USE OF INDUCERS IN LIQUEFIED PETROLEUM GAS AND CONDENSATE SERVICE FOR BETTER PERFORMANCE

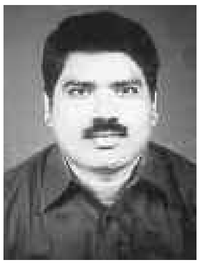
by

Trinath Sahoo

Deputy Manager (Maintenance)

Indian Oil Corporation Ltd.

West Bengal, India



Trinath Sahoo is Deputy Manager (Maintenance), with Indian Oil Corporation Ltd., in the Refinery Division, in West Bengal, India. His responsibilities include overseeing the maintenance function of the fuel oil block. Mr. Sahoo has more than 10 years of experience in design and engineering of piping and pressure vessels for process plants. He was involved in designing grass-root projects such as the Microcrystalline Wax Project and the Sulphur Recovery Unit at the Haldia Refinery.

Mr. Sahoo graduated (Mechanical Engineering, 1990) from the University College of Engineering, Orissa. He has published several papers in international journals such as Hydrocarbon Processing*,* Chemical Engineering*,* Chemical Engineering Progress*,* Hydrocarbon Asia*, and* World Refining.

ABSTRACT

The inducer is a very small booster pump, lifting the suction pressure to a sufficient level for the main conventional impeller. By adding the inducer to high speed centrifugal pumps, NPSHr can be reduced to a great extent. Liquid with high gas content can be pumped successfully with inducer equipped pumps. Even low NPSHr allows a smaller, higher speed low horsepower pump, saving energy and capital cost.

INTRODUCTION

Liquefied petroleum gas is a mixture of propane and butane and usually stored at a temperature close to vaporization. Its vapor pressure is nearly 7 kg/cm^2 at room temperature. So the available suction pressure to the first stage impeller is essentially only the head of the liquid in the storage tank. A conventional centrifugal pump would face problems in emptying out the tank. An inducer pump can strip the liquified petroleum gas (LPG) tank completely as inducer's NPSHr is the same range as the depth of the tank sump.

Condensate pumps operate at elevated temperature. Generally condensate is returned to the boiler at temperatures above 150°F. Initially when the system is commissioned it will work properly. But over a period of time the steam traps start leaking and the steam traps start condensing in the condensate lines. As a result the condensate temperature and vapor pressure will go up. Hence the pump will start cavitating.

A critical factor that should be investigated in the selection of pumps for liquids having high vapor pressure at pumping temperature is the NPSHr. NPSHr is the amount of suction head required to prevent pump cavitation and is determined by pump design. NPSHa is the amount of suction head available or the total useful energy above vapor pressure at pump suction. This is determined by system condition. Pump manufacturers must concentrate on the NPSH characteristics when designing pumps that pump liquids that are close to the vapor pressure at pumping temperature.

BACKGROUND

As liquid enters the eye of the impeller in a centrifugal pump, its pressure is reduced. If the absolute pressure at the impeller eye drops down to the vapor pressure of the liquid, vapor pockets begin to form. As the vapor pockets travel in the fluid along the vane of the impeller, pressure increases and the pockets collapse. This collapse is called cavitation. Cavitation is not only noisy but damages the pump impeller, shaft, and seal over time. Cavitation may also reduce pumping capacity.

A centrifugal pump's NPSHr characteristics are determined by a discernible drop in performance. The method used is to run the pump at constant capacity, reducing the NPSHa at a particular head drop, 3 percent by most standards. The degree of performance drop (head drop) is dependent upon the ratio of vapor to liquid volume (Vg/Vf) at the pump suction condition. For the same suction pressure, a liquid whose Vg/Vf is high will cause a greater performance drop than whose Vg/Vf is low. Thus, for the same degree of performance drop, NPSHr decreases with Vg/Vf. By Hydraulic Institute definition the NPSHr of a pump is the NPSHa that will cause the total head to be reduced by 3 percent due to flow blockage from cavitation vapor in the impeller inlet. NPSHr is by no means the point at which the cavitation starts, the level that is referred to as incipient cavitation. NPSHa at incipient cavitation can be two to 20 times the 3 percent NPSHr value, depending on the pump design and suction energy level.

