



Pump Suction Characteristics

An Online Continuing Education Course for Engineers

Course Number: M-1008

Credit: 1 Hour / 1 PDH / 1 CPD

Pump Suction Characteristics (1 PDH)

Introduction

I once presented this course to a group of mechanical engineers, and called it "What You Always Needed to Know About NPSH, But Were Afraid to Ask". They all knew that NPSH was important in designing a pumping system, but many of them who had been out of school for a few years would have had difficulty in calculating the NPSH available of a piping system without breaking out a text book.

NPSH is the link that connects the piping system designer to the pump specifier. It is not uncommon to hear the complaint "This pump is cavitating. Call the manufacturer!" More likely than not, the fault is with the piping system design, which is causing _____ the pump to cavitate.

A common source of difficulty (and errors) is dealing with all the various units of measure. It seems that everything in the formula for calculating NPSH is commonly expressed in different units.

There may be a few surprises, such as the fact the NPSH applies to positive displacement pumps as well as centrifugal pumps, and how suction specific speed can be used as a rough indicator for selecting a pump type.

Net Positive Suction Head (NPSH)

When specifying pump ratings and when diagnosing pump operating problems, few items are more discussed and less understood than net positive suction head (NPSH). Symptoms that may be attributed to inadequate NPSH include:

- Sudden drop in pump discharge pressure under certain operating conditions
- Excessive noise and/or vibration
- Poor pump efficiency, especially at low loads
- Excessive pump wear, such as pitting of impellers

Before getting into a discussion of NPSH, some basic definitions of terms and designation of symbols used throughout this discussion will be laid out. For the sake of uniformity, the definitions and symbols will be taken from the Hydraulic Institute Standards, the most widely used compilation of pump design, operating, and testing standards in the U.S.

Head (H)

Head is a measure of pressure, expressed in feet. The relation between pressure expressed in pounds per square inch (psi), and feet of head is: $h = \text{psi} \times 144/w$, where w = the specific weight in pounds per cubic foot of liquid being pumped, under pumping conditions. All pressure readings must be converted to feet of the liquid being pumped. The datum for gauge readings shall be taken at the centerline of the pump for horizontal pumps and double suction vertical pumps, or at the entrance eye of the first stage impeller for single suction vertical pumps.

Static Head, or Gravity Head (H_z)

The vertical distance between the surface of the pumped liquid and the pump datum. Where the liquid surface is below the pump datum, h_z is negative.

Velocity Head (H_v)

Velocity head shall be figured from the average velocity (V) obtained by dividing the flow in cubic feet per second (cfs) by the area of the pipe cross section in square feet at the point of the gauge connection: $h_v = V^2/2g$, where $g = 32.17$ ft/sec/sec at sea level, and V = the velocity in the pipe in ft/sec (fps).

Flooded Suction

The liquid must flow from an atmospheric vented source to the pump without the average pressure at the pump datum falling below atmospheric pressure with the pump running at specified capacity.

Total Suction Head, or Lift (H_s or H_L)

Positive suction head exists when the total suction head at the pump datum is above atmospheric pressure. It is the reading of a gauge at the pump suction converted to feet of liquid and referred to datum, plus the velocity head at the point of attachment. When the total suction head at the pump datum is below atmospheric pressure, (negative suction head) it is called suction lift, and is the reading of a gauge at the pump datum minus the velocity head.

Total Discharge Head (H_d)

The reading of a pressure gauge at the pump discharge converted to feet of liquid and referred to datum plus the velocity head at the point of attachment.

Bowl Assembly Head (H_b)

The difference between the total discharge head measured in the column pipe of

a vertical turbine pump, connected to the top of the bowl assembly, and the total suction head.

Total Dynamic Head (TDH)

Total dynamic head is the measure of the work increase per pound of liquid imparted to the liquid by the pump. It is the difference between the total discharge head and the total suction head. Where suction lift exists, total dynamic head is the sum of the total discharge head and the suction lift (which, remember, is expressed as a positive number). TDH can only be determined by the user and specified to the pump supplier along with the rated capacity.

Net Positive Suction Head (NPSH)

Net positive suction head is the total suction head in feet of liquid absolute determined at the suction nozzle and referred to datum, less the vapor pressure of the liquid in feet absolute. In simple terms, NPSH is the pressure at the pump suction port measured in feet of liquid absolute, less the vapor pressure. It is the analysis of energy conditions on the suction side of a pump to determine if the liquid will vaporize at the lowest pressure within the pump. The Hydraulic Institute uses the term **Net Inlet Pressure (NIP)** instead of NPSH in connection with rotary pumps. NIP is just NPSH expressed in psia instead of feet. It is mentioned here just to make the student aware of the term.

