ANSI/HI 9.6.1-2012

Approved American National Standard

ANSI

American National Standard for

Rotodynamic Pumps

Guideline for NPSH Margin

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Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
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Approved October 25, 2012

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth and well-being of pump manufacturers and further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation, and other problems of the industry, and to this end, among other things:

a) To develop and publish standards for pumps;

b) To collect and disseminate information of value to its members and to the public;

c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;

d) To increase the amount and to improve the quality of pump service to the public;

e) To support educational and research activities;

f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser, and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.

2) Use of Hydraulic Institute Standards is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the Standards.

Definition of a Standard of the Hydraulic Institute

Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

"An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and service for which designed."

Comments from users

Comments from users of this standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be sent to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of a Hydraulic Institute Standard or an answer provided by the Institute to a question such as indicated above, the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the Appeals Process.

Revisions

The Standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

Units of measurement

US customary units of measurement are predominantly used. Due to the reference to ANSI/ASME B73 standards for pump dimensions, conversion to metric units was inappropriate. Consistent units must be used in all calculations required by this standard.

Consensus for this standard was achieved by use of the Canvass Method

The following organizations, recognized as having an interest in the standardization of centrifugal pumps, were contacted prior to the approval of this revision of the standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

4B Engineering & Consulting, LLC
A.W. Chesterton Company
Bechtel
Black & Veatch (B & V)
Budris Consulting
Colfax Fluid Handling
DuPont Company
ekwestrel corp
GIW Industries, Inc.
Gorman-Rupp Company
Healy Engineering, Inc.
Hydraulic, Measurement, & Inspection Consulting
ITT - Industrial Process
J.A.S. Solutions Ltd.
LVVWD - Las Vegas Valley Water District
Mechanical Solutions, Inc.
MWH Americas, Inc.
Patterson Pump Company
Pentair
Pump Design, Development & Diagnostics, LLC
Sulzer Pumps (US) Inc.
Summit Pump, Inc.
Weir Floway, Inc.
Weir Minerals North America
Weir Specialty Pumps

Committee list

Although this standard was processed and approved for submittal to ANSI by the Canvass Method, a working committee met many times to facilitate its development. At the time it was developed, the committee had the following members:

Chair – Arnie Sdano, Pentair Water
Vice-Chair – Charles Cappellino, ITT - Industrial Process

Committee Members	**Company**
Stefan Abelin	Xylem Inc - Water & Wastewater
Graeme Addie	GIW Industries, Inc.
John Anspach	John Anspach Consulting
Jack Claxton	Patterson Pump Company
Michael Cropper	Sulzer Pumps (US) Inc.
Randal Ferman	ekwestrel corp
Thomas Hendrey	Whitley Burchett & Associates
Allen Hobratschk	National Pump Company
Al Iseppon	Pentair Water
Garr Jones	Brown and Caldwell
Dimitar Kalchev	Peerless Pump Company
Yuri Khazanov	InCheck Technologies Inc
Rodney Mrkvicka	Smith & Loveless, Inc.
Michael Mueller	Flowserve Corporation
James Roberts	Xylem Inc - Residential & Commercial Water
Mark Rosebraugh	Grundfos North America
Aleksander Roudnev	Weir Minerals North America
Paul Ruzicka	Xylem Inc. - Applied Water Systems
Ernest Sturtz	CDM Smith Inc.
Fred Walker	Weir Floway, Inc.

Alternate Members	**Company**
Michael Coussens	Peerless Pump Company
Gary Leander	Weir Minerals North America

Other Contributors	**Company**
Ed Allis	Formerly of Peerless Pump Company
Tom Angle	Formerly of Weir Specialty Pumps
Bill Beekman	Formerly of Weir Floway, Inc.

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9.6.1 Pump NPSH margin

This guideline addresses rotodynamic general purpose pumps with absorbed power levels up to 4 megawatts (MW) (5300 horsepower [hp]) and impeller inlet tip speeds less than 40 meters per second (m/s) (130 feet per second [ft/s]). It describes the benefits to pump longevity when the net positive suction head (NPSH) available is greater than the NPSH required by a suitable margin, and suggests margins for specific applications.

An NPSH margin may be required for several reasons related to pump performance and service life, to cover the uncertainties of what the NPSH available (NPSHA) will be over the range of operation, and to provide for adequate pump reliability and performance.

NPSH is the liquid's energy, above the vapor pressure, at the inlet of the pump.

Net positive suction head (NPSH) is the absolute inlet total head above the head equivalent to the vapor pressure referred to the NPSH datum plane.

This NPSH is referred to the *NPSH datum plane*, whereas inlet total head is referred to the *reference plane*.

NPSH: The absolute inlet total head, less the vapor pressure head of the pumpage, referred to a datum which is typically the inlet of the first-stage impeller.

NPSH datum plane: The horizontal plane through the center of the circle described by the external points of the entrance edges of the impeller blades; in the first stage in the case of multistage pumps. In the case of double inlet pumps with vertical or inclined axis, it is the plane through the higher center. The manufacturer should indicate the position of this plane with respect to precise reference points on the pump.

NPSHR: A minimum NPSH given by the manufacturer/supplier for a pump achieving a specified performance at the specified rate of flow, speed, and pumped liquid (occurrence of visible cavitation, increase of noise and vibration due to cavitation, beginning of head or efficiency drop, head or efficiency drop of a given amount, limitation of cavitation erosion).

The full published pump head will not, however, be achieved when the NPSHA equals the NPSH3 of the pump. The first-stage head will be 3% less than the fully developed value. The 3% head drop referred to throughout this guideline refers to the head drop in a single-stage pump. For a multistage pump it refers to the head drop in the first stage only, not the total head of the pump.

It is therefore important to note that the NPSHR curves historically provided by pump manufacturers may not show sufficient NPSH values to provide zero head loss or to eliminate cavitation. The manufacturer's curve, if produced using NPSHR values equal to NPSH3, gives the NPSH required such that cavitation will occur to the point where 3% of the first-stage pump head is lost through cavitation.

The 3% value was implemented as early as 1932 when it first appeared in published Hydraulic Institute Standards. The choice of 3% measured head drop is based on the fact that this is the smallest head drop practically measurable. The 3% measured head drop value continues to be the industry accepted norm for characterizing pump suction performance.

Furthermore, the general consensus at the time of implementation was that pumps operating under conditions of 3% head drop would achieve generally acceptable service lives. This was probably true at the time when pumps for a given application were typically larger and slower than pumps for the same application today. Today's higher speed, higher energy density pumps might not achieve acceptable service life under suction conditions without an adequate NPSH margin.

The purpose of this guideline is to establish margins over NPSH3 that will lead to acceptable pump performance and service life.

9.6.1.1 Introduction

Noise, vibration, and possibly the reliability of a rotodynamic pump and mechanical shaft seal may be affected if an appropriate NPSH margin is not provided by the system above the published NPSH3 for the pump.

The NPSHA is the total suction head available, over the vapor pressure of the liquid pumped corrected to the centerline of the impeller (or impeller inlet vane tip datum if vertically mounted), and measured at the inlet to the pump.

$$NPSHA = h_{atm} + h_s - h_{vp}$$

Where:

h_{atm} = atmospheric pressure head, in m (ft)
h_s = total suction head = h_{gs} + h_{vs} + z_s, in m (ft)
h_{gs} = suction gauge head, in m (ft)
h_{vs} = suction velocity head, in m (ft)
z_s = elevation from the suction gauge centerline to datum (see Figure 9.6.1.1a), in m (ft)
h_{vp} = liquid vapor pressure head (taken at the highest sustained operating temperature), in m (ft)

The NPSH margin is the NPSHA minus the NPSH3.

$$NPSH\ margin = NPSHA - NPSH3$$

NPSH margin ratio is the NPSHA divided by the NPSH3.

$$NPSH\ margin\ ratio = \frac{NPSHA}{NPSH3}$$

See ANSI/HI 14.6 *Rotodynamic Pumps – Hydraulic Performance Acceptance Tests* and ANSI/HI 11.6 *Submersible Pump Tests* for further details on determination of NPSHA and NPSH3.

