Solution Cavern LPG Storage
Instrumentation for Remote Operation and Supervision

by
S. Kurtis
Michigan Refining Division
Ohio Oil Company

ABSTRACT

The solution mined LPG storage caverns of the Ohio Oil integral part of the refinery. The proximity of underground salt mining operations in one of the Silurian Salina layers, necessitated the construction of the storage caverns at a location approximately one mile from the refinery site. This distance transmutes the control and supervision of the facility into an essentially remote operation, requiring extensive utilization of electronic and electro-mechanical devices, to yield a system as versatile and controllable as one immediately accessible to operating personnel. Additional safety features were superimposed upon the basic control system, the caverns being located within a populated, industrialized area.

The paper describes the controls and instrumentation employed for the operation and protection of the installation. Experience from three years of successful operation demonstrates the feasibility of remote operation and supervision applied to solution caverns for LPG storage.

INTRODUCTION

The Detroit area offers an ideal location for solution mined salt cavern storage facilities. They are: many salt beds at economical depths, good fresh water availability for solution mining, and a surrounding market for the stored products. These reasons led to the choice of solution mined underground caverns for the storage of LPG, at the Detroit Refinery, of the Marathon Oil Company.

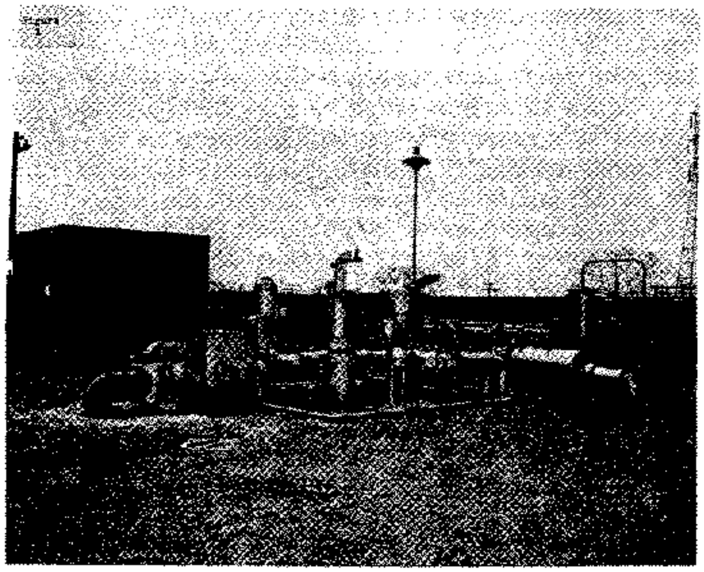
Construction was begun in July, 1958. Core samples were obtained for many of the strata, particularly in the final layers in which the solutioning was to be done; the choice of layers to be based on the results from the core analysis. The Silurian Salina layer (1160-1250 foot depth) was chosen for the development of the caverns; however, the specific geographic and stratigraphic location was of importance due to the existence of prior underground salt mining operations in those layers within the general vicinity of the Detroit Refinery.

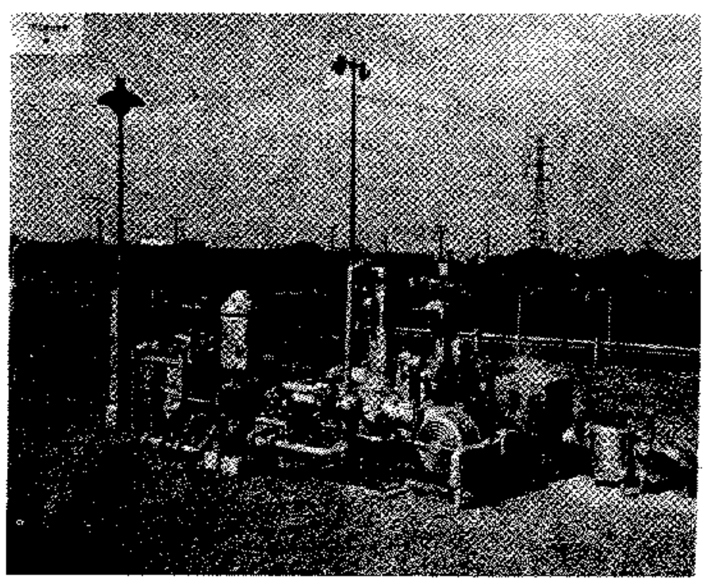
Four LPG storage wells were constructed on 350 foot centers with an ultimate capacity of 100,000 Bbls, each. An additional well, brine supply-storage, was drilled into a Sylvania sandstone strata, (500-530 foot depth).

The selected location is approximately one mile from the refinery site, within an industrialized area. This distance transmutes the control and supervision of the facilities into an essentially remote operation, requiring an extensive utilization of electronic and electro-mechanical controls, safeguards, and measurement equipment, to provide a system as versitile, safe, and controllable as one within the refinery areas. In addition, the location of the cavern sites within the industrial area, superimposes still additional requirements onto the control and safety provisions of the system.

The paper describes the controls and instrumentation necessary for these operations. Some of the types of instruments and controls utilized are: radio-active source densitometers; remotely operable, automatic electro-hydraulic control valves; magnetic flow rate meters; flow sensing switches; pressure sensing switches; level indicators; explosive vapor detectors; waste vapor igniters; pipeline rupture protection devices; a multiple-frequency tone, supervision and control system, with built-in alarm, shut-down, and fail-safe features.

Two views of cavern site #1 are shown in Figure 1 and Figure 2.





CONSTRUCTION

The construction of the facilities were performed by a rotary rig. During the drilling of the first hole, difficulties were encountered with mud circulation due to a porous water bearing zone and the surface glacial drift material. Therefore, a 13 5/8 inch casing was set and cemented to a depth of about 300 feet, beyond the sandstone and drift material. Subsequent drilling was performed, with a 12 1/4 inch bit, to a total depth of 1256 feet. A 8 5/8 inch casing was cemented to a depth of 1153 feet; this being the top of the salt layer selected for the development of the cavern.