The noise, the vibration, and possibly the reliability of centrifugal pumps and mechanical seals may be significantly affected if an appropriate NPSH margin is not provided above the published NPSHr of the pump.

NPSH characteristics of different pumps can be compared by the suction specific speed (Nss). The concept of suction specific speed is to define an impeller's suction geometry and performance regardless of size.

$$Nss = RPM \times Q^{0.5} / NPSHr^{0.75} \tag{1}$$

A centrifugal impeller with a high suction specific speed has a larger impeller eye. Higher flow velocities result in reduction in static pressure, which may then become dangerously close to the fluid vapor pressure, and cavitation will take place. Thus lower velocities result in higher localized static pressure, i.e., a safer margin from the cavitating regime. Since the velocity is equal to flow divided by the area, a larger area (for the given flow) reduces the velocity—a desirable trend. This is why a larger suction pipe is beneficial at the pump inlet. Cavitation usually occurs in the eye region of the impeller, and if the eye area is increased, velocities are decreased. The resulting higher static pressure provides a better safeguard against cavitation. So a larger impeller eye lowers the NPSHr. But the flow of fluid at the impeller eye region is not as simple and uniform as it is in a straight run of a suction pipe. The impeller eye has a curvature that guides the turning fluid. If a pump operates very close to its best efficiency point (BEP) the inlet velocity profile becomes proportionally smaller, but the fluid particles stay within the same paths. If, however, a pump operates below its BEP, the velocity profile changes, and no longer can maintain its uniformity and order. Fluid particles then begin to separate from the path of the sharpest curvature (impeller shroud) and the resulting mixing and wakes produce a turbulent, disorderly flow regime.

The outcome of all this is that a larger impeller eye does decrease the NPSHr at the BEP point, but causes flow separation problems at the off-peak low flow condition. In other words a high suction specific speed design is better only if a pump does not operate significantly below the BEP. Interestingly, with very few exceptions, there is hardly a case where a centrifugal pump operates strictly at the BEP. The flow demands at the plant change constantly, and the operator throttles the pump flow via the discharge valve.

DISCUSSION

To overcome the above problem an inducer is installed on the same shaft upstream of the centrifugal impeller, which allows secure cavitation-free operation of the high speed turbopump under limited inlet pressure condition. Parameters of the inducer and impeller should be well corrected to provide high pump suction performance and efficiency. The inducer is the axial inlet portion of the turbopump rotor whose function is to raise the inlet head by an amount sufficient to preclude cavitation in the following stage. The principal objective in the design of an inducer is the attainment of high suction performance, but the achievement of maximum performance is limited by structural design consideration. Every standard impeller features a pressure drop at the suction side, due to physical conditions. If a liquid is handled close to the vapor pressure, the vapor pressure can fall short locally in this area. Using an inducer acts as an integrated booster pump, which increases the suction pressure for the impeller. Thus the pressure in the area of the pressure drop of the impeller is raised so much that evaporation and also cavitation are being prevented.

In Figure 1, if the pressure distribution of a streamline looks like the dotted line, it is evident that for part of the streamline, the prevailing pressure is below the vapor pressure. This problem is solved by adding the inducer, which has such a low NPSHr that, even in cases like these, pressure along the streamline never drops below the vapor pressure.

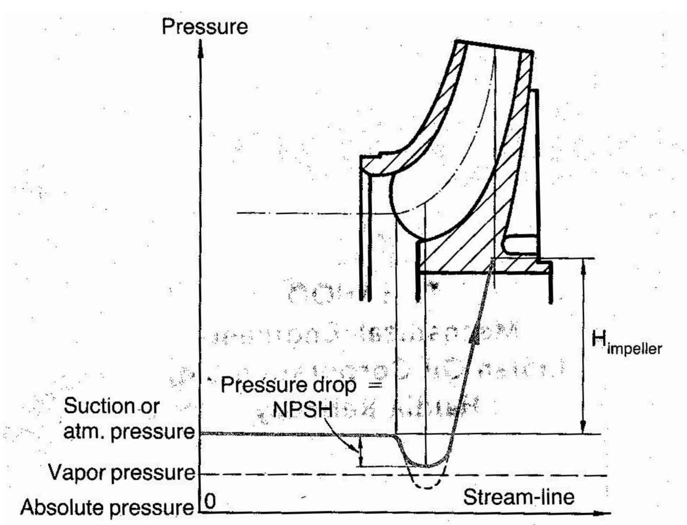


Figure 1. Pressure Profile in Impeller.

