Development of CO_2 Dry Cleaning System

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Current status of dry cleaning industry

Commercial cleaning service may be classified into laundry using water and dry cleaning using organic solvents. The latter has become predominant because of its adaptability to a wide variety of clothes. Statistics published by the Ministry of Health, Labour and Welfare shows that about 43,000 commercial dry cleaning machines were in operation in Japan in 2002. Consumption of chlorine-based solvents is decreasing because of its potential carcinogenicity and consequently more stringent regulations. Most of Japanese dry cleaning machines have thus adopted petroleum-based solvents. The process needs a drying step where energy corresponding to an estimated 1.23 million kiloliters of crude oil is consumed and an estimated 320 thousand kiloliters of the solvent is released to the air.

Environmental, energy-saving and resource-saving demands have urged the industry to seek alternative cleaning techniques. Particularly small and family businesses, accounting for the majority of consumer-oriented cleaning shops, have difficulties in responding to environmental problems and improving working environment.

Silicone-based solvents have been developed and commercialized as an alternative, but high prices have hindered their generalization. Another candidate solvent is liquid carbon dioxide, developed in the U.S. and Germany. A system using liquid CO_2 under a pressure of about 5 MPa (about 50 atomospheres) has been commercialized in some parts of the U.S., but it suffers from insufficient detergency and requires an auxiliary chemical detergent.

Development of the supercritical CO_2 dry cleaning in the Research Center of Supercritical Fluid Technology, Tohoku University was occasioned in an encounter at the Technology Licensing Organization of Tohoku University, which introduced the cleaning company Auto Laundry Takano Co., looking for effective solutions of the solvent problem, to the Center when it was conducting research on precision cleaning of machine parts and optical components with supercritical CO_2 as a Regional Consortium R&D Project (1997-1999). Results showed that CO_2 is a very powerful degreasing agent but high equipment costs would be a problem in commercialization. Thus the study of dry cleaning as a new application of supercritical CO_2 was launched on an industry-academia collaboration basis.

Principle of dry cleaning with supercritical CO_2

Carbon dioxide becomes supercritical at a temperature of 31° C and a pressure of 7.3 MPa, a condition mild enough to handle clothes. Supercritical CO_2 is capable of dissolving weakly or non-polar fats. Its diffusion characteristics are close to those of gases, enabling the substance to penetrate to every corner of the fabric. Even submicron-sized fine structure can be cleaned with this medium because the problem of capillary force is virtually absent. Furthermore, CO_2 is removed simply by evaporation after cleaning is finished, thus eliminating the drying process that may cause clothes shrink. Supercritical CO_2 can be thus an excellent dry cleaning solvent: in fact, experiments showed that no additional detergent is needed for satisfactory cleaning operation. Problems remained, however: how to handle the large quantity of clothes in the commercial-scale cleaning shops? How to achieve reasonable economic performance? How to prevent redeposition of dirt onto the clothes?

In order to study prevention of dirt redeposition and recovery of the solvent, an experimental supercritical dry cleaning apparatus (Fig. 1) was constructed which consists of a cleaning unit, a solvent recovery unit and a solvent recycling system. High thermal expansion coefficient of the supercritical CO_2 allows an increase of pressure by simple heating, which is used to supply the solvent at a high velocity. The low heat of evaporation of CO_2 at the subcritical region (i.e. at temperatures slightly lower than the critical point) is exploited for evaporation/condensation of the solvent for recovery and reuse. A simple closed-system dry cleaning apparatus without high-pressure pumps is thus realized. While the basics of the system had already been demonstrated, tests as a dry cleaning apparatus included minimization of cleaning time and energy consumption, optimization of the contact of the solvent with the clothes, improvement of cleaning performance by adding auxiliary detergents, and optimization/automation of operations. These studies were actually conducted by

