IMPROVE PROFITS THROUGH ENGINEERED PUMP STATION DESIGN

CHARLES R. HABERTHUR
Sun Oil Company

INTRODUCTION

Proper consideration of all pertinent factors when designing a pump station, especially pump suction requirements, pays big dividends throughout the life of the project. Savings will be realized through increased pump efficiency and reduction of maintenance expense.

This paper deals primarily with suction head requirements, suction and discharge piping and pulsation dampeners and is aimed particularly at reciprocating pumps; however, most of the engineering principles and practices described should be observed in the design of any pump installation.

SUCTION HEAD REQUIREMENTS

Any efficient reciprocating pump installation must maintain adequate suction head at all times to keep the fluid being pumped in the liquid state throughout the pumping cycle. If this is to be accomplished, the available head must overcome the following:

1. Vapor pressure
2. Entrance losses
3. Pipe friction
4. Acceleration head
5. Net positive suction head requirement of the pump.

Figure 1 graphically illustrates these requirements and losses.

Vapor Pressure

All liquids, at temperatures above their freezing point, have a corresponding vapor pressure. We are familiar with the vapor pressure of volatile liquids, such as propane and butane, but do not ordinarily think of water at moderate temperatures as having vapor

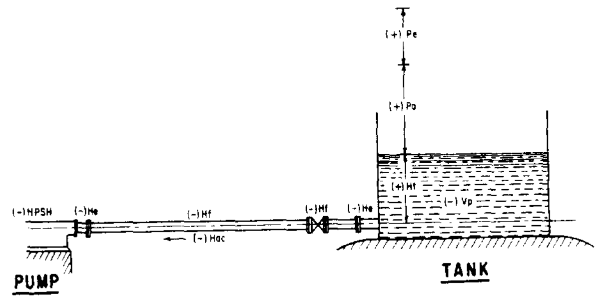

FIG. 1—RECOMMENDED SUCTION CONNECTION

pressure. Figure 2 illustrates the vapor pressure of water at temperatures normally encountered in oilfield operations. Water which contains carbon dioxide or other gas in solution can have a very high vapor pressure at low to moderate temperatures (think of soda water) and must be given special consideration.

If, at any time, pressure within the suction piping or fluid end cavity falls below this pressure, vapor will be flashed and cavitation will result.

Entrance Losses

Entrance losses result from a change in the flow section and are friction losses. These losses occur where pipe leaves the tank, in reducers and in manifolds where reduced pipe size is used as takeoff and are usually of a minor nature. The equivalent pipe length for entrance losses may be found by the following formula and added to the actual pipe length for friction calculation.

$$L = \frac{.000317(GPM)^2}{D^2}$$

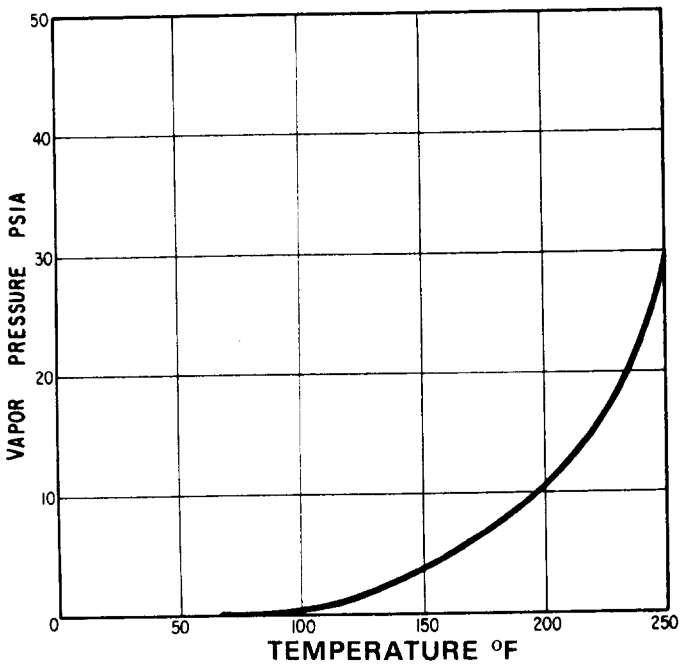

FIG. 2—THERMAL PROPERTIES OF WATER

Pipe Friction

Frictional losses in the suction piping and fittings are pressure losses which reduce the total pressure available to fill the pump cavity. Friction data should be calculated on all piping, being careful to include values for valves and fittings. If the suction piping is properly designed, these losses should be very small. Tables and nomographs are readily available which make these calculations simple.

