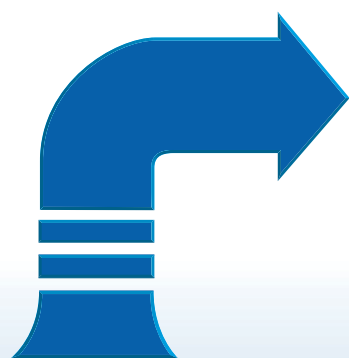
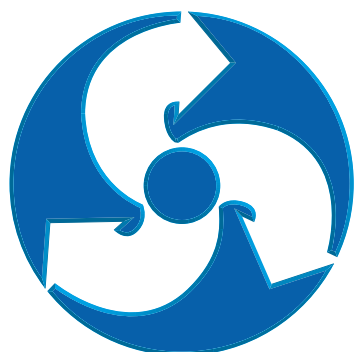




ANSI/HI 9.6.7-2015

American National Standard
for

Rotodynamic Pumps - Guideline for Effects of Liquid Viscosity on Performance



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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 users and 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, purchaser, and/or 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 directed 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 an Institute publication 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, to 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.

Disclaimers

This document presents the best method available for determining the effect of viscosity on rotodynamic pump performance available to the Hydraulic Institute as of publication. Nothing presented herein is to be construed as a warranty of successful performance under any conditions for any application.

Units of measurement

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

Because 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 be stated in reference to this standard. If no such statement is provided, metric units shall govern.

Consensus for this standard 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 standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

Black & Veatch
Brown and Caldwell
DuPont Company
ekwestrel corp
Fluid Sealing Association

Hidrostal
Kemet Inc.
Las Vegas Valley Water District
Patterson Pump Company
Weir Floway, Inc.

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 – Michael Coussens, Peerless Pump Company

Vice-chair – Trygve Dahl, Intelliquip, LLC

Committee Members

Mark Buckler
Richard Grauvogl
Kenneth Patton
James Roberts (Alternate)
Aleksander Roudnev
Paul Ruzicka
Bruce Ticknor, III
Simon Walsh

Company

Flowserve Corporation
Hydro, Inc.
Colfax Fluid Handling
Xylem Inc. - Applied Water Systems
Weir Minerals North America
Xylem Inc. - Applied Water Systems
National Pump Company
ClydeUnion Pumps, an SPX Brand

9.6.7 Guideline for effects of liquid viscosity on pump performance

This version of ANSI/HI 9.6.7 differs from the 2010 version in a few areas. New data has become available as outlined in Section 9.6.7.4.1, including new references in the bibliography. Expanded guidance on the effect of speed versus torque characteristics is found in Section 9.6.7.6.1. The calculation procedure for determining viscosity corrections has not changed.

9.6.7.1 Summary

Viscosity is one of the properties that characterizes all fluids. The performance of a rotodynamic pump varies with the viscosity of the pumped fluid. If the viscosity of the pumped fluid differs (is higher) significantly from that of water (which is the basis for most published performance curves), then the pump performance will differ from the published curve. For simplicity, the term *viscous fluid* is used within this document. In this context, viscous fluid is meant to describe a fluid with a viscosity greater than that of water, not to imply some fluids are not viscous. Head (H) and rate of flow (Q) will normally decrease as viscosity increases. Power (P) will increase, as will net positive suction head required (NPSH3) in most circumstances. Starting torque may also be affected.

The Hydraulic Institute (HI) has developed a generalized method for predicting performance of rotodynamic pumps on Newtonian liquids of viscosity greater than that of water. This is an empirical method based on the test data available from sources throughout the world. The HI method enables pump users and designers to estimate performance of a particular rotodynamic pump on liquids of known viscosity, given the performance on water. The procedure may also result in a suitable pump being selected for a required duty on viscous liquids.

Performance estimates using the HI method are only approximate. There are many factors for particular pump geometries and flow conditions that the method does not take into account. It is nevertheless a dependable approximation when only limited data on the pump are available and the estimate is needed.

