PDHonline Course M136 (2 PDH)

Understanding Pump and Suction Specific Speeds

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Course Introduction and Overview

A parameter for centrifugal pumps known as specific speed is one of the more ambiguous and difficult to come-to-grips-with hydraulic terms that has developed over time. In its originally intentioned form, it was a unitless quantity. Today, the computed specific speed has evolved into a number whose value has incomprehensible units (that are conveniently omitted), and that does not directly relate to a final rotational or angular velocity. As a matter of fact, for a given impeller diameter, specific speed remains unchanged with changes in rotational speed because both flow rate and head are proportionally changed with the rotational speed change. Contrasted to an actual speed, specific speed is an index that relates to pump geometry and performance.

Just because a certain amount of abstractness is associated with pump specific speed does not mean that it is an unimportant concept however. We will learn in this course that a pump's specific speed is directly associated to its hydraulic efficiency, its head and flow characteristics, its Net Positive Suction Head (NPSH), and its power consumption. The first concepts of specific speed were developed in 1937-38[1]. It has become a useful tool for pump designers. Everyday applications Engineers use it to a lesser degree; nevertheless, it is important for the practicing Engineer to have a general understanding of its principles and implementation.

Course Content

The best way to introduce an understanding of pump specific speed is with two of its classical definitions; unfortunately, the obscurity of both definitions is somewhat perturbing:

1. *Pump specific speed is the speed of an impeller in revolutions per minute at which a geometrically similar impeller would run if it were of such a size as to discharge one gallon per minute against one foot head.*[2]
2. *Pump specific speed is the speed of an ideal pump geometrically similar to an actual pump, which when running at this speed would raise a unit of volume, in a unit of time, through a unit of head.*[3]

These text-book definitions are abstract; we need something more down-to-earth. Here is an attempt to assign a simple, brief description to this pump parameter; the only one that is required to successfully make use of the concept. Taking a cue from the mathematic formula of pump specific speed,

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} \tag{1}$$

and trying not to be too academic,

Pump specific speed (N_S*) is a non-rotational, speedless, practically dimensionless index number,* *which is directly proportional to the product of the pump's B.E.P. speed (**N**) and a function of its flow rate (**Q**), and inversely proportional to a function of the pump's B.E.P. head (**H**).*

ADDITIONAL INFORMATION
B.E.P. is an abbreviation for "Best Efficiency Point". It is the point of pump's operation at which the peak hydraulic efficiency is exhibited. The B.E.P. speed, flow rate, and head would be those values at this point.

Is the Quantity of Pump Specific Speed Really Dimensionless?

Well, not precisely. With present day units, a dimensional analysis yields:

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} \quad = \quad \frac{\text{rev}}{\text{min}} \cdot \left(\frac{\text{gal}}{\text{min}}\right)^{0.5} \cdot \frac{1}{\text{ft}^{0.75}} \quad = \quad \frac{(\text{gal}/\text{min})^{0.5}}{\text{min}-\text{ft}^{0.75}} \qquad (2)$$

The resulting units in Equation 2 can not be considered relatable to any practical circumstance and, in-and-of themselves, are therefore meaningless. The point of the matter is, the units are inconsequential. Firstly, the importance of the pure number, with or without labels, is that of a comparative tool. Lower absolute numbers indicate a low specific speed; higher numbers, of course mean, high $\boldsymbol{N_S}$. Secondly, once determined, the number itself is not needed as a basis for further mathematical operations and therefore essentially requires no units. Moreover, the number, or should we say index, relates to the physical geometry of impeller style.

ADDITIONAL INFORMATION
Many sources aptly name or refer to $\boldsymbol{N_S}$ as *impeller specific speed*; this is indicative of the geometric emphasis rather than the impeller size or angular speed aspect of this index number.