The conceptual definition of NPSHR by a pump under certain conditions is the value of NPSHA at which a selected phenomenon induced by cavitation starts to appear. Several criteria are used to qualify the different phenomena associated with cavitation, which lead to several definitions of NPSHR. Additional information can be found in *NPSH for Rotodynamic Pumps: Reference Guide,* published by Europump.

One of the most noticeable effects of cavitation is the degradation of the pump performance due to the presence of the vapor phase induced by cavitation. Migration and coalescence of the vapor bubbles affect the flow within the impeller and cause the head developed by the pump to deteriorate.

By Hydraulic Institute definition, the required NPSH of a pump is the NPSH available that will cause the total head (first-stage head of multistage pumps) to be reduced by 3%, due to flow blockage from cavitation vapor in between the impeller vanes. The required NPSH qualified by this criterion will be referred to as *NPSH3*. The full published pump head will not, however, be achieved (by definition) when the NPSHA equals the NPSH3 of the pump (see Figure 9.6.1.1b). The value of 3% head drop for NPSH3 is based on accepted industry practice for defining a condition of head breakdown due to cavitation.

Margin above NPSH3 is necessary in order for the pump to develop its full-published performance as shown on Figure 9.6.1.1c.

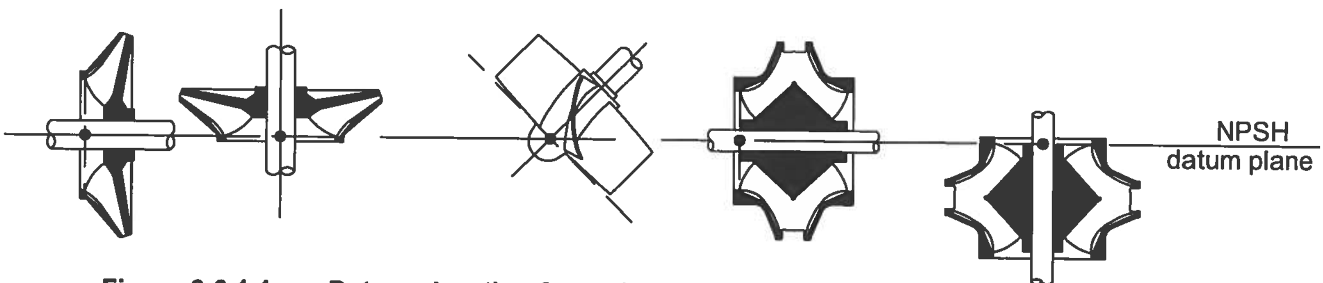

Figure 9.6.1.1a — Datum elevation for various pump designs at eye of first-stage impeller