Since the release of the previous version of this standard, use of computational fluid dynamics (CFD) by pump designers for simulation and optimization of the performance of rotodynamic pumps has dramatically increased. The code, expertise, and calculated outputs of this tool have greatly improved with maturity. Today's pump designers are finding CFD a valuable tool in the pursuit of high-performance hydraulics. However, little effort has been expended in the study of fluids other than water. The expectations are that this tool could add insight and increase the knowledge of the dynamics of pump flow with viscous fluids and lead to improved design in this application. It is the desire of the HI Effects of Liquid Viscosity on Rotodynamic Pump Performance Committee that CFD simulations of viscous fluids on pump performance would be an area of future research. Correlations of simulation results to the methodology offered in this standard and further test validation would be beneficial for the fluid handling industry.

Theoretical methods based on loss analysis may provide more accurate predictions of the effects of liquid viscosity on pump performance when the geometry of a particular pump is known in more detail. This document explains the basis of such theoretical methods. Pump users should consult pump manufacturers to determine whether or not more accurate predictions of performance for a particular pump and viscous liquid are available.

This document also includes technical considerations and recommendations for pump applications on viscous liquids.

9.6.7.2 Introduction

The performance (head, flow, efficiency $[\eta]$, and power) of a rotodynamic pump is obtained from the pump's characteristic curves, which are generated from test data using water. When a more viscous liquid is pumped, the performance of the pump is reduced. Absorbed power will increase and head, rate of flow, and efficiency will decrease.

It is important for the user to understand a number of facts that underlie any attempt to quantify the effects of viscosity on rotodynamic pump operation. First, the test data available are specific to the individual pumps tested and

are thus not of a generic nature. Second, what data are available are relatively limited in the range of both pump size and viscosity of the liquid. Third, all existing methods of predicting the effects of viscosity on pump performance show discrepancies with the limited test data available. Fourth, the empirical method presented in this document was chosen based on a statistical comparison of various possible correction procedures. The chosen method was found to produce the least amount of variance between calculated and actual data. Considering all of the above, it must be recognized that this method cannot be used as a theoretically rigorous calculation that will predict the performance correction factors with great precision. It is rather meant to allow a general comparison of the effect of pumping higher viscosity liquids and to help the user avoid misapplication without being excessively conservative. See Section 9.6.7.4.2 for types of pumps for which the method is applicable.

As a footnote to the preceding paragraph, it should be recognized that there are methods developed by individuals and companies that deal with the actual internal hydraulic losses of the pump. By quantifying these losses the effect of liquid viscosity can, in theory, be calculated. These procedures take into account the specific pump internal geometry, which is generally unavailable to the pump user. Furthermore, such methods still require some empirical coefficients that can only be derived correctly when sufficient information on the pumps tested in viscous liquids is available. The test data collected by HI from sources around the world did not include sufficiently detailed information about the pumps tested to validate loss analysis methods. It is nevertheless recognized that a loss analysis method will probably be more accurate than the empirical method in this document, especially for pumps with special features and particular geometry.

In addition to the correction procedures, the document provides a qualitative description of the various hydraulic losses within the pump that underlie the performance reduction. Procedures for determining the effect of viscosity on starting torque and NPSH3 are also provided.

The correction methods are based on data acquired prior to 1960 and that was expanded with new data through 2006. HI is seeking additional field data that may reference larger flows, heads, and specific speeds. Correction factors are influenced by the pump size, speed, and specific speed.

9.6.7.3 Fundamental considerations

9.6.7.3.1 Viscous correction factors

When a liquid of high viscosity, such as heavy oil, is pumped by a rotodynamic pump, the performance is changed in comparison to performance with water, due to increased losses. The reduction in performance on viscous liquids may be estimated by applying correction factors for head, rate of flow, and efficiency to the performance with water.