Figure 2 shows the pressure distribution in an inducer and an associated conventional impeller. Liquid enters at suction pressure. Because of the small pressure drop at the inducer entrance, pressure never gets below vapor pressure. The inducer subsequently generates enough head to provide adequate suction pressure for the conventional impeller. In spite of the large pressure drop at the conventional impeller inlet, the streamline never again approaches vapor pressure, avoiding any vaporization in the impeller. By increasing the generated head of the inducer, a large safety margin between the vapor pressure and the lowest pressure in the impeller can be achieved.

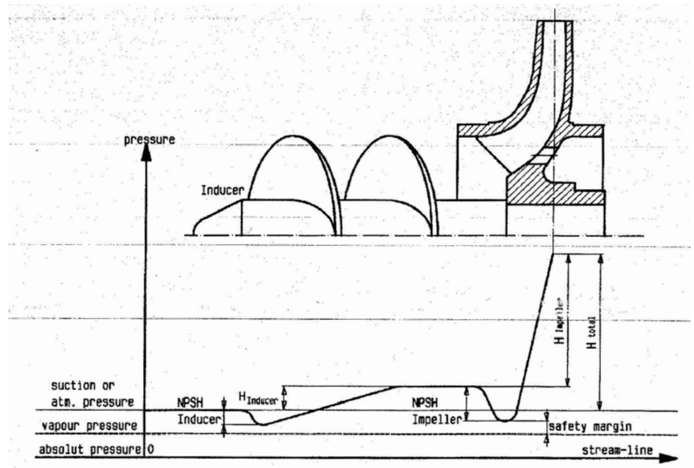


Figure 2. Pressure Distribution in Inducer Equipped Pump.

The inducer is inherently able to withstand problems associated with cavitation. When vaporization occurs at the inducer inlet, the liquid is vaporized into a lot of small bubbles that will eventually collapse. But, since the inducer is designed for a very small and steady pressure rise all along its vanes, the bubble implosions are spread over the entire vane length. As a result there is no big shock. The inducer continues to run smoothly, and vibration and erosion do not occur. In a conventional impeller, bubbles collapse along a very small portion of the vane length because the pressure rise is quite sudden and steep. The NPSH is of a lower capacity. Basically there are two types of inducers. The axial type of inducer reduces the NPSHr of the pump throughout the entire operating range of the pump. A helical inducer reduces the NPSHr of a pump for a specific flow range. Outside of the flow range, the NPSHr may be higher than what is required without an inducer. A helical inducer will lower the NPSHr more than an axial inducer for a specific flowrate, but care must be taken that the flow remains within the operating range of this inducer. Helical inducer designs lower the NPSH value of the pump in the range of the duty point, but they only allow a limited operating range of the pump (Figure 3).

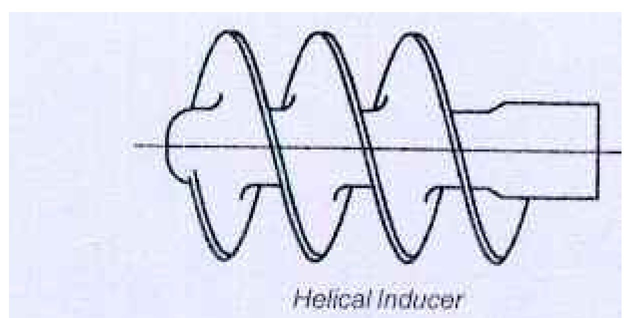


Figure 3. Helical Inducer.

The design parameter of an inducer (axial) equipped pump is given in Table 1 and shown in Figure 4. The pump is installed at a refinery in India and has been running smoothly for 10 years.

From the data in Table 1 it is observed that, though the margin between NPSHa and NPSHr is too small, the axial inducer cavitation is avoided. Even the minimum continuous flow is less than 30 percent.

Table 1. Design Parameters for Axial Inducer.

