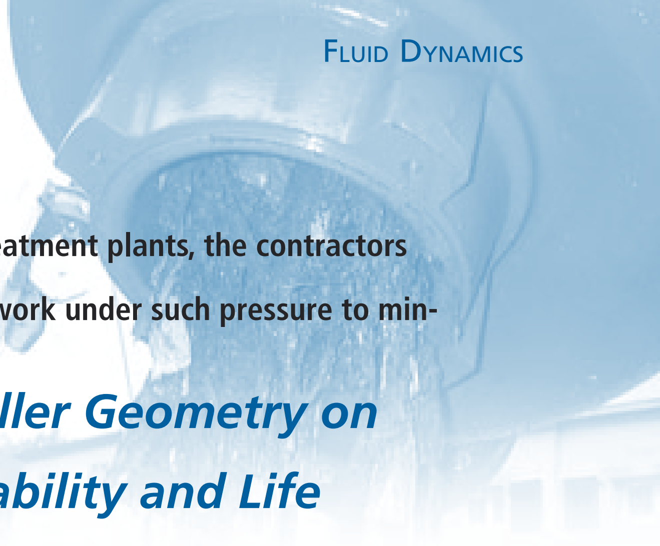

The engineers who plan pumping stations and effluent treatment plants, the contractors who build them, and their ultimate operators all have to work under such pressure to minimize costs, that many waste water systems are designed right along the borderline of technical and economic feasibility. That, of course, harbours the danger of crossing over that line. Hence, the criteria to be met by pumps handling raw waste water have changed considerably in recent years.

Effects of Impeller Geometry on Operating Reliability and Life Cycle Costs of Waste Water Pumps

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Saving Energy

The desire to save energy while implementing effluent treatment plants characterized by processes that are as uniform as possible has led to the increasingly frequent use of speed control via frequency inverters. However, such pumps' impellers and even their vertical piping can plug up if the pumps themselves are running too slowly, i.e., if the permissible speed of rotation or the permissible flow velocity is not maintained and if the defined minimum flow rate is not reached.

Long-Distance Waste Water Transport

Any further increase in *access levels*, particularly in Germany, will entail the transfer of waste water over long distances, e.g., from small villages or farms to the next main pumping station or effluent treatment plant. Such pumped drainage systems must be designed for pumping small capacities at high heads, and that calls for tailored solutions to ensure non-clogging operation of waste water pumps with small nominal diameters. Meanwhile, the need to further reduce maintenance costs is boosting the preference for screenless operation, and that places very high demands on the waste water pumps with regard to clogging avoidance. Last but not least, the measures taken to meet all these requirements are having the effect of promoting water conservation, while modified conditions of hygiene in highly developed and industrialized countries are substantially increasing the solids and fibres content of waste water, which in turn further intensifies the need for non-clogging pumps.

The Changing Nature of Waste Water

Due to major reductions in specific water consumption, the character of waste water in Germany has changed. While water consumption was running at 186 l per day and person in 1991, that rate had dropped to 128 l per day and person by 1998. Consequently, the share of water as transport medium has decreased sharply, while the relative fibre and solids contents have increased. This becomes very problematic during summer dry spells, when no rain has fallen for some time. Fibres and other solids tend to collect in the sewers, forming clods of crud that get dislodged by the next heavy rain and can in extreme cases cause disruption of pump station operation by plugging up the waste water pumps if the wrong impeller geometry has been chosen.

Clogging of Waste Water Pumps

A distinction is drawn between clogging with solids and clogging with fibrous material:

Clogging with solids
Scraps of wood, toys and sundry household waste are frequently found in pumps. Comparable solids-induced clogging can result from conglomeration.

Clogging with fibres
Fibres, particularly in the form of household refuse, hygiene articles and diverse

Access level: Percentage share of "introducers" with sewer system connections, as compared to the total number of waste water producers.

Conglomeration: A mixed, coherent mass of small solids.

industrial wastes, are the other major problem. They tend to collect either in the gap between the impeller and the casing, along the leading edge or at the impeller eye. The cross-section of a typical waste water pump hydraulic is shown in Illustration 1.

