ANSI/HI 9.6.3-2012

American National Standard for

Rotodynamic (Centrifugal and Vertical) Pumps

– Guideline for Allowable Operating Region

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Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
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Sponsor

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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 of the 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 and guidelines 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 and Guidelines

1) Hydraulic Institute Standards and Guidelines 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 and Guidelines is completely voluntary. Existence of Hydraulic Institute Standards or Guidelines does not in any respect preclude a member from manufacturing or selling products not conforming to these standards or guidelines.

Definition of a Hydraulic Institute Guideline

A Hydraulic Institute Guideline is not normative. The guideline is tutorial in nature, to help the reader better understand the subject matter.

Comments from users

Comments from users of this guideline will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this guideline 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 the contents of an Institute Standard or Guideline, or an answer provided by the Institute to a question such as indicated above, the point in question shall be referred to the Technical Director of the Hydraulic Institute, who shall initiate the Appeals Process.

Revisions

The Standards and Guidelines 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 or guidelines are reaffirmed using the ANSI canvass procedure.

Scope

This guideline applies to rotodynamic (centrifugal and vertical) pump types. It describes the effects of operating a rotodynamic pump at rates of flow that are greater or less than the rate of flow at the pump's best efficiency point (BEP).

Units of measurement

Metric units of measurement are used; corresponding US customary units appear in brackets. Charts, graphs, and sample calculations are also shown in both metric and US customary units.

Since values given in metric units are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this guideline. If no such statement is provided, metric units shall govern.

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

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

4B Engineering
Bechtel Power Corporation
Black & Veatch (B & V)
Brown and Caldwell
DuPont Company
ekwestrel corp
GIW Industries, Inc.
Gorman-Rupp Company
Healy Engineering, Inc.
ITT - Industrial Process
J.A.S. Solutions Ltd.
LVVWD - Las Vegas Valley Water District
Patterson Pump Company
Pentair Water
Powell Kugler, Inc.
Pump Design, Development & Diagnostics, LLC
TACO, Inc.
The Conservation Fund
Wasserman, Horton
Weir Floway, Inc.
Weir Minerals North America
Xylem Inc - Residential & Commercial Water

Committee list

Although this guideline 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	Yeomans Chicago Corporation
Aleksander Roudnev	Weir Minerals North America
Paul Ruzicka	Xylem Inc
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Alternate Members	Company
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Other Contributors	Company
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Tom Angle	Weir Spec. Pumps
Bill Beekman	Weir Floway, Inc.

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9.6.3 Allowable operating region

This guideline discusses the effects of operating a rotodynamic pump at rates of flows greater than or less than the pump's best efficiency point (BEP). These effects influence the power consumption and life of pump components and, therefore, considering the operating rate of flow is essential to reliable, efficient pump operation.

Design characteristics for both performance and service life are optimized near a rate of flow designated as the BEP. At BEP the pump operates with maximum hydraulic efficiency. The pumped liquid passes through the impeller vanes, casing diffuser (discharge nozzle), or vaned diffuser with minimal losses. Flow through the impeller and diffuser vanes (if so equipped) is relatively uniform and matched to the pump hydraulic geometry.

When the operating rate of flow moves far enough away from BEP, the flow through the pump is no longer uniform. Areas of flow recirculation and separation develop increasing hydraulic losses. Nonuniform flow and uneven pressure distributions in the pump result in increased hydraulic loads and vibration.

Pumps operating in the presence of fibrous materials and at low speeds and flows can lead to pump clogging. The minimum rate of flow, used to define the allowable operating region (AOR), may need to be increased to reduce the risk of clogging for these types of applications.

9.6.3.1 Preferred operating region

The preferred operating region (POR) is a range of rates of flow to either side of BEP within which the hydraulic efficiency of the pump is not substantially degraded. Within this region, the design service life of the pump will not be affected by the internal hydraulic loads or flow-induced vibration. Operating a pump within the POR ensures higher reliability and lower energy consumption.

The POR for most rotodynamic pumps is between 70% and 120% of BEP. For smaller pumps, less than 4 kilowatts (kW) (5 horsepower [hp]), or pumps with low specific speeds, $n_S < 15$ ($N_S < 800$), the manufacturer may recommend an alternate POR that could be more expansive or more restrictive. For larger pumps, greater than 1.0 MW, or pumps with an unstable head curve, the manufacturer may recommend a more restrictive POR.

