# Selecting a Centrifugal Pump to Handle a Viscous Liquid



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## Introduction

This course provides the student with an understanding of fluid viscosity and its effects on the performance of centrifugal pump operation. The different types and interrelation of viscosity values are discussed. Most importantly, it presents the established means to convert water standard pump performance curves so that they can be used to select or size pumps in viscous liquid service. Equations are provided to enable the student to estimate the flow, pressure, efficiency, and power required for a given pumping application.

## Content

*What exactly is viscosity anyway?*

Viscosity is a measure of a fluid's resistance to flow and molecular shear. Students interested in gaining a more in-depth, scientific explanation of viscosity are invited to visit:

http://www.pdhonline.org/courses/m102/UVIoriginalcontentforM102.pdf.

There are a number of subjects covered at the above website. Scroll down the page until the section entitled **Viscosity** is displayed.

**In reality, all that is practically important as it relates to this course is that fluid viscosity affects a centrifugal pump's performance.**

Viscosity is an elusive fluid parameter partly because of the layman's oversimplification of the physical phenomenon. Consider the following two common examples:

1. The adage *blood is thicker than water* imparts an incorrect three dimensional aspect to viscosity implying that it has something to do with volume.
2. One car owner asks another, "What weight oil are you using?" This expression incorrectly associates the oil's viscosity with its specific weight, or more accurately, it's fluid density.

Viscosity characteristics must not be confused with fluid density; they are totally independent of each other. Liquids that are dense, *i.e.*, those that have a high specific gravity, are not necessarily highly viscous. Mercury has a very high specific gravity while exhibiting an extremely low viscosity. Many lubricants that are less dense than water are extremely viscous. Is it no wonder that viscosity is a misunderstood fluid property that deserves a very important consideration in centrifugal pumping applications?

Because viscosity exists in two forms and in a multitude of dimensional units that are more or less convertible, can also be confusing. Viscosity units can consist of various impracticable, incomprehensible, or otherwise un-relatable quantities some of which are: $lb_f$-sec/ft$^2$, dyn-sec/cm$^2$, Saybolt Seconds Universal, and Reyns. Consequently, before we can really begin, we must embark on a very brief technical treatment of viscosity.

### *What's the difference and importance of absolute and kinematic viscosity?*

Viscosity is expressed in *absolute* and *kinematic* terms. (Absolute viscosity is also often referred to as *dynamic* viscosity). The absolute viscosity of a liquid is defined as the resistance to flow and shear under the forces of internal friction. This internal friction is caused by the resistance of the liquid's molecules moving relative to each other. The larger the molecules, the higher the internal resistance and consequently, the higher the viscosity. The base unit of absolute viscosity is the *poise*; one poise is 1 g/cm-sec. The commonly used engineering unit is the centipoise (1/100 poise), which is usually abbreviated cP and normally represented by the Greek letter ∴.

On the other hand, kinematic viscosity is a measure of a liquid's resistance to flow and shear under the forces of gravity. It is mathematically defined as the ratio of the absolute viscosity to the fluid specific gravity. The base unit of kinematic viscosity is the *stoke*; one stoke is 1 $cm^2$/sec. The commonly used engineering unit is the centistoke (1/100 stoke), which is usually abbreviated cs and normally represented by the Greek letter <.

**Now that we have these technical definitions behind us, let it be said that we only need to concern ourselves with the relational aspects of these two viscosity forms along with a comparative understanding of each.**

Because published technical references and physical property data for viscous liquids may provide either absolute or kinematic units, it is important for the student to know that absolute and kinematic viscosities are related, as previously stated, by:

$$\text{centistoke} = \frac{\text{centipoise}}{\text{specific gravity}}$$

Put another way, the absolute viscosity of a liquid is the product of the kinematic viscosity and the specific gravity.

*What are some examples of everyday fluids and their viscosity values?*

To provide the student with a relational feel for viscosity range, here are some common fluids, and their respective viscosity, arranged in ascending order. It should be intuitively obvious that viscosity is extremely dependent on temperature.

