New decanter generation with improved energy efficiency

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Decanter centrifuges have been used for many decades in the field of mechanical process engineering for separating mixtures. Nowadays, decanter centrifuges can be found in a wide range of applications in the food and chemical industries. Constant improvements have consistently increased the process engineering performance of the decanters. Depending on the specific size, the throughput capacities of modern decanters are between 1m³/h and 200m³/h.

In recent years, technical developments have increasingly focused on energy consumption as a result of higher costs and increased environmental awareness. This document explains the fundamental principles for calculating the energy requirement of a decanter centrifuge, and also identifies technologies which help to reduce the energy requirement of a decanter centrifuge by up to 30%.

1. Structure of a decanter

Figure 1 shows a cross-section of a decanter. The heart of the decanter is the bowl with the scroll. Both ends of the bowl rest in roller bearings. In turn, a scroll rests in bearings in the bowl. The scroll rotates at a lower relative speed compared with the bowl, and thus causes the solids to be conveyed. The mixture to be separated is fed into the scroll via a central tube. As a result of the high centrifugal forces, the heavy particles are separated from the liquid phase in the bowl. The clarified liquid flows through the scroll flights towards the bearing hub. The liquid is discharged through axial apertures in the bearing hub. The solids are transported to the discharge apertures along the cone as a result of the relative movement between the scroll and the bowl. The solids are discharged through the discharge apertures. They have to be conveyed against the centrifugal force of the particles along the cone. Depending on the product which is involved, the high centrifugal forces result in a range of torques. The torque which occurs between the scroll and bowl is generated via a gear. The power required for conveying the solids is supplied to the gear via a separate motor (secondary motor). In parallel, there is a primary motor which is connected to the rotor via a V-belt drive. The purpose of the primary motor is to supply the ejection power for the clarified liquid and separated solids. The primary motor also provides the idling power.

- Fig. 1: Cross-section of a decanter

a) Basic power requirement of the decanter without throughput (idling power)

Further information:
b) Ejection power for fluid and solids

c) Power for conveying the solids through the scroll

The mechanical power is defined as the power on the drive shaft of the motors. The electrical power of the decanter also compromises the internal energy losses of the motors and any other modules in the control unit. Particular mention also has to be made of a frequency converter which is frequently installed upstream of the motors.

The following diagram shows the entire electrical power requirement for a decanter as a function of throughput capacity. The diagram is applicable for a decanter with a bowl diameter of 400mm and a constant speed of 4300 rev/min.

The idling power is always constant, irrespective of the throughput. The performance requirement for the ejection power increases in line with the product throughput. This is also applicable for the conveyance power for the solids in the bowl. The electrical losses increase proportionately in accordance with the total mechanical power required for the primary motor and secondary motor.

Figure 3 breaks down the total energy requirement into the individual components for a specific product throughput of 36 m³/h.

Figure 3 shows that the ejection power of the clarified liquid is the most significant element (namely 45%) of the total power requirement. This is followed by the idling power (26%). The percentage of the transport power for the solids in the bowl is relatively small, namely 7% of the total electrical energy. This is also applicable for the ejection power for the solids. An aspect which is worthy of note is that losses in the frequency converter and rotors account for 30% of the total electrical energy requirement.

The above example is applicable only for a specific product application. A change in the solids concentration may result in a shift in the break-down of the performance components.

The individual power components are analyzed and possibilities of saving energy are identified in the following.
2. Analysis of the power components

The total mechanical power of a decanter can be calculated as the sum of the following elements:
\[ P_{\text{mech, total}} = P_{\text{drive}} + P_{\text{friction}} + P_{\text{transport}} \]

In the equation (1) \( P_{\text{transport}} \) defines the mechanical power required for transporting the solids in the bowl. This power is generally provided by the secondary motor. The other power components are covered by the primary motor. As detailed in figure 1, the primary motor is linked to the bowl via a belt drive, whereas the secondary motor feeds its power directly into the gear via a coupling. For the belt drive, equation (1) takes account of additional friction as a result of slip \( s \). The driven pulley has a driven velocity \( v \) which is lower (by the slip) than the driving pulley on the primary motor. The other power components are covered by the primary motor. As detailed in figure 1, the primary motor is linked to the bowl via a belt drive, whereas the secondary motor feeds its power directly into the gear via a coupling. For the belt drive, equation (1) takes account of additional friction as a result of slip \( s \). The driven pulley has a driven velocity \( v \) which is lower (by the slip) than the driving pulley on the primary motor. As detailed in figure 1, the primary motor is linked to the bowl via a belt drive, whereas the secondary motor feeds its power directly into the gear via a coupling. For the belt drive, equation (1) takes account of additional friction as a result of slip \( s \). The driven pulley has a driven velocity \( v \) which is lower (by the slip) than the driving pulley on the primary motor.