Thus the curves of head and efficiency for viscous liquids (η_{vis}) are estimated from the head, flow, and efficiency measured with water (η_w) by applying the correction factors C_H , C_Q , and C_η , respectively. These factors are defined in Equation 1:

$$C_H = \frac{H_{vis}}{H_w} ; C_Q = \frac{Q_{vis}}{Q_w} ; C_\eta = \frac{\eta_{vis}}{\eta_w} \quad (\text{Eq. 1})$$

Figure 9.6.7.3.1 (i and ii) shows schematically how the head, efficiency, and power characteristics typically change from operation with water to pumping a highly viscous liquid.

If measured data are normalized to the best efficiency point (BEP) when pumping water (BEP-W), the factors C_H and C_Q can be read directly on Figure 9.6.7.3.1-iii. A straight line between BEP-W and the origin of the H - Q curve ($H = 0$; $Q = 0$) is called the *diffuser* or *volute characteristic*. Test data reported in references 12 and 17 in the bibliography show that BEPs for viscous liquids follow this diffuser or volute characteristic. Analysis of test data on viscous pumping collected by HI from sources around the world also confirms this observation. It is consequently a good approximation to assume C_H is equal to C_Q at the BEPs for viscous liquids.

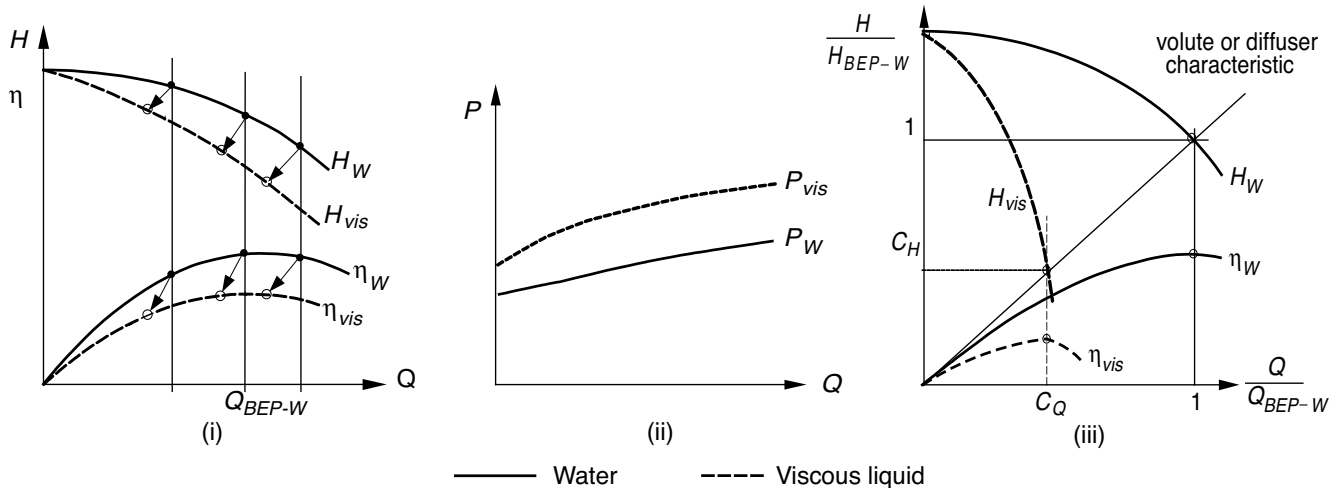


Figure 9.6.7.3.1 — Modification of pump characteristics when pumping viscous liquids

9.6.7.3.2 Methods for determining correction factors

Correction factors can be either defined empirically from a data bank containing measurements on various pumps with water and liquids of different viscosities or from a physical model based on the analysis of the energy losses in the pump. Examples of such loss analysis methods are given in references 9, 10, 11, and 23 of the bibliography.

Analysis of the limited data available shows that empirical and loss analysis methods predict head correction functions with approximately the same accuracy. Loss analysis methods are, however, more precise in predicting power requirements for pumping viscous liquids. It is also possible to investigate the influence of various design parameters on viscous performance and to optimize pump selection or design features for operation with highly viscous liquids by applying the loss analysis procedures.