- Unleaded gasoline at ambient temperature has a viscosity of 0.7 cs
- Water at 68.4º F has a viscosity of 1 cs, also 1 cP [the standard]
- 31.5% hydrochloric acid at 105º F has a viscosity of 1.6 cP
- SAE 10 lube oil at 60º F has a viscosity of 96 cP
- 40W motor oil at room temperature has a viscosity of 300 cs
- Castor oil at 100º F has a viscosity of 300 cs
- Varnish at 68º F has a viscosity of 300 cs
- No. 6 fuel oil at 60º F has a viscosity of 850 cP
- Peanut butter at ambient temperature has a mean viscosity of 11,000 cs

**Pumped liquids are generally considered viscous when their viscosity exceeds 40 centipoise.**

*The case for the Centrifugal Pump*

Of all of the generic types of pumps, the centrifugal pump is the most commonly used. It has found favor because of its many advantages: simple construction, low relative cost, low maintenance, quiet operation, and reliability.

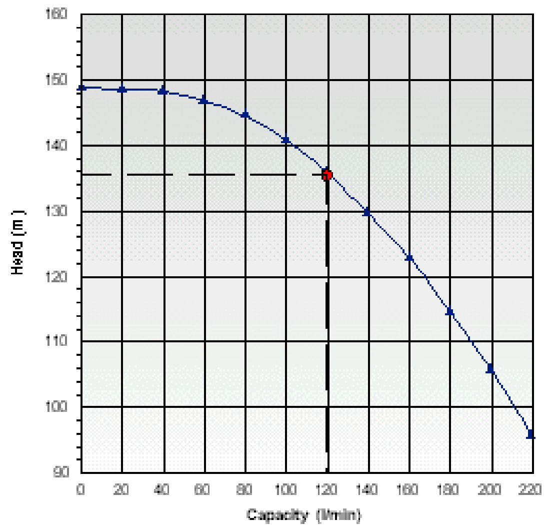
Unfortunately, the single biggest disadvantage of the centrifugal pump is its lowered efficiency in handling viscous liquids. It should be noted that the hydraulic losses and thereby hydraulic inefficiencies that occur in all pumps are due in large part to the viscosity of the fluid being handled.

Use of centrifugal pumps for a viscosity over 300 centistokes generally is not recommended because the pump efficiency is so poor. In some cases however, the high reliability of a centrifugal pump may make this type of pump the best overall economic choice even when the viscosity exceeds 300 centistokes.

Generally speaking, centrifugal pumps are extremely inefficient conveyors of liquids when fluid viscosity exceeds 1,400 centistokes. With that said, the published correction charts that will be discussed momentarily indicate centrifugal pump material handling applications where the fluid viscosity may range upward to 3,300 centistokes. It must be noted that extremely viscous fluid handling applications are best left to positive displacement, rather than centrifugal pumps.

## *The selection of a Centrifugal Pump*

Centrifugal pumps are normally selected by the Engineer for a hydraulic application from pump manufacturer's published pump curves. A pump curve in its simplest form is a plot of the pump's impeller performance indicating change in discharge head (pressure) versus pump capacity, *i.e.*, flow rate. These graphs are also referred to as pump performance curves or characteristic curves. Unfortunately for the Engineer, published pump performance curves are derived from laboratory test data utilizing clean water. This obviously presents no problem when the pump application at hand involves water or a fluid whose physical properties approximate those of water. However, when the fluid properties deviate significantly from those of water, serious error can be introduced by using the standard manufacturer's pump performance curve without correction.




This course will instruct you on how to normalize or correct the pumping requirements of a particular hydraulic application to compensate for a viscous fluid. These corrected values can then be used in conjunction with the manufacturer's standard pump water performance curves.

## *Selecting a Pump for a Viscous Liquid*

The student will follow a basic four-step procedure to select the proper pump when handling a viscous fluid:

1. Accurately determine or otherwise ascertain the required process (viscous) flow rate and total dynamic head at the process temperature;
2. Use an appropriate performance correction chart with these two design parameters along with the fluid's viscosity value, and extract three correction factors: one each for flow ($C_Q$), head ($C_H$), and efficiency ($C_E$);
3. Apply the correction factors to the viscous flow values to produce equivalent or augmented clear water pump performance values;
4. Use these *pseudo* values of flow and head in conjunction with the manufacturer's standard water performance curves to select the most efficient pump.

