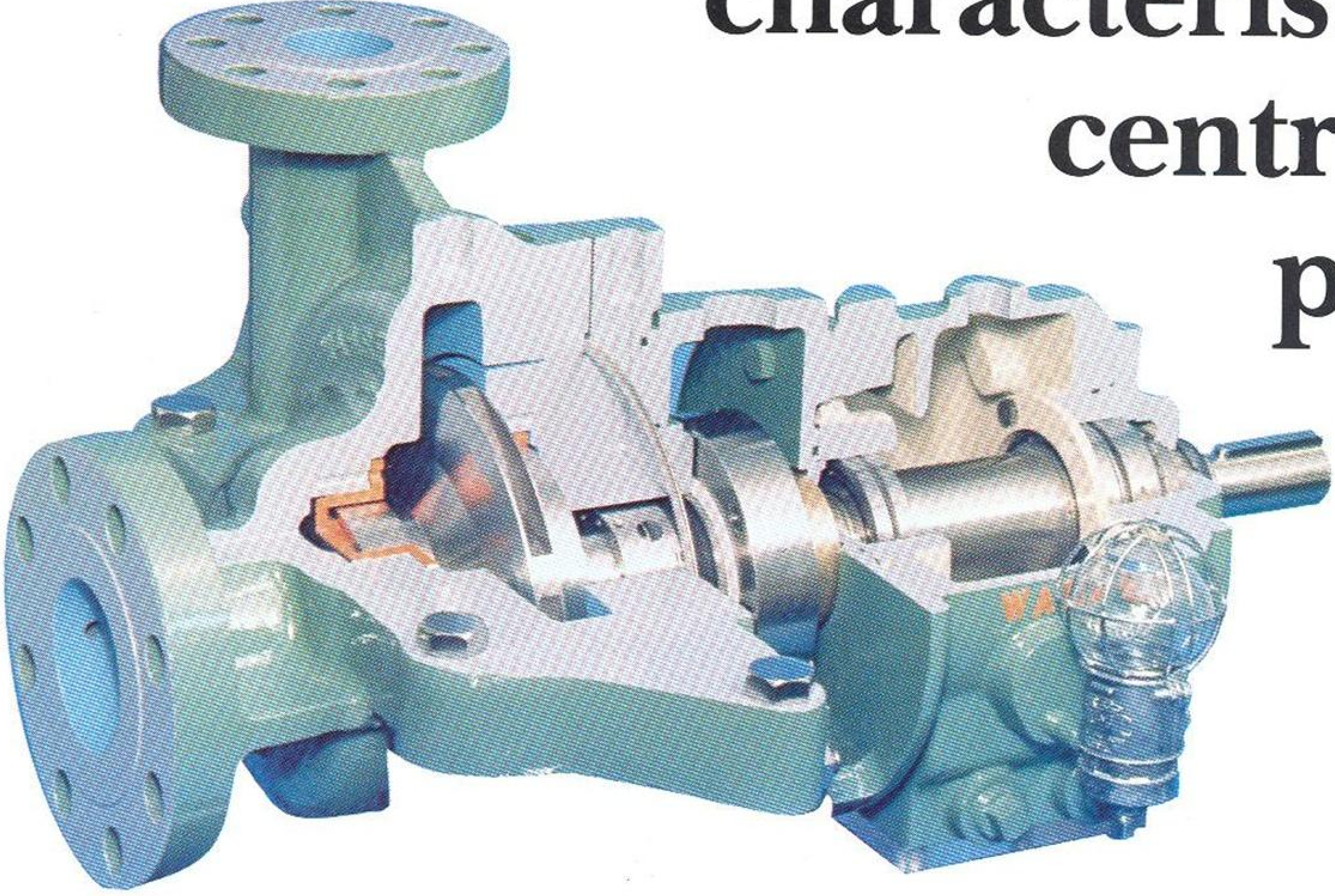
Head-vs.-capacity characteristics of centrifugal pumps



Engineering standards limit the use of pumps having head-vs.-capacity curves that do not rise constantly to shutoff. But in many cases such pumps are a good choice because of their high efficiency.

