Clarifying filtration is used mainly to remove solid contaminants from a liquid or emulsion in order to reuse it, or to use it as a product. Often the contaminating particles are not suited to building up a sufficiently permeable filter cake with satisfactory thickness and strength so that it can simply be removed from the filter media by mechanical means. In many of those cases, the solid particles are collected on the filter or in its depth, respectively, and disposed of together with it.

For the purification of liquid manufacturing auxiliaries (e.g. cooling-lubricating agents, hydraulic fluids, gear oils, scrubbing liquids), preferably band filters, cartridge filters or precoat filters are used to separate particles in the typical size range of 5…100 μm. These filters are characterized by specific advantages and disadvantages, and are suitable for different fields of application. Especially when small particles of about 5 μm at higher concentration are to be removed from liquids with viscosities above that of water, filtration becomes critical. A diagram of a filter is shown here, which can advantageously complement the stock of filters for such tasks.

1. Targets, working fields and peculiarities of clarifying filtration

Clarifying filtration is typically employed to remove solid impurities from liquids or emulsions, so that these media can be reused, or used as a product. Often the particles separated in this way do not form a sufficiently permeable, uniform and solid filter cake, for which reason cake growth and removal of the filter cake from the filter medium are obstructed. Typical working fields of clarifying filtration are the clarification of liquid end products (e.g. beverages, fuels, chemicals), the clarification of liquid intermediates (e.g. reactants, product components, solvents), and the clarification of auxiliary media used in manufacturing.

Clarifying filtration of such auxiliary liquids (e.g. cooling-lubricating agents, hydraulic fluids, gear oils, scrubbing liquids) is typically applied to limit the concentration of solid particles that could interfere with the reuse of the liquid. Therefore, owing to the recirculation of the auxiliary medium, concentration of solids in the filter inlet is often comparatively low. Low concentrations of solids, however, complicate the cake formation and the cake growth on the filter media, in particular in combination with small particle sizes and higher viscosity.

The cake formation rate \( \kappa \) is defined according to eq. (1) as the increase of the filtered solids mass \( m_{s,K} \) over time relative to the filter area \( A_F \),

\[
\kappa = \frac{dm_{s,K}}{A_F \cdot dt} = c_s \cdot \frac{dV_f}{A_F \cdot dt}
\]

in which \( m_{s,K} \) is obtained as the product of the filtrate volume \( V_f \) and a modified solids concentration \( c_s \). By inserting the well-known Carman equation for cake filtration /1/ into eq. (1), eq. (3) for the cake formation rate \( \kappa \) is obtained.

\[
\kappa = \frac{c_s \cdot \Delta p}{A_F \cdot dt} = \frac{\eta \cdot (R + (r_s \cdot c_s)/A_F)}{R + (r_s \cdot c_s)/A_F}
\]

The mass-specific filter cake resistance \( r_s \) is approximately inversely proportional to the square of the mean size of solid particles. Small particle sizes, high viscosities \( \eta \) relative to the filtration pressure difference \( \Delta p \), and low solids concentrations \( c_s \) thus constrain the formation of a sufficiently thick and heavy filter cake. A particular disadvantage of low solids concentrations is the low probability of bridge formation. Therefore finer filters must be
used in order to avoid turbidity, which, in turn, have a higher filter medium resistance $R$. Thereby, according to eq. (3), cake growth $\kappa$ is slowed even more. Especially with wide particle size distributions, there is also the risk of irreversible filter media clogging. Certain features of the particles (shape, deformation resistance, surface properties) and the particle size distribution can in addition affect the cake formation and solids removal from the filter medium.

Therefore, two strategies are used. Both principally renounce the formation of a sufficiently thick, filtering, completely removable filter cake. In the first case, the solid matter is retained on or in the filter medium, and discarded at least partially together with the filter medium. Precoat filters, filter sheets, disposable filter cartridges and nonwoven band filters work according to this principle. The second strategy uses frequent hydro-mechanical cleaning of the filter medium, in particular periodic backwashing. Back flush cartridge filters and constructed edge filters are typical representatives of this.