\[ P_{\text{friction}} = M_{\text{friction}} \cdot \omega_{\text{friction}} \]

Equation (3) using the formula for friction torque \( M_{\text{friction}} \) as shown in
\[ M_{\text{friction}} = \tau_{\text{Friction}} = \sigma_{\text{Friction}} \cdot D_{\text{Bowl}} \]

and the shearing stress \( \sigma_{\text{Friction}} \) between the ambient air at the surface of the bowl.

\[ \tau_{\text{Bowl}} = \frac{1}{2} \cdot \mu_{\text{Bowl}} \cdot \left( \rho_{\text{Amb}} \cdot \frac{D_{\text{Bowl}}}{2} + k \right) \]

Further transformed as follows
\[ \eta_{\text{Bowl}} = f_{\text{Bowl}} \cdot \rho_{\text{Amb}} + \frac{3 \cdot \tau_{\text{Bowl}}}{\mu_{\text{Bowl}}} \]

\[ P_{\text{friction}} = \frac{1}{2} \cdot \mu_{\text{Bowl}} \cdot \left[ \rho_{\text{Amb}} \cdot \frac{D_{\text{Bowl}}}{2} + k \right] \cdot D_{\text{Bowl}} \]

Equation (4) shows that the idling power very much depends on the speed \( n_{\text{Bowl}} \) and the diameter \( D_{\text{Bowl}} \) of the bowl.

Both parameters are combined in the peripheral velocity \( u_{\text{Bowl}} \).

The idling power increases with the third power of the peripheral velocity of the bowl. Because of the complex correlation of the friction coefficient \( f_{\text{Bowl}} \) of the peripheral velocity of the bowl and the surface roughness of the bowl, it is very difficult to directly calculate the idling power using equation (4). However, the idling power can be established empirically by measuring the power of the primary motor. The following diagram shows idling powers measured for decanters with two different bowl sizes. Graphs with a polynomial of the third degree show a very good correlation with the measurements, and confirm the fundamental correlations shown in equation (4).

However, for a decanter which is larger by a factor of 1.6, and with the same peripheral velocity \( u_{\text{Bowl}} \), the measurement shows a smaller increase in the idling power than was originally anticipated in accordance with equation (4). An explanation can be found in the friction coefficient \( f_{\text{Bowl}} \). The friction coefficient \( f_{\text{Bowl}} \) for the larger decanter declines as a result of the larger Reynolds number of the rotor flow and the smaller relative roughness of the surface.

The operation of the bowl in a vacuum can be mentioned at this point as an interring measure for reducing the idling power. According to equation (4), the density of the ambient air \( \rho_{\text{Amb}} \) has a directly proportionate influence on the idling power.

If a vacuum is created in the internal housing of the decanter, the friction can be eliminated almost completely. However, because of...
2.2 Ejection power

Apart from the idling power, the ejection power for the solids and the clarified liquid is the main power element which has to be provided by the primary motor. The ejection power for the clarified liquid or the solids can be calculated in accordance with the formula:

$$P_{eje} = \dot{m}_{\text{fluid}} \cdot a_{\text{eje}}$$  \hspace{1cm} (5)

with the specific energy $a_{\text{eje}}$ in accordance with Euler’s turbine equation:

$$a_{\text{eje}} = u_{\text{inlet,2}}^2 + c_{\text{inlet,2}}^2 - u_{\text{inlet,1}}^2 - c_{\text{inlet,1}}^2$$  \hspace{1cm} (5a)

using the velocities at the inlet and the outlet of the bowl. In equation (5a), the indices 1 and 2 each define the status of the fluid at the inlet and outlet of the balance scope. Because the solids and the clarified liquid are discharged from different places on the bowl, the power figures are calculated separately. The following diagram shows the balance scope of the bowl with the statuses for the inlet and outlet of the clarified liquid. The suspension is fed into inlet 1 in the centre of the bowl. The clarified liquid is discharged from the balance scope of the bowl via axial bore holes in the bearing hub at point 2. The ejection diameter for the liquid is adjusted by means of a regulating ring. The peripheral velocity $u_{\text{inlet,1}}$ can thus be calculated with the regulation ring diameter. The velocity $c_u$ in equation (5a) defines the velocity component of the fluid in the peripheral direction in the stationary system. Because the suspension is fed into the centre of the bowl, the second term in equation 5a is zero. The fluid is discharged in the axial direction at outlet 2. However, for a stationary observer, the liquid is rotating simultaneously with the velocity $u_{\text{inlet,2}}$. Accordingly, the velocity $c_u$ is $c_u = u_{\text{Bowl,2}}$. For the ejection power of the clarified liquid, this accordingly results in

$$P_{eje,\text{fluid}} = \dot{m}_{\text{fluid}} \cdot u_{\text{Bowl,2}} \cdot c_{\text{u}}$$  \hspace{1cm} (6)