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☐ Many pump standards such as API 610 require that centrifugal pumps operated in parallel have characteristic head-vs.-capacity curves that rise constantly to shutoff, as in Fig. 1a. However, high-head, low-capacity, single-stage pumps as used in the chemical process industries often have curves that do not do so: Rather, there is a peak head at some capacity, and from that point the head *falls* constantly to shutoff. Such a pump curve, shown in Fig. 1b, is known as a "drooping" curve.

This article explains why some centrifugal pumps have drooping head-vs.-capacity curves, and shows when and how such pumps can cause problems. The point, of course, is to prevent the problems.

As it turns out, the significance of a drooping curve is this: Two identical pumps having drooping head-vs.-capacity curves should not be operated in parallel under conditions that require wide ranges of capacity that approach zero. Such conditions are common in boiler-feedwater and fire-main systems. In chemical-process service, though, it is rare to find two pumps operating in parallel. They are often *piped* in parallel, but typically only one is operated at a time, and the other is a spare.

Thus, drooping-curve pumps can often be used in chemical-process applications. What is their advantage? Either greater efficiency or lower cost. Compared with a pump having a constantly-rising head-vs.-capacity curve, a pump of the same size but having a drooping curve will be more efficient. And, one of a smaller size can deliver the same capacity at the same head, with equal efficiency.

Head vs. capacity

Let us now look at head-vs.-capacity curves, and at why certain pumps do or do not have drooping curves. The head generated by a centrifugal pump can be expressed in the form:

$$h = AN^2 + BNQ + CQ^2$$

where h is head (ft), N is rotational speed (rpm), Q is flowrate (gpm), and A, B and C are constants for a given pump and impeller. For the typical case of a pump operating at constant speed, this head-vs.-capacity equation can be rewritten as:

$$h = a + bQ + cQ^2$$

The constants a, b and c are for a given speed.

