N-Pumps win Canada's Energy Efficiency Awards 2000. The energy-using equipment award for sustained efficiency in raw sewage.

Breaking New Ground in Efficient Sewage-Handling Pumps

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Abstract • Considerable resources have been expended, in the past, by engineers, operators, and manufacturers to reduce the energy consumption of pumps. Some of these historical developments are reviewed below. Work was centered on actual energy consumption in the field testing of two independent sewage-pumping stations. Analyses of the actual performance of three different impeller designs are presented as well as their effect on the energy consumed when handling media laden with soft solids.

In some instances, increasing the efficiency of the components, or adding the variable speed drive, produced the desired results. In other cases, however, this resulted in frustratingly disappointing results and wasteful capital expenditures.

Further initiatives have created the concept of wire-to-water efficiency, and subsequently, the concept of Specific Energy *(Es)*.

All of these energy-efficiency initiatives are based on the performance of equipment that handles clear water as the pumped media. The question is then asked: "What would be the impact when raw sewage is handled?"

1. Introduction

Hydraulic efficiency in clear water is generally the first element to be considered in undertaking efforts to reduce energy consumption by using 'higher efficiency components', or by adding new hardware, such as variable-speed drives. Published efficiencies are normally designated as the BEP (Best Efficiency Point), and any operation outside this BEP reduces the operating efficiency (see Figure 1, next page). The curve shown in red (overall efficiency) takes into consideration both hydraulic and motor efficiencies.

Motor efficiency varies, of course, with load, and the proper matching of the motor to the load thus improves efficiency. Generally speaking, motor manufac-turers publish efficiencies at 50%, 75%, and 100% of the nominal load. On request, they can supply a motor load/efficiency curve similar to that shown in Figure 2 (see next page). The actual operating efficiency may vary with the load, as is depicted in Figure 2.

In general, optimal energy efficiency is attained when the peak load of the pump is matched to the maximum motor efficiency. Use of safety factors added into the calculation of the load often forces the use of a larger-sized motor, which may result in a lower operating efficiency.

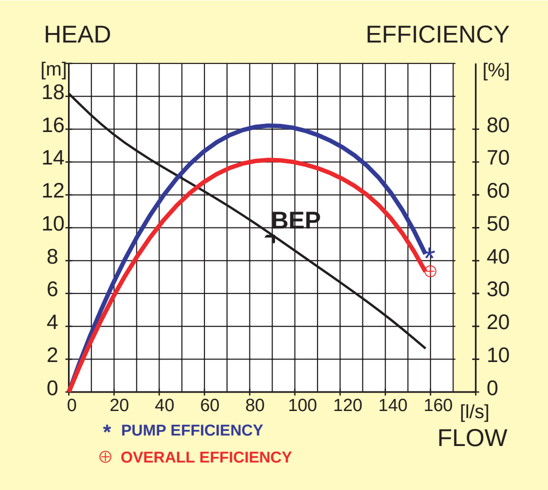

Figure 1. *Hydraulic efficiency performance curves for a typical centrifugal pump (BEP = Best Efficiency Point).*

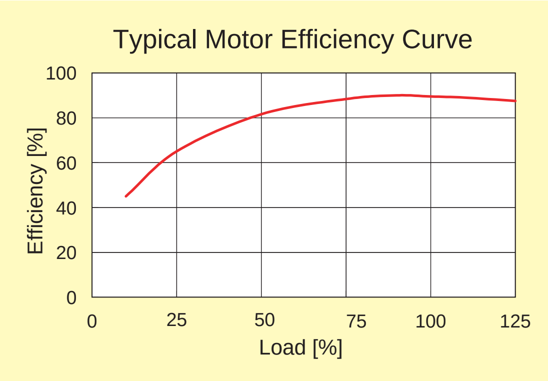

Figure 2. *Efficiency curve for a typical electric motor.*

2. Calculating wire-to-water efficiency

Wire-to-water efficiency is defined as the efficiency from the input, at the motor control box, to the output of the pump. It combines the hydraulic, motor, and, in certain cases, variable speed drive and gear and/or pulley efficiencies. It is accurate when measuring the performance of a complete pump unit. Its major shortcoming, however, is that it does not take the system curve and the actual system itself into consideration. Typically wire-to-water efficiency is calculated as follows:

$$\eta_{ww} = \eta_h \cdot \eta_m \cdot \eta_{misc}$$

where:

η_{ww} is wire to water efficiency
η_h is hydraulic efficiency
η_m is motor efficiency
η_{misc} is variable speed drive, gear or pulley efficiency.