An 88 foot strata of high purity salt was chosen, even though it contained a narrow dolomite layer. Downhole solutioning was performed through a 4 inch center pipe; the resulting brine being returned to the surface through the annulus between the 8 inch and the 4 inch. This was continued until an approximate cavity of 25,000 barrels was obtained. At this time, an additional 7 inch pipe was installed and set 30 feet from bottom hole. This arrangement provides for simultaneous storage and solution mining. The LPG entering and leaving via the annulus between the 8 inch and the 7 inch; fresh water entering via the annulus between the 7 inch and the 4 inch; and the brine entering and leaving via the 4 inch.

Density and volume of the salt brine were monitored, providing data for a computer program to evaluate the size of the caverns.

Subsequent sonar calipering of one of the caverns showed that the solution mining resulted in an essentially cylindrical shape, with a pronounced pinch at the elevation of the dolomite layer, in addition to verifying the volume calculations.

A plot of the gamma ray, neutron, resistivity, drilling time, compositions, salt purity, and subsequent sonar caliper is shown in Table I.

THEORY

The caverns were designed to operate as an integral part of the Detroit Refinery. Although remotely located, the system is nearly as versatile and controllable as one immediately accessible to operating personnel.

A simplified flow schematic is shown in Figure 3.

The joining link between the refinery and the caverns is an underground pipeline, through public property. Four 4 inch pipelines within a 12 inch casing connect the refinery to the caverns. The casing is welded gas tight to the 4 inch pipelines and pressurized. High and low pressure alarms and a pressure relief valve are provided. The monitoring pressure is maintained by nitrogen. Thus, a leak in the outer casing would yield a low pressure and a leak from one of the inner lines would yield a high pressure.

At both ends of the pipeline link, automatic shutdown valves are provided on the carrier lines to isolate the pipeline should a rupture occur. Only three carrier lines are necessary; the fourth is used as a common waste vapor return line from the four well locations. Pressure relief valves are provided on the carrier lines for high pressures caused by thermal expansion.

A 51 pair cable trunk provides the electrical links for the control, operation, and monitoring of the remote facilities.

The equipment at a well site consists of a multistage vertical LPG injection pump with automatic control valves on the suction and discharge, to isolate the pump in the event of pump seal disintegration, and a flow sensing switch to prevent the pump from operating with insufficient flow or suction line pressure, and a thermal pressure relief line. These are shown in Figure 4. An additional proportioning-type control valve is provided for the controlled return of LPG back to the refinery. The LPG is injected through the outer annulus between the 8 5/8 inch pipe and the 7 inch pipe.

Explosive vapor detection apparatus are installed in strategic locations at each cavern site, including one at the seal of the injection jump, to test for possible leakage of LPG into the area, or seal disintegration, (also Figure 4).

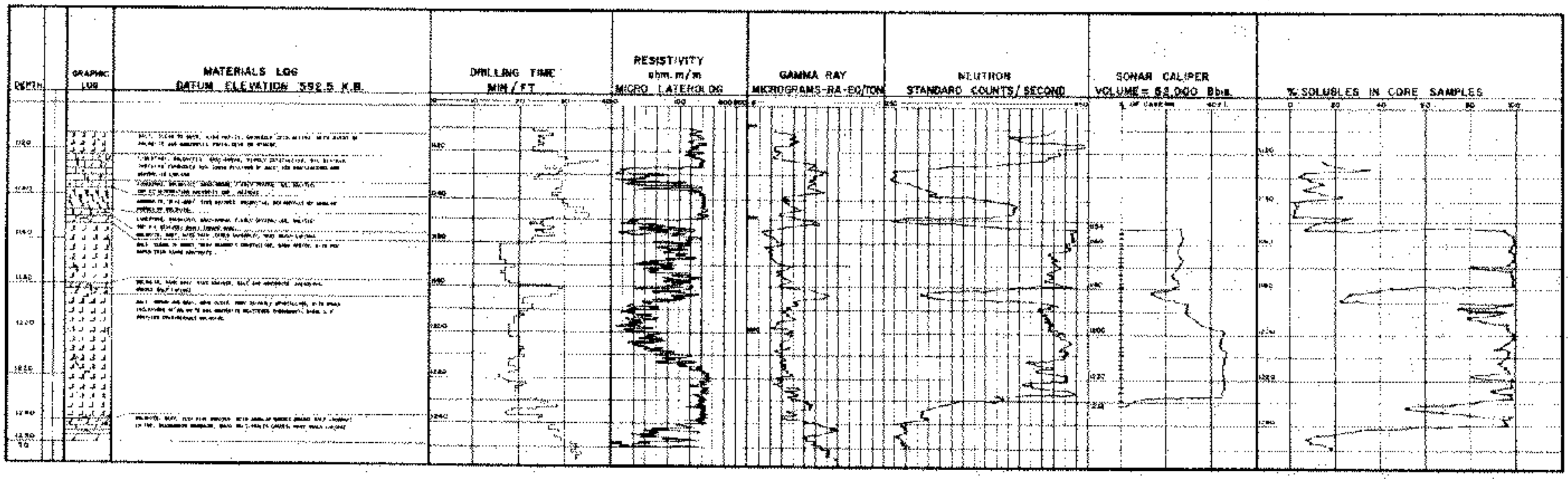

DEPTH
GRAPHIC LOG
MATERIALS LOG
DATUM ELEVATION 592.5 K.B.
DRILLING TIME
MIN/FT
RESISTIVITY
ohm.m/m
MICRO LATEROLOG
GAMMA RAY
MICROGRAMS-RA-EQ/TON
NEUTRON
STANDARD COUNTS/SECOND
SONAR CALIPER
VOLUME = 53,000 Bbls.
% SOLUBLES IN CORE SAMPLES

Table I.

