L IQUID P ROPEL LANT TRANSFER PROPERTIES

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ABSTRACT

A study of the transfer properties of 1.1'1846 was initiated with a series of stat ic tests designed to establish a safety envelope for the handling of liquid propellant under dynamic conditions. A pressure/temperature envelope has been identified and ignition or fulm-offof1.1'1846 at various conditions has been evaluated. Pumping tests were then conducted at about one-tenth scale, first with wat er to proof the system, then with a suitable simulant and finally with liquid propellant. Scaling was accomplished in two ways: 1) matching the Reynold's number at full-scale vs. one-tenth scale, and, 2) matching the mean flow velocity in the hose or pipe.

The pumping studies described in this report were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under the sponsorship of the U. S. Army Research, Development and Engineering Center through an agreement with the National Aeronautics and Space Administration.

BACKGROUND

LP XM46, the selected prop ellant for AFAS, offers significant logistical advantages. Pump transfer will enhance resupply operations and combat effectiveness; however, pump transfer of LP at logistic system requirements has not been demonstrated

The U.s. Army has selc.c[cdXM461.iquid Propellant (J .1') as the desired propellant for the Advanced Field Artillery System. LP, as an insensitive munition, offers reductions in the hazards, costs and vulnerabilities associated with current solid propellants. From a logistics standpoint, LP offers increased packaging, efficiency, reduced dunnage, increased efficiency of transporters and the potential for a significant reduction in the time required for transfer of munitions to the resupply vehicle and then to the gun. This last advantage is obtained through pump transfer of propellant from container to on-board storage on the resupply vehicle and subsequently to the gun itself. Pump transfer may be accomplished with relatively simple devices when compared to equipment required for automated transfer and handling of contain erized munitions.

However, pump transfer of LP under conditions envisioned in the logistics environment has not been demonstrated. Concerns have been expressed regarding certain aspects of the pumping system. These include propellant compression ignition sensitivity , exposure to shock hazards, effects of dissolved or entrained gases, reasons, a test program 10 gain insights into the transfer properties of 1,1' 1846 under dynamic (pumping and transfer) conditions was initiated. Results of these investigations will assist in the formulation of additional tests and provide information necessary in pump transfer system design and component selection.

SCOPE

Demonstration and characterization of LP transfer by pumping at scaled rates commensurate with operational requirements has been accomplished.

A test fixture to demonstrate and evaluate pump transfer of] .]' at 1/10th scale has been developed. (The current operational required 1 ate is 50 gpm.) Identificat ion and selection of pumps and associated hardware components were made based on availability, ability to meet scaled transfer rates and material compatibility. The selected hardware permits scale-up 10 full transfer rates using the same family of components. A centrifugal pump and a diaphragm pump were each operated in a closed-loop circuit and temperat ure and pressure data were co] lected for evaluat ion. Water hammer tests were also conducted using a quick closing valve inserted into the test loop. Analyses of the propellant were made to examine, for propellant defy adation, contaminant ion or decomposition as might occur.

TEST C ONFIG URATI ON ANI) METHODS

Scaling and System Verification

Scaling was completed 101110 and 1/4 models; selected critical parameters were exceeded to ease observation and press the operating envelope.

In fluid mechanics, true physical modeling or scaling depends on both geometric and dynamic similitude. Measurements made on a model fulfilling these, requirements can then be scaled up to predict What will occur in the full scale device. A 1/10th scale system was desired 10 minimize the amount of propellant required to initiate testing. If, then, it is desired that the model employ 10% of the "real" flow, the model should have linear dimensions which are 10%, of the "KM]" (Ic.vice. Furthermore, corresponding expressions for force, mass and time must be present to meet the corresponding dynamic scaling parameters. However, pump mechanisms are geometrically complex and it would be difficult, if not impossible, to control scaling using off-thcj-shelf equipment. Therefore, 1/1 0th scaling in all dimensions and parameters was sought only as reasonably possible.

This approach offered the significant advantage of allowing readily available components rather than custom-machined pieces. The apparatus was therefore easil y and rapidly reconfigurable, resulti ng in considerable savings in equipment costs and time.. Furthermore, the single test fixture was adaptable to more than one pump.

