GOUDSMIT MAGNETICS

The value of magnetic flux density measurements for magnetic separators

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Preamble

The main building of Goudsmit Magnetics in Waalre

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We often determine the degree of operation of a magnetic separation system using magnetic field measurements. In that case, we measure the *magnetic flux density* at one or more places in the separator.

We regularly use these measurements – consciously or unconsciously – as the only measure for the separation capacity of magnetic separators. In specific situations, these measurements can provide a sufficient picture thereof, such as for determining the decrease in magnetic force – and therefore separation power – of a specific separator over time. Or to compare the performance of two or more of the same types of separators that are used under the same process conditions.

In general, however, this is not the case and we have to include more aspects than just flux density measurements when determining the separation power of a magnetic separator. This is explained in this document.

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Flux density measurements and their interpretations

A magnetic separation system

To determine how well a magnetic separator works, we often measure the magnetic flux density in the immediate vicinity of the magnet and/or at some distance from it. The unit in which we measure this flux density is Tesla (T), which is the official (SI) unit, or often Gauss (G) (1T = 10000G); an unofficial and somewhat outdated unit.

The most common measurement is in the immediate vicinity of the magnet. Because the magnetic flux density varies across space, we look for the maximum flux density there. The measurement is often not on the magnet itself but on a stainless steel plate or tube around the magnet, which function is to increase the lifespan of the magnet and to meet hygiene requirements*. In doing so, we must be well aware that the magnetic flux density can then already be considerably reduced compared to the value on the magnet itself. This is because the magnetic flux density close to a magnet quickly decreases in magnitude with increasing distance to the magnet. This decrease can be considerable even over a few millimetres. This also implies that measurements never indicate the flux density directly on the magnet – or stainless steel sheet or tube around it – but a lower value: a measuring instrument (see figure on page 3) has a certain thickness and therefore measures at some distance from the surface.

The magnetic flux density in the immediate vicinity of a magnet is one of the determining factors for the force on the particles present here. This makes it a determining factor for the ability of a separation system to capture particles close to the magnet and keep them trapped there (until they are removed via a cleaning step).

Magnetic separators often consist of one or more stainless steel tubes that are placed in the product flow. These tubes contain both magnets and steel plates in which the magnetism is concentrated and guided outwards in the product stream. In the vicinity of these plates, the flux density is greatest. For such magnetic bar-based separation systems, we therefore often look for the maximum value (on the tube) directly above these pole plates when measuring ‘directly on the magnet’.

*EHEDG is a consortium of equipment manufacturers, food industries, research institutes and public health authorities and was founded in 1989 with as most important aim promoting hygiene during the processing and packing of foodstuffs and chemicals.

Flux density measurements and their interpretations continued

Another common measurement when determining the performance of a magnetic separator is a flux density measurement at a certain distance from the magnet. We use this measurement as a measure of the depth of the holding field. For this purpose, a target value of several hundred Gauss is often chosen and we determine the distance to the magnet where we measure this value. Goudsmit uses, for example, the target value of 0.3mT (300G). This value was chosen based on experiments, in which particles above a bar magnet are released and it is determined at what distance this magnet still attracts the particles.

The magnetic flux density at a certain distance from the magnet is indeed one of the determining factors for the force on the particles present here. This makes it a determining factor for the ability of a separation system to attract particles at that distance and attract them to the magnet.

Measurements of flux densities in magnetic separators can be carried out relatively easily using one of the widely available flux density meters (and possibly using some support pieces). As a consequence, these measurements are popular. However, even though magnetic flux densities determine the separation capability of a separator, they are *not the only* factors.

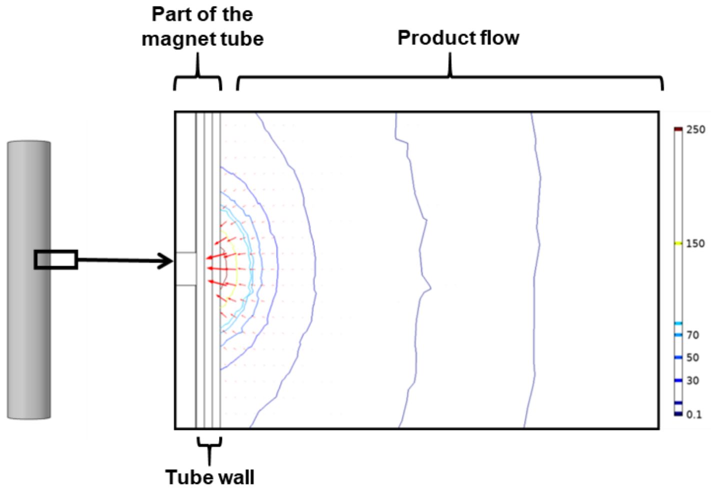
Consequently, these measurements can only be used to a limited extent to determine or compare the performance of one or more magnetic separators. This is for example the case when determining the decrease in magnetic force of a specific separator over time (for example, by high temperatures) or when comparing the performance of two or more of the same type of separators that are used under the same process conditions.