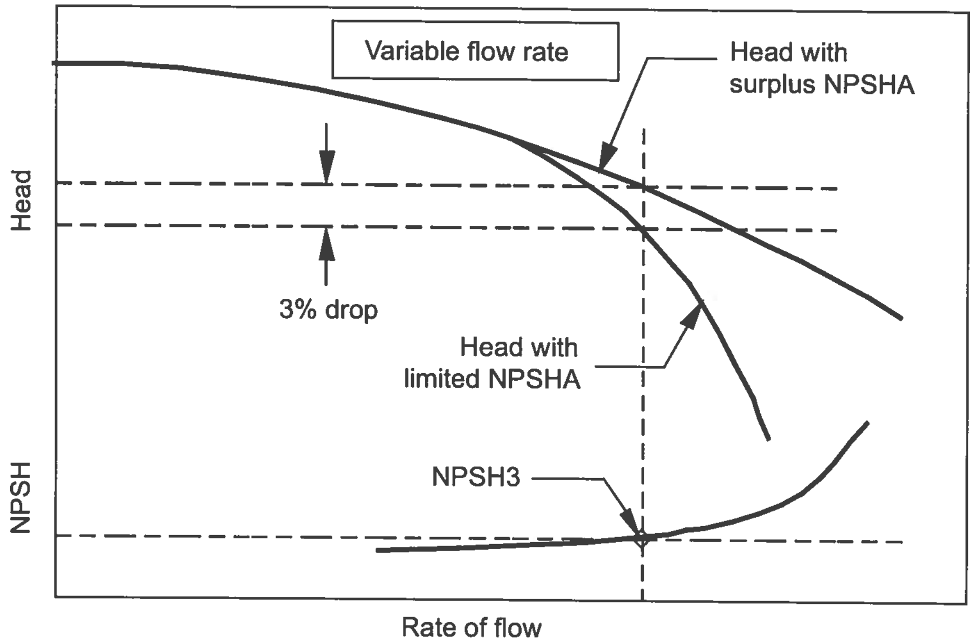

Figure 9.6.1.1b — NPSH3 determination for variable flow rate test

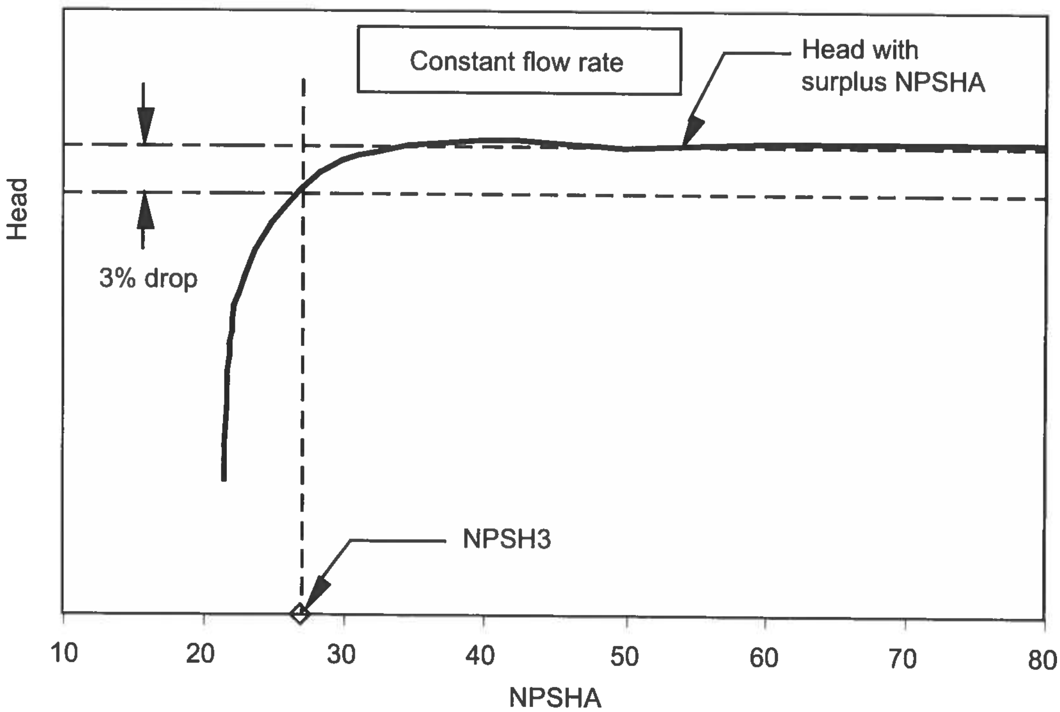

Figure 9.6.1.1c — NPSH3 determination for constant flow rate

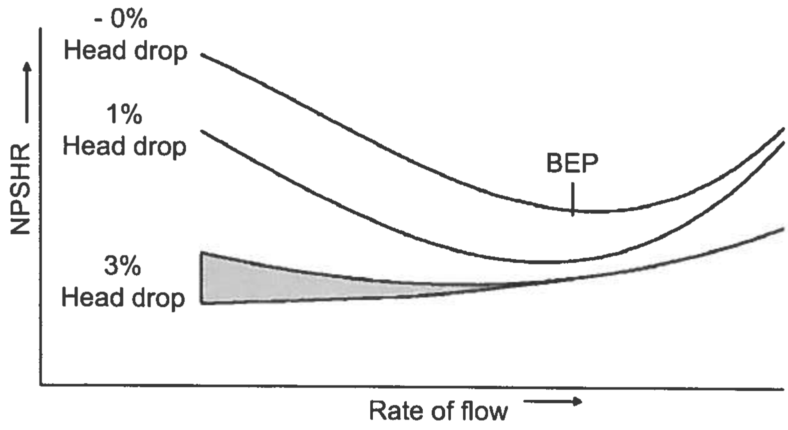

Figure 9.6.1.1d — NPSHR, various head drop criteria

Most pumps can operate satisfactorily with minimal margin above the NPSH3 value when operating near the best efficiency point (BEP) rate of flow (see Figure 9.6.1.1d). A greater margin may be required when operating throughout a wider operating region.

Many pump manufacturers use the industry standard 3% head drop for published NPSHR values and provide the NPSH margin recommendations separately. Manufacturers sometimes publish NPSHR values greater than those determined by the 3% head drop criteria. Unless advised otherwise, the user must assume that the published NPSHR is based on the 3% head drop criteria.

Application experience and factors such as allowance for system and piping losses (see ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping)*, minimum submergence required to prevent vortexing (see ANSI/HI 9.8 *Pump Intake Design)*, operating range (see ANSI/HI 9.6.3 *Rotodynamic (Centrifugal and Vertical) Pumps - Allowable Operating Region)*, and others may be considered in establishing NPSH margins. The NPSH margin guidelines provided in this document are not intended to supersede the specific recommendations of manufacturers or proven experience.

9.6.1.2 NPSH margin considerations

The sensitivity of a pump to NPSH-related problems increases with certain design and application factors, such as:

a) **Inlet tip speed:** occasionally used to lower NPSH3 values by lowering the liquid axial velocity at the impeller, is a direct function of the speed of rotation and the impeller eye diameter. Values below approximately 15 m/s (50 ft/s) are generally considered low, while values exceeding 30 m/s (100 ft/s) are considered high and should be evaluated for adequate NPSH margin. The severity of inlet tip speed effect generally decreases with lighter density pumped liquids or with higher temperatures.

b) **Larger impeller eye:** occasionally used to lower NPSH3 values by lowering the velocity at the impeller inlet and thereby increasing the static pressure head at that region of the impeller. However, the larger impeller eye diameter also increases the impeller inlet tip speed, intensifies the effects of suction recirculation, and increases the required NPSH margin to suppress cavitation damage at flow rates to the left of the BEP (lower than BEP rate of flow).

c) **Suction specific speed:** An index of pump suction operating characteristics determined at the BEP rate of flow with the maximum diameter impeller. Suction specific speed is an indicator of the net positive suction head required for a 3% drop in head (*NPSH3*) at a given rate of flow (Q) and rotative speed (n) and is expressed by the following equation:

$$S = \frac{n(Q)^{0.5}}{(NPSH3)^{0.75}}$$

Where:

S = suction specific speed
n = rotative speed, in rpm
Q = flow rate per impeller eye, in m^3/s (gpm)
= total flow rate for single suction impellers
= one half total flow rate for double suction impellers
NPSH3 = net positive suction head required in meters (feet) that will cause the total head (or first-stage head of multistage pumps) to be reduced by 3%. The required NPSH (NPSHR) qualified by this criterion will be referred to as *NPSH3*.

NOTE: Suction specific speed derived using cubic meters per second and meters, multiplied by a factor of 51.6, is equal to suction specific speed derived using US gallons per minute and feet. The US customary symbol N_{ss} is sometimes used to designate suction specific speed.

For most pump designs, suction specific speed values below approximately 145 metric (7500 US units) generally represent low values, while above approximately 250 metric (13,000 US units) are considered high and may result in a limited allowable operating region.

d) **Pumpage effects:**

- Abrasives in the pumpage may substantially increase the wear rate due to cavitation.

- Small amounts of entrained gas (1 to 2%) cushion the forces from the collapsing cavitation bubbles, and can reduce the resulting noise, vibration, and erosion damage. The lack of any entrained gas can have the opposite effect.

- Additives in the liquid may lead to increased cavitation damage. An example would be cooling tower water treatment agents.

- The corrosive properties of the liquid can accelerate the damage caused by cavitation erosion.

e) **Operating range:** impellers are usually designed to have a zero incidence angle between the inlet impeller vanes and the approaching liquid at a particular rate of flow (often referred to as the *shockless entry flow*). Higher or lower rates of flow cause a mismatch between the angle of the approaching liquid and the impeller vane inlet tips. The greater the incidence angle, the greater the potential for flow separation and cavitation to occur. For operation within the preferred operating region (POR), the minimum NPSH margin or margin ratio will be less than when operating within the broader allowable operating region (AOR) (refer to ANSI/HI 9.6.3). For pumps frequently operating outside of the POR, use the larger margin or margin ratio value across the entire AOR without reduction within the POR.

f) **Materials:** impellers can be manufactured using materials with a wide range of resistance to cavitation damage. Rigid plastics and composites are normally the least cavitation-resistant materials. Cast iron and brass will undergo the most damage among commonly used metals, while stainless steel, titanium, and nickel aluminum bronze will exhibit much less damage under the same cavitation conditions (see Section 9.3.2 Materials in ANSI/HI 9.1-9.5 *Pumps – General Guidelines for Types, Definitions, Application, Sound Measurement and Decontamination* for additional information on material selection and properties).

g) **Impeller vane overlap:** vane overlap is defined as the angular amount that the trailing edge of one vane overlaps the inlet leading edge of the following adjacent vane (see Figure 9.6.1.2). Low vane overlap values as a result of impeller design or excessive trim leads to a reduced length of channel between vanes. With radial flow impellers, this may allow the relatively high energy outlet conditions to interact with the inlet conditions (recirculation) and thereby affect impeller suction performance. The intensity of the recirculation can require a higher NPSH margin. The minimum allowed value of vane overlap varies with impeller design. Radial flow impellers, approaching minimum diameter of impeller trim values, may require testing to reconfirm the NPSH3 values.

h) **Pump size:** large pumps (impeller eyes over 450 mm [18 in] in diameter) can be more prone to problems from cavitation damage than smaller pumps.

i) **Duty cycle:** cavitation damage is time related. The longer a pump runs under cavitation conditions, the greater the extent of damage. Pumps for fire fighting, which run intermittently, rarely have a problem with cavitation damage for this reason.

