IVL rapport
IVL Svenska Miljoinstitutet AB

For Viking Sewing Machines AB

Evaluation of carbon dioxide cleaning system

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1. Background

Self-lubricating bearings are manufactured from powder-pressed, sintered steel. After the components have been sintered and dimension-calibrated, they contain calibration oil and impurities that must be removed before vacuum impregnation with a lubricant.

A couple of years ago, motivated by a desire to reduce negative impact on internal and external environments, work started on finding an alternative to cleaning by degreasing with the chlorinated solvent, trichloroethylene. In this connection, degreasing with water-based alkaline solutions (a common alternative) was judged unsuitable.

Degreasing with carbon dioxide was amongst the other possible alternatives. In its supercritical state, carbon dioxide acts as a solvent and was judged capable of cleaning the components adequately without creating any environmentally harmful emissions.

After testing the technology, Chematur Engineering devised and offered to supply a plant for degreasing with carbon dioxide. The cost of the plant was initially judged too high. However, when an application for a grant to modify the system for closed operation was approved, it was decided to purchase the equipment.

The use of carbon dioxide degreasing in this type of application is innovative. It is thus of great general interest to monitor the installation's performance. In accordance with the grant application, the installation is to be evaluated by IVL Swedish Environmental Research Institute AB. This evaluation will form part of a larger project in which different types of cleaning processes are being assessed. The environmental impact of various energy sources and the production of various chemicals will be further areas examined by the project.

2. The technology

2.1 Theory

In its supercritical state, carbon dioxide has the viscosity of a gas but the density of a liquid. It acts as an organic solvent and is commonly compared with hexane. The supercritical phase of carbon dioxide is shown in figure 1.

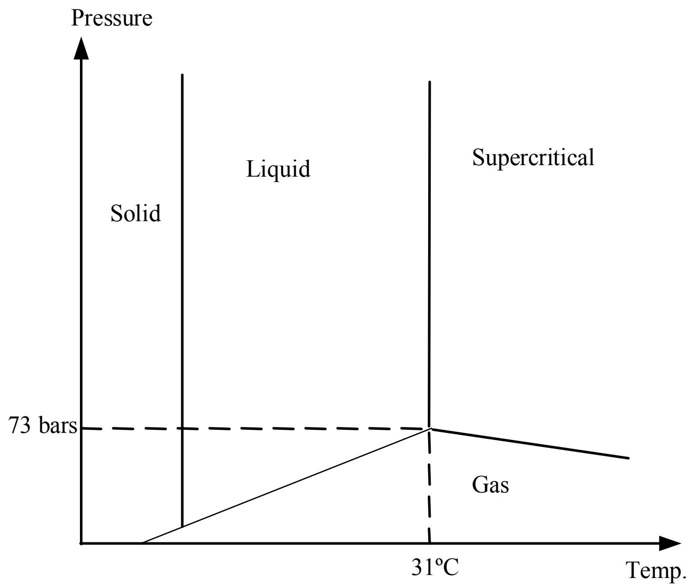

Figure 1: Phase diagram, CO_2

The critical point for the transition to the supercritical state is a pressure in excess of 73 bars and a temperature above 31ºC.

One of the main advantages of carbon dioxide as an extraction agent is the opportunity it offers for superior separation of solvent and extractable substances. This makes it possible for the carbon dioxide to be recirculated. Furthermore, extraction residues are not contaminated.

The foodstuffs industry makes wide use of this technology, e.g. in the decaffeination of coffee.

Treating with supercritical carbon dioxide is relatively expensive and is thus most competitive where product value easily covers treatment costs or where the carbon dioxide method returns the best performance.

2.2 The process

Figure 2 shows the principal elements of the carbon dioxide cleaning plant.

