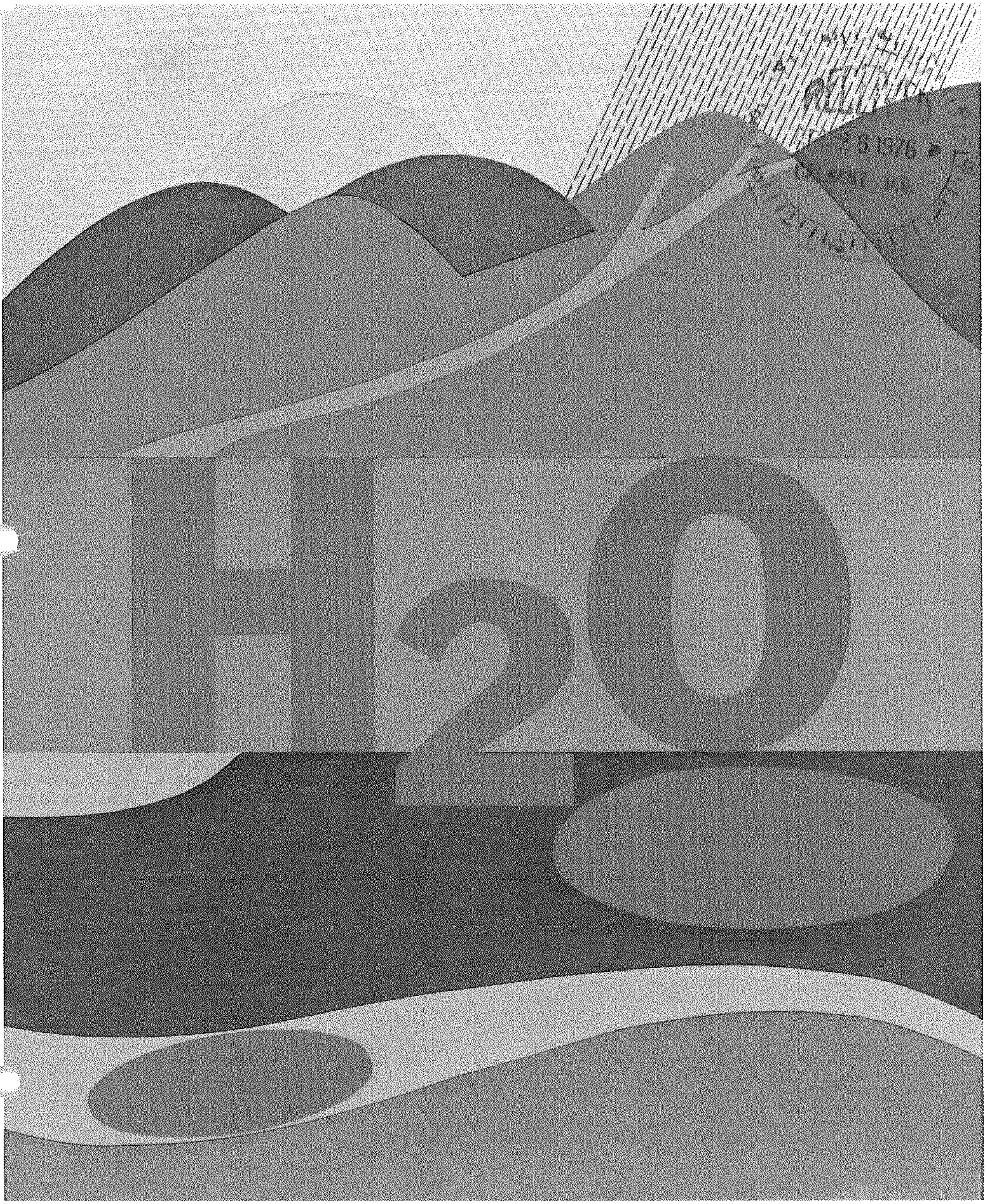
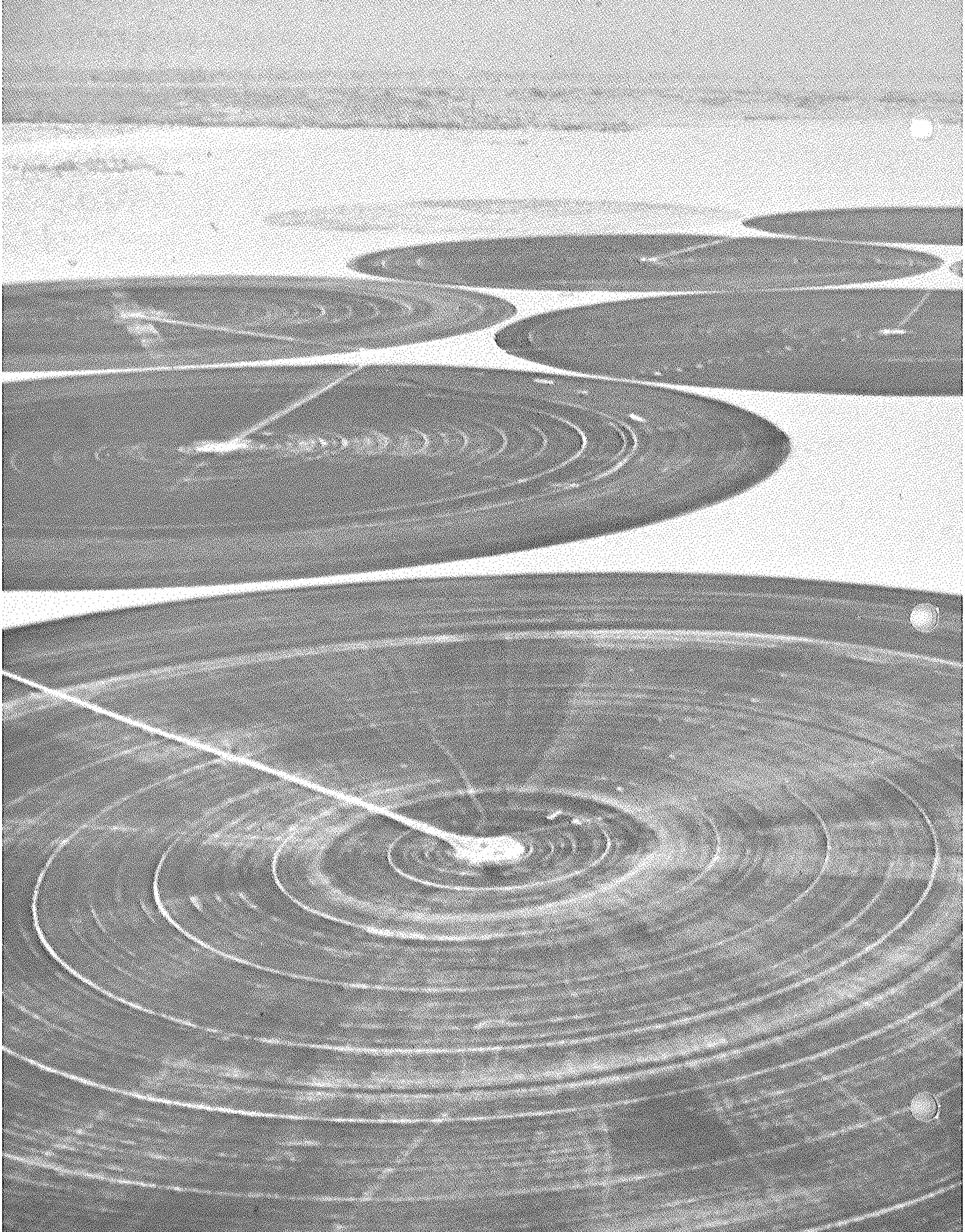
WORTHINGTON PUMP INC. 1976 VOLUME 2 / NUMBER 1

pumpworld





Water means life, its absence death, and nowhere is the line between drawn more clearly than in this aerial view of manmade oases. Each circle of earth is greened by underground water, a rotating sprinkler arm and a pump. One such 250-acre circular farm can produce tons of food—but only after consuming tons of water in the the process.

In most developing countries, where needs are most acute, water *is* available—often in underground reservoirs. Helping to put these hidden resources to work, for drinking and sanitation as well as irrigation, has been part of Worthington's job for more than 130 years.

But in addition to pumps, which Worthington continues to supply in record numbers to arid regions of the world, it's a job for dedicated long-range planners with a healthy respect for this vulnerable, life-giving commodity lest it be contaminated through abuse or misuse. The opinions of one specialist are given in the lead article in this issue of *Pump World*.

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Cover: Major rivers carry water to the oceans at the rate of billions of acre-feet a year, with only a fraction diverted by man for his use. Massive underground reserves remain untapped. In this collage, the artist depicts our water resources as a basic raw material to be mined wisely, as the lead article in this issue suggests.

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pumpworld

1976 VOLUME 2 / NUMBER 1

Water: managing a vital element for the benefit of mankind.

By Letitia E. Obeng

Water seems inexhaustible—to those who have it. Indeed, water *is* abundantly available on our planet. It's the distribution that is far from equable. And so, water resources must be redirected on a massive scale to support modern life.

Many areas of the world have impressive inventories of surface water hardly tapped as yet. Even the most drought-stricken areas of the world have ample supplies hidden beneath the surface. And that is good, because studies indicate that irrigated areas of the world must be increased by half again to meet food needs of the year 2000.

The year 2000, at hand to the long-range planner, seems lifetimes away to people of developing nations. For them, the need for water is *now*. Yet total commitment to water management is not without potential pitfalls.

Getting water to where it's needed is a colossal job. Lifting devices are essential, and this means pumps. Care is needed, too, because water is not only subject to deterioration in quality, but prone to harbor the carriers of disease. This article assesses some possibilities—and problems—of the complex subject of large-scale water management in developing nations.

Ms. Obeng is founder and director of the Institute of Aquatic Biology of the Council for Scientific and Industrial Research of Ghana.

Dependence on water is not a peculiarity of developing countries: Water is indispensible at all levels of development. It is, for example, essential in the manufacturing processes that meet the basic needs of industrialized countries. It takes over 40 quarts of water, from start to finish, to produce just one can of vegetables. And even oil, the golden blood of industry, depends so much on water (more than 10 quarts are needed to refine one quart of petroleum) that it is not surprising to find oil-rich but water-poor Saudi Arabia considering the investment of billions to produce fresh water from the sea.

From the beginning, water has influenced the actions of man. Along the Indus, the Nile, the Tigris and Euphrates—along the Danube, the Volga, the Po—the Mississippi and the Amazon—wherever the waters bubbled out to support a tiny oasis of green pasture in the desert—civilization has always followed the supply of water. Fierce tribal wars have been waged over water rights, and heated arguments rage even now over the control of international water systems.

Ample water unevenly distributed.

