Carbon dioxide is used particularly in the food, beverage, cosmetics and pharmaceutical industry for extracting natural substances, aromas, fats, oils, waxes, polymers, enzymes and colourants in their supercritical physical state. For despite its bad reputation as a greenhouse gas, CO$_2$ is a natural and environmentally-friendly solvent which has advantages over synthetic and harmful media such as n-hexane when it comes to sustainability. Oscillating displacement pumps are ideal for supercritical CO$_2$ extraction.
This process has a long tradition. More than 50 years ago, researchers and developers began working on this issue and the first systems, for example for decaffeinated coffee, were soon developed.

How do we get the caffeine out of the coffee bean? The carbon dioxide is compressed under very high pressure, causing the desired component to become separated from the raw material. When the pressure is reduced, the carbon dioxide releases the removed substances again and an extract is produced.

The arguments against chemical extraction processes

To avoid pathogenic, toxic and therefore dangerous traces in a product, it is safer to completely omit the use of any organic solvents. The environmentally-friendly disposal of chemical solvents is, however, complicated and involves significant costs. This creates conflicting objectives for any manufacturer who is committed to sustainability.

The arguments in favour of the organic solvent CO₂

In recent years, the pressure in extraction processes increased from approx. 300 bar to approx. 1,000 bar. This leads to a reduced processing time, allowing more efficient ingredients to be produced in a gentler manner. This makes commercial use overall more economically efficient and more effective. The current general trend among consumers towards biological products supports this development.

Why the CO₂ extraction process is still on trend

One classic application of this process is beer brewing: The selective extraction of alpha and beta acids changes the spectrum of bitter substances in the naturally grown hops according to the desired flavour.

Oscillating displacement pumps are ideal for supercritical CO₂ extraction.

This type of “beverage design” can influence how aromatic, mild or bitter a beer tastes. A hops extract without bitter substances allows trendy drinks such as “hops lemonade” with special flavours to become established on the market.

The resulting flexibility allows breweries to adapt to consumer trends and to manufacture healthy products which are tailored to customer

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requirements. Furthermore, in medicine there is also a growing focus on sensitive substances from naturopathy. Ever more intelligent and finely-tuned processes are being developed and used for extracting these substances for preventive medicine or therapeutics. In the same way, natural cosmetics, which are becoming increasingly popular among consumers, contain a variety of different allergens which have to be extracted from the substances.

The principle of CO₂ extraction

The process can be described with three keywords: extraction, separation and condensation. First, liquid CO₂ is supercooled and fed into the pump. Due to heavy compression, with pressures up to 1,000 bar, the CO₂ is heated up and transferred into a supercritical state. Under these conditions, it possesses the properties of a gas and a liquid and is characterised primarily by its excellent dissolving capacities. The high fluidity of supercritical CO₂ allows it to penetrate into the smallest pores of food and extract the desired substances from the raw material. The supercritical CO₂ is then expanded and heated up. It turns back into a gas and evaporates without a trace, leaving nothing but the pure extract. As CO₂ is inert, it neither reacts with the extract nor distorts its properties.

Comparison with beer brewing: chemical hops extraction with ethanol versus CO₂ as a solvent

The comparison, which is of course not exhaustive, looks at some of the facts from the areas of production, composition, purity and economic efficiency. As a starting point, the continuous process of the extraction uses fermentation alcohol to process hops umbels at temperatures of approx. 60°C. When CO₂ is used, this is referred to as a batch process with supercritical carbon dioxide as a solvent. Hops pellets are...
used as the primary product. They are processed at temperatures under 60 °C and with extraction pressures up to 300 bar.

Depending on the composition of the specific variety, the ethanol extract contains all bitter substances, while CO₂ allows selective extraction of so-called alpha or beta acids, which means that the unspecific bitter substances in the hops are hardly present in the extract afterwards. The process can achieve very good extraction of contained pesticides, nitrates and heavy metals, whereby the CO₂ application achieves better values. From an economic point of view, the production costs for the CO₂ extraction process are slightly higher, as hops pellets first have to be produced for the process and it is also a batch process. The ethanol extract has a stability of approx. one week, the CO₂ extract of approx. two weeks, whereby the packaged extracts can keep for six years or more at the right storage temperature.

Another keyword here is the optimisation of dead space in the fluid section of the pump: The optimisation always ensures a high volumetric efficiency. This volumetric efficiency is becoming increasingly important due to the rising processing pressure. Volumetric efficiency influences the flow rate and therefore the function of the entire pump. Particularly with very high pressures up to 1,000 bar, a design with optimised dead space volume in the fluid section is crucial to the general function of the pump. Incorrectly designed liquid end components can not only cause the pump to cease pumping but also merely to compress and expand without discharging the desired volume of the medium.