A Very Brief Dimensional History[7]

Let's look at the units of specific speed a little closer. The original concept of $\boldsymbol{N_S}$, designated $\boldsymbol{\sigma_S}$, employed units that when coupled with the gravitational constant $\boldsymbol{g}$ (31.17 ft/sec²), resulted in dimensions of unity, *i.e.,*without dimension:

$$\sigma_S = \frac{N\sqrt{Q}}{(gH)^{3/4}} = \frac{\text{rev}}{\text{sec}} \cdot \left(\frac{\text{ft}^3}{\text{sec}}\right)^{0.5} \cdot \frac{1}{(\text{ft}/\text{sec}^2 \ \ \text{ft})^{0.75}} = \frac{\text{ft}^{1.5}\ \text{sec}^{1.5}}{\text{sec}\ \text{sec}^{0.5}\ \text{ft}^{0.75}\ \text{ft}^{0.75}} = \frac{\text{ft}^{1.5}\ \text{sec}^{1.5}}{\text{sec}^{1.5}\ \text{ft}^{1.5}} = 1$$

Over time, a departure from the original capacity units of cubic feet per second were abandoned for the more popular units of gallons per minute (gpm). Likewise, the rotational speed units of revolutions per second were replaced by the more common speed per minute. Later, for convenience, and because the gravitational constant was just that, constant, the value of g was dropped. These changes brought us to the incomprehensible units of N_S we have today, Equation 2, and the numerical values of specific speed that we accept as a comparative standard.

IMPORTANT INFORMATION
The values of pump specific speed that are presented in this course are derived from the standard English volume units of gallons and height units of feet. The use of Imperial and metric units will result in entirely different values that are not directly comparable.

Why Bother with a Numerical Quantity that is Only Used to Identify an Impeller Style?

As it turns out, and as we will see, pump specific speed has been found to be a very useful tool to examine and compare other pump parameters. Before we go any further, let's depart from mathematic machinations and determine a pump specific speed. In reality, the best way to come to understand the parameter is to simply study the presented formula, Equation 1, above and the material that immediately follows.

To provide a concrete, illustrative example, look at the hypothetical performance curve below, Figure 1, as we go through the steps. Let's assume this pump operates at a rotational speed of 3,550 rpm:

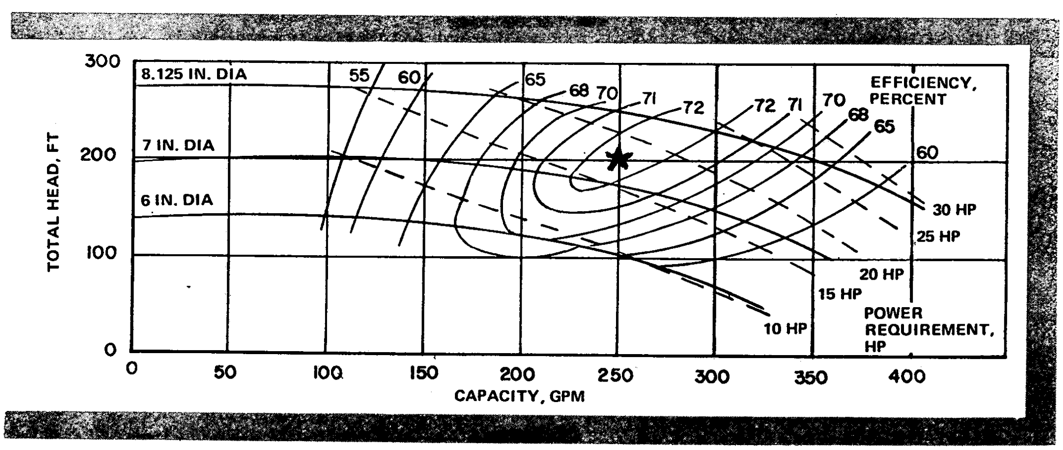

Figure 1 - Typical Pump Performance Curve

The Pump Performance Curve

A centrifugal pump's basic parameters are plotted on manufacturer's performance curves. The presentation of these parameters is somewhat standardized on a two dimensional coordinate plane. The ordinate axis usually serves a dual role of head and brake horsepower while the abscissa accommodates the flow rate or capacity.

Performance curves are generated for constant speed and multiple impeller diameters represented as a family of essentially parallel decaying parabolic plots that characterize the relationship of head versus flow.

Other data presented on the curves are:

1. Efficiency
2. *BHP*
3. $NPSH_R$

Lines of constant efficiency are plotted on manufacturer's pump performance curves as superimposed approximate hyperbolic arcs generally opening in a positive direction. An estimate of the efficiency value using these plots is usually the best that can be accomplished from the pump performance curve. For our example, this estimated efficiency will be quite sufficient.