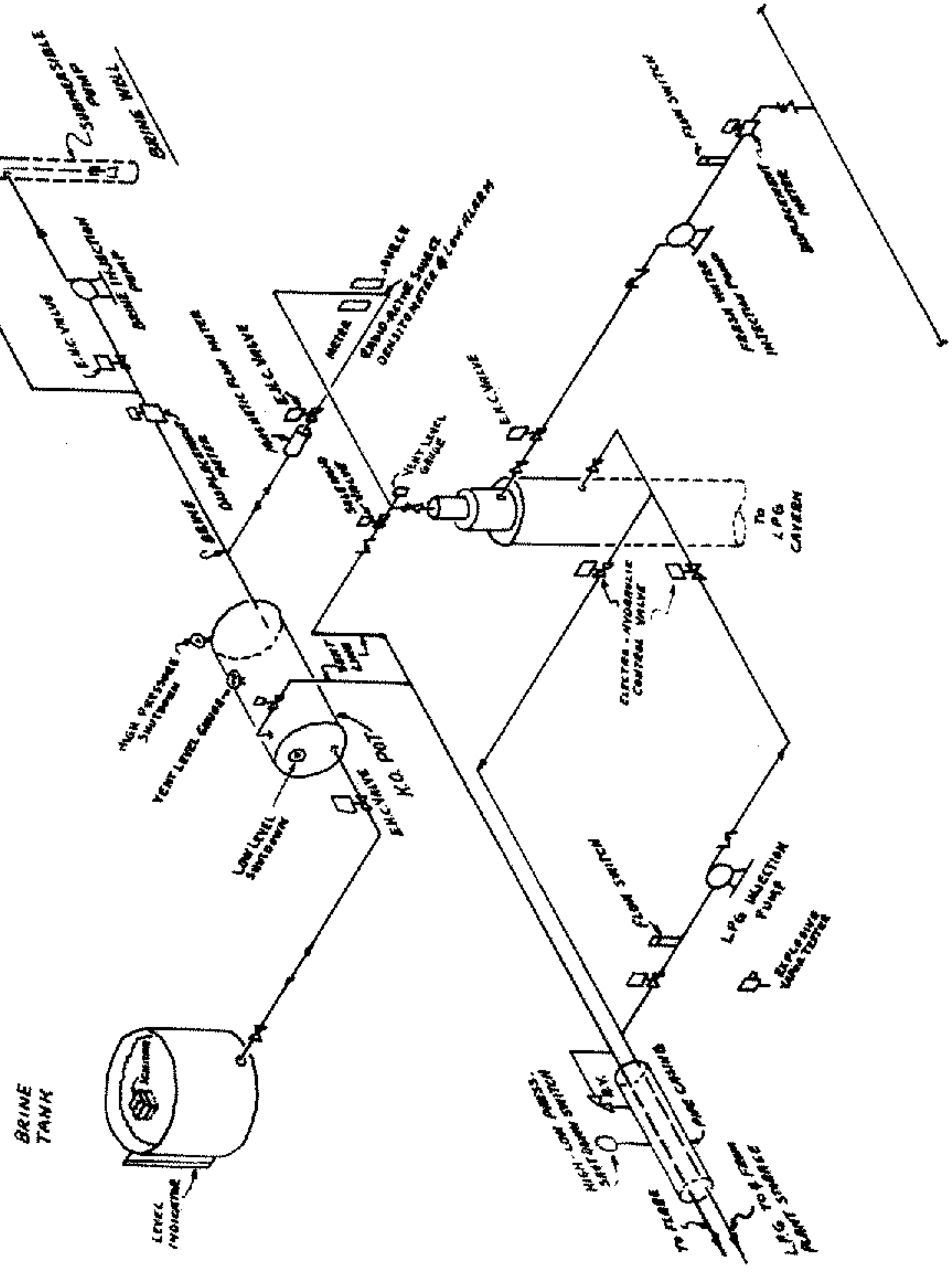
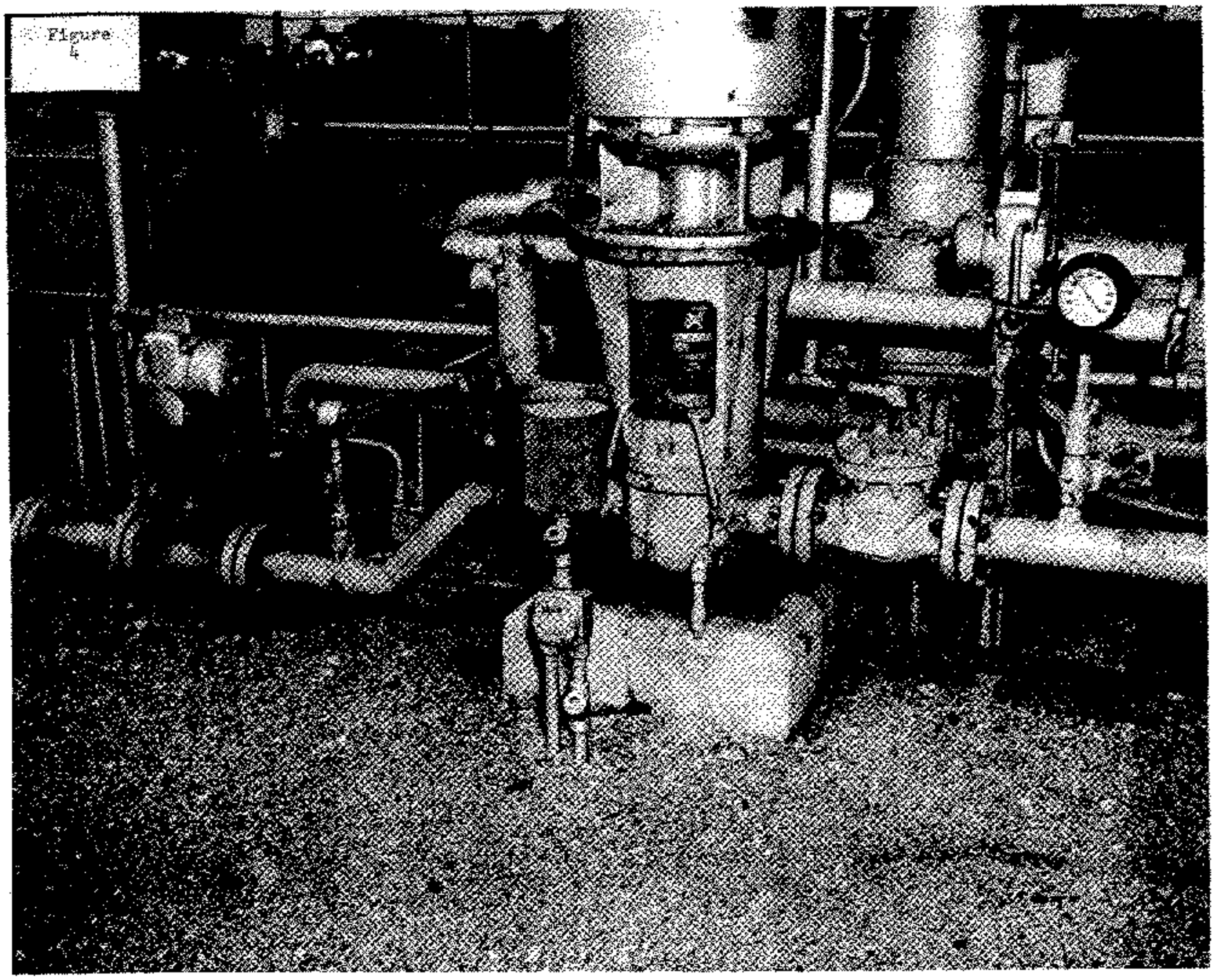