The ejection power for the solids can be similarly calculated. The inlet 1 is identical for the solids and clarified liquid. The point at which the solids are discharged from the bowl is defined by the external diameter of the apertures in the bowl wall on the solids side. Assuming that the solids are discharged in a purely radial direction out of the apertures of the bowl, the equation power for the solids, similar to equation (6), is as follows

$$P_{eje,\text{solid}} = \dot{m}_{\text{solid}} \cdot u_{\text{Bowl,2}} \cdot c_{\text{u}}$$  \hspace{1cm} (7)

According to equations (6) and (7), the ejection power for fluid and solid increases in line with the product throughput.

The square of the speed of the decanter is included in the ejection power via the peripheral velocity of the bowl. The ejection power can be calculated directly from the geometry of the bowl and the process parameters. As is the case with the idling power, correlation with measuring data is not necessary.

The equations (6) and (7) can be used to derive approaches for reducing the ejection power. The ejection power declines in line with the reduction in the peripheral velocity at the ejection points of the bowl. The peripheral velocity at the regulating ring and the solids discharge can be reduced by reducing the speed. However, this also results in a reduction of the clarifying surface and thus the process engineering performance of the decanter. A reduction in the diameter of the regulating ring or the diameter of the solids discharge also reduces the peripheral velocity, although this does not have a negative influence on the clarifying performance of a decanter. There are design limitations to any intended reduction in...
Let of the energy jet is purely tangential. The velocity \( w_{D2} \) depends on bowl rotation. In equation (8), it is assumed that the flow at the outlet of the energy jets in the rotating system, i.e. relative to the well as the number and size of regulating ring vanes. It can only be adjusted via the adjusting diameter \( D_2 \). \( D_2 \) has to be set as a function of the solids discharge diameter \( D_{fa} \). This is applicable particularly for incompressible solids (e.g. crystals) which are dewatered at the end of the conical section near to the solids discharge. For compressible sludges, a frequently chosen solution involves hydraulic support for conveying the material. In this case, the adjusting ring diameter \( D_2 \) is smaller than the solids discharge, and a solids seal is created in the conical section. In both cases, the reduction in the diameter \( D_2 \) is linked to the solids discharge. The aim of the design of modern decanter centrifuges is to reduce the solids discharge diameter in relation to the interior diameter of the bowl. Modern decanter centrifuges have a \( D_{fa}/D_{int} \) ratio of <0.5. Compared with older designs, this ratio has been reduced by more than 10%. Because the square of the ejection diameter is included in equation (5), this results in the formula

\[
P_{\text{scroll}} = \frac{P_{\text{trans}} \cdot \beta_{\text{diff}}}{\eta}
\]

(10)

The conveyor torque and the differential speed for the scroll is generated via a gear, as shown in figure 8. The primary motor drives the bowl via belts. The secondary motor is connected to the input shaft of the gear. In the example shown in figure 8, only the secondary motor supplies power to the gear for conveying the solids. The gear increases the torque of the secondary motor, and also creates the differential speed between the bowl and the scroll. Within the gear, additional losses are incurred during the conversion of torque and speed. The difference between the power supplied at the input shaft of the gear and the output power can be described by the efficiency \( \eta_{\text{gear}} \). The mechanical power supplied at the gear is thus defined as:

\[
P_{\text{gear}} = P_{\text{trans}} / \eta_{\text{gear}}
\]

(11)

The efficiency of a modern decanter gear is between 85 % and 95%. The main sources of losses are the flexing action of the oil between the teeth of a gear. The conveyor capacity of the solids in the bowl is generally relatively minor in relation to the total power requirement (approx. 10%). However, for applications with high differential speeds (>40revs/min) or a high solids content (>20%), the %age of total performance may increase to a level far beyond 10%.

