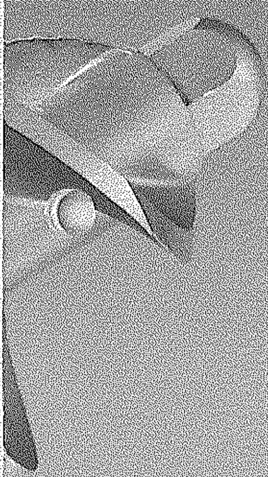
Trouble-free performance with inducer-equipped pumps

By John H. Doolin

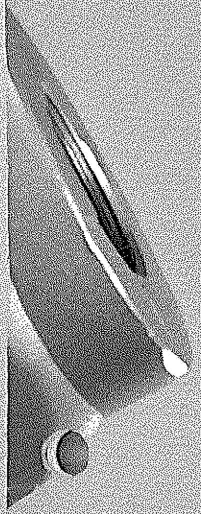


First introduced as part of a standard commercial line of pumps by Worthington in 1970, inducers quickly became popular as an economical way to reduce npsh requirements of a pump. The inducer is essentially a long, axially bladed first-stage impeller, and its primary function is to pressurize the flow enough to let the main impeller perform without appreciable cavitation in the desired capacity range.

How does it do this? By meeting the fluid in an area of lower flow velocity, with a smaller mean vane diameter and then adding energy with lower pressure gradient on the vanes. In other words, the inducer handles incoming fluid more gently than an impeller can.

This has worked very well, so that inducer-equipped pumps have established a reputation for excellent anticavitating performance. It has also raised some questions: Is the inducer applied as a sacrificial part? Existing, as it does, on the leading edge of trouble, can the inducer be expected to fail prematurely and perhaps compromise the good performance of the entire pump?

In this article, a Worthington pump expert shows that these worries are unfounded.



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A well-designed inducer, properly applied and installed, will probably deliver longer trouble-free service life than a conventional impeller. This can be shown by analysis, by laboratory test procedures, and by well over a decade of successful field experience of inducer-equipped pumps in a wide variety of applications.

Flow recirculation in inducers

When considering the service life of inducers, we think primarily about flow recirculation problems which might be brought about by the high-suction specific speeds of most inducers. High-suction specific speed generally means a narrower margin of safety between rated capacity and suction recirculation capacity.

High-suction specific speed normally associated with inducers does not necessarily mean that reliability of performance must suffer. In fact, calculations, tests, and experience all show that potentially damaging flow recirculation occurs at *lower* flow rates in inducers than impellers.

Figure 1 shows the relationship between suction recirculation and suction specific speed for both conventional impellers and inducers. From this chart it can be seen that suction flow recirculation in a standard impeller with S = 11,000 begins at 70 percent of the best efficiency flow. This is comparable to an inducer with S = 15,000.

Confirming recirculation values by test

The calculated relationship was confirmed by Pitot tube measurements of several different designs of inducers. The Pitot tube was inserted close to the inducer pointing in the direction of flow, as shown in Figure 3, so that it measured static pressure only and flow impact had no effect.

When suction recirculation occurs, there is a reverse flow from the inducer which is detected by the Pitot tube. Figure 4 shows a typical measurement as a function of flow. The Pitot tube measurement shows a marked change, signaling the onset of recirculation.

What all this means is simply that high-S-value inducers do *not* suffer from high-flow recirculation the same way impellers do. They do *not* incur the resulting hydraulic pounding and maintenance difficulties.

