Panel Discussion

Factors Affecting Design of Waterflood Systems

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Source Waters and Water Handling

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Dr. Walter Prescott Webb, the noted historian who heads the History Department of the University of Texas, in an article titled "The American West - Perpetual Mirage", published in Harper's Magazine, 1957, referred to most of the Western half of the United States as a vast desert. He included in this area all of New Mexico and parts of West Texas with an additional portion of Texas in the transition zone or part of the "rim of the desert". As might be expected, there was a rather harsh editorial reaction to these statements; and several denunciations of the article, and its author, were read into the Congressional Record.

Dr. Webb, in answer to his critics, has stated his intent to aid the people of this area in understanding and adjusting to the environment in which they live. Although they may not fully agree with Dr. Webb's description of their area, they must be prepared to recognize that water is a priceless and essential resource of seriously limited supply in much of West Texas.

Recognition of this fact leads to the conclusion that West Texans must be prepared to utilize any available source of water for waterflood no matter how unfavorable it may be. The available supply will allow the user to be too particular now, and the situation will become increasingly acute in the future. People must begin to think in terms of adequate volume being the only essential qualification of a water source for flooding. Corrosiveness, scaling tendencies, undissolved solids content, and similar detriments must be thought of only as factors which must be considered and dealt with through operational methods under control.

Operations now in progress are utilizing water from almost every imaginable source. A number of projects are using sea water, and increasing attention is being given sewage plant effluents and industrial plant wastes as possible sources of flood water. It is to be expected that efforts in this direction will be enlarged as water flooding increases and as the more easily handled water sources become less available. However, it is not the purpose of this short discussion to instruct in the techniques and processes of handling such waters; the point to be made is that the industry is being forced to these operations and that such waters can be and are being successfully injected.

The two major factors which control the cost of handling a given water are its cleanliness and its corrosiveness. As it is delivered to the formation a satisfactory injection water must be sufficiently clean to allow its displacement at satisfactory rates with acceptable pressures. Although some injected formations have a greater tolerance for undissolved solids than do others, it can be stated generally that undissolved solids contents in excess of 1-1/2 to 2 ppm are excessive and an upper level of 1 ppm is desirable. If larger amounts of solids are present in available source waters, processing for solids removal will be necessary. And if the water is seriously corrosive, it will be necessary to provide protection either in the form of physical coatings and linings or of chemical treatments to render the water less corrosive. Either form is certain to be costly.

The correct approach to the choice of an injection water at a given project is to determine, first, what sources capable of meeting volume requirements are in existence in the area. This source more often than not, will be the single controlling factor. In cases where there are more than one possible source, it is necessary to consider them separately and determine the costs involved in handling and processing each water so that the more economical source can be chosen.

There are reliable procedures which can be utilized to determine what processing, if any, is required for solids removal. Most natural surface waters such as lakes, rivers, ponds, etc. contain suspended silts and clays in amounts which are excessive for satisfactory injection. It is generally true, too, that these silts and clays can not be removed by simple filtration. In these cases, to achieve the required end, it usually is necessary to employ flocculation, coagulation and sedimentation upstream of filtration. This is the type processing which is routinely employed in municipal water systems and is adequately described in literature, and treatment of this type involves relatively high capital expenditures and requires almost constant operational attention. It is, therefore, much better suited, economically, to projects involving large volumes of water than to smaller installations.

In some instances, it is possible to "tap" surface water supplies by completing shallow wells in sand or gravel deposits in communication with the surface water. In many cases, water produced by such wells has been effectively cleansed by induced filtration through the sand and gravel deposits. Further, where alluvial deposits are sufficiently large, multiple wells can be used to meet the requirements of rather large projects, but wells of this type are frequently completed in unconsolidated sands and sometimes produce quantities of sand. Even so, sand removal can be accomplished without flocculation and attendant processes and it often is more economical to drill several such wells than to provide municipal-type treating facilities. This decision, of course, is particularly valid for smaller systems but may hold for larger systems as well.

In the vast majority of instances where water sources other than natural surface waters are employed, simple filtration through graded media filters will be adequate to provide water of satisfactory quality for injection. In a surprising number of cases where wells completed in a competent formation provide the water source, no processing of any kind is required for solids removal. More often than not, the question to be answered is, "Is it necessary or desirable to provide filtration?"