This approach yields an efficiency at a definite point of operation. In an actual pumping station, with on/off controls, the varying level in the sump varies the operating points; also, the variation of friction losses with the flow is not taken fully into account. In short, it fails to give an accurate indication of the cost of moving a certain volume of water from the pumping station to the delivery point.

2.1 Defining specific energy, E_s

Specific energy (E_s) is defined as the energy consumed per unit of pumped volume. Depending on the selection of the unit of measure, it is formulated in "Watt-hours per gallon" or "kWatt-hours per million gallons" or, in the metric system, "kWatt-hours per cubic meter."

The specific energy by definition is therefore the most accurate way of measuring energy consumption. It stretches the optimization efforts beyond the motor and pump entity to the complete design of the system and the piping. Full economical consideration of this principle should also include capital depreciation as well as yearly maintenance costs. This allows for simple comparisons when using equipment with different characteristics.

The E_s is easy to calculate in an existing pump installation, since we are able to measure the pumped volume as well as the electrical energy consumption. It is more difficult, however, to evaluate at the design stage when several parameters are involved, that is, the change in flow, the change in the liquid level in the sump, etc. The use of a flow-duration diagram yields results accurate enough for comparison purposes as well as for some indication of energy consumption. Modern computer expert software has improved the accuracy of this calculation.

3. Hydraulic efficiency and nonclog characteristics

Quoting from the *Pump Handbook,* (Karassik et al., 1976): "The so-called 'nonclog' pumps are all based on an original development by Wood at New Orleans. Actually, no pump has been developed that cannot clog, either in the pump or at its appurtenances. Experience shows that rope, long stringy rags, sticks, cans, rubber and plastic goods, and grease are objects most conducive to clogging."

The Wood design allows for larger openings to pass solids, but to the detriment of pump efficiency. For sewage pumps having a discharge smaller than 10 inches, the efficiency is well below the efficiency of clear-water pumps. High hydraulic efficiency and nonclog operations seem to be at opposite ends of the spectrum. This is due to the perceived physical constraints whereby designing for a nonclog operation meant lower efficiency.

From experience, it may be noted that plastics and fibrous material have a tendency to clog the impeller, thus forcing the pump to run at a lower hydraulic efficiency. Most of this blockage takes place at the leading edge of the vane or in the middle of the impeller. Whether it is apparent as low discharge pressure or low flow, pump suppliers are unanimous as to the reduced operating conditions and the resultant energy loss.

Furthermore, hydraulic efficiency data released by pump suppliers are for clear water in conformance with the Hydraulic Institute (HI) Test Standards for centrifugal pumps or the International Standards Organization (ISO). The consultant engineer and the end-user will base their selections on clear-water performance and efficiency data.

This begs the questions: "Would this efficiency hold true in a real sewage pumping station laden with soft solids such as plastics, rags, tissue, hair, etc.?" and "What is the impact of such blockage on energy consumption?" Both of these are often asked but seldom answered. The following extended field tests and results shed some light on these issues.

4. Lachenaie Pump Station: field test and results

The Lachenaie triplex sewage station was fitted with three pumps having different hydraulic ends. The station mainly handles residential sewage along with wastewater from a few restaurants. The choice of the station was favored by the absence of solid screening at the inflow, the result being the handling of unscreened raw sewage. The pumps used were:

- pump 1: 7.5 hp, equipped with a shrouded impeller with two vanes, conventional Wood-type nonclog design, similar to the one in Figure 3,
- pump 2: 10 hp, equipped with a single-vane nonclog impeller, similar to the one in Figure4, and
- pump 3: 7.5 hp, with a semi-open impeller having two back-swept vanes (Flygt N-type), Figure 5 .

