Design and Installation of the Capitan Reef Source Water Supply System to Serve West Texas

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INTRODUCTION

Crude oil, refined products and potable water have been transported through pipe lines for many years; however, it has been only recently that the oil industry has been confronted with the problem of handling highly corrosive waters such as that produced from the Santa Rosa, San Andres and Capitan Reef formations of West Texas and eastern New Mexico. As these formations afford the only adequate supply of source water in many locations, the proper design and operation of facilities to handle corrosive water is essential.

Shell is presently installing a 600,000 BPD system to produce and transport Capitan Reef water from Winkler County to various waterflood units in Ector and Andrews Counties. It is hoped that in reviewing the aspects of this endeavor, we may be of assistance to those who are or may become involved in the design and operation of this type facility.

HISTORICAL

Since the beginning of time, man's existence has been dependent on water.

As amply pointed out by poet, Charles Mackay, some 100 years ago,

"Water is the mother of the vine,
The nurse and fountain of fecundity,
The adorner and refresher of the world."

Needless to say, the procurement of economical source water by the oil operators of West Texas is a necessity, if, as Mr. Mackay would express it, "the economic aspect of the oil industry in this area is to be adorned and refreshed."

For some time, the oil operators in the Ector County, Texas area have been aware of the need for a dependable and economic supply of large quantities of water for use in secondary recovery projects. Early in 1962, a committee representing the major operators in this area was formed to study the availability of a suitable source of water and the feasibility of having the water delivered to all operators through a common system.

Bids, denoting location, quantities of usage and conditions for delivery were requested from various companies in the pipeline field. Shell Pipe Line was selected as the most favorable bidder and a contract was consummated in October, 1963. This contract requires that Shell produce water from the Capitan Reef of Winkler County and deliver it to 28 locations in Ector and Andrews Counties at a maximum rate of 600,000 BPD. The water must be delivered in its "as produced" state, free of contact with air and containing no oil or other foreign materials.

The facilities to be installed will consist of 18 wells to be drilled on the Capitan Reef in Winkler County, Texas, approximately 135 miles of pipe lines, 6 in. through 36 in. in diameter, metering facilities at each delivery point and engine-driven pumping equipment totaling 8,400 BHP. All wells and vessels will be gas blanketed to prevent air-water contact, and the water will be delivered to the purchasers' tankage or pump suction at pressures not less than 25 psi.

The system will serve waterflood units containing approximately 86% of Ector County's wells and presently producing about 68% of its total production of some 152,000 BPD. The fields include: Wheeler, TXL, North Cowden, Foster, South Cowden, Harper, Penwell, Jordan and Goldsmith in Ector County and Embar in Andrews County.

DESIGN AND PLANNING

Much has been said about what is a "Good Design" and the definition one may receive from the engineer, the operating personnel and the investor may not necessarily be compatible in view of each group's interests. Often, the engineer wants the facility containing the utmost in technical excellence, the operator of the facility, naturally, desires the one which accomplishes the objective with a minimum of trouble, with the tendency at times for the investor's requirement of a profit becoming a secondary issue. Much as we would like to design and install facilities containing engineering marvels which would operate forever with no inconveniences to the operating groups, our primary consideration must be to accomplish our objective to the greatest economic interest of the investor.

As the basic design of all fluid pipeline systems can be expressed in formulas, Shell has developed computer programs which are utilized to perform the mass of calculations formerly done by engineers and necessary to permit selection of the system which will provide the greatest return on the investment. By utilizing the computer, the engineer may explore many possible solutions which would be impossible if calculations were made manually. Variations of these computer programs have been developed to utilize basic known data which may vary with different propositions; however, the basic input data which must be supplied are as follows:

1. Hydraulic formula to calculated pressure drop in lines for fluid to be handled
2. Charaeteristic data of fluid to be handled
3. Throughput quantities expressed as B/D for each year of service
4. Diameter of pipe I. D. In. (may be incremented)
5. Profile data of terrain to be traversed

