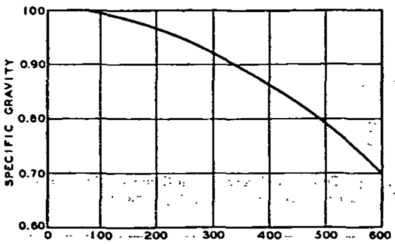

Fig. 2 .... Specific Gravity of Water as a Function of Temperature

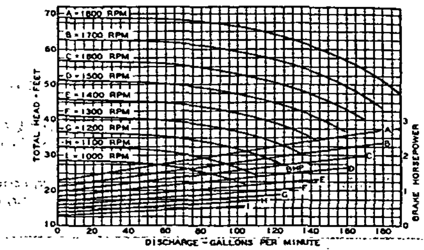

Fig. 3 .... Typical Performance and BHP Requirements for a Single-Suction, Long-Coupled Centrifugal Pump at Various Speeds

tion 2 is multiplied by the specific gravity of the fluid. Pump efficiency decreases somewhat with other fluids. This must be taken in account when computing pump horsepower.

Pump pressures are expressed in either pounds per square inch or in feet of liquid. A column of 2.3 ft of water at 62 F exerts a pressure of 1 psi. Pump selection charts usually give pressures or heads in feet. To convert readings given in pounds per square inch into feet of water they must be multiplied by 2.3. Dividing by 2.3 reduces readings in feet of water into pounds per square inch.

The unit for measuring head is the foot. Therefore:

$$\text{head in ft} = \frac{\text{psi} \times 2.31 \times 62.3}{W} = \frac{\text{psi} \times 2.31}{S} \quad (4)$$

where

W = specific weight in pounds per cubic foot.
S = specific gravity of fluid.

Pump capacity or volume is expressed in gallons per minute (gpm), cu ft per second (cfs), or gallons per 24-hr day (gpd), delivered against a specified head or pressure.

Specific gravity is the ratio of the weight of a substance to that of an equal volume of water at 39.2 F (the temperature of maximum density of water). The specific gravity of water at various temperatures is given in Fig. 2. For brines, refer to Chapter 21.

Pump speed is the speed at which the shaft rotates the impeller, and is given in revolutions per minute (rpm). *Tip speed* refers to the speed at the impeller periphery, and is given in feet per second. *Specific speed* is a type number or index used by the design engineer to select the most applicable speed for a pump designed to operate in a certain range. However, tip speed and specific speed will both be within satisfactory limits if pumps are selected from the data shown in manufacturer's catalogs.

When pump speed is changed, capacity varies directly as the speed, pressure (head) varies directly *as the square of the* speed, and power requirements vary directly as the cube of the speed. (See Fig. 3).

Performance Curves

A pump's performance is most commonly shown by means of plotted curves, as in Fig. 1, which relate the flow (gallons per minute), the pressure produced (head in feet of fluid), the power required (brake horsepower), the hydraulic efficiency (water hp output + bhp input), the specific gravity, and viscosity of the fluid, the shaft speed (revolutions per minute), and the net positive suction head (feet of fluid) required for normal operation of the pump. See section System Characteristics for *net positive suction head* (NPSH). For many small pumps, some of this information is omitted.

Pump curves present the average results obtained from testing several pumps of the same design under standardized test conditions. Manufacturers should be consulted for pump applications that differ considerably from ordinary practice.

There is a common but arbitrary classification of centrifugal pumps into *steep-curve* pumps and *flat-curve* pumps, which refers to the shape of the head capacity curve as shown in Fig. 4. Pumps with *flat-curves* are often preferred for closed circuit systems, because large changes in pump capacity can be achieved with a small change in head. This is valuable when balancing several circuits in a system. Steep-curve pumps are frequently selected for open circuit systems, such as for cooling towers. They have the advantage that a change in piping resistance, resulting from corrosion or scale accumulation, has a minimum throttling effect on the flow.