It is highly desirable that the water source be available for examination and study prior to final plant design and construction, and when this water is not available, all practical steps should be taken to make it so. When possible, supply wells should be completed and produced to waste for several weeks prior to plant construction, for this period provides the opportunity to determine accurately the amount and composition of solids present in the water. This determination, of course, will clearly indicate whether filtration is or is not needed.

When the water source for a flood can not be studied in advance of plant construction, it sometimes is desirable to design and build the simplest plant possible and to bear in mind the possibility of adding filtration, if needed, at a later date. This action is particularly desirable in instances in which supply wells will be completed in a competent zone or in which a neighbor's experience is available to show the probability of a clean water supply.

Filtration is much more likely to be required for handling brines separated from produced oil than for waters produced from water wells. This need for filtration is not due to inherent differences in the water but to the result of the degree to which the waters are handled and manipulated on the surface prior to gathering for reinjection. In a rod pumped well there often is opportunity for slight air entry down the casing or through a leaking stuffing box, and the entry usually will cause some precipitation of minerals which had been in solution under air free conditions. Too, heating for oil separation can cause precipitation of scale particles and in some instances sand particles and solid organic particles are present in water produced with oil. All these, and other factors, increase the likelihood that a brine separated from oil production will require filtration, but here in the majority of cases, simple filtration through graded media filters will provide satisfactory results. Small amounts of liquid oil which might be present in such waters usually creates no problem if steps are taken to prevent excessive oil accumulation in the filters, and traces of oil which pass through the filters can be displaced into the injected formation without difficulty so long as the undissolved solids content of the water is not excessive.

The preceding discussion assumes that water will be handled in a manner which will not destroy the chemical stability of the water. Stability, in this sense, means that no solids, in addition to those present in the water at its source, will be formed by chemical reactions as the water passes through the system. It is essential that an injection water be stable, and the most effective filtration possible serves little purpose if additional solids are precipitated from the water after it has been filtered. This requirement is basic and it influences the decision of whether the system should be "open" or "closed". Natural surface waters are saturated with oxygen and are stable in the presence of oxygen, hence there little point in preventing further contact of such waters with air. Most subsurface waters, on the other hand, contain ferrous iron and other metallic ions which will oxidize on exposure to air and be precipitated as a solid. In the majority of instances, such waters are best handled in a closed system so their natural stability as produced is maintained.

There are other possible causes of instability; these include certain corrosion reactions, bacteria activity, and a mixture of two or more waters containing constituents which react to form solids. The last of these is predictable in advance and can and should be avoided by proper planning. It is possible through chemical analysis to determine if two or more waters are compatible when mixed, and such tests should always be made to determine if the water produced from the injected formation can be mixed with supply water for reinjection or must be reinjected or disposed separately. Similarily, if a mixture of two or more source waters is contemplated, their compatibility must be assured in advance.

It might be observed here that it is not essential that injection water be compatible with water present in the formation to be flooded. It has been adequately demonstrated both in the laboratory and field that little or no plugging results from displacing a formation water with an incompatible injection water. Such a condition does in some cases lead ultimately to mineral deposition in producing wells and requires that produced brine be reinjected or disposed of separately. However, these problems almost always can be handled satisfactorily and are not prohibitive.

Corrosion is perhaps the most difficult of the problems which must be dealt with in water flooding. There are two basic approaches to minimizing corrosion: (1) to employ various forms of physical protection such as coatings and linings for all pipe and equipment in the system; (2) to utilize chemical inhibitors or other treatments or processes designed to render the water non-corrosive. There are many excellent coatings, linings, chemical inhibitors, and related services available to the industry; but there are many known instances in which the best of these have been inadequate. The corrosion environments encountered in waterfloods are generally more severe than are those encountered in primary oil production, and only the best of the corrosion preventive products available have any real chance of success. It follows that effective corrosion control is seldom, if ever, cheap: there is no corrosion control program sufficiently reliable and inexpensive enough to justify its recommendation as an "insurance" measure, regardless of circumstances.

The fundamental factors governing the need for corrosion protection and the type protection best suited to the project are: (1) The anticipated project duration, (2) the corrosiveness of the water, (3) the total volume of water to be handled, and (4) the amount of pipe and equipment which will be exposed to injection water.