Considerable abrasion of the casing wear ring causes gradually increasing leakage flow from the discharge side toward the suction side, and fibrous material can get into the clearance between impeller and casing (= side gap). In extreme cases, so much fibrous material can collect in the side gap that it blocks the impeller. Often, fibres collect for a short time along the leading edge of the impeller, but if the impeller has an optimally shaped leading edge, the fibres soon fall off and exit the impeller through the flow path. If, however, the leading edge has not been geometrically optimized, so much fibrous material can collect there that the entire impeller eye stops up. So, though modern waste water pumps are very reliable, their availability can be impaired by an impeller geometry that was not chosen to fit the specific application and composition of the waste water. On the other hand, it is often impossible to predict the exact composition of municipal waste water, and new "introducers" can alter it without warning.

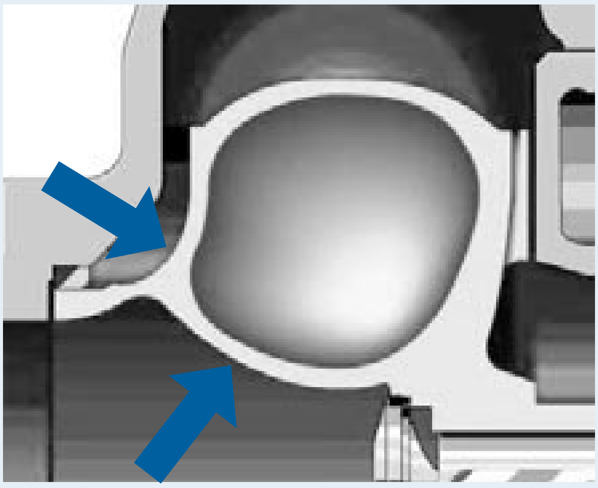


Illustration 1: Critical points where fibres tend to collect in a waste water pump hydraulic with closed impeller

What Kinds of Waste Water Are There?

DIN 4045 categorizes different kinds of waste water. It differentiates between storm water, or surface runoff, waste water and sludge. In most modern effluent treatment plants, positive displacement pumps such as progressive cavity pumps are used for handling sludge with a solids content > 5 percent.

By contrast, centrifugal pumps are mostly used for conveying waste water in the form of sewage as well as municipal, industrial and agricultural waste water. However, no precisely gaugeable parameters are defined for those types of waste water, which differ both according to their gaseous, fibrous, solids and sand contents and in terms of particle size (Illustration 2).

Consequently, each and every waste water handling task requires its own special analysis, and there is only limited leeway for generalization and broad-brush recommendations.

Illustration 2: Classification of the various types of waste water

	Gas content %	Fibrous content	Particle size	Solids content (%)	Sand content (g/l)
Storm and surface water	-	low	small	-	0 - 3
Waste water					
– Municipal waste water					
• Sewage	0 - 2	medium	medium	-	0 - 3
• Industrial waste water	0 - 2	high	large	-	0 - 3
– Industrial waste water	-	low	small	-	0 - 3
– Agricultural waste water	0 - 2	high	large	0 - 5	0 - 3
Water containing sand	-	-	-	-	8 - 10
– Activated sludge	2 - 4	low	small	1 - 2	-
– Primary sludge	2 - 4	low	small	2 - 6	-
– Secondary sludge	2 - 4	low	small	2 - 3.5	-
– Thickened sludge	3 - 6	low	small	2 - 5	0 - 2
– Stabilized sludge	-	low	small	5 - 10	-
– Dewatered sludge	-	low	small	20 - 30	-
– Dried sludge	-	low	small	30 - 50	-

Geometries of Waste Water Pump Impellers

Illustrations 3 and 4 survey the various design concepts for open and closed impellers.