9.6.1.3 Margin determination

The determination of an appropriate NPSH margin takes into consideration factors impacting performance and service life. Lack of adequate NPSH margin may affect pump head, noise, and vibration. Pump service life may be reduced due to material erosion and damage to bearings or seals.

Recommended margin ratios can vary by pump type and application, with higher values applying to pumps with higher operating speeds and/or continuous operation outside the preferred operating region of the pump.

A greater NPSH margin is not detrimental to the pump, but may not be desirable. Specifying a higher margin may result in a nonoptimal pump selection that will add costs to the pumping equipment (larger/slower pumps or pumps with inducers), reduced efficiency, or a reduced operating range due to selection of a higher suction specific speed pump.

Requiring a greater suction head to increase the NPSH margin may also increase the cost of the pumping station structure.

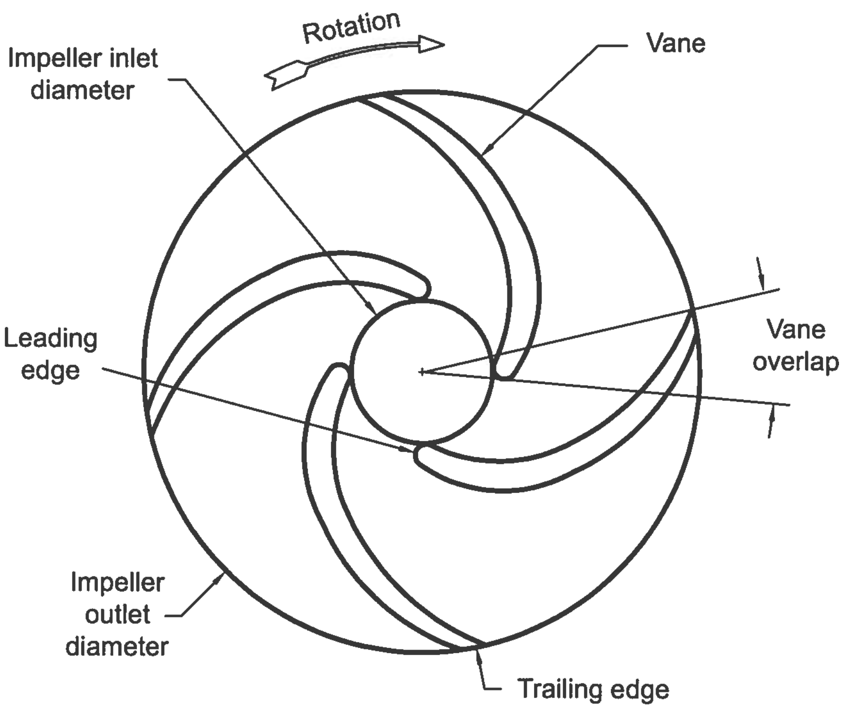

Figure 9.6.1.2 — Vane overlap, radial flow impeller

The recommended use of NPSH margin involves a known pump design having fixed NPSH3 characteristics that result in a reasonable and safe value of suction specific speed. In such a situation, the NPSH margin is applied to the NPSH3 at the flow rate of interest to obtain the minimal value of NPSHA. The use of a higher value of NPSH margin in such a situation generally results in more conservative conditions for the pump. If the recommended NPSH margin cannot be obtained, then choosing a lower operating speed for the pump for a fixed flow rate will generally result in a conservative selection.

The user is cautioned with regard to obtaining NPSH margin by specifying pumps with higher suction specific speeds that have lower NPSH3 values. Higher suction specific speed pump designs are more likely to experience objectionable noise and a narrower operating range as compared to lower suction specific speed pump designs.

This document offers users a general approach for assessing the appropriate NPSH margin. These guidelines are based on the experience of many pump manufacturers and users with many different pump applications. Field experience is the most accurate predictor of future performance and, where this information is available from the manufacturers or the users, it should be used to assist the pump selection and application process.

Extra margin may be necessary to account for changes in the pump geometry that can increase the NPSH3. For example, erosion can enlarge impeller running clearances and increase the internal leakage at the impeller eye, adversely affecting the NPSH3.

Added NPSH margin may be needed to cover uncertainties in the NPSHA or due to the actual operating rate of flow. If a pump consistently operates at higher than expected flow rates, then the NPSHA of the system may be lower than expected and the NPSH3 for the pump will be higher, thus giving a smaller, or possibly negative, NPSH margin. (See ANSI/HI 9.6.3.)

Poor suction conditions may result in flow separation and distorted flow at the impeller inlet, which can adversely affect the NPSH available to the pump. The negative effects of poor inlet/suction conditions are difficult to calculate. Greater NPSH margins might not correct the problem. Optimum pump performance requires that proper intake/suction piping design is followed, according to the Hydraulic Institute Standards (see ANSI/HI 9.8 and 9.6.6), to ensure a steady uniform flow to the pump suction at the required suction head.

The determination of an adequate NPSH margin is dependent on an accurate prediction of both pump NPSH3 and system NPSHA. Factory NPSH3 tests may be considered to validate the predicted pump suction performance. The determination of the NPSHA is the responsibility of the system designer.

9.6.1.4 Application considerations

9.6.1.4.1 Petroleum (hydrocarbon) process pumps

When pumping hydrocarbon liquids, because of their relatively low vapor volume, an NPSH3 reduction (hydrocarbon correction factor) may be applied. This NPSH3 reduction is applied to the water NPSH3 values to correct for the fact that the vapor volume of "flashed" hydrocarbon liquid is substantially less than that of "flashed" cold water. This has the effect of reducing the amount of NPSH required by the pump at a given rate of flow before cavitation results in a 3% drop in the developed head (first-stage head) of the pump.

For further information on NPSH requirements for pumps handling hydrocarbon liquids, see ANSI/HI 1.3 *Rotodynamic (Centrifugal) Pumps for Design and Application* and ANSI/HI 2.3 *Rotodynamic (Vertical) Pumps for Design and Application*.

It must be noted that API 610 (ISO 13709) requires that NPSH3 be based on water with no reduction allowed for other liquids.

Pumps used for petroleum (hydrocarbon) services can successfully operate with relatively small margins over NPSH3 for several reasons, including the following:

a) Processes are typically steady, with few system upsets (transients) or quick flow change demands. Process requirements are typically well-known and demands can be planned and predicted. (However, the trend towards use of varied feed stocks demands broader flexibility in the operating requirements for refinery pumps.)

b) Most hydrocarbon liquids have relatively low vapor-volume-to-liquid-volume ratios. This means that, if the liquid should vaporize at or near the pump suction (impeller inlet), the volume of the resulting vapor does not choke the impeller inlet passages as severely as does water vapor during cavitation. This results in a smaller drop in developed head for the same NPSH margin.

c) Less energy is released when hydrocarbon vapor bubbles collapse (implosion velocity is lower), and this means less material erosion occurs as a result of cavitation.

Typical NPSH margins for rotodynamic pumps on hydrocarbon services are as follows:

For operation within the allowable operating region (AOR) (refer to ANSI/HI 9.6.3), a minimum margin ratio of 1.1 or a margin of 1.0 m (3.3 ft), whichever is greater, is recommended at each particular rate of flow.

The majority of vertical turbine pumps in the petroleum industry are normally installed in a barrel or suction can as shown in ANSI/HI 2.1-2.2 – 2008, Figure 2.1.3.3a. The NPSHA must exceed the NPSH3 over the expected range of operation. The NPSHA reference is normally given at ground level or pump inlet level. The manufacturer then determines the length of the pump required to achieve sufficient NPSHA at the first-stage impeller inlet to account for the NPSH3, pump inlet losses (inlet to eye of first impeller). Caution must be exercised to provide for sufficient NPSHA to prevent cavitation where the suction nozzle joins the larger can diameter.