Further theoretical explanations of the principles of loss analysis methods are given in Section 9.6.7.5. Use of such methods may require more information about pump dimensions than is generally available to the user. A loss analysis procedure may be expected to provide more accurate predictions of pump performance with viscous liquids when such detailed information is available.

The HI method explained in Section 9.6.7.4 is based on empirical data. It provides a way of predicting the effects of liquid viscosity on pump performance with adequate accuracy for most practical purposes. The method in this document gives correction factors similar to the previous HI method. The new method matches the experimental data better than the old HI method that has been widely used throughout the world for many years. The standard deviation for the head correction factor, C_H , is 0.1. Estimates of viscous power, P_{vis} , are subject to a standard deviation of 0.15.

9.6.7.4 Synopsis of Hydraulic Institute method

9.6.7.4.1 Generalized method based on empirical data

The performance of rotodynamic pumps is affected when handling viscous liquids. A marked increase in power, a reduction in head, and some reduction in the rate of flow occur with moderate and high viscosities. Starting torque and NPSH3 may also be affected.

The HI correction method provides a means of determining the performance of a rotodynamic pump handling a viscous liquid when its performance on water is known. The equations are based on a pump performance Reynolds

number adjusted for specific speed (parameter B), which has been statistically curve-fitted to a body of test data. These tests of conventional single-stage and multistage pumps, with single and double suction impellers, cover the following range of parameters: closed and semi-open impellers; kinematic viscosity 1 to 3000 cSt; rate of flow at BEP with water $Q_{BEP-W} = 3$ to 2960 m³/h (13 to 13,030 gpm); head per stage at BEP with water $H_{BEP-W} = 6$ to 270 m (20 to 886 ft).

The correction equations are, therefore, a generalized method based on empirical data, but are not exact for any particular pump. The generalized method may be applied to pump performance outside the range of test data indicated above, as outlined in Section 9.6.7.4 and with the specific instructions and examples in Sections 9.6.7.4.5 and 9.6.7.4.6. Extrapolating the method to larger pumps will tend to give conservative performance predictions because larger pumps, at any given speed and viscosity, imply higher Reynolds numbers and lower viscous corrections.

When more accurate information is essential, pump performance tests should be conducted with the particular viscous liquid to be handled. Prediction methods based on an analysis of hydraulic losses for a particular pump design may also be more accurate than this generalized method.

9.6.7.4.2 Viscous liquid performance correction limitations

The correction factors are applicable to pumps of hydraulic design with essentially radial impeller discharge ($n_s \leq 60$, $N_s \leq 3000$), in the normal operating range, with fully open, semi-open, or closed impellers with either a single or double suction entry. Do not use these correction factors for axial flow type pumps or for pumps of special hydraulic design. See Section 9.6.7.6 for additional guidance.

Use correction factors only where an adequate margin of NPSH available (NPSHA) over NPSH₃ is present in order to cope with an increase in NPSH₃ caused by the increase in viscosity. See Section 9.6.7.5.3 to estimate the increase in NPSH₃.

The data used to develop the correction factors are based on tests of Newtonian liquids. Gels, slurries, paper stock, and other non-Newtonian liquids may produce widely varying results, depending on the particular characteristics of the liquids.

9.6.7.4.3 Symbols and definitions used for determining correction factors

See Section 9.6.7.8 for all notation definitions.

Other technical expressions are defined in HI Standards.

Equations for converting kinematic viscosity from SSU to cSt units and vice versa are shown in Appendix A.

Pump viscosity corrections are determined by the procedures outlined in the following Sections 9.6.7.4.4, 9.6.7.4.5, and 9.6.7.4.6.

9.6.7.4.4 Overview of procedure to estimate effects of viscosity on pump performance

The procedure is in three parts: first, to establish whether or not the document is applicable; second, to calculate the pump performance on a viscous liquid when performance on water is known; and third, to select a pump for given head, rate of flow, and viscous conditions.

The procedure for the first part is illustrated in Figure 9.6.7.4.4a.

