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Revision Memo

12/01 Reaffirmed with 2 minor editorial changes.

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SCOPE

This section presents information on the hydraulic performance characteristics of centrifugal pumps. This information is intended to aid in estimating pump performance, modifying existing pumps, and in reapplying pumps in new pumping services.

REFERENCES

GLOBAL PRACTICE

GP 10-1-1 Heavy Duty Centrifugal Pumps

OTHER REFERENCES

- ▶ API 610, *Centrifugal Pumps for Petroleum, Heavy Duty Chemical and Gas Industry Services*.
- Cameron Hydraulic Data*, Published by Ingersoll Rand.
- Pump Handbook*, Second Edition, Edited by Igor J. Karassik, William C. Krutzsch, Warren H Fraser and Joseph P. Messina, McGraw Hill, 1986.
- Stepanoff, A. J., *Centrifugal and Axial Flow Pumps, Theory, Design and Application*, Second Edition, by, John Wiley & Sons, 1957.
- Transamerica Delaval Engineering Handbook*, Fourth Edition, Edited by Harry J. Welch, McGraw Hill, 1983.
- Application Guide for Electrical Variable Frequency Drives (VFD's)*, EE.52E.94.

DEFINITIONS

Best Efficiency Point (BEP) - The point on a pump performance curve corresponding to the flow rate with the highest possible efficiency for that pump.

Cavitation - The formation and subsequent collapse of vapor-filled cavities in a liquid.

Head - The amount of energy per unit mass of a liquid. It is expressed in an equivalent column height of the fluid pumped, e.g., ft or m.

Net Positive Suction Head Available (NPSH_A) - The total suction head, in ft (m) of liquid absolute, determined at a datum elevation, minus the vapor pressure of the liquid in ft (m) absolute.

Net Positive Suction Head Required (NPSH_R) - The reduction in total head as the liquid enters the pump. This includes losses due to friction and turbulence. The NPSH_A must always be greater than the NPSH_R to avoid cavitation.

IMPELLER CLASSIFICATION, SPECIFIC SPEED

Centrifugal pumps are generally divided into three classes depending on the specific speed. The classes are as follows: Centrifugal or Radial-Vane, Mixed-flow, and Axial-flow.

Specific speed (N_S) is calculated using the following equations:

Customary Units

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

Metric Units

$$N_S = \frac{N\sqrt{Q}}{1.16 H^{3/4}}$$

- where:**
- N = The pump speed in RPM
 - Q = Volume flow rate at best efficiency point in gallons per minute (cubic m per hour), use Q/2 for double suction pumps
 - H = Pump head (per stage) at best efficiency point in ft (m), use the first stage head for multi-stage pumps

When used as a type number, specific speed is always calculated at the best efficiency point. Typically, pump impellers can be classified into the following specific speed ranges (see **Figure 1**).

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IMPELLER CLASSIFICATION, SPECIFIC SPEED (Cont)

N_S RANGE	IMPELLER TYPE
500 < N _S < 4200	Centrifugal or Radial Flow
4200 < N _S < 9000	Mixed Flow
N _S > 9000	Axial Flow

EXAMPLE 1: SPECIFIC SPEED CALCULATION

A pump is specified that will produce 100 ft (30.5 m) of head at a flow rate of 5000 gpm (1135.7 m³/hr) at a speed of 500 rpm.

Customary Units

Calculate N_S

$$N_S = \frac{500\sqrt{5000}}{100^{3/4}} = 1118$$

Metric Units

$$N_S = \frac{500\sqrt{1135.7}}{1.16 \times 30.5^{3/4}} = 1118$$

For the same head-capacity requirement, higher specific speed pump impellers will run at a higher speed and will be physically smaller. For the same speed and head, a higher specific speed pump will deliver a higher capacity.

PERFORMANCE

Typical pump performance curves include head, power requirement, efficiency, and NPSH_R as a function of capacity. The curve shapes vary very little between pumps that utilize the same impeller types. **Figure 2** shows average curve shapes for the main performance parameters for a radial flow impeller. This figure may be used to estimate the effect of a change in flow, but actual curves should, of course, be used on existing pumps of known characteristics. Deviation of performance characteristics of specific pumps from the average values of these figures should not be considered deficiencies, simply because they differ from the average values.

AFFINITY LAWS

Pump characteristics vary with speed and impeller diameter in such a way that the performance curves retain their characteristic features. The variation of head, capacity, and brake power with speed and impeller diameter follows definite rules known as the affinity laws. When curves are supplied that do not present performance at different speeds and impeller diameters, the affinity laws can be used to estimate the modified performance with reasonable accuracy.