The *maximum efficiency* characteristic of a pump is not always the most important feature in making a selection. A selection must be made in consideration of the system resistance if the pump is to operate at its peak efficiency. Systems in which there is no corrosion and systems that are protected against corrosion should not be designed from pipe

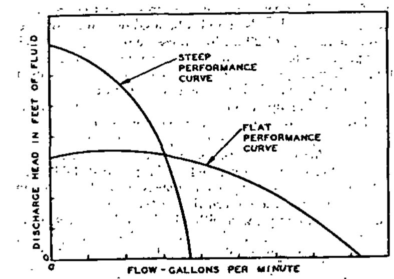

Fig. 4 .... Performance Curves for Steep-Curve Pumps and Flat-Curve Pumps

Table 1 .... Performance Characteristics of Various Types of Pumps

		Type of Pump			
		Centrifugal	*Rotary*	*Turbine*	*Reciprocating*
Characteristic Flow		Even	Even	Even	Pulsating
Pump Response to Throttling of Discharge	Pressure	Increase	With no Relief Valve—Increase to Destruction		
	Power	Decrease	Increases to Limits of Power		
Resulting Effect of Raising Head	Capacity	Decrease	None	Slight	None
	Power	Decrease	Increase	Increase	Increase
Resulting Effect of Lowering Head	Capacity	Increase	None	Slight	Slight to None
	Power	Increase	Decrease	Decrease	Decrease

friction loss tables containing high corrosion allowance. Use of such tables results in excessive heads and causes selection of a larger pump than actually is required, with consequent higher initial costs and increased power consumption. When determining friction loss for closed and corrosion-free systems, tables for resistance of clean pipe should always be used. It should also be noted that the pump user is always interested *in performance* at the actual pumping conditions of the system, rather than in performance at some other operating point on its performance curve.

It is a general rule that pumps for systems using liquids for heating and cooling should be hydraulically and mechanically designed for quiet operation, durability, simple service, minimum maintenance, and minimum suction requirements rather than for minimum cost or size.

HYDRAULIC SYSTEM CHARACTERISTICS

Particular attention must be given to the condition of the fluid as it enters the suction flange of the pump. If the absolute pressure on the fluid at the suction flange approaches the vapor pressure of the fluid too closely, vapor pockets will form in the impeller passages. This condition will interfere with pump performance, and the collapse of the vapor pockets will be noisy and even destructive. The amount of pressure in excess of the vapor pressure required to prevent the formation of vapor pockets, is known as the *required net positive suction head* (NPSH). The required NPSH varies considerably with pump capacity and increases rapidly at very high capacities, as shown in Fig. 1. This rapid increase of the NPSH explains the noisy and often unsatisfactory performance of centrifugal pumps at extreme capacities. A common rule is to operate a pump at no more than ⅞ of its maximum capacity. Particular attention must be given to this when operating with hot fluids or with fluids pumped from vacuum conditions. Then it is often necessary to calculate the *available net positive suction head*. This can be done simply by calculating the absolute static pressure at the suction flange, adding the velocity head of the fluid at the suction flange, and subtracting the vapor pressure of the fluid at the suction flange. The result will be the *available* NPSH. If the available NPSH is smaller than the pump manufacturer's recommended *required* NPSH, cavitation noise, inadequate pumping, and mechanical problems are to be expected. If the required NPSH is not given in the performance table, the pump manufacturer must be consulted.

A centrifugal pump responds to the hydraulic characteristics of the system to which it is applied and produces fluid flow and pressure related to the pressure conditions of the system for that flow (see Table 1). This *condition makes it* necessary to carefully predict the system characteristics for proper pump selection.

Pumps are applied to two general types of piping systems: *closed* systems and *open* systems. For a *closed* system, since the *hydraulic circuit* is closed, the system pressure can be arbitrarily changed. These systems usually have a compression tank to control the system pressure. A system having an expansion tank open to the atmosphere as described in Chapter 10, 1964 GUIDE AND DATA BOOK, is actually a closed hydraulic circuit. An *open system* has a break in the hydraulic circuit and therefore requires an analysis of the static pressure difference between the suction and discharge conditions.

In both types of systems there is resistance to fluid flow because of pipe friction. This resistance varies with the amount of flow approximately in proportion to the square of the change in velocity of the fluid. This relation can be shown graphically and is called a *system curve*, Fig. 5.

$$H_1/H_2 = (Q_1/Q_2)^2 \quad (5)$$

where

H_1 = pressure drop at design flow Q_1.
H_2 = system pressure drop at assumed flow Q_2.

When the pump capacity curve is superimposed on the system curve, the intersection of the two curves, as shown on

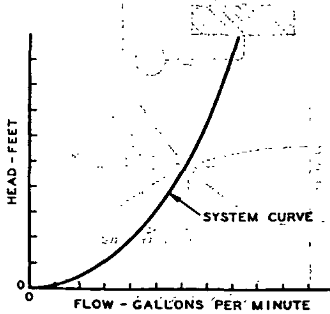

Fig. 5 .... Typical System Characteristic Curve