State Coalition for Remediation of Drycleaners
www.drycleancoalition.org
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Introduction

Drycleaning, by definition, is using organic solvents to remove soil, greases, paints, and other unwanted substances from garments or other fabric articles. In other words, it is cleaning without water. Certain fabrics are made of fibers that swell or distort on contact with water, and some garments have ornamental trims or patterns that may be destroyed by laundering. Garments that can not be laundered by traditional means can alternatively be cleaned by drycleaning.

The primary difference between laundering and drycleaning is the method by which wastes from the cleaning process are handled. When you launder clothes with water, the waste water and dryer air only contain soap, lint, and dirt, so they can be released safely into the community waste water system or atmosphere. Drycleaning solvents, on the other hand, present an environmental hazard and therefore must be contained and reclaimed after they are used.

Since drycleaning solvents are expensive, it is in the drycleaners’ financial interest to conserve and retain as much solvent as possible. Regular maintenance and appropriate improvement of drycleaning equipment serve to reduce the amount of solvent released into the environment and therefore reduce operating costs through expenditure on solvents.
History of Drycleaning

The first published reference to drycleaning, using the solvent turpentine, was in 1690, and the earliest known commercial drycleaning operation was Jolly Belin Cleaners in Paris in 1825. Although a variety of solvents, including turpentine spirits and camphor oil, was used in early drycleaning operations, the most widely used solvents were petroleum based and included naphtha, benzene, and kerosene.

At the turn of the century in the United States, white gasoline was the most widely used drycleaning solvent. Problems with fires and explosions led to the development of higher flash point petroleum solvents. In 1924 Lloyd E. Jackson of the Mellon Research Institute, working with William J. Stoddard, an Atlanta drycleaner, developed a petroleum-based solvent known as Stoddard solvent. Drycleaners began using Stoddard solvent in 1928. Stoddard and other petroleum solvents are still in use today, but one problem with their use is that they release volatile organic compounds which react with sunlight to produce ground-level ozone, a health and environmental hazard.

Carbon tetrachloride was the first chlorinated solvent used in drycleaning operations. Because of toxicity and corrosion problems associated with its use, it was phased out in the early 1950s in the United States. Perchloroethylene (also known as tetrachloroethylene, PCE, or perc) was first used as a drycleaning solvent in the US in 1934. It is non-flammable and therefore not a fire hazard.
Petroleum shortages in World War II and concerns with fire codes resulted in increased use of PCE, and PCE replaced petroleum solvent as the predominant drycleaning solvent in the United States in the late 1950s to early 1960s. PCE is still the most widely used drycleaning solvent in the U.S. where it accounts for over 80% of the market share.

Other drycleaning solvents that have been used in the U.S. include trichloroethylene (TCE) which is still used as a dry-side spotting agent; Valclene (1,1,2-trichloro-1,2,2-trifluoroethane), a chlorofluorocarbon introduced by DuPont in the late 1960s; and 1,1,1-trichloroethane (TCA), introduced by Dow Chemical as a drycleaning solvent in the early 1980s. Valclene (Freon 113) and TCA are no longer used in drycleaning operations because they are substances that deplete the stratospheric ozone layer, thus their production and use were phased out under the Montreal Protocol.

Newer drycleaning solvents include a number of higher flash point petroleum solvents such as DF-2000™, EcoSolv®, and Hydroclene™, to name a few. Two drycleaning solvents (Rynex and Impress™) are based on propylene glycol ether. PureDry™, known as a “hybrid solvent,” is a mixture of primarily petroleum solvent (isoparaffins) with some perfluorocarbons and hydrofluoroethers. GreenEarth® is a silicone-based drycleaning solvent (decamethylcyclopentasiloxane).
Summary of the Drycleaning Process

When you drop your clothes off at a drycleaner, they typically undergo the following steps on their way to being cleaned:

1. Marking or tagging – to identify your clothes
2. Classification – to sort clothes by weight, color, and fabric
3. Pre-treatment spot-cleaning – to remove obvious stains
4. Washing and extraction
5. Drying
6. Post-treatment spot-cleaning – to remove remaining water-soluble stains
7. Pressing
8. Assembly – to hang and bag clothes

