Redeposition in Textile Dry-cleaning with Carbon Dioxide

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Abstract

Perchloroethylene (PER) is commonly used as cleaning solvent in the dry-cleaning industry. Unfortunately, this chemical is toxic, potentially carcinogenic and harmful for the environment. One of the potential PER replacements is liquid or supercritical carbon dioxide (CO_2), which is non-toxic, cheap, and widely available.

Previous studies have indicated that the cleaning performance of CO_2 for non-particulate soil removal is comparable to that of PER. However, the particulate soil removal with CO_2 is lower. When the particulate soil removal of the CO_2 dry-cleaning process was studied, it was found that redeposition of the particulate soil occurs. Several experiments have been carried out to study this phenomenon.

In the experiments, several types of textiles soiled with different kinds of soils were cleaned using a 25 L CO_2 dry-cleaning set-up with a rotating inner drum. It was found that rinsing has no influence on the redepostion level. Furthermore, the redeposition level increases along with soil removal. The redeposited particles are evenly distributed and the redeposition is more severe using a longer washing time.

Keywords: Dry-cleaning, carbon dioxide, redeposition

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INTRODUCTION

Dry-cleaning is a process of soil removal from substrate, in this case garment/textile, which involves a non-aqueous solvent. This process is developed because some types of textile material are sensitive to water (wrinkle, shrink, etc). The most common solvent used in conventional dry-cleaning is perchloroethylene (PER). Despite good cleaning performance, PER has several drawbacks such as a toxic effect to the human body. It is a possible carcinogen and it causes air and ground pollution. These drawbacks of PER started the investigations of several replacement solvents for textile dry-cleaning, including hydrocarbon solvents, silicon based solvents and carbon dioxide (CO_2).

Carbon dioxide has several advantages compared to the other solvents. It is non-toxic, non-flammable, non-corrosive, safe for the environment, cheap, easily recovered and available on a large scale. Furthermore, the drying step is not necessary because CO_2 evaporates from the fabrics during the depressurization step.

Previous works [1, 2] indicated that the performance of CO_2 was comparable and in several cases even better than PER for non-particulate soil removal. This is because CO_2 is non-polar and thus interacts well with non-polar soil. On the other hand, the removal of particulate soil using CO_2 was significantly lower compared to that of PER. Big soil particles are more likely to be trapped between the fibers and yarns, while the adherence of small soil particles is primary caused by Van der Waals forces [3, 4]. From the common practice, it is known that particle removal can be increased by mechanical action and/or by using a surfactant.

When particulate soil removal of the CO_2 dry-cleaning process has been studied, it was found that redeposition of the particulate soil occurs. In a previous study by another group this phenomenon has also been mentioned [5]. Redeposition is a process of soil transfer from one textile to another in situations in which the released soil was not properly stabilized in or removed from the cleaning medium. The objective of this paper is to study the redeposition of particulate soil which occurs during washing with CO_2.

MATERIALS AND METHODS

Apparatus

The dry-cleaning experiments were conducted in a CO_2 dry-cleaning set-up, which is represented schematically in Figure 1. The set-up was designed and constructed at the Laboratory for Process Equipment, Delft University of Technology (the Netherlands). The cleaning-vessel was constructed at Van Steen Apparatenbouw B.V. (the Netherlands). It has an inside diameter of 0.25 m and volume of 25 L with a rotating inner drum to provide mechanical action. The inner-drum, with a diameter of 0.21 m and a volume of 10 L, is perforated and connected to a rotating shaft.

CO_2 from the storage is circulated through the closed system by a pump. During each cycle of circulation, it passes through a heat exchanger which serves to cool and/or to heat the CO_2, and thus regulates the pressure. Before the fluid from the vessel enters the pump, it passes through a filter with a pore size of 11 µm in order to remove unwanted particles. The temperature, pressure, density, and mass flow are monitored. After the washing step is finished, the used CO_2 is replaced by fresh CO_2 to rinse the fabrics. The process conditions used in this study are given in Table 1. These conditions gave the best cleaning results in a previous study [6].