The affinity laws are expressed by the following equations:

- As the speed varies and diameter is held constant:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \quad \frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

- As the diameter varies and speed is held constant:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad \frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \quad \frac{BHP_1}{BHP_2} = \left(\frac{D_1}{D_2}\right)^3$$

where: Q = Capacity, gpm (m³/hr)
H = Total Head, ft (m)
BHP = Brake Power, horsepower (kilowatts)
N = Pump Speed, RPM
D = Impeller Diameter, ft (m)

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AFFINITY LAWS (Cont)

EXAMPLE 2: AFFINITY LAW CALCULATION

A pump manufacturer has provided a performance curve (see **Figure 3**) for a pump at design (100%) speed. At a capacity of 1250 gpm (284 m³/hr), the pump provides 385 ft (117 m) of head at a brake power of 400 horsepower (298 kW). The following calculations demonstrate the shifting of performance parameters to 92% speed or impeller diameter:

	Customary Units	Metric Units
First, determine head at zero flow.	$H_0 = 450 \times (0.92)^2 = 380 \text{ ft}$	$H_0 = 137 \times (0.92)^2 = 116 \text{ m}$
To define any other point on the 92% speed curve proceed downward from the 100% curve to a point equal to $H \times (0.92)^2$. From Point 1 at 1250 gpm (284 m ³ /hr) and 385 ft (117 m) head:		
Calculate H_2	$H_2 = 385 \times (0.92)^2 = 324 \text{ ft}$	$H_2 = 117 \times (0.92)^2 = 99 \text{ m}$
Calculate Q_2	$Q_2 = 1250 \times 0.92 = 1150 \text{ gpm}$	$Q_2 = 284 \times 0.92 = 261 \text{ m}^3/\text{hr}$
Point 2 would be on the curve at 1150 gpm (261 m ³ /hr) and 324 ft (99 m).		
For the power curves at 92% speed or impeller diameter, proceed downward from point 3 on the 100% speed curve to a point equal to $BP \times (0.92)^3$:		
Calculate Power	$BHP = 400 \times (0.92)^3 = 312 \text{ hp}$	$BP = 298 \times (0.92)^3 = 232 \text{ kW}$
Calculate Q_4	$Q_4 = 1250 \times 0.92 = 1150 \text{ gpm}$	$Q_4 = 284 \times 0.92 = 261 \text{ m}^3/\text{hr}$
Point 4 would be on the 92% curve at 312 BHP (232 kW) and 1150 gpm (261 m ³ /hr).		

IMPELLER SPEED & DIAMETER CHANGES

- ♦ The affinity laws remain fairly accurate for a wide range of speed changes (up to about 50%). The pump's efficiencies, however, will change significantly when there is a decrease in speed. There are accepted rules of thumb that can be used to approximate the change in efficiency for pumps with specific speeds of 1000 - 2000 (radial flow). They are summarized by the following table:

SPEED CHANGE	EFFICIENCY CHANGE
Increase	No Significant Change
Decrease Down to 20%	No More than 2 Percentage Points Decrease
Decrease 20% to 50%	2 to 8 Percentage Points Decrease

In general, the affinity laws are only accurate for diameter changes that are limited to within 20% of the maximum diameter impeller.

SUCTION SPECIFIC SPEED

Suction specific speed (S_{SS}) is an index of pump suction operating characteristics determined at the best efficiency point with the maximum-diameter impeller. It is an indicator of the net positive suction head required for given values of capacity and rotative speed and provides an assessment of a pump's susceptibility to internal recirculation. It is calculated using the following equations:

Customary Units

$$S_{SS} = \frac{N\sqrt{Q}}{(\text{NPSH}_R)^{3/4}}$$

Metric Units

$$S_{SS} = \frac{N\sqrt{Q}}{1.16 (\text{NPSH}_R)^{3/4}}$$

where: N = The operating speed in RPM
 Q = Volume flow rate at best efficiency point in gallons per minute (cubic m per hour)
 NPSH_R = Net positive suction head required at best efficiency point in ft (m)

GP 10-1-1 limits S_{SS} to 12000. Values of S_{SS} range from 7000 to approximately 13000 for commercially available pumps. Higher specific speed pumps have large inlet eye areas and are generally prone to internal recirculation when operated at flows away from the BEP. The intent of the GP requirement is to avoid these problems, provide adequate turndown capability, and improve pump reliability at reduced flow operation.