Each of these steps, along with an extended discussion and demonstration of the logistical and environmental considerations that drycleaners must address during their workday (primarily handling of the drycleaning solvent), will be shown and described in detail on the following pages.
Marking and Classification

Clothes can be dropped off by the customer in bags or just handed over the counter to be tagged. Today, many drycleaners who have more than one store have “drop-off” locations from which clothes are transferred to a large central facility for drycleaning.
Pre-Treatment Spot-Cleaning

These clothes are being checked and treated for obvious stains prior to drycleaning. At left is the spotting board (see also following slide) and a rack of pre-treatment chemicals that can remove different types of stains. A wide variety of chemicals is used in the spotting process. They can generally be grouped into three broad categories: “wetside” agents that are used to clean water-soluble stains (acids, bases, neutrals); “dryside” agents that are used to clean paint, oil, fat, and grease stains; and oxidizing and reducing bleaches such as sodium hypochlorite, hydrogen peroxide, titanium sulfate, and oxalic acid. The spotting board is served with steam, compressed air, and a vacuum line. The steam, air, and vacuum are actuated by pedals located at the base of the spotting board. Wet or dry steam is applied with a “gun” and removed by vacuum.

Wetside spotting agents:

Acidic/Tannin spotters:
- Acetic, hydrofluoric, oxalic, glycolic, sulfuric acids

Basic/Alkaline/Protein spotters:
- Lye, ammonia, potassium hydroxide, sodium hydroxide, protein formula detergents (enzymes)

Neutral spotters:
- Neutral synthetic detergents (surfactants)

Dryside spotting agents:

- Perchloroethylene
- Trichloroethylene
- 1,1,1-Trichloroethane
- Carbon tetrachloride
- Methylene chloride
- Amyl acetate
- Acetone
- Alcohols
- Methyl isobutyl ketone
- Petroleum drycleaning solvents
Pre-Treatment Spot-Cleaning

Here are several spotting boards and a diagram of a spotting station. The picture above shows a neat work station with a drip tray and attached bucket for catching drops of solvent. The picture at left shows a larger rectangular steel pan under the spotting board that will catch and contain any falling spotting wastes and prevent them from entering the environment. The vacuum system that services the red vacuum lines shown at left and at right will be discussed near the end of this presentation.
Once the clothes are inspected and pre-treated, they are ready to be washed. This is an old three-piece drycleaning machine which uses petroleum solvent. This type of machine is called a "transfer" machine because the clothes must be transferred between the different pieces of equipment to complete the wash, extraction, and dry cycles of the cleaning process (see the next slide for an explanation of the three steps). These transfer machines are known as “first-generation drycleaning machines.” First-generation machines are not in common use today, and most of the remaining functional ones use petroleum (usually Stoddard) solvent. PCE transfer machines are especially rare because their use results in high solvent losses through vapor emissions during the transfer operation. In some states, transfer machines are no longer allowed.
1. Above is the washer, known in the industry as a belly washer. It is made of two cylinders mounted on a belt-driven horizontal rotating axis. The inner cylinder holds the solvent and clothing.  

2. After washing, the clothing is transferred to the extractor (above right) which rotates on a vertical axis. The centrifugal force separates or extracts the free solvent from the garments. This is equivalent to the spin cycle on a washing machine.  

3. After the solvent is extracted, the clothing is transferred to a tumbler or dryer where it is circulated in warm air. The photo at right shows a tumbler (right) and a petroleum solvent storage tank (left). After being dried in warm air, cool air is circulated in the tumbler. This particular tumbler does not recover solvent, so some solvent is lost to the environment upon tumbling as well as during the transfer between the three pieces of equipment.
Here are several other examples of transfer equipment, from quite old (above left) to relatively new (above). The Petro-Miser (above) is a petroleum solvent recovery tumbler/dryer that recovers solvent vapors for reuse. The photo at left shows both a transfer washer and dryer.
Beyond First-Generation Machines

Due to high solvent losses from first-generation transfer machines, drycleaning equipment has gone through several additional “generations” to reduce solvent loss, as explained below.

