SWEDISH STANDARDS INSTITUTE

Teknisk rapport
SIS-ISO/TR 17766:2006

Utgåva 1

Februari 2006

Pumpar – Centrifugalpumpar som hanterar viskösa vätskor – Korrigeringar av prestanda

Centrifugal pumps handling viscous liquids – Performance corrections

ICS 23.080

Språk: engelska

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Foreword

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ISO/TR 17766 was prepared by Technical Committee ISO/TC 115, *Pumps*, Subcommittee SC 3, *Installation and special application*.

Centrifugal pumps handling viscous liquids — Performance corrections

1 Scope

This Technical Report gives performance corrections for all worldwide designs of centrifugal and vertical pumps of conventional design, in the normal operating range, with open or closed impellers, single or double suction, pumping Newtonian fluids are included.

2 Symbols and abbreviated terms

A complete list of symbols and definitions used in this document is given below[1)].

A	=	Suction geometry variable used in the calculation to correct net positive suction head required
B	=	Parameter used in the viscosity correction procedures; the B parameter is used as a normalizing pump Reynolds number and to adjust the corrections for the pump specific speed
BEP	=	Best efficiency point (the rate of flow and head at which pump efficiency is a maximum at a given speed)
C_{η}	=	Efficiency correction factor
$C_{\eta\text{-RR}}$	=	Efficiency correction factor due to disc friction only
C_{H}	=	Head correction factor
$C_{\text{BEP-H}}$	=	Head correction factor that is applied to the flow at maximum pump efficiency for water
C_{NPSH}	=	Net positive suction head correction factor
C_{Q}	=	Rate of flow correction factor
d_2	=	Impeller outlet diameter in m (ft)
g	=	Acceleration due to gravity in m/s^2 (ft/s^2)
H	=	Head per stage in m (ft)
$H_{\text{BEP-vis}}$	=	Viscous head in m (ft); the head per stage at the rate of flow at which maximum pump efficiency is obtained when pumping a viscous liquid
$H_{\text{BEP-W}}$	=	Water head in m (ft); the head per stage at the rate of flow at which maximum pump efficiency is obtained when pumping water
H_{L}	=	Hydraulic losses in m (ft)
H_{th}	=	Theoretical head (flow without losses) in m (ft)

1) A derogation has been granted to ISO/TC 115/SC 3 for this document to use the industry abbreviation NPSHR in the mathematical symbols $\text{NPSHR}_{\text{BEP-W}}$, and NPSHR_{W}.

H_{vis} = Viscous head in m (ft); the head per stage when pumping a viscous liquid

$H_{\text{vis-tot}}$ = Viscous head in m (ft); the total head of the pump when pumping a viscous liquid

H_{W} = Water head in m (ft); the head per stage when pumping water

N = Pump-shaft rotational speed in rpm

N_{S} = Specific speed

(USCS units) $= \frac{NQ_{\text{BEP-W}}^{0,5}}{H_{\text{BEP-W}}^{0,75}}$

n_{s} = Specific speed

(metric units) $= \frac{NQ_{\text{BEP-W}}^{0,5}}{H_{\text{BEP-W}}^{0,75}}$

The specific speed of an impeller is defined as the speed in revolutions per minute at which a geometrically similar impeller would run if it were of such a size as to discharge one cubic meter per second (m^3/s) against one meter of head (metric units) or one US gallon per minute against one foot of head (USCS units). These units shall be used to calculate specific speed.

NOTE The rate of flow for the pump is used in this definition, not the rate of flow at the impeller eye.

NPSHA = Net positive suction head in m (ft) available to the pump

NPSHR = Net positive suction head in m (ft) required by the pump based on the standard 3 % head drop criterion

$\text{NPSHR}_{\text{BEP-W}}$ = Net positive suction head in m (ft) required for water at the maximum efficiency rate of flow, based on the standard 3 % head drop criterion

$\text{NPSHR}_{\text{vis}}$ = Viscous net positive suction head in m (ft) required in a viscous liquid

NPSHR_{W} = Net positive suction head in m (ft) required on water, based on the standard 3 % head drop criterion

P = Power; without subscript: power at coupling in kW (hp)

P_{m} = Mechanical power losses in kW (hp)

P_{u} = Useful power transferred to liquid; $P_{\text{u}} = \rho g H Q$ in kW (hp)

P_{RR} = Disc friction power loss in kW (hp)

P_{vis} = Viscous power in kW (hp); the shaft input power required by the pump for the viscous conditions

P_{W} = Pump-shaft input power required for water in kW (hp)

Q = Rate of flow in m^3/h (gpm)

$Q_{\text{BEP-W}}$ = Water rate of flow in m^3/h (gpm) at which maximum pump efficiency is obtained

Q_{vis} = Viscous rate of flow in m^3/h (gpm); the rate of flow when pumping a viscous liquid