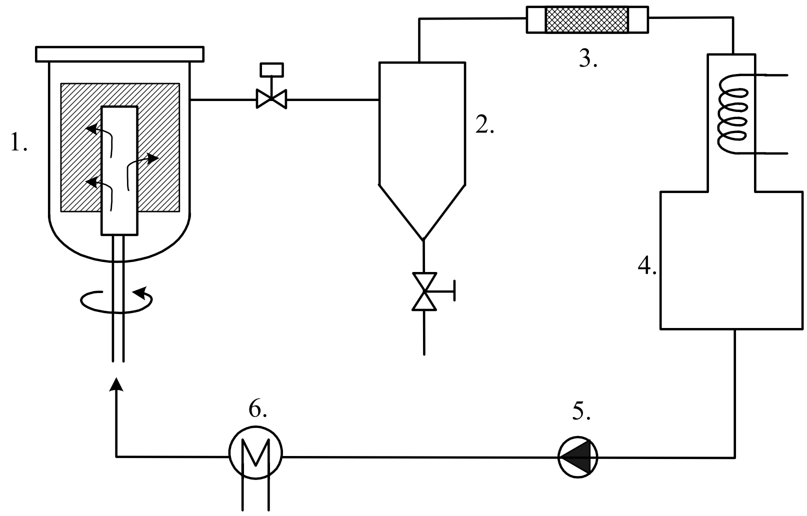

Figure 2: Cleaning with carbon dioxide

1. Wash chamber

The components are placed in a basket which rotates at 900 rpm during the wash cycle. Carbon dioxide is fed to the centre of the basket at a rate of 0.75 kg per min; the carbon dioxide/oil solution is collected at the periphery. The pressure and temperature in the chamber are 400 bars and 100°C respectively. There are electric heating coils in the chamber walls.

2. Separator

The extracted substances/oil are separated from the carbon dioxide here. The oil is drained off manually and the carbon dioxide reused.

3. Filter

An activated carbon filter is used to separate any oil residues from the carbon dioxide.

4. Condenser

Here, the carbon dioxide is cooled to return it to the liquid state.

5. High-pressure pump

A diaphragm pump, driven by pressure from a hydraulic unit, is used to raise the pressure of the carbon dioxide to 400 bars.

6. Heater

An electric coil for preheating the carbon dioxide.

2.3 The wash cycle

The metal components to be degreased are placed in a basket which is then lowered into the wash chamber. Approximately 24 kg of components can be treated per wash.

The system is filled with carbon dioxide. Pumping begins when pressure reaches 50 bars and continues until 400 bars is achieved. Before it enters the wash chamber, the carbon dioxide is preheated to 100°C. This brings it within the supercritical area. A temperature of 100°C is maintained throughout washing.

The flow from the wash chamber is reduced to a pressure of 30 bars and fed into the separator. Here, a temperature of 30°C is maintained so that, while the oil remains in a liquid state, the carbon dioxide vaporises. The oil is collected at the bottom of the separator.

After separation, the carbon dioxide is fed to the condenser where a further temperature reduction allows it to condense to its liquid form. It is stored in the condenser in this form.

The wash cycle takes around 40 min. When it is finished, a pressure of approximately 50 bars is maintained in all parts of the system except the wash chamber, which is reduced to atmospheric pressure. The wash chamber lid opens and the basket holding the components is raised.

3. Evaluation of the CO_2 cleaning plant

The plant has been in use since 1999. Around 24 kg of components is treated per wash. The full cleaning cycle takes 1 hour. The plant is run 3 to 5 times a day; this corresponds to approximately 20,000 kg of treated components per year.

3.1 Power consumption

The electric coils and the electric motor for wash basket rotation account for most of the power consumption.

To measure the plant's power consumption, a current meter connected to a logger was wired into the plant's power circuit. The recorded power consumption was 7 kWh per wash. This equates to a power consumption of 0.3 kWh per kg of components.

3.2 Carbon dioxide consumption

When the degreasing (wash) cycle is finished, pressure is reduced to and held at approx. 50 bars in all parts of the system except the wash chamber. Here, atmospheric pressure is achieved by venting carbon dioxide. A new degreasing cycle is started by filling the degreasing vessel (wash chamber) with more carbon dioxide until pressure reaches 50 bars.

Carbon dioxide consumption thus depends on the free volume in the degreasing vessel. This, in turn, depends partly on the quantity of components loaded into the vessel.

Initially, carbon dioxide consumption was assessed as being less than 1 kg per wash. Actual consumption has been around 4 kg per wash. The cost of carbon dioxide is SEK 6 per kg. This corresponds to SEK 24 per wash or SEK 1 per kg of components.

So far, carbon dioxide has been supplied in gas bottles but, in future, a tank will be used. This will raise the efficiency of and simplify handling. The cost of carbon dioxide cleaning will thus fall.

3.3 Cleaning efficiency

After production/calibration, approx. 50% of the fillable volume of the components is taken by calibration oil. Once the calibration oil has been washed out, the components are impregnated with lubricating oil. Cleaning efficiency is systematically monitored by measuring the amount of calibration oil remaining in the components after degreasing and the degree to which the components can be impregnated with lubricating oil.