Tests were not restricted to the scaled point of operation. By varying the dynamic parameters of fluid velocity and pressure from lower to higher, we could start a series of tests in a predictabl y safer region of operat ion and then proceed to the operat ing limits of the dc.vice. For example, matching mean velocity approximately models the behavior of cavitation and water hammer effects of the full scale device. Further increase of the flow reaches into the dynamically scaled regime, where turbulent behavior and pressure. distribution are modeled in scaled fashion. Increased flow also promotes cavit at ion effects and amplifies water hammer effects, making, them easier to observe.

At the conclusion of the task, a near 1/4th scale system was achieved through the substitution of 1/2 in lines on the return side of the pump.

A simulant was identified to verify system operation and provide a safe approach to configuring the test apparatus and experiments.

To proof the system and determine operating, parameters, a suitable 1.1' simulant was identified to characterize the transfer environment prior to the introduction of live propellant Forty-four percent aqueous monobasic sodium phosphate was selected on the basis of density and viscosity and used to verify system similitude and safety.

Pressure versus temperature profiles were developed 10 assist in defining initial safety criteria for the test device.

Additionally, a number of combustion bomb tests were conducted in an attempt to determine pressure/temperature thresholds to be avoided in the pump transfer system. While these data suggest a pressure/temperature envelope, no correlation may yet be drawn regarding the surface area to volume ratio required to initiate a reaction for a given pressure. Further, each piece of equipment selected for transfer application must be evaluated for potential development of local heating, (rate) and resident time (capture) of contacted propellant.

Pump Selections

Two pumps were selected for testing, one centrifugal and one diaphragm, Both were selected based on material compatibility y and predicted ability to pump LP at 5 gpm. Particular attention was directed to pumps offering minimum potential in development of local "hot spots," which might serve to initiate an LP reaction. A brief description of each pump is provided,

Centrifugal Pump -- Sealless, magnetic drive. Polypropylene coated magnet. Porcelain spindles. Glass-filled polypropylene housing. Viton O-rings. Rated at 17 gpm with 115 VAC motor operating at 3200 rpm.

Diaphragm Pump -- Air-driven, double diaphragm. Polypropylene bod y. Teflon PFTE diaphragms. Variable flow by adjusting inlet pressure. Rated at 14 gpm with 100 psi inlet pressure. A regulated nitrogen source was used to power the pump.

Each pump was selected off-the-shelf from a famil y of pumps affording scale-up for fut ure testing at the proposed operational delivery rate of 50 gpm.

Test Fixture Design and Data Collection

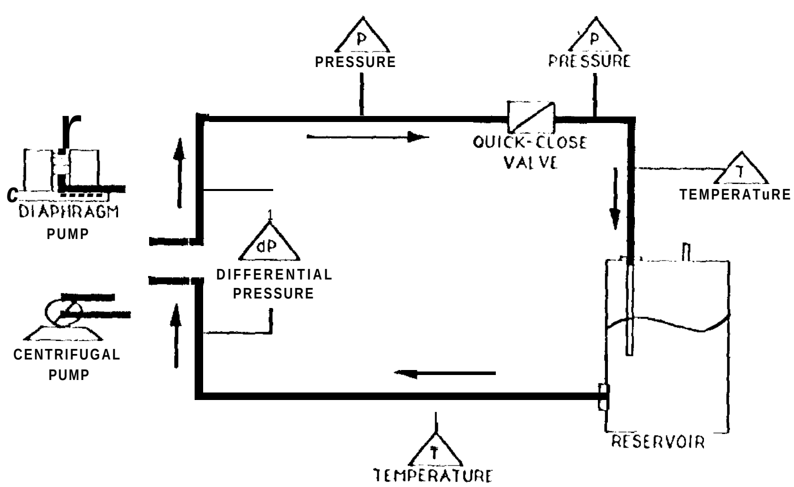
The test apparatus was essentially a closed-loop, recirculating system consisting of a 1-gallon (later increased to 2 gal ions) reservoir tank that served as both propel i ant donor and receiver during operation. Typical volume in the system was about 3 liters. The reservoir was fitted with a down-tube to reduce turbulence during the transfer operation. This tube was removed in later tests to increase turbulence and allow the propellant to "foam," thereby permitting a significant amount of air to be entrained in the fluid flow. The lid of the reservoir was provided with a fitting to attach a nitrogen source in order to purge the system anti provide the LP with a nit rogen blanket during test i Jig. This safety precaution was removed as confidence in the propellant behavior grew.