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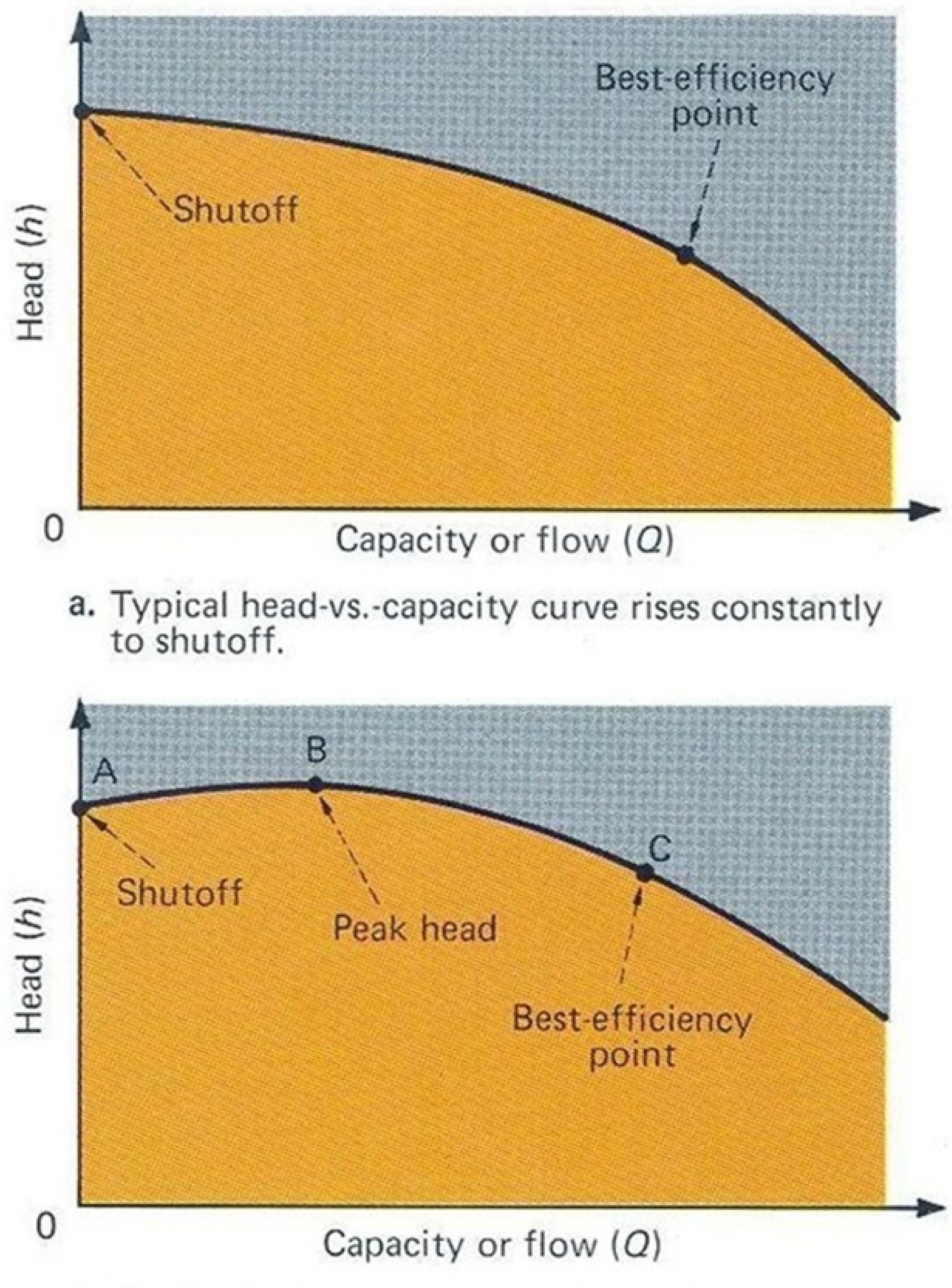
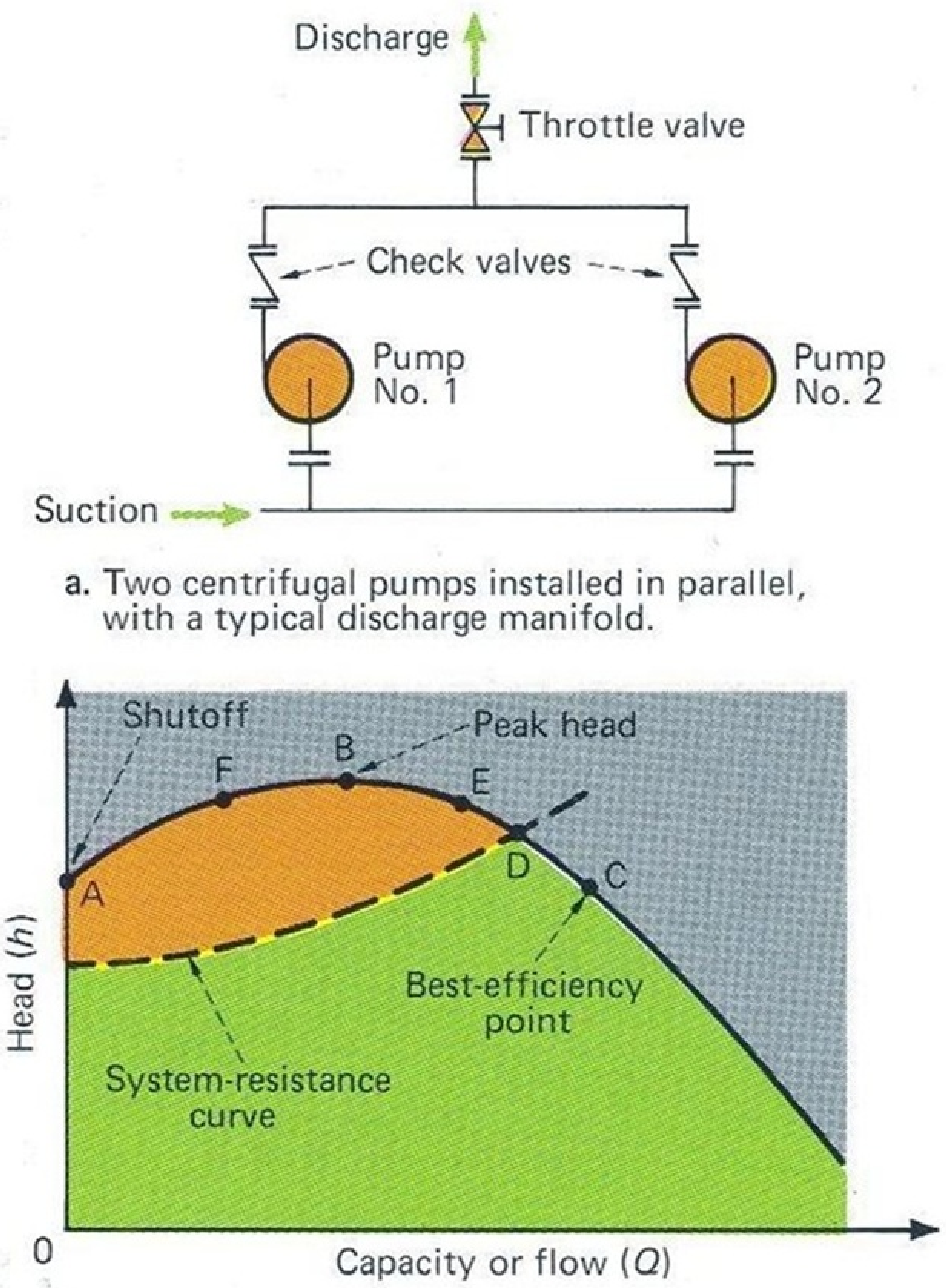