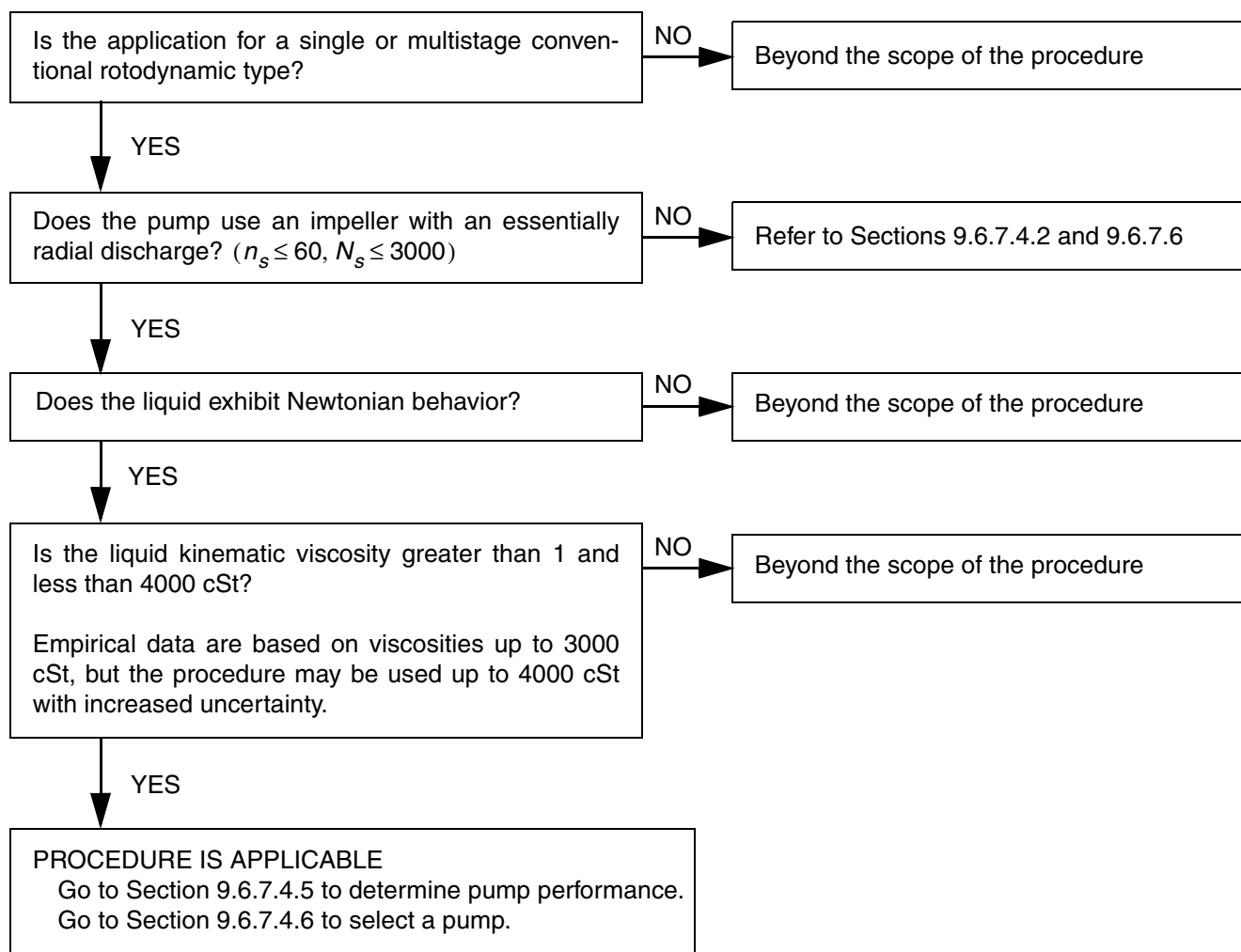


Figure 9.6.7.4.4a — Flowchart to establish if the procedure is applicable

The procedure for the second part is defined in Section 9.6.7.4.5 starting on page 8 and summarized in Figure 9.6.7.4.4b.