Well-matched flow in higher specific speed pumps occurs in a narrower flow range. The POR for such pumps is shown in Table 9.6.3.1.

Table 9.6.3.1 — Preferred operating region related to specific speed

Specific Speed		Preferred Operating Region (POR)
Metric	US customary	
≤ 87	≤ 4500	Between 70% & 120% of BEP
> 87	> 4500	Between 80% & 120% of BEP

For slurry pumps handling high concentrations of abrasive solids, the generally acceptable range of rates of flow is primarily determined by wear considerations of the wear components. Refer to ANSI/HI 12.1-12.6 *Rotodynamic (Centrifugal) Slurry Pumps for Nomenclature, Definitions, Applications, and Operation* for information.

9.6.3.2 Allowable operating region

A wider range of rates of flow, outside the POR, over which the service life of a pump is acceptable, is designated the allowable operating region (AOR). The limits of AOR are determined by requirements other than energy consumption, and should be defined with the help of the pump manufacturer. Operation in regions that are not fully defined by the pump curve (head, efficiency, and NPSH) should not be undertaken without consultation with the manufacturer.

AOR depends on a large number of factors, some of which are application-specific. This discussion is limited to those factors related to operating rates of flow and pump design. For the purpose of this guideline it is assumed that the pumped liquid is a Newtonian pure liquid with no vapor, gas, suspended solids, or abrasives.

Certain fluid mixtures may have other characteristics that affect the AOR. For example, the minimum rate of flow when pumping a fluid that contains entrained gasses may be limited by gas accumulation at the eye of the impeller. These considerations are outside the scope of this guideline.

Factors such as proper equipment selection, installation, maintenance, and operation, which also greatly affect pump reliability, are not factors in defining the AOR.

Bearing life will be reduced and noise, vibration, and component stresses will be increased when a pump is operated outside its POR. As a result, service life of a pump operated within the AOR may be lower than within the POR. While the predicted bearing life will vary significantly over the AOR, it is recommended that the calculated bearing life be a minimum of two years of operation in this range (basic rating life L10 equal to or greater than 17,500 hours).

When a manufacturer's recommendations deviate significantly from these guidelines, or a concern exists regarding the ability of the pump to operate reliably at the specified rate of flow, a factory test should be specified. Characteristics that may be monitored during the test include one or more of the following as appropriate:

- Stability of rate of flow being pumped
- Bearing housing vibration (Refer to ANSI/HI 9.6.4 *Rotodynamic Pumps for Vibration Measurements and Allowable Values.*)
- Shaft vibration
- Motor vibration
- Bearing temperature
- Noise (Refer to ANSI/HI 9.4 *Measurement of Airborne Sound.*)

The manufacturer and purchaser should agree to acceptance criteria for the above at the time the pump contract is developed.

9.6.3.3 Factors affecting AOR

Following is a list of the factors that a pump manufacturer considers when establishing the AOR. Within the AOR, the manufacturer has determined that none of the factors exceeds limits that will severely impact the service life of the pump. The factor that determines the upper or lower limits of the AOR will normally vary with pump type and specific design, and may not be evident from the manufacturer's literature. This list, and the following discussion of each, is provided as an aid in understanding the acceptable operating limits.

- Hydraulic loads - dynamic effects on:
  - Bearing life
  - Shaft seal life
  - Internal mechanical contact
  - Shaft fatigue life
  - Thrust reversal

- Temperature rise
- Vibration
- Noise
- Power limit
- Liquid velocity
- Net positive suction head available (NPSHA) margin
- Head – rate-of-flow curve
- Suction recirculation
- Pump size

9.6.3.3.1 Hydraulic loads

Hydraulic loads acting on the impeller depend on type of discharge casing, vary significantly with the rate of flow, and impact the magnitude and direction of the loads and deflections on the shaft, seals, and bearings.

9.6.3.3.1.1 Bearing life

Manufacturers may limit the AOR for pumps to achieve a specified bearing life. Pumps with sleeve type and hydrodynamic bearings do not have a calculated bearing life with respect to rate of flow. Operating range limitations may be considered in calculating bearing whirl, lubrication, bearing materials, and maximum bearing load. ANSI/HI 1.3 *Rotodynamic (Centrifugal) Pumps for Design and Application* and ANSI/HI 2.3 *Rotodynamic (Vertical) Pumps for Design and Application* provide additional information on bearing life.

