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HANFORD ENGINEERING DEVELOPMENT LABORATORY
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P.O. Box 1970, Richland, Washington 99352

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Hanford Engineering Development Laboratory
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Summary

An engineering design and operating experience of a large, isothermal, lithium-coolant test loop are presented. This liquid metal coolant loop is called the Experimental Lithium System (ELS) and has operated safely and reliably for over 6500 hours through September 1981. The loop is used for full-scale testing of components for the Fusion Materials Irradiation Test (FMIT) Facility. Main system parameters include coolant temperatures to 430°C and flow to 0.038 m^3/s (600 gal/min). Performance of the main pump, vacuum system, and control system is discussed. Unique test capabilities of the ELS are also discussed.

Introduction

Due to the unique requirements of the FMIT facility, a lithium test loop (the ELS) has been built. The ELS provides design data for the FMIT and tests key components under non-neutronic FMIT operating conditions.

Little experience exists in long-term operation of large liquid lithium systems. The largest existing lithium loop in the US prior to the ELS is the Lithium Processing Test Loop at Argonne National Laboratory,[1] which contains ~0.23 m^3 of lithium. The ELS has a capacity of 3.8 m^3 of lithium. The FMIT design requires a vacuum/lithium interface, and yet experience with operating lithium systems under vacuum is nonexistent. Also, since lithium is a candidate tritium breeder medium and coolant for some proposed fusion reactor designs, more experience is needed. The ELS will provide the experience needed in the design, operation, and maintenance of large liquid lithium systems.

System Design

The ELS is designed to hydrodynamically test target configurations for the FMIT project[2] using flowing lithium. The ELS is essentially a full-scale model of the lithium system planned for the FMIT facility, which is being built to provide a high flux, high-energy neutron source for fusion reactor materials development. The target is the FMIT component where the reaction between an accelerated deuteron beam and the flowing lithium produces a high-energy neutron source. The ELS required development of a large electromagnetic (EM) pump, and lithium purification and impurity characterization components. Testing of commercial liquid-lithium valves and other components is also being performed on the ELS. Lithium circulates under either an argon cover gas blanket or vacuum at temperatures to 430°C and flow rates to 0.038 m^3/s (600 gal/min).

An isometric view of the ELS coolant system is shown in Figure 1. The main loop includes an Annular Linear Induction Pump (ALIP), 7.6-cm (3-in.) throttle valve, 10.2-cm (4-in.) EM flow meter, target, surge tank, air dump heat exchanger, and dump tank. The supply line from the pump to the target is 10.2-cm Schedule 40 pipe, while the return line is 15.2-cm (6-in.) Schedule 40 pipe.

A small isolable branch loop circulates lithium through a cold trap, flow-through sampler, and plugging temperature indicator (PTI). This branch piping, called the chemistry loop, has a test section for small valves, orifices, and mechanical fittings and includes a 2.5-cm (1-in.) EM pump and flow meter, as well as a small surge tank. Purification capability will soon be expanded to include a hot trap. Characterization capability will also be expanded to include on-line hydrogen and resistivity meters.

All pressure boundary materials are AISI Type 304 stainless steel. All pressure boundary piping and components are trace heated and insulated. The pressure boundary was designed and fabricated to the ASME Code, but was not "N" stamped. Commercially available components were used wherever possible. However, the main pump was designed and fabricated by HEDL personnel.

The ALIP is suited for high-flow, low-pressure and moderate-temperature applications. This ALIP-type pump consists of a pump duct, flux return (torpedo), stator assembly, windings, outer case, temperature sensors, and power factor correction equipment.

Specifically, the ALIP 600-30 is a 3-phase, delta-wound design. The pump operates at a power supply frequency of 60 Hz and has full-pitch windings with 12 coils per phase. Graded pole windings were utilized to reduce end losses. The pump also has 42 kVAR of power factor restoration capacity. This pump will operate with either solid-state or variable transformer controls.

Physically, the ALIP 600-30 pump measures 152 cm (60 in.) end to end with a 40.6-cm (16-in.) diameter. The annular gap is 7.9 mm. The pump weighs 513 kg. All pressure boundary material is 304 stainless steel with a duct wall thickness of 3.4 mm. The magnetic center core (torpedo) and stator are low-carbon, AISI 1018 steel. The core is helium-filled to 157 kPa at room temperature. A more detailed description of the other coolant loop components is given in Reference 3.