6. Unit investment costs
   a. \$/ft. for pipe installed
   b. \$/H. P. for operating H. P.
   c. \$/Fixed for special features, tankage communications, etc.
7. Operating expense schedule
   a. \$/mi. for maintenance of lines
   b. \$/H. P./ year for operating H. P.
   c. \$/year for personnel, automotive, overhead, etc.
8. Tax depreciation rates
9. Ad valorem and income tax rates
10. Discount rate for present value calculations (may be incremented)
11. End of life salvage and valuation
12. Tariff (\$/bbl) or rate of return (may be incremented)

Calculated data for each incremented input which may be read from the computer run sheets are as follows:

1. Total investment
2. Operating horsepower
3. Operating pressures
4. Revenue, operating costs, tax credits and amounts of ad valorem and income taxes
5. Profit before and after taxes
6. Cash generation
7. Payout
8. Present value of investment, cash generation, profits
9. Rate of return or tariff

Utilization of the computer has not only provided the information necessary to evaluate the economic feasibility of a proposition and thereby, eliminate the need for additional work on non-profitable projects; but has also provided the basic design information with regard to correct line sizes and horsepower requirements on projects which are to be completed. By determining this basic information in the initial phases of the project, the engineer is freed to concentrate on solving the problems peculiar to the system to be installed and on the planning necessary for the efficient completion of the overall project.

Much has been said and numerous articles have been written regarding job planning. On jobs of the nature of the Capitan system, a project manager is assigned the responsibility of not only assimilating the contributions of the Shell specialists into the design and execution phases of the project, but also, in coordinating and scheduling the activities of the various contract companies performing the field work. Approximately 2-1/2 years will have elapsed from the time initial contact was made with the 11 companies signing contracts to purchase water before the first delivery will have been made. During this period, the commencement of certain phases of the project has been contingent on the successful completion of another portion; hence, it has been necessary to develop a visual aid to planning and scheduling to minimize lost time. Referring to Exhibit 1, an arrow diagram was developed denoting the functions required and their priority with regard to other phases of the project. Admittedly, this diagram has been in a continual state of change; however, it has been when one function was not completed on time that the chart has been of greatest benefit by serving as an automatic reminder to reschedule the functions that are affected by the delay.

The basic problems encountered which are peculiar to the Capitan system are those created by the highly corrosive characteristics of the water and the necessity of building an air-free or closed system as required by the contractual obligation to the water buyers.

WATER QUALITY AND CORROSION CONTROL

The Capitan Reef water contains approximately 10,000 ppm solids of which 178 ppm is H_2S. The composition of this water may vary as a result of water removal from the producing formation, or by the effects of temperature and pressure changes as it is produced. The third possibility is the introduction of contaminants by the transporting system. The first 2 possibilities are beyond our control and may affect long term corrosion; however, until we obtain more experience with the system, we plan no corrosion mitigation around them. Our program is designed primarily to detect and mitigate against contaminants introduced by the pipeline system.

The only anticipated contaminants of any consequence are oxygen introduction and pieces of defective internal coating or lining being entrained in the water. Removal of solids is to be accomplished by installing strainers at each delivery point.

Introduction of oxygen into the system would not only tend to accelerate corrosion, but could possibly generate corrosive products which might impair the quality of the water for use in water floods. The presence of oxygen in water can be determined by the chemical analysis of oxygen demand and by electrolytic cells or "oxygen meters" which measure the dissolved oxygen content. The fact that oxygen accelerates corrosion permits the use of the shielded corrosometer probe to detect small amounts of oxygen which would induce oxygen cell pitting corrosion. Weighed corrosion coupons also offer a means for detection of accelerated corrosion. The use of millipore filters to detect any increase of solid corrosion products in the water may be used; however, its accuracy is questionable. Routine employment of these oxygen sensing devices and techniques at selected locations along the pipeline system should enable us to detect and avoid water contamination.

The program to be initiated on this system for corrosion and water control shall consist of 2 series of analyses. An initial series of analyses will be made which will establish a base with which later analyses can be compared. Subsequent routine tests made throughout the life of the system will be designed to guide our corrosion mitigation program and to insure the maintenance of the water quality.