Figure 3. *Typical two-vane impeller.*

The impellers in pumps 1 and 2 are based on the Wood design. The new impeller used in pump 3 (see Figure 5) was designed so that soft solids cannot adhere to the leading vanes. It is fitted with a relief groove that assists solids in their passage from the eye of the impeller into the volute.

All of the pumps were set to alternate at the end of every cycle in order to equalize operation requirements and allow a safe estimation of equally pumped volume over the nine-month test period. The error margin was less than 5%.

The use of alternation is standard in this type of application. In the *Submersible Sewage Pumping Systems Handbook (SWPA, 1997)*, automatic alternation is referred to as the most common technique for sewage pump operation. Its purpose is to distribute wear evenly on all pumping units. Automatic alternation also results in an even distribution of the pumped volume on all pumps. The longer the period of time, the more accurate will be the even distribution of pumped volume—since the peaks or valleys are evened out.

Figure 4. *Typical single-vane impeller.*

We have used this characteristic in determining the average pumped volume, which, combined with the power and running time, allows us to recalculate the actual specific energy (E_s).

Figure 5. *New impeller with relief groove (ITT Flygt N-pump).*

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Lachenaie Pump Station	Pump 1	Pump 2	Pump 3
Impeller Design	Shrouded two-vane	Shrouded single-vane	Semi-open two-vane N-type
Nominal motor shaft power [hp]	7.50	10.00	7.50
Head at BEP [feet]	18.10	23.50	26.50
Flow at BEP [USGPM]	915.00	968.00	847.60
Efficiency at BEP [%]	65.70	63.10	77.80
Actual operating head [feet]	17.80	20.40	20.10
Actual operating flow [USGPM]	932.50	1,077.30	1,063.80
Clear-water hydraulic efficiency at op. point [%]	65.60	62.60	73.50
Motor efficiency at operating point [%]	84.30	85.00	84.00
Input Power at operating point [kW]	5.60	7.70	6.50
Specific energy in clear water [kWh/Mgal]	99.70	121.50	101.70

Table 1. *Summarized pump characteristics for the Lachenaie Pump Station.*

4.1 Results

The pump characteristics are summarized in Table 1 above. For a normal pump selection, Pump 1 would have been specified and used, since it offers the most economical energy consumption profile.

During the nine-month test period, the pumps were checked and cleaned periodically. Pump 1 had the highest frequency of the presence of solids and necessitated frequent unclogging. Pump 2 had fewer clogging incidents, while pump 3 was cleaned only once, and this was due to the presence of a tree branch.

The number of starts and running hours, and the input current, as well as other operational data, per pump, were logged almost daily by the city operators. This data was collected and averaged out.

The average operating hours/month for each pump as well as the specific energy were recalculated. The formula used in the actual calculation of the E_s is as follows:

$$E_s = \frac{motor\,input\,power \bullet running\,time}{average\,pumped\,volume}\left[\frac{kWh}{MUSG}\right]$$

From the actual results, one can see that pump 1 (shrouded two-vane impeller) moved from being the best to being the worst performer, with a specific energy increase of 56%, or up from 99.70 to 155.90 (see Table 2).

Figure 6. *ITT Flygt N-pump after three months of operation at the Ste-Thérèse field test station.*

Lachenaie Pump Station	Pump 1	Pump 2	Pump 3
Impeller Design	Shrouded two-vane	Shrouded single-vane	Semi-open two-vane N-type
Theoretical specific energy in clear water [kWh/Mgal]	99.70	121.50	101.70
Average monthly operation [h]	212.00	163.00	120.00
Monthly average pumped vol. (9-month average)[Mgal]	7.70	7.70	7.70
Actual specific energy in sewage [kWh/Mgal]	155.90	164.00	102.10
Per cent change in specific energy	56.00	35.00	0.40

Table 2. *Results from the Lachenaie Pump Station test. The new swept-back vane impeller showed constant performance.*

The single-vane nonclog-type shrouded impeller was less affected by clogging, and the specific energy increased by 35%, or up from 121.50 to 164.

