An introduction to energy consumption in pumps

Saving energy is such a big topic it's sometimes hard to know where to start. In this first article in a planned series on energy savings in pumps, Hans Vogelesang, director of design consultancy PumpSupport in the Netherlands, looks at the important facts and reveals where the first savings can be achieved when determining targets.

There are several reasons why one should try to save as much energy as possible. Of course, any saved energy means a direct saving in costs, but energy saving also contributes significantly to the improvement of our environment.

A study by Dena (Deutsche Energie-Agentur GmbH), a German energy agency, revealed that in the year 2000 industry in the European Community (EC) consumed 951 TWh of energy (1 TWh = 1 000 000 MWh) in total. About 65% of this energy was consumed by machines driven by electric motors, many of which were pumps.

What can be achieved?

Centrifugal pumps account for 80% of all pumps and it is a known fact that most centrifugal pumps have an overcapacity of 20–30%. It has been calculated that the energy wasted by all the pumps operating at present in the EC is 46 TWh on a yearly basis. What does this mean? The biggest power station within the Netherlands is the Eemscentrale in Delfzijl, with a generating capacity of 2400 MW. Even when operating 365 days per year, 24 hours per day at full capacity, the electricity production of this station would not amount to more than 21 TWh per year. So, the equivalent of more than two large or several smaller power stations permanently operating are needed just to generate all the energy that is wasted by pumps in Europe.

What this represents is an enormous potential saving. Moreover, it shows that if designers were to make more pumps more energy efficient we would immediately need fewer power stations. Need we mention Kyoto?

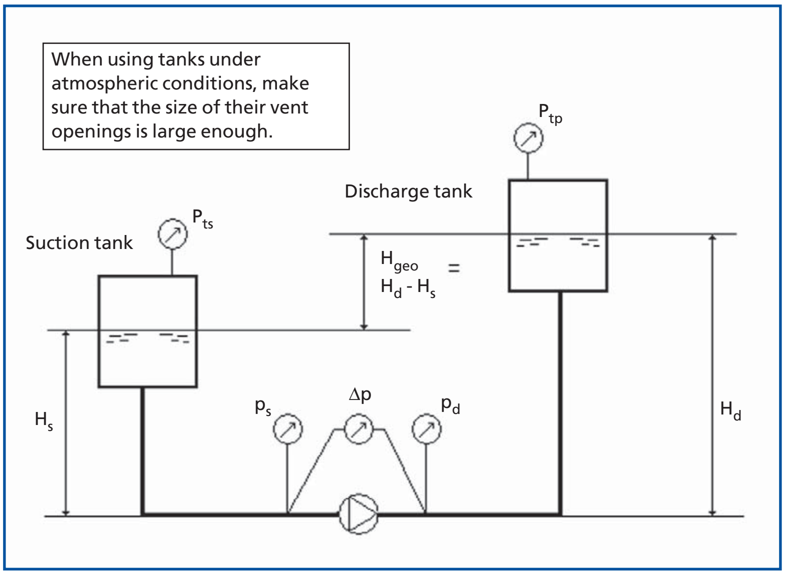

Figure 1. Example A: the geodetic differential head consists of the vertical difference in height between liquid surfaces in the suction and discharge tanks.

Pump manufacturers' role

As a socially responsible organization, Europump pays a lot of attention to the saving of energy with pumps. Of course the associated pump manufacturers are doing their best to develop new pumps with a higher efficiency rate. But in many cases it turns out that the largest energy saving can be achieved by simply improving the installation design. With this in mind, in 2006 Europump compiled a guide for designers of pump systems called *System Efficiency*. By following the guidelines it is possible for designers to increase the efficiency of both their existing pumps and future models. In many cases this can also lead to a considerable reduction in maintenance, killing two birds with one stone.

"If designers made pumps more energy efficient we would immediately need fewer power stations."

Where should we start?