a. Typical head-vs.-capacity curve rises constantly to shutoff.

b. "Drooping" pump curve has a peak head.

Some high-head pumps have head-vs.-capacity curves that do not rise constantly to shutoff **Fig. 1**



a. Two centrifugal pumps installed in parallel, with a typical discharge manifold.

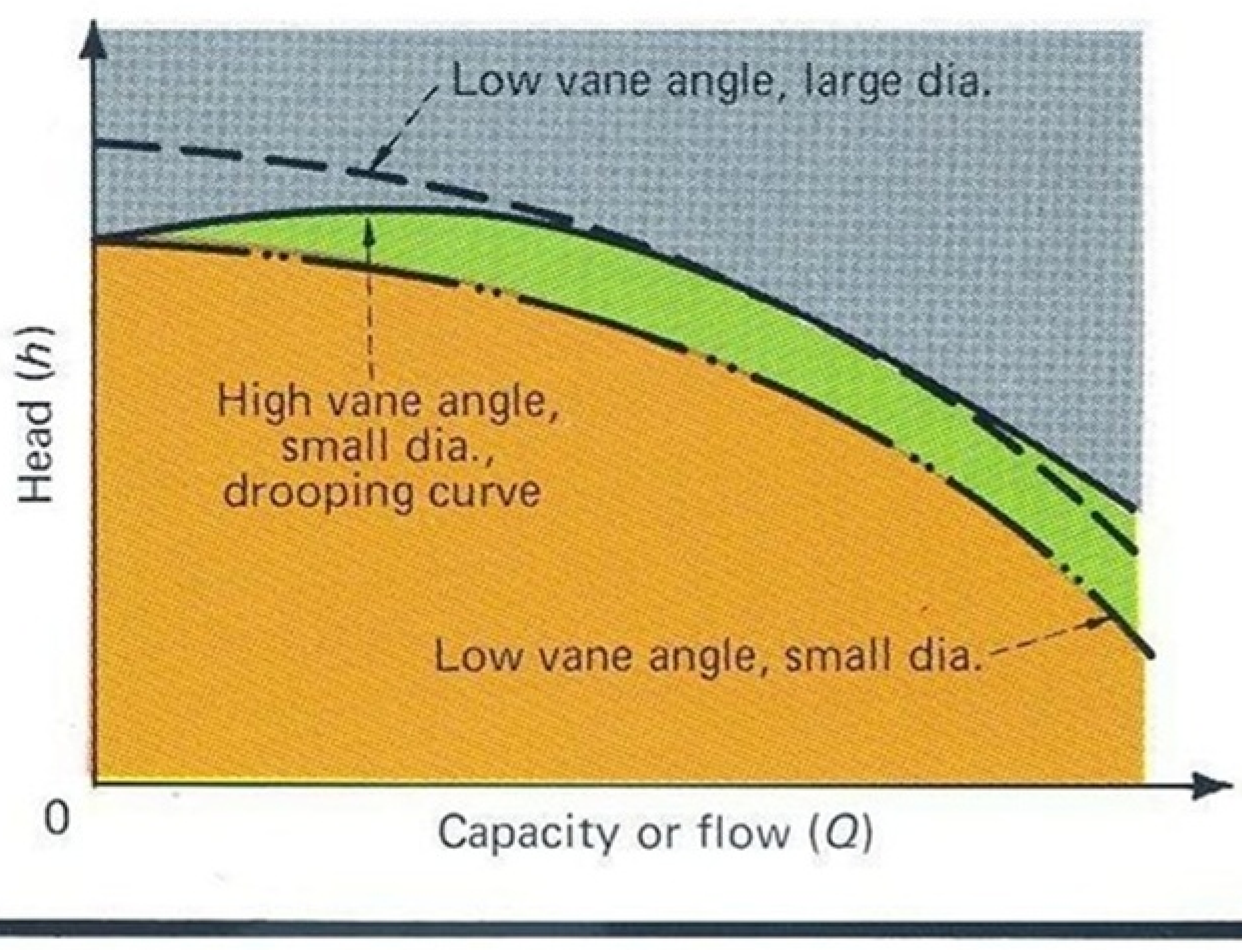
b. Characteristic curve for two drooping-curve pumps operating in parallel.

Operating two or more drooping-curve pumps in parallel can lead to some problems **Fig. 3**

This equation describes a parabola having its axis parallel to the h axis, as in Fig. 1, and its apex at $Q = -b/2c$. If this apex is far enough to the right of shutoff, then a head-vs.-capacity test will show a detectable droop: The shutoff head (a) will be detectably lower than the peak head.

Whether a pump has a drooping curve or not is decided by the designer: Pumps are designed to be run at their best-efficiency point (see Fig. 1), and where the designer puts this point determines where the peak head falls.

It turns out that high-head, low-capacity pumps designed for optimum efficiency will tend to have drooping head-vs.-capacity curves. In pump terminology, pumps whose specific speed ($N_s = N(Q^{1/2}/h^{3/4})$) is less than 1,000 will tend to have drooping head-vs.-capacity curves if they have an optimum number of vanes (7 or 8) and an optimum discharge angle (23 − 27 deg).