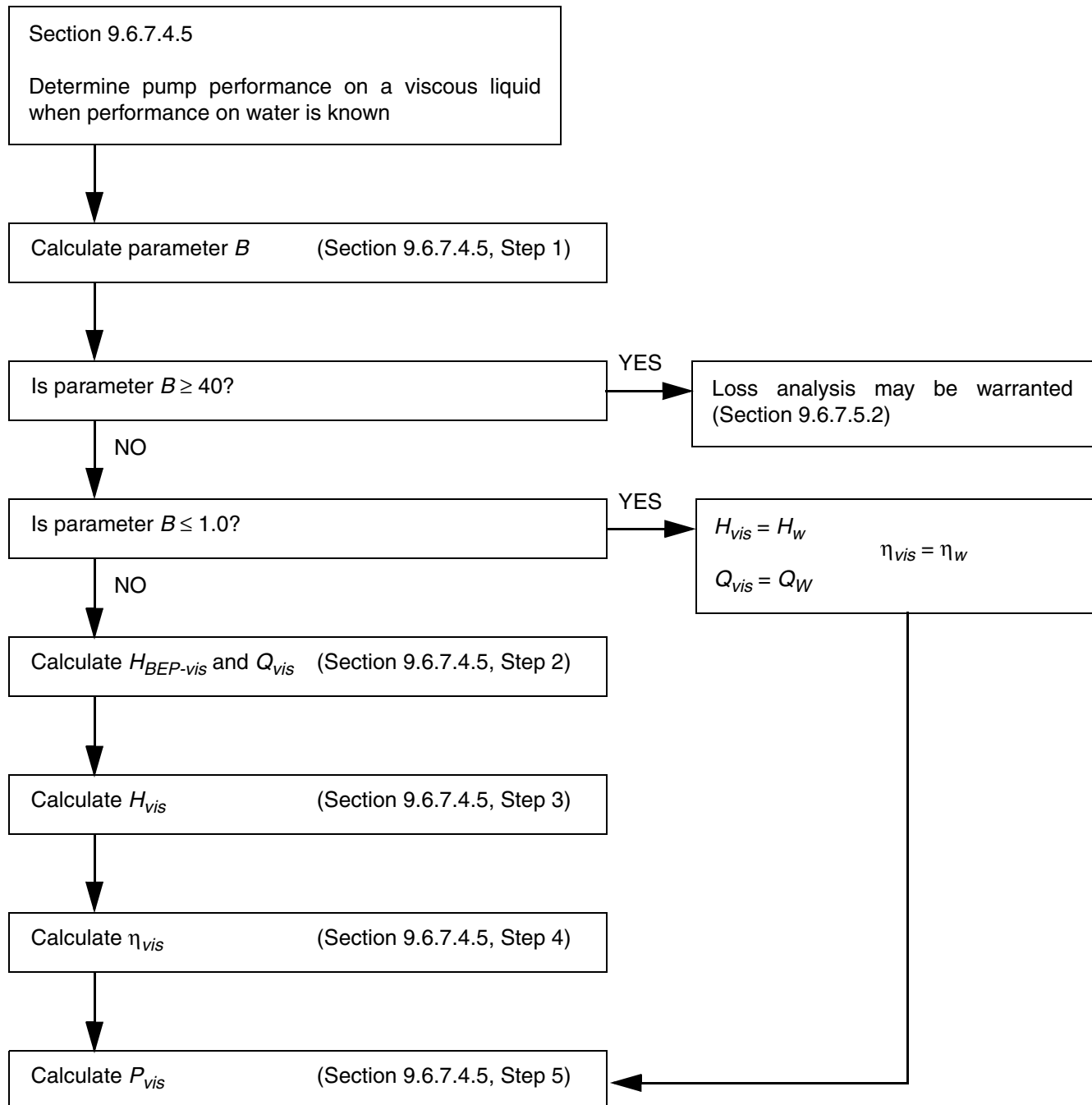


Figure 9.6.7.4.4b — Flowchart to determine pump performance on a viscous liquid when performance on water is known