2. Clarifying filters for auxiliary liquids

The term “auxiliary liquid” in this paper summarizes those liquids and emulsions that do not become part of the final product but are essential for the correct functioning of a production process or a technical system. Inter alia, these include:

- Cooling lubricants for the manufacturing of components
- Scrubbing liquids for the cleaning of components after machining
- Hydraulic fluids for energy transfer in hydraulic systems
- Lubricating oils for gear units and similar assemblies with wear-sensitive components.

Such fluids are generally circulated and they require loop maintenance that often includes filtration. This ensures the limitation of the solids concentrations and/or the maximum particle size according to the needs of the respective application. Particles that entered in the fluid beforehand as chips or swarf or surface contaminants must therefore be constantly removed from the fluid. The typical size range of particles to be filtered out is $5 \ldots 100 \, \mu m$; larger particles (e.g. chippings) are often separated upstream to filtration by means of sedimentation and/or magnetic separation. Besides filters in isolated operation, centralized systems and mobile filters are utilized, especially for coolants. Both full-flow filtration and bypass filtration is practised. Therefore the filtration of auxiliary media covers immense capacity ranges, from several liters per hour up to several hundred cubic meters per hour and more.

The filtration of auxiliary media is mainly applied in the metal-working industry and in the past has not attracted much attention among chemical and process engineers. This fact, together with the application-specific requirements, led to independent trends and developments, which in some cases differed from those in the chemical and process industry. Robustness, low service and maintenance costs with little capital investment and low running costs are expected to a large extent; specialized process engineering staff are rarely available.

Several band filters with disposable nonwoven filter bands are widely used for the filtration of coolant solutions and emulsions. In basic flat-bed band filters or inclined bed band filters (Fig. 1), nonwoven filter bands from polymeric or cellulose fibers are used as disposable filter media for purely hydrostatic filtration. The filter band forms a trough into which the product to be filtered is fed. While the filtrate is collected below the band, the solid matter that was retained in and on the media reduces its permeability, causing the liquid level in the pool to rise. A float switch then triggers the band drive, whereby fresh fleece is unwound from the roll and dirty nonwoven - if necessary after separate solids removal - is deposited in a sludge collection box, or is wound up on a reel. The simple design and the availability of modular systems for different variations allow cost-effective production and relatively low acquisition costs. Because the band feed is activated depending on load, such a filter adapts itself to variable...
conditions and is therefore robust in this respect and less susceptible to interference.

The relatively slow filtration is accompanied by sedimentation of fast sinking particles that form a precoat, improving the particle retention. However, this segregation makes the filter cake non-homogeneous and may increase the cake resistance, resulting in more frequent band feed and increased filter medium consumption. The fundamental disadvantages of band filters include small usable pressure difference, low compactness \( AF/A_{st} \) (large footprint relative to the filter area) and consumption and waste of filter media. Numerous variations of the basic design try to limit these disadvantages. These include, inter alia, the application of vacuum beneath the filter band, or excess pressure above the band, during the filtration (pressure differences approx. 0.6 bar and/or 1 bar). The sealing of the underpressure or overpressure zones against atmosphere must be resolved during the band feed – which is a technical challenge, basically prone to wear and failure and significantly increasing manufacturing and acquisition costs. Other derivative designs can be made more compact by using several stacked filter beds /2/, or wrapping the band partially around the outer periphery of a submerged, perforated drum that is operated in an inside-out mode /3/. The smallest economically removable particle sizes range - depending on design and application case - from 10 to 100 μm. In the upper particle size range, endless bands with cake removal and band washing instead of disposable non-woven bands are used as well.