A 3/4 in o.d.. aluminum tube served as the feed to the pump inlet and was fitted for temperature and differential pressure connections. 'he pump outlet line was baselined at 3/8th in o.d. teflon tubing, again fitted for temperature and pressure monitoring. Fittings and tubing connectors, as well as shut-off valves, pressure relief valves, pressure transducers and the remainder of the wetted parts were stainless steel. A quick closing valve was installed to conduct water hammer tests.

For all tests other than water hammer, data was collected for pump output pressure, differential pressure across the pump and fluid temperature at the inlet and exit of the pump. For water hammer tests, pressure data was collected for pump output pressure and line pressure downstream from the quick closing valve.

Temperature data was collected using Type K thermocouples connected to digital thermometers (Omega Model 2809). A Statham Model PM-280TC transducer connected to a Beckman Model 600 digital readout was used to gather differential pressure data across the pump. Pump head pressure and downstream line pressure data were collected using a Taber Model 21 7NA transducer connected to a Doric Model 420 digital readout. All output signals were conditioned for input to an AST 486 computer running Labview software All tests were videotaped with particular attention directed to recording propellant turbulence, frothing and foaming in the reservoir tank,

Figure 1 is a simple schematic of the test configuration.



Propellant Use and Evaluation

The limited supply of LP required that propellant be reused in as many tests as possible.

Because of the limited amount of LP available (5 gallons), it was determined that LP would be reused so long as periodic sampling and analysis did not indicate adverse propellant degradation. At the initiation of the pump transfer tests in early August, 3 liters of propellant was drawn from the 5 gallon container and a sample taken for analysis to establish a reference. Following the first live propellant transfer tests in mid-August, a sample of the used propellant was taken. Since no significant degradation was noted within the accuracy of the test methods, the original propellant was used for the duration of the test series, with small losses replaced as required.

RESULTS

Both the diaphragm and centrifugal pumps performed predictably. From sort duration tests and reduced pressures, LP remained well-bchowd to the maximum rated capabilities of the pump. Excursions into critical areas of operation were safely done.

Results are presented in graphic form, with those representations that best typify the data.

Diaphragm Pump

The first series of tests utilized the diaphragm pump. As shown in the Figure 2, over a long duration run of 84 minutes, the temperature rise was 17°C. This duration also included 2 stop periods of 10 and 7 minutes in which to observe possible reactions in the test fixture. A significant amount of aeration due to splashing and turbulence in the reservoir tank was observed. Examination of the data series show small pressure fluctuations as evidence of air entrainment.

Figure 3 illustrates the pressure pulses exhibited in the pump operation. Drive pressure at the pump diaphragm was slightly over 100 psi, near the maximum rated operating pressures. Data was collected at a rate of 100 samples/see.

A series of tests were performed with a quick closing valve to investigate the water hammer effect. The valve was repeatedly activated at intervals of three to five seconds. As can be seen in Figure 4, single pulses with different peak pressures arc obtained depending on the moment the valve is activated. A similar test series was conducted in which the valve was activated 32 times in a 2 minutes period of operation.

Figure 5 displays an expanded single cycle of the effects of activating the quick closing valve. A clear reverberation attends the closing action of the valve, an effect due to the non-rigid nature of the diaphragm and the lines.

A closer view provided by Figure 6 indicates a maximum peak of about 165 psi. However, it may be noted that the peak appears slightly cropped, a truncating effect of the rate of sample collection. Interpolation of the data series yields a maximum pressure peak of about 180 psi.

Centrifugal Pump

A twenty minute duration test run of a centrifugal pump (Figure 7) shows a constant head pressure and differential pressure. A temperature rise of 2 to 3 "C is exhibited. It should be noted that the pump output was about 2,2 gpm rather than the desired 5 gpm rate. In later tests, the output line sire. was changed to 1/2 in, resulting in a 4.6 gpm rate.

Figure 8 displays a series of quick closing valve activations. Pressures rises are very repeatable with the exception of the peak occurring at 18.5 sec. The temperature peaks attendant with the opening of the closed valve indicates a release of propellant being heated in the pump. Roughly, a 4°C/min rise in temperature is noted.

