up the hot-salt loop a long run of cable had to be replaced, which resulted in a very long downtime.

2. Band heaters are vulnerable to leaks, especially around valves and flanges.

What would you do differently on this heat trace if you had to build a plant?

1. Shorter lengths of heat trace runs.

2. Install heat trace in a way that makes replacement easier.

3. Use MI cable and insulation to create oven effect around valves; this eliminates band heaters.

Did the heat trace do its job?

1. Yes.

Does heat trace require more testing? How?

1. No--properly installed MI cable, with redundant loops, are long lasting and reliable.

2. Be sure to use the correct MI cable, seamless welded, and operate with low-wattage densities.

3. Methods that facilitate replacement of MI cables more easily should be explored.

CONTROL SYSTEM
BAILEY NET 90

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Experienced module failures and some problems with maintenance. These problems did not significantly affect testing.

What would you do differently on this Controls - Bailey Net 90 if you had to build a plant?

1. Better integration with heat trace.

2. A better informational thermocouple input would be an improvement (e.g., a scanner).

Did the Controls - Bailey Net 90 do its job?

1. Yes, very successful for both process control and equipment protection--easy to maintain software.

Does Controls - Bailey Net 90 require more testing? How?

1. No, similar distributed controls systems will also work.

PACKING MATERIAL
CRANE 1625 (GRAPHITE)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. The material disintegrates in high-temperature salt which can lead to valve packing blowout.

2. Some of the packings blew out in the cold-salt loop, but it is not clear that they were packed properly.

What would you do differently on the Crane 1625 Packing (Graphite) if you had to build a plant?

1. Use a different packing material in the hot loop. Test other packings for the cold-salt loop.

Did the Crane 1625 Packing (Graphite) do its job?

1. No. There is a danger of rapid packing blowout and spraying molten salt.

Does Crane 1625 Packing (Graphite) require more testing? How?

1. No, do not use.

PACKING MATERIAL
CRANE 287I (FIBERGLASS)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. No real problems. This packing developed a small leak on FCV 653, but the valve had a scored shaft. The leaks could be controlled.

2. Minor leaks can be fixed by tightening the packing ring.

What would you do differently on this Crane 287I (Fiberglass) if you had to build a plant?

1. Nothing--except it should be tested in the cold-salt loop with the higher pressures.

2. Keep the temperature in the packing region below 600°F.

Did the Crane 287I (Fiberglass) do its job?

1. Yes, it worked well. This material was in FCV-658 (the failed bellows valve) for over 4000 hours of operation. There were no catastrophic failures.

2. The Teflon™ washers are needed to control leakage.

Does Crane 287I (Fiberglass) require more testing? How?

1. Yes, more hours on control valves and hand valves in the hot-salt and cold-salt loops.

2. Needs to be tested in the cold-salt loop with the higher pressures and on rotary-operated valves.

PACKING MATERIAL
GARLOCK 1200 PBI

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Minor leakage on FCV-653, but at an acceptable rate. Material did not blow out.

What would you do differently on this Garlock 1200 BPI if you had to build a plant?

1. Keep the temperature in the packing region below 600°F.

2. Test on cold-salt loop with higher pressures.

Did the Garlock 1200 BPI do its job?

1. Yes.

2. The Teflon™ rings are needed to make this packing work.

Does Garlock 1200 BPI require more testing? How?

1. Yes, more testing is required on both hot-salt and cold-salt loops. This application is outside the manufacturer's specification.

3. Needs to be tested on the cold-salt loop with higher pressures.

HEAT EXCHANGERS

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. No significant problems with hot-salt loop heat exchanger.

2. There were many problems with the cold-salt loop heat exchanger. The strip heaters used to preheat failed (cal-rod heaters should have been used with the cold junction outside the heated area). The heat exchanger was not skirted or shielded sufficiently to prevent the wind from blowing through and lowering the cooler temperature. The heat exchanger did not drain when flow stopped. Coupled with the wind problem, salt would freeze up.

What would you do differently on these Heat Exchangers if you had to build a plant?

1. These would not be required as "on-line" components in a commercial plant. If used at all, it would be in a utility role (in transfer or cleanup lines). Better designs to insulate the cold salt cooler should be devised to facilitate heat-up and draining.

Did the Heat Exchangers do their job?

1. Yes, but there was significant downtime because of problems with the cold-salt loop heat exchanger.

Do the Heat Exchangers require more testing? How?

1. No.

PIPING FLANGES AND HANGERS

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. The stainless steel piping in the hot-salt loop was difficult to weld. This was believed to be caused by faulty piping materials.

2. No problems with the piping or insulated hangers.

3. Flanges were a constant source of leaks--heavier flanges in the commercial system may eliminate this problem.

What would you do differently on the Piping and Hangers if you had to build a plant?

1. Minimize flanged connections as much as practical. Where required, flanges with higher than required pressure ratings should be used.

Did the Piping and Hangers do their job?

1. Yes, there was no corrosion or cracking.

Do the Piping and Hangers require more testing? How?

1. No.

CAM-FLEX™ CONTROL VALVE (MASONELIAN)
(FCV-603)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. This valve responded very slowly to its actuation signal. It was not capable of the rapid flow control required. The valve required one minute for 45° of rotation. The problem was really a positioner problem.

What would you do differently on this control valve if you had to build a plant?

1. Don't use as a flow control valve--it could be used as a shutoff or fixed-throttling valve.

Did the control valve do its job?

1. No, because it's too slow. However, it was stepped to a fixed position at 10% intervals in the 40 to 60% range and performed well.