**Dry-to-dry machines:** All new drycleaning machines are dry-to-dry machines. These machines derive their name from the fact that the clothing goes into the machine dry and comes out dry – there is no transferring of wet garments. Dry-to-dry machines were developed in Germany in the 1960’s. There are several “generations” of these machines. Photos of this type of machine are shown on the following pages.

**Vented dry-to-dry machines:** In the first dry-to-dry machines, or second generation machines, vapors are vented to the atmosphere from the machine washing drum when the machine door is opened after the drying cycle.

**Third generation dry-to-dry machines:** These were the first “closed-loop” machines. The vapors from the dryer are routed to a refrigerated condenser for solvent recovery.

**Fourth generation dry-to-dry machines:** These closed-loop machines utilize both refrigerated condensers and carbon adsorbers to recover solvent vapors.

**Fifth generation dry-to-dry machines:** In addition to a refrigerated condenser and carbon adsorber, these closed-loop machines have an inductive fan and a sensor-actuated lockout device that will not allow entry to the machine door, button trap, or filters until solvent vapors in the machine are below certain levels (generally 300 parts per million (ppm)).

The table below (from *Clearing the Air on Clean Air*) demonstrates how improvements in machine design have reduced solvent emission and loss from drycleaning machines using PCE. The units are pounds of PCE used per 100 pounds of clothing cleaned.

<table>
<thead>
<tr>
<th>Emission source</th>
<th>Transfer Machine</th>
<th>Vented Dry-to-Dry</th>
<th>Non-Vented Dry-to-Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine vent</td>
<td>4.0</td>
<td>3.1</td>
<td>0</td>
</tr>
<tr>
<td>Fugitive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clothing transfer</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Equipment leaks</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Losses in waste</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12.2</strong></td>
<td><strong>8.8</strong></td>
<td><strong>5.7</strong></td>
</tr>
</tbody>
</table>
Washing, Extraction, and Drying - Dry-to-Dry Machines

Here are several examples of **dry-to-dry machines**. In addition to conserving solvent, these machines are also less labor-intensive to use. Solvent is stored in tanks located in the base of the machines: The round ports in the bases of the two machines at right are the route of access to these storage tanks (a diagram of the many parts of a dry-to-dry machine is presented later).
Here are two more examples of dry-to-dry machines.

In addition to drycleaning, most drycleaning businesses also offer standard water-based laundry services, shown below.
Washing, Extraction, and Drying - GreenEarth® Machines

GreenEarth® is a relatively new, man-made solvent that a number of drycleaners are now using. GreenEarth® is a proprietary chemical based on liquid silicone, a substance similar to the base ingredients in underarm deodorants, shaving lotions, and cosmetics. The picture at left is of the back of a GreenEarth® dry-to-dry machine. These complex pieces of equipment are typically more expensive than PCE or petroleum machines. As seen below, the front of a GreenEarth® machine looks similar to a PCE dry-to-dry machine.
Below is a brief description of what happens during the washing, extraction, and drying processes. A schematic of the entire drycleaning process and a cut-away diagram of a dry-to-dry machine are provided on the next two slides, and the different parts of the process are described in detail on subsequent slides.

After the clothing is loaded into the drum of the machine, the drum is “charged” with solvent from the tanks located at the base of the machine. Detergent (approximately 1 – 2% of the solvent volume) is injected into the drum. Some operators also add a small amount of water for removal of water soluble stains. Another additive may be sizing, used to impart body to a fabric. Sizing is composed of hydrocarbon resins (polymers or polymer blends). It often contains anti-static agents and optical brighteners.

The cleaning cycle for a typical dry-to-dry machine runs approximately 40 to 45 minutes. After the drum is filled with solvent, the wash cycle runs about five minutes. During the wash cycle, the solvent is circulated through the machine filtration system. The solvent is then drained from the drum and the dirty solvent is distilled.

While the dirty solvent is being distilled, the drum is re-filled with clean solvent from the base tank and the clothing is rinsed for approximately three minutes. The solvent is extracted from the drum and drained to the base tank for reuse.