The first two concern the need for corrosion protection. If the project is to have an extended life - perhaps 15 yr or longer, it can be concluded that corrosion protection will be required. There are very few waters which are not sufficiently corrosive to cause failures in 15 to 20 yr. If, on the other hand, the project is to be completed in 5 or 6 yr, corrosion protection will be needed only if the injection water is quite corrosive.

The major difficulty is in predicting the corrosiveness of a water so that the need for protection can be determined prior to project initiation. But it is possible to detect, from water analysis data, extremes of corrosiveness or non-corrosiveness. For example, a heavy brine containing sulfides and carbon dioxide and exhibiting a low or acid pH will be severly corrosive. At the other extreme, a fresh air-free water of neutral pH, in the absence of sulfides, will be non-corrosive. Between these extremes, experience with a specific water is the only truly reliable criterion of corrosiveness. Water analysis data will allow an educated guess, but when possible this guess should be supplemented by determining the experiences of others in the area with waters from the same source.

The choice between using physical protection such as coatings and/or linings or of employing chemical treatments will be determined to a large extent by the total volume of water to be injected and the amount of pipe and equipment exposed to the water. The cost of chemical treatments to render the water non-corrosive will be directly proportional to the volume of water to be treated. The costs of using coatings or linings will be independent of water volume but directly related to the amount of pipe and equipment in the system. These factors, in general, favor the use of chemical inhibitors in lower-volume shorter-life projects and coatings and linings for higher-volume longer-life projects. This statement is obviously an over simplification but is intended to illustrate the economic basis on which such decisions should be made.

There are numerous exceptions to the generalities which have been stated above; and, associated with water handling, there are other problems which have not been mentioned. Discussions of many of the more exceptional circumstances and specific problems are in published literature, but it is hoped that this more fundamental discussion will be of some benefit to those not yet experienced in water handling procedures.

Design of Water Distribution Systems

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In any water distribution system, the design of the system will be indicated by a number of different but related items. The actual method of distributing water to individual wells will be directly determined by the injection pattern. For instance, if a five-spot pattern is used, it may be advantageous to utilize some type of main distribution line with branching lines to strategic locations where meter stations can be located for handling groups of wells. However, if a peripheral injection pattern is used, the injection lines may loop the entire field in such a manner as to pass close by each injection well.

The size of the line will be determined by the volume of water to be transmitted and the distance of transmission. To determine line size, one must determine liquid flow requirements in terms of BWPD and also in GPM. With the volume requirements available, a calculation of pressure drop in terms of feet of head loss per linear unit of line can be calculated, or, as is the common practice, reference is made to prepared tables which indicate feet of head loss per linear unit of line at various flow rates for various pipe diameters. Lines must be designed with sufficient capacity so that over the required distance, the pressure drop will not become excessive. A method of maintaining a desired pressure at a distant point in a distribution line would be to use higher plant discharge pressures; this method entails the use of larger equipment such as pumps and motors and increased power costs. Many operators design a distribution system so that the pressure drop at the end of the system will be not more than 75 psig of the plant discharge pressure. Lines should not be oversized since this will greatly increase the required investment. Another item heretofore not mentioned but which should be given careful attention is that of the terrain. In designing any distribution line, accounting must be made for any head loss or gain because of changes in elevation. It also should be borne in mind that the routing of lines may be greatly affected by surface anomalies, such as elevation changes, river or stream crossings, and rocky or swampy terrain. Normally, a distribution line will be of varying diameter, so that as groups of wells are serviced and the quantity of water being transported from the plant to the outlying wells decreases, line size also decreases. In addition to the above, future requirements must be considered and some additional volumetric "safety factor" should be considered.

In designing a water injection system, not only must future or anticipated throughput be taken into account, but the types of various waters must also be considered. In most cases, a water flood will be initiated by using a fresh water or brine not native to the formation being water flooded. Since it is known that as the flood progresses water production increases, an increasing volume of produced water must either be disposed of or reinjected. Flood economics dictate the reinjection of produced waters rather than attempting some other disposal scheme. Since at some stage in the flood the mixing of the makeup and produced waters for injection would become a possibility, attempts are usually made to secure samples of the produced water and mix this water with the proposed injection water in varying ratios to determine compatibility. It may be possible to mix the two waters and operate a single system of injection, but more often, this procedure entails a split system, that is, part of the field utilizing produced water and part of the field using the make-up water. Sometimes the two waters are compatible, but field experience indicates that if laboratory compatibility tests indicate some difficulty such as scaling, actual conditions very often are more severe; and if not correctly considered in the original installation, the conditions might entail the redesign of a system in the very early stages of flood life.