Item no.	33-P-11
Liquid pumped	Furfural (hydrocarbon)
Capacity (normal/rated/minimum)	167/184/50 m^3/hr
Suction pressure (max)	0.35 kg/cm^2(g)
Discharge pressure (max)	13.0 kg/cm^2(g)
Pumping temperature	169°C
Specific gravity at PT	0.86
Diff. head	147 m
Vapor pressure at PT	1.2 kg/cm^2 (a)
Viscosity	0.31 cst
NPSHa	1.8 m
NPSHr	1.6 m
No. of stages	One
RPM	2900
Design efficiency	69 %
Motor rating	110 kW
Maximum amplitude of vibration (pk-to-pk) (velocity)	5.5 mm/sec

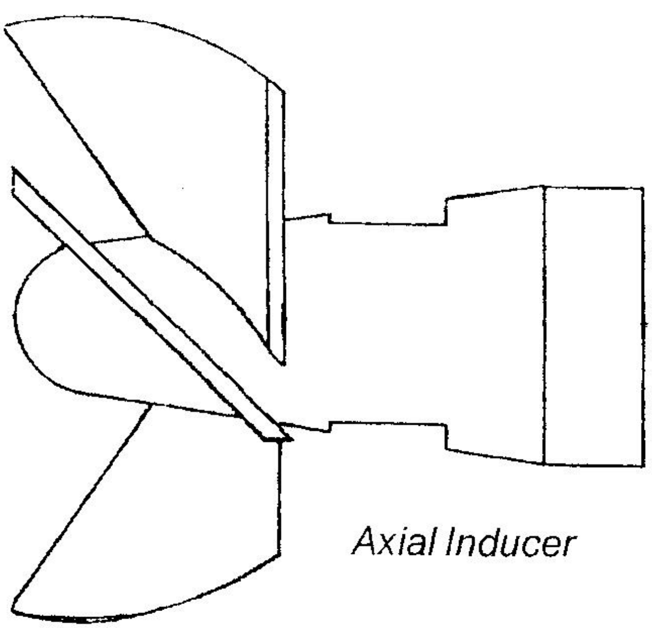


Figure 4. Axial Inducer.

The design parameter of an inducer (helical) equipped pump is given in Table 2. The pump is installed at a refinery in India and has been running smoothly for five years.

From the data in Table 2 it is observed that, though the pumping temperature (PT) is 120°C and vapor pressure at PT is 2.1 kg/cm^2 (a),

Table 2. Design Parameters for Helical Inducer.

Item no.	24-P-05
Liquid pumped	Boiler feed water
Capacity (normal/rated/minimum)	31.8/38.2/19.1m^3/hr
Suction pressure (nor/max)	2.9/6.6 kg/cm^2(a)
Discharge pressure (max)	57.079 kg/cm^2(a)
Pumping temperature	120°C
Specific gravity at PT	0.943
Diff. head	574 m
Vapor pressure at PT	2.1 kg/cm^2(a)
Viscosity	0.266 cst
NPSHa	5.6 m
NPSHr	4.7 m
No. of stages	One
RPM	12,300
Design efficiency	46.9 %
Motor rating	132 kW

suction pressure is 2.9 kg/cm^2 (a), and rpm is 12,300. Helical inducer cavitation is avoided.

Here the minimum continuous flow is 50 percent of rated flow, which was less (30 percent) than in the case of the axial flow inducer. This happens because in a conventional inducer the NPSH increases below certain minimum flow. But in a universal inducer the NPSH decreases as flow decreases (Figures 5, 6, 7, 8, and 9).

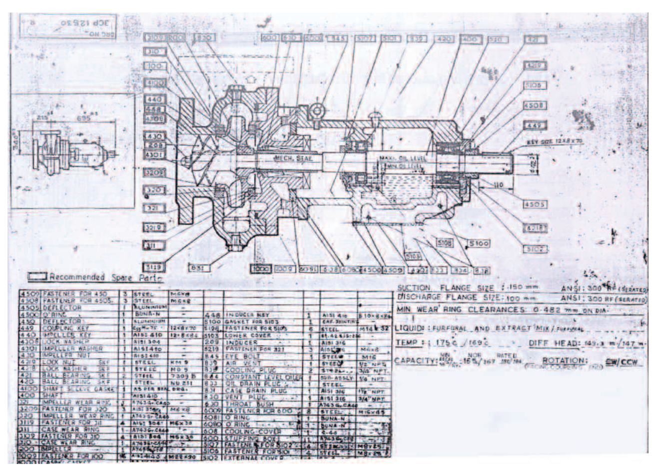


Figure 5. Cross Section of Pump with Axial Inducer.