Cartridge filters and constructed edge filters /4/ are preferably used for pressure filtration where the liquid flows - typically outside-in - through the filter material of filter elements that are arranged in a filter housing (Fig. 2). The solid matter is separated on and in the filter material. Disposable cartridges and backwashable filter elements are available in a large variety and with typical separation limits down to approx. 1 μm. Constructed edge filters have defined slot-shaped channels for the filtrate flow which widen in the main flow direction. Their lower separation limit is approx. 0.2 μm /6/. In relation to the floor space \( A_{st} \), medium to large filter areas \( AF \) are possible. Disadvantages are the complexity of equipment and the space requirements for precoating and body feed, plus costs for the procurement and disposal of the filtration aids, which also bind additional quantities of the liquid product and hence reduce the filtrate yield.

For clarifying filtration of products that are very difficult to filter (e.g. fermentation products), body feed is traditionally used on pressure filters for cake filtration. Cartridge backflushable filters and centrifugal discharge plate filters are the main types. For precoat filtration, rotary vacuum drum filters are also used, in which the upper, soiled filter aid layer is peeled off pseudo-continuously. The lower separation limit is approx. 0.2 μm /6/. In relation to the floor space \( A_{st} \), medium to large filter areas \( AF \) are possible. Disadvantages are the complexity of equipment and the space requirements for precoating and body feed, plus costs for the procurement and disposal of the filtration aids, which also bind additional quantities of the liquid product and hence reduce the filtrate yield.
3. Evaluation of clarifying filters

The filter principles as described differ substantially in their advantages and disadvantages and their preferential application areas. These differences are illustrated below by means of a fictitious application case. The suitability of the filter principles is verified for compact, isolated “stand-alone” units (i.e. small and medium-sized throughput rates) at filtrate viscosities of 5 cP and higher, solid-volume concentrations Φ ≤ 0.1% and particle sizes d < 20 μm. These conditions may appear isolated or combined and are typical for auxiliary liquids that are difficult to filter. Table 1 overviews the results of evaluation. The viscosity, and the high filter cake resistance, owing to (small) particle sizes, disqualifies hydrostatic band filters; high equipment expenses are arguments against vacuum-operated and pressure-operated band filters, and band filters in general are unfavorable due to large space requirements. Disposable cartridge filters meet almost all requirements but are disqualified by the high expense and workload for cartridge replacement. The rating of back-flush filters is basically moderate; the large concentrate volume, however, is unfavorable. Precoat filters are not particularly suitable for somewhat small “stand-alone” filter systems because of the large floor space required and the effort needed for precoating. Thus the filter principles as evaluated cannot be considered as ideal solutions. The filter systems widespread in the classical process industry, especially in the chemical industry, (e.g. rotary vacuum drum cell filters, horizontal vacuum band filters), might offer advantages, but they often encounter price reservations. A search should therefore be made for filter principles that are easier to implement.

On closer inspection, it becomes obvious that disposable cartridge filters are unsuitable for medium and high solids concentrations, whereas vacuum and pressure-operated band filters can handle them. It seems obvious to maintain the specific advantages of the two filter classes, and to eliminate their disadvantages, through the combination of the principles (see Table 1). A cartridge filter would therefore be desirable whose filter material is renewed automatically and without any cartridge replacement when its limit load is obtained. From another point of view, it would be advantageous to use a band filter in a closed container, designed in a more compact manner than the standard market models and without complicated seals to be released during the band feed. These requirements represent a task for engineering.

4. A suggested solution

Fig. 4 shows schematically how the foregoing task could be performed /7, 8/. The suggested filter system is based on a filter drum whose shell surface is perforated with the exception of the peripheral zones and a bridge connecting them. This filter drum is rotatably placed in a housing or container; the drum axis can be arranged horizontally or vertically. The filter drum is connected with the environment by a hollow rotatable shaft that is guided through the housing wall. The perforated part of the drum shell is covered by a filter band (nonwoven) that reeves off a dispenser roll and ends up on a collector roll. The drum stands still during filtration, which can be pressure or vacuum filtration. The filtrate flows through the filter band into the drum and leaves it via the hollow shaft. When the filter resistance has been reached a limit value, the pressure levels in the housing and the interior of the drum are equalized. Afterwards, the filter drum is turned through one full revolution, whereby the spent leg of the filter band is wound up on the collector roll and is replaced by new material unwound from the dispenser roll. Then filtration can be continued. This cycle of filtration and band replacement can be repeated until the dispenser roll is empty. Not till then do the dispenser roll and the collector roll need to be replaced.