BRINE TANK
LEVEL INDICATOR
K.O. POT
E.H.C. VALVE
LOW LEVEL SHUTDOWN
VENT LEVEL GAUGE
HIGH PRESSURE SHUTDOWN
BRINE
DISPLACEMENT METER
MAGNETIC FLOW METER
E.H.C. VALVE
BRINE INJECTION PUMP
SUBMERSIBLE PUMP
BRINE WELL
METER
RADIO-ACTIVE SOURCE DENSITOMETER & LOW ALARM
FRESH WATER INJECTION PUMP
DISPLACEMENT METER
FLOW SWITCH
TO LPG CAVERN
ELECTRO - HYDRAULIC CONTROL VALVE
FLOW SWITCH
LPG INJECTION PUMP
EXPLOSIVE VAPOR TESTER
HIGH-LOW PRESS. SHUTDOWN SWITCH
PIPE CASING
TO FLARE
TO & FROM LPG PLANT STORAGE

Figure 3

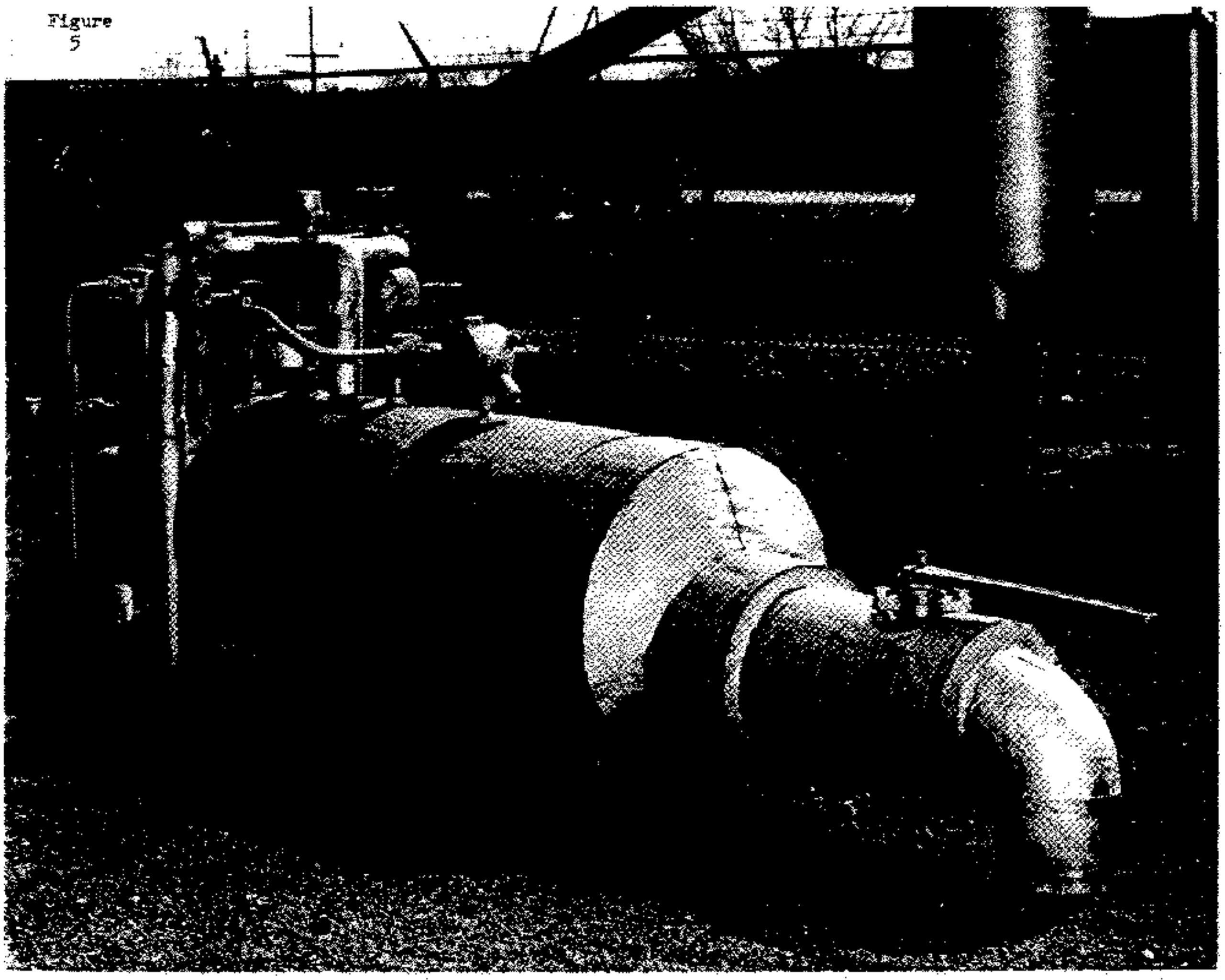


A remotely controlled fresh water pump provides metered, high pressure water to the annular area between the 7 inch and the 4 inch piping, for solution mining.

The brine system is composed of a control valve on the outlet of the 4 inch center tubing, a venting device to eliminate small amounts of entrained gas accumulation, a radioactive source densitometer, and a magnetic flow meter. The line connects into a main brine header, which passes through a vessel which acts both as a vapor disengager, to remove trace volumes of entrained LPG, and as a safety check point, to detect more than trace volumes of entrained LPG or higher than normal pressures. The vessel is equipped with a high pressure alarm and a "low-level" capacitance probe. The outlet of the vessel is equipped with an emergency shutdown control valve. These are shown in Figure 5. A PVC line connects the header to an open top, brine surge tank of 5,000 barrel capacity. Injection of brine from the brine header into the brine storage well is controlled by the level in the tank.