Pump-design changes that eliminate "drooping" also reduce performance **Fig. 2**

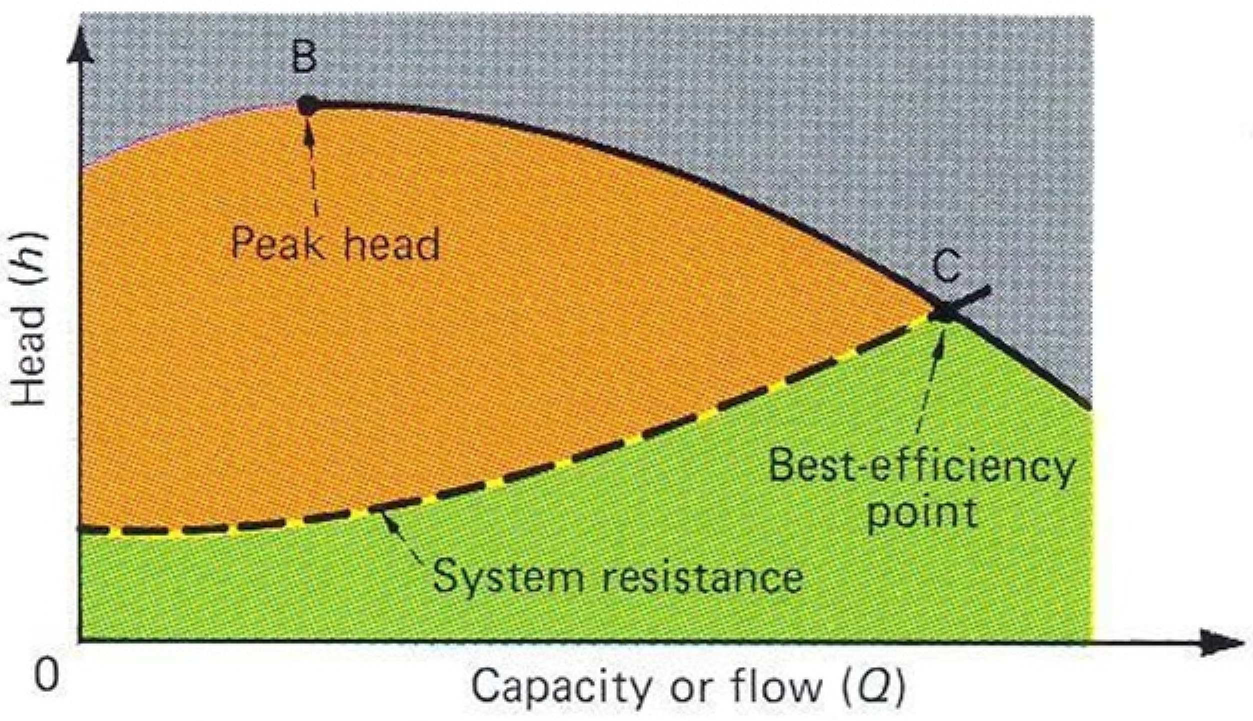
A pump design can be modified to avoid drooping, but there is a penalty for doing so. Reducing the vane discharge angle (to, say, 18 deg) does away with drooping, as shown in Fig. 2, but it also creates higher fluid velocities in the impeller passages and thus reduces head and efficiency. To get the head back up requires a larger impeller.

So the drooping-curve pump has an advantage in either efficiency or capital cost. Considering today's high power costs and interest rates, it makes sense to use the drooping-curve pump. But when is it possible to do so?