It also appears, as shown in Figure 9, that enough propellant is heated to pass through the receiver tank and raise the indicated temperature at the pump inlet location. Though this heating effect is rapidly damped out, it is clear that the overall temperature increase is due in part to the heating of the propellant while the closing valve is activated.

CONCLUSIONS

LP can be pumped at scaled rates with off-the-shelf hardware. LP recirculated in the tests shows no adverse effects.

LP has been successfully pumped at 1/10 scale using available, off-the-shelf hardware. Appropriate scalable material is available to continue the transfer investigations at larger or full scales.

An approximate 1/4 scale system was configured at the end of the test program consisting of the diaphragm pump equipped with 1/2 in lines operated at maximum drive pressure of 120 psi, A pumping rate of nearly 12 gpm was achieved for a 7 minute period.

The centrifugal pump was demonstrated at 2.2 gpm, with a pumping rate of 4.6 gpm achieved with 1/2 inch lines.

The diaphragm pump,..

-- has operated for nearly a total of 3 hours in pumping LP. Total residence time of propellant in the system is about 40 hours.

-- raises the propellant to relatively high pressures (200 psi) in a stoppage condition, but does not attain temperature necessary to initiate a reaction.

-- possesses an inherent safety feature in that the pump will stall at 1 pulse following a stoppage condition.

The centrifugal pump

-- has operated for nearly a total of 3 hours in pumping LP. Total residence time of LP in the system is about 26 hours.

-- raises the propellant to about 25 psi in a stoppage condition. Temperature increases are apparent in a no-flow condition.

The LP was recirculated and reused in all tests. Small losses (100-2.00 ml) upon system emptying were replaced each test day. At least 1.2 liters of the 3.4 liters of used LP remaining has been circulated for 7 hours in the operating systems and exposed to the system for about 66 hours in a three month period, ICP analyses show several ppm increases in Al and Fe, not surprising with an aluminum inlet pipes and various stainless steel components. FTIR data are currently being reviewed.

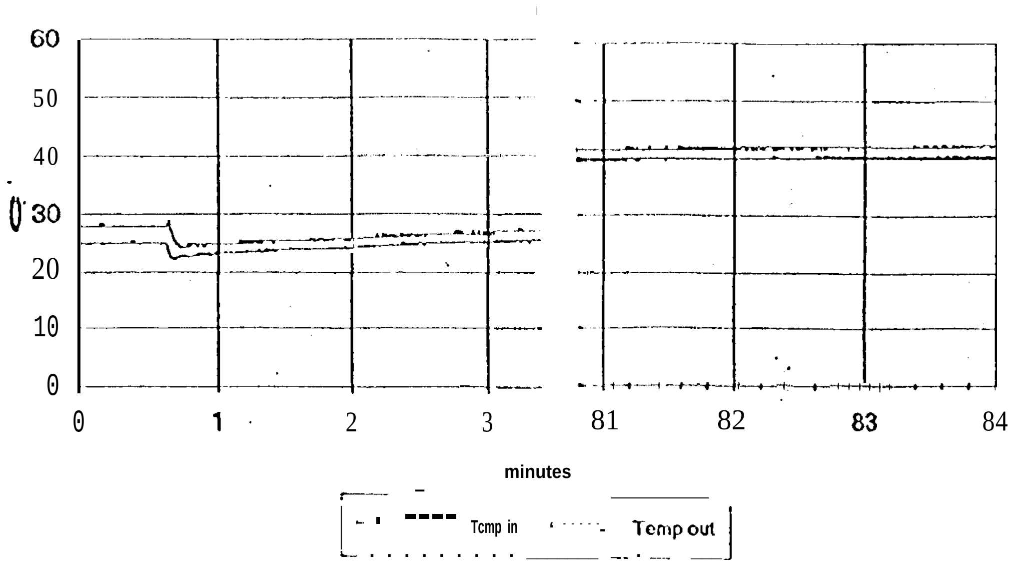


Figure 2. Diaphragm Pump. Drive pressure and long duration test. Scan rate: 5/sec