Based on this basic principle, numerous individual designs are conceivable and advantageous (Fig. 5), which can be supplemented by optional additional components. Inter alia, these include:
- dispenser roll and collector roll mounted in a submerged or dry position
- peripheral sealing by means of endless sealing strips and deflecting pulleys
- cake scraper blades and other band cleaning devices
- band pretensioners
- band stock detectors.

A filter system designed in such a way cannot and should not replace the available choice of filters, but it may offer a reasonable extension. Its application range is the filtration of particle-containing liquids and emulsions, in particular in cases where the particles clog up the filter medium instead of building up a thick, well-filtering filter cake. The typical particle size ranges from 5 to 50 μm. Some of the fundamental advantages over the conventional band filters are:
- more compact design; A2/A1 ≈ 2 (i.e. 3…7 x greater)
- 10…300 times greater applicable pressure difference
- better filter medium utilization, i.e. lower media consumption
- applicable with finer media and at higher viscosities
- complete encapsulation extremely simplified
- easier structural design compared to conventional pressure and suction band filters.

Advantages compared to disposable cartridge filters are
- applicable at higher solids concentrations
- filter media replacement frequency lowered by a factor of 10…30 for equal exposure to solid matter
- considerable reduction of filter media replacement costs (labor, material, disposal).

Based on the specific features and benefits, the potential application fields include the maintenance of cooling lubricant circuits that are difficult to filter, clarification filtration of washing fluids, and particle removal from lubricating oil circuits and hydraulic circuits. General application possibilities, apart from auxiliary liquids, are pre-filtration upstream of ultrafiltration or microfiltration systems, as well as polishing filtration downstream of filters and centrifuges.

5. Summary and conclusions

For clarifying filtration of auxiliary liquids, somewhat basic filtering equipment is used, whose principal drawbacks become obvious especially in difficult separation jobs with disabled cake formation and complicated conditions. Common solutions reach their limits especially at rising viscosities of the filtrate, increased solids concentrations and small particle sizes. Increasing use of the more efficient filter equipment widely used in classical process engineering applications will be an alternative. In addition, a simple filter system which combines the characteristics and advantages of band filters and cartridge filters would be able to complete and enrich the range of filter equipment.

List of Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$A_F$</td>
<td>filter area</td>
</tr>
<tr>
<td>$A_{st}$</td>
<td>footprint</td>
</tr>
<tr>
<td>$c_s$</td>
<td>ratio of solid mass $m_s$ in the feed to filtrate volume $V_F$</td>
</tr>
<tr>
<td>$m_s$</td>
<td>solids mass in the feed</td>
</tr>
<tr>
<td>$m_{s,c}$</td>
<td>solids mass in the filter cake</td>
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<tr>
<td>$\Delta \rho$</td>
<td>filtration pressure difference</td>
</tr>
<tr>
<td>$R$</td>
<td>filter media resistance</td>
</tr>
<tr>
<td>$r_s$</td>
<td>mass-specific filter cake resistance</td>
</tr>
<tr>
<td>$t$</td>
<td>filtration time</td>
</tr>
<tr>
<td>$V_f$</td>
<td>filtrate volume</td>
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<tr>
<td>$\eta$</td>
<td>dynamic viscosity of the filtrate</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>cake formation rate</td>
</tr>
</tbody>
</table>

Literature:

/7/ Utility model DE 20 2013 101 108.8, 14.03.2013
/8/ Patent Application DE 10 2013 101 994.6, 28.02.2013