A set of three igniters floats on the brine. Their purpose is to ignite any accidental LPG releases that are not stopped by the preceding equipment.

Figure 5



The brine well facility consists of a pump to inject brine into a Sylvania sandstone strata and a submersible pump to retrieve it. Each of the two pumps has an independent control valve to control the flow in the proper direction. A meter is provided for brine accounting purposes.

EQUIPMENT DESCRIPTION

Remote Control Equipment

The system consists basically of three sections. One section, the control panel, is located at the refinery and is equipped with relays, control switches, and indicating lights to provide control and indication of the state of valves, pumps, and alarms at the storage caverns.

The second section is a transmitter-receiver also located at the refinery. It transmits the control codes and receives the indication signals.

The third section, part of which is shown in Figure 6, is a transmitter-receiver located at the storage caverns. It receives control codes and initiates operations through interposing relays, as well as transmitting valve, pump, and alarm indications. The two transmitter-receiver

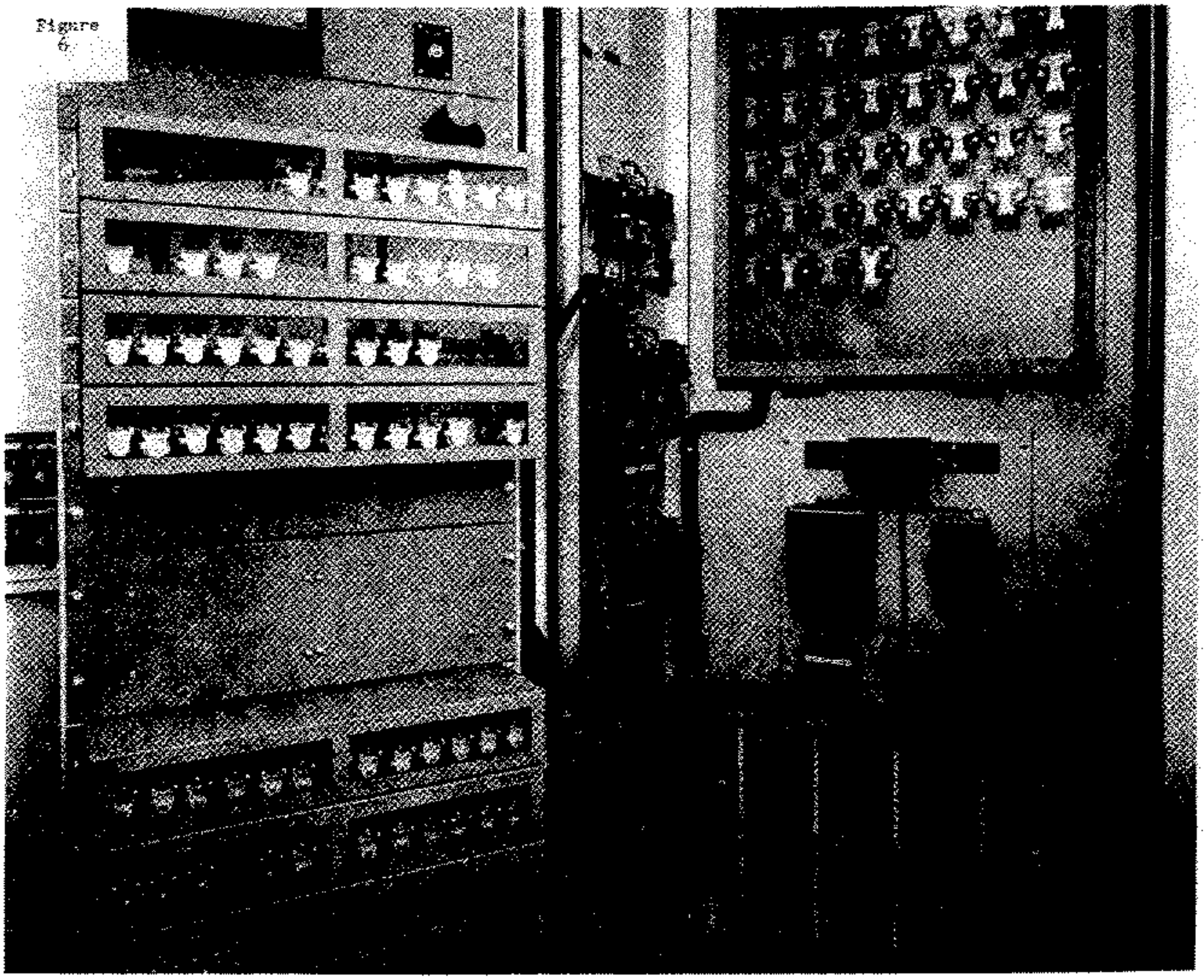


Figure 6

sections are connected by a single pair of wires. An additional communication channel through a separate pair of wires provides an alarm shutdown function for the system.

The control system uses serialized five impulse, four tone, code signals to perform the operations. This code is received by the equipment at the storage caverns, where it is checked for validity and encoded to energize the proper interposing relay to perform the selected operation. The validity checks made on the code are important to assure that no misoperation occurs due to spurious signals that may be induced on the communication channel. If the code received does not meet six specific checks, it is rejected.

When the selected operation is performed, a signal is transmitted back to the refinery, verifying the completion of the operation via an indicating light display.