The clothes are then dried for approximately twelve minutes with heated air (at approximately 140° F). The air from the drum is circulated through a refrigerated condenser to strip the solvent from the air for reuse. Following the heated air drying cycle is a twelve-minute drying cycle with air cooled by the refrigerated condenser. In closed-loop machines, the cool air is routed from the drum to a carbon adsorption unit for recovery.
Dry-to-Dry Machine Diagram

Key to numbers at left:

1. base tank
2. solvent pump
3. base frame
4. refrigerator compressor
5. body
6. water separator
7. main drive
8. gauge box
9. cleaning cage (drum)
10. cartridge filter
11. air heater
12. air cooler (compressor)
13. control cabinet
14. panels
15. compensator bag
16. refrigerator condenser
17. fan
18. air filter
19. button trap
20. distillation unit

The picture of the machine below shows many of the same features as the diagram at left.
Solvent is purified during the drycleaning process by two methods, filtration and distillation. These processes extract soils, greases, fats, dyes, and other non-volatile residues from the solvent so that they will not be re-deposited onto the garments.

There are two general types of filtration systems in use in drycleaning today: cartridge filters and roto-disk or spin-disk filters.

Most cartridge filters consist of an outer perforated metal shell or housing which traps lint. A rosin-treated pleated paper shell to remove insoluble soil is housed in the metal shell. Inside the pleated paper shell is a perforated metal inner shell. Carbon cartridge filters contain activated carbon within the core of the filter. The activated carbon retains dissolved dyes by adsorption. Some cartridge filters contain only the pleated paper shell and are used as polishing filters.

Adsorptive cartridge filters (also known as jumbo split or jumbo full-sized cartridge filters) contain activated carbon and activated clay or only activated clay in the filter core. Activated clay (attapulgite or montmorillonite) adsorbs non-volatile residues from the solvent. Activated clay can remove water, alcohol, acids, ketones, aromatic compounds, paraffins, and natural esters.

Spin-disk or roto-disk filter systems consist of a series of polyester mesh disks mounted on a hollow shaft. Impurities in the solvent are filtered out as the solvent flows through the polyester disks. Periodically, the soils and impurities that are deposited on the outer surface of the disks are removed by spinning the shaft on which the disks are mounted. The impurities are spun off and are fed by gravity into the distillation unit for solvent recovery. Some spin-disk filtration systems utilize a filter powder (diatomite) which is deposited on the outside of the disks to aid in the filtration process. Spin-disk filtration systems are becoming more common largely because they generate less waste (there are no cartridges to be disposed).
Cartridge Filters

Cartridge filters remove residue from the drycleaning solvent during the washing and drying steps. These pictures show several examples of cartridge filters. The filter below left is a carbon filter which removes fugitive dyes from the cleaning solvent as it cycles through the drycleaning machine. Behind the soda can (included for size comparison) is a pleated paper/carbon core filter which removes lint from the solvent.
It is becoming more common for both carbon and spin-disk filtration systems to be used in combination on modern drycleaning machines. In the picture above left, the two carbon filter housings are at top, the spin disks are beneath, and the still is at bottom. A cut-away diagram of a spin-disk filtration system is above right (diagram courtesy of International Fabricare Institute. Disk Filtration. Silver Spring: IFI Technical Services Division Bulletin Reprint, Technical Operating Information No. 620). Solvent flows into the polyester disks to the hollow drive shaft, leaving impurities in the solvent adsorbed onto the filtering disks.
Distillation is the most effective method to remove solvent-soluble soils and dyes from drycleaning solvent. The distillation unit can be a separate piece of equipment, but in most new drycleaning machines, the distillation unit is contained in the machine. In the distillation process, dirty solvent is routed to a distillation unit (still) where it is heated until it boils. Pure PCE boils at 250° Fahrenheit but the presence of water and other impurities effectively lowers the boiling point of the mixture. The solvent and water (and any other substance whose boiling point is less than the solvent) are vaporized in the still. The vapors are routed to a condenser where they are cooled and condense into liquid. The residues left behind in the still are known as still bottoms. These residues can contain up to seventy-five percent solvent, by weight. Some drycleaners recover additional solvent from the still bottoms by steam sweeping, a process in which steam is added to the still bottoms and the resulting mixture is distilled.

Drycleaning operations that use powder filtrate material generate what is known as muck, a mixture of powder filtrate material and dirty solvent. Some drycleaners recover solvent from muck in a distillation unit known as a muck cooker. The waste product generated by a muck cooker is known as cooked powder residue.

