Energy efficiency

Pump choice to optimize energy consumption

In this fourth article in a series on energy savings in pumps, Hans Vogelesang of PumpSupport discusses the factors that must be considered when choosing a pump in order to optimize the energy consumption of the system.

The most important aspect in the choice of a pump is its energy consumption. After purchasing a pump you generally have to live with this choice during the full life span of the system. Unfortunately in practice the wrong choice is often made. Let’s look at the pitfalls to avoid.

From the three previous articles it should be clear that it is of importance not only to design a system to be as energy efficient as possible but also to use a pump that delivers the highest possible efficiency during the pumping process. This sounds logical but it is easier said than done. We can design an installation to suit the design conditions but in practice an installation is generally rarely used in this specified operating condition.

The correct pump for your system

When choosing the correct pump, many factors have to be taken into account, such as the material resistance, the location, the power, the shaft seal, explosion safety, and so on. Of course it should also be a pump that guarantees a flow with the desired capacity in the system concerned. Because every system differs, the pump has to be selected with care so it is suited for use under all the varying operating conditions for the system in question and will not cause failure or undesired phenomena such as cavitation.

Hence, it is necessary to make an exact calculation for each system before the correct pump can be bought. The system characteristic can be determined on the basis of these calculations, as was discussed before. Once the system characteristic is known we can determine which pump will meet our requirements under all operating conditions that may occur.

The operating point

The design operating condition is that condition at which the pump will deliver the correct amount of flow at the desired design conditions. This amount is usually determined by a desired filling speed or quantity of cooling water, but how do we determine the required differential head?

We will illustrate this with the installation shown in Figure 1, which contains a pump to convey a liquid from a supply reservoir to a higher-positioned delivery reservoir (discharge tank). The
differential pressure demanded from the pump consists of the geodetic differential head plus the friction loss in the suction and discharge pipes. The pump will have to be able to deliver enough pressure at the desired capacity, \( Q \). When starting to fill up the delivery reservoir the geodetic differential head is low, but as the level in this reservoir rises the geodetic differential head, \( H_{geo} \), increases as well. The fall in the liquid level in the supply tank further increases \( H_{geo} \). So, to determine the highest differential pressure required you have to start with the situation of the highest geodetic differential head. This situation occurs when the liquid level in the supply reservoir is at its lowest and that in the delivery reservoir is at its highest. When the liquid level in the supply reservoir is higher and that in the delivery reservoir is lower the geodetic differential head is lower, and the required differential pressure of the pump will also be lower. This differential pressure reaches its lowest point when the supply reservoir is completely filled and the delivery reservoir is empty. Figure 2 shows the corresponding system characteristics.

Imagine acquiring a pump that at design capacity will deliver enough pressure for the highest necessary geodetic differential head. In accordance with the corresponding system characteristic, this has to be a pump for operational point A (Figure 2). So for a suitable pump this operational point must also be on the pump characteristic. When both characteristics are superimposed the operational point is where they intersect. Operational point A lies on both the system and the pump characteristic curves, for this is the only capacity at which the pump can deliver the exact differential head necessary for the required flow through the system.

This argument also applies to deviant operational conditions and therefore the intersection of the system and pump characteristics always offers an easy reading of what capacity will flow through the system under different conditions. So, in practice, the volume of flow at operational conditions that deviate from the design situation will always differ from the design capacity.

When installing a pump in our system with the pump characteristic shown in Figure 2, the system characteristic will shift in a parallel fashion downwards at decreasing geodetic differential head. The intersection will move to the right on the pump characteristic. You will see the pump capacity increase when the differential head in the system decreases. In the situation with the lowest geodetic differential head the capacity has increased to point B.

In practice the volume of flow will always be higher than the specified design capacity. This is rarely a problem and is often considered to be an advantage. After all, under all deviant circumstances the discharge reservoir will always be filled faster than under the design conditions. This needs a comment though. First of all the danger of cavitation arises but, when designing an energy-efficient installation, we also have to take into account the efficiencies between the shifting operational points.
Design operational point at highest head

With a pump that is well suited for the design capacity and the maximum required differential head, the highest pump efficiency will be at the design operational point. This situation is shown in Figure 3. However, as soon as the differential head drops below the optimal value, the operational point of the pump shifts to the right on the curve. (NB: You run the risk of ending up in the cavitation region!)