FLOW INSTABILITY

As the pump inlet pressure is gradually decreased the inducer head rapidly decreases, and an asynchronous vibration occurs at the same time. The cause was judged to be a large backward flow from the inducer in the direction upstream of the inlet. That is, if the pump inlet pressure drops, liquid flows backward from the tip

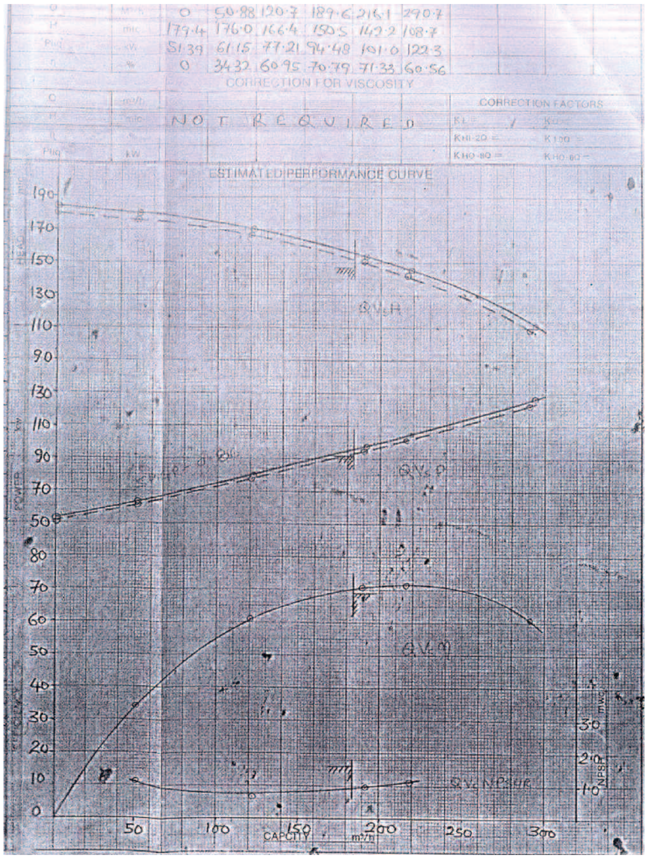


Figure 6. Characteristic Curve of Pump 33-P-11.

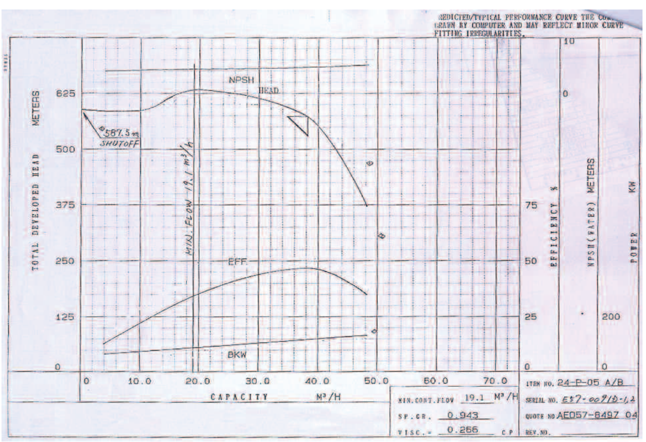


Figure 7. Characteristic Curve of Pump 24-P-05.

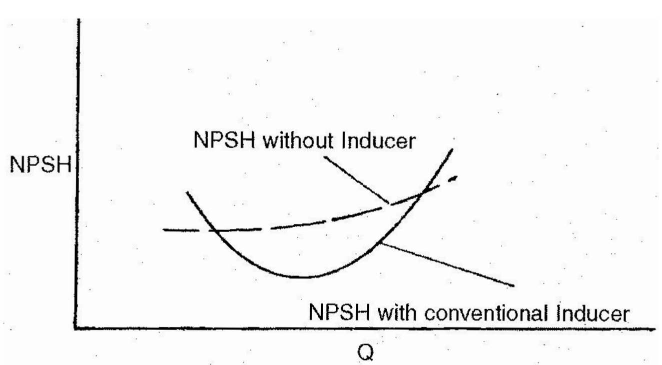


Figure 8. NPSH with Conventional Impeller.