Coupled with the selection of the proper line size is the consideration of material. Since significant pressures are nearly always encountered, steel pipe is most frequently used for injection lines. Aluminum pipe can be used in specific cases but it does not have the general application of steel, and plastic pipe in common use today will not withstand normal operating pressures.

The problem of internal coating and the method of joining sections of pipe will depend on the life of the project and the type of water to be handled. If a water which is only mildly corrosive is to be handled in a rather short term flood, unprotected pipe using threaded connections is often used. However, if a corrosive water is utilized, protected piping is usually installed, unless a very short project life is anticipated. Long term projects should utilize internal protective coatings which can be either plastic coatings or cement linings. Present operating practices indicate that cement linings are used more frequently than plastic coatings for injection lines. The method of coupling may vary, but if cement linings are used, the sections of pipe are usually joined by welding using an asbestos gasket. The grooved pipe clamp is now being extensively field tested and holds promise of widespread application in the future. External coatings and wrappings are normally not used except in specific cases if required. This usage also applies to anodes and insulators.

Metering of water volumes may be done at the main plant utilizing an integrating recording orifice meter or a positive displacement meter or rotary type meter. Metering of individual well injection volumes is normally accomplished using positive displacement meters which may be located on individual wells or grouped at meter stations and which can be read manually on a scheduled basis or automatically. The methods of automatically reading meters and relaying data to the central control area involves the adoption of an impulse counter to the positive displacement meter which, for every set interval of injection, will send out a pulse which is transmitted and recorded in some manner at a central location. This recording may utilize visual counters, printed or punched tape. Plant discharge pressure can be automatically regulated at the water plant; but pressure control at the individual wells is usually made on a manual basis by the use of a regulating valve. Since this valve is subjected to turbulent flow conditions, a valve having a replaceable seat is often used.

The foregoing discussion is a general review of problems encountered in the design of water injection system. Every installation will involve the examination of each item to determine method of distribution, proper line size, the requirement of internal and external coatings, method of accumulating injection data and regulation of plant discharge pressure and pressures at each injection well.

Plant Design

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Obviously a topic of such magnitude and complexity as that of water injection plant design cannot possibly be covered in any great detail in the time allotted. Consequently, it should be made clear at the outset that (1), there are likely to be as many good injection plant designs as there have been engineers who have had to design such plants; and (2) I do not make a pretense of being an engineer with all the answers in such design work. I intend only to discuss, in general, an outline of some of the more important considerations in the design of injection plants.

The design phase of any water injection station or plant certainly cannot be completely divorced from the water source or its ultimate use or destination. Volumes to be handled, expected pressures to be encountered, and the life of the flood are all factors which must be analyzed. In addition, the physical and chemical characteristics of the water or waters to be handled and their effect on the equipment with which they come in contact must be taken into consideration. Another important factor which will surely affect the design of the station is whether or not it will be designed to handle produced or recycled water from the flood. The basic assumptions utilized when considering the above listed items will all have some effect on the ultimate design; and should any of these assumptions be in too great error it is likely that somewhere down the road one will find that he has either over-or under-designed his facilities. Most assuredly in nearly all cases in the design of the station, room should be left for further expansion based on changes in volume or of pressures which were not anticipated at the time of the initial study.

In the design of any water station or plant the main components of equipment to be considered are the injection pumps, prime movers, and such auxiliary equipment as controls, speed reducers or increasers and couplings, air compressors, cooling systems, and pulsation dampeners. Of course, a prime consideration of any design such as this, where there are several choices in types of equipment, is the economics which probably is best considered in terms of present worth.