Pumps are usually used to make fluids flow through pipes by an increase in pressure. This is mostly the case when we want to transport fluids in storage or in production systems from one place to another. It is also often the case when we want to transfer heat through cooling or heating systems, using circulating water or oil as the carrier.

Of course, any such units need to meet our requirements. They should be neither too small nor too large. However, what frequently happens with a pump that is big enough to meet requirements is that we only use it part load. In general, the output is then much lower than under design conditions, resulting in the consumption of an unnecessary amount of energy. Therefore, it is of the utmost importance to determine as accurately as possible the demands a system has to meet on a daily basis. Once this has been established, it will then be possible to incorporate the resulting design data into the specification demands. The designer can then devise the best system.

The design specifications for a pump system mainly comprise the two most important demands: capacity and differential head. Generally it is not difficult to determine design capacity. But this is obviously not the case with differential head, because this will depend on many factors. The required differential head partly depends on the counterpressure and the vertical differences in height you want to bridge, but will also be affected by friction losses in the piping system. Because friction losses can be of great significance, we will return to this subject extensively in the next article.

Energy consumption

The differential head that the pump has to bridge, not taking into account the flow losses within the system, consists of the counterpressure and the vertical difference in height. A pump will always have to bridge the difference between the lower suction-side pressure p_s and the higher discharge-side pressure p_d (see, for example, Figure 1). So, ignoring flow losses, the pressure difference Δp across the pump is:

$$\Delta p = p_d - p_s$$

When we take a look at a typical system using examples A, B and C (Figures 1-3), we see that in each case the suction pressure can be calculated as follows:

$$p_s = p_{ts} + H_s \rho g$$

where p_s and p_{ts}, the pressure at the suction tank, are in N/m^2 (1 bar = 10^5 N/m^2); height H_s is in m, ρ, the density of the fluid, in kg/m^3; and g, gravitational acceleration, is 9.81 m/s^2.

The discharge pressure is calculated similarly:

$$p_d = p_{td} + H_d \rho g$$

It is then possible to calculate the difference in pressure the pump has to deliver as follows:

$$\Delta p = p_{tp} + H_d \rho g - p_{ts} - H_s \rho g = (p_{td} - p_{ts}) + (H_d - H_s)\rho g$$

In the calculation, $(H_d - H_s)$ is the vertical difference in height that has to be bridged between the two fluid levels. This is known as the geodetic (or static) differential head and is usually denoted as H_{geo}.

The difference in pressure to be delivered by the pump is determined by the differences in pressure in the two reservoirs and by the geodetic differential head, and can be calculated using the following formula:

$$\Delta p = (p_{td} - p_{ts}) + H_{geo} \rho g$$

In the case of centrifugal pumps, the differential pressure is usually referred to as the manometric (or indicated) differential head H_{man} in metres of liquid column. When we want to convert the difference in pressure to a comparable differential head, this can be done as follows:

$$H_{man} = \Delta p/\rho g = [(p_{td} - p_{ts}) + H_{geo}\rho g]/\rho g$$

$$= H_{geo} + (p_{td} - p_{ts})/\rho g$$

To provide the pressure/differential head at a particular capacity the pump requires power, which we can calculate as follows:

$$P = (Q \times \Delta p)/36\eta_{pump}$$

where the power to the shaft P is measured in kW; capacity Q in m^3/h; Δp in bar; and pump efficiency η_{pump} in %/100.

In this case, the electrical power taken from the electricity supply is:

$$P_{elec} = Q \times \Delta p/(36\eta_{pump}\eta_{trans}\eta_{motor})$$

where η_{pump}, η_{trans} and η_{motor} are, respectively, the efficiency (in %/100) of the pump, the transmission (flexible transmission, belt transmission, flexible coupling, etc) and the electric motor.

Let's take an easy calculation as an example. A pump with a capacity of 100 m^3/h, a difference in pressure of 1 bar and an efficiency of 75% will require an output at the pump shaft of (100×1)/(36×0.75) = 3.7 kW.