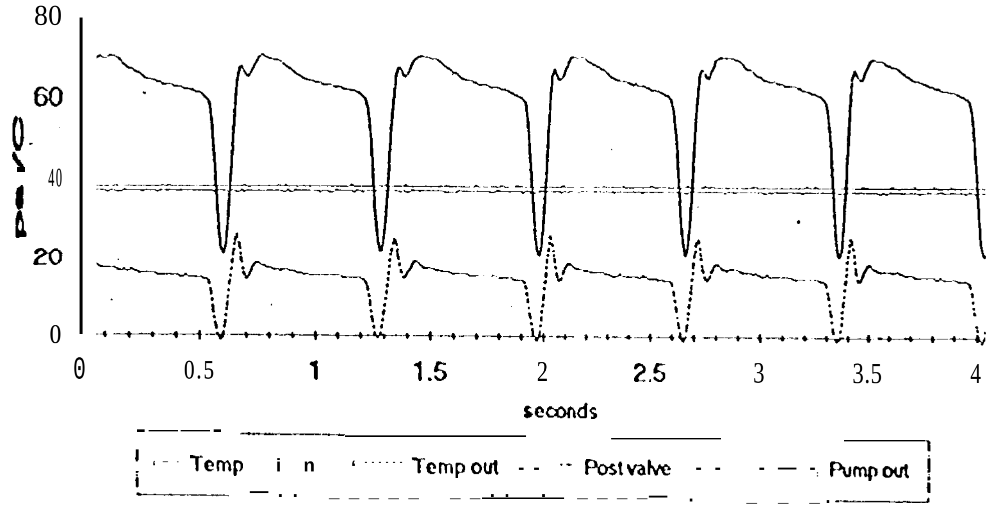


Figure 3. Diaphragm Pump, Pump pulse characterization. Scan rate: 100/sec

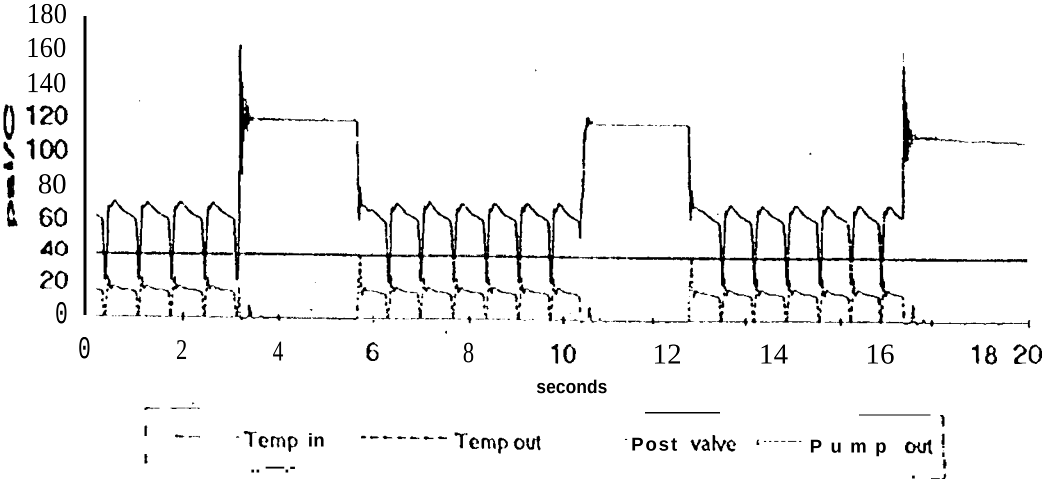


Figure 4. Diaphragm Pump. Variable cycling of quick closing valve. Scan rate: 100/sec