9.6.3.3.1.2 Shaft fatigue life

Hydraulic loads originating in the impeller and casing are transmitted through the shaft to the bearings. Pump casing design and operating point can have an impact on the magnitude and direction of the radial loads imposed on the shaft. Pump casing designs such as volute, circular, and diffuser types are used to optimize the combination of hydraulic loading and performance. It is the responsibility of the manufacturer to identify the AOR for the selected casing and shaft design to achieve an acceptable shaft fatigue life.

9.6.3.3.1.3 Internal mechanical contact

Hydraulic loads acting on the impeller produce deflections in mechanical components. The loads may be steady or varying, but usually change as the operating rate of flow changes. As loads increase, deflections may become so large as to result in contact between rotating and stationary parts. This may not be harmful if the parts are compatible (i.e., nongalling combinations of impeller and casing rings) and if the contact is not sustained. Each manufacturer evaluates their design and operating experience to determine AOR limits, to avoid damaging internal mechanical contact.

9.6.3.3.1.4 Shaft seal life

Excessive shaft deflection will cause an angular misalignment at the faces of a mechanical seal, which subsequently will reduce the shaft seal life. Most process pump manufacturers limit the AOR to operating conditions where the shaft deflection by design at the seal faces is 0.05 mm (0.002 in) or less. Since most seal designs and all compression-packed pumps permit greater deflections, the continuous rates of flow limits (both maximum and minimum) are application-specific. See the joint HI and FSA publication *Mechanical Seals for Pumps: Application Guidelines* for additional information.

9.6.3.3.1.5 Thrust reversal

Change in momentum of the flow through the impeller eye, which in a centrifugal impeller makes a turn from axial direction to radial, produces a thrust force away from the suction. This force increases proportionally to square of the rate of flow. If the thrust bearings are not designed to absorb this thrust reversal, then the maximum allowable rate of flow should be limited.

9.6.3.3.2 Temperature rise

ANSI/HI 1.3 *Rotodynamic (Centrifugal) Pumps for Design and Application* provides a recommended practice for calculating the minimum thermal rate of flow. This rate of flow is dependent on the specific heat, density, and the vapor pressure–temperature relationship of the pumped fluid. Consequently the minimum thermal rate of flow is application-specific.

9.6.3.3.3 Vibration

The HI Standards specify the maximum allowable vibration for rotodynamic pumps. These pumps typically exhibit a minimum vibration near the BEP, with increases in vibration at higher and lower rates of flow. Vibration levels should be considered when establishing the AOR. Refer to ANSI/HI 9.6.4 *Rotodynamic (Centrifugal and Vertical) Pumps for Vibration Measurements and Allowable Values.*

9.6.3.3.4 Noise

A certain amount of noise is expected from any pump. Pumps that operate at higher energy levels typically emit higher noise levels.

It is often found that, at higher and lower rates of flow, and lower NPSH margins, the noise changes from a sound characterized as sand sliding down a chute, to one of gravel or rocks. This change in sound is often not distinguishable on a sound-level meter, but the change in sound characteristic is detectable by the human ear. Gravel and rock sounds are usually caused by cavitation in the pump suction, and may result in mechanical damage and can limit the AOR.

9.6.3.3.5 Power limit

Low specific speed pumps may have power curves that increase with increasing rate of flow, whereas high specific speed pumps have power curves that increase with decreasing rate of flow. The torsional stresses produced by the higher power requirements may limit the AOR. Driver power capabilities may also limit the AOR.

9.6.3.3.6 Liquid velocity

High liquid velocities occur in the discharge casing. In some designs the velocity head at high rates of flow may constitute most of the total head. In such cases, the static head may drop below the vapor pressure, resulting in cavitation. When this happens, the manufacturer will limit the maximum flow to avoid cavitation damage.

9.6.3.3.7 NPSH margin

Figure 9.6.3.3.7a illustrates a typical relationship between NPSHA and NPSH3 for pumps with suction piping. As the rate of flow increases, the NPSH margin varies and can cause a restriction in the AOR. *NPSH3* is defined as 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. NPSHR published by pump manufacturers may include a margin and be greater than NPSH3 determined from testing.