Acceleration Head

Acceleration head is that pressure required to maintain flow at the suction opening of a reciprocating pump. The flow of fluid to (and also away from) a reciprocating pump has a pulsating flow pattern determined by the speed and number of plungers. The velocity pattern of the flow consists of peaks and valleys and consequently the total mass of fluid in the suction system must follow this pattern. The acceleration head must supply enough force to accelerate this mass from near stoppage to maximum velocity in the short period of time that the plunger is moving back and the cavity must be filled. If enough force is not present at the suction inlet to accelerate the mass as required, the internal pressure will fall below vapor pressure and cavitation to some degree will occur.

The acceleration head requirement may be calculated from the following empirical formula:

$$Hac = \frac{LVNC}{Kg}$$

Where:

L = Length of suction piping in feet
V = Average velocity in suction piping in ft/sec
N = Revolutions per minute of pump
C = Constant based on flow pattern of pump
= 0.115 for double acting duplex
0.066 for single or double acting triplex
0.040 for single or double acting quintuplex
K = Gravity and viscosity constant for fluid pumped
= 1.4 for water
= 2.5 for hot oil
g = Acceleration of gravity = 32.2 ft/sec^2

Example problem:

Calculate Hac for 4-in., 6-in. and 8-in. suction piping for a triplex plunger pump operating at 360 rpm and pumping 3000 BWPD. Suction piping will be 15 ft long in each case.

Solution for 4-in. Piping:

$$V = 2.2 \text{ ft/sec}$$

$$Hac = \frac{(15)\,(2.2)\,(360)(0.066)}{(1.4)\,(32.2)} = 17.4 \text{ ft}$$

Solution for 6-in. Piping:

$$V = 1.0 \text{ ft/sec}$$

$$Hac = \frac{(15)\,(1.0)\,(360)\,(0.066)}{(1.4)\,(32.2)} = 7.9 \text{ ft}$$

Solution for 8-in. Piping:

$$V = 0.56 \text{ ft/sec}$$

$$Hac = \frac{(15)\,(0.56)\,(360)\,(0.066)}{(1.4)\,(32.2)} = 4.4 \text{ ft}$$

Allowance for acceleration head requirements is the key to successful suction design for reciprocating pumps. For pumps operating at high speeds, with relatively large plungers, all other losses or requirements are small by comparison. Many users are not aware that such a requirement exists and the consequent failure to allow for acceleration head requirements is without doubt the most common cause of poor pump operation and pump failure.

Net Positive Suction Head (NPSH)

The net positive suction head requirement is a characteristic of a specific pump and is that head required to overcome valve spring loading, weight and inertia of valves, friction losses and fill the pump cavity. This requirement is influenced by plunger size and rpm as shown in Fig. 3.

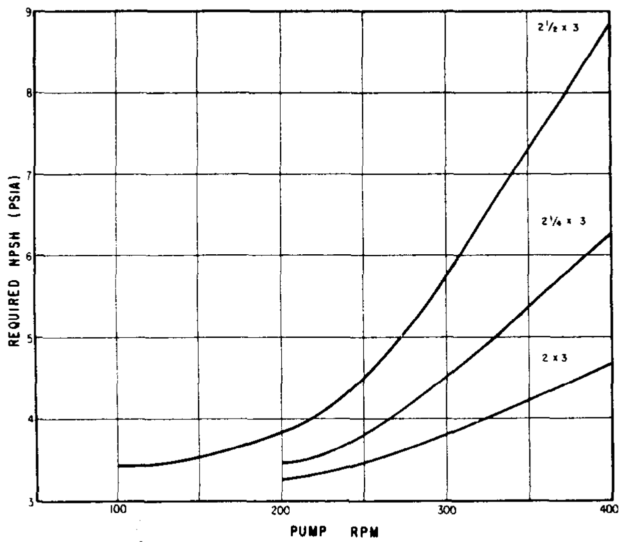

FIG. 3—TYPICAL NPSH CURVE

Valve design is of particular importance in the magnitude of this requirement. High spring loadings and heavy discs with consequent large inertial forces require large differential pressures to open. Each of these losses is magnified by larger plunger sizes and higher rpm.

The total available suction head must, in every case, be equal to or greater than the sum of the above requirements and losses. This available suction head may be in the form of tank head, atmospheric pressure or some external pressure acting on the suction system. (See Fig. 1). Thus, the following equation may be written:

$$Ht = Pa + Pe \geq Vp + He + Hf + Hac + NPSH$$

Where:

- Ht = Tank head
- Pa = Atmospheric pressure
- Pe = Pressure from an external source applied to the suction side of the pump
- Vp = Vapor pressure of the fluid being pumped
- He = Entrance losses
- Hf = Pipe and fitting friction losses
- Hac = Acceleration head requirement
- NPSH = Net positive suction head required at the pump

Each installation should be carefully engineered to assure that all suction requirements are met. The penalty for failure must necessarily be poor pump operation and performance.

