EMULSION TYPE DRY CLEANING SYSTEM

FOR REDUCTION OF LAUNDRY DRAINS IN NUCLEAR PLANTS

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ABSTRACT

Protective clothing against radioactive contamination used in the radiation controlled areas of nuclear plants has been washed by the same wet washing as used for underwear washing, but recently dry cleaning is coming into use in place of wet washing, which generates a large quantity of laundry drain. However, it was required to use wet washing once every five to ten dry cleanings for washing protective clothing, because conventional dry cleaning is less effective in removing water-soluble soils. Therefore, in order to eliminate wet washing, and to decrease the quantity of laundry drains, the emulsion type dry cleaning system capable of removing both oil-soluble and water-soluble soils at a time has been developed. The results of developmental experiments and actual application are presented in this paper.

INTRODUCTION

In nuclear plants, personnel wear protective clothing in radiation controlled areas to protect themselves against radioactive contamination. The clothing is generally used repeatedly and washed after each wearing.

In nuclear plants in Japan, such protective clothing has been washed by wet washing. However, wet washing generates a large quantity of laundry drain (e.g. 4000 ∿ 5000 m^3 per year from a twin-unit PWR plant). In general, it is necessary to treat the laundry drains by liquid waste disposal systems, such as evaporators, R/O (reverse osmosis) systems, or filters in order to remove radioactive substances. It is therefore desirable to reduce the quantity of such laundry drain and simplify such disposal systems.

Recently, in place of wet washing, dry cleaning is coming into use because it basically generates no laundry drains. But wet washing is still being used in combination with dry cleaning, because clothing which has been cleaned only by conventional dry cleaning soon becomes malodorous due to the accumulation of sweat-soils. Conventional dry cleaning is less effective in removing water-soluble soils such as sweats, because it employs a hydrohobic solvent, e.g. trichlorotrifluoroethane; $C_2Cl_3F_3$, for cleaning. Therefore, protective clothing must be wet washed periodically, for example, once every five to ten dry cleanings.

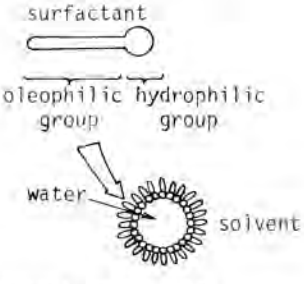


Fig. 1. Concept of Emulsion.

So if it is possible to eliminate this periodic wet washing, the quantity of the laundry drain will be substantially reduced and the disposal system for its treatment eliminated. For the purpose of improving the ability of dry cleaning to remove water-soluble soils, we have developed a new water-solvent emulsion type of dry cleaning system.

In our emulsion type dry cleaning system, the clothing is washed by an emulsion which is, as depicted in Fig. 1, made by emulsifying a little water and solvent with the action of surfactants in the special detergent, making it possible to remove water-soluble soils by "the water and surfactants" in the emulsion. In this paper, the results of developmental experiments and actual application are presented.

DEVELOPMENT OF EMULSION TYPE DRY CLEANING SYSTEM

Selection of the Detergent for Emulsion

Trichlorotrifluoroethane ($C_2Cl_3F_3$; so-called "Freon R113") is used because of its high efficiency and safety as the solvent for dry cleaning in nuclear plants. However, no detergents containing suitable surfactants for emulsifying water and "Freon R113" are on the market because of the difficulty in emulsifying "Freon R113" and the lack of demand for an emulsion in commercial dry cleaning. So it was necessary to develop such a detergent in order to apply the emulsion type dry cleaning system to nuclear plants.

In the tests to select a detergent, a closed beaker filled with the solvent ("Freon R113"), water and detergent was shaken and then allowed to stand and the resultant solution was observed. First, nine kinds of detergents for conventional dry cleaning were tested. Various ratios of solvent, water and detergent were tried, but only confirmed that the detergents for conventional dry cleaning would not creat an emulsion or would cause gelation. Therefore, a special detergent for emulsifying water and "Freon R113" was made by improving the kind and the composition of surfactants contained in the detergent.

Cleaning Efficiency of Emulsion Type Dry Cleaning

Tests with the detergent selected in the beaker-scale tests were performed in an actual dry cleaning machine and the cleaning efficiency of emulsion type dry cleaning was measured by cleaning protective clothing. In these tests, the effects of various proportions of water and detergent in emulsion, the cleaning time, etc. were researched in order to find the most suitable operating conditions for the emulsion type dry cleaning system and comparisons with the other washing methods, such as wet washing and conventional dry cleaning, were made.

A general view of the dry cleaning machine used for this test is shown in Fig. 2. This machine can handle 12 kg of clothing per batch and is a converted commercial dry cleaning machine.

Fig. 2 General View of Test Machine

For measuring the cleaning efficiency of emulsion type dry cleaning, three garments on each of which the test cloths soiled by several kinds of simulated soils were put as many as three pieces of such cloths per each kind of the soils were cleaned together with other 12 garments which had no test cloths. The cleaning efficiency for each kind of soils was calculated by measuring the quantity of each kind of the soils in the test cloths before and after the cleaning.