**High pressure plunger pumps are suitable for use in the food, dietary supplements, cosmetics and pharmaceutical industry.**

**Challenge for CO₂ high pressure pump technology**

The challenge for the pump technology is the medium CO₂, which is gaseous under normal ambient conditions. It has to be constantly kept in a liquid state through precise monitoring of the process parameters to prevent cavitation damage in the pump. Poor lubrication properties and the high compressibility of liquid CO₂ require specially developed pumps with a high level of process reliability. Specifically this means that the pump has to be specially developed for the CO₂ application: The power end has to be able to withstand the rod forces resulting from the high suction pressure and optimum lubrication of the bearing points has to be ensured. At the same time, pressure increases up to 1,000 bar create a correspondingly higher temperature increase: This requires effective cooling of the fluid section with cooling channels in the stuffing boxes and valve blocks. As some components cannot be cooled directly, it is important to adapt the materials and the design so that as little as possible of the generated compression heat is absorbed. Because the CO₂ is alternately subjected to compression and expansion, it is necessary to minimise or avoid the temperature rise and the resulting losses.

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CO₂ high pressure pump technology in use

High pressure plunger pumps which were adapted to these kinds of special challenges are particularly suitable for use in CO₂ extraction. For this, the fluid section of the pumps was re-designed and integrated into a variety of different proven high pressure plunger pumps, customised for each model. The pumps are used worldwide for a variety of different CO₂ extraction processes in many different industries, including in a pilot system for CO₂ extraction of colourants and flavourings from tomatoes.

The variety of substances to be extracted is immense, so that the exact parameters and therefore the precise design of the high pressure plunger pump have to be defined individually during the project planning phase. A general statement as to which pump is the right one in a system is simply not possible.

All pumps combine sturdy and compact design with innovative and flexible technology, meeting all requirements of state-of-the-art production technology with regard to size, weight and energy efficiency. The functional design of the described high pressure plunger pump achieves a mechanical efficiency of over 90%, that means it offers an optimum level of energy efficiency and sustainability.

The system concept in pump engineering

In order to meet the customer demands of today, a system concept is required including plug-and-play solutions in pump engineering as well: customers want complete drive and control units in the pumps, consisting of a compact frequency converter device, an asynchronous three-phase motor and a control and operating unit (see fig. 3). The air cooled IE3 asynchronous three phase motor is suitable for continuous speed control via the frequency converter and drives the plunger pump in the required working range. The frequency converters monitor the temperature, current and speed of the motor.

The continuous speed/pressure control for the asynchronous three-phase motor is provided by the attached, air cooled frequency converter (FC) compact unit with different wide range voltages and a nominal energy efficiency of at least 97%. The FC unit is fully ready to connect. It consists of a load break switch for secure disconnecting, power and motor connection, power electronics, control and monitoring unit, EMC input filter and FC display with intuitive menu navigation for all FC functions. It can be adapted to customer requirements if necessary.

For an individual, reliable and comfortable pump operating, monitoring and control application, an additional small housing with an integrated S7 failsafe PLC can be used, for example. This allows customisation to meet the applica-
tion-specific and customer-specific safety functions and requirements.

Display, operation and parameterisation on site can be carried out via a convenient touch panel with intuitive menu navigation – e.g. for setting parameters/set values and for displaying actual value/set value, error and status as well as pump and motor data. Discreet and analogue signals or bus interfaces (Profinet standard) serve to connect to a higher level controller.

**Great variety of applications for the promising organic solvent**

Countless applications can be observed in the food, dietary supplements, cosmetics and pharmaceutical industry: the demand for the extraction of high quality oils, waxes, extracts, colourants and active substances is continuously rising. The natural substances can be refined through the extraction process with the organic CO₂ in many different ways: for example by removing fat and oil, fragrances and aromas, active substances or harmful substances. Medicinal plants as well as common plant substances – such as algae, fruit and vegetables, berries, herbs and spices, seeds, cereals and nuts – provide the raw materials. This process can even be useful for extracting harmful substances from contaminated raw materials.

**Customised pumps for a variety of processes**

In principle, “extraction” is about removing a certain substance from the primary product and then providing it in its pure form to use the extracted substance for further processing. The large variety of raw plant materials also requires a corresponding variance in processes, whereby the suitable parameters have to be defined individually in each case to allow optimum extraction of the natural agents.

The use and the engineering of customised and standardised drive and control assemblies are the basis for such technically sophisticated high pressure CO₂ pump applications which have substantial requirements for process reliability and personal safety. All system parts have to be adapted to the process, the function, the safety and the application with regard to energy efficiency and system availability.

Modern and sustainable manufacturing practice strives for optimum overall efficiency and an efficient structure in a compact design.

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