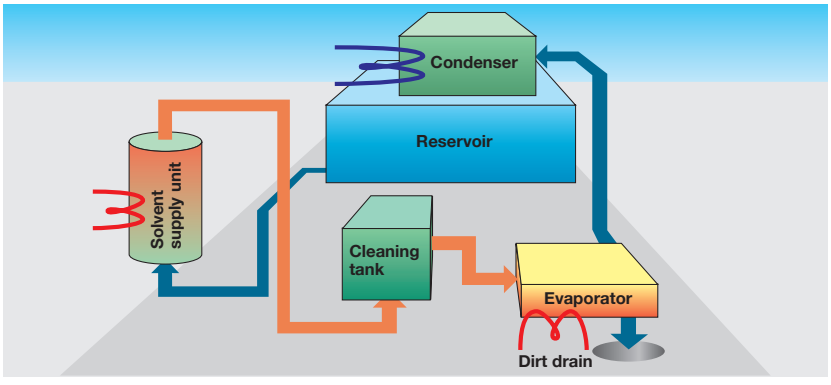

Fig. 1 : Concept of the dry cleaning system based on a supercritical solvent cycle

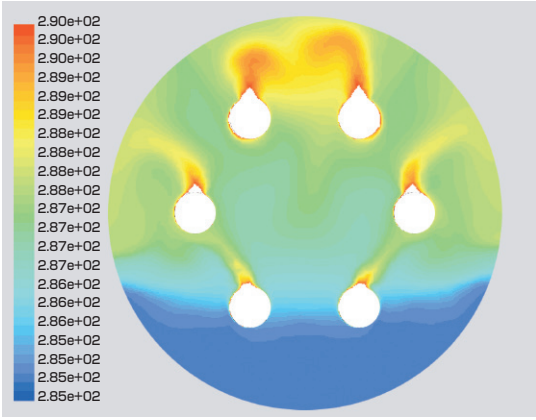

Fig. 2 Temperature distribution in the solvent supply unit immediately after a pressure of 10 MPa is reached

a consortium comprising Takano and other companies, AIST and Tohoku University. While demonstration operations were carried out by the industry members, the University performed analysis of heat flow in the solvent supplying unit (Fig. 2) and other scientific studies. AIST contributed assistance in engineering.

Results of cleaning tests with supercritical CO_2

The cycle time for a cleaning batch is about 30 to 40 minutes, which is considerably shorter than that in the current system including drying time. The system without a drying step gives less damage as well as better feeling of the fabric after cleaning. The cleaned items have, of course, no odor. The development targets have thus almost been achieved.

Commercial prospects

Following the experimental studies that have cleared basic problems, a prototype of the commercial cleaning apparatus has been completed. It is intended for monitor tests for market evaluation. The system will be improved further for a full-fledged commercial application. The new dry cleaning system is expected to spread in many countries, thus contributing to improved environment and health.


Fig. 1 : Experimental apparatus for supercritical CO_2 cleaning

Industry-Academia Collaboration Program for Commercialization of New Dry Cleaning System

Yoshinori Kato
Auto Laundry Takano Co.

The cleaning industry faces the problem of adverse effects of organic solvents on the natural and working environment. We started development of a novel dry cleaning process based on the patent (to Arai, Inomata and Smith, Tohoku University) on cleaning with supercritical CO_2, using a closed-system cleanig apparatus driven by heat.

Our developmental research was a part of Consortium R&D Project for Regional Revitalization (2002-04) led by Prof. Inomata, which is commissioned by the Ministry of Economy, Trade and Industry. The research was conducted on a cooperative basis between the industry, Supercritical Fluid Research Center of AIST and Professors Arai, Inomata and Smith.

Fig. 2 : Results of CO_2 cleaning of different fabrics stained with fluid paraffin and oil red dye under dual solvent supply

The research resulted in the supercritical CO_2 dry cleaning apparatus shown in Fig. 1, the world's first unit of this category. The apparatus comprises 30- and 40-liter cleaning tanks, four solvent supplying uinits, an evaporator, a condenser and a reservoir. Not only being favorable in terms of energy and environment, supercritical CO_2 permits finishing with less damage and better feeling, because the clothes need not be agitated during the cleaning operation owing to the high penetration of the medium.

Fig. 2 shows several samples of soiled fabric cleaned with supercritical CO_2 without an additional detergent. All the samples indicate performance of CO_2 comparable to or better than conventional solvents. Another merit of supercritical CO_2 cleaning is compatibility with chemical sensitivity, because no chemical substance is employed except CO_2.

Test cleaning using the experimental apparatus offered to patients throughout the country via the Internet have received favorable responses including those from serious cases.

The research project has been granted from the Ministry of Economy, Trade and Industry from 2004. Commercial service will start in 2006 for chemically sensitive people as well as high-quality cleaning of high-grade wears.