Determining the Net Positive Suction Head of a Magnetic Drive Pump

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Abstract

Cavitation accompanied by metal removal, vibration, reduced flow, noise and efficiency loss can occur in the operation of a pump if the suction pressure is only slightly greater than the vapor pressure of the fluid. Cavitation can be avoided by maintaining or exceeding the *required* net positive suction head, $NPSH_r$. This paper describes a simple and inexpensive laboratory set-up for determining the $NPSH_r$ and developed head for a centrifugal pump in a closed circuit by observing the onset of cavitation as the temperature of the feed reservoir is increased. A secondary, but also very important purpose of the exercise is to provide students with an opportunity to observe cavitation in a laboratory setting. In examining the results from the experiment, $NPSH_r$ ranged from 2.6-10.7 ft, which is reasonable for small pumps, and increased with pump capacity. The developed head ranged from 7.2-19.2 ft, and decreased with pump capacity. The experiment could be improved by employing a 3600 rpm pump with a larger impeller, which would then cavitate at a lower suction temperature and permit a wider range of operating flow rates and the ability to generate a pump curve.

Introduction

In the operation of pumps, cavitation can occur if the suction pressure is only slightly greater than the vapor pressure of the fluid. Furthermore, if the suction pressure is less than the vapor pressure, vaporization will occur in the suction line and liquid can no longer be drawn into the pump.[1] During cavitation, some of the liquid flashes to form vapor inside the pump. These vapor bubbles are then carried to an area of higher pressure, where they suddenly collapse. Cavitation is to be avoided since it is accompanied by metal removal, vibration, reduced flow, noise and efficiency loss.[2]

Cavitation can be avoided by maintaining or exceeding the *required* net positive suction head, $NPSH_r$, defined as

$$NPSH_r = \frac{P_a - P^*}{\rho g} - H - h_L \tag{1}$$

where $NPSH_r$ = required net positive suction head requirement, ft
P_a = pressure at the free liquid surface, psi
P^* = vapor pressure of the fluid at the operating temperature, psi
ρ = density of the fluid, lb_m/ft^3
g = gravitational constant, 32.2 ft/s^2
H = height of pump above the surface of the fluid in the tank, ft
h_L = head loss due to friction in the suction line of the pump, ft

Since the pressure in the impeller eye can be lower than the pressure in the suction pipe, it is usually necessary to determine $NPSH_r$ experimentally.[3] Turbine Technologies Ltd.[4] presents a detailed on-line procedure for experimentally determining $NPSH_r$ in a see-through pumping system. Pump manufacturers publish curves relating $NPSH_r$ to capacity and speed for each of their pumps. In applying net positive suction head to fluid system design, the *available NPSH* or $NPSH_a$ must be considered since the *NPSH* required for operation without cavitation and vibration (or $NPSH_a$) must be greater than the theoretical *NPSH* (or $NPSH_r$). *Perry's Chemical Engineers' Handbook*[2] recommends using the larger of the two $NPSH_a$ values found from the equations

$$NPSH_a = NPSH_r + 5\text{ ft} \tag{2}$$

$$NPSH_a = 1.35\, NPSH_r \tag{3}$$

McCabe *et al.*[1] recommend an $NPSH_a$ of 2-3 m (5-10 ft) for small centrifugal pumps, but caution that $NPSH_a$ increases with pump capacity, impeller speed and discharge pressure. For very large pumps, $NPSH_a$ should be as high as 15 m (50 ft).

The purpose of this paper is to demonstrate a simple and inexpensive laboratory experiment for determining $NPSH_r$ and developed head for a centrifugal pump in a closed circuit. With help from the instructor, junior level Chemical Engineering students at the University of Arkansas developed and performed this activity as part of the requirements for CHEG 3232, Chemical Engineering Laboratory II. $NPSH_r$ was found by pumping water through the system while also slowly increasing the temperature of the water (to increase the vapor pressure) and observing the onset of cavitation. The lowest temperature causing cavitation was recorded, and the $NPSH_r$ of the pump was determined from Equation (1). A secondary, but also very important purpose of the exercise was to provide students with an opportunity to observe cavitation in a laboratory setting.