Q_{W} = Water rate of flow in m^3/h (gpm); the rate of flow when pumping water

q^* = Ratio of rate of flow to rate of flow at best efficiency point: $q^* = Q/Q_{\text{BEP}}$

Re = Reynolds-number: $Re = \omega\, {r_2}^2/\nu$

r_2 = Impeller outer radius in m (ft)

s = Specific gravity of pumped liquid in relation to water at 20 °C (68 °F)

V_{vis}	=	Kinematic viscosity in centistokes (cSt) of the pumped liquid
V_W	=	Kinematic viscosity in centistokes (cSt) of water reference test liquid
η	=	Overall efficiency (at coupling)
$\eta_{BEP\text{-}W}$	=	Water best efficiency
η_h	=	Hydraulic efficiency
η_{vis}	=	Viscous efficiency; the efficiency when pumping a viscous liquid
η_{vol}	=	Volumetric efficiency
η_W	=	Water pump efficiency; the pump efficiency when pumping water
μ	=	Dynamic (absolute) viscosity in N·s/m^2 (lb·s/ft^2)
ν	=	Kinematic viscosity in m^2/s (ft^2/s)
ρ	=	Density in kg/m^3 (slugs/ft^3)
ψ	=	Head coefficient
ω	=	Angular velocity of shaft or impeller in rad/s

3 Summary

The performance of a rotodynamic (centrifugal or vertical) pump on a viscous liquid differs from the performance on water, which is the basis for most published curves. Head (H) and rate of flow (Q) will normally decrease as viscosity increases. Power (P) will increase, as will net positive suction head required (NPSHR) 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.

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.

Calculations based on the Hydraulic Institute's Viscosity Correction method (VCM) have been mathematically modeled in a web-based HIVCM™ tool.

Available at www.pumps.org, the HIVCM™ tool allows pump users, manufacturers, and third-party software providers access to rapid analysis of a pump's hydraulic performance on water vs. specified viscous liquids. Use of the HIVCM™ tool in pump selection will provide reliable and consistent calculations based on the methodology outlined in this Technical Report.

HIVCM™ is a trademark owned by the Hydraulic Institute. Please visit www.pumps.org for more information.

4 Introduction

The performance (head, flow, efficiency [η], 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 Clause 6 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 NPSHR are also provided.

The previous HI Standard for viscosity correction in Reference [24] was based on data supplied up to 1960. This new document is based on an expanded data set up to 1999 which has modified the correction factors for rate of flow, head, and power. Updated correction factors are influenced by the pump size, speed, and specific speed. In general, the head and flow have an increased correction while the power (efficiency) correction is less. The most significant changes in the correction factors occur at flows less than 25 m^3/h (100 gpm) and $n_s < 15$ ($N_s < 770$).

5 Fundamental considerations

5.1 Viscous correction factors

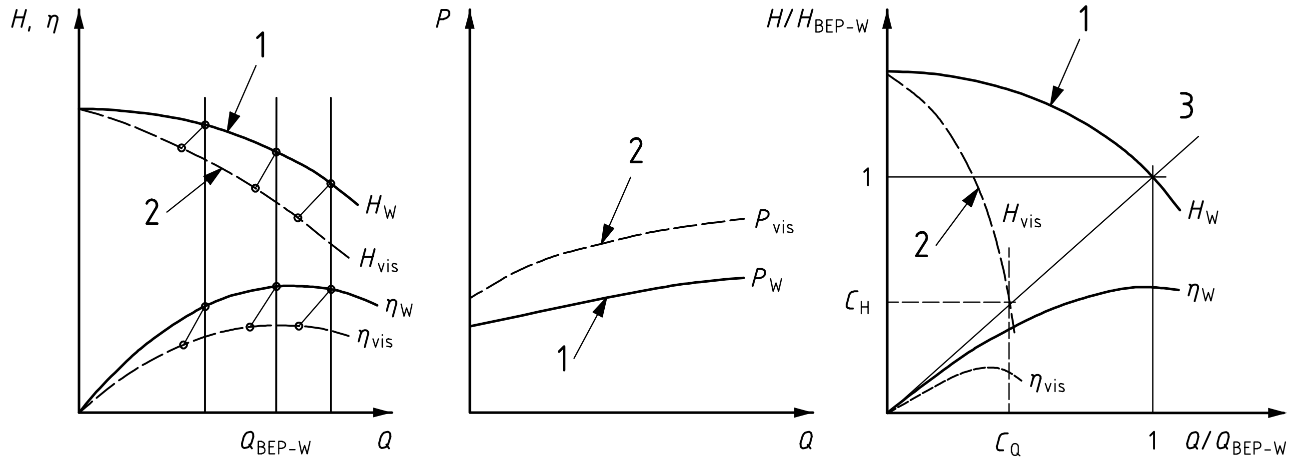
When a liquid of high viscosity, such as heavy oil, is pumped by a rotodynamic pump, the performance is changed in comparison to performance with water, due to increased losses. The reduction in performance on viscous liquids may be estimated by applying correction factors for head, rate of flow, and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

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

$$C_H = \frac{H_{vis}}{H_W} \quad ; \quad C_Q = \frac{Q_{vis}}{Q_W} \quad ; \quad C_\eta = \frac{\eta_{vis}}{\eta_W} \qquad (1)$$

Figure 1 (a) and (b) 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 1 (c). 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 [10] and [14] 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.