Precipitation varies tremendously among the developing regions. The Congo Basin has an average annual rainfall of 60 to 70 inches—some years as much as 200 inches! On the same continent, the Sahara undergoes long, fierce years of total drought.

In some regions of the developing world, surface water is abundant. The Amazon, world's longest river, drains over 2.5 million square miles. The Congo drains nearly 1.5 million, the Nile 1.1 million, and the Niger and Zambesi a million square miles between them. With the Mekong in Southeast Asia and the Indus in Pakistan, these rivers form an impressive inventory of water resources in developing countries. And there are many thousands of smaller rivers, streams, and ponds which contribute to the watering of the land. Developing Africa alone includes some 375,000 square miles of lakes.

The developing world seems well supplied with subterranean water, too. Aquafers beneath the Sahara and Arabian deserts began with old waters, built up 15 or 20 thousand years ago when rainfall in these areas was much heavier, are recharged by present-day rain or by infiltration from neighboring rivers.

Development is essential.

In agriculture, water holds the key to increased production through irrigation. As early as 5000 BC, Nile water was used for irrigation, while in Persia, North Africa, Spain and Greece, *foggaras* (underground conduits to tap the groundwater and lead it to the surface) are probably at least 2000 years old. There is ample evidence from China, Peru and Mexico as well to confirm the antiquity of irrigation practices and the storage of irrigation water.

Modern technology encourages the construction of sophisticated multi-purpose river-basin projects, and these in turn contribute to extensive, year-round irrigation. But on the whole, irrigation is not practiced in the developing world as much as land and water resources could permit.

It has been estimated that of the world's 8 billion acres of *potentially* arable land, nearly 5 billion are located in the developing regions of Africa, Asia and South America. Although water now available could irrigate at least 3 billion of those acres, the total cropped area today is less than half of that.

Accessibility is the key.

The key point is accessibility of water resources. Surface water is often far from where it is most needed. Pipelines and canals must be built, requiring investment in imported equipment or development of local materials for the purpose. Similarly, underground water must be made available where it can be utilized. The method of development is usually drilling and pumping, raising the usual capital problems, and sometimes such side issues as maintenance: hot underground water, found under many of the world's deserts, corrodes metals and equipment at a surprising rate!

Threats to satisfactory irrigation.

Once the problems of providing the water have been overcome, the very fact of irrigation can produce problems of its own. Salinization, for example, is a constant threat. In the arid lands, evaporation tends to concentrate and finally precipitate the water's natural content of salts. Some of these salts are injurious to man, others are injurious to vegetation, and they must be taken into account when dealing with the water situation in arid lands.

"Waterlogging," too, can be a problem. In the Sudan and Egypt, along the Nile, and in India and Pakistan within the Indus valley, large areas of land have been lost because of soil salinization and waterlogging. The Punjab region, after decades of water dumping, is now faced with the need for drainage projects to reclaim 8 million waterlogged acres!

Waterborne health problems.

But perhaps the most serious problem associated with water management is in the field of health. It is a complex situation of water use and management, involving people, their habitation, sanitation and contact with water.

Malaria, schistosomiasis and many other diseases have waterborne phases, with manmade waterways the perfect breeding ground. Almost invariably, the incidence of these diseases rises as farm workers come into contact with disease—transmitting agents on water supply projects. In areas where irrigation is practiced year-round, the diseases are endemic, greatly impairing the general health and reducing life expectancy.

A comprehensive program.

Malaria is transmitted by mosquito, schistosomiasis by snails. Ideally, control of these diseases should be approached comprehensively, taking into account safe water supply and good sanitation, as well as social and cultural practices affecting land and water use, and health and environmental education within affected communities. Since the supply of adequate drinking water and irrigation seem indispensible to improved standards of living, integrated programs for control of health problems will require even more attention.

Hydroelectric projects: opportunities and problems.

Countries poor in oil or coal but rich in water resources look to hydroelectric power for energy. In recent decades, a number of large dams have been built in connection with hydro projects in developing countries. In Africa, the Kariba Dam turned the Zambesi into an enormous lake. The Volta Dam in Ghana, Nigeria's Lake Kainji, and Lake Nasser, formed by the Aswan High Dam and supplying water for Egypt and the Sudan, may well be forerunners of a whole chain of mammoth, manmade lakes stretching the length of Africa.

Such water-resource projects are obviously of high value in the emergence of nations, but their complex environmental impact may have adverse effects. Most obvious, their construction poses problems in natural and human ecology, as whole regions are disrupted by the inundation of a river basin.

The physical accumulation of water produces stresses in the land itself. It may affect the underground water tables and even increase seismic activity. Within the lakes, there is usually a gradual accumulation of sediment and silt, which may be heavy enough to reduce the useful life of the reservoir. For example, before the construction of the Aswan High Dam, the Nile carried some 125 million tons of silt and clay in its annual flow. This sediment now dumps with equal regularity into Lake Nasser.

Increased biological production can also be a problem, as algae and aquatic weeds deter the efficient use of dam and river water. Along sections of the Nile and many other rivers, water hyacinth has become a major nuisance, interfering physically with access to water sources, increasing evaporation through their leaves, and supplying breeding grounds for disease-transmission.

Biological bonuses?

Of course, there are many advantages on the credit side. While dams primarily store water for the production of electricity, they may serve other purposes as well: flood, sediment and salinity control; public water supply; fisheries and agriculture; transportation; wildlife conservation—even, eventually, recreation. In particular, dams greatly enhance fish production—an important supply of protein.

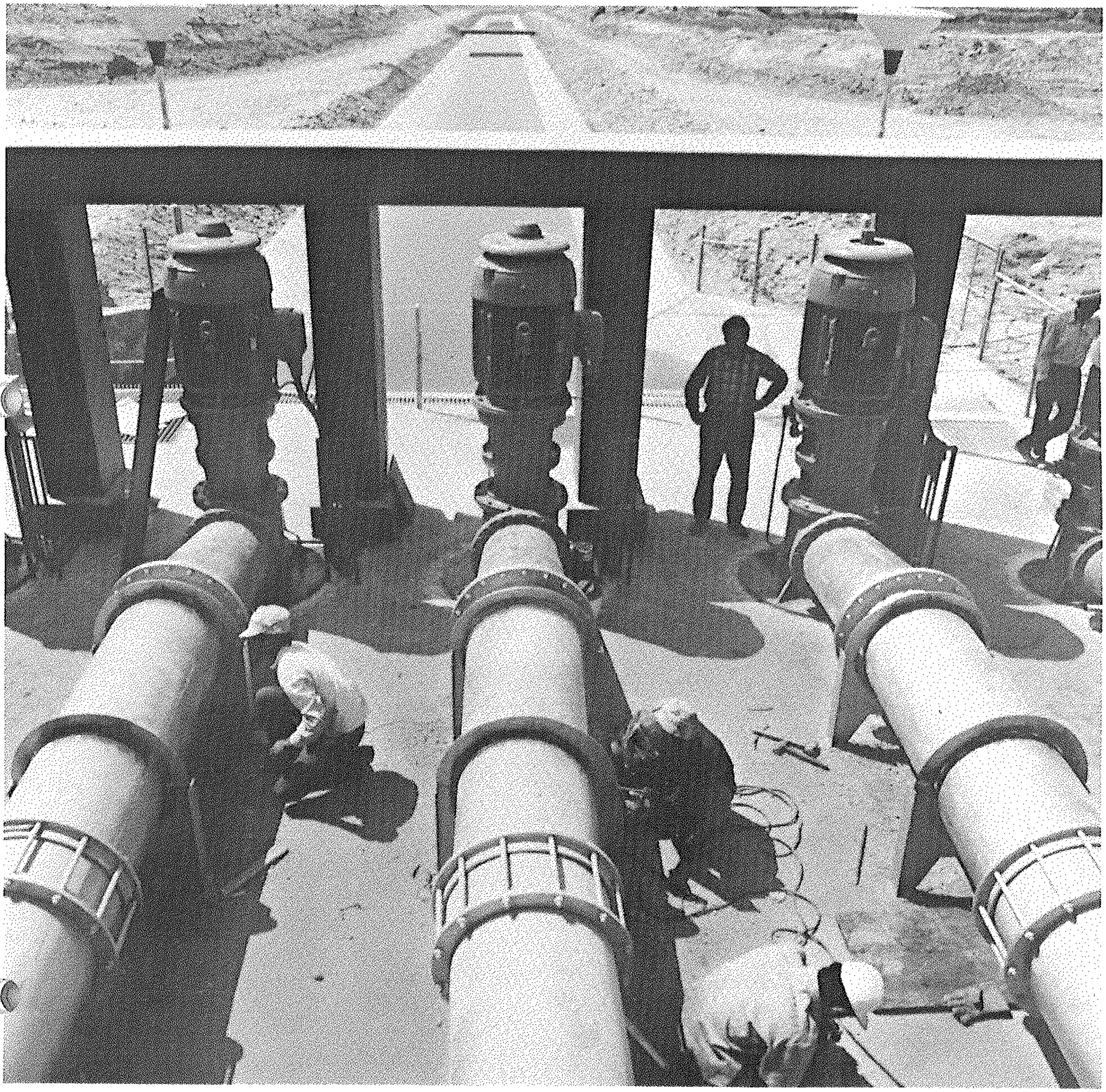
The careful consideration of precautionary measures at the planning stage will go a long way toward increasing the usefulness of water development projects.

Developing a healthy respect.

There is no doubt that water resources are vital to the development process in the emerging nations. But they are terribly vulnerable to contamination from human and domestic wastes, agricultural chemicals and various industrial discharges. They are subject to deterioration in quality as their basins and sheds are violated, protective forests and vegetation destroyed, and erosion and sedimentation induced and increased.

Conserving the quality and quantity of water, practicing multiple uses, managing resources to avoid or minimize adverse impacts—these are some needed precautions to help ensure its continued availability.

For this, a healthy respect for water must be developed—on a global basis—and soon!



A modern pumping station in Iran, part of a multi-purpose development project designed to bring water, electric power and flood control to a populated river basin area.