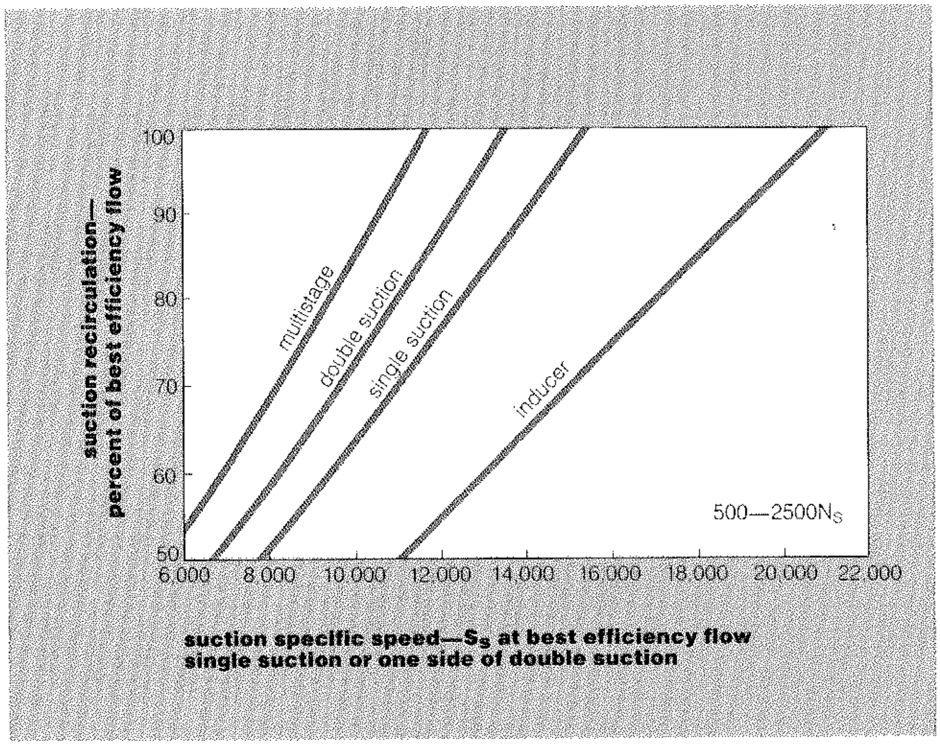
Verifying field performance

Calculations and lab tests indicating the reliable performance of inducers are backed up by extensive industry experience with inducers, particularly in smaller sizes, during the last decade-plus. For example, one manufacturer of very high-speed, gear-driven single-stage pumps has probably shipped many thousands of inducer-equipped pumps in the 2-inch and 3-inch diameter range. There are no reports of undue maintenance requirements attributable to the use of inducers.

In Worthington's experience, thousands of pumps ranging up to 500 hp, equipped with inducers in sizes up to 10-inch diameter, have been operating successfully for years. Worthington's inducer designs are based on data gathered during an extensive worldwide program during the late 1960's, involving Worthington researchers in Harrison and East Orange, New Jersey; Brantford, Ontario; Desio, Italy; and Vienna, Austria. Many inducer design variables were tested. In addition to suction performance, characteristics such as endurance and flow stability were investigated.

There have been a few problems with sizes above 500 horsepower, where the pumps were operated in the suction flow recirculation mode. In this regard, inducers are no different from conventional impellers. Both will suffer if operated extensively with suction flow recirculation. The point is that an inducer can operate down to a lower flow before running into difficulties.

Figure 1



Resistance to cavitation

Inducers are no more susceptible to cavitation or erosion damage than conventional impeller vanes. Both logic and experience indicate the contrary.

Inducer vanes are drawn down below the normal impeller hub diameter, which means that the mean peripheral velocity at which the inducer engages fluid is lower than with a conventional impeller. Relative velocities and energy levels are lower, and the rate at which energy is added—the vane loading—is also lower. Consequently, damage caused by cavitation and erosion is less severe.

In endurance tests of inducers on cold water, there was no significant damage after 300 hours of cavitation. In fact, on one such test at about 50 percent of design flow, the impeller was badly pitted but *not* the inducer.

Design for longevity

The essential simplicity of the inducer configuration belies the care that should be taken in designing it. It is most important to match the inducer to the impeller it will operate with. Both must be designed for the same flow, and the inducer must develop enough head to suppress cavitation in the impeller.

Other factors include the number of vanes, overlap between vanes, amount of sweepback of the leading edge, vane angle, attack angle between vane and fluid, vane profile, hub diameter, and so on. Combinations of these factors add up to a large variety of possible designs. Only extensive research, plus years of successful field experience, can ensure success.

Inducer material is also important. For example, Type 316 stainless steel is much more resistant to cavitation damage than bronze, steel, or cast iron and optimum for many applications. Of course, harder and tougher materials may do even better, but at higher cost because of difficulties in manufacturing.