9.6.1.4.2 Chemical process pumps

Pumps for these applications frequently share the following characteristics:

a) Operation frequently occurs at a wide variety of rates of flow.

b) Materials of construction often include stainless-steel alloy impellers, which have a greater resistance to cavitation damage.

c) They may operate with relatively low NPSHA.

Taking these issues into consideration, the following minimum NPSH margins are suggested for chemical process pumps:

- For pumps with suction specific speeds below 210 metric (11,000 US units), the minimum NPSH margin ratio, at each particular rate of flow, should be 1.1, or 0.6 m (2.0 ft) margin, whichever is greater, for operation within the AOR

- For pumps with suction specific speeds equal to or above 210 metric (11,000 US units):

    1) For operation within the preferred operating region (POR) (see ANSI/HI 9.6.3), the minimum NPSH margin ratio at each particular rate of flow should be 1.1, or 0.6 m (2.0 ft) margin, whichever is greater.

    2) The NPSH margin ratio at each particular rate of flow should be 1.2, or 1.0 m (3.3 ft) margin, whichever is greater, for pumps frequently operating outside of the POR (within the AOR).

Table 9.6.1.4.3 — NPSH margin, electric power plant pumps (non-nuclear)

Pump Type	Power (kW/stage)	POR NPSH Ratio	AOR NPSH Ratio/Margin
Boiler feed	< 225	1.1 ratio	1.3 ratio
Boiler feed	≥ 225 and < 500	1.2 ratio	1.5 ratio
Condensate	All	1.0 ratio	1.0 ratio
Cooling tower	All	1.1 ratio	1.3 ratio
Circulating/Cooling water	All	1.05 ratio	1.0 m

9.6.1.4.3 Electric power plant (non-nuclear) pumps

Power plant pumps are water pumps. Cavitation when pumping cold water can cause severe damage. Unlike hydrocarbon liquids handled by petroleum pumps, cold water, when it vaporizes (flashes), expands tremendously. This results in higher impact velocities when the vapor bubbles implode with higher destructive energy.

Hot water, on the other hand, can act similarly to hydrocarbon liquids. When water is heated to 120-150 °C (250-300 °F), the vapor volume characteristics become similar to that of a typical hydrocarbon.

Typical power plant operating cycles are not constant. A pump rate of flow can vary widely with power demands. System transients occur that may result in rapid changes in pump suction conditions, such as pressure and temperature. This is especially true for pumps in the boiler water systems, such as boiler feed pumps and boiler feed booster pumps.

Other pumps in the power plant are not usually exposed to such severe transients as those in the boiler water system. An NPSH margin requirement based on a minimum required impeller life may be specified for certain applications. See Table 9.6.1.4.3 for suggested margins.

Condensate pumps have special demands or operating conditions that affect NPSH margin requirements. Since they are typically required to operate with very low NPSHA, they are designed to function with some cavitation present. Condensate applications typically require pumps that can operate at very low absolute pressures. The vertical canned arrangement provides NPSHA by virtue of water elevation above the first-stage impeller. For such an application, there often is minimal NPSH margin at the maximum flow rate; and the pump must be designed to withstand cavitation. Cavitation-resistant materials should be supplied for the first-stage impeller. Impeller inlet peripheral velocity for condensate pumps should be below 21.3 m/s (70 ft/s).

Circulating/cooling water pumps typically have an impeller inlet peripheral velocity below 26 m/s (85 ft/s).

Pumps on cooling tower applications require special attention to NPSH margin. The water circulated through pumps for cooling towers is highly aerated and has high levels of dissolved oxygen. Larger margins may be required to achieve suitable impeller life. Considerations should be made to the selection of cavitation-resistant impeller materials due to the aggressive nature of the pumpage. In such conditions, based on the fluid being pumped, bronze or alloy steel materials may be selected rather than cast iron in order to improve impeller life.

9.6.1.4.4 Nuclear power plant pumps

Nuclear power plant pumps are characterized by the need to operate reliably over a wide range of start-up, testing mode, continuous, and transient operating conditions. This is particularly the case with the primary reactor and

Table 9.6.1.4.5 — NPSH margin, water/wastewater pumps

Pump Type	Power (kW/stage)	POR NPSH Margin (1.0 m minimum)	AOR NPSH Margin (1.5 m minimum)
Wastewater (cast-iron impeller)	< 45	1.1 ratio	1.2 ratio
Wastewater (stainless-steel impeller)	< 45	1.05 ratio	1.1 ratio
Wastewater (cast-iron impeller)	≥ 45	1.2 ratio	1.3 ratio
Wastewater (stainless-steel impeller)	≥ 45	1.1 ratio	1.2 ratio
Water (stainless or aluminum–bronze impeller)	< 75	1.05 ratio	1.1 ratio
Water (stainless or aluminum–bronze impeller)	≥ 75	1.1 ratio	1.2 ratio

safety-related pump applications. Nuclear reactor duty pumps within the containment vessel, and safety-related pumps, typically have well-defined performance specifications, including NPSH margins that are beyond the scope of this standard.

9.6.1.4.5 Water/wastewater pumps

The municipal water and wastewater applications use a variety of types and sizes of pumps operating with various types of fluid service, from raw water, treated potable water, and raw sewage, to other fluids used in the treatment processes. The two most distinct categories of service are clear water and solids-bearing waters. Pump power requirements vary from fractional kilowatts to over 1000 kW per unit.

Many pumps are driven by constant speed motors. Where the system requires the pump(s) to deliver variable flows and heads, a variable speed drive can be used. It is therefore important to plot the system head curve at varying flow conditions using friction coefficients for new and old pipes so that the range of operating points can be determined. The pumping system NPSHA at different operating conditions can be calculated and compared to the NPSH requirements of the pump. Systems controlled by throttling valves may require increased margins to compensate for operation outside the POR.

Experience indicates that an NPSH margin of 1.0 m (3.3 ft) is adequate to resist cavitation damage for most municipal-type water and wastewater pumping applications when operating within the POR. For pumps equipped with impellers made from materials resistant to cavitation damage, lower NPSH margins are allowed (see ANSI/HI 9.3 for additional guidance on material cavitation resistance). See Table 9.6.1.4.5 for specific recommendations.

The following considerations apply to pumps for this application:

a) Many applications involve variable flows, wet well levels, pump speeds, heads, and number of pumps operating. The pump operates over a range of capacities and not at a fixed duty point. In variable speed mode of operation, the speed and rate of flow may vary considerably. It is important that the pump can function properly over the full operating range of the system curve. A flow duration diagram can be used to determine where the pump will operate most frequently.

b) Actual operating system head curves may differ from the calculated values. This will cause the NPSH margin calculation to be incorrect. For existing systems, it is possible to measure the head and flow at a number of points to develop the system head curve. Two system curves should be calculated for new installations: one for the system as it will be installed and a second to represent the condition of the system after some increase in pipe roughness that is expected to occur with time. It is very important to ensure that the calculated system head curves be as close as possible to the actual, or the specified NPSH margin should be increased to compensate for the system unknowns.