The initial analysis will be made at a sufficient number of producing wells to be representative of the water entering the system and at the discharge of each delivery point. This analysis shall consist of the following:

1. Chemical constituents
2. Total solids
3. Total acid-soluble solids
4. Total suspended oil
5. Oxygen demand
6. pH

In addition to periodic water analyses, a program of routine tests consisting of the following analyses will be maintained:

1. Corrosion mitigation

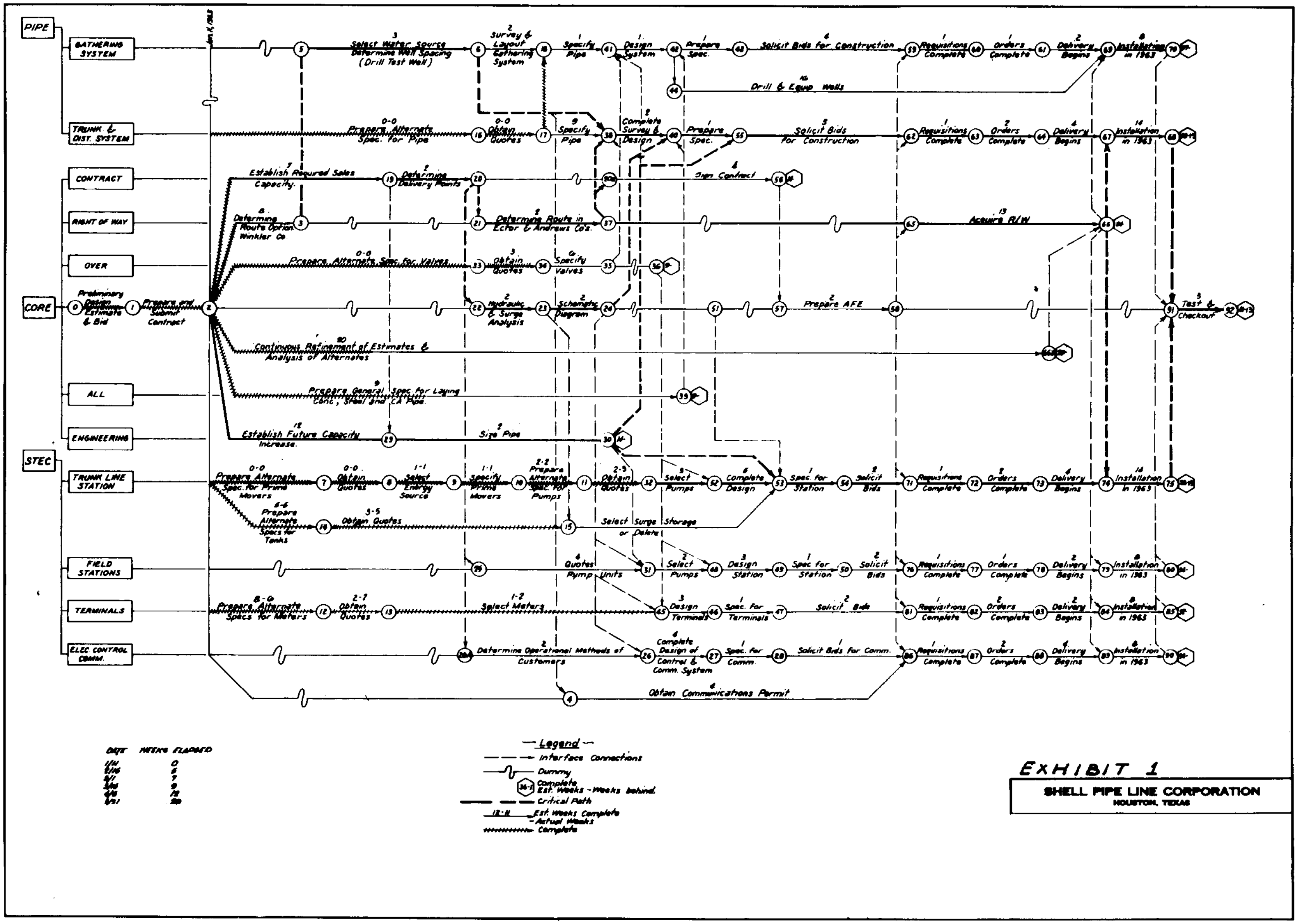


EXHIBIT 1

SHELL PIPE LINE CORPORATION
HOUSTON, TEXAS

a. Shielded corrosometer probes will be placed at each meter delivery point. These probes will be monitored once a month when the meters are read.
b. Weighed metal coupons will be placed at each meter delivery point and analyzed every 2 months or as required.
c. An oxygen demand analysis will be made at the mainline pump station every 6 months. If the shielded corrosometer probes, corrosion coupons or other observations indicate accelerated corrosion, additional analyses will be made using techniques to pinpoint the source of trouble.

Other tests for water quality control which have been considered but not deemed applicable to this system are those for sulfate reducing bacteria, turbidity, dissolved iron, millipore filter and iron sulphide.

SELECTION OF MATERIALS

The planned program of corrosion mitigation and oxygen exclusion should minimize the corrosion damage to the facilities in this system; however, damage can be expected if the proper corrosive resistant materials are not used, or if the conventional steel materials are used and not protected.