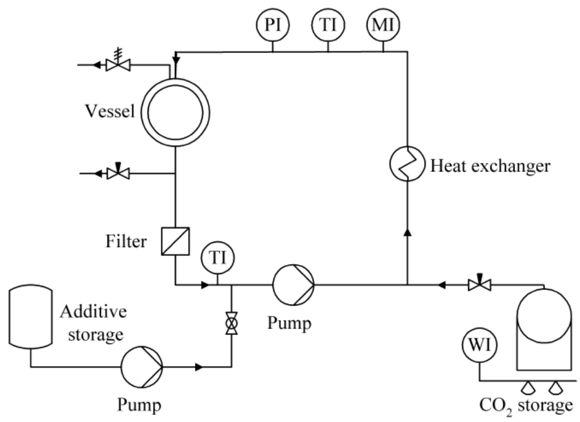

Figure 1: Schematic representation of dry-cleaning set-up

Table 1: Process conditions of CO_2 dry-cleaning

Process Condition	Value	Unit
Temperature	283	K
Pressure	50	bar
Rotational speed of inner drum	75	rpm
Washing time	20	min
Rinsing time	10	min
Washing load	400	gram

Materials

CO_2 grade 2.7 was obtained from Linde Gas Benelux B.V. (the Netherlands). The amount of CO_2 used in the washing and rinsing step was 6 kg for each step. In each experiment, 10 g Amihope LL, 250 g IPA, 25 g water, and 10 g sand were used. This formulation gave good cleaning results in previous experiments [7]. Amihope LL (*N*-lauroyl-l-lysine) was purchased from Ajinomoto Co. Inc. (Japan) and 2-Propanol (IPA) from Prolabo (the Netherlands) with a stated purity >98%. Furthermore, tap water was used. The 200 μm sand which was used as additional particles to enhance the mechanical action was purchased at Filcom B.V. (the Netherlands).

Soiled test fabrics (6.5 x 7.5 cm^2) have been used to monitor the cleaning-results. The test fabrics were purchased from the Center for Testmaterials B.V. (the Netherlands). Three different kinds of soils (see Table 2) on three different kinds of textiles (cotton, polyester and wool) respectively were used in the experiments. Along with the monitors some cotton filling materials (25x25 cm^2) are added to reach the desirable washing load.

Table 2: Type and size of particulate soil

Type of Soil	Size (μm)
Sand	20-100
Sebum colored with carbon black	0-20
Clay	0-10

Analytical Method

To monitor the cleaning-results, the color of the test fabrics was measured before and after dry-cleaning with a spectrophotometer (Data Color 110) using Standard Illuminant C as light source (average daylight, excluding ultraviolet light). The viewing angle used was the CIE 10º Supplementary Standard Observer. The test fabrics were measured using the L*a*b* color space, where L* indicates the lightness, and a* and b* are the chromaticity coordinates; $+a^*$ is the red direction, $-a^*$ the green direction, $+b^*$ the yellow direction, and $-b^*$ the blue direction. In this color space, the color difference (ΔE) is defined by Equation 1:

$$\Delta E_{1-2} = \left((L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2 \right)^{0.5} \quad (1)$$

The soil removal is represented by Cleaning Performance Index (CPI), which is defined in Equation 2:

$$CPI = \left[1 - \frac{\Delta E_{washed-unsoiled}}{\Delta E_{soiled-unsoiled}} \right].100\% \quad (2)$$

The color difference of the cotton filling used in these experiments was measured before and after washing to estimate the level of redeposition.

To get more insight about redeposition process, some textile and soil samples were also analyzed with Scanning Electron Microscope (SEM) - JEOL JSM 5400 and Electron Microprobe (EMP) - JEOL 8800 M JXA Superprobe. SEM was used to provide images of surface topography of the fabric samples while EMP was used to provide qualitative measurement of soil elements.

RESULTS

Redeposition as function of type of soil

The experiments were performed with only one type of soil present on different types of fabrics. To have a comparable soil load, 12-15 pieces of soil monitors were used in each experiment. The cleaning results of these experiments are shown in Figure 2. These results are the average values. From this figure it is shown that clay monitors have lower CPI values than the other soils. This might be because these particles are more difficult to remove due to the small size of the clay particles. The negative CPI observed for the clay-wool monitors shows the redeposition. Redeposition is most visible for this monitor due to its low reflectance compared to the other monitors.

The ΔE of the cotton filling is given in Table 3 for each type of soil used in the experiments. These table shows that all types of particulate soils released during the washing process lead to redeposition.