The N-pump demonstrated constant performance, and its energy consumption remained unchanged between the clear-water and raw-sewage applications.

The change in E_s from the theoretical clear-water to the raw-sewage test site is several times greater than the margin for error, and the results are deemed to be conclusive.

5. Ste-Thérèse Pump Station: field test and results

The Ste-Thérèse field test station is a duplex station fitted with two pumps, each having different hydraulic ends. The station mainly handles residential sewage with high concentrations of fibers, hair, and other soft solids from apartment buildings. The station is fully underground at the corner of a street crossing. The unavailability of solid screening at the inflow and the high concentrations of fibers and hair and other soft solids favored the choice of the station. It was fitted with two pumps: pump 1, with a single-vane impeller similar to the Wood design, and pump 2, the ITT Flygt N-pump.

The pumps were alternated at every cycle to even out wear and the volume pumped. This operation did not include routine inspection and unclogging of the pumps, owing to the location of the installation under the paved street. The operator would clean or unclog the pumps whenever they generated an alarm caused by either overload or high temperature.

The conventional pump had to be cleaned on several occasions, whereas the N-pump never clogged. The test was run for a period of nine months, which yielded highly accurate results.

5.1 Results

Table 3 below summarizes the pump characteristics as well as the actual results from the field tests that were based on the operator data. The results from this station led us to the same conclusion: the E_s for the conventional shrouded impeller increased by 67.3%, and its actual energy consumption increased considerably. The N-pump again exhibited uniform performance.

Part of the reason for the high variance in the specific energy of the first pump is that it was cleaned only when an alarm was generated. This raises the importance of being able to supply energy-efficient pumping as well as reliable trouble-free pump operation.

The importance of trouble-free, reliable operation was well outlined in an article entitled *Life Cycle Costs—The True Cost of Infrastructure* (da Silva, 1997). Mr. da Silva reported that the "ongoing operation, maintenance, and replacement of time-worn equipment are estimated at 75 per cent of total life-cycle costs. The capital costs for construction are 23.5 per cent." The higher specific energy and the need to frequently clean the pumps dramatically increase the life-cycle cost of the plant. The proper quality-based selection at the planning stage should outweigh competitive bidding.

Ste-Thérèse Pump Station	Pump 1	Pump 2
Impeller Design	Single-vane nonclog	Two-vane N-type
Nominal motor shaft power [hp]	10.00	10.00
Head at BEP [ft]	23.50	31.40
Flow at BEP [USGPM]	967.90	968.20
Efficiency at BEP [%]	63.10	80.00
Actual operating head [ft]	26.00	28.10
Actual operating flow [USGPM]	885.60	1,063.80
Clear water hydraulic efficiency at operating point [%]	62.80	79.00
Motor efficiency at operating point [%]	84.80	84.70
Input power at operating point [kW]	8.10	8.50
Specific energy in clear water [kWh/Mgal]	152.90	131.10
Average monthly operation [h]	382.60	190.50
Monthly average pumped volume (9-month average) [Mgal]	12.16	12.10
Actual specific energy in sewage [kWh/Mgal]	255.80	133.10
Per cent change in specific energy	67.30	1.50

Table 3. *Pump characteristics at the Ste-Thérèse Pump Station.*

6. Conclusions

The results challenge an old myth: "the better the nonclog characteristics of a pump, the lower the efficiency and the higher the energy consumption." The design, shape, and characteristics of the hydraulic end play an important role in improving energy efficiency in sewage stations, while they concurrently improve the nonclog characteristics.

Typical efficiency ratings in clear water serve as an indication, but may prove to be completely different in sewage, where solids accumulation and buildup in the pump may significantly alter the outcome. Nonclog capability and high pump efficiency in sewage handling, together, are certainly feasible, and pumps offering these benefits are now available.

Improved specific energy and reduced maintenance requirements greatly affect the overall life-cycle costs of these installations.

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