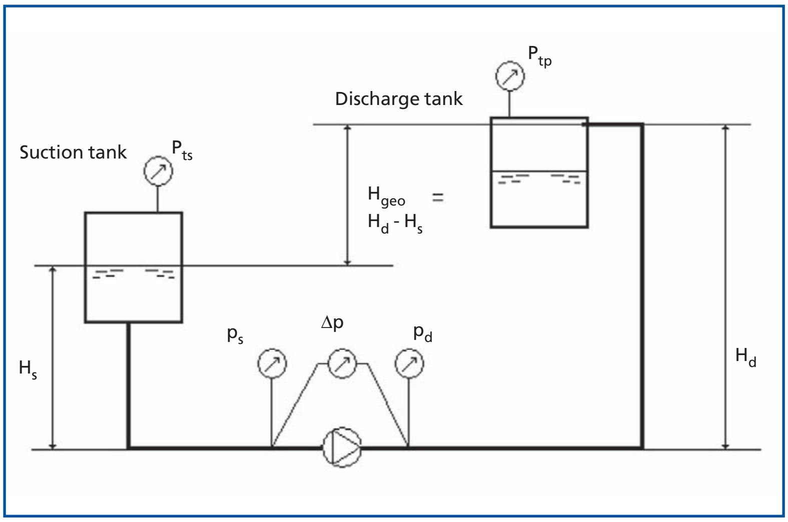

Figure 2. Example B: here the geodetic differential head is higher than in example A.

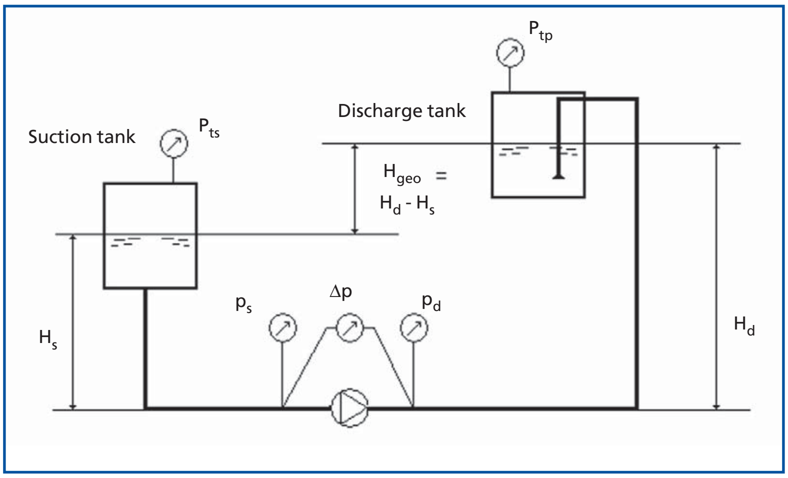

Figure 3. Example C: because of siphon action, the geodetic differential head is similar to that in example A.

If we set the efficiency of the transmission and the electric drive at 90%, then the power taken from the grid is 3.7/0.9 = ca. 4 kW. So, for every operating hour this pump will cost us ca. 4 kWh. For a pump with a capacity of 50 m^3/h at a difference in pressure of 1 bar this will be 2 kW and 2 kWh, respectively.

Note, when pumping a particular quantity it should be realized that this will always take a certain amount of energy, regardless of the pump's capacity, as the following example demonstrates.

We want to pump 100 m^3 at a difference in pressure of 1 bar. If there is a pump available with a capacity of 100 m^3/h, the pump will operate for 1 hour, have a power uptake of approximately 4 kW and therefore use approximately 4 kWh of electricity in total from the grid. But in the case of a pump with a capacity of only 50 m^3/h, the power uptake will only be approximately 2 kW. For every hour the pump operates it will consume approximately 2 kW, but in order to pump the full 100 m^3 this pump actually has to operate for two hours. The total power used will therefore always remain approximately 4 kWh, regardless of the pump's capacity.