Equipment and Procedures

A flow schematic of the experimental apparatus for measuring $NPSH_r$ is shown in Figure 1, and a photograph of the inexpensive apparatus is shown in Figure 2. The pump employed in the experiment was a Magnetek, Model JB15056N, 115 V, 50/60 Hz, 3000 rpm, 1/5 hp magnetic drive pump. A breakdown of the pump is shown in the photograph of Figure 3. The pump was directly connected to the reservoir (a 5 gal plastic bucket) with nylon fittings and barbs. This simple coupling arrangement is shown in Figure 4. Tygon® tubing (3/4 in ID x 1 in OD) was used to circulate water through the system, and ¼ in copper tubing was used to inject live steam into the reservoir to raise the temperature of the water. Type K thermocouples connected to Omega HH82A thermocouple readers were used to monitor the water temperature inside the suction and discharge lines. A 0-15 psig pressure gauge was installed in the discharge line to measure developed head. Finally, a ½ in ball valve and 0-10 gpm rotameter were installed in the discharge line to adjust and monitor the flow rate through the system.

To initiate the experiment, the pump was started to circulate water through the system, initially with the ball valve in the fully open position. The flow rate and developed pressure head were measured. The water level in the reservoir was maintained at a height of 2 in (0.167 ft) above the suction centerline of the pump. During system heating, steam was allowed to slowly enter the reservoir to increase the water temperature. During steam addition, the water level in the reservoir tended to increase; thus, occasional water removal was required to maintain the water level at 2 in. When pump cavitation occurred, the flow rate immediately dropped to zero. No pump noise was heard during cavitation. The obvious conclusion from these observations is that the magnetic coupling was lost when the pump cavitated. When cavitation occurred, the pump and steam were both turned off and the temperature was recorded. After allowing the pump to cool, the pump was once again started. The procedure was repeated at several flow rates by the adjusting the ball valve.

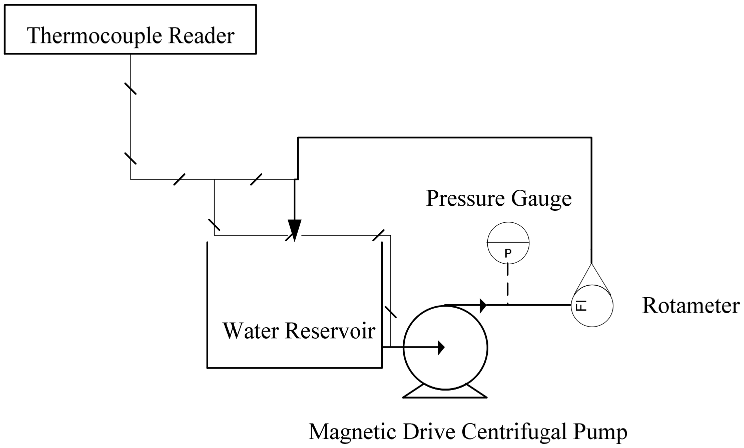

Figure 1. Schematic Flow Diagram of the NPSH Experiment for a Magnetic Drive Centrifugal Pump