The cleaning efficiency of emulsion type dry cleaning of the following kinds of soils was measured in this test:

(1) Standard water-soluble soils

(2) Standard oil-soluble soils

(Various kinds of standard soils applied to test cloths are generally used in Japan for detergency tests of commercial cleaning detergents/machines.)

(3) Potassium chloride

(This was used instead of sodium chloride contained in sweats for a precise analysis.)

(4) Butyric acid, the element causing sweat odor

(5) Radioactive soils

The method for calculating the cleaning efficiency in respect to each kind of soils in described briefly in the following. For soil (1) and soil (2) the quantity of soil in the test cloth was measured from the reflectance of light and the cleaning efficiency was calculated from the quantities of the soil in the test cloth before and after cleaning.

For soil (3), the cloths put into an aqueous solution of potassium chloride (12 g/l kCl) and dried were used for the test. In order to obtain the cleaning efficiency, potassium chloride in the cloth was completely dissolved in hot water and the density of the solution was measured by ultraviolet absorptiometry. The method for soil (4) was similar to soil (3), except that gas chromatography was used instead of absorptiometry. For soil (5) ^{58}Co and ^{134}Cs were used as radioactive crud and radioactive ionic soil, respectively. Their quantity was measured with a Ge(Li) semiconductor counter.

The conditions and part of the results of this test are shown in Table I, Fig. 3, Fig. 4 and Fig. 5. Fig. 3 and Fig. 4 show the relation between the cleaning efficiency and the proportions of water and detergent in the emulsions having a constant water to solvent ratio.

In Fig. 3 the cleaning efficiency when the proportion of water in the emulsion was fixed and the ratio of detergent to water was changed is shown. The cleaning efficiency grows higher as the ratio of detergent is increased, but the quantity of the secondary waste, i.e. the surfactants removed from the used emulsion in the distiller, increases. So it was decided to keep the ratio of detergent to water as low as possible in order to minimize the waste quantity while maintaining sufficient cleaning efficiency for practical use.

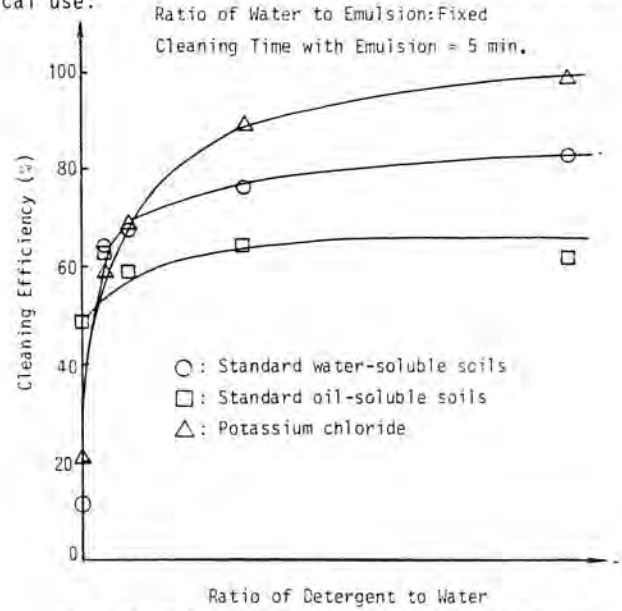


Fig. 3 Relation between Cleaning Efficiency and Ratio of Detergent to Water

In Fig. 4 the cleaning efficiency when the ratio of detergent to water was fixed at the value decided from the results in Fig. 3 and the proportion of water in the emulsion was changed is shown. From the results in Fig. 4, the proportion of water in the emulsion was kept as low as possible while still having enough practical cleaning efficiency and decreasing the drain from the used emulsion.

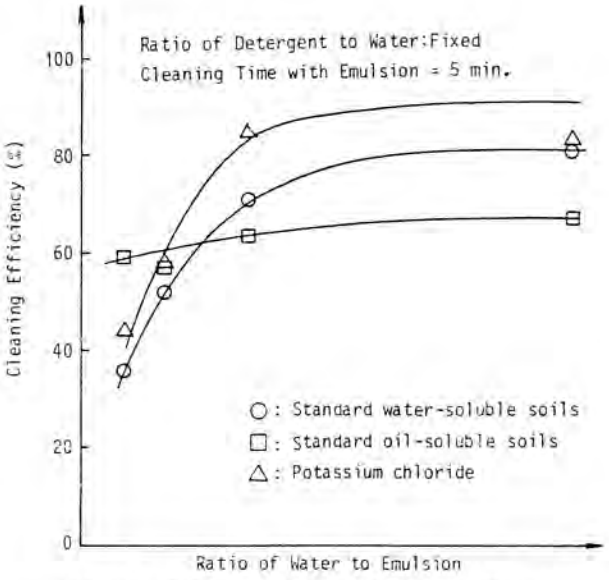


Fig. 4 Relation between Cleaning Efficiency and Ratio of Water to Emulsion

Figure 5 shows that the cleaning efficiency depended on the cleaning time with an emulsion which had a fixed composition determined from the results of Fig. 3 and Fig. 4. The cleaning efficiency was improved gradually in response to the extension of the above cleaning time. However, it was decided to keep the cleaning time as short as reasonable in order to increase the hourly cleaning capacity.