Figure 8 shows a regular differential drive. The Summation-Drive is further development of the differential drive. It is characterized by the fact that one gear can be used for various differential speed ranges. Power is only supplied to the system without circulating power in any way. Figure 9 shows the SummationDrive. The left-hand side of figure 9 shows the SummationDrive for the lower differential speed range of 1-25revs/min. The hollow shaft at the inlet of the gear which is highlighted in red is in this case fixed via the hollow shaft in the SummationDrive. The drive is further development of the differential drive. It is characterized by the fact that one gear can be used for various differential speed ranges. Power is only supplied to the system without circulating power in any way. Figure 9 shows the SummationDrive. The left-hand side of figure 9 shows the SummationDrive for the lower differential speed range of 1-25revs/min. The hollow shaft at the inlet of the gear which is highlighted in red is in this case fixed via a bracket. The entire power for conveying the solids is provided via the secondary motor. A frequency converter is used to control the secondary motor, which means that the speed of the motor can be varied, enabling various differential speed to be adjusted in the range 1 to 25revs/min. If a higher differential speed is required, the hollow shaft is driven by the primary motor via a belt, as shown on the right in figure 9. The differential speed range is now shifted to
25-50revs/min. According to equation (11), if the differential speed doubles, and if the torque remains the same, the power must be doubled. The additional power for the higher differential speed is supplied by the primary motor in the Summation-Drive. The primary motor handles the power element for the basic differential speed (in the above example 25revs/min). The secondary motor supplies the controlling power range for the interval from 25-50revs/min. If a different pairing of the belt pulley diameters is chosen for the drive of the hollow shaft, a further range is obtained for the differential speed 50-70revs/min. Because of the innovation involving the summation of the power supplied by the secondary motor and the primary motor, the drive is known as the SummationDrive. With the Summation-Drive, differential speeds of 1-70revs/min are possible with one gear. The intervals are approx. 25revs/min in each case. The ranges can be defined by the transmission of the belt pulleys in relation to the drive of the hollow shaft. Three ranges are currently available: 1-25revs/min, 25-50revs/min and 50-70revs/min.

2.4 Influence of speed
Chapters 2.1 to 2.3 have developed a physical model which can be used to calculate the mechanical power requirement of a decanter. If the process parameters are known (product throughput, solids concentration,…), it is possible for the power requirement of the decanter to be calculated in advance, and the optimum size of motor can be chosen for the specific application. The performance of a decanter is influenced by its geometry and also by the speed or bowl speed and throughput. Figure 2 has already shown how the power for a fixed speed increases in line with the throughput. Figure 10 shows the change in power as a function of the speed for a fixed throughput of 36m³/h.

The power requirement of a decanter increases in line with the bowl speed in accordance with a polynomial of the third degree. In the example shown in figure 10, the ejection performance which increases with the square of the bowl speed is the predominant factor. In order to reduce energy, the aim should be to achieve a low bowl speed; however, the clarification throughput also rises and falls with the square of the bowl speed. As a result of these conflicting objectives, a reduction of the bowl speed must be adjusted individually to meet the requirements of the specific process.
The electrical rating of a motor can be calculated with the aid of the efficiency from the mechanical performance in accordance with

\[ P_{\text{Electrical, total}} = \frac{P_{\text{Electrical, mech}}}{\eta_{\text{Mech}}} \]  

(12)

In general, three-phase induction motors are used in decanters. According to the standard IEC/ EN60034-30, the efficiencies of induction motors are classified in various classes. Figure 11 shows the efficiency classes for quadripolar induction motors.

Overall, there are three efficiency classes IE1 to IE3 for the efficiencies. The efficiency IE1 was the standard class until as recently as 2010. However, as a result of legal regulations, only motors with an efficiency class of IE2 or better are nowadays approved in many countries. Where possible, GEA Westfalia Separator only uses motors of the efficiency class IE2 or IE3.

As a result of the changeover from IE1 to IE2 motors, it is possible to achieve an increase of up to 10% in the efficiency particularly in the case of motors of relatively low ratings of up to 10kW. However, for a mid-size motor with a 45kW rating, the increase is only 1 %age point (from 92% to 93%).

Compared with the other measures detailed above, the use of IE2 motors for decanters generally makes only a minor contribution to power reduction. Conversely, an efficiency of 93% for a 45kW motor is reflected in a power loss of 7%. However, this is only applicable if the motors are operated on mains power. If the motor is driven via a frequency converter, different electrical losses are encountered as a result of the power conversion in the frequency converter of approx. 5%. However, in general, the frequency converter is only required for starting the centrifuge. If it were possible for the motor to be operated directly on the mains in stationary operation, it would be possible to avoid the 5% additional losses due to the frequency converter. GEA Westfalia Separator offers a special type of starting up a decanter for the new CF decanters. As shown in figure 12, the frequency converter of the secondary motor can be used for starting up the primary motor. When the primary motor has attained its nominal speed, it switches over to mains operation.