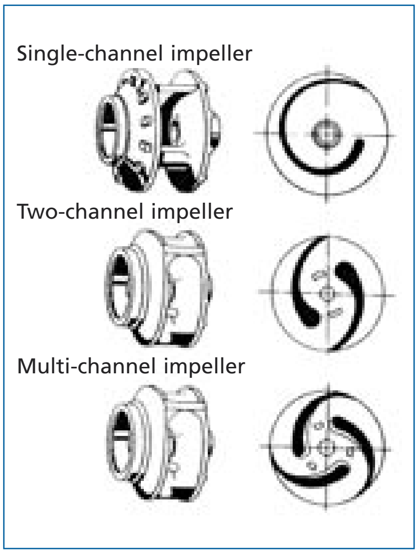


Illustration 3: Overview of closed impeller designs for handling waste water and sludge

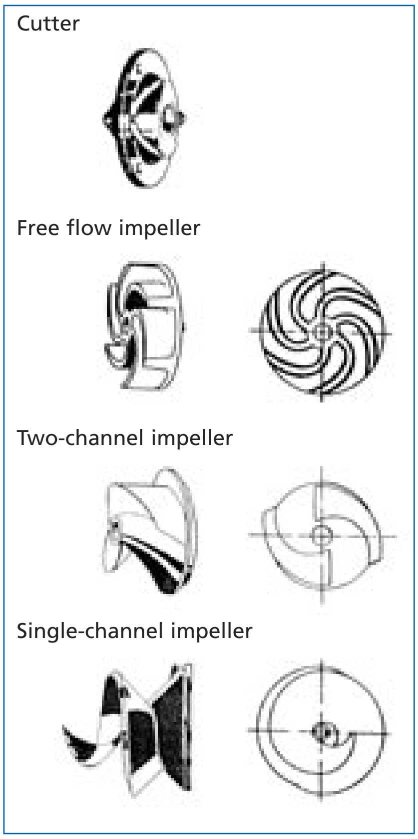


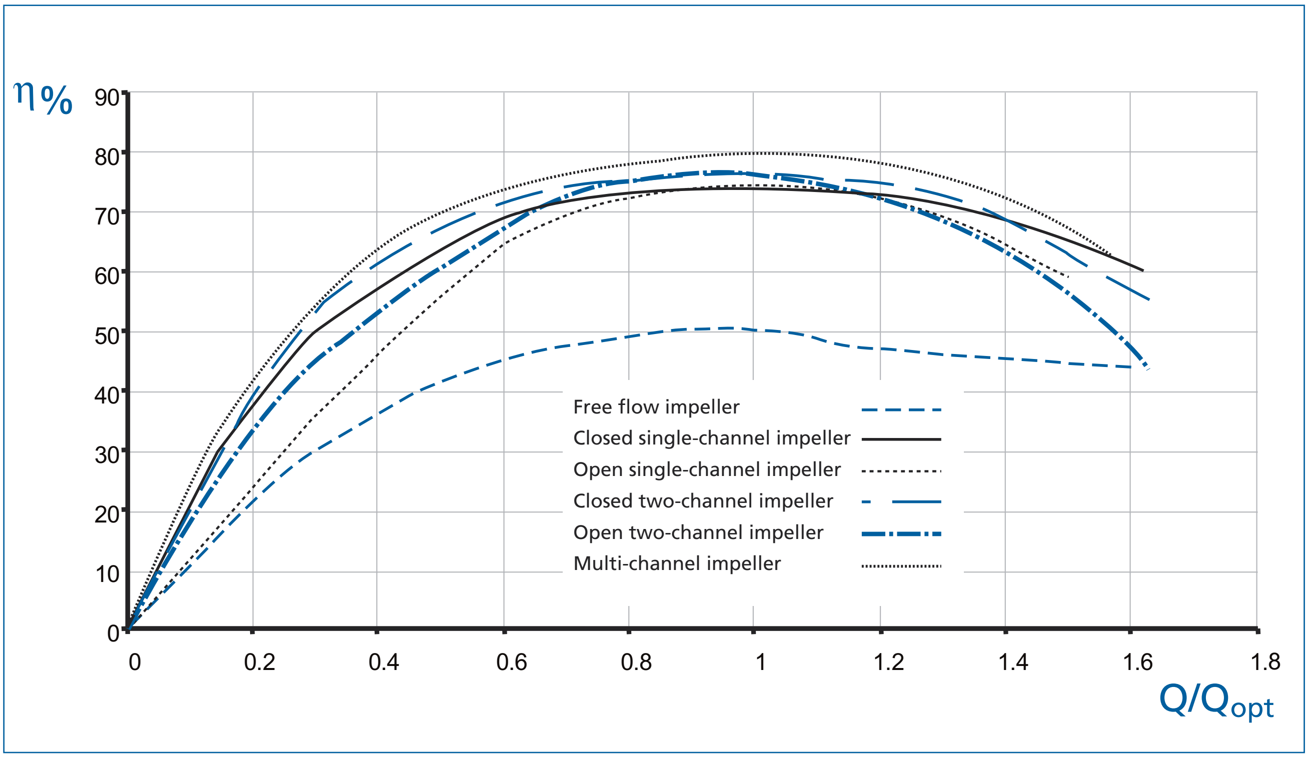
Illustration 4: Overview of open impeller designs for handling waste water and sludge