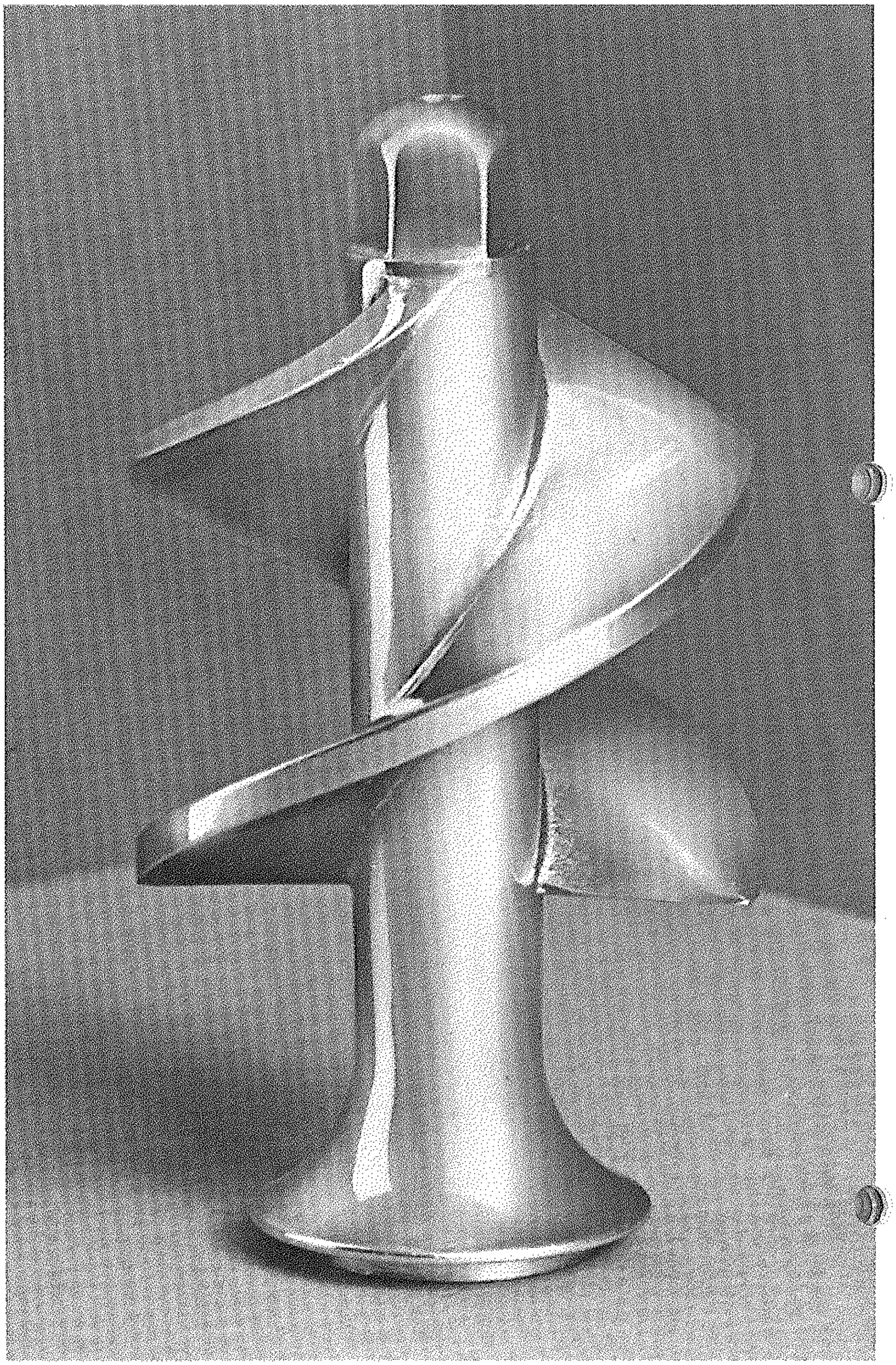
Inducers: optimizing pump performance in industrial applications.

By A. Janigro and F. Ferrini

How does a pump achieve its desired performance? There are many, many factors for the designer to integrate. And as conditions of service become more demanding, the complexities increase.

Although not a new concept (the first patent covering inducers was issued to O. H. Dorer of Worthington in 1926), inducer pumps are now being widely employed in a variety of general and process services. First introduced as part of a standard commercial line of pumps by Worthington in 1970, inducers have established their reputation in terms of excellent anticavitating performance accompanied by optimum reliability and endurance. This article is excerpted from a technical treatise presented by two pump design experts from Worthington S.p.A. (Italy) before the Von Karman Institute for Fluid Dynamics in Belgium. It reflects only a small part of the extensive research conducted by Worthington in the U.S., Canada, Germany and Italy in response to the increasing demand for low npsh pumps, particularly in the petrochemical field.

Pump specifiers are often confronted with the problem of achieving required performance in the face of many conflicting hydrodynamic and system requirements. Today, cavitation



Messrs. Janigro and Ferrini are managers of Research & Development and Manufacturing, respectively, for Worthington S.p.A. (Italy).

represents one of the most stringent limitations on pump design and application.

Why is cavitation such a problem? The basic reason is rotative speed. If the size and weight of the pump were immaterial, a suitable combination of speed and dimensions could be found to eliminate virtually any problem of cavitation. Obviously, we rarely have such freedom!

Nevertheless, an increasingly large number of industrial applications call for pumps with lower npsh (net positive suction head) required. In order to be economical, this improvement in npsh should be achieved with minimum additional complexity.

Lower npsh may be obtained in several ways: by applying double-suction pumps; by using jet pumps which recirculate part of the high-pressure discharge fluid back to the inlet to add momentum to the incoming flow; by adding low-speed booster stages; or by adding an inducer.

Of these methods, the inducer appears the most promising because of its simplicity and small additional weight, and it is now being used for a variety of industrial applications.

The measure of susceptibility: cavitation parameter K.

The measure of susceptibility of an impeller to the effects of cavitation is given by the cavitation parameter K, based on the inlet relative velocity dynamic head, the upstream static pressure and the vapor pressure of the fluid:

$$\text{npsh} = \frac{V_z^2}{2G} + K\frac{W^2}{2G}$$

where Vz = fluid velocity at impeller inlet eye in feet per second; W = relative velocity of fluid to the impeller blades at the point of fluid entrance in feet per second; K = cavitation parameter, dimensionless.

For any particular pump specific speed (N_S), K depends on various impeller parameters such as vane loading, number of vanes, inlet vane angles and leading edge profile, degree of prerotation and surface finish. Conventional pump impellers in the N_S range from 750 to 4000 have K values varying between 0.15 and 0.30. A well-designed centrifugal impeller may be expected to operate with cavitation numbers $K \approx 0.3$ without any appreciable deterioration in performance.

In one extreme case — rocket pump technology — missile propellant pumps are called upon to operate satisfactorily with values of $K \cong 0.03$, although with some loss of efficiency and with cavitation damage. In general, this operation can be tolerated in a propellant pump, owning to its short service life and to the overriding, stringent requirement to reduce pump size and weight.

An industrial centrifugal pump may be required to operate without appreciable signs of cavitation in the impeller at values of K as low as 0.05. Generally, an overall head drop-off of 3 percent from non-cavitating conditions is considered the maximum which can be tolerated in industrial applications. Beyond this limit, cavitation damage would significantly reduce the service life of the impeller. Since cavitation-free flow cannot be obtained at cavitation numbers less than $\cong 0.1$, the inlet portion of high suction specific speed pumps must be designed to perform satisfactorily *with* considerable cavitation — and it is readily apparent that its configuration will be quite different from a conventional machine. It must be long enough to ensure the desired operating range, and the blades must be predominantly axial to avoid high local velocities. For convenience, this inlet is often made separately and later joined to the main impeller. Following supercharger terminology, the separate piece is called an *inducer*, and its primary function is to pressurize the flow enough to let the main impeller perform without appreciable cavitation in the desired capacity range. Helical inducers have K values on the order of 0.04 — 0.03, and may reach 0.015.

How the inducer works.

As a result of the inducer's shape, sufficient momentum is more or less gradually added to the fluid. Vapor bubbles begin to be generated in the region of the vane leading edge. As bubbles enter more advanced sections of the blading, they undergo a gradual recompression until they collapse. Under normal operating conditions, with K above the minimum, this process takes place in the inducer vane passages. The main impeller downstream can operate without cavitation.

Total head generated by the inducer usually needs to be only about 10 percent of the head rise of the system. The power consumption of the inducer is therefore not an overriding consideration, and some cavitation can be tolerated within the inducer blades without greatly affecting over-all efficiency.

Optimizing performance.

The first consideration in the design of the inducer is the assessment of the value of npsh which can be achieved for incipient cavitation or, according to a generalized practice, assessment of the suction specific speed level which can be considered as a target for design capacity:

$$\text{suction specific speed (S)} = \frac{N\sqrt{Q}}{\text{npsh}^{3/4}}$$

where N = rotational speed in rpm;
Q = capacity in gpm; and npsh = net positive suction head in feet.

Figure 1 shows test results obtained with a number of inducer pumps for industrial application, compared with the suction performance of similar pumps without inducer.

Matching inducer and impeller.

The impeller must be designed to match the main impeller, both geometrically and hydraulically. The higher the suction specific speed and therefore the lower the cavitation parameter, the greater the inlet diameter of the impeller. Hence a

Figure 1 – Comparison of suction performance of process pumps with and without inducer. Test results at 3 percent head drop.