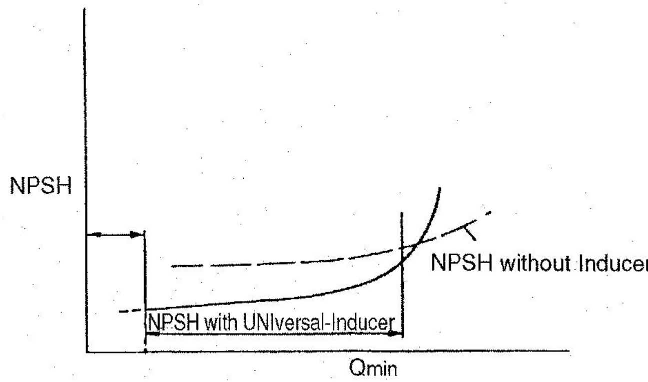


Figure 9. NPSH with Universal Inducer.

clearance to the inlet, and its evaporation is promoted there. As it is relatively hot, this causes a rapid head drop and instability. To ameliorate the backward flow, the design inlet flow coefficient was made somewhat larger, and the outer diameter was reduced in the inlet side. In many cases the inducer is exposed to oscillating pressure loading during operation. The oscillating pressures are induced by flutter, cavitation, upstream obstruction, or other pressure wave generators that exist in the pumping system. Because inducer blades are fatigue oriented, effort should be made to prevent resonant vibration.

The inducer-impeller combination shall present a smooth meridional flow passage with an axial spacing consistent with hydrodynamic and mechanical requirements. The inducer discharge hub and tip diameter should match with the impeller inlet eye dimensions closely enough that a smooth contour may be drawn. For easy clearance control on unshrouded blading, the tip diameter should be cylindrical if head rise requirements of inducer and impeller permit.

CAVITATION AND SUCTION RECIRCULATION

Cavitation in an inducer is most severe at the blade tip, where blade speed is highest. As blade speed increases, the cavity at the leading edge becomes larger and increasingly blocks the flow. The high head inducer blades, which are designed for high speed operation, normally are rigid enough to place their natural frequency well above the cavitation induced high amplitude, low frequency pressure oscillation.

Another form of cavitation is recirculation cavitation caused due to formation of vapor filled pockets. It is most often caused by suction recirculation. As the pump is operated back on its curve, eddy currents begin to form in the eye of the impeller. There is no reduction in mass flow through the pump at a given point on this curve. This means that the velocity through the impeller fluid channel must have increased. When the velocity increases, the pressure drop due to friction increases. If the drop is large enough to cause the pressure to fall below the liquid's vapor pressure, the pump will cavitate because of initiating action of recirculation cavitation. Recirculation cavitation causes pitting damage about halfway along the vanes and results from a variety of hydraulic conditions that manifest themselves when operating the pump at a flow rate that is too low (Figure 10).

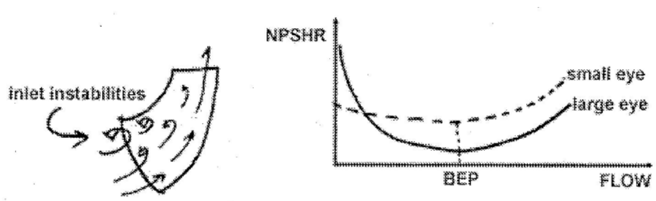


Figure 10. Suction Recirculation.

CONCLUSION

Pumps with an inducer-impeller combination provide smooth and safe operation, even under conditions that would lead to cavitation with conventional impeller pumps. Liquid with high air or gas content often cannot be handled by a conventional impeller. The gas or air is separated out on the suction side of the impeller vanes, causing the impeller vanes to lose suction. An inducer raises the pressure at the impeller inlet, so the separation does not occur.