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Net Positive Suction Head Analysis for Testing the Condition of a Centrifugal Pump

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Abstract

Background/Objectives: To manage centrifugal pump acceptably, it is essential to establish Net Positive Suction Head (NPSH) analysis which compute the usable energy at the pump inlet. **Methods/Analysis:** The NPSH analysis indicates that the pump will be operating outside the cavitation region or inside the cavitation region. This is achieved by analyzing the values of $NPSH_A$ and $NPSH_R$ and also the 3% head drop. **Results/Findings:** Based on the manufacturer's graph and NPSH 3% head drop curve cavitation condition of centrifugal pump is obtained. A decrease in pump efficiency was also observed prior to 3% head drop criteria. **Conclusion/Applications:** NPSH analysis helps to obtain valuable information about the cavitation condition of centrifugal pump and also provide the safer operating range of chosen pump.

Keywords: Cavitation, Centrifugal Pump, 3% Head Drop, NPSH Analysis, Pump Efficiency

1. Introduction

NPSH is a major factor prevailing pump routine. It is defined as the pressure of the suction of the pump at the impeller eye[1]. NPSH available ($NPSH_A$) is a calculated measure based on the suction side of the pump scheme. It is an attribute of the system and is a calculated value. It is the energy in a liquid at the pump suction and must be more than the energy in the liquid due to its vapor pressure so that the liquid does not vaporize in the suction line. NPSH required ($NPSH_R$) is designed into the pump chosen and is the energy desirable to fill the pump on the suction side. This is supplied by the pump manufacturer and is usually on the pump performance curve and is a function of flow[2]. Noise, vibration and reliability of a centrifugal pump may be affected if $NPSH_A$ is not provided by the system above $NPSH_R$ for the pump. If $NPSH_A$ is larger than the $NPSH_R$, the pump will be upsetting to drive a vapor; if it is smaller the pump may cavitate[3]. This occurs often; as a result it is necessary to analyze NPSH values.

1.1 NPSH and Cavitation

The net positive suction head available ($NPSH_A$) is the difference between the total head on the suction side near the pump impeller inlet, the liquid vapour pressure head and the reference position of the elevation head that passes through the centerline of the pump impeller inlet[4].

$$NPSH_A = H_A + H_Z - H_F + H_V - H_{VP}$$

Where H_A - Absolute pressure on the surface of the liquid in the tank
H_Z - Vertical distance with respect to datum position
H_F - Friction losses
H_V - Velocity head
H_{VP} - Absolute Vapour Pressure

The reason, a pumped liquid enters the impeller is due to the pushing force created by the reduction of pressure at the pump inlet. When liquid is flowing through a centrifugal pump, there may be great differences in the local velocities of the liquid. This causes significant pressure

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difference throughout the liquid[5]. Differences in pressure mean that under certain conditions, the pressure in some regions of the pump may drop below the vapor pressure of the liquid and vapor filled cavities begin to appear within the liquid[6]. This phenomenon is usually called the onset of cavitation. In centrifugal pump, cavitation is an influential parameter as it decides the lower boundary for the size of the pump and the upper boundary for speed.

1.2 Effects of Cavitation

Cavitation is serious undesirable phenomena which affect the performance of centrifugal pump and leads to machinery damage which reduces life of pump[7]. There are two effects of cavitation in centrifugal pumps. First, the vapor bubbles created within the impeller passage obstruct the flow of the pumped liquid and reducing the pump performance. This causes the pump to drop off the expected head and efficiency of the performance curve[5]. Second, when the bubbles reach the end of impeller vane, the pressure on the outside of the bubble is greater than the inside pressure and the bubble collapses vigorously. It does not explode but it implodes. This is shown in Figure 1 as cavitation occurrence.

This collapsing bubble is surrounded by hundreds of other bubbles collapsing at approximately the same point. The implosion may exert enormous local stress on the pump surfaces and cause serious mechanical damage. In addition, the implosion accompanies a distinctive noise similar to growling sound[8]. Noise, vibration as well as reduced pump performance and damages in the mechanical part of the pump is an undesirable result of cavitation[7]. In addition, if a pump is operated under cavitation for a period of time, the erosion of blade surfaces proceeds rapidly[6]. Traditionally, when $NPSH_A$ is less than $NPSH_R$, the insufficient suction pressure will create the cavitation. Therefore to avoid cavitation, $NPSH_A$ must be greater than or equal to the $NPSH_R$. According to API 610 standard the onset of cavitation is by 3% drop of the head delivery[9]. Thus, Net Positive Suction Head Available ($NPSH_A$) monitoring is an indirect indicator of cavitation.