In the rest of this document we will discuss which other factors we need to obtain a complete picture of the separation capability of a magnetic filter.

The magnetic flux density alone is not enough – the Force Index

The magnetic force on a particle to be captured is not only a function of the magnitude of the flux density, but also of the *degree of change* of this magnitude *over* space. This degree of change is called *gradient*. To be more precise: if the magnetic flux density in and around a particle to be captured is low, the magnet can still properly capture this particle as long as the gradient of this flux density is high enough. Goudsmit uses this principle in High Gradient magnetic separators (HGMS).

More specifically: the force on a particle to be captured is a function of the multiplication of flux density and its gradient. We refer to this product as *Force Density* of *Force Index* (^{T2}/m). Force Index values at the wall of a magnetic bar around the steel pole plate are shown in the figure below:



*Force Index / Density (T*T/m) near a magnetic bar in the vicinity of a pole plate.*

The Force Index has a direction as well as a magnitude; this is shown in the figure by the direction or length of the red arrows. These indicate the direction and magnitude of the force that works on the particles. The figure also shows contours of constant Force Index magnitude.

The magnetic flux density alone is not enough – the Force Index continued

As can be seen in the previous figure, the Force Index increases as the distance to the pole plate decreases. As the direction and size of the arrows indicate, the particles are drawn towards the pole plate. This also explains why the largest deposits of captured particles can be found near these plates in practice, as can be seen in the figure below.

Magnetic bars used in magnetic separation systems. Particles collect on the tube near the pole plates because the Force Index is highest there.

The deposits on the tube take place approximately over the thickness of the steel pole plates. It therefore seems logical to choose this thickness as much as possible. However, the Force Index values on the tube for the pole plates also decrease with increasing pole plate thickness. The choice for a certain thickness for these pictures is therefore a balance between, on the one hand, a greater holding force of the particles (thin pole plate desired) and, on the other hand, the *capacity* of the separator, i.e. the amount of space on the bar to hold particles (thick pole plate desired).

We calculated the Force Index values in the figure on the previous page using the so-called *finite element method*. Goudsmit makes frequent use of this in the evaluation of magnetic separators, in addition to testing them.

Influence of flow conditions

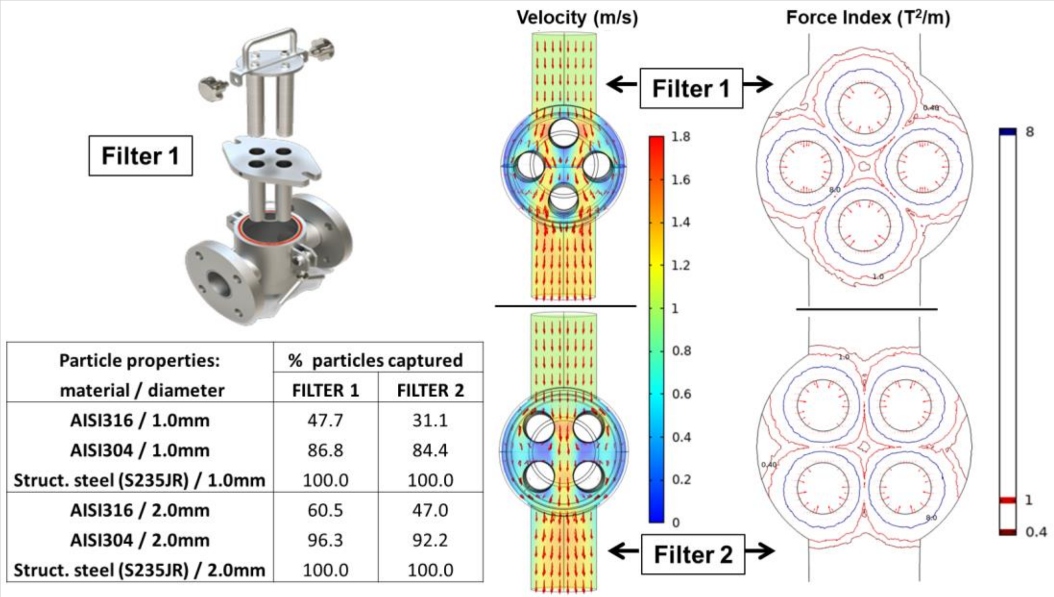
It is also good to realise that the flow conditions (product speed, viscosity, ...) in the separation system have at least as much of an important influence on the degree of separation as the strength and depth of the magnetic holding field. For example, a higher speed will cause a lower separation capability because the particles are given less time to be attracted towards the magnets. The choice of stronger magnets in a separation system will lead to an increased separation capability, but that positive effect cannot be guaranteed if the speed of the product flow in the system increases at the same time.

The viscosity of the product flow also affects the separation potential of a magnetic filter. A higher viscosity of this flow will make it more difficult for particles to flow through the product flow and pull towards the magnets.