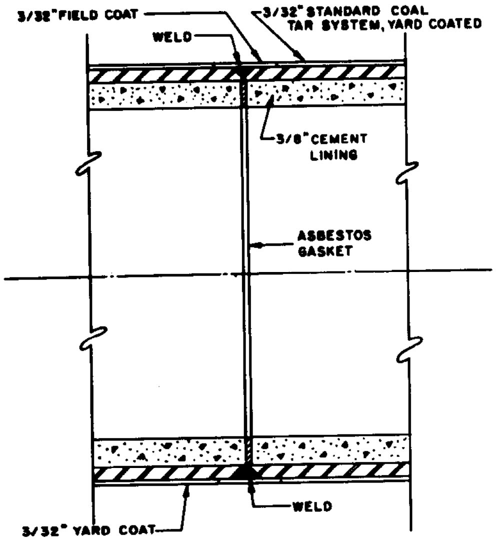
The cost of pipe in a pipeline system not only represents approximately 75% of the total initial investment, but is also the most costly item to maintain if corrosion damage is experienced. Steel pipe, lined with mortar or coal tar enamel, concrete cylinder and concrete asbestos pipe are to be used with their selection being made primarily on an economic basis. Failures have occurred on all 4 types of pipe in like service, with these failures generally being attributed to faulty workmanship in installation. The lines to be installed in this system shall consist of pipe types and sizes as follows:

6" thru 14" with operating pressures less than 150 psi	Cement Asbestos
6" thru 14" with operating pressures greater than 150 psi	Mortar lined steel
16" thru 36" with operating pressures less than 175 psi	Concrete cylinder
36" with operating pressures greater than 175 psi	Coal tar lined steel

Mortar lined steel pipe will be used in the Ector County distribution lines where pressures in excess of 200 psi will be required. This pipe is internally lined by centrifugally spinning a 3/8 in. mortar mix containing not less than 40%, nor more than 60% by weight of Portland cement confroming to ASTMC150-Type III, except that the tricalcium aluminate content shall be zero. The remainder of the dry mix shall consist of either raw or calcined natural pozzolans conforming to ASTMC402; or granulated blast furnace slag conforming to ASTMC205 and glass sand (silica flour) ground so that 100% will pass a No. 200 sieve and conform to ASTMC146-43. The silica flour content is limited to a maximum of 20%.