2. This was a flanged valve and there were no leaks at the flanges in 2400 hours of operation.

Does control valve require more testing? How?

1. No.

GLOBE CONTROL VALVE/PACKING STEM SEAL (COPES-VULCAN) (FCV-605)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Initially there was a problem with differential thermal expansion between the shaft and the packing follower. The valve had to be disassembled and the clearances opened up.

2. There was a small amount of salt leakage around the stem, but this did not warrant packing replacement.

What would you do differently on this control valve if you had to build a plant?

1. Pay careful attention to clearances at temperature.

2. Need a close-fitting stem guide and reduce the volume below the stem guide.

Did the control valve do its job?

1. Yes.

Does control valve require more testing? How?

1. No.

GLOBE CONTROL VALVE/BELLOWS STEM SEAL (COPES-VULCAN) (FCV-608)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Several mechanical failures caused by loop vibrations. The actuator bolts loosened, the valve stem failed, the linkage from the valve body to the positioner broke.

2. There were problems with calibration of the positioner.

3. The bellows were never inspected.

What would you do differently on this control valve if you had to build a plant?

1. Suggest not using bellows valves in a commercial system.

Did the control valve do its job?

1. Yes. Although the valve experienced a lot of mechanical problems.

Does control valve require more testing? How?

1. No.

GLOBE ISOLATION VALVE (ATWOOD & MORRILL)
(HV-602)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. None note; however, this valve was never operated in the closed position.

What would you do differently on this isolation valve if you had to build a plant?

1. Nothing, except test with Garlock 1200 BPI or Crane 287I packing material.

Did the isolation valve do its job?

1. Yes; however, this valve was never operated in the closed position due to the design of the loop. Most of the time this valve was backseated.

Does isolation valve require more testing? How?

1. More experience with this valve would be desirable. It was not operated frequently, but no problems are foreseen.

GATE ISOLATION VALVE (CRANE)
(FCV-604)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. There were two packing blowouts with the Crane 1625 gf packing. There were questions as to whether the valve was initally packed correctly.

2. The valve was not operated with pressure (except for 8 hours).

What would you do differently on this isolation valve if you had to build a plant?

1. Nothing.

Did the isolation valve do its job?

1. Yes; however, this valve was only operated for 8 hours with pressure on the packing region (after it was repacked with Garlock 1200 BPI packing material). The majority of the time this valve was backseated.

Does isolation valve require more testing? How?

1. More testing with the valve closed would be beneficial.

GLOBE CONTROL VALVE/PACKING STEM SEAL (FISHER CONTROLS) (FCV-653)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. Prior to automatic operation the clearances between the plug and cage had to be opened to prevent the valve from binding at operating temperature.

2. Some pitting of the valve shaft was noted. The shaft was made of a high nickel alloy (inconel). This did not seriously affect the valve operation.

What would you do differently on this control valve if you had to build a plant?

1. Consider adapting the valve design to a stainless steel (316) valve shaft.

2. Pay careful attention to clearances at temperature.

Did the control valve do its job?

1. Yes, after the clearances were opened up and the valve was repacked with Garlock 1200 BPI.

Does control valve require more testing? How?

1. No.

DISK CONTROL VALVE (VALTEK)
(FCV-655)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. This valve was flanged (not welded) in and the flanges always leaked. All types of fixes were tried, such as different bolts and gaskets and an additional pipe hanger, but nothing helped.

2. The original valve body was replaced due to a faulty casting.

What would you do differently on this control valve if you had to build a plant?

1. Do not use "water" type valve.

2. Better quality control on valve manufacture.

Did the control valve do its job?

1. The valve did a good job controlling flow.

2. The valve was removed at 3700 hours of service because of the flange leaks. (The valve was replaced with an orifice.)

Does control valve require more testing? How?

1. No.

GLOBE CONTROL VALVE/BELLOWS STEM SEAL (FISHER CONTROLS) (FCV-658)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. The bellows ruptured at 700 hours of service. The bellows and shaft were not replaced because of cost and time. The valve operated for >5000 hours with Crane 287I packing.

2. There was some pitting noted on the inconel shaft.

What would you do differently on this control valve if you had to build a plant?

1. Have replacement parts on hand.

2. Packed valves should be used in a commercial application.

3. Consider 316 stainless steel shaft.

Did the control valve do its job?

1. Yes.

Does control valve require more testing? How?

1. No.

GATE ISOLATION VALVE (CRANE)
(HV-652)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. This valve would occasionally bind due to thermal expansion and not allow the valve to be closed.

What would you do differently on this isolation valve if you had to build a plant?

1. Nothing.

Did the isolation valve do its job?

1. Yes, the valve was closed early and had zero leakage.

Does isolation valve require more testing? How?

1. Yes, operate the valve more under pressure.

2. Test with better packing materials.

GLOBE ISOLATION VALVE (CRANE)
(FCV-654)

What were major problems? (design, installation, or operation)

- **List Details - How did you solve?**
- **Use drawings if necessary. (Be specific)**

1. There were both bonnet gasket and packing material failures.

2. One of the packing material failures may have been due to a stem guide that came loose in the valve. The stem guide should have been welded in place at the factory.

3. If the valve was closed too tightly, the bonnet bolts stretched and caused a leak.

What would you do differently on this isolation valve if you had to build a plant?

1. Use different bonnet bolts.

Did the isolation valve do its job?

1. Yes.

Does isolation valve require more testing? How?

1. Yes, more testing without the valve backseated would be beneficial.

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