A magnetic separator in operation

Influence of flow conditions continued

Not only does the *magnitude* of the velocity of the product stream through the separation system play a role, but also *the pattern* with which this stream flows internally through the system. Another distribution of the flow rates along the magnets of a particular separation system can lead to a different separation performance. This is because particles could flow along the magnets at a higher speed and/or at a greater distance, significantly reducing the chance of these particles being captured. We see this, for example, in the figure below. Here we compare the flow profile and percentage of captured particles for a Goudsmit separation system (Filter 1) with that of the same system under the same flow conditions but with the bars rotated 45° (Filter 2). As we can see, the separation percentage for Filter 2 is considerably lower, particularly for stainless steel AISI 316 particles. The probable cause of this is that a larger amount of particles flows through the middle of the filter, where they do not encounter a tube and where the Force Index is low.

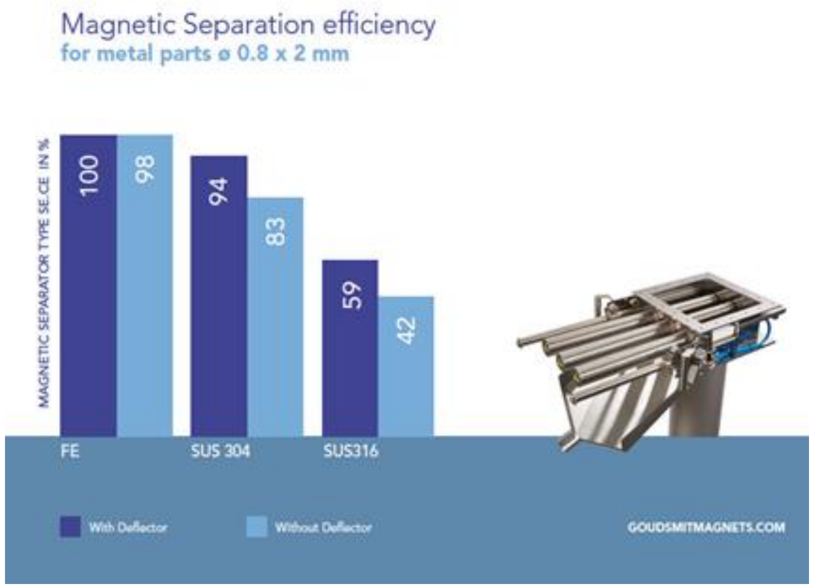


Particle properties: material / diameter	% particles captured	
	FILTER 1	FILTER 2
AISI316 / 1.0mm	47.7	31.1
AISI304 / 1.0mm	86.8	84.4
Struct. steel (S235JR) / 1.0mm	100.0	100.0
AISI316 / 2.0mm	60.5	47.0
AISI304 / 2.0mm	96.3	92.2
Struct. steel (S235JR) / 2.0mm	100.0	100.0

Comparison of the separation capabilities of (i) the SSFN005038 Goudsmit magnetic filter (Filter 1) and (ii) that the same filter with the bar magnets rotated 45° (Filter 2). Water flows through both filters with an inlet speed of 1 m/s and with a pressure at the output of 1 bar.

Particle properties also play a role

As we can clearly deduce from the previous example, the chance of catching a particle in a magnetic separation system also depends on the *material* and the *size* of that particle. N.B. AISI 304 and AISI 316 are less magnetic than structural steel S235JR, which results in lower particle capture percentages. In addition, the *shape* of the particle also affects the chance of being caught. These dependencies are not expressed in measurements of the magnetic flux density.



A Goudsmit magnetic separation system (right) and associated separation capability values, expressed as a percentage of captured particles (left). A deflector is an object - a tube or strip - that is purposely placed in the flow to change the flow pattern and to thereby increase the separation capability.

In the example on the previous page, we again used the finite element method, both for calculating the magnetic field and the velocity and pressure distribution of the product. With *particle tracing we* calculated how many particles of a certain type of steel and with a certain diameter can be captured.

What is the value of flux density measurements when evaluating magnetic separators?

In magnetic separation, the magnetic flux density is a determining factor, but not the only factor for the magnetic force that works on the particles to be captured. As a result, measured flux densities in a magnetic filter are a valid but not sufficient measure for the separation capability of that filter. For the complete evaluation of a magnetic separation system, we must also take into account the gradient of the magnetic flux density (or, equivalently, the Force Index), the flow conditions of the product and the properties of the particles to be captured.

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YouTube:

The relationship between magnetic flux density and separation:
https://drive.google.com/file/d/1SRY0esYJWPIolFgPQaJnLADba6dwQUsS/view?usp=sharing

How to measure magnetic flux densities:
https://www.youtube.com/watch?v=XBqD7HFXWd0

Force index:
https://www.youtube.com/watch?v=zgEG_Baqsrs

FEM - Finite Element Method:
https://youtu.be/97RcfKic3y8
https://youtu.be/OOaClbPLxCs

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