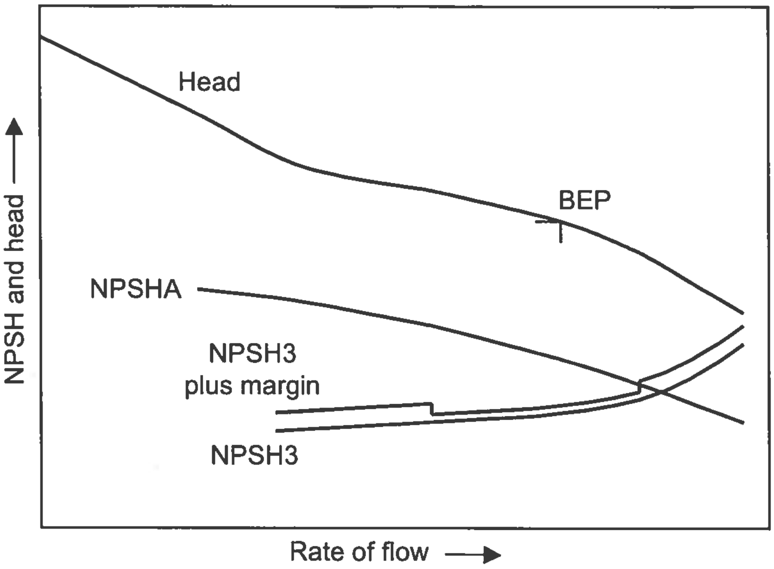

Figure 9.6.3.3.7a – NPSH versus rate of flow

For a submerged pump application with a stable suction level, the NPSHA remains constant while the NPSH3 may increase, when operating away from BEP (refer to Figure 9.6.3.3.7b below).

In Figure 9.6.3.3.7b, while NPSH margin may be conservative at operating condition B, margin may be only adequate at condition A and insufficient at condition C.

For more information on this subject, see ANSI/HI 9.6.1 *Rotodynamic (Centrifugal and Vertical) Pumps Guideline for NPSH Margin*.

This limitation is application-specific.

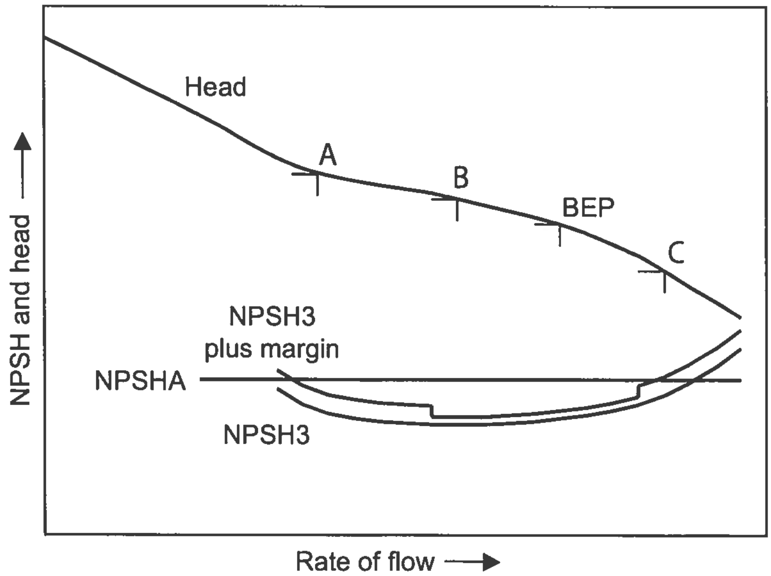

Figure 9.6.3.3.7b – NPSH margin versus rate of flow

9.6.3.3.8 Head – rate-of-flow curve

Some centrifugal pump head – rate-of-flow curves exhibit a characteristic commonly referred to as *droop* (see Figure 9.6.3.3.8a). A drooping head – rate-of-flow curve is one for which the zero rate of flow head (shutoff head) is lower than the maximum head on the curve. This phenomenon often occurs in low to medium specific speed pumps, n_S < 68 (N_S < 3500) that have been designed to optimize efficiency. Droop does not present an application problem unless one or more of the following conditions exist:

a) The system head curve intersects the pump curve at two or more rates of flow.

b) The pump is operated in parallel with one or more other pumps at a system head that is greater than the pump shutoff head.

c) A continuously rising curve is required for control purposes. For example, systems such as those requiring pressure control.