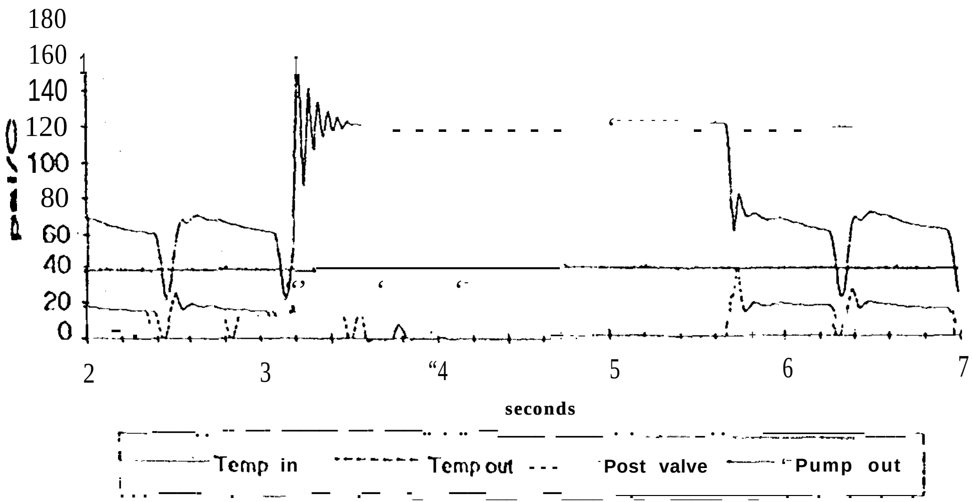


Figure 5. Diaphragm Pump. Pressure peak at valve closure. Scan rate 100/sec

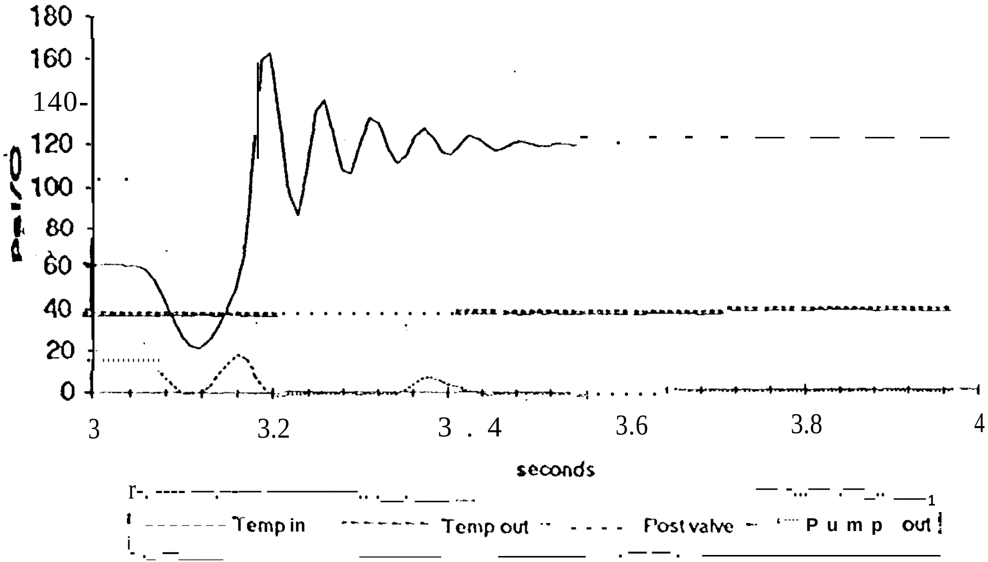


Figure 6. Diaphragm Pump. Maximum pressure peak. Scan rate 100/sec

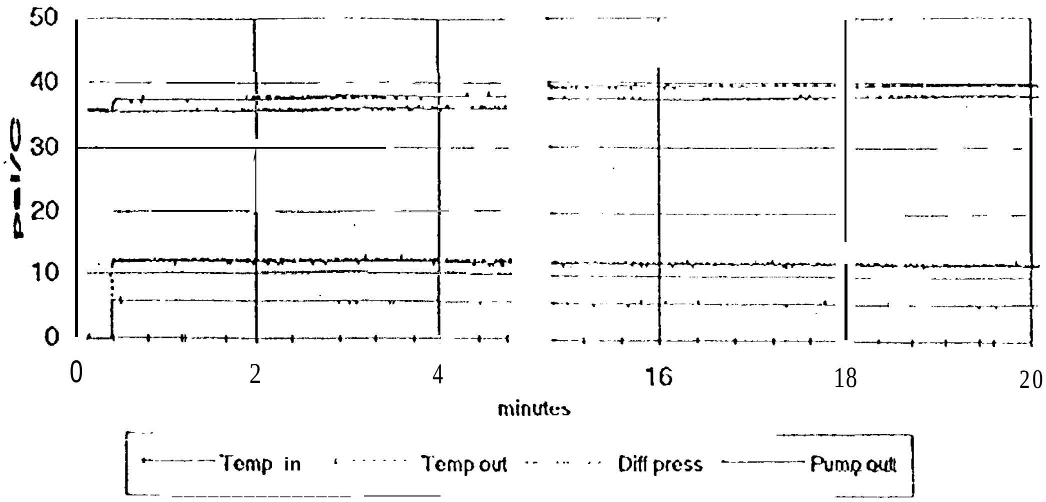