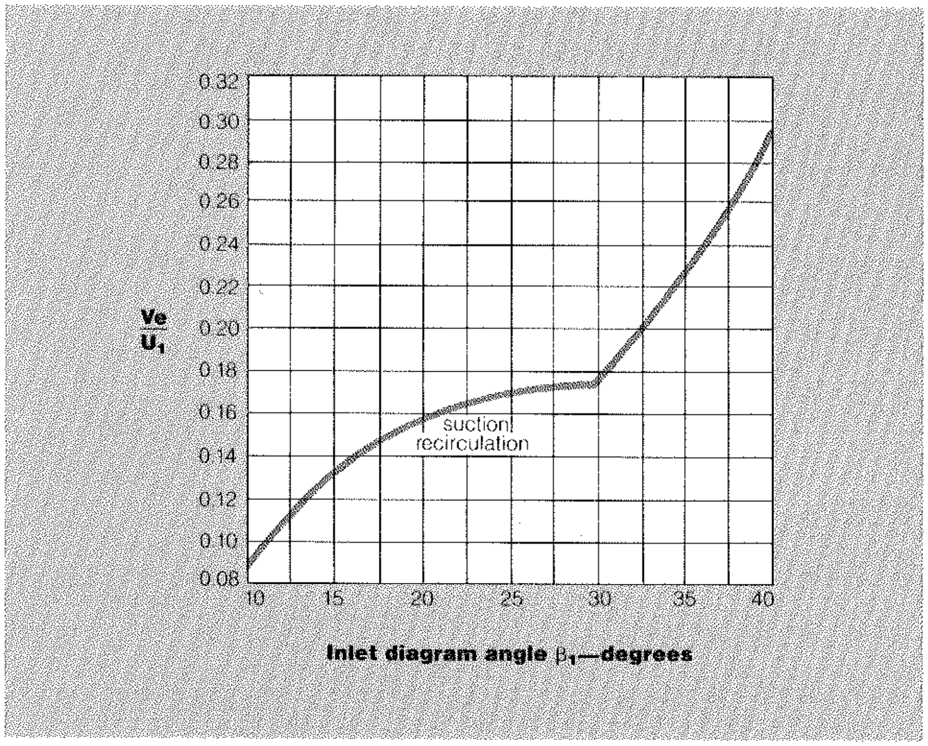


Figure 2

Application factors

In addition to all the manufacturer can do to provide the most reliable impeller/inducer team, the system designer can contribute to satisfactory operation. For example, most inducers work best with straight, uniform velocity of fluid approaching the inducer. With end-suction pumps, this is simple enough to achieve. Five to ten diameters of straight pipe approaching the inducer will generally be enough. Where this can't be provided, there are other ways to straighten the flow. The system designer should consider straightening vanes after the last turn, guide vanes in the elbow, reduction in pipe size after the elbow, or special straightening elbows.

When considering use of inducers above 500 hp, first consider the fluid to be handled. If the fluid is water, it is best to avoid operation in the suction recirculation mode altogether (see Figure 1). If the fluid is a hydrocarbon, however, inducers can safely operate at 60 percent of the recirculation flow.

Figures 1 and 2 and the inlet vector angle relationship β were developed by Warren H. Fraser in his article, "Flow recirculation in centrifugal pumps," originally presented at the 1981 ASME annual meeting and published in Power & Fluids, Vol. 8/No. 2. The inducer recirculation line on Figure 1 was developed by Mr. Fraser for this article.