2. Materials and Methods

2.1 NPSH 3% Method

A 3% drop in head is interpreted as indicating the $NPSH_A$ and this method of analyzing is simple and cheapest pump cavitation test. Because of the difficulty in determining the instant at which the change starts, a drop in head of 3% which is the standard value in determining NPSH is accepted as evidence that cavitation is present[4].

For determining NPSH characteristics of centrifugal pump, the pump is supplied from a closed tank in which the level is held constant and the $NPSH_A$ is adjusted by varying the air or gas pressure over the liquid. Normally in this type of closed circuit, which is shown in Figure 2, the measurement of the NPSH value is made by reducing the system pressure by means of a vacuum pump. By using this test arrangement the pump is run at constant rate of flow and speed with the suction condition varied to produce cavitation. Water is used as the test medium. The flow rate is measured using orifice and pressure measurements are made using calibrated pressure gauges. Pump performance test also been conducted before NPSH and compared with manufacture's graph. Plots of head shall be made for various NPSH values. As $NPSH_A$ is reduced, a point is reached where the curves break away from a straight-line trend as shown in Figure 3, indicating a condition under which the performance of the pump may be

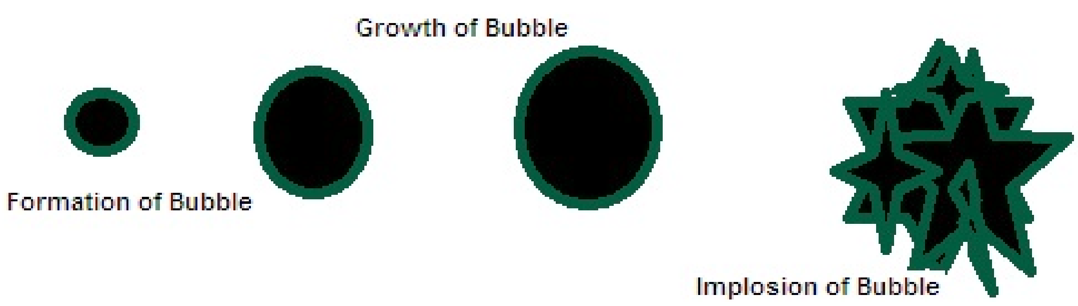

Figure 1. Cavitation occurrence.

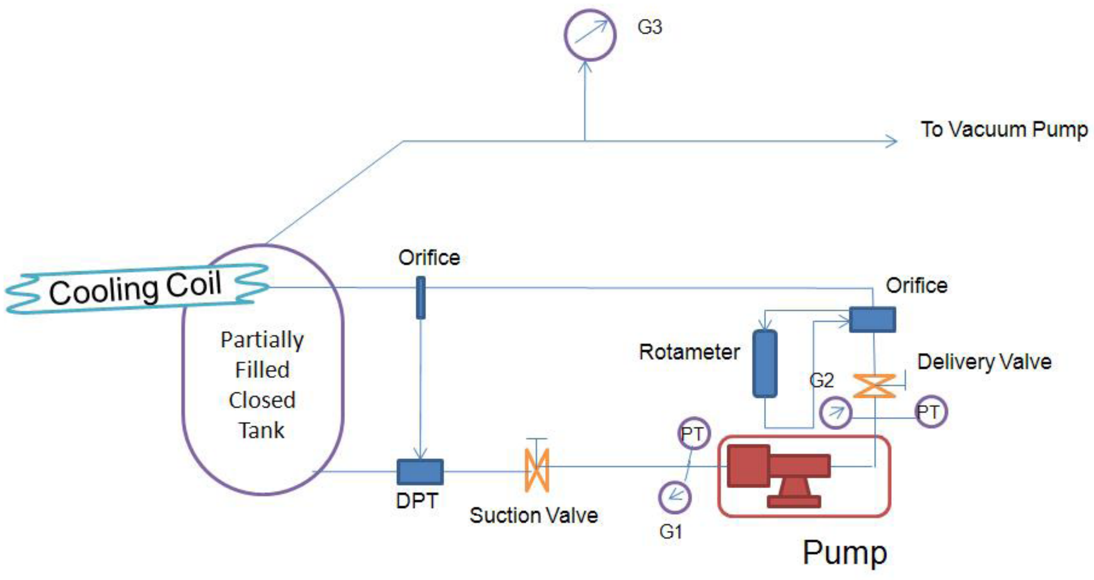

Figure 2. Experimental test loop.

impaired. The degree of impairment will depend upon the specific speed, size and service of the pumps, etc. The 3% drop in head is the standard to determine NPSH.