INJECTION PUMPS

In making a choice of the type of injection pump that best fits the particular design, there are several factors to consider, i.e., cost of equipment, which not only includes the cost of the pump but also the comparative cost of the installation, housing, if any, and auxiliary equipment peculiar to the type of pump being considered. Another consideration is that of the expected life of the injection station and the possible salvage value of the pump at the end of operations. Expected operating expenses are very important and these are influenced particularly by the efficiencies of the pump together with the cost of operating and maintaining the equipment. Naturally the choice of the type of pump is greatly influenced by the choice of the prime mover, and a possible factor that may sometimes need to be considered is the space requirement of the installation. The types of pump avilable for consideration are vertical turbine, plunger, and centrifugal.

Vertical Turbine

The vertical turbine pumps should be given particular consideration where design requirements are in the middle range of pressures and volumes. They can be very well adapted in pilot waterfloods or in floods with anticipated short life. Some of the advantages of the vertical turbine pump are low first cost, low installation cost, small space requirements, and generally low maintenance, at least over a short span of life. However, it is quite possible that maintenance over a long period of time may result in higher costs and excessive down time. A particular disadvantage of this type of pump is its relatively low efficiency (70-80%).

Plunger

The plunger pump seems to be particularly adapted to high pressure service in low or medium volume requirements. As a rule reciprocating or plunger pumps would be well adapted in situations where volumes of 15,000 BPD or less with discharge pressures at 1,000 psig or greater are necessary. One advantage of the plunger pump is high efficiency (in the range of 90%). It also has a successful and long record of use in the above type of service. Some possible disadvantages are the original high initial cost, high installation cost, higher maintenance cost than other types, and a tendency to present pulsation and vibration problems.

Centrifugal Pumps

Centrifugal pumps are available in nearly all ranges of pressure and volume and should be given consideration in nearly any application. Advantages of this type pump, like those of the vertical turbine, are low initial cost, small space requirements, low installation cost, as well as low maintenance and operating expense. A large degree of flexibility of pressure and volume requirements within the capacity of the particular pump chosen can be obtained with the use of a variable speed drive. Centrifugal pumps generally can be expected to have long operating life and are capable of fitting into automatic operations with simple controls. However, the greatest single disadvantage of this type of pump is its efficiency, which in low volumes (below 5,000 BPD per pump) is in the range of 50-75%. As the volume capacity of the pump increases above 5,000 BPD, there can be selected efficiencies ranging from 75-85%. In the case of the low volume centrifugal pump in a low pressure operation, the power or fuel consumed may be small enough that the low efficiency of this pump would not seriously detract from its usefulness.

PRIME MOVERS

As previously mentioned, the choice of prime movers goes hand in hand with the choice of pump to be utilized; and among the more important considerations involved in the choice of a prime mover are the avilability and cost of fuel or power, the first cost of installation includ ing foundations, auxiliary equipment such as spee increasers or decreasers, the life expectancy desired, the type of pump which the prime mover must drive, the total operating expense including the energy cost, maintenance, and attendance. The type of prime movers for this discussion which should be given consideration in any plant design are the (1) gas engine, (2) electric motor, and (3) gas turbine.

Gas Engines

The prime advantage of the gas engine is variable speed control which aids in flexibility of plant thru-put. In most waterflood areas where gas is a relatively cheap source of energy the total cost of the energy consumed is relatively low. But the investment cost for installed horsepower of gas engines is high and the maintenance of gas engines can be expected to be considerably more than that of electric motors and likely much higher that that of gas turbines. Furthermore, they are less easy to automate than are the other types of prime mover, although certainly gas engines can be made to operate fully automatically if desired. The industry usually thinks in terms of two types of gas engines -- slow speed - 300-720 rpm and high speed 900 rpm and up. It may be said of the slow speed engine that its advantages are long life (25-30 yr), lower operating cost on fuel and oil, and lower maintenance cost in comparison with the high speed engine. Some of its disadvantages are high initial cost and higher installation cost. Too, complete engine overhaul may be required every 2 - 3 yr. The slow speed engine has a 98-100% availability; that is, ready to run when needed.

On the other hand the high speed engine has a lower investment cost and a shorter life than the heavy duty units and will require more frequent overhaul and higher maintenance cost. These factors will result in higher operating costs.

To try to tie down an accurate total maintenance cost for a gas engine-driven plunger pump unit is not easy and it is not difficult to find figures that will range from \$5-\$6 per hp per year to \$12-\$14 per hp per year.