Because the maximum efficiency is tied to the design condition, as the differential head decreases and pump capacity increases the efficiency will decrease more and more. So with this choice you run the risk not only of cavitation but also that the efficiency of the pump will always be lower than the optimal attainable efficiency. Maximum efficiency only occurs in the extreme situation where the supply reservoir is empty and the discharge tank is completely full. In practice you will always use more energy than necessary. This is not an energy-efficient solution.

Design operational point at lowest head

This situation is shown in Figure 4. The pump has its design operational point at the design capacity and the lowest geodetic differential head. In this situation the pump has optimal efficiency when the supply reservoir is completely full and the delivery reservoir is completely empty. As soon as the differential head increases and the system (piping) characteristic shifts upwards, the intersection of the system and pump characteristics will move further left on the pump characteristic curve. This means that the pump capacity decreases and the flow rate will be lower than the desired design capacity. This results in a longer period to fill the delivery reservoir than required or permitted. Moreover, the pump efficiency will decrease continuously as the tank is filled. This choice will also result in using more energy than necessary, which means this is also not an energy-efficient solution.

Moreover, the risk exists that the pump capacity may decrease to the minimum permitted flow rate or lower, or that the pump will not be able to reach the maximum necessary differential head at all. In that case the pump will operate without any flow. This is very bad for the pump and must be avoided under all circumstances!

Design operational point at average head

In this situation a pump is chosen with its optimal operational point at the design capacity and a differential head between minimum and maximum. This choice is shown in Figure 5. As can be seen, in practice the capacity can sometimes be higher and sometimes lower than the design capacity but the efficiency will always be around the optimal value, $\eta_{\text{max}}$. Generally, this is the most energy-efficient solution and, moreover, the operational point will remain within the preferred operating range (POR). The POR is the working range that is usually specified from ca. $0.9Q_{\text{opt}}$ to $1.1Q_{\text{opt}}$ (where $Q_{\text{opt}}$ is the optimal capacity). Within the POR, all the operating conditions are more or less equal to those at the design specifications of the pump. The efficiency is optimized and all the flows, hydraulic and mechanical loads are optimal. You will have an operational situation for your pump with the best possible performances, minimal energy costs, optimal life time and minimal maintenance costs.

Note that in this situation the capacity is sometimes higher than the design capacity and you will have to prevent the risk of cavitation.

Things to take into account

Whatever pump we choose, in practice the pump capacity will always deviate from the design capacity if the operational conditions of the pump system vary. The scale of these deviations will evidently depend on the process specifications but the choice of the pump will also be a significant factor.

If the chosen pump has a characteristic curve that is flatter than that of the pump
in Figures 3, 4 or 5, the intersections with the system characteristics will be much further apart. This will increase the capacity variation.

In the case of a steeper pump characteristic, however, the capacity variation will be much smaller. In practice, the operational point of the pump will remain more often within the POR even for large variations in the process conditions, with all the advantages thereof. Moreover, the chance of cavitation is reduced.

So it is important not only to determine the design operational point precisely but also to know what the pump characteristic looks like in all cases. Most pump suppliers and manufacturers have the pump characteristic available on request or even print them in their sales documentation. Take into account, however, that no guarantee can be derived from the shape of these graphs. The pump manufacturer will supply the pump you ordered for the design operational point you specified, but operational points for other capacities and differential heads of the pump characteristic cannot always be guaranteed. If the shape of the pump characteristic curve is of vital importance to your business, specify a second or third design operational point in your order.

Another important aspect is the purchase price of the pump. Too often a pump is chosen that has a cheaper purchase price but also an efficiency that is somewhat lower than a more-expensive alternative. Do not forget you will earn back your purchase costs rather quickly with the slightly more expensive pump because during operation you will have lower energy costs and often also less maintenance costs. Through analysing the total costs across the entire installed life span (TLCC, total life cycle costs; or TCO, total cost of ownership) of the various alternatives you can always make an informed purchase decision.

Conclusion
For an energy-efficient pump installation it is important when choosing the pump to take into account all the situations that might arise during operation. In that case, the performance of the pump will not only be high at a specified design situation, but will also remain reasonably high under all deviating process conditions.

Also take care that the pump characteristic is not too flat. This requires an extensive calculation and careful pump selection but when you take this into account you can purchase a pump with an operational point that will remain within the POR as much as possible under varying circumstances. This will guarantee a stable and failure-free process with a long pump life and minimal energy and maintenance costs during the installed life span. It should be clear that misguided economy when purchasing a pump will lead to higher costs over the total life span of the installation.

References

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