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Project Summary

Fail-Safe Transfer Line for Hazardous Fluids

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A fail-safe transfer line for hazardous liquids was designed, fabricated, tested in the laboratory, and then used in actual fluid transfer operations. The system provides a 2-in.-ID flexible hose line for offloading tank cars or trucks and detects leaks by monitoring flow inventory with corrosion-resistant, turbine-type flow meters at the inlet and outlet ends. Reliable shutdown of the line at leak rates as low as 1% of flow is achieved. As an example, at a flow of 6 liters/sec (100 gal/min), shutdown occurred within 8 sec with a fluid loss of less than 500 ml (1 pint). The line is also automatically shut down when electrical power or valve actuator pressure is lost, or when any sensor or control cable is severed. The system meets the National Electrical Code explosion-proof standards for Class I, Division I, Group C or D environment. Use-demonstration tests at a chemical plant were satisfactory except for occasional fouling of the flow meters with material that solidified in the transfer hose between operations. The system is recommended for use with materials that remain in a liquid state under all normal conditions.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The report describes the development of a fail-safe transfer line for hazardous liquids. The principal requirement was the reliable, automatic shutdown of the transfer line in response to a leak that was well below the magnitude that could be controlled by an excess flow valve (rising ball type). Additional requirements included shutdown of both ends of a leaking or severed line to prevent back-siphoning, shutdown of the line when any of the conditions necessary for its reliable operation (e.g., electrical power or air pressure) were not satisfied, a means to verify operability at time of use, and the ability to handle many types of hazardous liquids. The contract specified that the entire system be constructed from off-the-shelf components of standard industrial quality. The transfer line was designed to handle the loading and unloading of railroad tank cars and tank trucks.

The project encompassed four areas of effort.

Systems Design

This task involved the analysis of alternative methods for sensing leaks and the design of all components for the transfer line. The governing criteria were reliability, cost, and compatibility with the hazardous materials to be handled during the demonstration tests.

Assembly and Development Tests

This task included the acquisition of all components, construction of the line, and testing of the line in a controlled environment using water as the liquid. During the development phase, the design was optimized to achieve the best practical capability for detection of small leaks.

Use-Demonstration Tests

In this task, the line was used in an industrial environment at the Goodyear synthetic rubber plant in Houston, Texas, to offload railroad tank cars of TAMOL-L, an aqueous solution of the sodium salt of a naphthalene-sulfonic acid.

Analysis and Reports

This task included analysis of data and the preparation of a final report.

Application of this transfer line (or its principle) to all loading and offloading of hazardous and polluting liquids could result in a significant reduction in the number of spills. According to a study of reported spills of hazardous materials in the United States during the period of January 1, 1971, to June 30, 1973, the failure of a hose or transfer line resulted in 92 spills or 7% of all spills reported. Similarly, an analysis of bulk liquids spills at U.S. marine terminals during 1974 and the first 8 months of 1975 revealed that 7.5% (108 out of 1,441) during cargo transfer operations resulted from the failure of the hose or pipeline. When these data are considered along with the frequency of loading and offloading operations they indicate that a hose or pipe failure results in one spill for every 1,000 transfers. The spill rate for all causes of spills at marine terminals during loading and offloading of bulk liquid cargos is approximately 12 per 1,000 operations.

Design and Development

The basic concept of the transfer line is illustrated in Figure 1. A flexible line is equipped with essentially identical inlet and outlet assemblies. Each assembly contains a fast-acting, remotely operated valve and a device to measure fluid flow. A control module compares the flow measurements at each end. Upon detection of a flow imbalance, the control module automatically causes the valves at each end to close. In addition to flow comparison, the system incorporates other fail-safe features:

1. Automatic valve closure when any of the conditions necessary for safe operation are not satisfied (e.g., loss of air pressure or electric power).
2. A means for verifying proper operation at any time during a transfer operation.

As specified in the statement of work, the criteria for selecting components, materials, and techniques were reliability, compatibility with the material to be handled, off-the-shelf availability, cost, and (for the portable parts of the system) weight.

In the original plan, the material to be handled during the use-demonstration phase was aniline, which required that the electrical portions meet the National Electrical Code explosion-proof standards for Class I, Division I, Group C and D materials.