The most popular performance correction charts are those developed by The Hydraulic Institute, Parsippany, New Jersey. They are contained in the publication *ANSI/HI Pump Standards set, 2002 Release*. This organization's performance correction charts for viscous liquids are widely published and reproduced. If a copy of *ANSI/HI Pump Standards* is not accessible to the student, reproductions of the correction charts can be viewed in any of the following or similar publications:

- Messina;Heald;Cooper;Karassik, *Pump Handbook*, McGraw-Hill, ISBN: 070340323
- Perry;Green;Maloney, *Perry's Chemical Engineers' Handbook*, McGraw-Hill, ISBN: 0070498415.
- Avallone;Baumeister, *Marks' Standard Handbook for Mechanical Engineers*, McGraw-Hill, ISBN: 0070049971.
- ITT Industries, Goulds Pumps, *GPM 2004 Pump Section System & Catalog*, (CD ROM).
- Hicks;Hicks, *Standard Handbook of Engineering Calculations*, McGraw-Hill, ISBN: 0070288127.
- The Duriron Company, Inc., *Pump Engineering Manual*, A.P. Wherry & Associates.

*Let us take an illustrative example:*

Assume for our example that project specifications dictate that a 30,000-gallon capacity storage tank of a hypothetical liquid at 60º F must be routinely emptied in a time not to exceed two hours. Let us also assume that after consulting a technical reference, it is determined that this hypothetical liquid has a viscosity of 850 centipoise at the stated temperature. In a like fashion, it is determined that the liquid has a specific gravity of 0.993 at 60º F. From the given information it can be quickly determined that the pump's capacity or rate of flow must be,

$$Q_V = \frac{30{,}000\,\text{gal}}{1} \cdot \frac{1}{2\,\text{hr}} \cdot \frac{1\,\text{hr}}{60\,\text{min}} = 250\,\text{gpm}$$

**This is the pump's required viscous capacity**. Let us further assume that after conducting a careful hydraulic analysis of the piping system to which this pump will be connected, it has been determined that the pump will operate with a total dynamic head of 150 feet when pumping at this rate of 250 gpm. **This is the pump's required viscous head ($H_V$)**. Simply relying on a pump manufacturer's standard water performance curve at this point, with these viscous flow and head quantities, will result in the erroneous selection of a pump that will not satisfy the project specifications. **This is because the pumped fluid's viscosity has not been taken into consideration. Increased fluid viscosity decreases pump capacity, head, and efficiency.** In essence, a pump must be selected with water pumping capacity and head greater than that determined for the pumped liquid in order to compensate for the reduced performance. The logical question that follows is: how much should these actual viscous fluid performance values be increased to insure the reliability of the data plotted on the manufacturer's water performance curve?

The answer lies in the correction factors derived from The Hydraulic Institute's performance correction charts for viscous liquids. Two viscosity correction factor charts are divided by flow rate: one chart for flows of 100 gpm and below, and one chart for flows exceeding 100 gpm. In the now superseded 14th Edition of *The Hydraulic Institute Standards*, these charts appear on opposing pages starting at page 112. (Highly significant revision to viscosity correction data rarely takes place; nevertheless, the student would be wise to periodically consult the Hydraulic Institute's web site at www.pump.org to determine the relevance of the latest release of the *ANSI/HI Pump Standards)*.

It must be recognized that The Hydraulic Institute performance correction charts are at best approximations of estimated viscous pump performance. They were created based on empirical rather than rigorous analytical techniques. Their use assumes uniform (Newtonian) liquids and use of pumps of conventional design in a normal operating range. The student must also be aware of the fact that certain groups of fluids do not behave as one would logically expect. Newtonian fluids (water, water-like, most oils, *etc.*) react in a logical flow behavior; they are unaffected by the magnitude and kind of motion to which they are subjected. Non-newtonian fluids, two groups of which are known as dilatants and thixotrophics, react counter intuitively to external agitation or motion. Fluids in these categories are beyond the scope of this course. Examples of non-newtonian fluids are sand slurries, gels, paper stock, and the like.