Figure 3

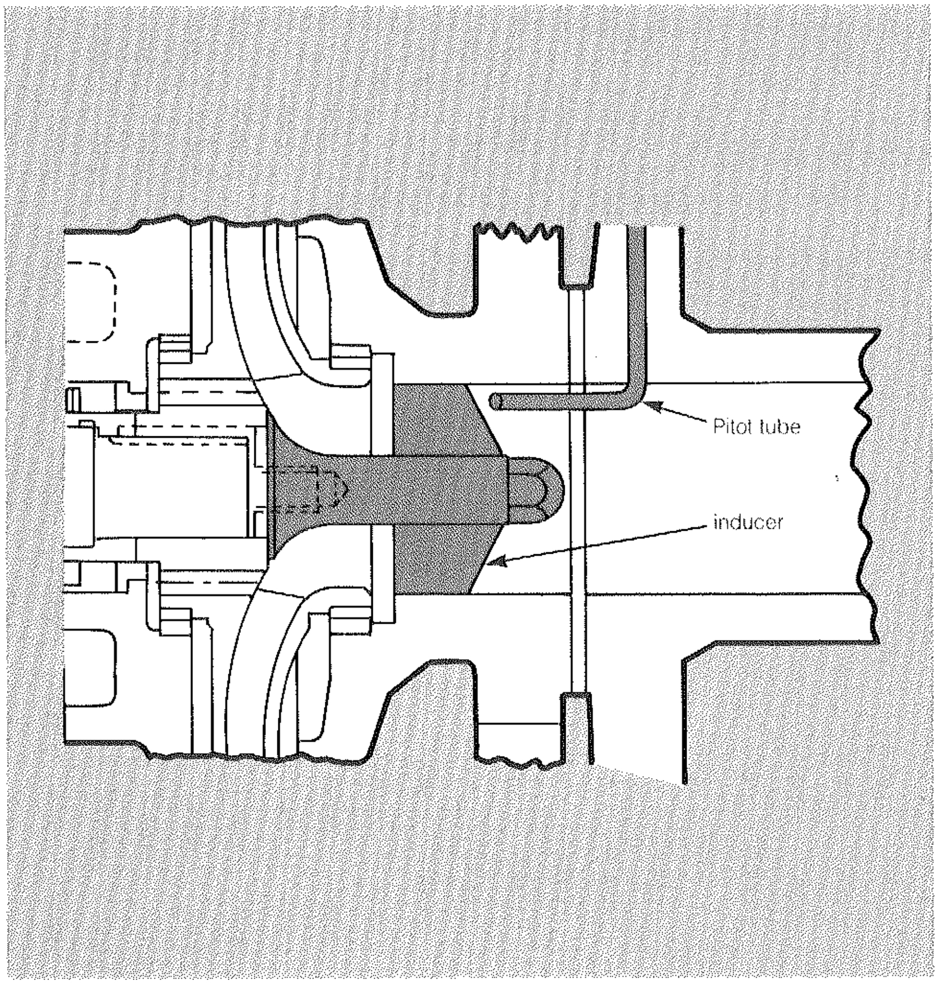
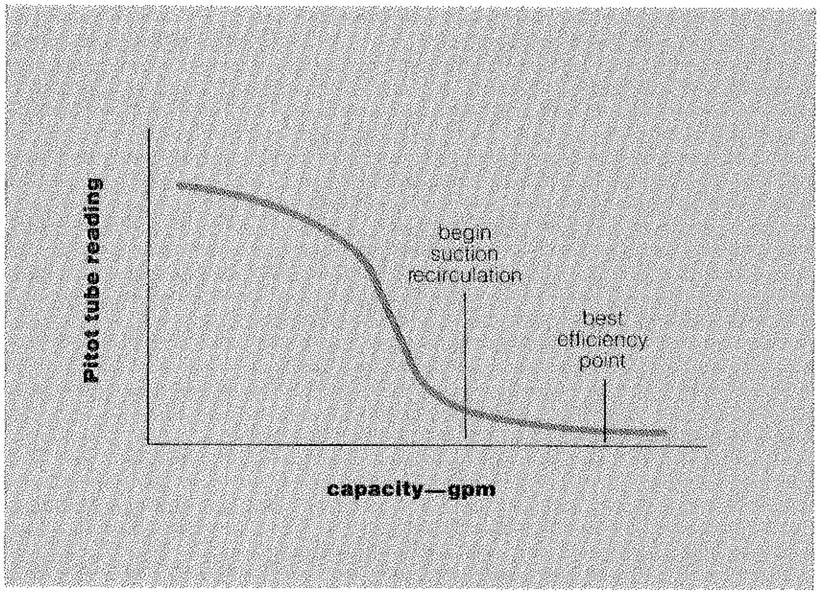


Figure 4



Predicting inducer recirculation values by calculation

The line for inducers in Figure 1 is based on this formula:

$$R_s = \frac{D_1 (D_1^2 - H_1^2)}{93.45} \times \text{rpm} \times \frac{V_e}{U_1} \qquad \text{where:}$$

R_s = flow at onset of recirculation

D_1 = inducer diameter at inches

H_1 = shaft diameter through inducer in inches

$\frac{V_e}{U_1}$ = ratio of eye velocity to peripheral velocity at recirculation (see Figure 2)

For example: A 5.5-inch diameter inducer is designated for 1100 gpm, 3560 rpm and 13.5 ft. npsh. It has a 1.65-inch-diameter shaft and an inlet area $F_1 = 6.9$ inches square. $S = 16{,}700$.

1. The inlet vector angle $= \text{arc sin.} \frac{1.273 \times 6.9}{5.5^2 - 1.65^2} = 18.50°$

2. From Figure 2, $\frac{V_e}{U_1} = .154$

3. From above, $R_s = \frac{5.5 (5.5^2 - 1.65^2) \times 3560}{93.45} \times .154 = 888$ gpm

   or 80% of best efficiency point.

From Figure 1, recirculation occurs at 78% of BEP when S = 16,700.