Gas Turbine

The present initial cost of gas turbines is approximately that of slow speed gas engines but with considerably reduced installation cost. In the present stage of development, gas turbines are somewhat more inefficient than are gas engines, but this difference in efficiency is being decreased as new and better gas turbine designs are made. Because of the simplicity inherent in the design -- that is, rotating motion rather than reciprocating -- it could be expected that maintenance of a gas turbine would be considerably less than that of a gas engine. Where the price of gas is low this difference in maintenance cost could more than offset the difference in efficiencies of the two. The use of gas turbines is relatively new in industrial application and although the dependability of the turbine has not been proven as yet for the type of service which is under consideration here, what has been observed to date is pleasing. Gas turbines are particularly compatible with centrifugal pumps since their torque and horsepower curves are similar in nature as both are rotating machines. In summary, it can be said that initial costs are not cheap for gas turbines. However, these costs are partly offset by economical installation cost. And it is expected the gas turbine will require less maintenance than do engines, but fuel cost could be higher unless exhaust heat can be utilized. They, too, offer simplicity of design lending themselves easily to control and automation, requiring little foundation work and occupying much less space than do gas engines of equal horsepower rating.

Electric Motors

Electric motors are undoubtedly one of the cheapest installations to make, although cost of power lines and transformer banks should not be overlooked. They naturally lend themselves quite easily to automation and have low maintenance costs. Also their initial investment and operating costs, exclusive of energy costs, are less than any other type of prime mover and they are dependable for long life projects and have high salvage values. But their prime disadvantage is the high energy cost as compared to that of gas engines or turbines. However, this high energy cost can often be offset by their automation features that result in the reduction of operating personnel which together with their low initial. installation, and maintenance costs make them quite an attractive installation. In one particular location load factors and demand have increased to such an extend that costs are an average of somewhat less than 7 mils per KW and when this stage is reached, electrically driven stations should receive serious consideration. This stage of operation is expected to be reached in a number of other localities.

In West Texas it seems that the trend at the moment in some station design is electrically driven centrifugal pumps where economics permit.

AUXILIARY EQUIPMENT

As in any plant design the need for auxiliary equipment is directly related to the type of prime movers and pumps selected. Such equipment includes speed increasers or decreasers and couplings, controls, air compressors, cooling systems, and pulsation dampners.

Speed Reducers and Couplings

The type of equipment used here can range from V-belt drive to large heavy-duty gear boxes and will depend largely upon horsepower requirements. With the use of gas engines or turbines as prime movers it is thought that the engine manufacturers should be responsible for proper selection of gears and couplings. A torsional analysis should be made of all rotating parts and couplings selected for the particular speed ranges desired; and the greater the speed range the larger and more flexible the coupling should be. Variable speed couplings of the hydraulic or magnetic type are reliable and may be advantageously utilized to vary the speed of the pump for control of both pressure and volume delivered by the pump where it is not desired to bypass water. The coupling used between prime movers and speed reducers and pumps should be given careful consideration for they are a very important component of any plant design and no coupling or gear box will have a long life if the equipment is out of alignment, or if it us not selected on the basis of good engineering practices and installed properly.

Controls

(1) Operating: Where variable speed couplings are not utilized, motor valves pilot operated together with a bypass system may be used to control line pressure. Though this equipment is reliable valve repairs may be excessive. The use of variable speed couplings to control pressure and volume delivered by pump has been mentioned previously. Another method of operating (or plant control) when either gas engines or gas turbines are the prime movers is in the use of pneumatic controls which sense either pressure or flow rate and adjust fuel valves or governors accordingly by means of valve operators to change operating speed.

(2) Safety controls are generally those which, because of malfunction of the equipment will shut-down equipment. If the controls are remotely operated they are generally pressure actuated, and telemetering systems have also been successuflly utilized. Some of the more important safety devices required for good operation include the following: bearing temperature checks on electric motors and centrifugal pumps, pressure switches on suction and discharge of pump, low oil-pressure switches, vibration switches for both prime mover and pump, and standard engine and turbine safety switches.

Air Compressors

Air compressors may be utilized for a variety of functions in a water injection plant.

For instrument air, a compressor with ample capacity to control station valving and instruments should be selected. These are usually air cooled types and are not designed for 24 hr operation; therefore, their operating time should be limited to pump-up time and time allowed for compressor to cool. Heavy-duty air filters should be selected and the air discharged should be put through filters and dried to clean the air of oil and moisture. Air compressors in this range are normally rated at 50-60 psig. Non-lubricated construction is available for instrument air compressors if desired, and this feature offers oil-free air for instruments.