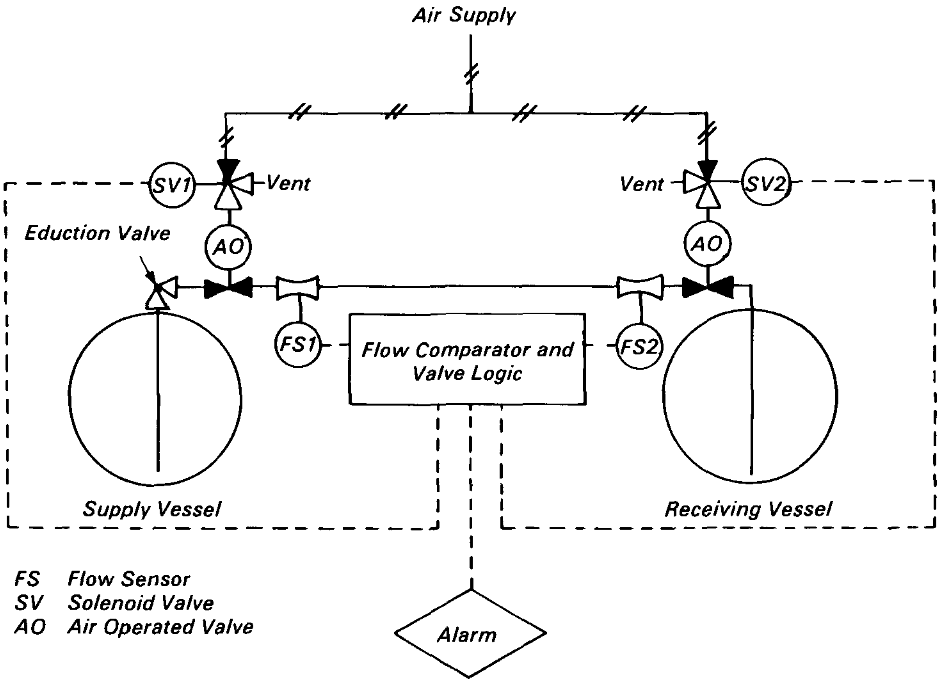
The selection of valves and actuators quickly converged upon pneumatically operated, stainless steel ball valves. Gate and globe valves require motor driven actuators. These assemblies are relatively slow-acting and are heavier and more expensive than the ball valve/pneumatic actuator combination. Solenoid actuators were available for the ball valves but were too heavy (more than 60 lb) for portable use. Brass is incompatible with many fluids, and reliability considerations argued against the use of aluminum. The pilot valve required for remote operation of the pneumatic actuator weighed less than 1 lb and is available in a compatible, explosion-proof configuration.

Stainless steel was selected for the pipe fittngs because of its superior reliability. Further, since no margin of safety was needed to compensate for corrosion, lighter weight pipe could be used. The dominant criterion for the hose was reliability. A 2-in.-ID, rubber-impregnated, steel-reinforced steam hose was selected. This hose was essentially identical to those used at the use-demonstration site for offloading aniline.

The flow measurement sensors that were evaluated were (in order of increasing cost) thermistors, thermal probes, turbine flow meters, and venturi tubes with differential pressure gauges. Analysis indicated that any available thermistor with an envelope compatible with aniline would have too slow a time constant to meet the leak detection objective. Thermal probes appeared to meet all criteria and were initially selected for the development phase. These sensors operated well with clear liquids. However, with slightly dirty fluids, the probes developed instabilities that were unacceptable. Turbine flow meters were next selected and were satisfactory.

The control module was designed with integrated circuits throughout for reliability and small size. Transistor-Transistor Logic (TTL) was selected because of its reliability.

The major hardware items were assembled and set up in a laboratory shop. A 200-gal tank and a 2-HP pump were used to provide a flow through the system. A reducing tee with a needle valve and a ball valve in series was inserted between the flow meters to permit controlled leakage. The electronic circuits were breadboarded for easy access to test points, and special circuits



Note: All valves are shown in the de-energized position.

Figure 1. Basic concept of fail-safe transfer line.

for diagnostics and data acquisition were fabricated. Figure 2 shows the inlet assembly. The outlet assembly is identical except that the strainer is omitted.