Reduction of energy consumption

If we look again at the formula used to calculate the uptake of electrical power, when trying to reduce energy consumption we should always aim to keep:

- the pump capacity Q as low as possible
- the differential pressure of the pump Δp as low as possible
- the efficiency rates of the pump, transmission and drive all as high as possible.

Pump capacity

The pump capacity chosen should never be unnecessarily high. As we saw in the example above, the choice of pump capacity does not affect energy consumption when transporting a particular quantity. Although with a lower pump capacity the engine power is lower, the pump will operate longer. So the total amount of energy consumed remains the same. However, reduction of the pump capacity is important with closed systems such as heating and cooling systems. When a lesser amount of liquid with a higher difference in temperature is circulated in these systems, less pump energy will be required. Moreover, such circulation systems are often in continuous operation. It is possible to save many hours worth of energy during the time these pumps are operating, simply by reducing the chosen pump capacity.

Differential pressure

With identical pressure in both tanks there is no pressure difference for the pump to overcome. In fact, this is often the case because we usually work with open tanks at atmospheric pressure.

In such cases, you should always ensure that the air in both tanks can flow in and out freely through the vent openings. If the passages are too small, an underpressure in the suction tank and/or an overpressure in the discharge tank can still build up. This is a potentially dangerous situation, as well as an unfavourable one as far as energy consumption is concerned.

Another important issue is the geodetic differential head. Let us look again at examples A, B and C. The fluid levels in the tanks are similar in all three cases. Example A (Figure 1) is the simplest situation. Here, the geodetic differential head is equal to the vertical difference in height between the fluid levels in the suction and discharge tanks.

In example B (Figure 2) the pipe to the discharge tank is connected to the top of the tank. The fluid is pumped to this level after which it pours down freely into the tank. Here, the geodetic differential head is unnecessarily higher than in example A and the system will needlessly consume a lot more energy. This situation must be avoided!

"In order to design an energy-efficient system, determine in advance what you want to achieve."

In example C (Figure 3) the situation is a little more favourable because the pipe into the discharge tank extends right down to the bottom. Siphon action ensures that the geodetic differential head is now very similar to that in example A. However, this model is extra vulnerable to malfunction because of the high point in the pipe line where air can collect. This situation should also be avoided as much as possible.

Optimize efficiencies

The efficiency rates of the pump, transmission and drive should all be kept as high as possible. This is a simple guideline but in practice it can be difficult to make the best choices. The efficiency of transmission elements such as flexible couplings, belt drives, etc. is of course always quite high regardless of load. However, the situation is more complicated when it comes to electro-motors and pumps. When striving for energy savings you will of course want to purchase highly efficient pumps and electro-motors, but the efficiency rate will depend largely on the load.

In addition to selecting your system carefully, it is extremely important to choose and use pumps and drives that are specifically designed for the duty. This can be done by calculating what will happen in various operational circumstances. Bear in mind that it does not pay to design a system with the best efficiency at design conditions if the system is only rarely going to be used under these conditions. If, for instance, a heating system is designed for a maximum outside temperature of –10°C, these design conditions will only occur sporadically. It is worthwhile determining what the most common operating conditions will be at an average load profile over the course of the year. If you then design a system so that it operates most efficiently at that capacity, you will be certain of benefiting from a higher efficiency rate over a long period of time.