Air compressors for engine starting are also usually air cooled units designed for 250 psig. However, they are not considered heavy duty and are rated as intermittent duty compressors. To size starting air systems a rule-of-thumb is the square root of the installed horsepower equals the cubic feet of tank required for air storage. A compressor is then sized to pump-up in volume from 175-250 psig in approximately 15-20 min. If the plant is large enough to require frequent overhaul, then a plant air compressor is desirable for operating air drills, grinders, impact wrenches and hoist plus cleaning and painting; a 125 cfm-100 psig air compressor could handle most of the above jobs very easily. In any event care should be exercised to insure that the total capacity of the air compressors is sufficient to meet present as well as anticipated demand in possible future plant expansion.

Cooling Systems

Cooling systems are required with gas engines and can consist of either radiator or heat exchangers utilizing the pump water to cool the engine cooling water. In some cases ebullition cooling might be utilized to increase engine efficiency, and in these cases fin-fan coolers are desired. In some of the larger installations it may be necessary to provide cooling for lube oil used in the prime mover, gear boxes, and pump. A choice of this type of equipment is affected by many factors, among which are the temperature of the water being pumped, the corrosive effects of this water, and the maximum and minimum ambient temperatures expected. In most waterflood stations it has been found that heat exchangers are more desirable, cheaper, and easier to install; and because of the corrosiveness of water it is generally desirable to install oversized heat exchangers for fouling factors. This oversizing may be as much as 10-15%. On gas engines treated water is utilized in engine jackets which can be sub-cooled for use in oil coolers. In this manner only one raw-water heat exchanger is used and this is placed in the suction line to the waterflood pumps with valving generally being used to control automatically water and oil temperatures. And to avoid scaling as much as possible it is best to keep the raw-water velocities high.

Pulsation Dampners

Pulsation dampners are nearly always required when plunger pumps are used, but, on the other hand, they are normally not required with the rotating type pumps. The amount of pulsation occuring in a station can be directly affected by the design of the piping, and all efforts should be made to reduce, to a minimum, abrupt changes in flow through the piping system. All types of pumps must have ample suction pressure to insure good operation and particular attention should be given to the design of suction headers and lines to insure that net positive suction head requirements are met. A good design for water velocity on suction and discharge line is 3-4 ft per second with long radius pipe bends utilized to avoid sharp T connections. This design is particularly valid with the reciprocating pumps. Suction lines should be kept free of air and should slope so they will stay full of water (not air) and have vents installed at high points. However, high points should be avoided if at all possible. Ample pressure gauges should be provided to record suction and discharge pressures. Pulsation dampners may not be absolutely necessary but they will generally eliminate some vibration -- provided the pump suction design is adequate -- and they definitely prolong pump discharge valve life. In summary proper line size and good layout are essential.

Present Worth Considerations

As previously stated the most important consideration in the design of any water injection station is economics. One way of evaluating these economics is to make a present worth study of the several possibilities for a particular application. There are, of course, a number of ways to calculate the present worth and different companies will use various approaches to this problem, but the principal factors involved in any such calculation are the number of years of operation, the investment cost, the operating cost, the depreciation, income tax credits, other taxes, and the expected rate return or interest on investments. Maintenance and operating costs are vital factors in this calculation and all too often are underestimated.

CONCLUSION

In conclusion, it must be stressed that only the more important considerations of water plant design have been included in this discussion. There are many detailed items and problems that must be studied and worked out before a plant design can be considered as complete which have not been touched on in this dissertation.

In closing I desire to express my appreciation to Gulf Oil Corporation for permission to appear on this panel on a matter of such importance to the oil industry and especially important to operators in the Permian Basin. I also wish to express my sincere thanks for the cooperation and help that I have received from the many engineers of Gulf Oil Corporation, especially Mr. C. W. Williams, Area Engineer for Gulf at Goldsmith and Mr. R. G. Wingate, a Senior Petroleum Engineer in the Monahans Area, as well as to Mr. Frank Hayhurst of the Ingersoll-Rand Company, who have all contributed material and opinions for this discussion.