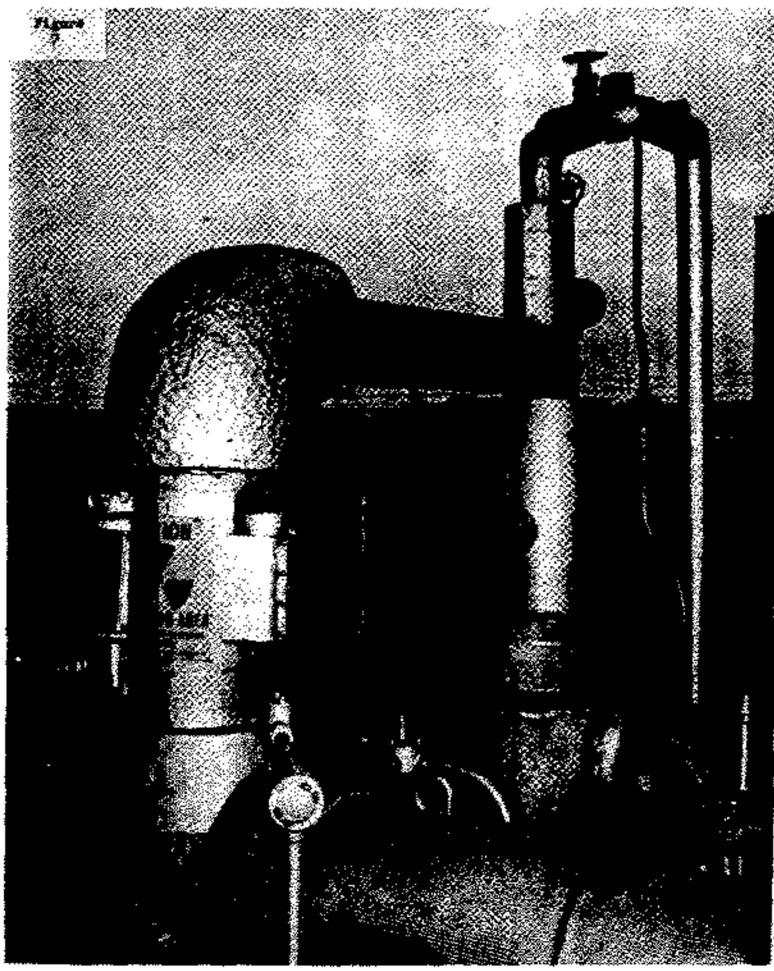
All alarms and controlled devices are continuously monitored. If an alarm occurs a signal is transmitted to the refinery. An audible alarm is sounded and the display lights on the control panel indicate the source of the alarm. Total shutdown of the system, via fail-safe type of equipment, is initiated by any alarm.

This system allows a single operator to perform operations, with the complete knowledge of what is happening throughout the system.

An additional feature is a local override control option, at the remote station, which prevents against accidental operation of the equipment, from the supervisory station, during local maintenance or testing.

Radioactive Source Densitometers

It is felt that a radioactivity density gauge has a number of advantages over conventional density measuring systems. The components are located external to the pipe containing the material to be measured; thus, conditions of temperature, pressure, etc., do not interfere with the measurement. Their operation depends on the fact that gamma radiation is absorbed as it passes through a material and that this absorption is a function of the density of the material. Utilizing a 100 millicurrie source of Cesium 137 and a 6 inch pipe section, an accuracy of about 1 percent can be obtained for the brine density. The components of a typical gauge installations are shown in Figure 7. It is seen that a unit containing a source of gamma radiation is placed on one side (right) of the pipe containing the brine to be measured, and a measuring cell is located on the opposite side (left).

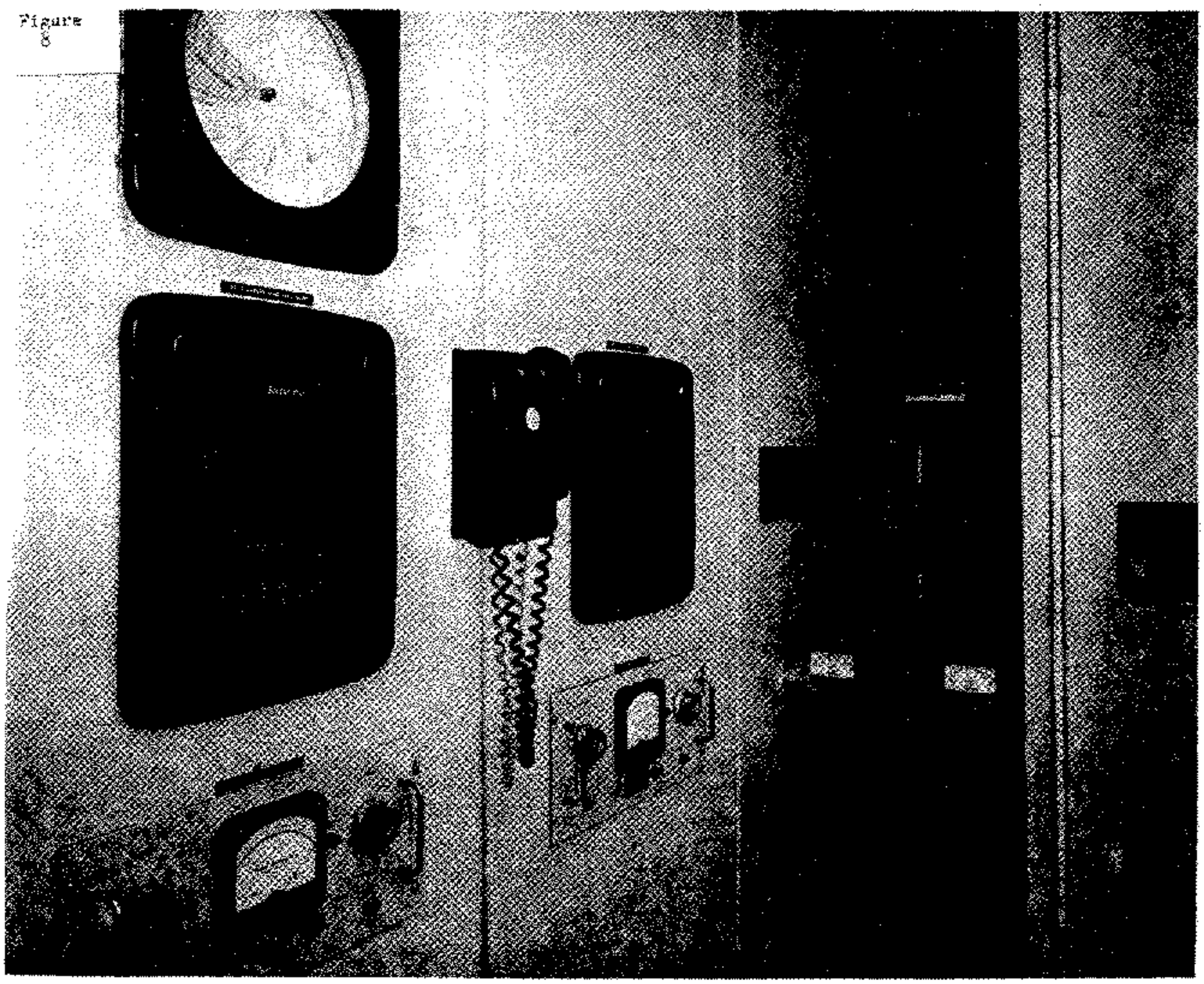


The Cesium 137 utilized has a long half-life (37 years) and a low energy gamma radiation (0.662 MEV), which is readily absorbed; hence, good instrument stability and sensitivity are achieved. The radioactive source material is welded into a metal capsule so that there is no possibility of leakage. The long half-life of the source assures minimal maintenance as significant changes in the radiation output do not occur and only bi- or tri-monthly calibrations are necessary. The source is mounted in a shielding holder, thus, in addition to serving as a container for the source it provides shielding for the area.