SUCTION PIPING

From the foregoing discussion it is readily apparent that suction piping which is short, of large diameter, and with a direct flow pattern will be required. The pipe, valves and fittings should be designed and located to avoid vapor and air pockets and the following points kept in mind:

1. The pump should be located as near the supply as possible. This is not always the most convenient layout, especially when a number of pumps have a common source; however, the savings over the life of a project will normally offset the initial inconvenience and added cost.
2. A common suction header serving two or more reciprocating pumps should be avoided if at all possible. The acceleration head requirement for several pumps on a common suction line is not the sum of the single pump requirements, but increases approximately by the square of the number of pumps. For instance, if three similar pumps operating at the same rpm have a common suction line, the acceleration head requirement is approximately nine times that of a single pump.
3. Pipe fittings should be kept to an absolute minimum and those used selected and installed carefully to avoid pockets where air or gas can accumulate. Should it become necessary to use ells in the hookup, only 45° or long radius 90° ells should be used. Full opening gate or butterfly valves

should be used and if reducers are necessary, only eccentric reducers installed (with the flat side up to avoid formation of an air pocket).

4. The suction outlet on the tank should be slightly higher than the pump inlet so that gas or air accumulating in the system may flow back into the tank rather than through the pump.
5. The pump inlet size has no bearing on the required piping size. The available suction head, along with the suction requirement, and losses should be considered and the piping sized on this basis, regardless of pump inlet size.
6. The discharge bypass system should never be tied into the suction piping.

DISCHARGE PIPING

Just as fluid flows to a reciprocating pump in a pulsating flow pattern, it is discharged in the same manner. It has been shown that these pressure surges travel through the fluid in a straight line and are reflected back toward the source by restrictions or bends in the system. Also, when two or more pumps are discharging into a common header, these pressure surges may be amplified, causing damage to the pumps and piping. When designing a discharge piping system for reciprocating pumps:

1. Avoid sharp bends, reducers, valves with less than full opening, etc., near the pump which would reflect pressure surges back toward the machine.
2. Manifolds where two or more pumps are tied into a common system should be located as far from the pumps as practical to allow dampening of surges. For most applications, 100-150 ft is adequate.
3. Discharge piping should be securely anchored as near the pump as practical to prevent system vibrations from acting directly on the pump.
4. Pressure relief valves should be installed in the discharge piping near the pump and certainly upstream of the first block valve. Relief valves should be sized to handle the entire capacity of the pump in the event of a plugged line or accidentally closed valve.

PULSATION STABILIZERS

There is no doubt that pulsation stabilizers (desurgers, pulsation dampeners) on either the suction, discharge or both of a reciprocating pump can greatly reduce pressure surges within a system. Many such devices are available from reliable manufacturers and hundreds of field tests have proven their reliability and effectiveness. However, they should be carefully engineered for each specific application and systematically maintained, if their full value is to be realized. They should not be considered a substitute for good piping design because in the event of overinflation or deflation, they become useless and damage caused by cavitation or hydraulic shock can occur rapidly.

CONCLUSION

Although reliable design methods are well-known and dependable equipment is readily available, many reciprocating pump installations are operating at something less than peak efficiency. In many cases the problem lies not in lack of knowledge, but in the failure to put this knowledge into practice in the field.

Probably the single most important factor in realizing any lasting and significant improvement in the industry's overall experience is through the development of an effective training program for all those persons whose responsibilities are directly related to this type operation. The training effort should include field supervisory and engineering personnel, as well as lease and pump station operators, if it is to be effective.

Only through increased knowledge and awareness can we expect to realize any sustained and worthwhile improvement in the operating efficiency of this important facet of our producing operations.

BIBLIGRAPHY

1. Hughly, Dale: Pulsation in Pumping Systems, *Petr. Equip. and Serv.*, May/June 1967.
2. Hughly, Dale: Acceleration Effect is Major Factor in Pump Feed System, *Petr. Equip. and Serv.*, Jan./Feb. 1968.
3. Zaba, J. and Doherty, W.T.: "Practical Petroleum Engineer's Handbook," Gulf Publishing Co., Fourth Edition, 1956.

4. Kern, Robert: Pump Piping Design, "Chemical Engineering Deskbook," Oct. 11, 1972.

ACKNOWLEDGMENTS

Appreciation is expressed to the management of Sun Oil Company for permission to publish this paper and also to the Sun employees who furnished valuable advice and assistance in the preparation.

The author wishes to express a special thanks to Mr. R.H. Gault, Bethleham Steel Company, Midland, Texas, for his aid and advice and permission to use selected material from Bethlehem's installation guide.