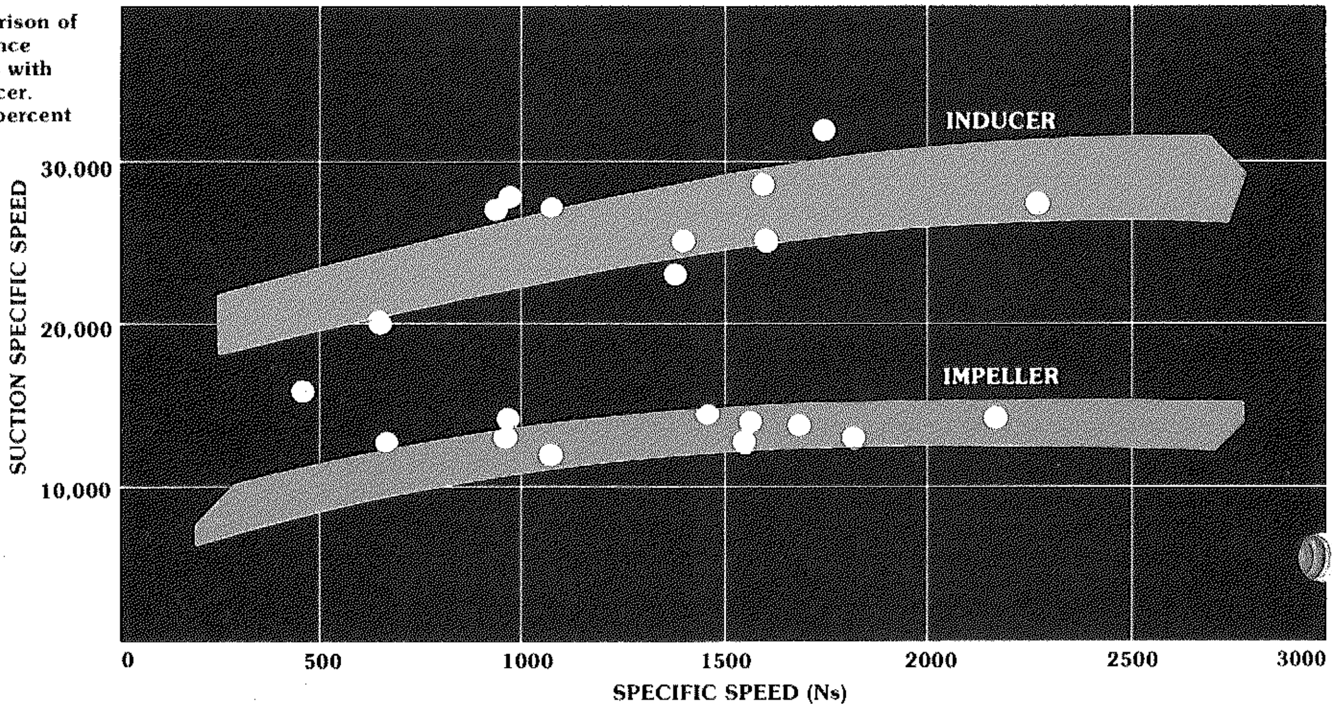
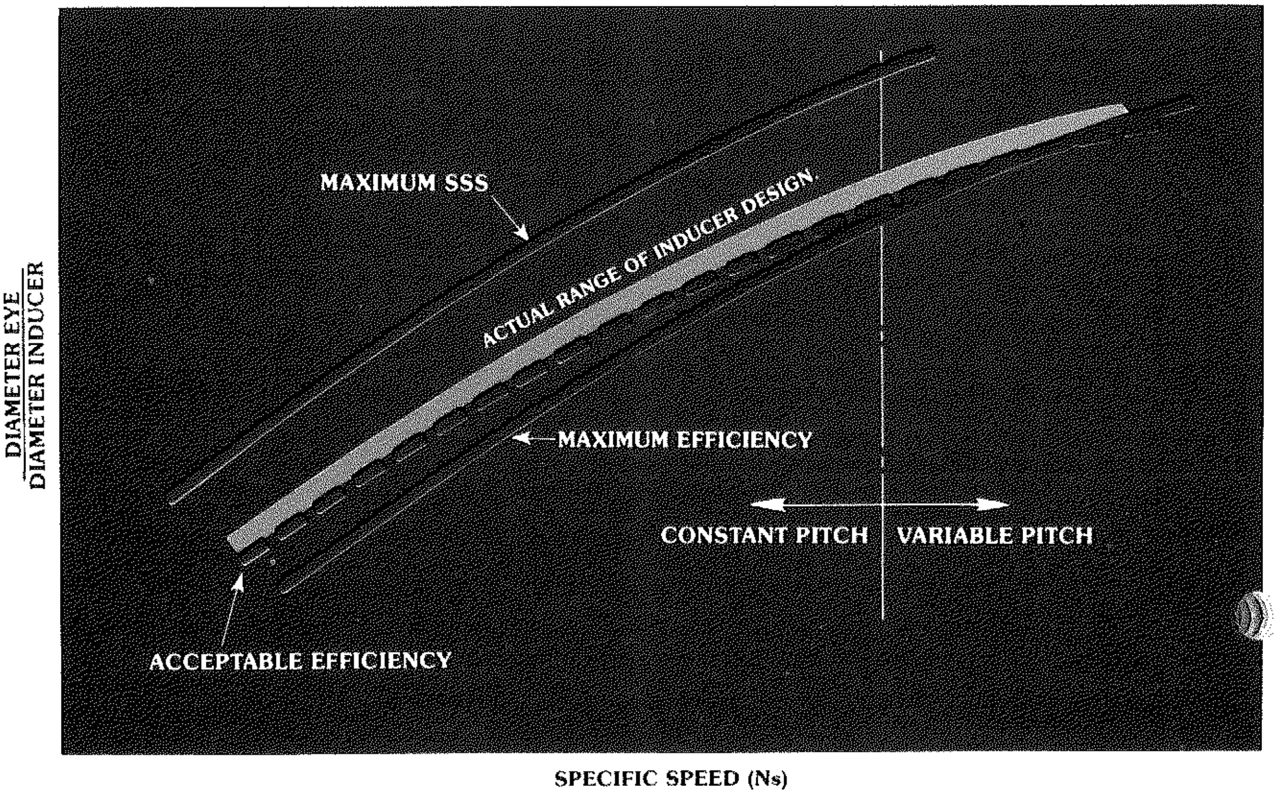


Figure 2 – Qualitative solutions for impeller eye and outer inducer diameters.



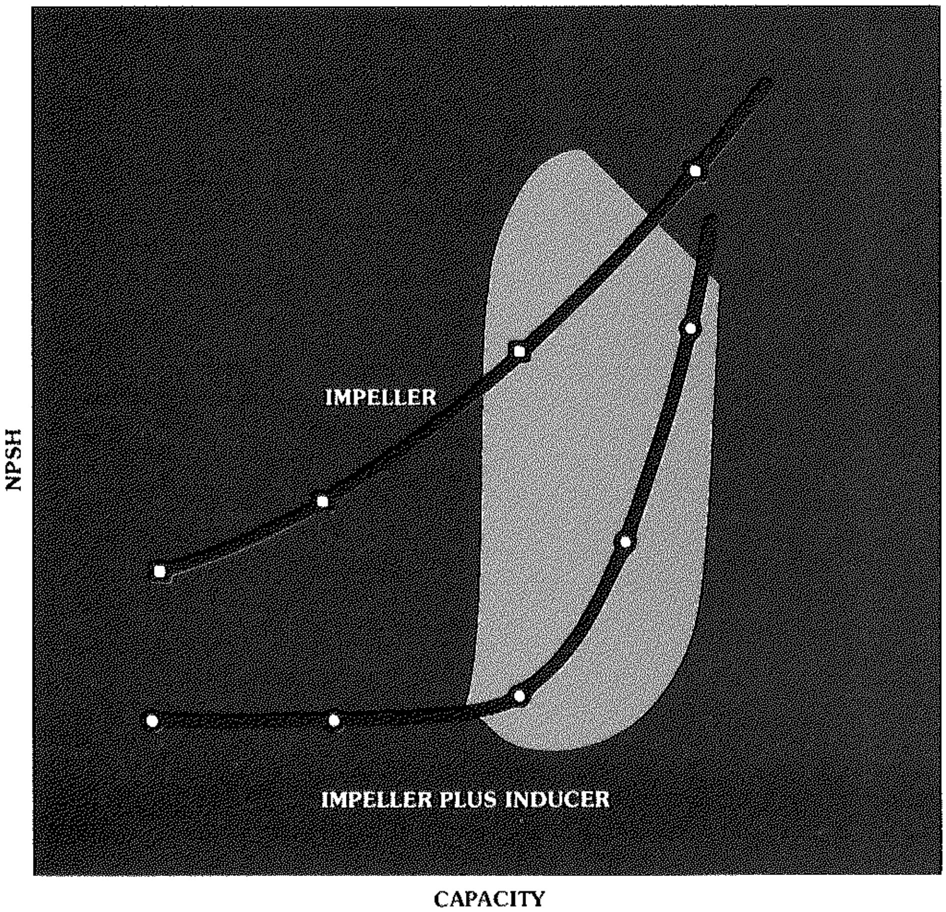


Figure 3—Influence of prerotation on cavitation performance of inducer-impeller system.

pump designed to cavitate will have a bigger inlet diameter than a noncavitating one. Similarly, an inducer will tend to have a bigger diameter than a conventional pump. As a result, matching inducer with impeller can be a complex process.

Geometric matching mainly consists of selecting the inducer OD in accordance with the impeller eye diameter. The kind of compromise which is normally required between impeller eye geometry (for optimum efficiency) and inducer OD (for optimum suction performance) is qualitatively shown in Figure 2. Solid lines represent the impeller eye-to-OD ratios resulting from maximum suction specific speed or maximum efficiency criteria. The dotted line indicates a convenient modification of the impeller design philosophy to achieve a good match between impeller and inducer. Hydraulically, the inducer must be designed to achieve desired npsh while generating the head required to suppress cavitation in the impeller. Having determined the outer diameter of the inducer on the basis of purely geometrical considerations, the profiles of the vanes and the vane angles are practically the only parameters which remain to be selected.

For good suction performance, vanes are normally very long, and set at low angles. As a consequence, the flow picture through the vane passages is strongly affected by secondary flows even near design capacity, resulting in relatively high losses. It is therefore desirable to design the inducer for the minimum head compatible with the suction requirements of the impeller, in order to minimize the penalty on the overall efficiency of the pump.

It's also important that the range of operation of the inducer agree with that of the main impeller. From experiments, we know the npsh curve of an inducer/impeller system becomes quite steep at high capacities, as shown in Figure 3.

What are the reasons for the abrupt increase of npsh required by an inducer pump at high capacities? Within the operating range of the pump, the inducer controls the suction performance of the inducer/impeller system. Impeller suction requirements are met by the inducer head-rise:

$$(NPSH_{imp})_{pre} < NPSH_{ind} + \Delta H_{ind}$$

where $(NPSH_{imp})_{pre}$ is npsh required by the impeller in the presence of prerotation generated by the inducer and H_{ind} is head developed by the inducer. At a certain critical capacity, control of the system is transferred from the inducer to the impeller, and system npsh shifts toward the characteristic curve of the impeller alone.

From the design point of view, the critical capacity at which system npsh starts to rise steeply must be controlled and displaced outside the nominal capacity of the pump. Qualitatively, the procedure is indicated in Figure 4.

Once the inducer outer diameter has been fixed in first approximation, the designer determines a family of npsh and head-rise curves. He selects the inducer vane angle on the basis of head generated. A check is then made on npsh required by the inducer, to be sure the desired target has been achieved. The procedure is repeated to find a suitable combination of OD and vane angles which fulfills both the npsh required by the impeller and system npsh for the given design capacity.

Controlling unstable cavitation.
One of the most serious problems to be considered in the design of inducers for industrial applications is the region of unstable cavitation. This phenomenon occurs at reduced capacities and low npsh, and appears as flow oscillations accompanied by low frequency and high amplitude vibrations.

The onset of instability and the extension of the unstable cavitation region is essentially controlled by design of the inducer vanes. The extension of the region can be effectively reduced, and also displaced toward lower npsh values —in some cases beyond the zone corresponding to the 3 percent head drop, a major step toward ensuring stable operation of the inducer at low flow rates. This solution slightly reduces the maximum achievable suction specific speed, but the improved range of stable operation of the pump at off-design flow rates is usually well worth this sacrifice.