The measuring cell is of the type that converts radioactive energy directly into electrical energy. A compensating cell is used to provide a null system of measurement. A highly stable, vibrating capacitor, feedback amplifer is utilized. It has essentially zero drift and maintains calibration over long periods of time. The overall alarm time constant of a typical system can be made as short as two seconds.

The instrument is connected to a continuous density recorder with alarm contacts to provide an alarm should the density of the material being measured drop below that of pure water. This is shown in Figure 8, as part of a view of the remote station control system.

Figure 8



Control Valves

All control valves utilized in our facilities provide for remote control, fail-safe operation, and two wire hookup. The valves are of a slide tube design with a directly connected actuator which provides a smooth opening and closing under high pressure drop conditions. An example is shown in Figure 9. The actuator frame is a cast structure supporting the power unit, actuating cylinder, and return spring. A small hydraulic pump supplies the fluid pressure to the actuating cylinder and is driven by a directly coupled electric motor. Upon completion of valve stem travel a switch shuts off the pump motor. A small electrical current holds an electromagnetic relief valve closed; thus, maintaining the actuator in the open position. Power failure, or electrical interruption causes the relief valve to open and the spring loaded piston to return the valve actuator to the closed position. A small flow orifice in the relief line provides smooth, non-shock closing.

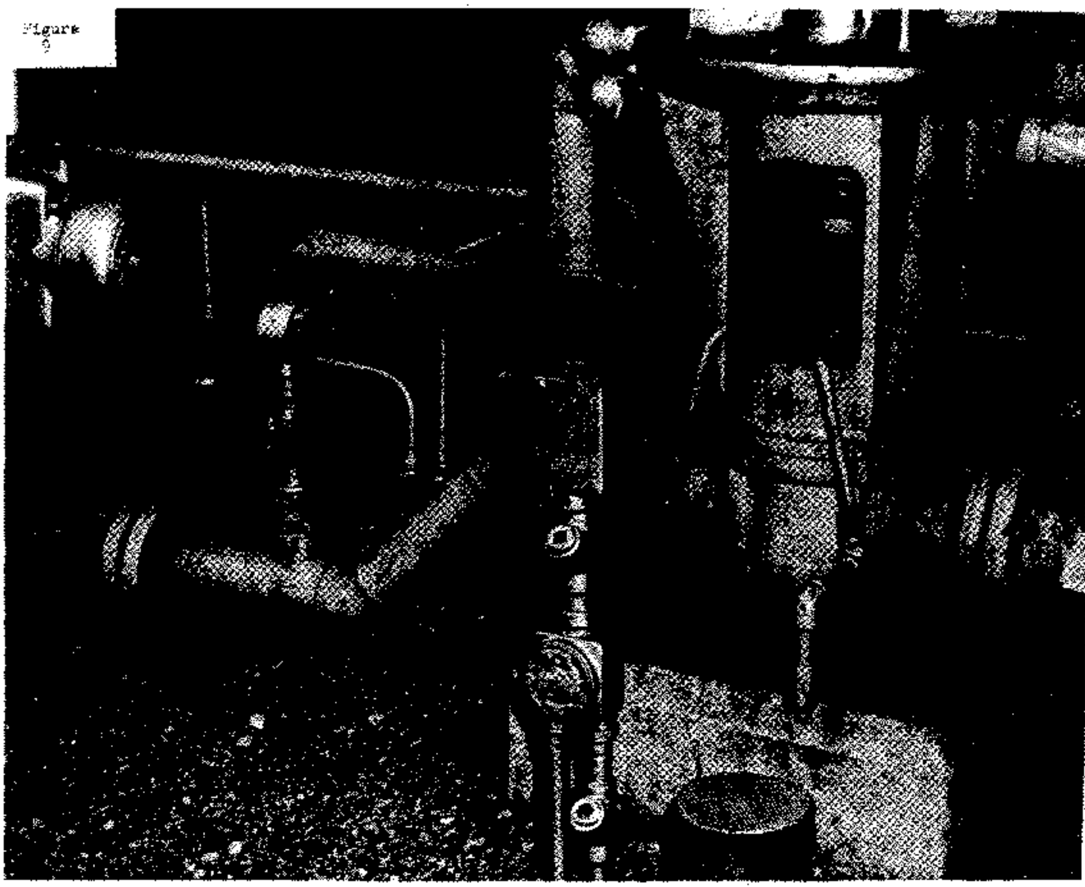


Figure 9

Magnetic Flow Meters

Magnetic flow meters are utilized to measure the flow rate of the effluent brine. The magnetic type of meter was chosen because of the entrainment in the brine of pieces of stone and anhydrite, and the brine's corrosiveness. In this instrument a magnetic field is produced around and through the brine flow pipe. As the brine crosses the field a voltage is generated. This voltage is proportional to the velocity of the fluid through a calibrated cross section, within the flow pipe. This voltage is amplified, transmitted and displayed to show the rate (GPM) of brine flow.