Applying pumps with drooping head curves in these conditions may cause the pump either to be pushed back to shutoff, or to "hunt" between two operating points. Neither condition is desirable. In such cases, the AOR may require further limitation and/or appropriate system controls may be implemented. In the absence of any of the above conditions, pumps with drooping head curves can perform as well as pumps with continually rising curves.

Mixed flow and axial flow pumps may exhibit a "dip" in the head – rate-of-flow curve. To the left of the dip the head increases steadily with decreased rate of flow; to the right of the dip the head decreases steadily with increased rate of flow. Figures 9.6.3.3.8b illustrates a head – rate-of-flow curve exhibiting dip.

Continuous operation in the dip region should always be avoided due to possibly damaging vibration and noise. In addition, for pumps with specific speeds above 120 (6000 US customary units), continuous operation must be avoided to the left of the dip region. If the system curve crosses the pump curve in two or more places, the pump should not be started against a closed discharge valve. In such cases the pump may not be able to pass beyond the first point of intersection with the system head curve.

The existence of a dip in the head – rate-of-flow curve of a pump is not detrimental to use of the pump to the right of the dip region.

9.6.3.3.9 Suction recirculation

Suction recirculation is associated with a partial (below BEP) rate of flow condition in which the flow in the inlet area of an impeller separates from the vanes and forms recirculating eddies. These eddies can produce large forces on the impeller, vibration, or damage.

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

NOTE: Q is the BEP rate of flow entering the impeller eye. Use m^3/s for the metric flow rate. In double suction pumps, use one-half total rate of flow.

Experience has shown that suction recirculation has a correlation to suction specific speed. Higher suction specific speed designs undergo an earlier onset of, and more intense, suction recirculation. Suction specific speed values

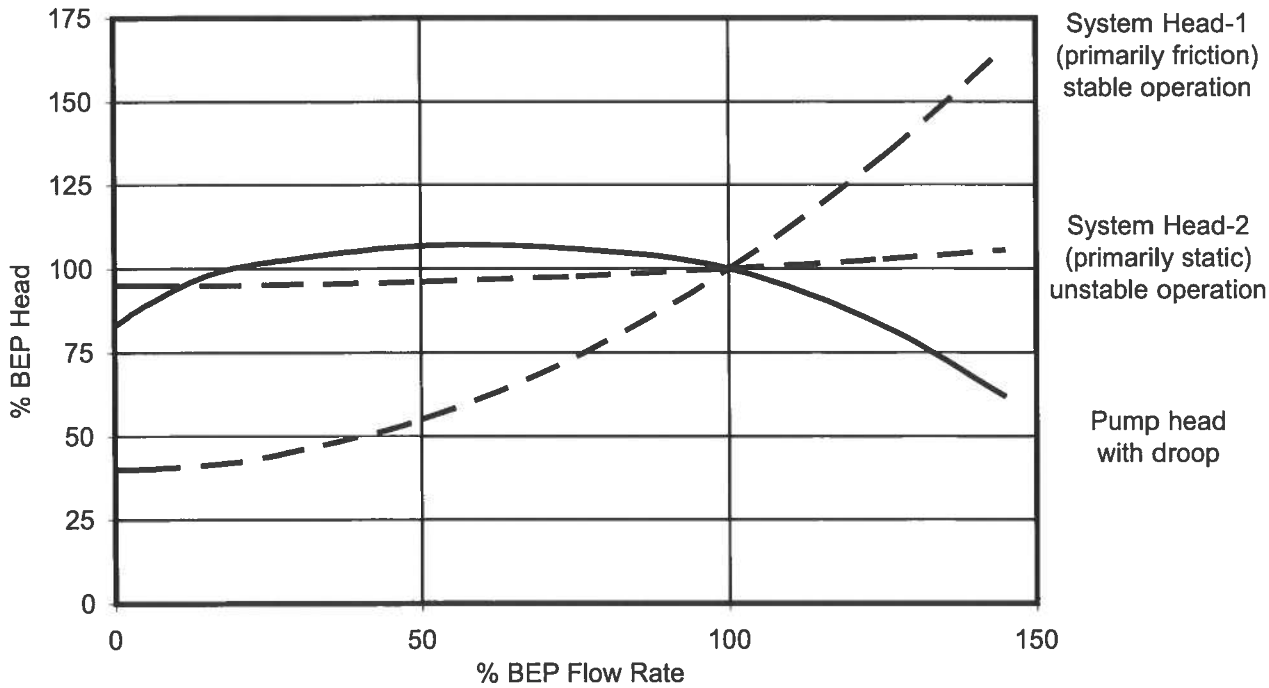

Figure 9.6.3.3.8a – Pump head versus rate-of-flow curve illustrating a "droop"

below 145 metric (7500 US customary) units usually represent low suction specific speeds. Values above 290 (15,000) are classified as high.