2.2 NPSH Analysis

The $NPSH_A$ value was used as a source to resolve the significant detection of the cavitation conditions. To detect cavitation conditions of the centrifugal pump the total head can be determined at a constant speed (2900 rpm), with varying $NPSH_A$ conditions. For each $NPSH_A$ conditions, suction and discharge pressure and pressure at the top of suction tank, voltage and current, temperature and speed are noted down for particular flow. Typical pressure and flow readings during the suction pressure reduction and the corresponding $NPSH_A$ and total head were calculated and tabulated in Table 1.

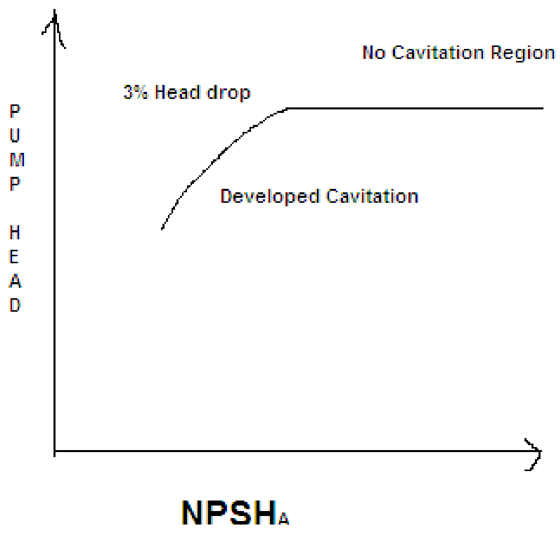

Figure 3. NPSHA curve.

The measurement and estimation of hydraulic feature values are made by means of dewetron 5000 data acquisition system. All appropriate data are recorded and obtainable with dewe5000. After termination of the measurements, the data is transferred to the computer for analysis.

As the suction pressure is decreased, the bubbles start to develop and/or grow which indicates onset of cavitation. As the suction pressure was further decreased bubble formation was more pronounced, then the process is governed by a collapse and implosion of the bubbles which indicates severe cavitation stage. 3% head drop value corresponds to this stage.

2.3 NPSH Calculation

The discharge pressure (Pd) and suction pressure (Ps) for various flow conditions are measured to calculate suction head and velocity head, motor current and voltages are

Table 1. Observed and calculated parameters from NPSH test

Vacuum	P_d	P_s	Current	Voltage	Corrected for 2900 rpm H	PWR$_{in}$	P_{out}	Efficiency	NPSH
mmHg	Kg/cm^2	mmHg	(A)	(V)	mWc	Kw	Kw	%	mWc
0	3.2	20	16.9	440	**33.38**	7.73	4.58	59.22	9.72
-50	3	140	17.02	440	33.68	7.78	4.66	59.94	7.85
-100	2.9	200	17.25	436	33.61	7.82	4.66	59.66	6.98
-150	2.8	240	16.97	438	32.97	7.72	4.56	59.08	6.38
-200	2.8	300	17.14	420	33.65	7.48	4.65	62.10	5.46
-220	2.7	320	17.53	396	32.83	7.21	4.53	62.77	5.05
-240	2.7	340	17.16	400	33.11	7.13	4.57	**64.02**	4.71
-260	2.6	360	17.48	398	**32.82**	7.23	4.56	63.05	4.36
-280	2.4	380	17.02	396	**31.00**	7.00	4.30	61.46	4.00
-300	2.3	390	16.26	402	**30.13**	6.79	4.18	61.60	3.63
-320	2	400	15.5	408	**27.21**	6.57	3.78	57.56	3.50
-340	1.8	410	14.7	408	**25.04**	6.23	3.47	55.60	3.24
-360	0.8	420	11.89	410	**14.59**	5.07	2.00	39.47	2.87
-380	0.4	420	10.41	412	**10.34**	4.46	1.40	31.51	2.72

measured to calculate pump input (P_{in}) and output power (P_{out}). Then based on pump input and output power the pump efficiency is calculated. After that with different pressure measurement, total head of a pump is calculated. Then $NPSH_A$ has been calculated and correction has been carried out for 2900 rpm speed. Table 1 shows the observed and calculated parameters from NPSH test. In this paper, only 50,000lph flow condition is considered for analysis purpose.