Efficiency Comparison

Illustration 5 presents an efficiency comparison of various impeller types for a typical design point. Obviously, there is no difference between the open single-channel impeller and the closed single-channel impeller or between the open two-channel impeller and the closed two-channel impeller. The use of two-channel impellers yields an efficiency gain of about two percentage points.

With a view to ascertaining the maximum achievable efficiency, comprehensive analyses were conducted for all the market‘s better-known waste water pump hydraulics. The best achievable efficiency levels for pumps of the nominal size DN 80 (grey), DN 100 (light blue) and DN 150 (dark blue), i.e., for the most frequently employed pump sizes, are shown in Illustration 6. The maximum efficiency that can be achieved with free flow impellers amounts to a mere 55 % for all sizes.

Illustration 7: Comparison of efficiency curves of various impeller geometries



The efficiencies of open and closed single-channel and two-channel impellers range from 75 % to 85 %. Three additional percentage points can be extracted from an open single-channel impeller, but only at relatively high specific speeds and large capacities (which roughly corresponds to DN 150). Systematic hydraulic optimization has made it possible to achieve very high efficiency levels of more than 80 % with a closed two-channel impeller.

Hence, the efficiencies that can be achieved with closed two-channel impellers occupy the same high level as those of multi-channel impellers, while those of open two-channel impellers, such as the "N impeller" of a Swedish manufacturer, are about five percentage points lower than those of the closed version. Apparently, losses occurring in the gap between the casing and the impeller vanes and in a special fibre-repellent groove are substantially higher than the impeller-shroud and internal leakage losses of closed impellers.

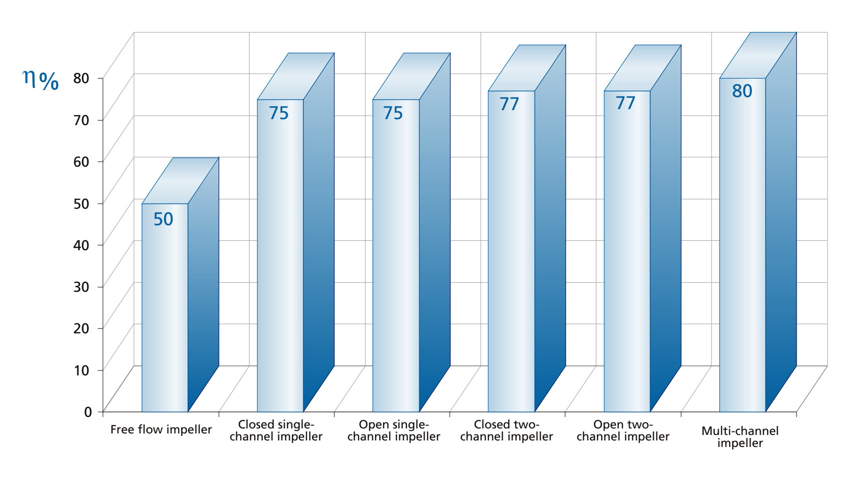


Illustration 5: Comparison of average efficiencies of various impeller geometries (design data: Q = 80 l/s, H = 13 m, n = 1450 1/min, nq= 60 1/min)