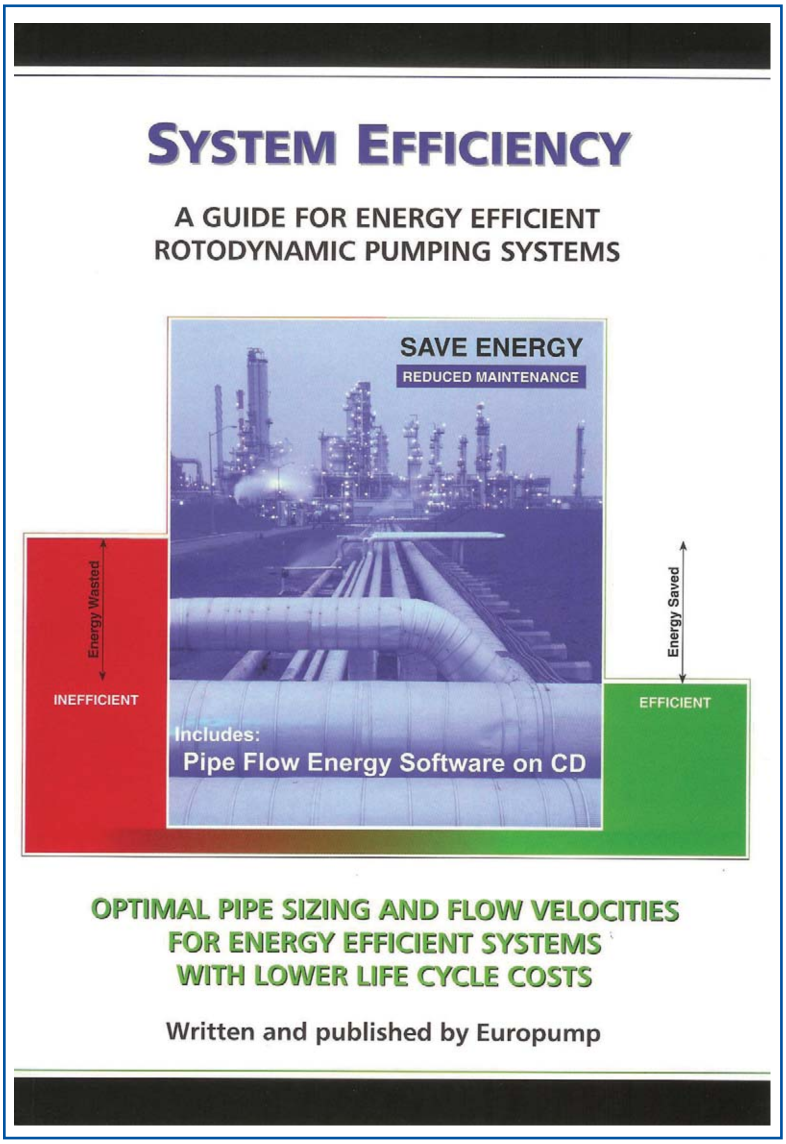

Figure 4. Europump's *System Efficiency* guide has been compiled for designers of pump systems. For more information please refer to www.pumpsupport.nl.

Conclusions

In order to design an energy-efficient system it is necessary to determine in advance what you want to achieve. When pumping a particular volume, the choice of the pump capacity does not make that much difference to the energy consumption. Although with a smaller pump capacity the energy consumption per hour will be lower, it will mean operating for longer. However, in the case of circulation systems it is actually possible to reduce the energy consumption by choosing a smaller pump capacity.

To reduce energy consumption it is also important to keep the differences in pressure as low as possible in your design. Do not forget that, for a difference in pressure of 1 bar, you will need 4 kWh of energy for each pumped 100 m^3 of fluid. So, if you can limit the difference in pressure to no more than 0.5 bar, you will have reduced the energy consumption by 50% to only 2 kWh.

In order to come up with accurate specifications for the most energy-efficient design, with a pump with the lowest possible capacity and differential head, the operating demands over a whole year should be taken into account. These will indicate under which circumstances the system generally operates, so that a system can be designed that operates optimally under those conditions. ■

Contact
Hans Vogelesang
PumpSupport (NL)
Charley Tooropstraat 38
3343 RE Hendrik Ido Ambacht
The Netherlands
Tel: +31 78 682 0602
Fax: +31 78 682 1833
E-mail: info@pumpsupport.nl
www.pumpsupport.nl

About the author
Hans Vogelesang is director of PumpSupport, an independent consultancy for the design of pump systems in Hendrik Ido Ambacht, The Netherlands. He is also a lecturer in pump engineering at several educational institutes.

This article was originally published in Dutch in *Fluids Processing Benelux*.