9.6.1.4.6 Pulp and paper stock pumps

For horizontal end suction paper stock pumps operating in the AOR, it is normal to add sufficient NPSH margin to account for the uncertainties in the actual NPSH3 and NPSHA from poor suction piping and entrained air. The following NPSH margins are suggested for stock consistencies up to 6%:

- For pumps with suction specific speed values below 145 metric (7500 US units), the NPSH margin ratio should be 1.1, or an NPSH margin of 0.6 m (2 ft), whichever is greater

- For pumps with suction specific speed values 145 metric (7500 US units) and above, the NPSH margin ratio should be 1.2, or an NPSH margin of 1.0 m (3.3 ft), whichever is greater

For stock consistencies above 6%, consult with the pump manufacturer for appropriate margin determination.

9.6.1.4.7 Building services

Fluid systems for the building trades or heating, ventilation, and air conditioning (HVAC) industry are comprised of both closed and open pumping systems. NPSH is generally not a concern when designing closed pumping systems. The typical closed system is filled and then pressurized to a "fill" pressure of 30 to 70 kPa (4 to 10 psig). If an inadequate NPSHA condition should occur, it can usually be remedied by increasing the fill pressure.

For open systems, NPSH margin is a very important consideration. The following NPSH margins are suggested for building service pumps in open systems:

- For low suction specific speed pumps, values below 145 metric (7500 US units), the NPSH margin ratio should be greater than 1.0 throughout the AOR

- For pumps with suction specific speed values above 145 metric (7500 US units), the NPSH margin ratio should be 1.1, or an NPSH margin of 0.6 m (2 ft), whichever is greater

9.6.1.4.8 Slurry pumps

Pumps designed for slurry services typically use either hard metals or elastomers in their construction. It is also common for the slurry concentration and flow rates to change rapidly, imposing significant loads on the impeller, shaft, and bearings. Because of this, and the erosive nature of many slurries, slurry pumps are of an extremely rugged design, making them relatively insensitive to the mechanical effects of cavitation.

Effects of solids on pump cavitation performance are dependent on the slurry type and the pump design and can be highly variable. For settling slurries of low to medium concentration, a modest increase in NPSH3 can be expected. For a particular application, this increase can be conservatively estimated by dividing the value of NPSH3 on water by the head reduction factor.

Slurry pumps often operate at low speeds (less than 1200 rpm) to minimize erosion. As a result of this, they normally fall into the medium or low suction specific speed category, and have NPSH3 values below 6 m (20 ft) before calculating the NPSH ratio or margin.

Slurries are typically water-based and at ambient temperatures. Suction flow is often gravity fed. Consequently the NPSHA is normally in excess of 9 m (30 ft), resulting in NPSHA/NPSH3 margin ratios in excess of 1.5.

The recommended NPSH margin ratio for slurry pumps operating within the AOR is 1.1, or a margin of 0.6 m (2.0 ft), whichever is greater. For applications where the margin is less, characteristics of the slurry and the NPSH3 of the pump should be reviewed to ensure satisfactory performance (refer to ANSI/HI 12.1–12.6 *Rotodynamic (Centrifugal) Slurry Pumps for Nomenclature, Definitions, Application, and Operation for further information)*. For viscous and nonsettling slurries, or slurries with entrained air, the effect on NPSH3 can be significantly greater. The pump manufacturer should be consulted for guidance regarding slurry effects on pump cavitation performance.

9.6.1.4.9 Oil and gas industry pumping applications

Pipeline pumps. For this guideline, pipelines are defined as conduits for the long-distance transport of hydrocarbons. Pumps used for pipeline service normally share the following application criteria:

a) The NPSHR curves provided by manufacturers of these pump types are application specific, and include NPSH values much more conservative than the NPSH3 values.

b) Specifications may require alternate criteria for suction performance. One is the conventional NPSH3 curve, and a second is NPSH "required" values based on a 1% head drop (NPSH1).

c) An NPSH margin requirement based on a minimum required impeller life may be specified for certain applications.

Water injection pumps. Water injection pumps are used for flooding of underground formations. The system requirements may vary with time, and normally these variations are gradual. NPSH margins may have to be reevaluated when operating conditions change.

Typical NPSH margins for injection pumps are set based on:

a) Pump NPSH3 at maximum expected flow rate.

b) Minimum NPSHA expected at this maximum flow rate.

An NPSH margin requirement based on a minimum required impeller life may be specified for certain applications. Injection pump service can be quite demanding with high impeller velocities. It is recommended that the manufacturer be consulted for guidance on an appropriate NPSH margin.

9.6.1.4.10 General industrial pumping applications

Pumps for this application are used to pump a great variety of liquids. These pumps are often sold as standard catalog pumps.

Since most general industrial pumps are used in applications with a flooded suction, operation of the pump within the POR without any NPSH margin does not normally cause substantial damage to the internal components of the pump. The larger of a minimum margin ratio of 1.05 or a margin of 0.6 m (2.0 ft) is recommended.

For operation within the broader AOR, the larger of a minimum margin ratio of 1.1 or an NPSH margin of 1.0 m (3.3 ft) is recommended.

For applications that are equivalent to those used in other defined industry segments, the NPSH margins in that section may be applied.

9.6.1.5 Summary

The following key points should be understood about cavitation in a centrifugal pump, NPSH margin requirements, and how these are affected by the range of operation of the pump:

a) Some degree of cavitation typically exists even when NPSHA is greater than NPSH3 of a pump.

b) The operating range of a pump installed in a system determines what NPSH margin is required to minimize cavitation damage. Pumps required to operate well away from the POR for extended periods of time may experience reduced life if sufficient NPSH margin is not provided.

c) Low suction specific speed pumps, operating with low inlet tip speeds, can normally operate at or near their NPSH3 with little or no consequences from cavitation, except for the 3% head drop.

d) High suction specific speed pumps, operating with high inlet tip speeds, are likely to be noisy with higher vibration and will possibly experience less than optimum pump life if sufficient NPSH margin is not provided and without restricting the AOR.

e) Pumps can be subjected to cavitation damage due to poor suction inlet piping (refer to ANSI/HI 9.6.6 for additional information).

f) Specifying an excessive NPSH margin may result in a nonoptimum pump selection, adding to the pumping equipment, station, and operating costs.

Appendix A

Reduction of NPSHA with time

This appendix is not part of Hydraulic Institute Standard 9.6.1, and is included for informational purposes only.

For applications where the pump may have a considerable length of suction piping, an increase in pipe roughness over time will also result in a reduction of the NPSHA at the pump. Refer to the two figures attached, each of which shows two NPSHA curves and one NPSH3 curve.

This figure illustrates a condition where there is initially adequate NPSHA at all flow rates. The difference between the initial and later NPSHA curves is that initially the friction loss is such that the NPSHA is acceptable at all flows while, at some time in the future, the friction loss increases so that the NPSHA curve crosses the NPSH3 curve. The changing of friction characteristics with time can be caused by a number of conditions including:

- Filter or a strainer in the pump suction line that gradually becomes plugged
- Valve in the suction line that is no longer wide open
- Scale buildup in the suction pipe
- Obstruction in the suction line
- Obstruction of forebay or changes of suction flow patterns

This figure also illustrates a condition where there is initially adequate NPSHA at all flow rates. The difference between the initial and later NPSHA curves is that initially the NPSHA is acceptable at all flows while, at some time