Result: a good, troublefree pump.
A performance curve for a typical inducer pump for industrial applications is shown in Figure 5. This shows the modes of cavitation of an inducer designed to reduce the instability region to a minimum and displace it toward low flow rates: beyond the useful range of operation of the pump. A safety margin is normally allowed, to avoid pitting the inducer vanes at high flow rates, and unstable pump operation at low flow rates.

If the pump is not called on to operate at npsh values below those specified by the curve, it can be expected to be quite satisfactory for a long period of time. Coupled with the use of suitable erosion-resistant materials, these designs have permitted excellent, troublefree operation of inducer process pumps in the field for the last 4 to 5 years.

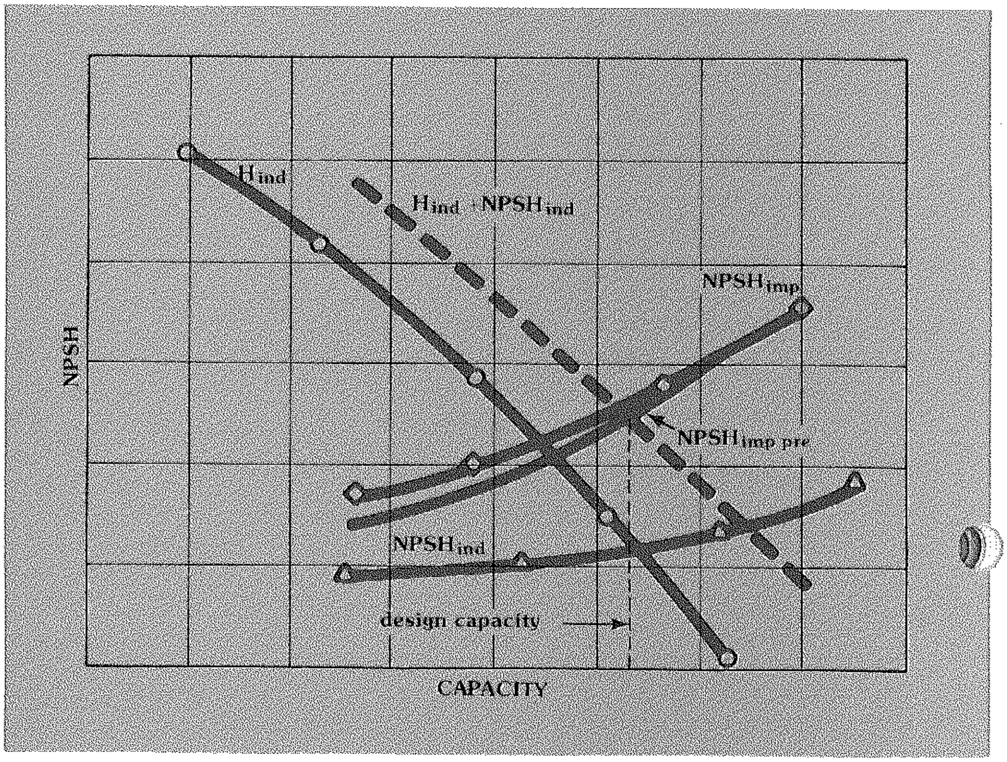


Figure 4 — Typical npsh curves for a pump with impeller only and with inducer.

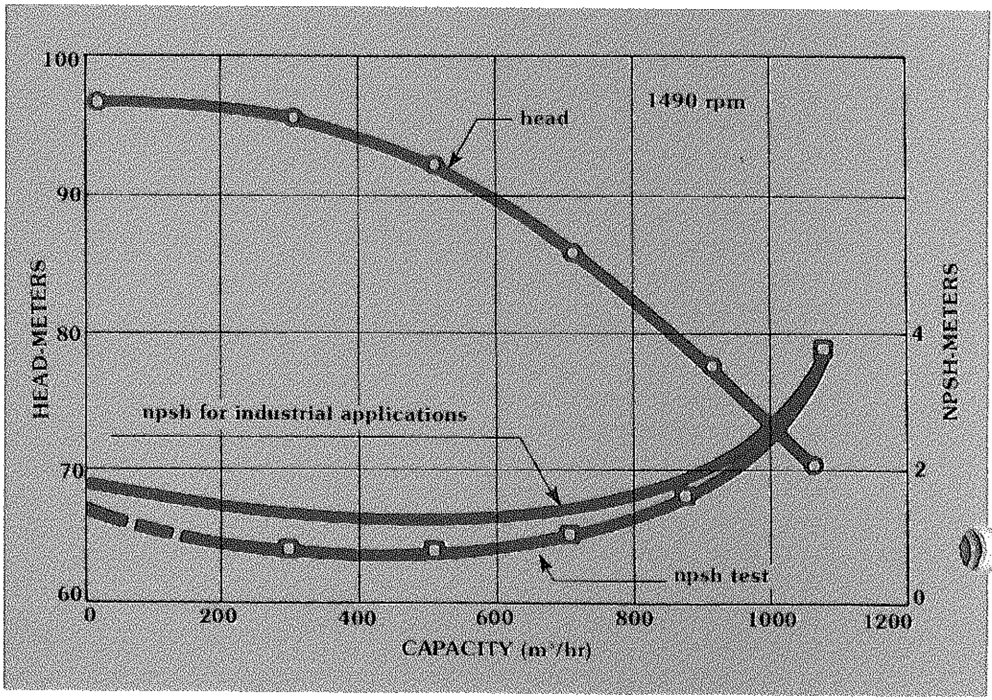


Figure 5 — Suction performance of an inducer pump.

Coping with pump progress: the sources and solutions of centrifugal pump pulsations, surges and vibrations.

By Austin R. Bush, Warren H. Fraser and Igor J. Karassik

rt II: Treating internal recirculation.

In the last issue we examined the paradox that the very fact of technological progress may well magnify problems that were of previously minor importance. We looked in some detail at the problem of pressure pulsations caused by vane passing frequencies in high-speed, high-head-per-stage boiler feed pumps, and analyzed various remedies. Part II covers two other phenomena, both associated with internal recirculation, which can also lead to very serious pressure pulsations centrifugal pumps and their systems.

At certain flows above or below that of best efficiency, centrifugal pumps are subject to internal recirculation in the suction and discharge areas of the impeller. The result is a great increase in pressure pulsations (Figure 1).

Internal recirculation is a fairly mysterious phenomenon. Only recently have pump designers become aware of it and analyzed its effects. Only more recently have they learned to predict and control the actual flows at which recirculation occurs. Better understanding among pump users is important, so they may appreciate the dilemma in which the pump designer sometimes finds himself, and avoid specifying operating conditions which inevitably lead to poor operation, premature wear and deterioration.

Internal suction recirculation, a predictable phenomenon.

Constant demand for pumps with lower and lower npsh values forces manufacturers to design impellers with larger eye diameters and lower velocities than conservative practice would dictate.

These lower velocities may have little effect on pump performance at or near its best efficiency capacity. When the pumps run at part capacity, however, this design can lead to noisy operation, hydraulic surges and premature wear: symptoms caused by internal recirculation at impeller suction.

At lower capacities, the flow at the outer eye diameter has a tendency to

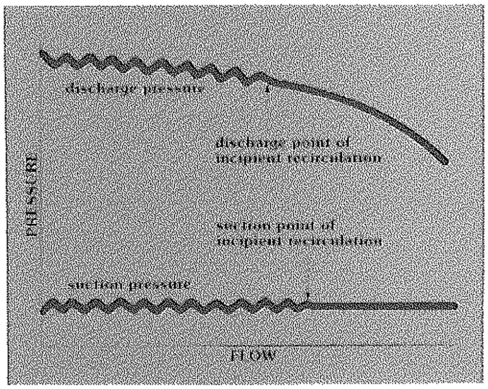


Figure 1 – Characteristics of internal recirculation.

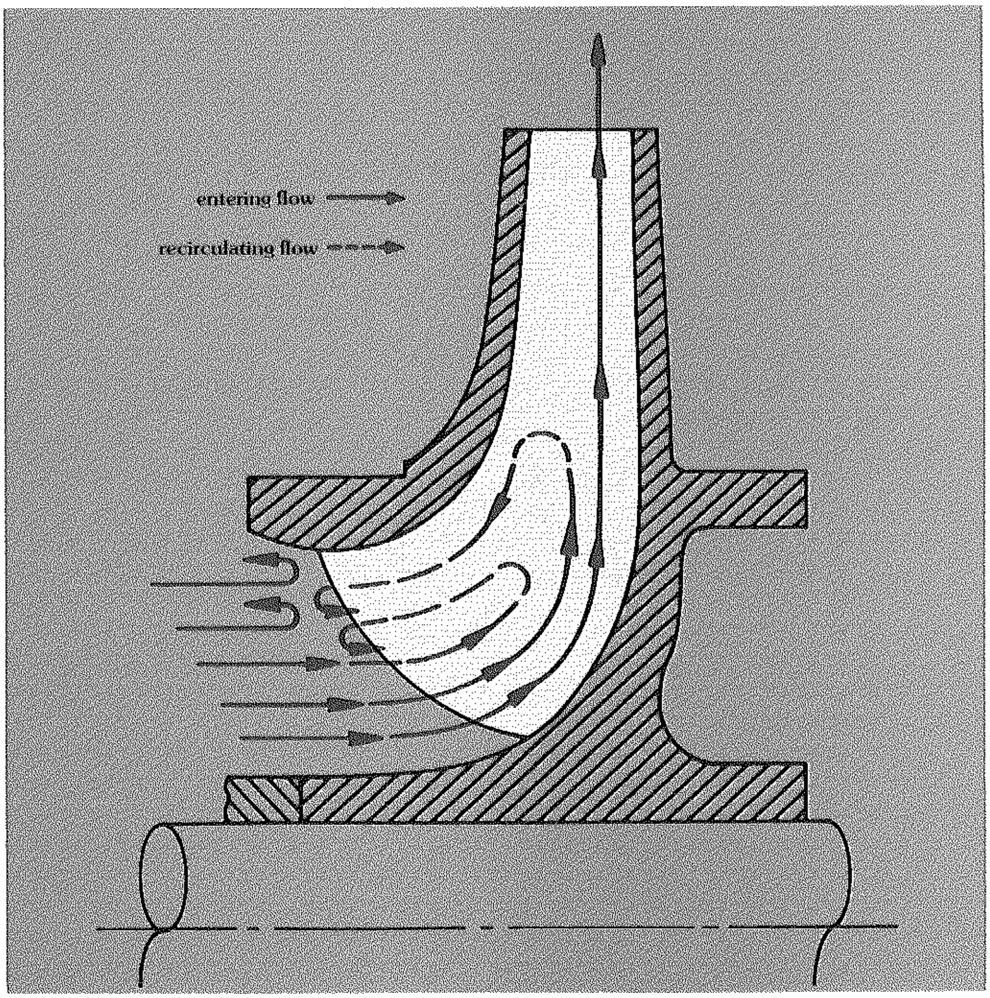


Figure 2 – Section through a single suction impeller indicating schematically the recirculation of liquid at the inlet during operation at low capacities.

essrs. Bush and Fraser are Chief Engineer-Multistage Pumps and Chief Design Engineer, respectively, for Worthington Pump Corporation (U.S.A.)'s Engineered Pump Division. Mr. Karassik is Director of Pump Technology for Worthington Pump Inc.

reverse itself. Part of the liquid flows out the outer portion of the eye at a high rotational velocity. It then "folds back" into the main flow in the form of a vortex, shown schematically in Figure 2. The turbulent mixing of flow entering and leaving the impeller in this vortex action gives rise to surges and pulsations, and to rapid deterioration by cavitation of impeller metal in the entrance area. Figures 3 and 4 show an impeller damaged by cavitation caused by suction recirculation. The damage has taken place at the back of the inlet vanes and can only be seen with the help of a mirror. The small pits appearing on the visible side are actually breakthrough points of cavitation damage started in back.