The turbine flow meters used consist of a turbine wheel mounted axially in a short length of non-magnetic pipe. Two of the turbine blades have magnets inserted into their outer ends, and a coil on the outside of the pipe produces a low-level AC signal when the turbine rotates. The frequency of the signal is proportional to the flow rate over the operating range of the device. Flow meters are individually calibrated, and it is unlikely that two will have identical K factors (the K factor is the number of alternating current cycles that will be generated for each gallon of fluid passing through the meter). Furthermore, it is necessary to provide compensation for unequal wear with prolonged use. A rate multiplier circuit is used with the fastest (highest K factor) meter. The output of the rate multiplier circuit, f(out), is

$$f(\text{out}) = \frac{f(\text{in}) \times m}{4096}$$

where m is any desired integer between 0 and 4095. Thus the meter indication can be synchronized to within 2.4 parts in 10,000.

The basic logic circuit is an up-down counter. The pulses from the inlet flow meter (normalized by a rate-multiplier circuit) cause the counter to count up; those from the outlet flow meter cause the counter to count down. After a pre-set number of total pulses (a frame) is received, the balance shown by the up-down counter is read electronically, after which the counter is reset for the start of the next frame. The assumption is that there is no line leakage when the count balance is zero, however, there may actually be a net count (but no leak) because of air bubbles, hose pulsing, solid particles, or other flow anomalies.

The distribution of the balances on the counter was recorded for leak rates from 0% to 4% of flow. Experiments show that a frame of about 1,000 total pulses provides an adequate sample period to average out most naturally occurring variations in flow. For convenience in using digital logic, the frame count is set at 1,024 pulses, corresponding to the passage of about 7.1 liters (1.88 gal) through the system. Figure 3 shows the distribution of indicated flow imbalances for leak rates of 0% and 1.5% of flow rate.

Since the up-down counter reading, A, differed from zero too frequently under no-leak conditions and the line was shut down too often, a comparator was built to

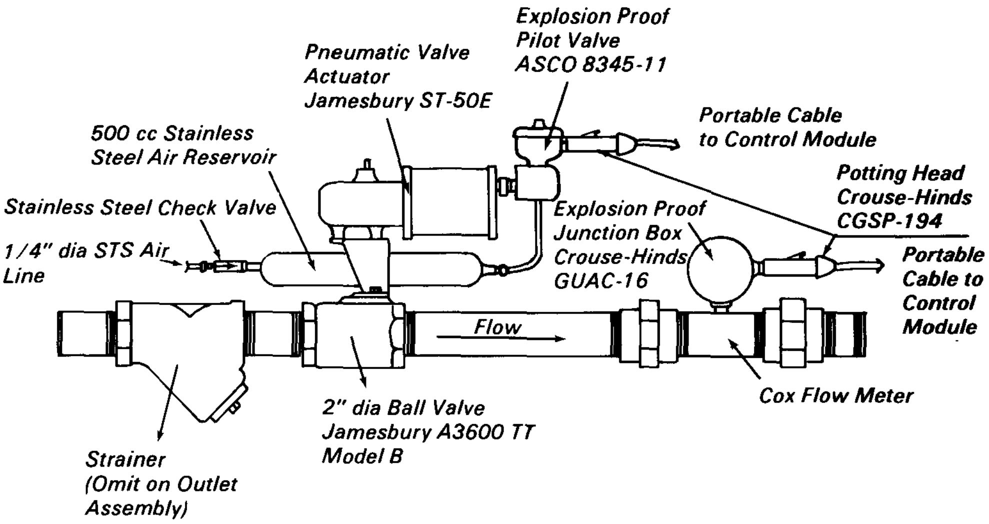
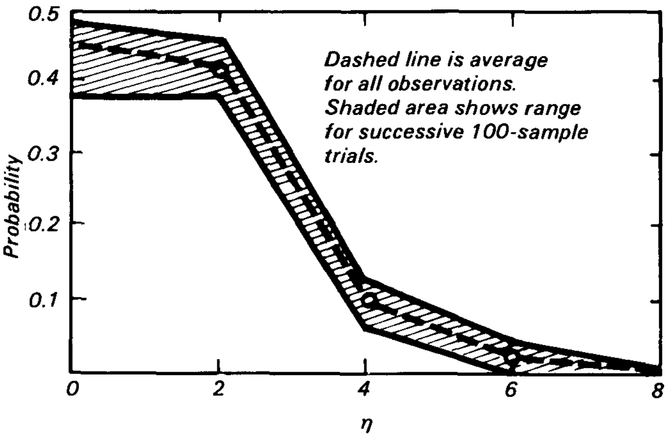
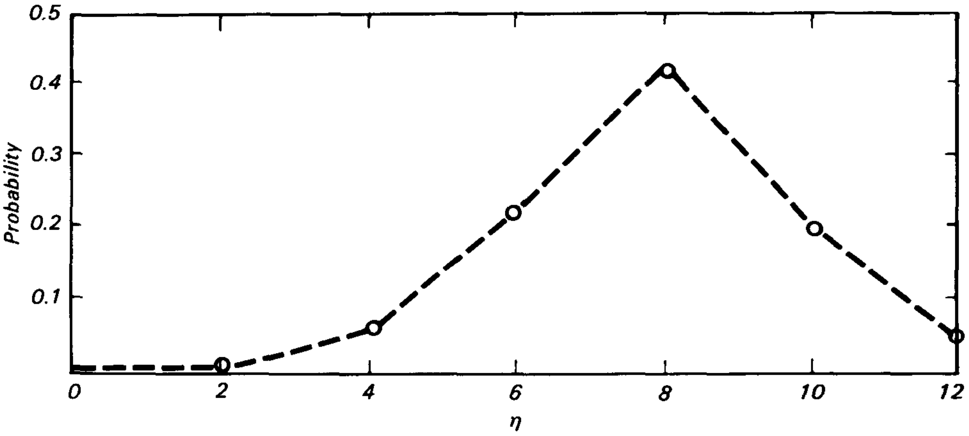