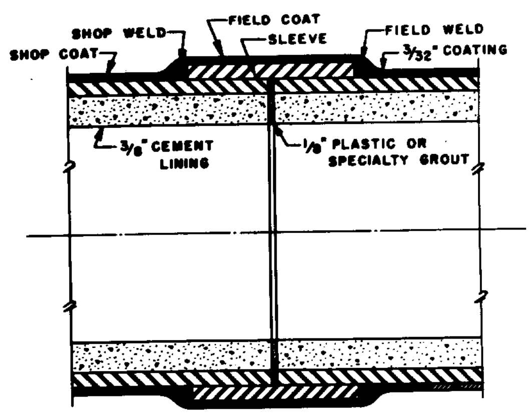
After lining and externally coating with coal tar enamel, the line is installed either by butt welding and utilizing an asbestos gasket at each point as indicated on Exhibit 2, or by welding a sleeve on the adjoining segments and using a plastic grout to seal the joint as shown on Exhibit 3. Both systems have been used; however, we prefer the asbestos gasketed joint. In either system, extreme care must be exercised to insure a tight joint to prevent water contact with the steel.

EXHIBIT 2



GASKET JOINT FOR 10.750" O.D.- 0.156" WALL STEEL PIPE-CEMENT LINED & COAL TAR COATED

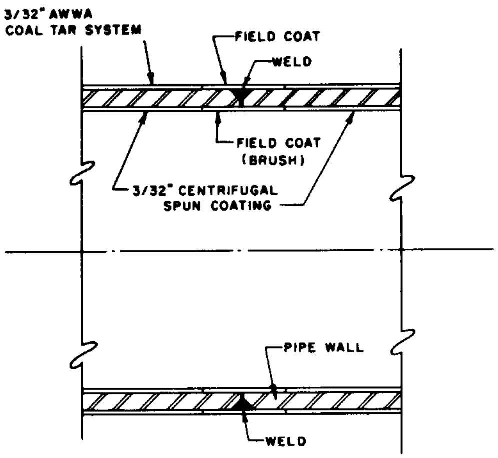
EXHIBIT 3



SLEEVE JOINT FOR 10.750 x .156 STEEL PIPE - CEMENT LINED AND COAL TAR COATED

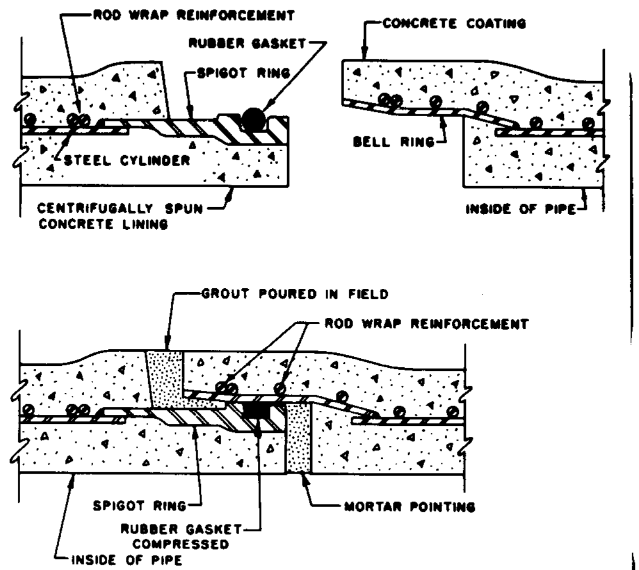
The initial 20 mi. of the mainline will consist of 36 in. spiral weld, 0.281 in. and 0.250 in. wall, grade X-42 steel pipe, internally and externally coated with coal tar enamel and joined by butt welding. The lining is 3/32 in. thick and is applied over a sand blasted and primed surface by centrifugal spinning, all in accordance to AWWA Specifications C203-62. Referring to Exhibit 4, each joint must be field coated both internally and externally after the weld has been completed. The internal coating operation limits the minimum size pipe which can be used to that in which a man can work. After the field joints have been completed, the coating and lining is inspected by the conventional holiday detector, and the necessary repairs are made.