A "star" symbol has been inserted in our illustrative pump performance curve, Figure 1, to indicate the location of the B.E.P. So, the procedure to follow to determine this pump's specific speed would be to:

1. Locate the point of best hydraulic efficiency: .72%;
2. Move to the left of the B.E.P. horizontally to the y-axis, and see that the total dynamic head (***H***) is .200 feet;
3. Drop vertically down from the B.E.P. to the x-axis and observe that ***Q***: .250 gallons per minute;
4. Calculate the pump specific speed from Equation 1 with these determined values.

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} \quad = \quad \frac{3550\sqrt{250}}{200^{0.75}} \quad = \quad 1{,}055 \qquad (3)$$

Practical specific speeds range from 500 to 8,000; values reaching 15,000 can be encountered. Figure 2 shows the impeller styles that correspond to the practical range of numbers.

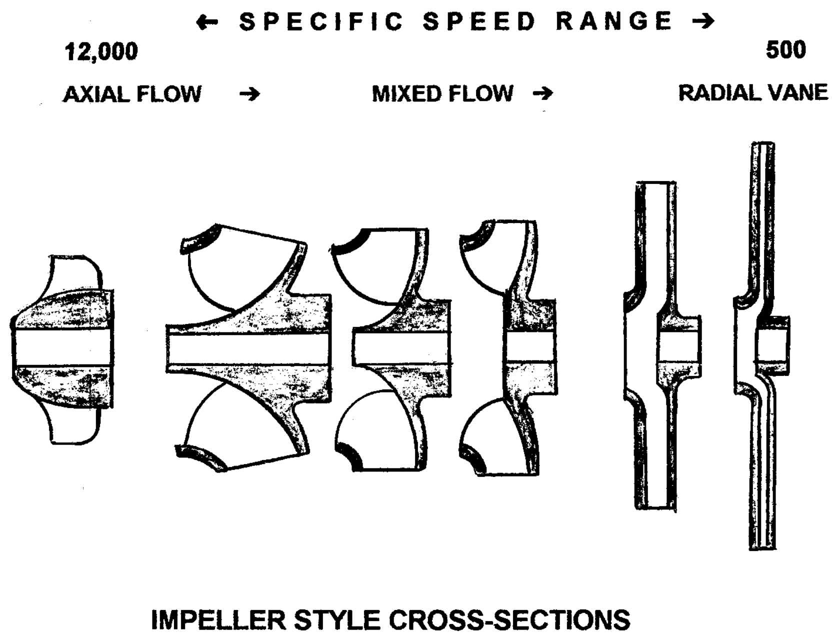

Figure 2

Relation of Specific Speed to Flow, Head, and Efficiency

Beyond the simplistic correlation of impeller geometry and pump specific speed just illustrated, some generalizations can be drawn for the numerical values of this index number. Put succinctly, higher pump head generation is associated with lower values of specific speed, at the expense of lower flow rates and lower relative hydraulic efficiency. Conversely, low pressure (head) values are experienced with higher values of specific speed, accompanied by higher values of flow rate at correspondingly relatively higher hydraulic efficiencies. As in most cases, there are trade offs that must be weighed when selecting the impeller style, *i.e.*, specific speed. Each individual hydraulic service must be carefully evaluated to insure that the proper pump, impeller style, and rotational speed, are accurately addressed.

It has been shown through extensive research that for all flow rate values, hydraulic efficiency gradually increases until N_S reaches a value of 2,500[4], and declines thereafter. A graphical representation of this relationship is shown in Figure 3.

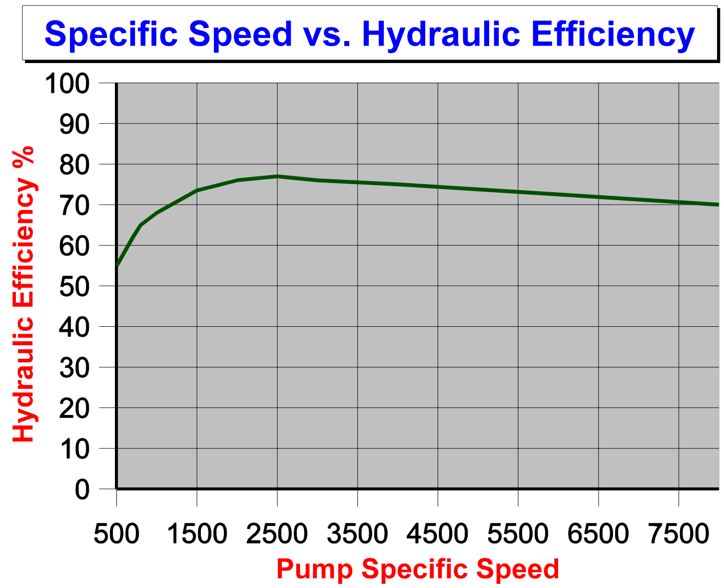

Figure 3

This relationship is important because we can take any hydraulic set of conditions and estimate the proper rotational speed that would theoretically maximize hydraulic efficiency. Let's look at an example.