Figure 2. *Inlet assembly.*



Probability that meter outputs will differ by η counts in one frame under no leak conditions.



Same as Above, but with a 1.5% of Flow Leak Introduced

Figure 3. *Distribution of flow imbalance indicators, 0 and 1.5% leak rates.*

show how A compared with B, a preselected number or threshold for shutdown. The comparator output indicates whether A is greater than, equal to, or less than B. At the end of each frame, the comparator output is read. When, for example, B is set at 4 and A has a value of 6, the flow imbalance exceeds the switch-selected threshold, indicating a leak (or, more properly, the possibility of a leak). Under no-leak conditions, the up-down counter balance rarely exceeded 4 but did occasionally read higher.

The system was then operated with various leak rates and values of B. The ratio of leak to normal indications, the number of successive leak indications occurring between two normal indications, and the number of successive normal indications occurring between two leak indications were recorded and their distributions were determined.

These data formed the basis for designing additional circuitry. Analysis of the data showed that the reliable detection of small leaks (less than 2% of flow) could not be done on a single frame indication without a high false alarm rate. By increasing the number of frames used to conclude that a leak existed, the false alarm rate could be suppressed. The penalty imposed was an increased time duration for the leak to exist before shutdown.

Based on the above stated conclusions, an additional count register circuit was installed. The count, C, displayed on the register increased each time the comparator (A vs. B) output indicated a leak (A>B), but the register was cleared to zero each time two successive normal (A=B or A<B) indications were received. The shut-down circuit was activated whenever the C-counter reached a preselected count (selectable from 2 to 8). The ability to select both a threshold value for leak indication and a shutdown decision criterion permits: (1) configuration of the system to detect small leaks reliably with minimum chance of false alarms, or (2) acceptance of a high false alarm rate in return for the assurance that even a very small leak will cause rapid shutdown. The latter option should be selected for particularly hazardous materials.

With the leak indication threshold (B) set at 4 and the shutdown activating counter (C) set at 3, the introduction of 1% leak caused rapid shutdown. At a flow of 6 liter/sec (100 GPM), fluid loss before shutdown was between 250 and 500 ml, with most cases being at the lower value. False alarms under these settings were quite rare, but operating time and funding were not sufficient to gather statistically significant data.