Key

1 water

2 viscous liquid

3 volute or diffuser characteristic

Figure 1 — Modification of pump characteristics when pumping viscous liquids

5.2 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 [7], [8], [9], [10] and [18] 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 Clause 7 of this document. 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 Clause 6 of this document 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.

6 Synopsis of Hydraulic Institute method

6.1 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 NPSHR 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 multi-stage pumps cover the following range of parameters: closed and semi-open impellers; kinematic viscosity 1 to 3 000 cSt; rate of flow at BEP with water $Q_{\text{BEP-W}} = 3\ \text{m}^3/\text{h}$ to $260\ \text{m}^3/\text{h}$ (13 gpm to 1 140 gpm); head per stage at BEP with water $H_{\text{BEP-W}} = 6$ m to 130 m (20 ft to 430 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 Clause 6 and with the specific instructions and examples in 6.5 and 6.6. There will be increased uncertainty of performance prediction outside the range of test results.

When 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.

6.2 Viscous liquid performance correction limitations

Because the equations provided in 6.5 and 6.6 are based on empirical rather than theoretical considerations, extrapolation beyond the limits shown in 6.5 and 6.6 would go outside the experience range that the equations cover and is not recommended.

The correction factors are applicable to pumps of hydraulic design with essentially radial impeller discharge ($n_{\text{s}} \leqslant 60$, $N_{\text{s}} \leqslant 3\,000$), in the normal operating range, with fully open, semi-open, or closed impellers. Do not use these correction factors for axial flow type pumps or for pumps of special hydraulic design. See Clause 8 for additional guidance.

Use correction factors only where an adequate margin of NPSH available (NPSHA) over NPSHR is present in order to cope with an increase in NPSHR caused by the increase in viscosity. See 7.3 to estimate the increase in NPSHR.

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 media.

6.3 Viscous liquid symbols and definitions used for determining correction factors

A = Suction geometry variable used in the calculation to correct net positive suction head required

B = Parameter used in the viscosity correction procedures; the B parameter is used as a normalizing pump Reynolds number and to adjust the corrections for the pump specific speed

BEP = Best efficiency point (the rate of flow and head at which pump efficiency is a maximum at a given speed)

C_{η} = Efficiency correction factor

C_{H} = Head correction factor

$C_{\text{BEP-H}}$ = Head correction factor that is applied to the flow at maximum pump efficiency for water

C_{NPSH} = Net positive suction head correction factor

C_{Q} = Rate of flow correction factor

$H_{\text{BEP-vis}}$ = Viscous head in m (ft); the head per stage at the rate of flow at which maximum pump efficiency is obtained when pumping a viscous liquid

$H_{\text{BEP-W}}$ = Water head in m (ft); the head per stage at the rate of flow at which maximum pump efficiency is obtained when pumping water

H_{vis} = Viscous head in m (ft); the head per stage when pumping a viscous liquid

$H_{\text{vis-tot}}$ = Viscous head in m (ft); the total head of the pump when pumping a viscous liquid

H_{W} = Water head in m (ft); the head per stage when pumping water

N = Pump-shaft rotational speed in rpm

N_{S} = Specific speed

(USCS units) $= \dfrac{NQ_{\text{BEP-W}}^{0,5}}{H_{\text{BEP-W}}^{0,75}}$

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The specific speed of an impeller is defined as the speed in revolutions per minute at which a geometrically similar impeller would run if it were of such a size as to discharge one cubic meter per second (m^3/s) against one meter of head (metric units) or one US gallon per minute against one foot of head (USCS units). These units shall be used to calculate specific speed.

NOTE The rate of flow for the pump is used in this definition, not the rate of flow through the impeller eye.

NPSHA = Net positive suction head in m (ft) available to the pump

NPSHR = Net positive suction head in m (ft) required by the pump based on the standard 3 % head drop criterion

$\text{NPSHR}_{\text{BEP-W}}$ = Net positive suction head in m (ft) required for water at the maximum efficiency rate of flow, based on the standard 3 % head drop criterion

$\text{NPSHR}_{\text{vis}}$ = Viscous net positive suction head in m (ft) required in a viscous liquid

NPSHR_{W} = Net positive suction head in m (ft) required on water, based on the standard 3 % head drop criterion