The ELS argon/vacuum system is shown schematically in Figure 2. The argon system of valves, pressure regulators, and gauges includes a large standby argon reservoir for rapid flooding of the system should air inleakage occur during vacuum operation. The vacuum system includes a rough pump, roots blower, block valves, pressure gauges, viewport, and a dual-function gauge to measure pressure and nitrogen levels, which on the ELS, is used to detect and alarm air in-leakage.

The lithium system normally operates under vacuum to prevent gas entrainment, a condition that could cause voids in the target lithium jet region. Operation under vacuum will prevent a large gas load from entering the FMIT accelerator beam tube, which will normally operate at 1.3 x 10^{-4} Pa. See Reference 4 for a more detailed discussion of target design and development.

The ELS is computer controlled and capable of continuous, unattended operation. The computer (PDP-8/e) has the capability for magnetic-tape program storage, 255 channels for both data and control, and a 24,000-word core memory. A printer is provided for hard copies. Several critical parameters, such as main loop flow and PTI flow and temperature, are continuously recorded. A block diagram of the ELS control system is shown in Figure 3.

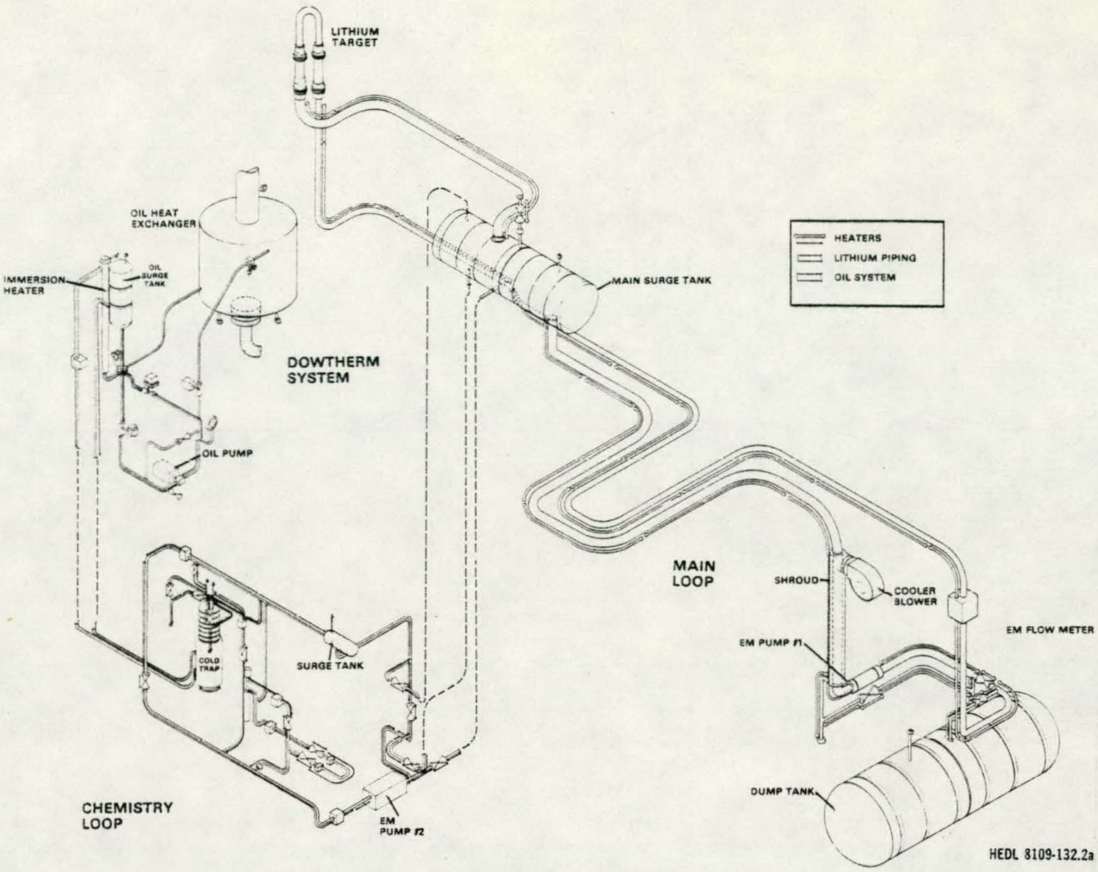

FIGURE 1. Experimental Lithium System. Neg 8108297-1

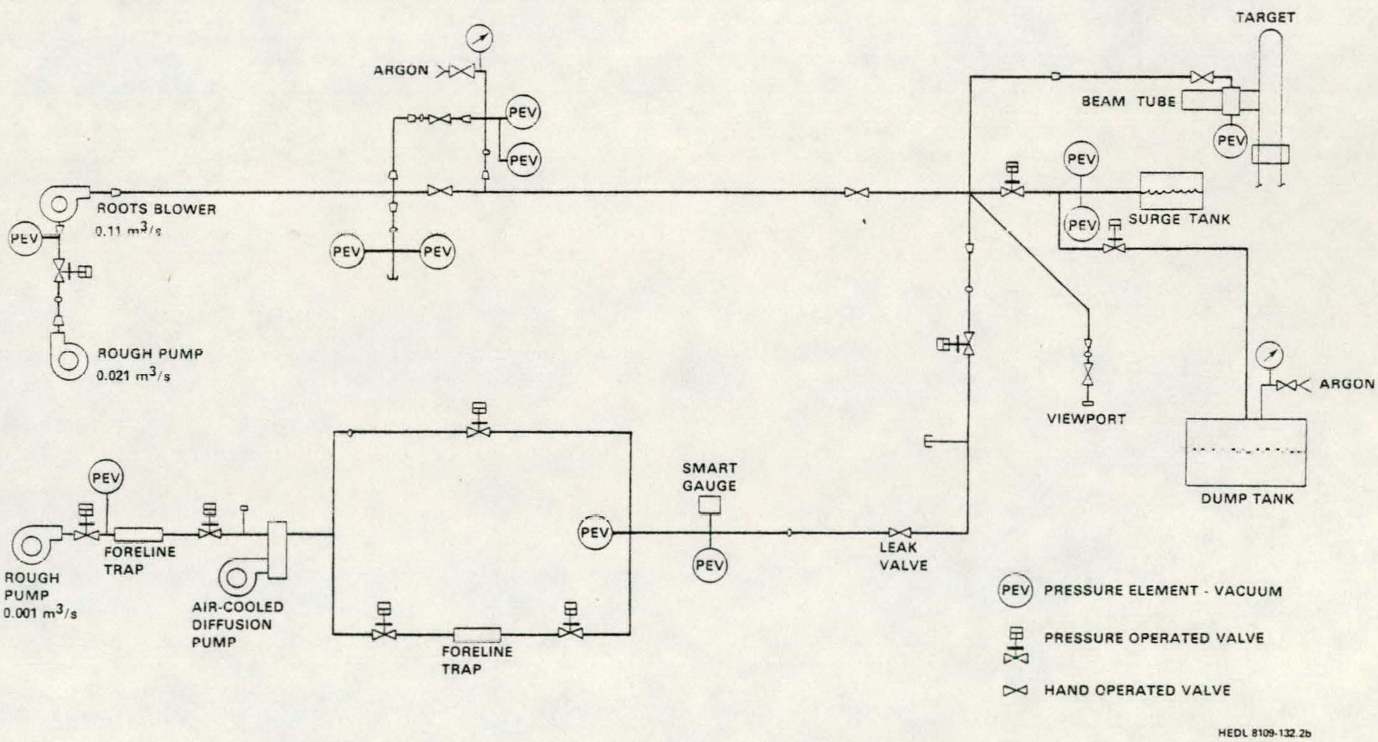

FIGURE 2. ELS Argon/Vacuum System. Neg 8108362-2

System Performance

The ELS is one of the largest operating lithium systems in the world. This 3.8-m^3 loop has now operated safely and reliably for over 6500 hours through September 1981. Much of the success can be attributed to the use of existing sodium and vacuum technology, where applicable.

The trace heat system was the first system to be operationally verified. A quantitative temperature scan of the ELS lithium piping trace heat system was completed using contact pyrometry. This test revealed three problem areas: 1) sections of the piping system exhibited damaged or faulty insulation, 2) a hot spot was located in the chemistry loop, and 3) a number of cold spots were observed around many components in both the main and chemistry loops. These problems were all corrected: 1) additional insulation was added and damaged insulation was replaced, 2) one control thermocouple was moved, and 3) additional heaters and insulation were added to components.