Vapor Pressure (Hvp)

Vapor pressure is one of the physical properties of a liquid. By definition, it is the pressure exerted by the vapor of a contained liquid. It varies with temperature. Vapor pressure of a liquid is of little concern in many pumping applications, such as pumping water or # 2 fuel oil at moderate temperatures from an open container. In such cases, vapor pressure is well below atmospheric pressure, and can be ignored and left out of the calculation for NPSH. It is usually expressed in mm of mercury or psia.

However, confusion over the term “vapor pressure” can lead to errors when calculating NPSH in cases where the vapor pressure of a liquid is significant. This is true for hot (saturated) water, volatile liquids such as gasoline and other petroleum products, ammonia, and LP gas, which have relatively high vapor pressures, and must be stored in pressurized containers. For such liquids, the vapor pressure may be expressed in psig, and should not be ignored when calculating NPSH. For example, when calculating the NPSH available from a deaerating feedwater heater pressurized to 5 psig (~20 psia), where the water is near the saturation temperature for that pressure, it nearly cancels out the pressure within the deaerator. Therefore, the NPSH available at the feedwater pump is due primarily to the gravity head alone, or the elevation of the deaerator above the feedwater pump suction nozzle minus frictional losses in the suction

pipng.

NPSH available and NPSH required

NPSH must be indicated as NPSH available (NPSHa) or NPSH required (NPSHr) in order to be meaningful. NPSHa is a function of everything in the system on the suction side of the pump up to the suction nozzle of the pump. This includes the pressure on the surface of the liquid in the supply tank, the difference between the liquid level and the centerline of the pump suction nozzle, the line losses, velocity head, and vapor pressure. NPSHr is based on everything from the pump suction nozzle to the point in the pump where the pressure starts to increase. This includes the entrance losses and the friction losses or pressure drops getting into the pumping elements.

Since NPSHa is the absolute pressure available less the vapor pressure of the liquid, the NPSHa should always be greater than the NPSHr. If this were not the case, the pressure at some point in the pump suction area will be less than the vapor pressure of the liquid, and cavitation will occur. Cavitation is the formation of pockets of vapor, or bubbles, at a point inside the pump where the liquid pressure drops below its vapor pressure. These vapor bubbles are carried along to the higher pressure area of the pump, where they collapse. It is the violent collapse of the bubbles that cause the damaging effects of cavitation; noise, erosion, and short service life. Cavitation also reduces capacity and efficiency, as well as causes pulsations in the discharge pressure.

There is a widely used formula for calculating NPSHa, which should be reviewed and thoroughly understood. NPSHa is a function of the suction piping system, the operating conditions, and the liquid being pumped. For a system in the design stage, or for one in use, NPSHa can be calculated from the formula:

$$\text{NPSHa} = H_a + H_z - H_f + H_v - H_{vp}$$

An example of how this formula is applied is given below:

$$H_a = (14.7 \text{ psia}) \times (2.31 \text{ ft H}_2\text{O per psi}) / 0.88 \text{ s.g. of fuel oil} = 38.8 \text{ ft of fuel oil}$$

(To convert pressure in psia to ft of liquid, multiply by 2.31 and divide by specific gravity of the liquid).

$$H_z = -10 \text{ ft of fuel oil (worst case)}$$

$$H_f = 2.9 \text{ ft of fuel oil (from piping pressure loss calculation)}$$

$$H_{vp} = 1 \text{ ft of fuel oil (maximum)}$$

NPSHa = 24.9 ft of fuel oil.

If the liquid being pumped were gasoline instead of fuel oil, the NPSHa would be quite different. The specific gravity would change from 0.88 to 0.71, and the vapor pressure to 8.5 psia.

$$H_{vp} = 8.5 \times 2.31 / .71 = 27.6 \text{ ft of gasoline.}$$

NPSHa = 7.3 ft of gasoline. (From a practical standpoint, the total lift should not exceed 6 ft when pumping gasoline.)

Notice that the NPSHa is less than the NPSHr. This means that the pump system is operating in a region where cavitation will occur. The liquid at the first stage of the pump will be vaporized, and the pump will lose efficiency. The NPSHa must be greater than the NPSHr for the pump to operate properly. The NPSHa is a function of the liquid being pumped, the elevation of the liquid, and the pressure in the suction system. The NPSHr is a function of the pump design and the flow rate. The NPSHa is a function of the liquid being pumped, the elevation of the liquid, and the pressure in the suction system. The NPSHr is a function of the pump design and the flow rate.

Entrain

The fact that the vapor pressure of a liquid is constant and predictable, while the vapor pressure of a liquid is not always precise. While the vapor pressure of a liquid is constant and predictable, it is possible to have entrained or dissolved air or gas in the liquid with the result that the fluid acts as though it had a higher vapor pressure than the figures for pure liquid would indicate. The higher apparent vapor pressure would decrease the NPSHa. In this case, as the pressure in the suction system is reduced, entrained air or gas in the liquid would tend to expand or to be released. As this occurs, a centrifugal pump would tend to cavitate and a positive displacement pump would experience a loss of volumetric efficiency. This situation could happen when the