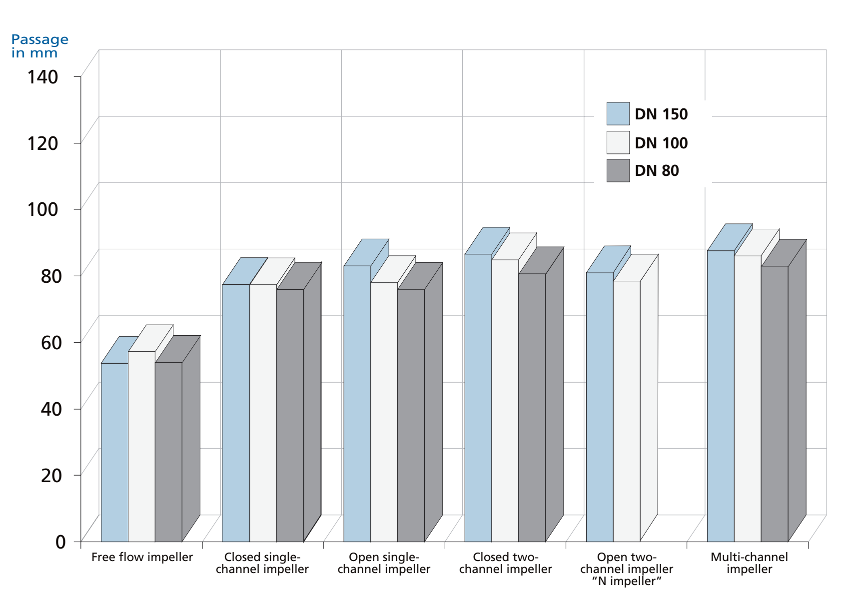


Illustration 6: Comparison of the best achievable efficiency levels of various impeller geometries

Low-flow Efficiency

What the efficiency curves look like in the low-flow range is just as important as the best efficiency point. Here, the impeller geometry is seen to have a great impact in general.

To facilitate a detailed analysis, Illustration 7 shows typical efficiency curves of various impeller geometries as functions of pump capacity. All of the curves are normalized for the best efficiency point Q/Q_{opt} = 1.0. Free flow impellers maintain constant, though low, efficiency over a broad range of pumping capacity. Their poor efficiency is attributable to their underlying fluid dynamic principle and is only amenable to marginal improvement. Multi-channel impellers, with their higher number of vanes, are the most efficient at converting energy over the entire operating range, but they are only suitable for handling pre-treated waste water.

Closed impellers have flatter efficiency curves than do open impellers, and therefore offer better low-flow efficiency. For example, the difference between a closed single-channel impeller and an open single-channel impeller can amount to as much as 10 percentage points in the low-flow range, even though one is just as efficient as the other at the best efficiency point. The same is true of two-channel impellers. Thus, the concept of efficiency should not always be considered a question of "best" efficiency, but also and in particular as one of low-flow efficiency, because the latter is often what counts most for waste water pumps in their actual service environments.