Table 3: ΔE difference of cotton filling for different types of soil

Type of Soil	ΔE
Clay	2.4
Sebum colored with carbon black	5.6
Sand	1.9

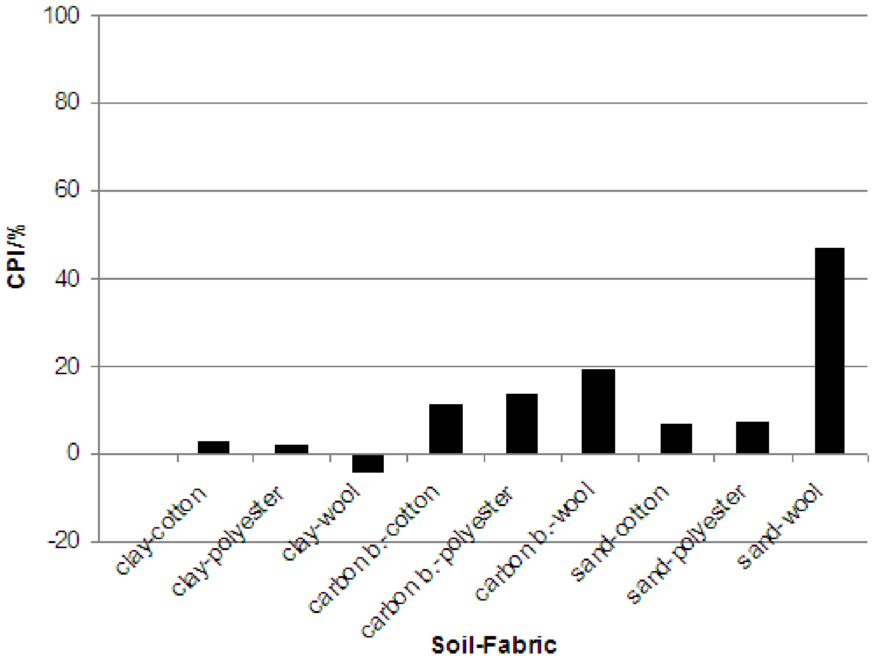

Figure 2: Influence of type of soil on cleaning result

Influence of rinsing on redeposition

In each of these experiments, all types of particulate soils were present on different types of fabrics. The soil load was kept similar to previous experiments (12-15 pieces of soil monitor per experiment). The effect of rinsing is examined. In the first experiment, normal rinsing (pressure in vessel is kept constant; while used CO_2 flows out of vessel, clean CO_2 enters the cleaning vessel at the same time) is used. In the second experiment, the rinsing step is eliminated and in the third experiment the vessel is completely emptied between the washing step and rinsing step. The results are shown in Figure 3. In general, the cleaning performance of the three different types of rinsing is almost similar except for clay on wool and sand on wool. The inconsistence washing performance of wool fabric was also observed in previous study [6].

The ΔE of cotton filling for different type of rinsing processes is given in Table 4. These values are the average of several cotton fillings used in each experiment. It seems that the effect of rinsing on the redeposition level is not significant, maybe because the redeposition process has already occurred during the washing process and it seems that this process is hard to reverse.

Table 4: ΔE difference of cotton filling for different type of rinsing

Type of rinsing	**ΔE**
Normal rinsing	2.6
Without rinsing	2.7
Rinsing with completely empty vessel	2.8