Next, the ELS was cleaned prior to lithium fill. The objective of this test was to attain impurity concentrations less than 50 ppm oxygen and 200 ppm nitrogen. Cleanup consisted of a single series of vacuum/argon purge cycles with the system temperature between 150°C and 260°C. Each individual system flow path was purged with argon for ≤10 minutes for the small chemistry loop piping and ≤30 minutes for the large main loop piping. System cleanup was terminated when the first argon sample showed 6 ppm oxygen and 40 ppm nitrogen.

Then, the ELS was filled[3] with 3.8 m^3 of lithium, and loop circulation began March 26, 1980. All initial testing was performed with the loop pressurized to 122 kPa while the lithium was at 260°C. Start-up chemistry of the lithium system is presented in Reference 5. Impurity concentrations in the lithium have remained low (N_2 < 20 ppm and H_2 < 60 ppm). Initial loop shakedown showed no serious dynamic instabilities. The main loop piping displayed some low frequency, low amplitude motion typical of a system with soft suspension.

The ALIP has been thoroughly tested and meets all performance criteria. The developed head at the design flow rate of 0.038 m^3/s was 221 kPa with 122 kPa in the surge tank. The ALIP performance curve with the surge tank pressure at 2.7 x 10^{-1} Pa is shown in Figure 4. Cavitation inception Net Positive Suction Head (NPSH) at 0.038 m^3/s was 39.3 kPa.

Pump coast-down tests were performed. When power was interrupted, pump flow typically dropped from 0.041 m^3/s to zero in approximately 6 seconds. Pump internal temperatures were closely monitored during all phases of pump testing. This air-cooled pump design showed no heat-up problems. Even with the ELS piping system throttled to 0.019 m^3/s, pump coils ran less than 38°C higher than the bulk lithium temperature.

Two pump power control systems were evaluated: solid-state and variable transformer controllers. No problems were encountered with either controller; however, the variable transformer control system demonstrated greater rate and ramp control and was capable of supplying 540 volts. This additional voltage, above the 480-volt solid-state controller capability, produced a 41-kPa pump head increase at the design flow rate of 0.038 m^3/s.

The ELS vacuum/argon system shown in Figure 2 is a second generation design. The original vacuum system consisted of a 2-stage rough pump with a molecular sieve foreline trap to prevent back diffusion of pump oil and trap lithium vapors before they reach the pump. Argon gas was supplied directly from a liquid argon tank/evaporator unit through a 2.54-cm (1-in.) Schedule 40 pipe.

Two deficiencies were identified during initial operation of the ELS vacuum system. First, the ultimate vacuum level attained with the original vacuum components was only 67 Pa. The design criteria for ELS specified a vacuum level of 130 Pa at the dump tank and 1.3 x 10^{-1} Pa at the main surge tank and target. A second problem was encountered two times during lithium transfer under vacuum conditions. Failures of an argon supply regulator and vacuum valve caused air in-leakages into the vacuum system resulting in rapid localized internal temperature increases. These air in-leakages were detected by the thermocouples added to the dump tank vacuum line for lithium transfer. Once detected, the system was quickly flooded with argon and the leaks were corrected. Temperatures did not exceed the maximum design temperatures. In addition to the thermal transients associated with this air in-leakage, the air/lithium reaction presents serious operational concerns because of increased impurity burdens.

As a result of this experience, the vacuum system was modified to the current configuration. Subsequent loop operation has shown that very small amounts of air in-leakage can be detected, and vacuum can now be broken quickly and safely (≤1 minute). The current vacuum system reaches 1.3 x 10^{-1} Pa in approximately 1 hour. Frost phenomenon was observed through the viewport and found to be particularly prevalent after long shutdowns. A typical vapor deposit had the following composition (%) after dissolving in water: lithium, 67%; sodium, 25%; and potassium, 8%. Concentrations of sodium and potassium observed in the vapor were much higher than found in the lithium pool.

The ELS closed-loop control system is essentially a duplicate of the system used on the three sodium-filled Source Term Control Loops operated by HEDL. This type of control system is ideal for real-time applications and has proven to be very reliable with only two hardware failures in over 10 years of operation. The system affords easy loop parameter changes, i.e., set points and deviation and alarm limits. However, software changes are relatively difficult to make on the standalone operating system in PDP-8 assembly language. The system currently has a limited capability for additional data acquisition and may be supplemented with a new data logger.