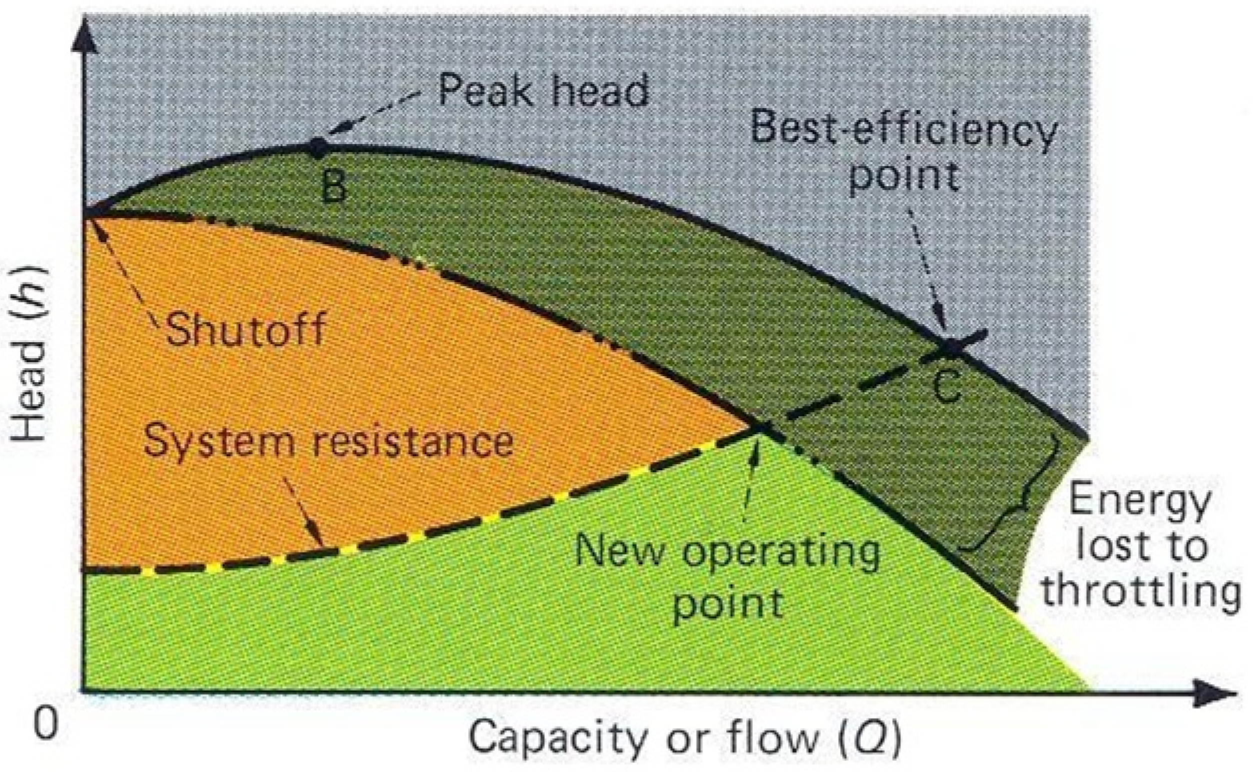
Single and parallel pumps

A pump system should not have surges, i.e., undesirable swings in head, capacity and power. But surging can occur in a pumping system when three conditions are present. It rarely happens in a single-pump system, but is more common in systems having two or more pumps operating in parallel:

The mass of liquid must be free to oscillate. This condition exists when the mass of water (or other liquid) is suspended between two free surfaces, i.e., when the suction is taken from a vessel containing a free surface, and the discharge is to another such vessel. This is the case in a boiler feedpump system: suction from a feedwater heat-



a. A bypass in the discharge line enables pumps to be operated in parallel beyond Point B.



b. Throttling each pump discharge enables parallel operation but increases head loss in system.

Parallel pumping system can be modified so as to prevent surging **Fig. 4**

er, discharge to a header. Also in a condensate system: suction from a condenser, discharge to a deaerating feedwater heater.

Some part of the system must be able to store and give back pressure energy. In a boiler-feedpump system, the steam cushion in the boiler serves this purpose. So does a static water column, or entrained gas in a long piping system, when those are present.

Some part of the system must provide impulses to start the swing. Usually, this means another pump, operating in parallel. The impulse can come from startup, shutdown, or discharge throttling. [However, single-pump systems (e.g., for boiler feedwater) can swing from cavitating to noncavitating operation. This creates a "chugging" noise, and is accompanied by wide variations in flow and head. Of course, this can occur whether a pump has a drooping curve or not, but it is more violent in the case of a drooping-curve pump operated at or near shutoff.]

It is unusual for all three of these conditions to be present, except when pumps are operating in parallel. Let us consider what happens in that case.