The design that evolved is illustrated in a block diagram (Figure 4). An added feature (not discussed above) is the pilot valve current sensor. (The pilot valve controls the pneumatic valve. Refer to Figure 2.) This feature is required only when a hazardous situation could be created by continued operation of the pump with no flow in the line. Severing of one of the cables to a pilot valve is a possibility. Should this occur, the affected pilot valve would cause closure of its valve, but the system would not shut down because both meters would sense the same (zero) flow. The pilot valve current sensor monitors the current to the pilot valves. If either pilot valve circuit shows open, the sensor outputs a signal that will cause a shutdown, thereby alerting the operator to stop the pump. An alternative use for the signal would be direct connection to the pump motor relay.

Demonstration Tests

After the system was substantially completed, it was necessary to change the planned application. Instead of aniline, the fluid actually used in the tests

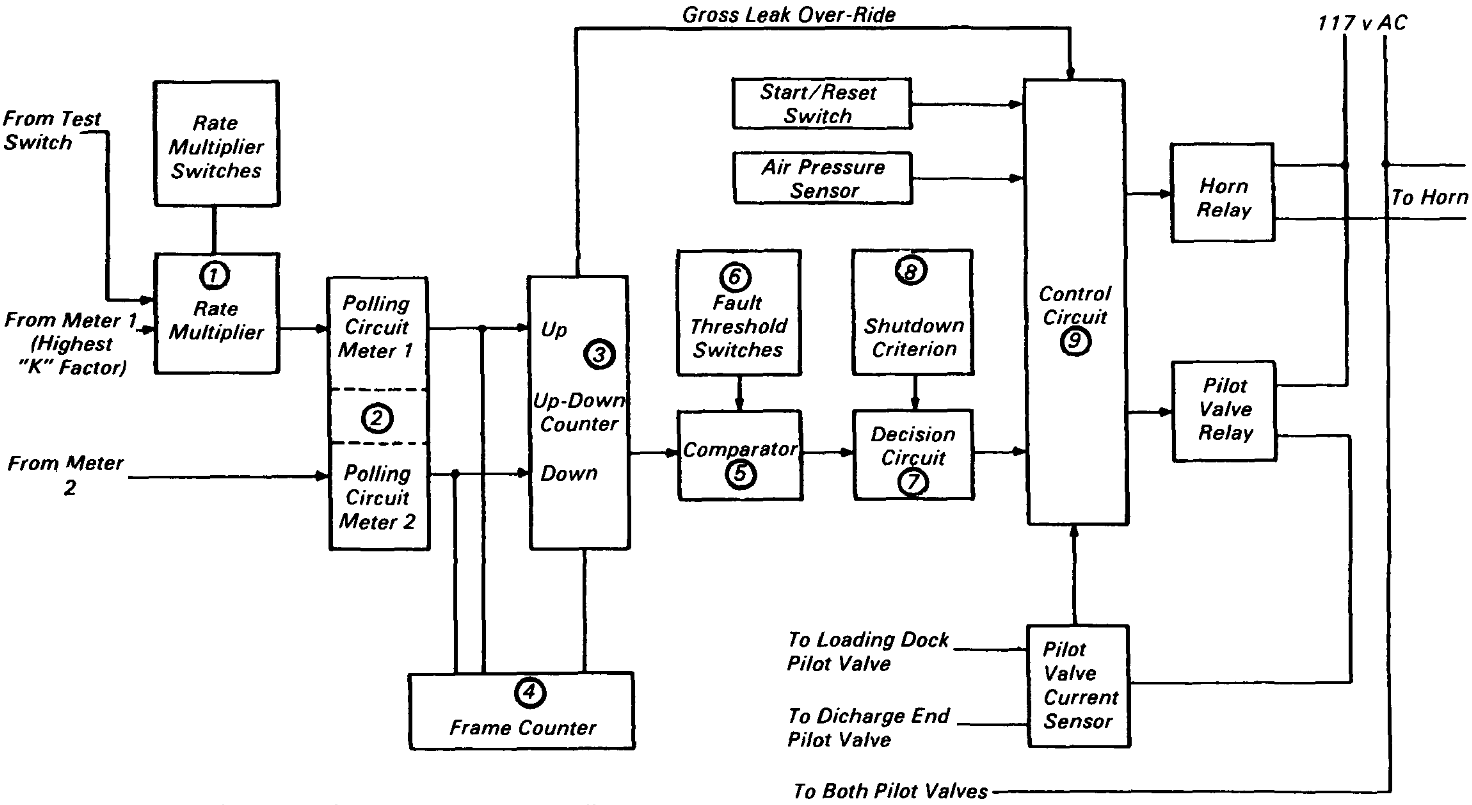


Figure 4. *Fail-safe transfer line control module block diagram.*

was TAMOL-L concentrate, an aqueous solution of the sodium salt of naphthalenesulfonic acid. The testing site was the Goodyear synthetic rubber plant in Houston, Texas. The system was installed by Goodyear personnel at the TAMOL-L concentrate storage tank site. Offloading stations for both tank cars and tank trucks were in the immediate vicinity of the tank. An expansion of the plant was in progress, and access to the truck offloading stations was blocked by construction work. Consequently, only tank cars were offloaded. Seven tank cars with an average load of 8,000 gal each were offloaded in 6 test days. No actual leaks were encountered. During the third unloading operation, a small leak was induced by loosening a pipe coupling at the point where the hose was attached to the outlet (storage tank) exit. The line shut down automatically within 8 sec. An estimated 1 pint of fluid was lost before shutdown.

Some difficulties were encountered in the demonstration tests, all attributable to the nature of the material handled. TAMOL-L contains more than 50% dissolved solids. Upon prolonged exposure to the atmosphere, the vehicle (water) evaporates, leaving a residue that varies from semi-solid to solid. When the transfer line was not completely purged after each use, the residual material dried out, leaving a coating of solids on the internal surfaces. Upon reuse of the line, the fresh fluid caused pieces of the solid material to slough off, fouling the outlet flow meter. A period of 2 to 15 min of flow (depending on the temperature of the fresh fluid and the degree of solidification of that which coated the internal surfaces) was usually required to establish trouble-free operation.