Refer to Figure 1 on page 9; it is a schematic or *skeleton* representation of the much more richly data populated published correction chart (© The Hydraulic Institute). Follow the procedure below to use the chart. As a reminder, we are seeking a pump that will handle liquid at 250 gpm at a total dynamic head of 150 feet. We know that our viscosity is 850 cP.

The Hydraulic Institute correction charts only display kinematic viscosity values; therefore, we must first convert the absolute viscosity of 850 centipoise to the kinematic units of centistokes. This is performed by,

$$\nu = \frac{\mu}{S} = \frac{850}{0.993} = 856\,\text{cs}$$

*(Instructor's note: It is apparent in this case that the liquid's specific gravity is so close to that of water that the conversion is somewhat academic. This is not always the case however).*

Now that we have the proper viscosity units, enter the chart (Figure 1) at the bottom along the horizontal axis with 250 gpm, go up to 150 feet head line, over left or right (left in this example), to the 856 cs line, and then up to the correction factors curves. Project over horizontally to the left and read the correction factors:

$C_Q = 0.88$ (the correction factor for capacity, dimensionless)
$C_H = 0.87$ (the correction factor for head, dimensionless)
$C_E = 0.52$ (the correction factor for hydraulic efficiency, dimensionless)

*Once determined for a particular application, how do I use the correction factors?*

The following equations are used for approximating the equivalent water performance when the required viscous capacity and head are known and the values of $C_Q$ and $C_H$ have been determined:

$$Q_W = \frac{Q_V}{C_Q} \quad \text{and} \quad H_W = \frac{H_V}{C_H}$$

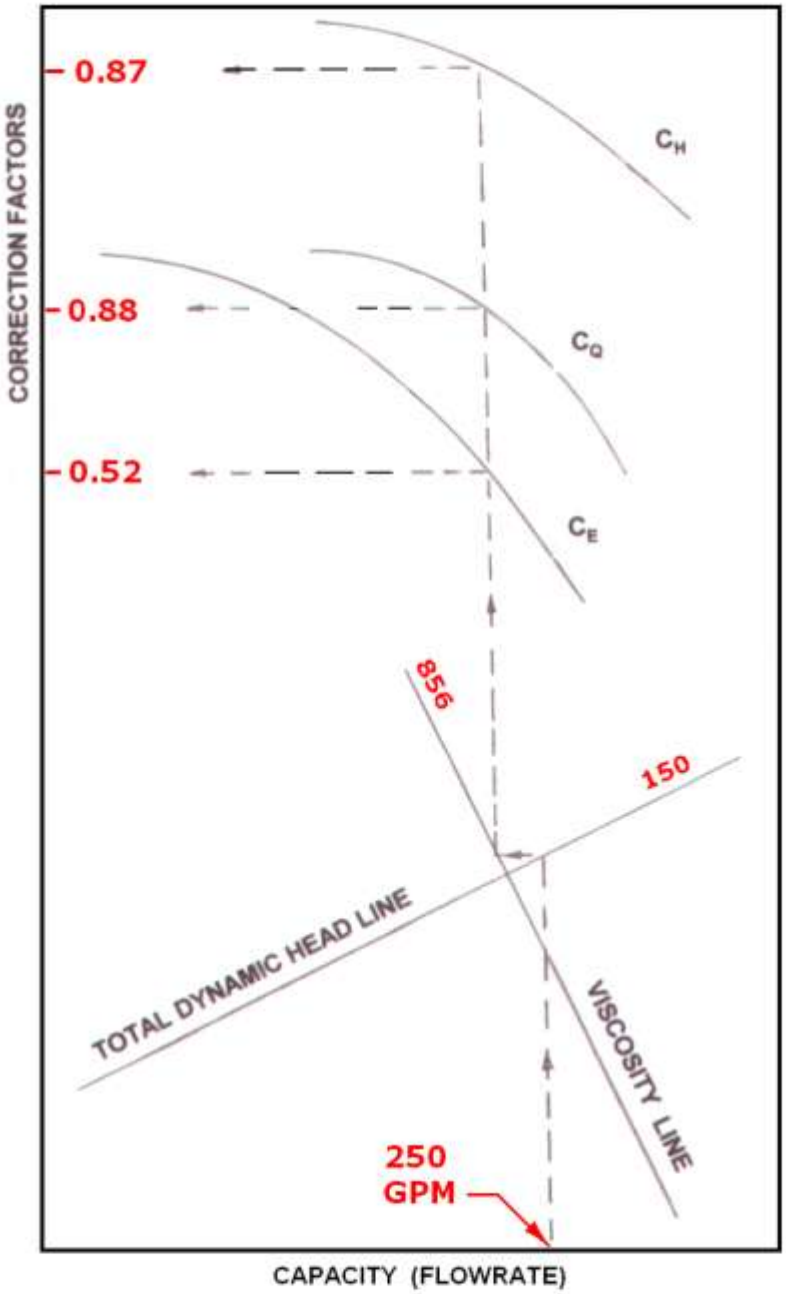



Fig. 1 SCHEMATIC OF HYDRAULIC INSTITUTE PERFORMANCE CORRECTION CHART FOR VISCOUS LIQUIDS

Where $Q_W$ = the equivalent water capacity, gpm
$Q_V$ = the viscous capacity, gpm
$H_W$ = the equivalent water total dynamic head, feet $H_2O$
$H_V$ = the viscous total dynamic head, feet of liquid

In our example this translates to:

$$Q_W = \frac{250}{0.88} = 284\,\text{gpm} \qquad \text{and} \qquad H_W = \frac{150}{0.87} = 172\,\text{feet}$$

Based on these *pseudo* head and capacity values, commercially available pump performance curves would be researched to select a pump that can operate at these conditions and simultaneously demonstrate the best or highest hydraulic efficiency. For the purpose of our example, let us assume that a suitable pump is found for the capacity (284 gpm) and the head (172 feet) requirements, and that the performance curve for this pump indicates a hydraulic efficiency of 68% at these conditions. In order to estimate our viscous efficiency we need to employ a formula that uses the efficiency correction factor *($C_E$)* just determined from the chart (0.52):

$$E_V = E_W C_E$$

Where $E_V$ = the resulting hydraulic efficiency, percent
$E_W$ = the water efficiency, percent

In our example this reduces to:

$$E_V = (68)(0.52) = 35\%$$

Now that we know the viscous hydraulic efficiency, we can determine the required power input to the pump to transfer this hypothetical liquid. The student may recall that hydraulic brake horsepower is given by:

$$\text{bhp} = \frac{QHS}{3960\,E}$$

Where bhp = brake horse power
$Q$ = capacity, gpm
$H$ = total dynamic head, feet of liquid
$E$ = hydraulic efficiency, expressed as a fraction
$S$ = fluid specific gravity, dimensionless, (water @ 68.4° F =1.0)

We will of course use the viscous (actual) values that were dictated by the example project specifications, not the pseudo values, and the viscous efficiency. The resulting required power becomes,

$$\text{bhp} = \frac{(250)(150)(0.993)}{(3960)(0.35)} = 26.9\ \text{hp}$$

*(a 30 hp motor would probably be selected)*

## Summary

Viscosity is a measure of a fluid's resistance to flow. Pumped liquids are generally considered viscous when their absolute viscosity exceeds 40 centipoise. This is the point at which the effect on pump performance becomes appreciable; at 100 centipoise the effect is pronounced.

A centrifugal pump handling a viscous liquid must develop a greater capacity and head, and it requires a larger power input than the same pump handling water. When the required viscous performance of a pump is known, it is possible to select a pump with a greater *pseudo* water performance that will in turn produce the required actual viscous performance. This selection process is accomplished through The Hydraulic Institute's performance correction charts which must be used with caution. The charts should not be used for mixed-flow or axial flow pumps or pumps of special design. Use of the charts should be limited to pumps handling uniform liquids; slurries, gels, paper stock and other binary mixtures will cause incorrect pump selections.

In essence, the viscosity correction factors obtained from The *ANSI/HI Pump Standards* enable the Engineer to derive the viscous performance curve of a pump from its standard water performance curves.