EXHIBIT 4



36" O.D.-0.281" WALL STEEL PIPE JOINT
COAL TAR LINED & COATED

EXHIBIT 5

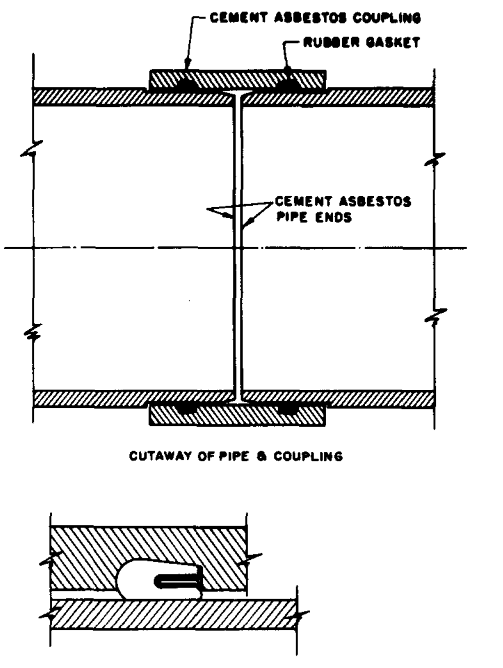


PRETENSIONED CONCRETE
CYLINDER PIPE JOINT

The balance of the main distribution line will consist of 45 mi. of concrete cylinder pipe in diameters ranging in size from 16 in. through 36 in. This pipe is manufactured by using the light gauge steel cylinders, reinforced with rod wrapped under tension to give added strength. The interior is mortar lined while the exterior is coated with concrete. The pipe joints are of the bell and spigot type, grooved to receive a rubber gasket. The joints are of the self-centering type in order that on proper closure, the gasket will not support the pipe, but will be suitably compressed to effect a watertight seal. Referring to Exhibit 5, mortar is placed in the joint area to prevent water contact with the steel in the bell and spigot area. On pipe sizes less than 20 in. diameter through which a man cannot traverse, an asphaltic ring, which may be placed prior to closure, is used in lieu of the internal grout. Special attention should be given the bedding and compaction of the backfill when installing concrete cylinder pipe to prevent its movement after being placed in service.

Cement asbestos pipe will be used in the well field gathering system. This pipe is joined by utilizing cement asbestos couplings with the water seal dependent on a non-load bearing rubber gasket as indicated in Exhibit 6. Cement asbestos is impervious to corrosive action of water, and if installed correctly, should require minimum maintenance. As in the case of the concrete cylinder pipe, proper bedding and compaction of the backfill is essential to prevent pipe movement and joint failure after the line is placed in service.