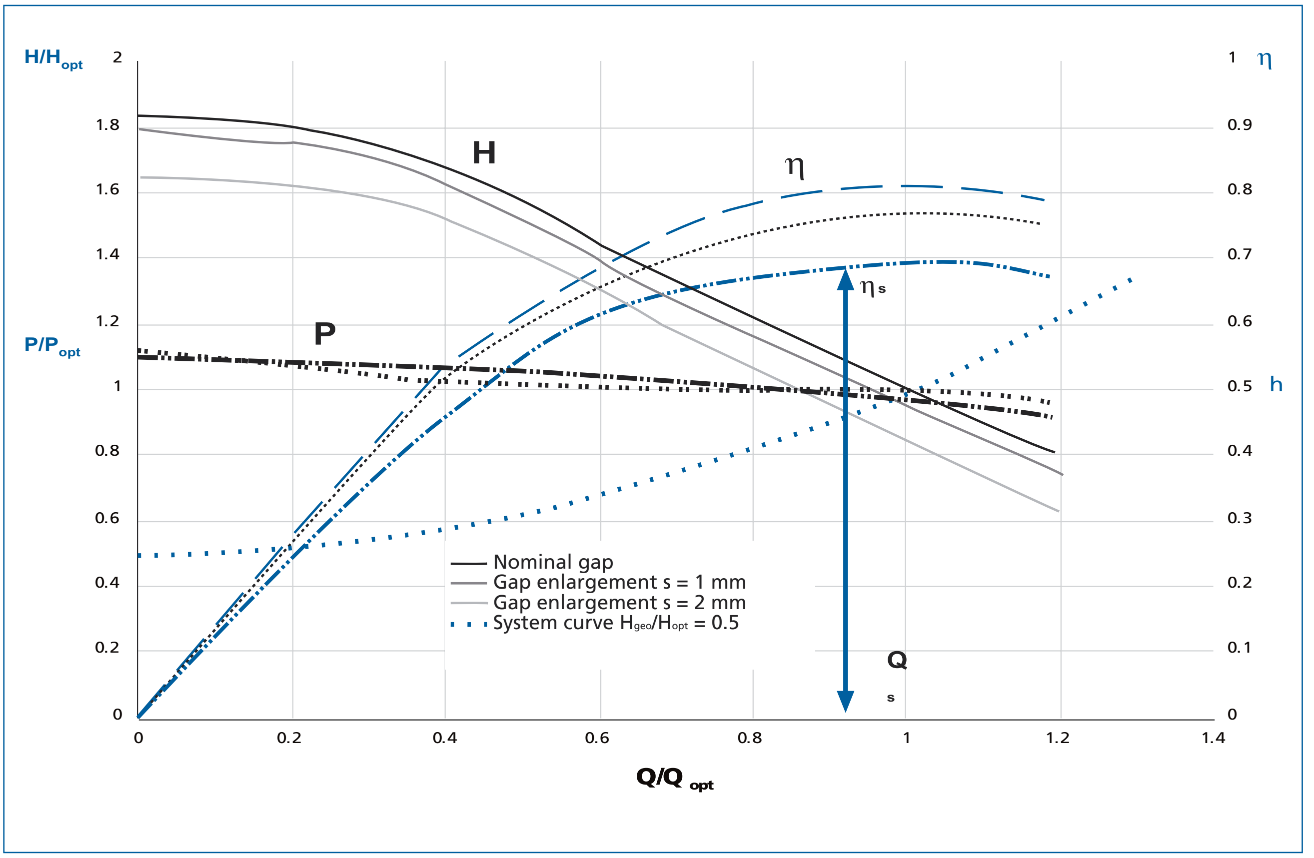


Illustration 8: Effects of wear-induced sealing gap enlargement on the characteristic curves and the duty point of an open single-channel impeller