Figures 9.6.3.3.9a and b show typical values that may be used to approximate the onset of suction recirculation. Barrel pumps, such as used for boiler feed and pipeline services, are excluded from this figure due to the typically large shaft diameters that distort the relationship between the shaft and the impeller eye. The pump manufacturer may use pump-specific knowledge of suction recirculation onset, along with other parameters that affect measurable performance or reliability, to determine the AOR. A given impeller design may exhibit a substantially higher value of minimum rate of flow to avoid suction recirculation. This might be attributed to one or more of the following: inlet flow prerotation, suction casing design, impeller eye diameter, impeller vane angle, impeller vane number, and impeller vane overlap.

9.6.3.3.10 Pump size

It should be noted that smaller pumps are inherently more robust than larger pumps with respect to the imposed loads. A manufacturer considers mechanical robustness in determining the AOR, and a broader range of operation can frequently be set for smaller pumps.

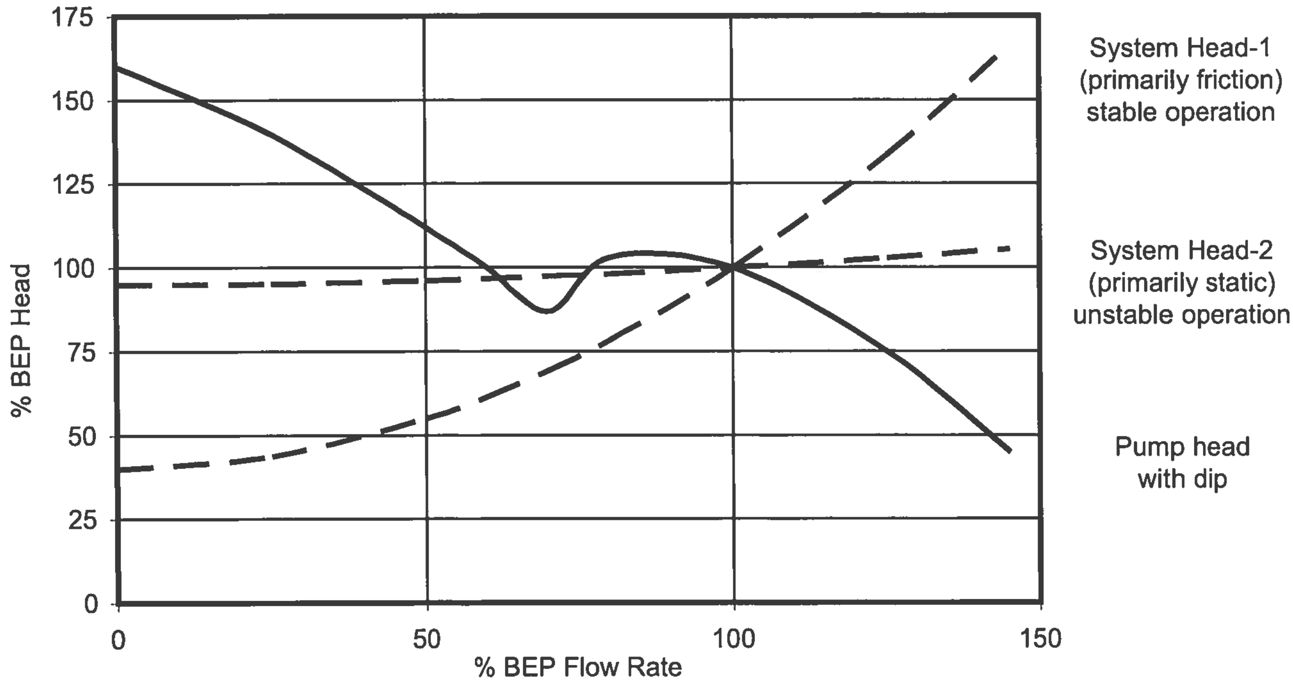

Figure 9.6.3.3.8b – Pump head versus rate-of-flow curve illustrating a "dip"