Figure 7. Centrifugal Pump. Duration test (at 2.2 gpm). Scan rate: 5/sec

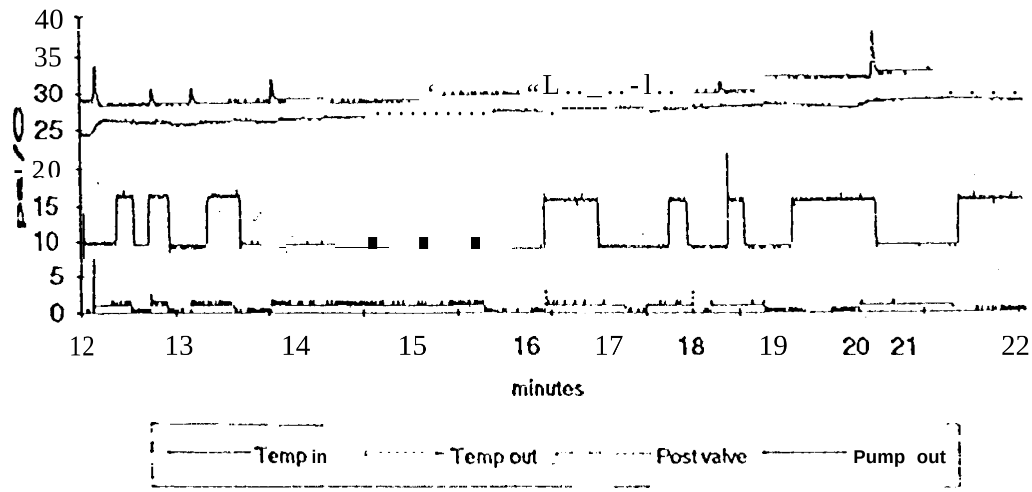


Figure 8. Centrifugal Pump. Variable cycling of quick closing valve. Scan rate: 100/sec

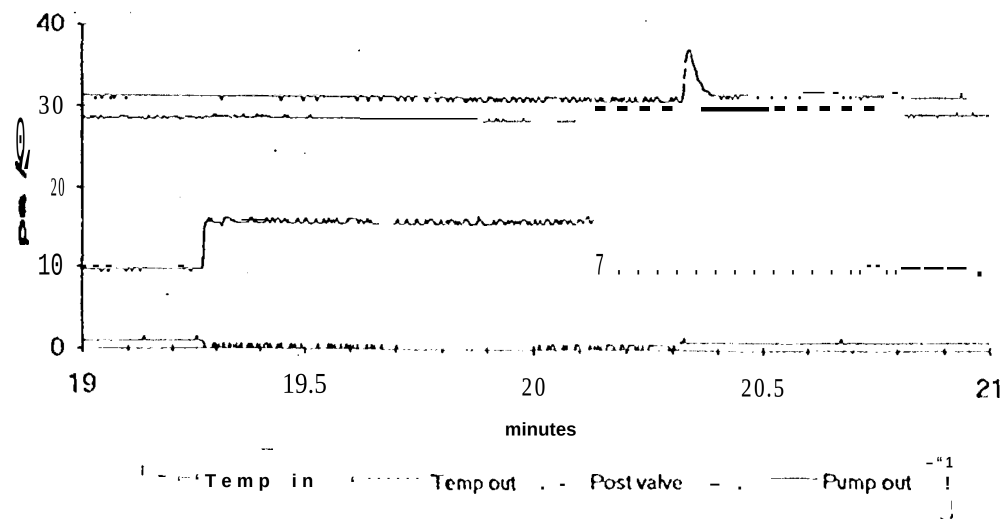


Figure 9. Centrifugal Pump. Temperature peak on valve release. Scan rate: 100/sec