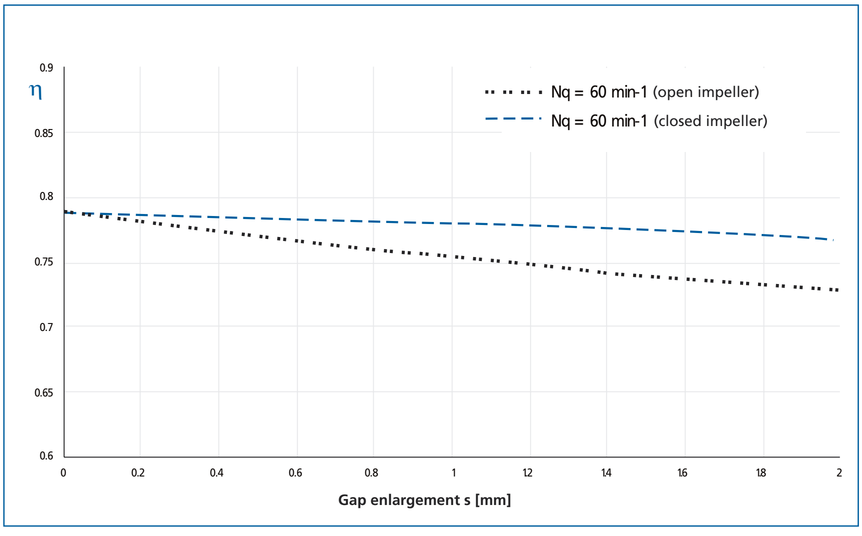
Wear Reduces Efficiency

In the course of time, both the efficiency and the performance characteristics are subject to gradual change, and that must be given due consideration in the planning of waste water pumping stations. Illustration 8 shows the effects of wear-induced gap enlargement on the characteristic curves of an open single-channel impeller. The best-achievable efficiency is seen to deteriorate by up to 10 percentage points.

Progressive wear also alters the head curve. In our example, the flow rate eventually declines by about 8 % in connection with the system curve. However, no one working at a waste water pump station is ever likely to notice such a thing, because most such stations have no flow measuring equipment and the power input remains practically constant due to the decrease in the flow rate.

Illustration 9 shows the continuous loss of efficiency as a function of gap enlargement. It is plain to see that with open impellers like the “N impeller” efficiency deteriorates much faster than with closed impellers.

Illustration 9: Wear-induced loss of efficiency as a function of sealing gap enlargement



COMPARISON OF CLOGGING PRONENESS LEVELS

Free passage, which is defined as the diameter of the largest ball that can pass through the impeller, is an important criterion for evaluating the ability of waste water impellers to keep from clogging up. Illustration 10 delineates an analysis of the maximum free passage of various commercially available impeller geometries. Free passage depends on the size of the pump and on how many vanes it has.

Few impeller geometries can provide the minimum free passage of 80 mm (or even 100 mm) that many users stipulate for handling raw waste water. Both free flow impellers and single-channel impellers provide relatively wide free passage for all sizes, and both have served reliably for many years in the pumping of raw waste water containing solids of large particle size. The free passage offered by open single-channel impellers is somewhat smaller, but still above 75 mm for all sizes. In fact, DN 150 has a free passage of 100 mm. Closed two-channel impellers have free-passage dimensions comparable to those of open single-channel impellers.

Open two-channel impellers and multi-channel impellers, however, have narrower, design-dependent free passages and therefore cannot guarantee non-clogging operation in the presence of sizeable solids. Two-channel impellers have limited free passage, which is also true of the "N impeller".

Only specially designed types referred to as "canned impellers" are able to offer free passages in excess of 75 mm for DN 80 and DN 100 (and > 100 mm for DN 150 and above) with closed two-channel impellers. To ensure reliable pumpage of raw waste water and equally reliable operation of waste water pumps, the free passage should amount to at least 100 mm. The latest edition of Germany's waste water pump selection directives, ATV-Druck-134, dated June 2000 and issued by Deutsche Vereinigung für Abwasser, confirms that criterion. On the basis of discussions held with pump station operators, ATV decided not to change this time-tested dictate for free passages > 100 mm and has documented that decision in the latest version.