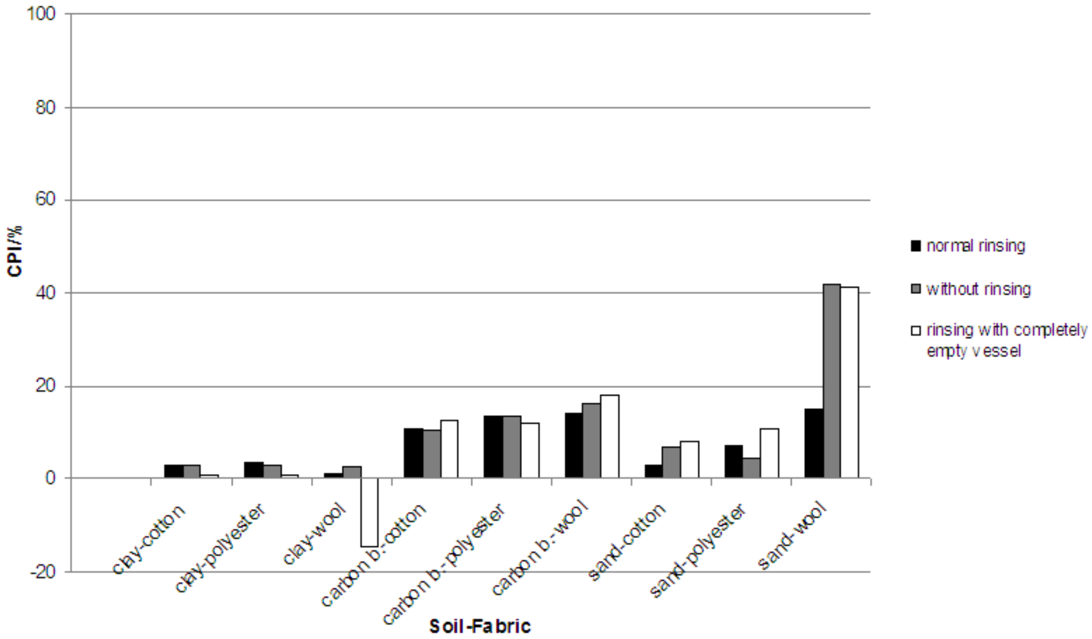

Figure 3: Influence of type of rinsing on cleaning result

Influence of cleaning time on redeposition

The redeposition level as function of cleaning time has been studied (Figure 4 and Table 5). In each of these experiments, all types of particulate soils on different types of fabrics are mixed together but the soil load was kept similar to other experiments. It has been found that in general a longer washing time has a (slightly) positive influence on the cleaning performance especially for big particulate soil (sand), but a negative influence on redeposition. Since more soil is removed, thus the chance on redeposition is thus higher.

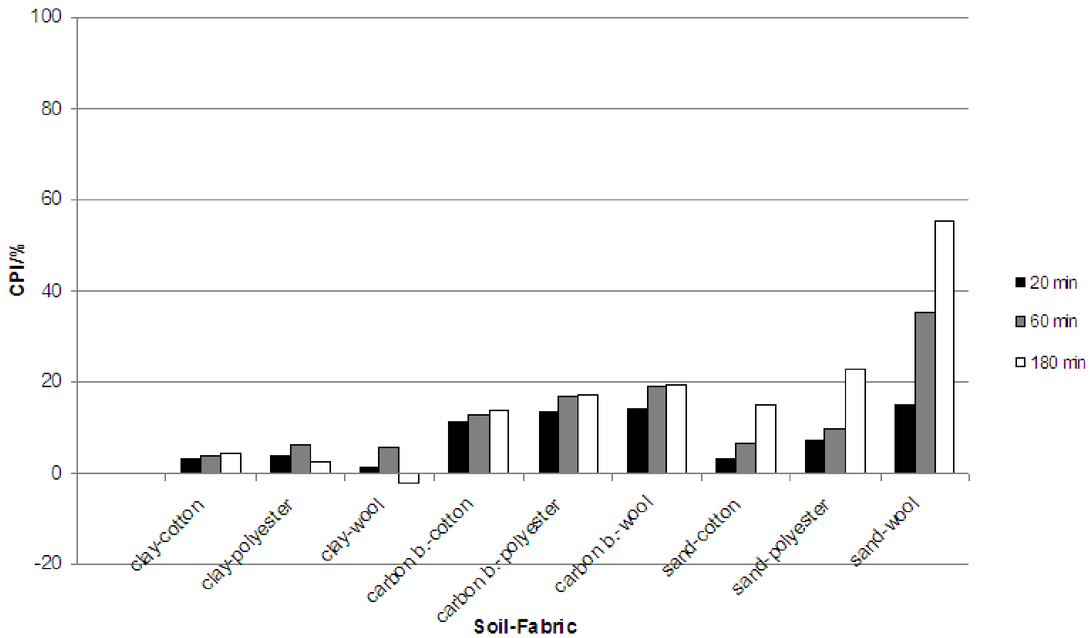

Figure 4: Influence of washing time on cleaning result

Table 5: ΔE difference on cotton filling for different washing time

Washing time (min)	**ΔE**
20	1.9
60	3.4
180	4.2

The color difference of the individual cotton filling pieces after the longest cleaning time (180 min) is almost equal (standard deviation = 0.85) showing that the redeposition is evenly distributed over the filling material.