In general, since most of the compounds contained in petroleum drycleaning solvent have high boiling points (over 300° F), distillation of petroleum solvent is performed under a partial vacuum. Because of this added complexity, many petroleum drycleaning operations do not perform distillation but instead utilize adsorptive cartridge filters to purify dirty solvent.
The photograph above is of the distillation unit at the back of a drycleaning machine. The blue bucket on the right receives distillation residues or “still bottoms,” and the white bucket on the left receives water from the water separator (note: this bucket should be covered to prevent spills or evaporation of residual solvent present in the separator water – water separation will be discussed in more detail later). Above right is another view of still bottoms and muck being collected in a rectangular pan. If the still bottoms are “cooked” to evaporate additional solvent, the solid residue is disposed of as hazardous waste.

At right is the view inside a distillation unit. The ridged pieces at the bottom of the unit are hot steam coils.
A chiller or refrigerated condenser, such as the one above, is used to remove solvent from the distilled vapor and from the exhaust gas from the drying cycle. The picture above right shows the housing which holds the condenser coils. At right is a sight glass which shows condensate moving between the condenser coil and the water separator unit. A properly functioning condenser (thermometer below) on a PCE drycleaning machine should be at 45°F for the cool-down cycle and should have a temperature drop of at least 20°F.
The liquid produced in the condenser is routed to a **water separation unit** (see picture at left) where any water that has entered the process from the atmosphere or from the clothes (or added to the process in small quantities by the operator) is separated by gravity from the solvent. A gallon of PCE weighs 13.5 pounds, while a gallon of water weighs 8.34 pounds, so in a PCE drycleaning system, PCE will sink to the bottom of the water separator and water will rise to the top (see diagram above). Petroleum solvent is less dense than water, 6.59 to 6.8 pounds per gallon, and will thus float on water. The solvent collected in the water separator is routed back to the drycleaning machine base tank where it is stored for re-use.

Water separators receive liquids (solvent and water) from three sources in closed-loop drycleaning machines: from the distillation unit via the condenser, from the dryer where warm solvent-laden vapors are routed to a refrigerated condenser, and from the dryer via carbon adsorption of solvent vapors during the cool-down cycle. The solvent vapors are desorbed from the carbon adsorption unit by regenerating the carbon with steam. Most new drycleaning machines employ two water separators to reduce turbulence and effect better separation of water and solvent.
Above are two more examples of water separator units. At left, the separated water is being collected in an open bucket located behind the drycleaning machine. Separator water is saturated with drycleaning solvent and sometimes contains free-phase solvent. Depending on the type of drycleaning solvent utilized, the separator water may be a hazardous waste. Because of the presence of solvent in this liquid, the bucket should be covered with a lid to prevent spills and escape of residual vapors. Alternatively, the separator water can be plumbed directly to a water treatment unit (next slide).
Some drycleaners dispose of separator water through a hazardous waste disposal firm, but others have on-site capacity to treat the separator water and reclaim some of the solvent. In on-site reclamation, the water is treated, often with either granular activated carbon or polymer filters, to remove most of the dissolved solvent before evaporating or misting (atomizing) the treated wastewater to the atmosphere or discharging it to the sanitary sewer. Some operators evaporate the water without treatment or dispose of untreated water directly to the sanitary sewer, though both of these disposal methods are illegal in many parts of the country.