EXAMPLE 1 (Determination of Optimum Rotational Speed)

Assume: Ideal Pump Specific Speed is N_S = 2,500

Given: Total Dynamic Head (***H***) = 90 feet and flow rate (***Q***) = 4,000 gpm

Find: Optimum rotational speed (***N***) (*i.e.,* real speed at which maximum efficiency is estimated to occur).

Solution:
Rearranging Equation 1 to isolate ***N*** on the left side:

$$N = \frac{N_S\, H^{3/4}}{\sqrt{Q}} \qquad (4)$$

And now taking the stated assumption, and substituting the value of 2,500 for N_S yields,

$$N = \frac{2500\, H^{3/4}}{\sqrt{Q}} \qquad (5)$$

the equation to determine optimum rotational speed. In our example,

$$N = \frac{(2500)(90)^{0.75}}{\sqrt{4000}} \quad = \quad 1{,}155 \text{ rpm}$$

Perhaps an AC synchronous motor with a nominal rotational speed of 1,200 rpm (actual . 1,170 ! 1,180) could be selected for the above example. Alternatively, some type of variable speed prime mover, such as a steam turbine, could be employed to more closely target the optimum speed.

Obviously, system variables could be substituted in Equation 5 that would essentially preclude its usefulness. For example, changing the flow rate in the example just presented to 100 gallons per minute results in an optimum rotational speed of . 7,556 rpm. This theoretical value far exceeds most practical possibilities. For instance, present day two pole squirrel cage induction motors are limited to speeds of approximately 3,600 rpm. And while on the subject of the selection of rotational speed, one must be ever mindful that higher rotational speeds do not come without consequence. Additionally, first and second critical speeds (the determining function being primarily associated with allowable shaft deflection, the subject of which is beyond the scope of this course), should be avoided.

IMPORTANT INFORMATION

It should be understood that the value of ***H*** in all the equations presented in this course is head, in feet, per pump stage. Appropriate values should be selected to determine pump specific speed in the case of multistage pumps.

NPSH and Cavitation

Net Positive Suction Head (NPSH) is another important pump parameter; it exists in two forms. NPSH available ($NPSH_A$) is the resulting pressure value of the liquid entering the pump. NPSH required ($NPSH_R$) is the resulting pressure drop produced as the liquid passes through the pump. $NPSH_A$ is defined by the system within which the pump operates; it must be calculated. $NPSH_R$ is a characteristic of the pump itself; it is determined from tests conducted by the pump manufacturer. A discussion of Net Positive Suction Head (NPSH) in essence is a discussion of cavitation. As fluid moves through the pump inlet its pressure is reduced. If the decrease in pressure results in the liquid equaling or going below its vapor pressure, then a portion of the liquid *boils* or vaporizes. As the now gas-entrained liquid enters the high pressure section of the pump these “bubbles” rapidly collapse releasing large amounts of damaging energy to pump internals. This process is known as *cavitation*. The greater the margin between $NPSH_A$ and $NPSH_R$, the lesser the possibility of cavitation. Therefore, pump suction designs which maximize $NPSH_A$ are superior to those that subject the suction liquid to pressure reductions which approach the liquid vapor pressure.

ADDITIONAL INFORMATION
It is recommended that the student study PDHcenter.com's course number M124 entitled *Understanding Net Positive Suction Head* for an in-depth treatment of this subject.

Exploring a Comparable Suction Index

An important aspect of pump hydraulic system design is the suction or inlet conditions. Disregard for proper allowances can result in vortices, cavitation, and loss of prime. In addition to poor performance, truly bad designs can, in some cases, actually result in physical damage to the pump or its parts. Excessive suction lift, shallow inlet submergence, or insufficient Net Positive Suction Head available ($NPSH_A$), all spell serious trouble from vibration, cavitation, lowered capacity, and reduced efficiency.