SEM and EMP measurements

SEM pictures for sebum colored with carbon black on cotton monitors before and after washing are given in Figure 6. The monitor was washed with all other soils (standard soil load) with standard rinsing procedure and process conditions according to Table 1. These monitors show hardly any visible particles before washing. A theory for this is that the sebum layer covers the carbon black particles making them invisible before washing. After cleaning, particles are shown on the surface. After cleaning (especially with co-solvent), the sebum layer is removed and the carbon black particles are exposed. Possibly other soil particles are redeposited on the fabric. Analysis with EMP on the particles present on the monitor after washing showed that beside Carbon and Oxygen, elements such as Aluminum and Silica are also present. These elements can only originate from other particulate soils then carbon black (clay or sand). This proves the presence of other particulate soil on the textile monitor after washing and thus the redeposition. Redeposition of particles is also observed for cotton filling, see Figure 7.

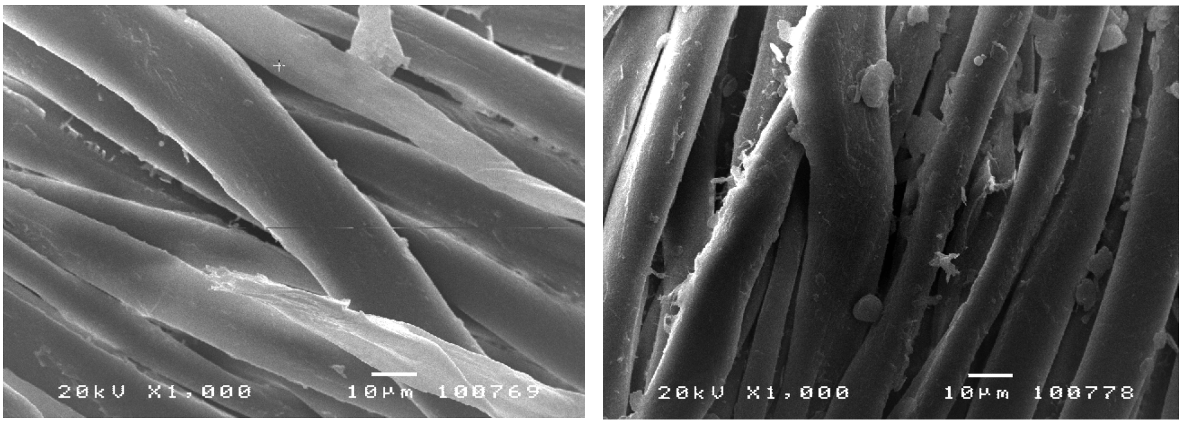

Figure 6: SEM of sebum colored with carbon black on cotton before (left) and after (right) washing

CONCLUSION

Several experiments have been carried out to study the phenomenon of redeposition in CO_2 dry-cleaning. Each type of particulate soil used in the experiments shows redeposition. Rinsing has no positive effect on redeposition. It is also found that the redeposited particles are evenly distributed and that the redeposition is more severe using a longer washing time.

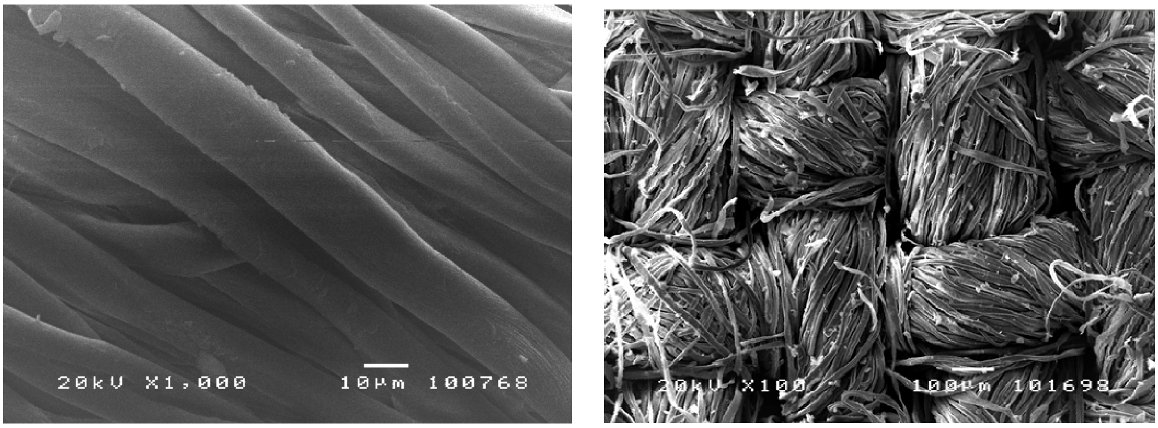

Figure 7: SEM of cotton fillings before (left) and after (right) washing

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