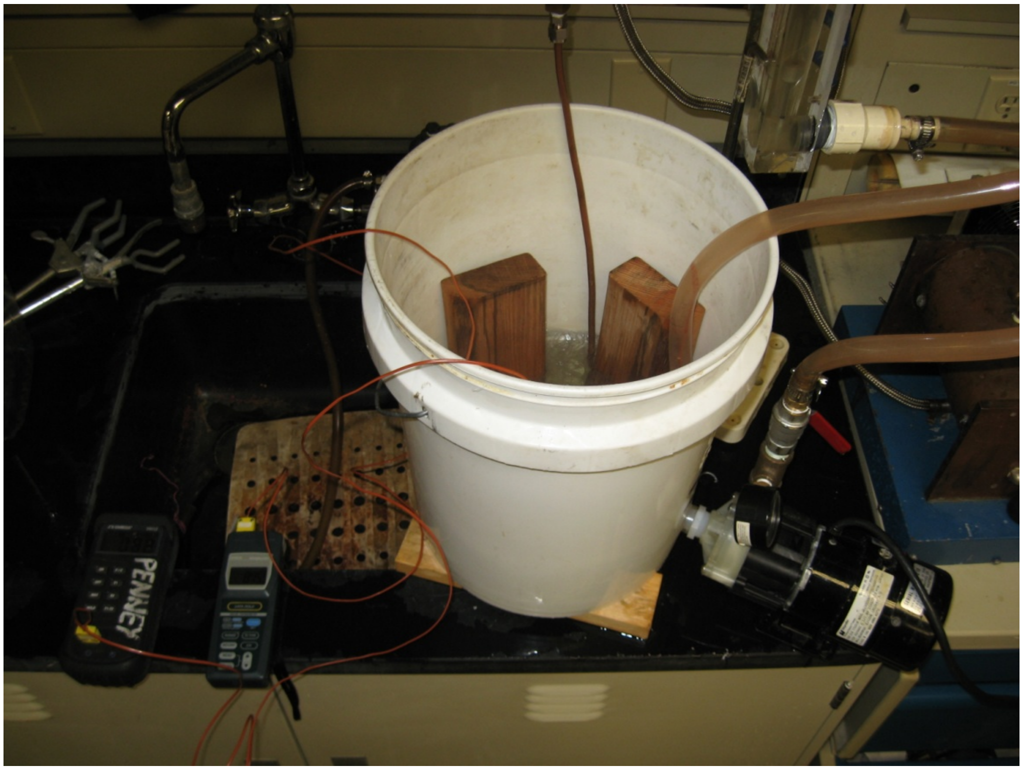

Figure 2. Photograph of the Experimental Apparatus

Figure 3. Photograph of the Disassembled Pump

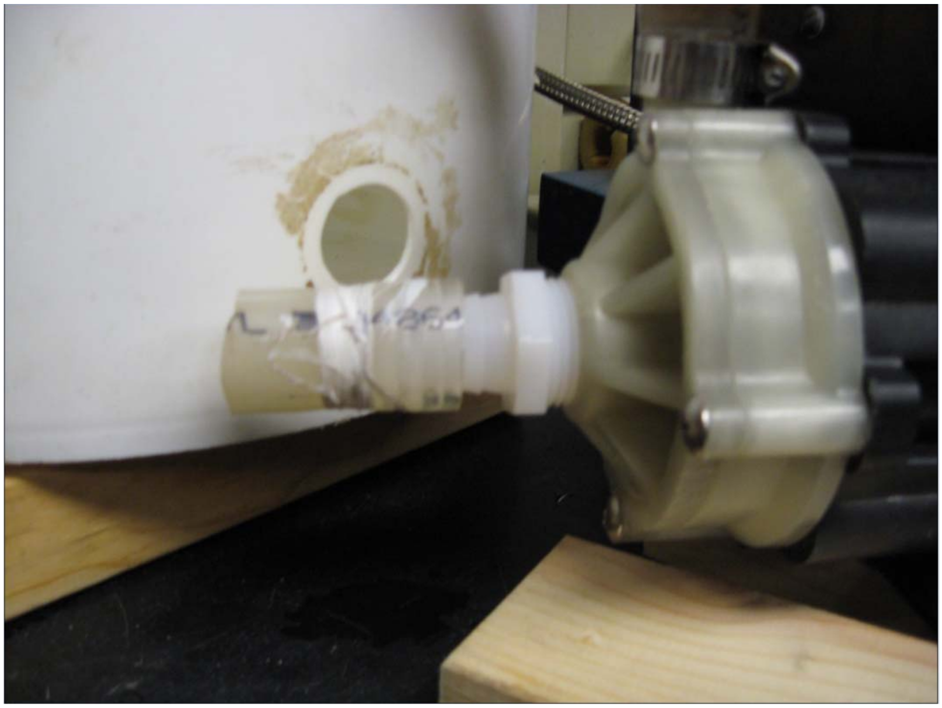

Figure 4. Photograph of the Fittings Connecting the Pump to the Reservoir

Results and Discussion

Table 1 presents the raw experimental data from the cavitation experiments, performed with the Magnetek magnetic drive pump. As expected, the pressure head and temperature at cavitation increased with decreasing flow rate (pump capacity). The variations in cavitation temperature at constant flow rate were most likely due to turbulence at the pump suction or movement of the thermocouple in the suction line during steam addition. These problems will be a focus of future experimentation in order to improve the reproducibility of the experimental results.