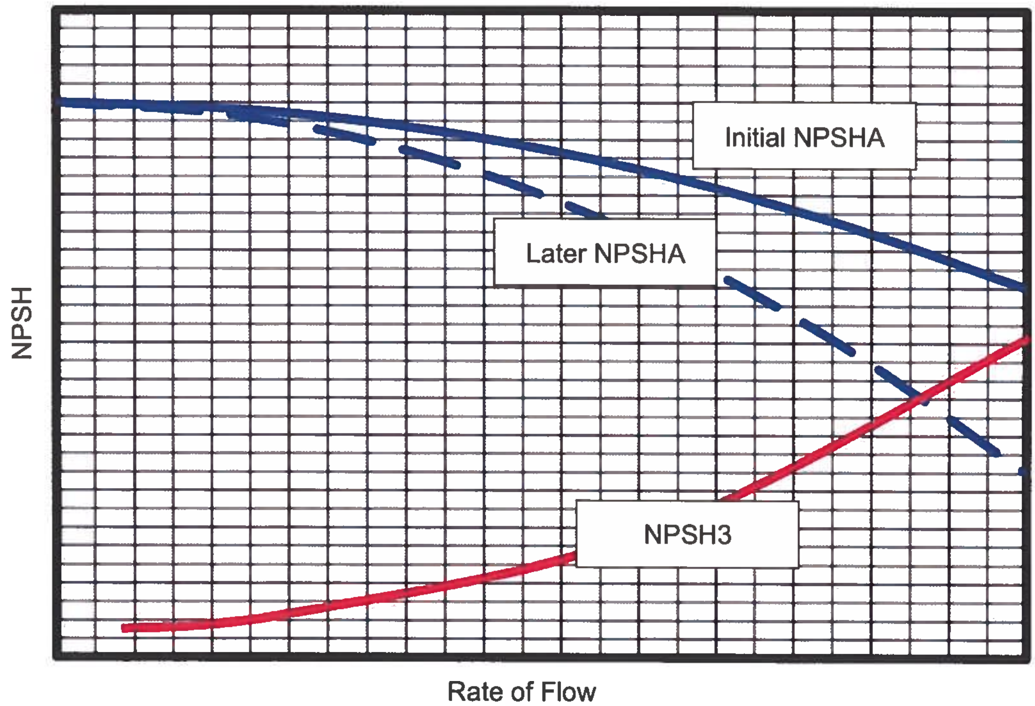

Figure A.1 — NPSH versus rate of flow – change in system dynamic component

in the future, the suction static head decreases or the vapor pressure increases so that the NPSHA curve crosses the NPSH3 curve. The changing of suction static head or vapor pressure with time can be caused by a number of circumstances including:

- Suction liquid level decreases, reducing NPSHA
- Fluid temperature increases, increasing the vapor pressure, which reduces NPSHA
- Suction pressure decreases (decreased fill pressure), reducing NPSHA

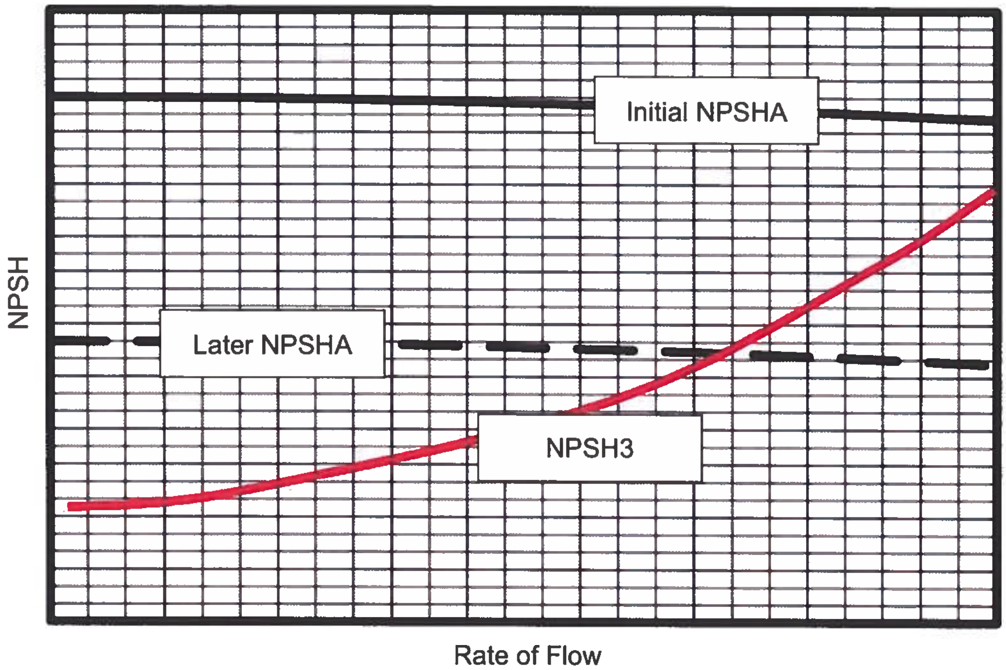

Figure A.2 — NPSH versus rate of flow – change in system static component

A.1 Increase in NPSH3 due to cavitation erosion

Cavitation is caused by a localized reduction in pressure, below that of the liquid's vapor pressure, with accompanying vapor bubble formation. These bubbles are carried into a zone of higher pressure resulting in vapor bubble implosion. If the bubbles implode near an impeller surface, erosion damage occurs. Over time this will result in surface irregularities. The adverse change in surface geometry due to erosion can result in further localized flow velocity accelerations and decelerations with intensified cavitation erosion removing greater volumes of material, to greater depths or over a wider area. Thus the rate of cavitation erosion tends to increase over time. Depending on the pump design and the particular application conditions, the NPSH3 may also be increasing over time as the erosion damage progresses.

A.2 Rotative speed limitations, water and wastewater pumps

The maximum operating speed for a pump can be limited by the available NPSH in the system and the suction characteristics of the first stage. Excessive pump speed can result in unacceptable noise and vibration levels, abnormal wear, cavitation damage, and possible pump failure.

Water and wastewater pumps are frequently supplied with soft bronze impellers or cast-iron impellers, neither of which provides significant cavitation resistance (see ANSI/HI 9.1-9.5, Section 9.3, for more information regarding cavitation-resistant materials). To further complicate the situation, municipal water and wastewater pumps are frequently operated at flow rates above or below the POR, to match the required demand. A conservative suction specific speed may be used to ensure an adequate margin on NPSH, to prevent damage due to the wide operating range, or the soft impeller material. A suction specific speed limitation (S) of 165 (8500) is frequently used in this market to set the maximum speed of rotation (n) that can allow for an acceptable pump life.

The maximum speed for a pump (n) due to the NPSHA can be calculated from the suction specific speed formula by expressing the rotative speed as a function of NPSHA, pump rate of flow (Q), and suction specific speed (S) as follows:

$$n = \frac{S(NPSHA^{0.75})}{Q^{0.5}}$$

Figures A.3 and A.4 are examples based on a suction specific speed of 165 (8500) while operating at or near best efficiency for single suction pumps. For double suction pumps, use one half of the total rate of flow. This represents a practical value for a typical pump handling cold water and liquids with similar properties. Operating speeds may be lower than the ones shown. Also, alternate pump design and materials may allow for reliable operation of pumps with suction specific speed values greater than 165 (8500), resulting in lower NPSHR.

Example (metric): Given a rate of flow of 2.778 m^3/s (10,000 m^3/h) and NPSHA of 15 m, what is the rpm limit for 165 suction specific speed?

$$n = \frac{S(NPSHA^{0.75})}{Q^{0.5}}$$

Therefore:

$$n = \frac{165(15.0^{0.75})}{\left(\frac{10{,}000}{3600}\right)^{0.5}} = 755 \text{ rpm}$$

Referring to the curve, Figure A.3, the intersection of the vertical line for 10,000 m^3/h and the horizontal line for 15 m of NPSHA corresponds to 754 rpm.