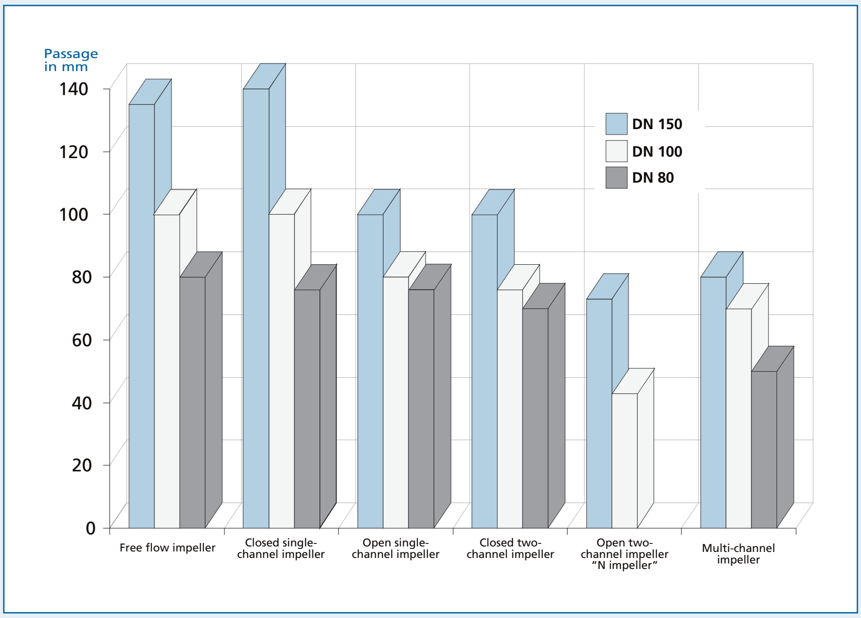


Illustration 10: Comparison of the maximum free passages of various impeller geometries

Illustration: Typical damage of clogged waste water pumps

Selection Criteria for Optimal Impeller Geometry

One other selection criterion that is becoming increasingly important are the life cycle costs of waste water pumps. In the intermittent operation mode, which is very frequently the case at waste water pump stations, the cost of energy only accounts for about 50 % of the overall life cycle costs.In the continuous operation mode, energy expenditures can account for more than 80 % of the overall costs, with that mode being encountered quite frequently in the intake structures of effluent treatment plants. Of course, these illustrations are only valid for non-clogging, trouble-free waste water pumps. If clogging does occur, the cost of remedying the problem, including the consequential costs of pump failure, is the sole decisive cost factor and can easily add up to more than the acquisition value of the pump. Hence, waste water pump station operators attach maximum importance to operating reliability, and efficiency is only their second decision-making criterion. Choosing a particular impeller for a particular waste water pump in a particular service situation always entails a compromise between freedom from clogging, overall operational efficiency, and wear behaviour. Naturally, the geometry of the impeller can only be decided with due allowance for the specific composition of the waste water, so there is no such thing as a universal impeller, even though one major Swedish producer is trying to promote one.

Specific Merits and Drawbacks

Illustration 11 lists some recommendations on how to choose an optimal impeller geometry. Free flow impellers are still the best choice for water containing lots of gas, and good results are obtained with open single-channel and two-channel impellers for high fibre contents. In the case of medium fibre contents like those customarily encountered in municipal waste water, closed single-channel and two-channel impellers are preferred for their high operating reliability levels. If the water is extremely emburdened with industrial process waste or large amounts of household refuse, the good old free flow impeller makes the best choice, despite its somewhat inferior energy efficiency. This applies in particular to small-size pumps (DN 80 and DN 100).

These assertions have been confirmed by extensive experiments involving fibres of diverse type and concentration conducted at the KSB model waste water test bay.

Summary

Efficient waste water transport will always require well-trained specialists with long-standing experience to select just the impeller geometry needed to cope with the pumped medium on hand. In the near future, there will be no such thing as a universal impeller that can handle any and all waste water transfer tasks.

Illustration 11: Application limits for different impeller types as a function of the characteristic waste water parameters

	Gas content %	Fibrous content	Particle size	Solids content (%)	Sand content (g/l)
Cutters	-	medium	-	2	-
Free flow impellers	8	high	large	6	6 - 10
Closed single-channel impeller	2	medium	large	6	4
Open single-channel impeller	4	high	large	6	6
Closed two-channel impeller	-	low	medium	4	4
Open two-channel impeller	4	high	medium	6	6
Multi-channel impeller	-	none	small	4	4