Additional Testing

While ongoing target testing continues, additional testing includes performance evaluations of both the cold- and hot-trap designs, an ELS Mark II pump, advanced lithium chemistry meters, frost/vapor traps, and mechanical piping connectors for lithium and vacuum. The vacuum region will be further characterized with the aid of a residual gas analyzer and special instrumentation to measure vapor generation rates. Materials examinations are also planned in some of the high velocity regions of the loop. Specialty instrumentation being developed includes ultrasonic cavitation sensors and a lithium-level induction switch. As equipped, the facility offers a unique test bed for lithium system research and development.

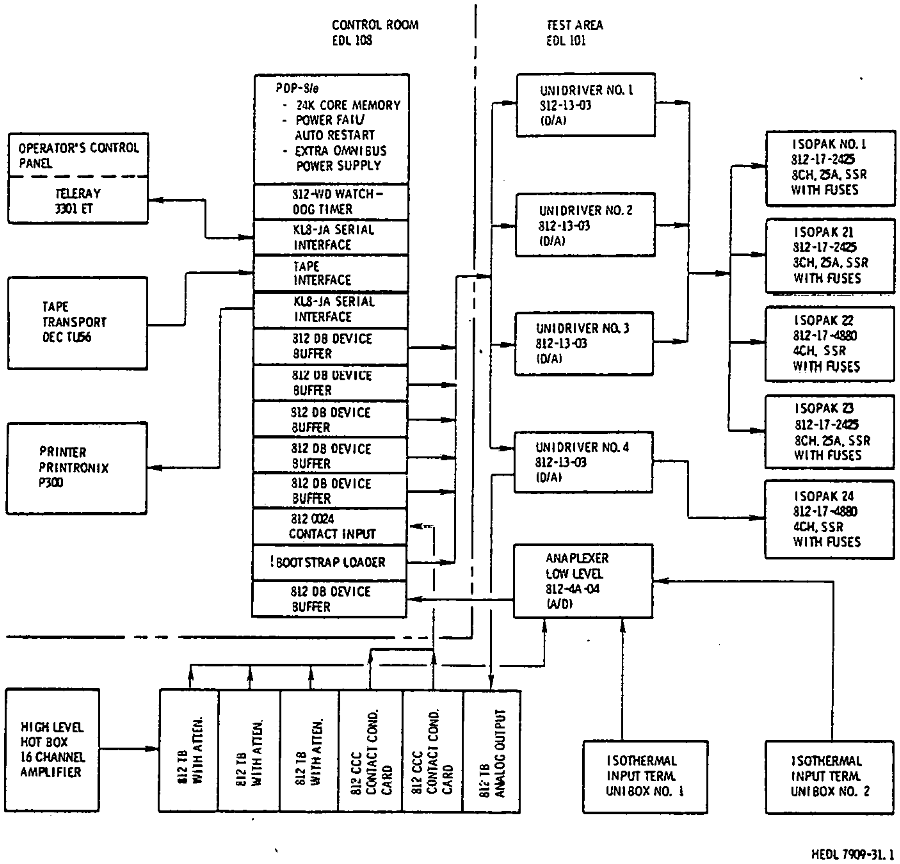

FIGURE 3. ELS Control System Block Diagram. Neg P11765-1

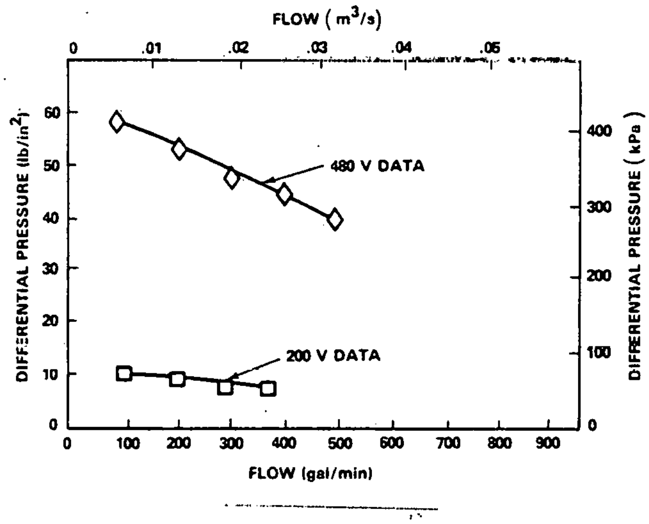

FIGURE 4. ALIP 600-30 Performance at 2.7×10^{-1} Pa in Surge Tank and Solid-State Controls. Neg 8108183-1

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