Incidentally, it's quite simple to find the cause when impeller metal is eroded. If the pump has suffered from classical cavitation damage because of operation with insufficient npsh at maximum flows, the attack and erosion will take place on the *visible* side of the inlet vanes. If, however, erosion occurs on the *non-visible* side and can only be detected by feeling behind the vanes or by holding a mirror between them, the cause is internal suction recirculation.

The culprit can also be pinpointed by the nature of the pulsations. If caused by internal recirculation, they have a random frequency, while pulsations caused by vane passing exhibit peaks at various multiples of vane frequency at running speed.

Treating the symptoms is a common solution.

Just as in the case of vane-passing pulsation problems, there has been a tendency on the part of some designers to treat the symptoms, recommending noise filters, pressure-pulse damping devices and the like (usually with little success). They may argue that the pumps did not show serious pulses or vibration when tested in the lab, and so assign guilt to piping system resonance.

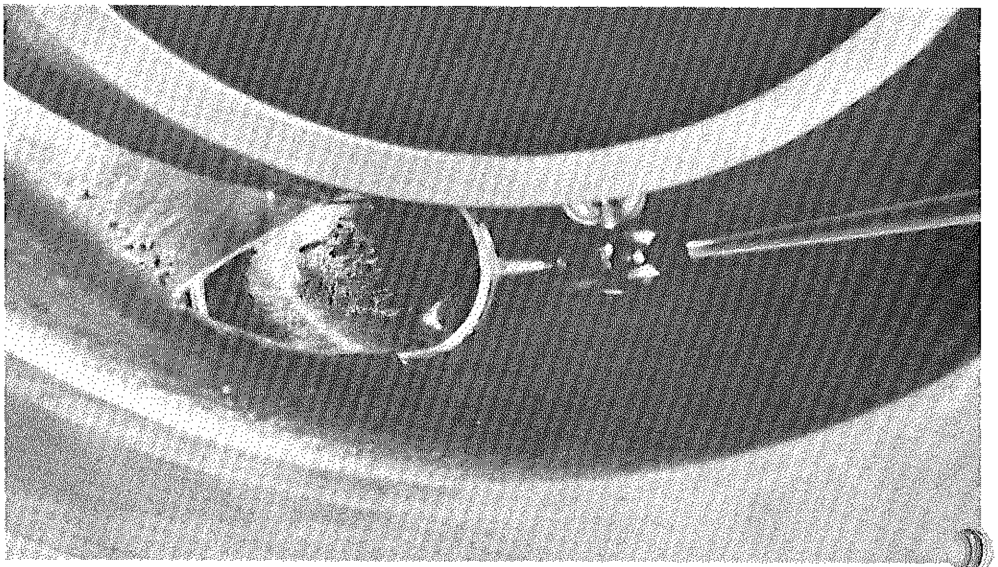


Figure 3 – Cavitation damage on the non-visible side of inlet vanes, seen with a small mirror.

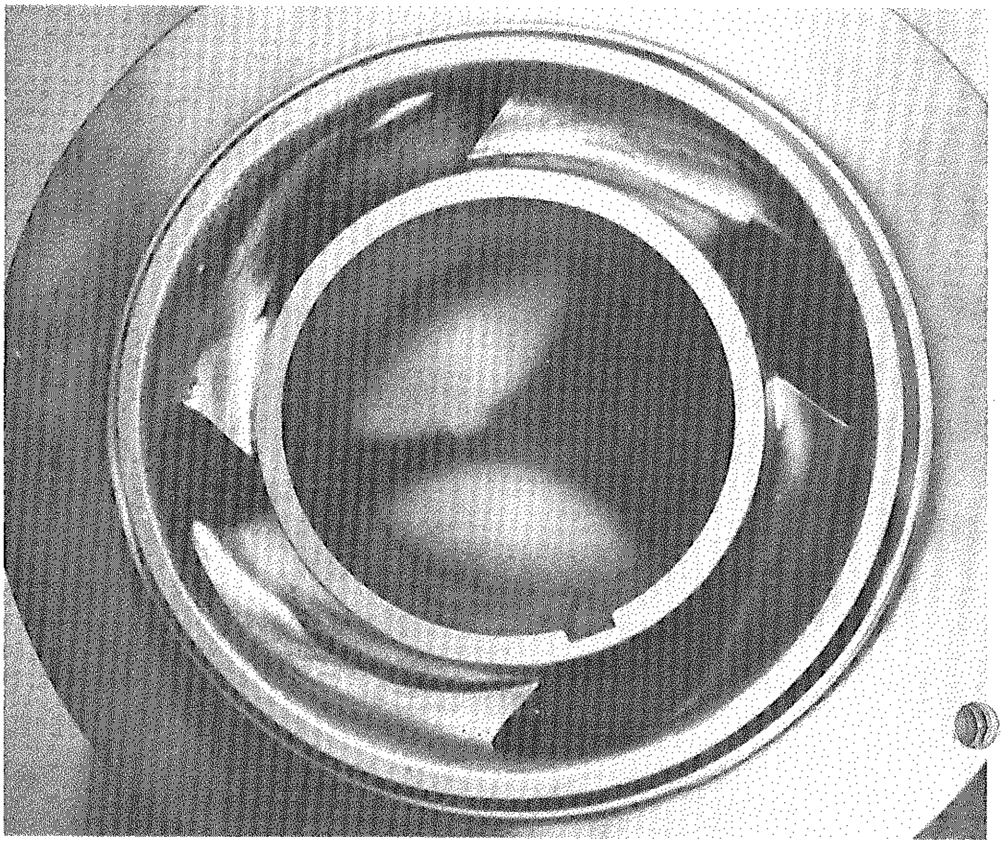


Figure 4 – Cavitation damage seen on the visible side of inlet vanes. The damage has broken through from the non-visible side.

The fact is that the excitation is probably there, even in the laboratory test loop. But because the loop does not have the elasticity of a full-scale, complete system, it will not necessarily respond to the excitation. In addition, in many cases the system includes a free liquid surface which does not exist in a closed test loop. This free surface heightens the fluctuating hunting of the pulsations.

Designing out the problem.
If suction recirculation starts at flows as high as 100 to 110 percent of the best efficiency capacity, the pump will generally exhibit strong hydraulic pulsations, sufficient to cause piping vibration. Obviously, it is not possible to eliminate recirculation entirely, or even have it start in the range of flows where pump bypass takes place. But if suction recirculation inception can be brought down to 65 or even 80 percent of best efficiency, the ill effects created by this phenomenon are attenuated or actually eliminated.

Fortunately, various proprietary design procedures have been developed to predict and control the flow at which suction recirculation starts. These procedures do generally increase the minimum required npsh (Figure 5), but that seems a fair tradeoff to avoid the multiple problems of internal recirculation.

Writing out the problem in your specs.
The pump user can go far toward providing a smooth-running pump system by avoiding unreasonable demands in his specs. For example, if the pump application requires frequent and extended operation at low flows, it is unwise to reach for the lowest limits of required npsh at operating speed (or highest possible value of suction specific speed). Better practice is to provide sufficient npsh, so a pump can be selected which will not suffer from the effects of suction recirculation.

It's also wise to size the pump to fit its intended operating conditions. If a pump

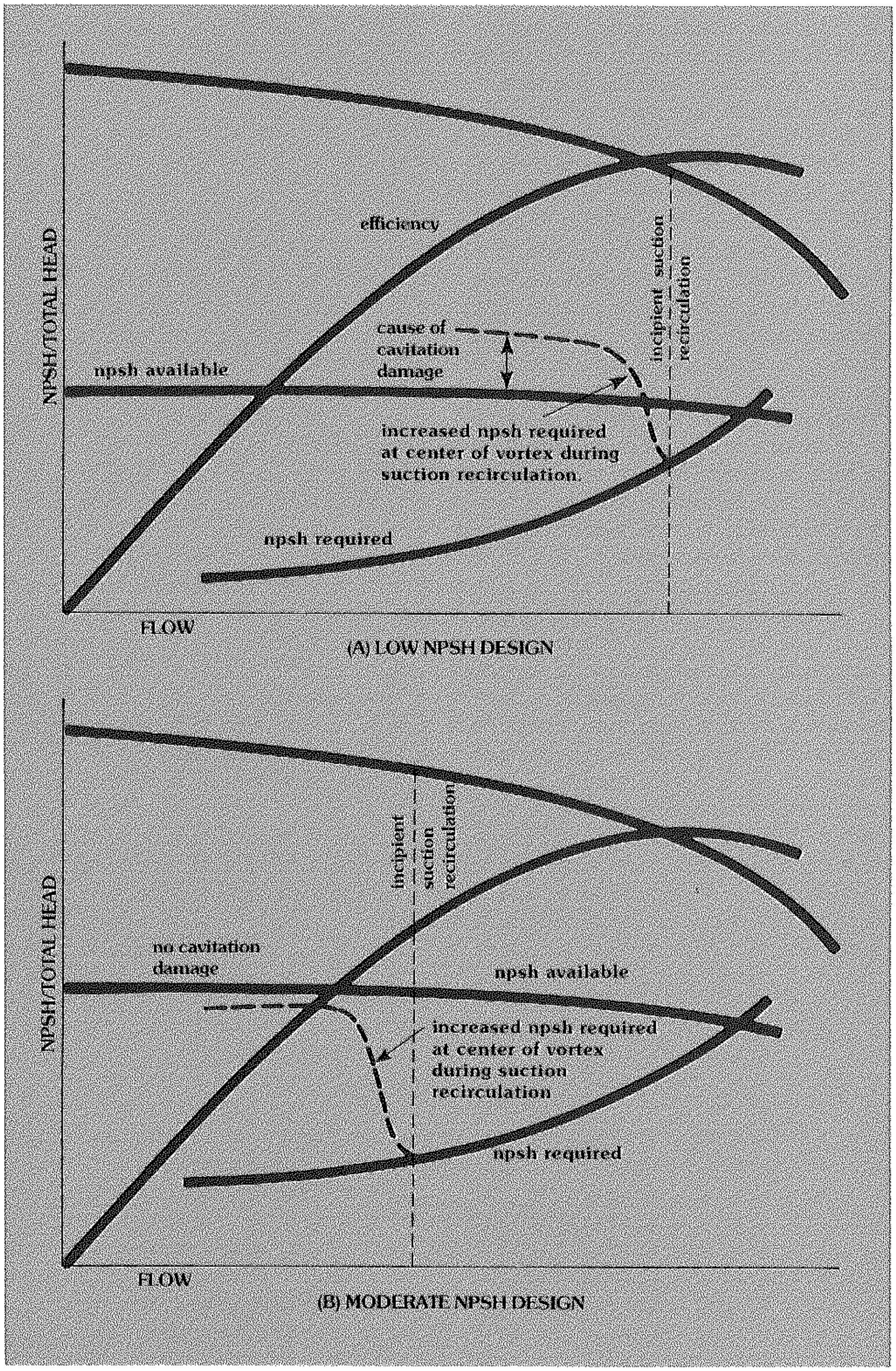


Figure 5—Relation between npsh, suction recirculation capacity, and cavitation damage.