EXHIBIT 6

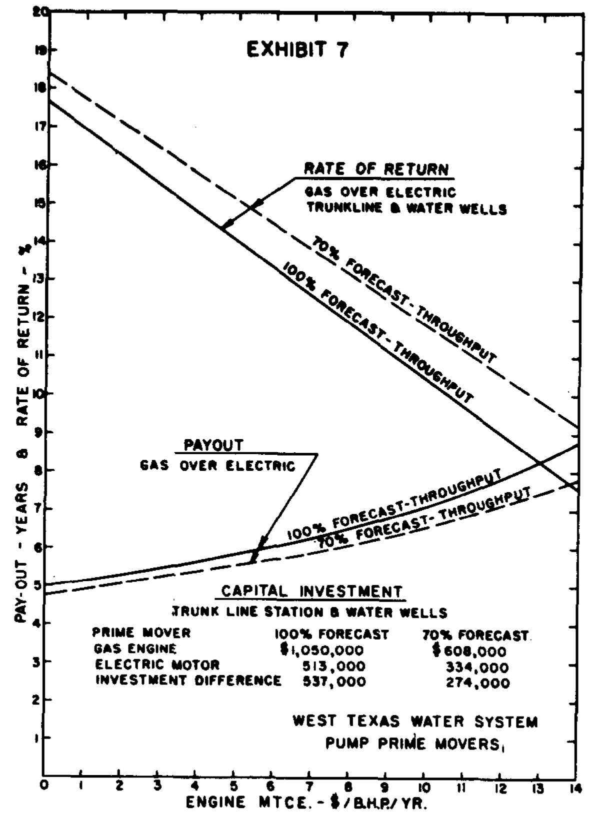


CEMENT ASBESTOS PIPE JOINT

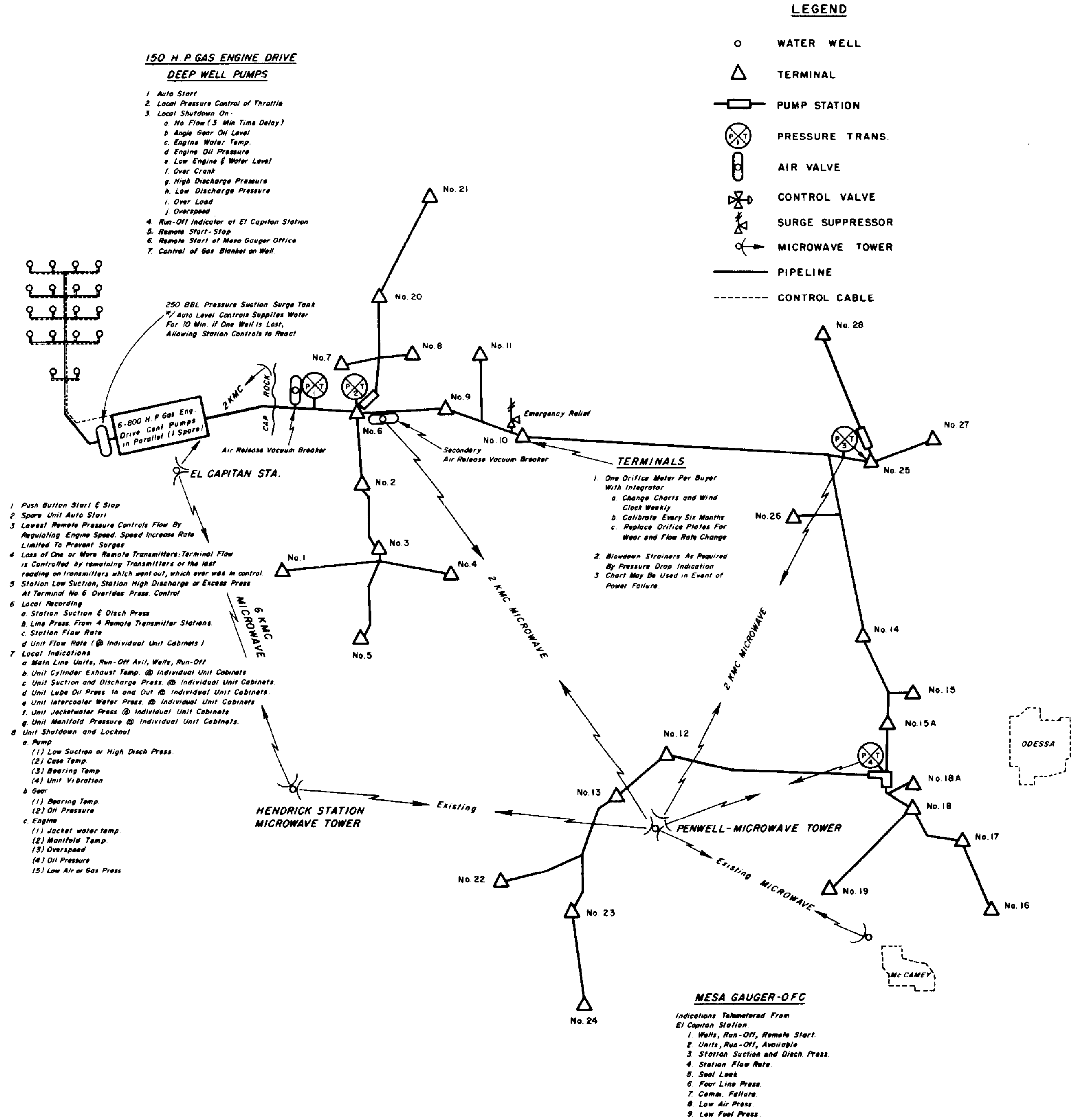
OPERATING FEATURES

The movement of water through a closed system in lieu of utilizing large surge tankage at both the delivering and receiving terminals as is the conventional practice in water handling, will require facilities having a high degree of operational control. The uninterrupted movement of water from 18 wells directly to a 5,000 BHP booster station, thence, through 135 mi. of line to some 50 water flood units having individual usages varying from 1,000 BPD to 150,000 BPD, without the use of large storage tankage, may at first appear insurmountable. It is felt, however, that the science of automation has progressed to the point that the closed system facility in this case can be more economically provided, and also retain the required reliability for uninterrupted service.