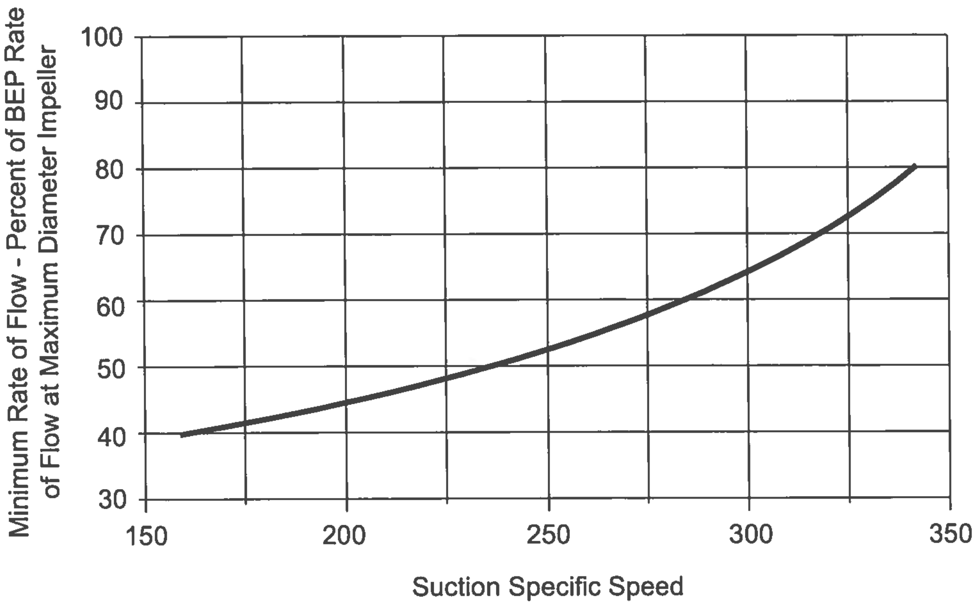

Figure 9.6.3.3.9a – Estimated minimum rate of flow to avoid suction recirculation (metric units)

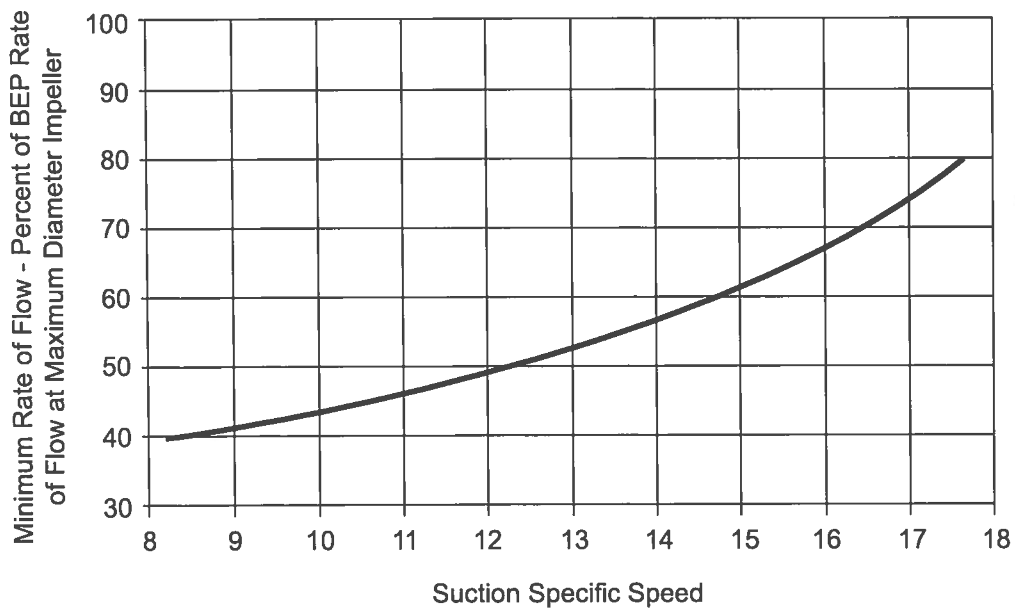

Figure 9.6.3.3.9b – Minimum rate of flow to avoid suction recirculation (US customary units, in thousands)

Appendix A

Index

This appendix is included for informative purposes only and is not part of this standard. It is intended to help the user gain a better understanding of the factors referenced in the body of the standard.

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

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