Operating pumps in parallel

Fig. 3a shows a typical setup for two centrifugal pumps operating in parallel. Suppose that the pumps are identical, each having a drooping head-vs.-capacity curve; their combined curve (adding their capacities) is shown in Fig. 3b. Here are three problems that can occur:

First, suppose one pump is operating at a head (say, D) greater than the head at shutoff (A). Then the other pump cannot be put on line, as its head at zero capacity will not be enough to open the check valve against backpressure.

Now, suppose both pumps are operating at Point C, and flow demand is reduced by partly closing the throttle valve to Point E. In this case, one pump or both may operate at E, but one or both may also operate at F, where the head is the same but the flow is lower. In this case, the pumps will not be sharing the load equally, and flow and pressure may start fluctuating.

What happens if the throttle valve is now opened, in response to a demand for greater flow? A pump at Point E will increase its flow, but one at Point F will reduce its flow and may cease delivering entirely. This will cause pressure fluctuations, the impulse necessary to start a surging. If surging begins, it will stop only if the pump or pumps at F are shut down.

Surging in such a system can be prevented, though.

One way is to install in the discharge line a bypass that will pass all flow to the left of (i.e., less than) that at Point B, in Fig. 4a. Now, the system will operate only to the right of Point B (i.e., at greater flow and lower head), and so it will not start surging if head increases and flow decreases. The bypass will also protect the pump from overheating at low flowrates, when there might otherwise not be enough liquid to carry heat away.

Another way is to put a throttle valve or orifice on each of the discharge lines, either in place of or in addition to the single valve on the combined discharge. This changes the effective pumping curve to a constantly rising one, as shown in Fig. 4b. However, this will take more power, due to the presssure drop added by the valves or orifices.

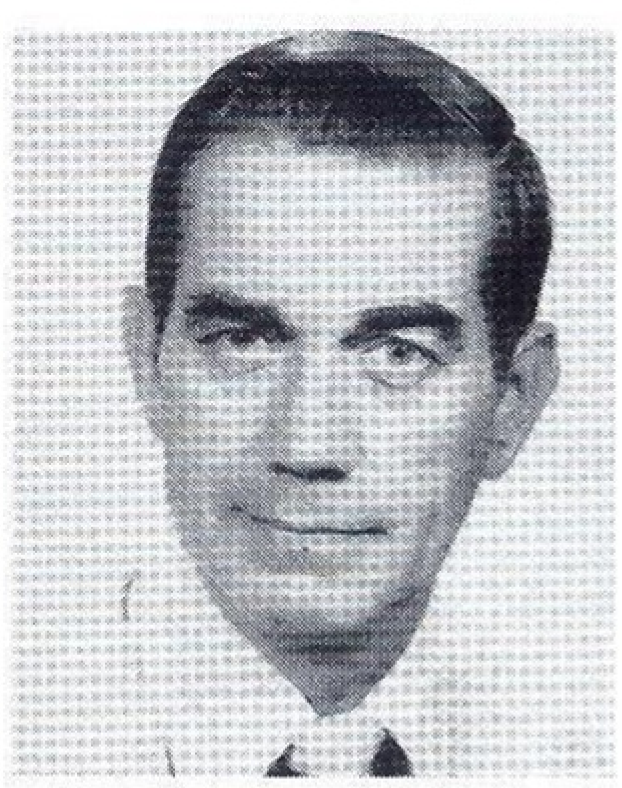
As for operating at low capacity—to the left of the peak head—it is not advisable to operate drooping-curve pumps in parallel in this range.

Conclusions

Summing up, there are some problems associated with using high-head, low-capacity pumps that have drooping head-vs.-capacity curves. However, the situations that cause problems are rare in chemical process applications—pumps are not often operated in parallel, even if they are installed in parallel. And the problems may be prevented in most cases. Thus, since drooping-curve pumps can provide greater efficiency, or save on capital, it is worthwhile to consider whether they can be used in a given situation.

***Mark Lipowicz**, Editor*

The author



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