Before any type of automation could be planned, the decision on the type of prime mover to be used and the degree of reliability for uninterrupted service had to be ascertained. Upon investigating the facilities installed in the water flood units, it was revealed that a part of the units would have nominal surge tankage while others would take suction directly from the distribution line, and would be shut down on a failure to receive water. Further, the units would be operated unattended and manual restarting would be required when shutdowns occurred. It was concluded that a temporary slowdown in line rates could be permitted while a complete loss of throughput, even if for short durations, would shut down all units and could not be tolerated. Admittedly, the electric motor can be more economically automated and is a more reliable prime mover than the gas engine if its source of power is not interrupted. It has been our experience, however, that the engine driven station will experience practically no complete outages while the outages resulting from power supply failure on the electric drive station is not infrequent. Actual costs of both electric and gas equipment, and power and fuel rates for the operating horsepower were obtained, and with the use of the computer, the 2 types of prime movers were compared. This study revealed, as indicated on Exhibit 7, that the gas engine was the more economical prime mover for this application. Accordingly, 800 HP engines were specified for the main booster station and 150 HP engines for each well unit.



Facilities have been provided to permit unattended operation with personnel required for servicing equipment during the daylight shift. Twenty-four hour observation of the system will be maintained by the dispatching personnel located at the Mesa gauger office in McCamey, Texas. Refer to Exhibit 8.



GENERAL CONTROL SCHEMATIC
EL CAPITAN WATER LINE

EXHIBIT 8

All engines will be equipped with the conventional safety devices, will have automatic lube oil regulators and utilize heat exchanger cooling. The 150 HP well engines may be automatically started from either the Mesa office or the Capitan Station and will be speed controlled by line pressures.

It is tentatively planned that the number of wells to be operated at a given throughput rate be chosen whereby the engines will operate at 850 RPM. Should one well shut down or the required throughput rate increase, the remaining well engines will automatically speed up to provide the additional water. The speed control will be limited from 700 RPM to 1,000 RPM.

The 800 HP Capitan Station units will be equipped with automatic starting and speed control in order that the throughput rates may be varied as necessary to insure a 25 psi minimum delivery pressure to all water flood terminals. Four pressure transmitters are to be located along the delivery lines to monitor and transmit the delivery pressures to the station control system. The transmitter recording the lowest pressure will provide the control intelligence and effect the necessary speed variation of the mainline pumps to either raise or lower the delivery rate. The stand-by mainline unit will be fully automated to come on the line should one of the operating units shut down or if the required throughput exceeds the units in operation at their maximum speed. The conventional low suction and high discharge pressure control system is incorporated to prevent complete loss of throughput when a large variation in requirements is experienced.

The only tankage to be installed in this system will consist of a 250 bbl. suction surge tank with automatic level controls and gas blanketing equipment. This tank will provide additional water equal to approximately 10 min. operation of one well. This stand-by water supply will not only permit the use of slower acting control devices having more reliability, but will also eliminate the surge pressure conditions which would be experienced with a fast acting control system.

SUMMARY

Our approach to the corrosion problem has been to endeavor to retain the water at its minimum corrosive state by excluding air contact and to select those materials which are corrosive resistant and could be economically justified. Only time and observation will indicate how successful we have been.

The control system has been designed to handle normal variations in flow rates. The unscheduled starting and stopping of the smaller units in sizes up to 20,000 BPD can be easily handled; however, although the system will allow unscheduled shutdowns of the larger units, their restarting will require scheduling.

ACKNOWLEDGMENT

Appreciation is expressed to the various technical specialists of Shell Oil Co. and Shell Pipe Line Corp. for their assistance in preparing this paper.