The frequency converter is then switched to the secondary motor and is then used for regulating the differential speed. The special feature of operation is that the frequency converter of the secondary motor performs two tasks. Firstly, it is used for starting the decanter, and secondly, it is subsequently used for regulating the differential speed via the secondary motor in stationary operation. A saving of a frequency converter in the control unit is thus achieved.

3. Specific energy consumption

The specific energy costs per processed cubic meter of product are very frequently relevant for calculating the operating costs of a decanter. The specific energy requirement is also very frequently used as a parameter for comparing various decanters. However, there are no fixed regulations for considering the energy requirement. For instance, mechanical power is occasionally considered to be equivalent to electrical power. Equally, when flocculants are used, it is necessary to establish whether the specific energy requirement relates only to the product stream or to the sum of product stream and flocculants. The following explains how the specific energy requirement is determined for a decanter in the CF series.

The hydraulic flow comprises all additions to the product stream, such as dilution water or flocculants. The diagram shows two curves. The area between the two curves shows the %age of conveyer power. The torque and differential speed are fluctuating parameters during operation, and it is accordingly necessary for a range to be specified at this point. The lower curve represents a situation in which there is no conveyor power of the scroll. The upper curve illustrates the situation in which the conveyor power is 100% of the secondary motor. The maximum power is...
only achieved in conjunction with the combination of 100% torque of the gear plus maximum differential speed. This situation is relatively rare. 80% of applications are operated in conjunction with medium differential speeds and medium torque. According to equation (11), the conveyor power in this case is only 25% of the maximum power. We therefore always tend to be in the quarter of the range for the conveyor power. The curves in figure 13 are applicable only for one bowl speed and one regulating ring setting. If the diameter of the regulating ring is changed, the energy requirement also changes. The electrical rating is specified for mains operation of the primary motor. If, during stationary operation, the primary motor is actuated via a frequency converter, the readings must be increased by a further 5% in view of the energy losses of the frequency converter. The specific energy requirement constantly declines as the product throughput increases, as the fixed idle capacity is related to a larger volume stream. The specific energy requirement asymptotically approaches the specific ejection power with increasing product throughput.

As can be seen in figure 13, the current example shows a specific energy consumption of 0.7 kWh/m³ for the maximum clarifying throughput of 45 m³/h. As a result of using energy jets, the specific energy requirement declines by a further 10% to 0.63 kWh/m³. Compared with older decanter types, the new CF series in total enables savings of 30% to be achieved with regard to the specific power requirement.

Formular sign:

- \( a \) = Specific work
- \( A \) = Surface area
- \( c_f \) = Air friction coefficient on rotating bowl
- \( c \) = Flow velocity in the absolute system
- \( D \) = Diameter
- \( H \) = Pond depth
- \( k \) = Adaption constant to the bowl surface
- \( m \) = Massflow
- \( M \) = Torque
- \( n \) = Speed
- \( P \) = Power
- \( Q \) = Volumeflow
- \( L \) = Length
- \( s \) = Slippage
- \( u \) = Peripheral speed
- \( v \) = Velocity
- \( w \) = Rotary frequency
- \( \omega \) = Drehfrequenz
- \( \rho \) = Density fluid
- \( \tau \) = Shear stress rotating flow to surface

4. Summary

This article describes the power elements which are encountered during the operation of a decanter. The new CF decanter series is used to show what new innovations are being introduced in order to reduce the power requirement. These include a pond depth version of the bowl, a new SummationDrive as well as energy jets or an optimised method of starting-up the decanter. In total, the energy requirement has been considerably reduced. An example is used to show that the specific energy consumption of a decanter has been reduced to 0.63 kWh/m³.

Energy-efficient algae harvesting

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1. Solid-liquid separation in process engineering

Mechanical separation methods such as filtration and sedimentation are important stages in many process operations. The quality of the separation process is frequently a critical success factor determining the quality of the final product as well as the cost-effectiveness and environmental friendliness of the process.

The most important criteria for selecting the right separation method are the filtration properties of the product to be separated.

When separating materials with good filtration qualities (crystals and coarse-grained materials), filtering centrifuges, i.e. machines with a screen bowl, are most commonly used. Solid bowl centrifuges such as decanters, disc stack centrifuges, and tubular centrifuges, however, are used for separating materials which are difficult to filter, i.e. suspensions with fine, soft solids which form a paste-like and compressible sediment.

Among the solid bowl centrifuges are models such as decanters which are more solids-oriented and those such as disc stack centrifuges which are rather liquids-