One requirement placed on carbon dioxide cleaning is that, after the washing process, a maximum of 4% of fillable volume is taken by residual oil. Monitoring has so far shown low quantities – well below 4% – of residues after carbon dioxide washing.

The cleaned components must then be capable of being at least 91% impregnated (open porosity) with oil. This requirement has also been met.

3.4 Waste

The oil obtained from carbon dioxide degreasing is of a clear appearance – no foreign chemicals have been added. However, as it is a mixture of different oils, it is impossible to return the oil to production. On the other hand, after refining, it may be possible to use the oil in other applications.

Presumably, the oil may be classed as a fuel. There should thus not be any waste disposal costs.

About 0.12 l of oil is recovered per wash. This equates to around 100 l per year.

3.5 Maintenance and supervision

Apart from the loading/unloading of components and the draining of oil from the separator, the plant is fully automatic. No supervision is required during operation and the plant stops automatically on the completion of the wash cycle. Operating the plant thus takes up minimal manpower/time.

3.6 Operational experience

It has been reported that the plant is easy to maintain. The only noteworthy disruption experienced so far was a failure in the bearings of the rotating wash basket. For a short time, the plant was then run without the basket being rotated. The wash results remained within the set limits.

4. Evaluation of trichloroethylene washing

Trichloroethylene washing was discontinued on the start-up of carbon dioxide washing.

4.1 Power consumption

The power consumption for heating in trichloroethylene washing was not measured while this system was in use. Instead, power consumption during preheating, operation and system temperature maintenance has been calculated from the power rating of the heater.

Power consumption has been estimated at 50 kWh for 6 washes comprising, in total, 100 kg of components. This equates to 0.5 kWh per kg of components.

As the heater was still in circuit, power consumption for drying after trichloroethylene immersion could be measured. The heater was measured as drawing 12 kW. Normal drying time was 4 h. and component quantity 100 kg. This corresponds to a power consumption of 0.5 kWh per kg of components.

Altogether, power consumption was around 1 kWh per kg of components.

4.2 Trichloroethylene consumption

Trichloroethylene consumption was approx. 1,000 kg per year. At a cost of SEK 12 per kg, and with 20,000 kg of components being treated a year, this equates to a cost of SEK 0.6 per kg of components.

4.3 Cleaning efficiency

Monitoring of oil remaining after trichloroethylene washing showed residual quantities of around 15%.

4.4 Waste

There was approx. 1,000 l of waste (a mixture of trichloroethylene and oil) per year. Waste disposal cost was around SEK ___ per year.

5 Summary

Viking Sewing Machines AB, Husqvarna, replaced trichloroethylene washing of powder-pressed, sintered steel with a new cleaning system – degreasing with carbon dioxide. In its supercritical state (high pressure and high temperature), carbon dioxide has solvent-like properties. Carbon dioxide washing equipment was delivered by Chematur Engineering and has been in use since the spring of 1999.

The foodstuffs industry is one area in which supercritical carbon dioxide is used. The cleaning of metals is, on the other hand, a new application. If it proves to be technically sound, it will be an extremely attractive replacement for trichloroethylene washing as it does not have the latter's negative impact on the environment.

Carbon dioxide degreasing has been evaluated and compared with traditional trichloroethylene washing (see table 1).

Table 1: Comparison of operating costs – carbon dioxide washing versus trichloroethylene washing

		Carbon dioxide	Trichloroethylene
Power consumption	kWh per kg components	0.3	1.0
Chemical consumption	kg per kg components	0.15	0.05
Cost of chemicals	SEK per kg components	1.0	0.6
Waste	litres per year	100 [1)]	1000 [2)]

1) Oil

2) Oil + trichloroethylene

Compared with trichloroethylene degreasing, the carbon dioxide system has slightly lower energy costs but higher costs as regards the degreasing agent. However, as waste disposal costs are lower and the equipment requires considerably less staff supervision, the operating cost of the carbon dioxide system should be lower. As the investment cost is high, total treatment cost could be comparatively higher for carbon dioxide plants.

Carbon dioxide degreasing gives excellent results – components are cleaner than when degreased with trichloroethylene. There are other methods which would also give a satisfactory degree of cleaning. Washing in petroleum ether is one possibility, but this has the disadvantage of a considerable risk of fire and explosion.

The carbon dioxide system has a low risk of fire and explosion. A further additional benefit is that there is little danger of personnel being exposed to harmful substances.

All in all, carbon dioxide washing may involve slightly higher washing costs than the traditional trichloroethylene method but, at the same time, the washing results should always be better and the carbon dioxide system is friendlier to the environment.