is oversized, with best efficiency point selected at this "overstated" capacity, it will always operate at a lower efficiency than it could have—a waste of energy (see "Design and operate your fluid system for improved efficiency" in the Summer 1975 issue of *Pump World*). What may be even worse, the pump may constantly have to operate in a range where serious pulsations and hydraulic surges can take place.

While some margin is necessary to make up for wear and contingencies, there are two ways to provide margin: it can be added to the desired capacity, or to the required total head. Net result on the head-capacity curve is essentially the same, but adding the margin to the total head has the advantage of keeping design capacities nearer the best efficiency point on the pump curve.

One other special situation can also lead to oversizing a pump. When two half-capacity pumps are used to share the load in parallel to meet full-load conditions, the system designer may wish to provide as much capacity as possible with a single pump, in case the other pump is out of service for any reason. Once again, this practice leads to the selection of a pump which will normally be operating well below its best efficiency capacity, increasing the risk of pulsation problems resulting from internal suction recirculation.

Is the risk worth running for the possible advantages? This is an evaluation the system designer must make.

Ricirculation at impeller discharge.
An internal recirculation vortex can also form at low flows in the area of the impeller discharge (Figure 6).

Demand for ever-higher pump efficiency has led some designers to reduce the impeller diameter as much as possible, while still producing the same head. This is done by increasing the discharge areas which, in turn, increases the head coefficient with a reduction in the disc friction loss of the impeller shrouds.

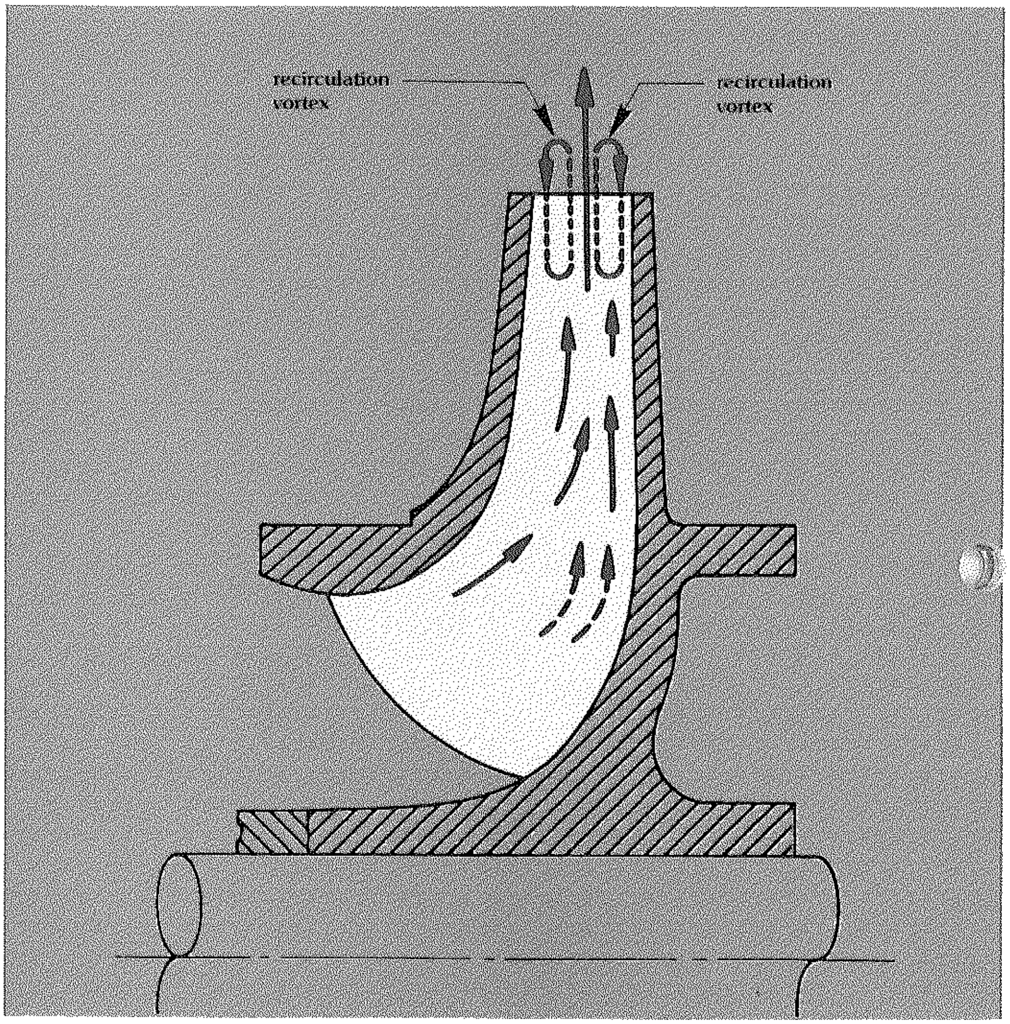


Figure 6—Schematic illustration of liquid recirculation at the impeller discharge at low capacities.

The result is an increase in efficiency—but the point of discharge recirculation is pushed closer to the best efficiency capacity point. In the most extreme manifestations of this hunt for higher efficiency, hydraulic designs may have their best efficiency point near or even actually at the point of incipient recirculation—leading to pumps with head-capacity curves that are not predictible or repeatable (Figure 7).

Effects of recirculation.
Like suction recirculation, discharge recirculation creates hydraulic surges and local cavitation at the impeller tips

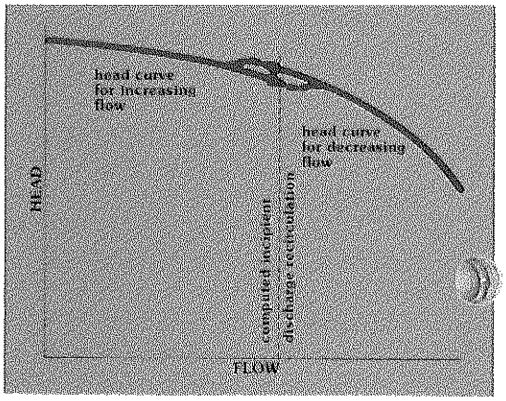


Figure 7—Discontinuity due to discharge recirculation

(Figure 8). Incidentally, the fact that these effects (for both suction and discharge recirculation) are a form of cavitation is illustrated by the observation that in a multistage pump physical damage is generally limited to the first stage. Subsequent stages have a greater margin between the prevailing pressures and the liquid vapor pressure, and the effect is either minimized or eliminated.

The flow at which discharge recirculation takes place does not necessarily coincide with that where suction recirculation occurs. It may be higher or lower.

A hysteresis effect also exists for both discharge and suction recirculation: as flow is decreased, recirculation commences at some specific capacity; but as flow is increased, recirculation persists until some higher flow. It seems that once a strong vortex forms, it takes an appreciable amount of energy to break it up and dissipate it (Figure 7).

Another effect frequently observed in connection with recirculation at the discharge of both single and double suction impellers is marked axial instability of the rotor: the result of strong fluctuations in pressure outside the impeller shrouds. As pressures acting on the two sides of the impeller vary, the axial balance is disturbed and the rotor moves now in one direction, now in the other. Of course, this motion only takes place if the thrust bearing configuration and supporting structure permit it. If the pump has a ball thrust bearing, motion can only take place if the mounting structure deflects: but the bearing may overload and fail.

Select your pump considering all conditions.

Here again is an example of the conflict between optimum performance at rated conditions and performance at low flows. If a pump is to operate mostly in the vicinity of its best efficiency point, the conflict disappears. But if extended operation at low flows is anticipated, the pump manufacturer should be alerted so he can offer the pump least likely to suffer from such operation.

It's not necessary to completely scrap efficiency in favor of reliability: the designer has various recourses. For example, solutions used to reduce the intensity of vane passing pulsations will be equally effective in dealing with discharge recirculation problems. If too little clearance is allowed between rotating and stationary vanes, vortexes caused by discharge recirculation will collapse in the proximity of the metal surfaces and cause cavitation damage. If the gap is increased, vortexes will tend to collapse harmlessly within the gap. A favorable geometric relationship between rotating and stationary vanes also tends to lessen discharge recirculation effects, even while very attractive efficiency levels are being attained.

Where do we go from here?

Centrifugal pumps have been operating for many years. Why is it only recently that designers have become aware of the effects of recirculation, and begun developing an understanding of the relation between the capacity at suction or discharge recirculation and the configuration of an impeller? The fact is that recent pump designs are more prone to recirculation at flows troublesomely near the best efficiency point. Only recently have energy levels in terms of size and horsepower created an environment in which impulses generated by recirculation are destructive.

Is there a lesson to be learned here? There certainly is! At our present state of technology, it appears that some characteristics are mutually contradictory. For instance, maximum efficiency and maximum reliability are not always attainable simultaneously. Similarly, you can design a pump to operate with extremely low values of npsh, or one capable of operating at very low flows, but you cannot achieve both objectives in one pump.

It remains for us to learn how to set the right priorities for these characteristics in our systems, and to recognize where we must compromise between the optimum values of the individual pump characteristics: efficiency, cost, npsh, flexibility and reliability.