Example (US customary units): Given a rate of flow of 90,000 gpm and NPSHA of 50 ft, what is the rpm limit for 8500 suction specific speed?

$$n = \frac{S(NPSHA^{0.75})}{Q^{0.5}}$$

$$n = \frac{8500(50.0^{0.75})}{90{,}000^{0.5}} = 533 \text{ rpm}$$

Therefore, the recommended maximum operating speed is 533 rpm.

From Figure A.4, note that the intersection of the vertical line for 90,000 gpm and the horizontal line for 50 ft of NPSHA corresponds to approximately 533 rpm.

References:

NPSH for Rotodynamic Pumps: Reference Guide, published by Europump

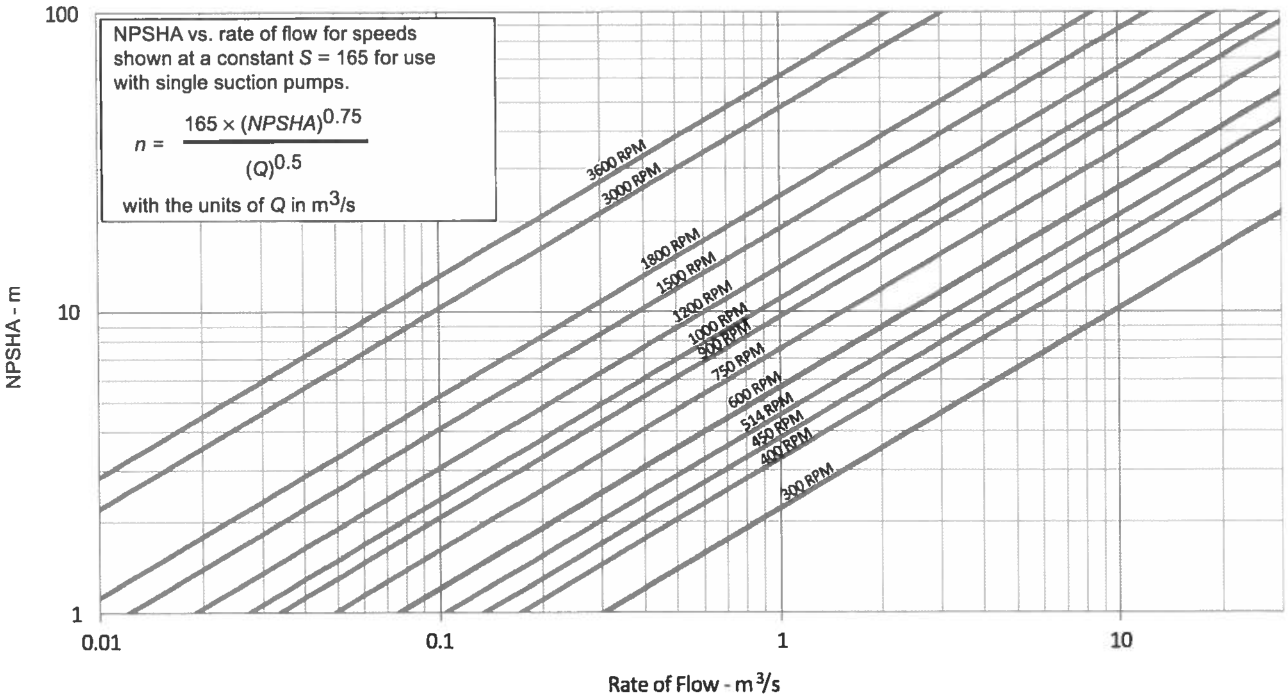

Figure A.3 — Recommended maximum operating speeds (metric)

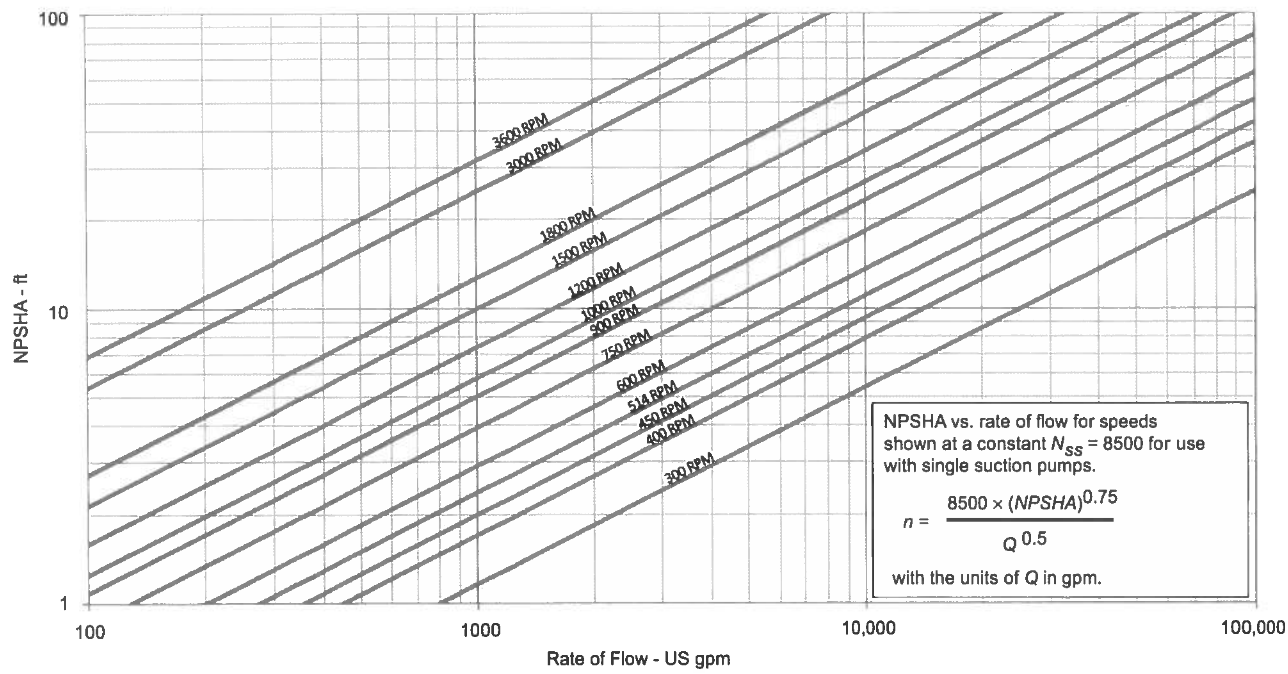

Figure A.4 — Recommended maximum operating speeds (US customary units)

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Appendix B

Index

This appendix is not part of this standard, but is presented to help the user in considering factors beyond this standard.

Note: an f. indicates a figure, and a t. indicates a table.

Available at eStore.Pumps.org

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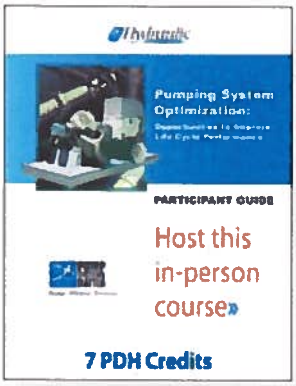

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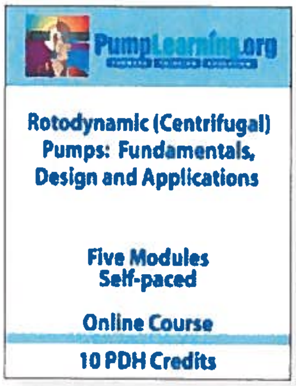

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