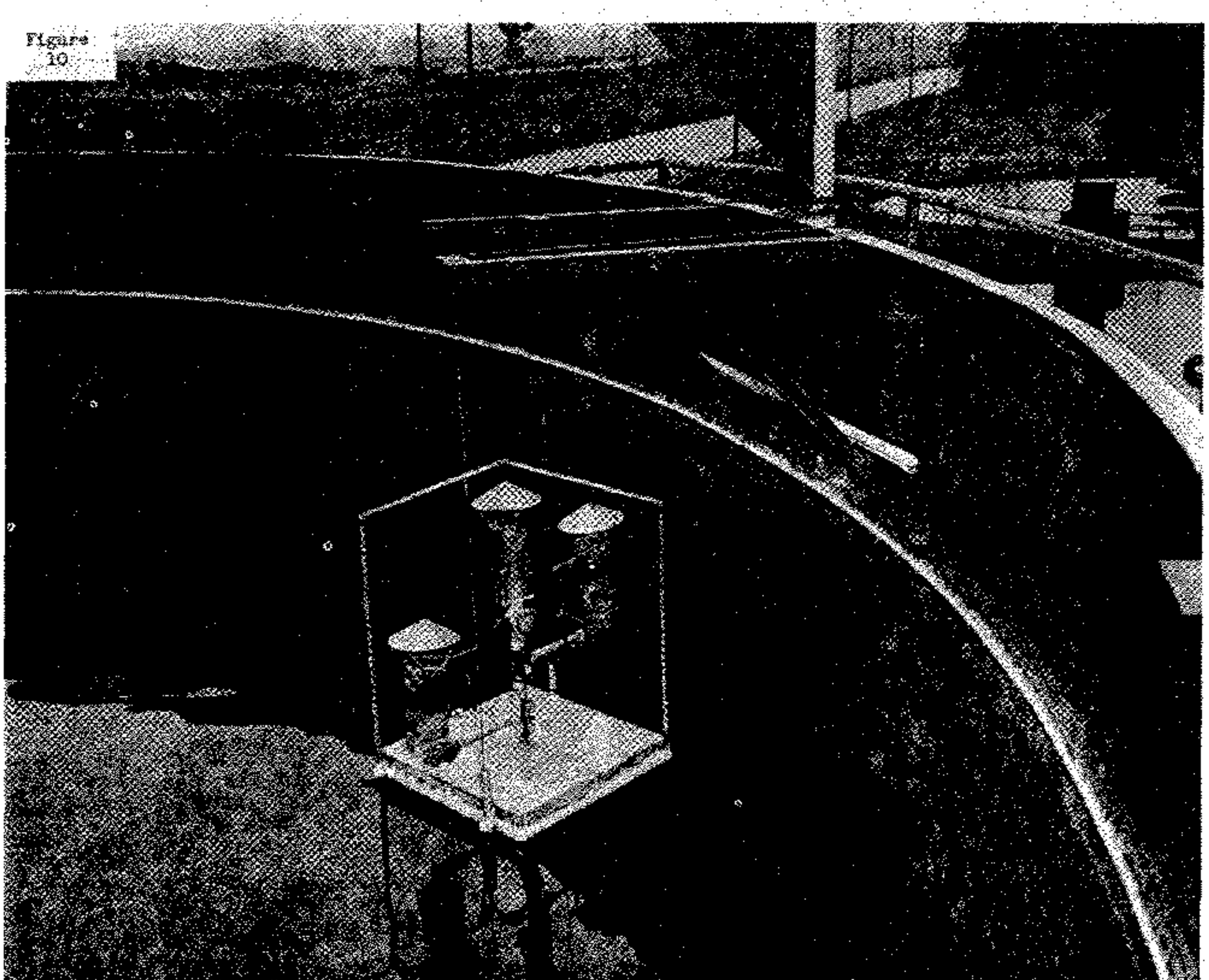
Explosive Vapor Testers

The temperature rise resulting from the catalytic combustion of combustible gas mixtures at concentrations below the lower explosive limit activates the sensing element of the explosive vapor testers. The system is set to alarm at 30 percent of the lower explosive limit. One of the remote heads is shown in Figure 9. The explosion proof remote analyzing heads obtain a continuous sample by convection and diffusion. Also, the testers are constructed to alarm from any internal trouble occurring in the electronics of the circuits.

Waste Vapor Igniters

The igniters floating in the brine tank are our own design, utilizing Ni-Chrome hot wire elements, similar to those in gas clothing dryers. Their operation is checked by an integral thermocouple. They supply a sufficient ignition temperature for any of the gases that may accidentally be released. Ignition is aided by the catalytic action of the oxide film on the surface of the wire. A bank of three elements is provided to assure maximum reliability and protection. Should two elements fail, an alarm would be generated. The bank of elements is shown in Figure 10.

Figure 10



Level Indicators

The level indicators utilized are of the capacitance measuring type. Since the capacitance of the probe is different when submerged in vapor than when submerged in liquid, a change in capacitance thereby provides either an alarm or a control signal of the status of the submergent fluid.

Flow Sensing Switches

The flow sensing switch is basically a paddle mounted on a pivot, which is mounted within a pipe. A flow through the pipe moves the paddle flapper which activates an internal magnet assembly, which operates on open-close microswitch. The switch can provide either an alarm or a signal.

Pressure Switch

The pressure switch used to sense subnormal or abnormal pressures, is a standard Bernoulli tube, with variable contacts, provided within an explosion proof housing. It, too, can provide an alarm or a signal.

RESULTS

The results of over three years of operation of the caverns and its associated equipment have resulted in a minimal number of problems: (1) A foam is sometimes formed in the effluent brine, during high rate solutioning, due to the entrainment of small amounts of LPG in the brine. This can result in an inaccurate reading from the radioactive density gauges. (2) The original flow switches utilized had corrosion products build up on the pivot element. When the paddles were replaced with stainless steel the problem was eliminated. (3) Some of the original control valves utilized were of the globe type design. It was found that when the valves were closed, with high pressure drops across them, extensive deformation of the internals was encountered. These valves were replaced with valves of the slide tube design, which provide for perfect shutoff with any pressure drop across the valve up to 600 pounds per square inch, with no deformation. (4) The original brine tank igniter was a continuously burning, propane, pilot flame. However, the brine and vapor spray corroded and contaminated the burner and rendered it inoperative. The hot wire igniters were subsequently designed and have proved very satisfactory.

CONCLUSION

The operation of this system for the 3 year period has shown that remote operation, supervision, and protection of solution mined LPG caverns can be obtained satisfactorily. The problems that arose have been coped with adequately, with a minimum of expense and effort. In addition, it is felt that with the knowledge and experience obtained, subsequent installations can be constructed, installed, and put into operation, which would provide a high degree of control, versatility, safety, and supervisibility.