3. Results and Discussions

3.1 Detection of Cavitation Conditions

From Table 1, the maximum head value is 33.38mWc (metre of water column) hence 3% drop value is 32.38mWc. The vacuum conditions which have a head value greater than or equal to 32.38mWc is no cavitation signal and the conditions less than 32.38mWc is cavitation signal. This is shown as a graph (indicated as red line) in Figure 4.

Figure 4 shows the relationship between Head and $NPSH_A$ for 50,000 LPH flow rate. During the decrease of suction pressure, the calculated $NPSH_A$ was also reduced gradually. There is a sharp drop in Head upon cavitation existence in the centrifugal pump. From the graph Maximum head value is 33.38mWc and 3% drop head value is 32.38mWc. Hence 0 – 260 mm of Hg of the vacuum pressure are no cavitation signals and 280 – 380 mm of Hg of the vacuum pressure is cavitation signal. Hence from 31.00mWc to minimum head value 10.34mWc is considered as cavitation Signal and above 31.00mWc head values are considered as no cavitation Signal.

Figure 5 shows the manufacturer graph for the chosen pump. The $NPSH_R$ in the pump characteristics curve provided by the manufacturer indicated the required NPSH value. From the graph, this value corresponds to 3.5m for 50,000lph flow. If $NPSH_A$ is lesser than 3.5m cavitation shall take place. Hence from Table 1, below 320 mm of Hg vacuum conditions falls on this range and referred as cavitation signals. But based on 3% head drop curve, vacuum conditions of 280 mm of Hg – 380 mm of Hg are cavitation signals and 0 mm of Hg – 260 mm of Hg suggesting no cavitation signals.

In addition, maximum efficiency of pump was also observed from Table 1 which is 64.02% at 240 mm of Hg vacuum condition. After this vacuum condition the efficiency gets decreased. The reduction in efficiency of pump may be due to cavitation. Hence the cavitation signal starts from 240 mm of Hg onwards. These three results based on vacuum signals of no cavitation and cavitation conditions are indicated in Table 2.

4. Conclusion and Future Scope

An experimental study for analyzing cavitation conditions of centrifugal pump through NPSH analysis is carried out. Pump is tested under 50,000lph flow rate conditions. The results of NPSH analysis showed a clear relationship between NPSH and cavitation conditions. Thus NPSH

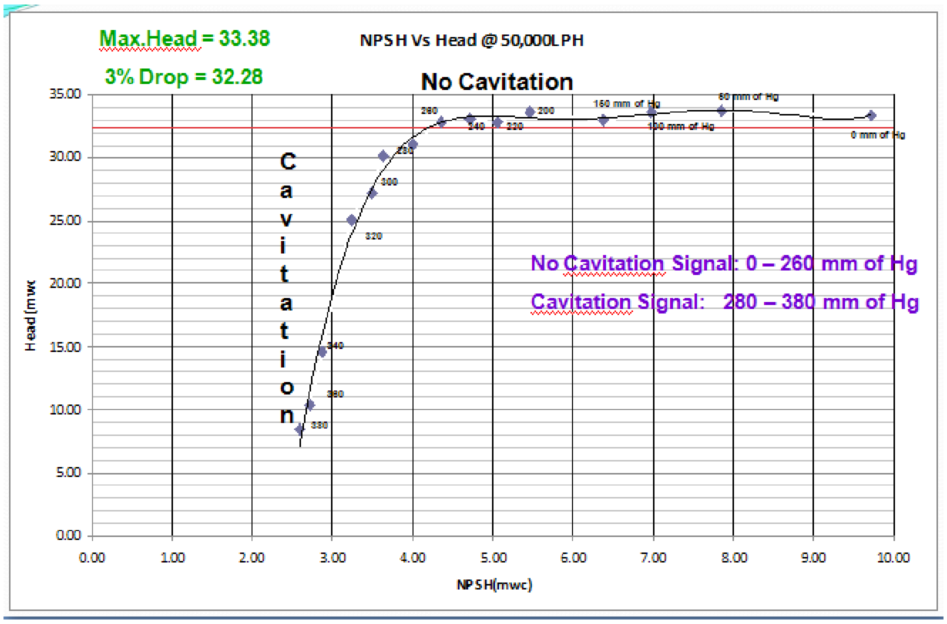

Figure 4. Experimental result based NPSH curve for 50000 LPH.