Interestingly enough, by expanding the specific speed concept with the substitution of Net Positive Suction Head for the value of ***H*** in Equation 1, new meaning and importance are brought to the already stated comparative significance of this index.

$$N_{SS} = \frac{N\sqrt{Q}}{(NPSH)^{3/4}} \tag{6}$$

This number is known as suction specific speed.

Just How Many Specific Speeds Does a Pump Have?

In short, three. Three, that is, for any set of fixed conditions. In addition to pump specific speed, there exists two values of suction specific speed depending on the form of NPSH used in equation 6. Suction specific speed *required* is obtained when:

$$N_{SSR} = \frac{N\sqrt{Q}}{(NPSH_R)^{3/4}} \tag{7}$$

Generally, the larger the numerical value of $\boldsymbol{N_{SSR}}$, the more favorable the pump's suction capabilities are. Normal pump designs exhibit $\boldsymbol{N_{SSR}}$ values ranging from 6,000 to 12,000. Greater values are not uncommon.

It logically follows that the concept of suction specific speed *available* would be,

$$N_{SSA} = \frac{N\sqrt{Q}}{(NPSH_A)^{3/4}} \tag{8}$$

It was mentioned earlier that pump specific speed was primarily a pump designer's tool. As it turns out, N_{SSA} is a very useful number even to day-to-day applications Engineers. With this number, the on-set of cavitation can be predicted. While just an index number, it, like $NPSH_A$, describes the system conditions available to the pump's suction side. N_{SSR} must exceed N_{SSA} in order to preclude liquid cavitation. The difference between the two quantities is known as margin. Ideally,

$$N_{SSR} >> N_{SSA} \tag{9}$$

Much that is known about pumps has been determined largely by experience; it is fairly well known among pump designers that cavitation usually occurs beyond N_{SS} = 10,000 (based on cold water)[6]. Special pump designs can accommodate suction specific speeds of 12,000. Occasionally, cavitation can be experienced even when the value of N_{SS} is well below the 12,000 limit.

This opens the door to more knowledge; N_{SSA} can be used to determine or select the optimum rotational speed. Much like the optimum N_{SS} number of 2,500, through extensive pump industry experience, it has been determined that the optimum suction conditions exist at suction specific speeds less than 8,500[2,5]. Armed with this fact and the fact that the evaluation of $NPSH_A$ is easy accomplished for a given hydraulic system, Equation 8 can be rearranged to appear as,

$$N = \frac{8500(NPSH_A)^{3/4}}{\sqrt{Q}} \tag{10}$$

Equation 10 allows the Engineer to determine the probable upper limit of rotational speed that a pump should be subjected to in order to achieve the optimum suction conditions. Let's look at a specific example.

EXAMPLE 2 (Estimation of Limiting Cavitational Rotational Speed)

Assume: Ideal Suction Specific Speed is $N_{SS} < 8{,}500$

Given: Net Positive Suction Head Available ($NPSH_A$) = 45 feet and flow rate (***Q***) = 60,000 gpm

Find: Upper-limit rotational speed (***N***) (*i.e.,* real speed which should not be exceeded to avoid cavitation).

Solution: Use Equation 10 for the solution:

$$N = \frac{8500\,(NPSH_A)^{3/4}}{\sqrt{Q}} = \frac{(8500)(45)^{0.75}}{\sqrt{60{,}000}} = 603 \text{ rpm}$$

IMPORTANT INFORMATION

When computing suction specific speeds, the value of ***Q*** is flow rate, in gallons per minute, per suction inlet, or impeller eye. Therefore, 50% of the total flow rate would be used for the value of ***Q*** in the calculation of suction specific speed for a double suction pump.

Summary

The description of a pump impeller's geometry (shape) is numerically accomplished by an index number known as pump (impeller) specific speed. While somewhat abstract from a dimensional standpoint, it has become a useful analytical tool to both pump designers and applications Engineers alike.

Specific speed is often used to determine which type of pump (impeller) to use. Applications that demand relatively high flow rates but not at high heads, such as power plant circulating water systems, tend toward the axial or mixed flow style (high specific speed) impeller because of the high efficiency. Situations where the primary hydraulic task is to pressurize the pumped liquid are assigned to the lower hydraulic efficiency, relatively speaking, lower flow, low specific speed (radial vane style) impeller.

Through empirical methods, milestone values of specific speeds have been identified and are utilized to back-calculate estimated rotational speeds that yield maximum hydraulic efficiency and promote optimum suction conditions for a given set of pump parameters.

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