In general, the use-test period was successful in that it demonstrated that the system did not impose any significant increase in labor or inconvenience during its use. However, the specific nature of the material handled created problems that would require an additional step—flushing the system with water—when the time between transfer allowed the material to solidify.

Conclusions and Recommendations

The detection of small leaks (on the order of 1% of flow rate) in a liquid transfer line between storage facilities and tank cars or tank trucks is feasible using a flow balance comparison system constructed of commonly available components. Rapid, automatic closure of both ends of the line upon detection of a leak is simple to accomplish.

Naturally occurring variations in volumetric flow (presumably caused by dissolved compressible gases, flow cavitation, and the elasticity of the transfer line) preclude the reliable detection of very small leaks within the tolerance of the flow sensors on a single-event basis.

As built under this contract with standard discrete components, the fail-safe system for the automatic shutdown of a transfer line in response to a small leak is relatively cumbersome. A significant portion of the size and weight results from the need for pip-unions, nipples, couplers, junction boxes, and other items required to integrate the components.

A fail-safe transfer system that embodies the features of the system described in this report is applicable to nearly any transfer line or conduit handling noncompressible fluids with a viscosity and flow rate within the operating range of available turbine flow meters. The size of the line and the materials used may be varied to suit different flow rates and fluids. The size, weight, and cost of a system comparable with the one described in this report can be significantly reduced by: (1) the development of inlet and outlet modules that have integral valves, activators, pilot valves, flow meters, junction boxes, etc., and (2) the development and certification of an intrinsically safe control module. The foregoing recommendations for improved design are not economically practical for systems manufactured in small quantities. However, the prototype system was deemed usable without special handling equipment by product transfer personnel at the industrial plant where the system was evaluated.

A fail-safe transfer system functionally similar to the one described in this report should be considered for use in the transfer of particularly hazardous materials between storage facilities and tank cars and tank trucks.

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***John E. Brugger** is the EPA Project Officer (see below).*

The complete report, entitled "Fail-Safe Transfer Line for Hazardous Fluids," (Order No. PB 84-112 705; Cost: $8.50, subject to change) will be available only from:

National Technical Information Service
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