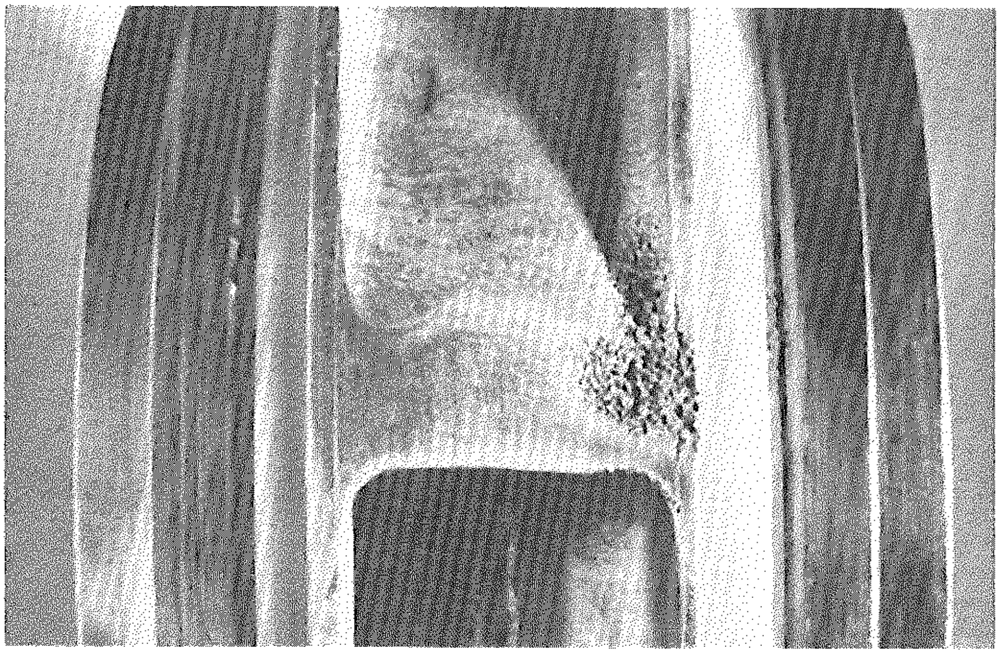


Figure 8 – Cavitation damage caused by recirculation at the discharge.

Vertical pumps: a new generation bids for tough cryogenic and chemical service.

By M. Grohmann

In European practice, vertical turbine pumps are shaping up as an important consideration for many difficult petrochemical and chemical process applications. Why vertical pumps? Favorable installation, operating and maintenance costs and troublefree service are cogent reasons. An extra degree of safety is another well-appreciated advantage. This article presents recent thinking on evaluation, specification, installation and operation of these unusually simple, reliable pumps.

Since 1966, Worthington-Vienna has supplied vertical turbine pumps to handle LNG, LPG, ethylene and chemical products. Originated as cargo pumps with the special application of unloading liquefied gases from cryogenic tankers, these pumps are rapidly coming ashore to find a permanent berth in process service; not only cryogenic, but high-temperature into the bargain.

Advantages of a vertical pump.

A vertical pump may well be the optimum selection, for a number of good reasons:

1. Because the rotor is immersed in the fluid to be pumped, a vertical pump needs no priming. Also, since the rotor operates in a column, only the first impeller (or inducer) need be submerged.

2. No cooling-down procedure is required for cryogenic pumping, because the pump operates at the temperature of the fluid. For this reason, too, the pump discharges at high efficiency, without heat dissipation by the driver in the tank.

3. In high temperature service, fluid pumped serves to cool and lubricate.

4. Driver, thrust bearing and seal are convenient for maintenance.

5. Installation costs are relatively low. With most of the shaft and all the impellers, diffusers and column suspended straight down, support structure can be minimal. (Of course, for cargo service the pump must be adequately braced against the side of the tank or by a steel frame stiff enough to withstand wave shocks against the column. The heavy bowl section, in particular, must be held stationary in the radial direction.)

6. A standard electric motor can be used.

7. The vertical design is an excellent protection against contamination and the risk of explosion. The driver is completely separated from the fluid and tank and can, in fact, be set as far off as desired.

Operating range.

Standard vertical turbine pumps for difficult fluid services are available at capacities up to 500m³/hr (2200 gpm), and can generate heads as high as 200 meters (656 feet), according to the number of stages. If higher head is necessary, pump discharge can be fed to a high-speed booster pump.

Design of a vertical turbine pump.

A vertical pump is quite simple mechanically; an excellent reason for its popularity. Essentially it is composed of the bowl section; line bearings and shaft, column pipe; and the discharge head, including seal and thrust bearing, which supports the driver.

The bowl section.

The bottommost section of the vertical pump is the suction bowl, and it may be equipped with an inducer for improved npsh capabilities. Next there are a number of stages, or bowls, depending on required head. The impeller shaft is supported by sleeve bearings, and the impellers are simply mounted on the shaft with tapered bushing and keys.

Because the multivaned diffuser creates no radial load on the impeller and no hydraulic vibration, operation is extremely smooth and loads on the bearings are extremely light.

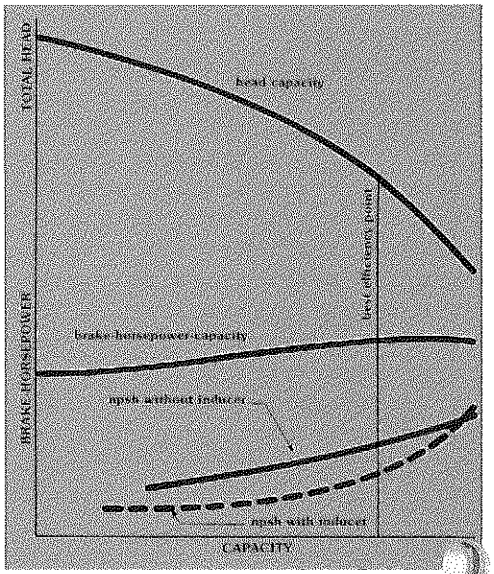


Figure 1 – Vertical turbine pump performance.

The inducer option.

The end of the impeller shaft, extending into the suction bell, may be equipped with an inducer for improved npsh capabilities. This is of particular value in cargo service where, in conjunction with a minimal sump arrangement, the single pump can efficiently strip the tank. As the cryogenic liquids are stored only a few degrees below vaporization, the available npsh is more or less only the liquid level in the tank. Therefore a very low npsh of the impeller is important for stripping completely.

The pump column.

Functionally, the lineshaft connects driver and rotor, supporting the hydraulic downthrust and transmitting torque, while the column pipe contains the shaft, and serves as a discharge pipe.

On the longer vertical pumps for tank or cargo service, a number of standard-length shafts are used, to solve the logistical problems of making them, shipping them, and getting them into place. These lineshafts are coupled with a key type coupling which is insensitive to direction of rotation, and axial thrust is transmitted via a two-piece clamping ring.

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Discharge head.
This component literally holds the pump together. The oil-lubricated thrust bearing and driver are mounted on top of the head; the shaft and column suspended from it. To accept hydraulic axial thrust generated by the impellers, a heavy, tapered roller bearing is used, guided radially by a deep-groove ball bearing.

Pump sealing.
Sealing arrangements are incorporated in the discharge head. Mechanical seals are used for cryogenic services, while a double stuffing box design with drainback line from the interior box usually proves reliable on high-temperature process applications. Good seal performance depends on smooth pump operation, so [illegible] optimized performance, a grease-lubricated roller bearing is installed just above the seal, where it is easily removed for service.

For LPG and ethylene pumping, two mechanical seals are used in tandem arrangement. The inner seal is cooled and lubricated by the fluid being pumped, the outer one by an unpressurized oil system. During startup, the oil lubricates and cools both seals.

For LNG, which is held and pumped at lower than −110°C, a single metallic, bellows-type mechanical seal is used. The seal is cooled by inert gas, as no cooling oil exists for such low temperatures. In operation, the seal is lubricated by the pumped fluid, but to avoid too long a dry run, it must be chilled and flushed before startup by bleeding cold gas through it.

Mechanical seals must be run-in several times before proper sealing is attained. Since there will always be some slight leakage, the seal cooling arrangements must always be open to ambient atmosphere, so the leakage cannot build [illegible] pressure in the cooling system.

Grease-lubricated packing for chemical products needs little maintenance. The main thing is to tighten the gland bolts properly to avoid excessive wear—and keep the grease cup full!

Operation.
Francis-type impellers generate a steep and stable head-capacity curve (see Figure 1). Because of this, operation at high capacity is theoretically possible, but limited by available npsh. A vertical pump should never be run continuously below 15 percent or above 110 percent of capacity, but its stable capacity/head curve allows accurate adjustment so this should not be a problem.

Improving the npsh.
If the pump is equipped with an inducer, part-load rated npshr may be as low as 0.4 meters (1.3 feet), according to pump capacity and speed. Capacity should be reduced as liquid level in the tank decreases.

Actually, in operation the pump can accept even lower npsh. Ratings of npshr are based on testing with water as the pumped fluid and 3 percent head drop, but in actual operation the inducer can accommodate a greater drop without vibrating. Additionally, the cryogenic fluids are less prone to cavitation than water. As a result, an inducer-equipped vertical pump can usually be relied on to completely strip the tank of a cryogenic fluid, even though a small npshr value is indicated by water test.

Controlling the pump.
Pumping cryogenic fluids, it's very important to protect the pump from running dry. As the specific heats of LPG and LNG are low, vaporization can easily occur. And, since all line bearings are lubricated by the liquid being pumped, running against shutoff would result in lubrication starvation and excessive bearing wear.

For this reason, a flow control acting on the dynamic head of flow is recommended. This avoids any possibility that a valve might inadvertently be closed, forcing the pump to run against shutoff. This type of flow control is especially advisable in cargo service, as it protects the pump against running dry at the end of the stripping procedure.

All control devices should include a brief time delay. For one reason, a pump requires a few seconds to generate pressure after startup. Then, the pump can exceed its capacity limits for a short time without damage. The time delay can also be used to adjust to the proper head-capacity point, and so on.

To reduce torque requirement and avoid reverse rotation (resulting in water hammer), start and stop the pump only against a closed discharge valve.

Maintenance.
Maintenance accessibility is a major advantage of a vertical pump. The thrust bearing and seal, parts most subject to routine wear, can easily be changed without dismantling or lifting the pump.

To change the thrust bearing, the rotor is lowered gently until the impellers rest against the stage casings; the bearing is then under no load.

To work on a mechanical seal, use the second seal, which is designed so it can be threaded down, avoiding any risk of leakage out of the full tank. With the seal down, the spacer type coupling is opened and the complete mechanical seal internals, including shaft sleeve, can be removed.

If the pump has a packed stuffing box, the stuffing can be renewed by removing the intermediate piece of the coupling.

Materials of construction.
Special high-alloy, low-temperature steels are used to attain high ductility in cryogenic operation. Below −50°C, only stainless steel can provide the required ductility. For chemical products, material selection depends on the liquids to be pumped and maximum operating temperature.

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