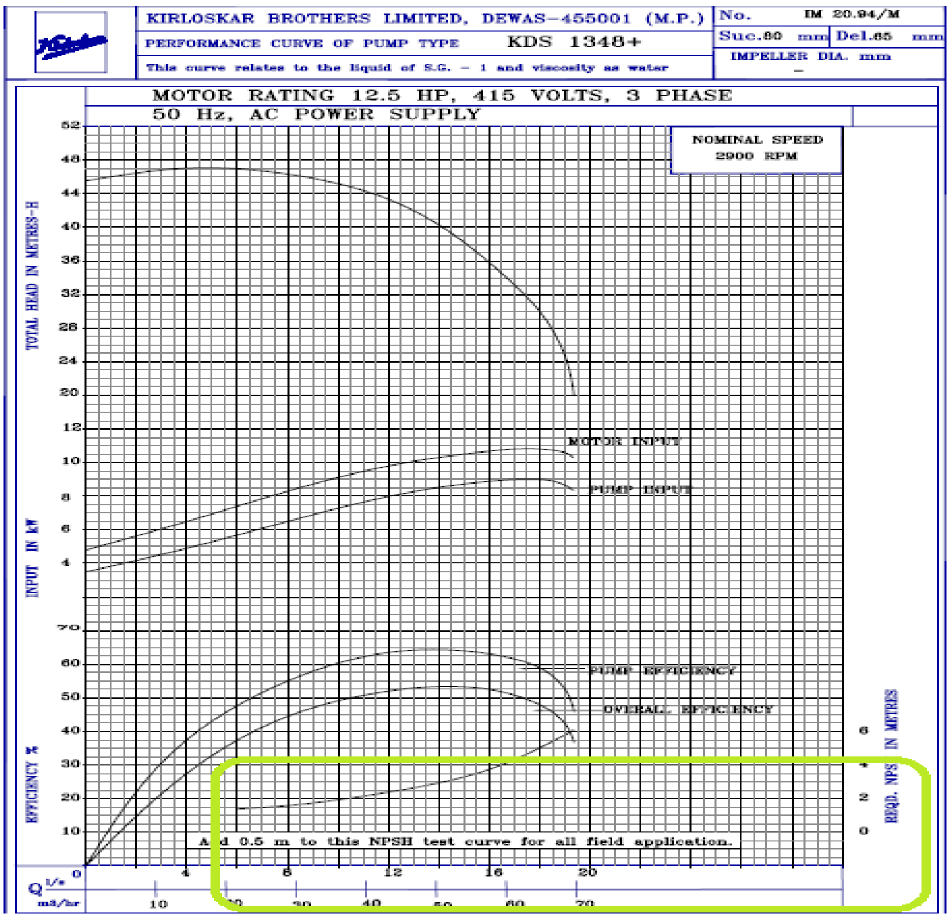

Figure 5. Pump Manufacturer graph (Courtesy: Kirloskar Brothers Limited, DEWAS).

Table 2. Condition of a centrifugal pump with respect to vacuum pressure

S.NO.	Methodology/Parameter Considered	No cavitation Conditions	Cavitation Conditions
1	Based on Manufacturer's Graph	0 – 300 mm of Hg	320 – 380 mm of Hg
2.	3% Head Drop Curve	0 – 260 mm of Hg	280 – 380 mm of Hg
3.	Pump Efficiency	0 – 220 mm of Hg	240 – 380 mm of Hg

was found to be looming in determining cavitation conditions in centrifugal pump. This analysis can help to obtain valuable information about the cavitation conditions of centrifugal pump that can be put up with the particular range of vacuum conditions. In addition, it was observed that the efficiency of the pump also decreased prior to 3% head drop criteria. Thus the safer operating range of selected pump is between 0 – 240 mm of Hg vacuum pressure conditions. A future effort will concentrate on NPSH analysis of centrifugal pump for different flow conditions to obtain cavitation inception point.

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