The photos at right show separator water treatment units with activated carbon filters (white cylinders). The raw separator water can be introduced into the treatment unit by pouring it from the separator water collection bucket into the unit or by directly piping the water from the separator to the treatment unit. Above right, the treated water is collected in another bucket. This water has been treated and can be disposed into the sanitary sewer provided it meets the local pre-treatment standards for discharge. The carbon or polymer filters, once they are spent, are generally discarded as hazardous waste.
Activated carbon is very effective at removing solvent residues from exhaust air. At high air flow rates and low solvent concentrations, carbon adsorption can remove up to 95% of the solvent in waste air. The picture above left shows a **carbon adsorption unit** (known as a “sniffer”) that collects solvent vapors from a transfer machine dryer. In some old PCE transfer operations, vapors were collected from inside the drycleaning plant by exhaust hoods and floor pickups and was routed to a carbon adsorption unit. Periodically, the solvent is stripped from the carbon adsorption unit by circulating steam through it. The spent steam is routed to a condenser, the tall black cylinder on the right side of the picture and the condensed liquids (solvent and water) flow into a water separator (small steel cylinder mounted beneath the condenser). Above right is another example of a carbon adsorber.
Lint, seen in the box above, constantly accumulates at a drycleaning facility. Lint is a hazardous waste and must be handled as such. Above right, a clean lint bag is being installed into a machine lint filter, seen at right. Lint is flammable and can therefore cause fire to spread rapidly. Just like lint from your dryer at home, it can escape the machine and settle onto everything in the facility, thus it is critical to remove excess lint buildup from exposed surfaces, including the ceiling and machine parts, at regular intervals.
Air Filtration

The air involved in the drycleaning process can also be cleaned, if desired (although it is generally not regulated). Pictured above and at right are two types of air filters with their respective housings that are used to remove particulate matter from the process air. These filters require regular cleaning.
The **boiler**, left, and the **air compressor**, right, are the sources of heat and air for garment drying as well as heat and steam for distillation, spot-cleaning, pressing, and equipment cleaning. Steam from a boiler can also be used to regenerate carbon adsorption units and cartridge filters. The boiler must be checked regularly to prevent conditions which may lead to over-pressurization.
Pressing

Now we will leave solvent issues and return to the clothes!

Once garments undergo post-treatment spot-cleaning (which is similar to pre-treatment spot-cleaning using spotting boards, various cleaning solvents, and steam), they need to be **steam pressed** and **starched** so that they look and feel crisp for the customer.

On this page are examples of presses for shirts and pants. Steam presses such as these are served by steam and vacuum lines. The garment to be pressed is placed on the pad of the steam press. The pad contains holes through which a partial vacuum is applied to hold the garment to the pad. The garment is pressed by lowering the top portion of the press onto the garment and depressing a foot pedal that releases the steam. The vacuum system collects some of the spent steam which is routed to a vacuum unit.
In some drycleaning and laundry facilities, newer finishing equipment is replacing traditional presses. Above is a “sleever” for shirt sleeves: Instead of pressing the sleeves flat and giving them a crease, steam is used to inflate the arms of the shirt to give them a smooth finish. Above right, the body and sleeves of a shirt can be finished in unison, saving a step in the pressing process, but the collar and cuffs still have to be pressed separately.
Vacuum Units

During post-treatment spot-cleaning and pressing, spotting wastes and steam are removed from the garments with vacuum. The vacuum unit, two examples of which are shown here, receives return steam from the steam presses and the spotting board. This condensed water contains small concentrations of solvent. Depending on the type of solvent used and the local or state waste regulations, this waste stream may be a hazardous waste.

In the pictures, the smaller cylinder mounted on the top of the unit is a vacuum pump. The larger tank at the base of the unit collects the steam condensate, known as “vacuum water” or “press return water.”
One specialized piece of equipment is a cabinet dryer, also known as a drying cabinet or steam cabinet. These cabinets are used to dry items like sweaters that should not be tumbled. In addition to drying delicate garments, some operators put spent cartridge filters in the cabinet and recover additional solvent from the spent filters by pulling air or steam through the cabinet and then routing the recovered vapors to a carbon adsorber.
We are getting close to the end: Here are the clean clothes, on hangers and ready to be bagged, …
…Clean Clothes!

…and here they are, the clean garments which have been through the entire drycleaning process, ready to be retrieved by the eager customer!

This brings us to the end of our Drycleaning Virtual Tour. If you would like to learn more, please see the “Glossary of Drycleaning Terms” found on the State Coalition for Remediation of Drycleaners (SCRD) Web Site under the “Reference” Section (http://www.drycleancoalition.org/). Also refer to “Chemicals Used in Drycleaning Operations” under “Publications” on the SCRD website.

If you are interested in learning more about regulatory issues which must be addressed at drycleaning facilities, see the upcoming Virtual Tour to be posted soon on the SCRD website.

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