Table 1. Raw Experimental Data

Flow Rate (gpm)	Gauge Reading (psig)	Temperature at Cavitation (°C)
6.8	3.0	89
6.9	3.0	91
6.9	3.0	90
6.9	3.0	91
7.0	3.0	93
5.1	5.8	94
3.1	8.0	97
3.1	8.0	97

The vapor pressure of the water, $P*$, may be found from the steam tables at the temperature of cavitation. Alternatively, the appropriate Antoine equation[5] may be used to estimate the vapor pressure, as noted in Equation (4):

$$\ln P^{*} = 18.3036 - \frac{3816.44}{T-46.13} \tag{4}$$

In Equation (4), the temperature, T, is in K and the vapor pressure P^{*}, is in mm Hg. Once the vapor pressure is found, Equation (1) may be used to find $NPSH_r$. Assuming the pressure drop in the suction line is small because the length of the line is small with a large diameter, $h_L = 0$. Thus, Equation (1) reduces to:

$$NPSH_r = \frac{P_a - P^{*}}{\rho g} - H \tag{5}$$

The developed head, H_D, is simply the pressure gauge reading (relative to atmospheric pressure, P) converted to ft of head:

$$H_D = \frac{P - P_a}{\rho g} \tag{6}$$

where P_a = 735 mm Hg (14.22 psia), the observed barometric pressure,
H = 2 in, and
ρ = the density of water, a weak function of temperature

Table 2 shows $NPSH_r$ and developed head for the Magnetek magnetic drive pump as a function of pump capacity. As is noted, $NPSH_r$ ranged from 2.6-10.7 ft, which is reasonable for small pumps, and increased with pump capacity. The developed head ranged from 7.2-19.2 ft, and decreased with pump capacity. As was noted earlier, the variation in cavitation temperature, and thus $NPSH_r$ (average of 9.0 ft, but ranging from 6.9-10.7 ft at a capacity of 6.9 gpm) was likely due to turbulence at the pump suction or movement of the thermocouple in the suction line during steam addition.

Table 2. $NPSH_r$ and Developed Head as a Function of Pump Capacity

Pump Capacity (gpm)	Temperature at Cavitation (°C)	Water Vapor Pressure (psia)	Water Density[2] (lb_m/ft^3)	$NPSH_r$ (ft)	Developed Head (ft)
6.8	89	9.74	60.25	10.7	7.2
6.9	91	10.50	60.17	8.9	7.2
6.9	90	10.11	60.21	9.8	7.2
6.9	91	10.50	60.17	8.9	7.2
7.0	93	11.32	60.09	6.9	7.2
5.1	94	11.75	60.04	5.9	13.9
3.1	97	13.12	59.91	2.6	19.2
3.1	97	13.12	59.91	2.6	19.2

Conclusions and Recommendations

Within the limits of the equipment, this simple method is fairly accurate and effective in determining the $NPSH_r$ of a pump, and is very effective in demonstrating cavitation and how it occurs in a laboratory setting. It is easier to determine the cavitation point of a magnetic drive pump than a normal centrifugal pump, due to the fact that when the magnetic drive pump cavitates, it stops pumping the liquid completely, while a normal centrifugal pump exhibits a relatively slow decrease in developed head and flow. Turbine Technologies Ltd.[4] has an excellent discussion of the behavior of a mechanically coupled centrifugal pump under cavitating conditions. The experiment can be improved by employing a 3600 rpm pump with a larger impeller, which will cavitate at a lower temperature. With a non-slip drive, a pump curve can be drawn from the data, which will significantly improve the experiment.

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