From the test results as mentioned above, the most reasonable operating conditions for the emulsion type dry cleaning system were determined. And comparison tests of the emulsion type dry cleaning and other washing methods, such as wet washing and conventional dry cleaning were performed. The conditions and the results of these tests are shown in Table I, Fig. 6 and Fig. 7. Emulsion type dry cleaning offered almost the same high cleaning efficiency as wet washing for standard water-soluble soils, potassium chloride and butyric acid, in contrast to the quite low cleaning efficiency of conventional dry cleaning. The cleaning efficiency of emulsion type dry cleaning is higher than that of conventional dry cleaning for standard oil-soluble soils and radioactive soils, too.

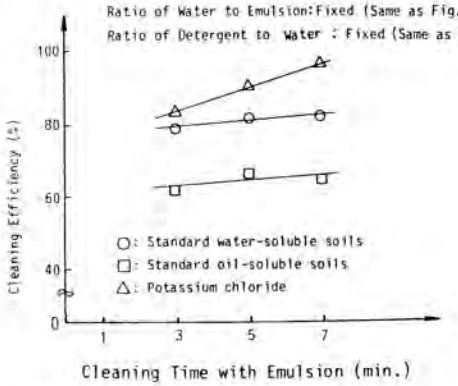
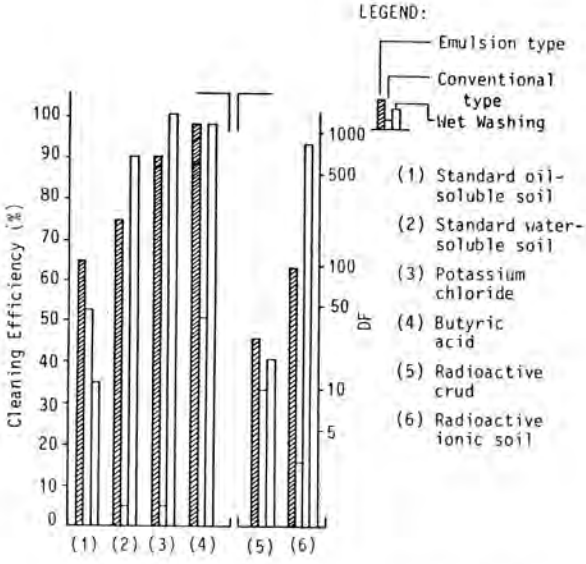


Fig. 5 Relation between Cleaning Efficiency and Cleaning Time with Emulsion



$$\text{Cleaning Efficiency} = \frac{\text{Quantity of soil removed by cleaning}}{\text{Quantity of soil given before cleaning}} \times 100(\%)$$

$$\text{Decontamination Factor (DF)} = \frac{\text{Activity given before cleaning}}{\text{Activity remained after cleaning}}(-)$$

Fig. 6 Comparison of Cleaning Efficiencies of Emulsion Type Dry Cleaning, Conventional Dry Cleaning, and Wet Washing

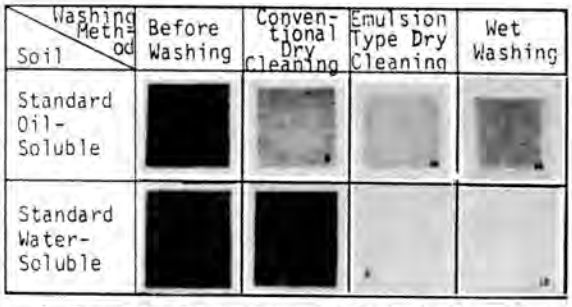


Fig. 7 Results of Cleaning of Test Cloth Soiled by Standard Soil, Either Oil-Soluble Soil or Water-Soluble Soil

TABLE I

Test Conditions of Comparison of Cleaning Efficiencies by Various Washing Methods

Washing Method		Dry Cleaning		Wet Washing
		Emulsion Type	Conventional	
Solvent		Trichlorotrifluoroethane ("Freon R113")		Water
Detergent		Detergent Developed for Emulsion	Detergent for Conventional Dry Cleaning	Detergent for Wet Washing
Test Machine		Commercial Dry Cleaning Machine (modified for the test)		Conventional Wet Washing Machine
Capacity per Batch		12 kg		2.8 kg
Contents of Clothing per Batch		° 3 garments with test cloths soiled with simulated soils, 3 cloths per one kind of the soils ° 12 garments without test cloths		° 1 garment with test cloths soiled with simulated soils
Kind of Fabric		Cotton		
Washing Process	Pre-Washing	1.5 min. (solvent 30ℓ)		-
	Main Washing	5 min. (solvent 56ℓ, water with detergent 4ℓ)	5 min. (solvent 59.7ℓ, detergent 0.3ℓ)	10 min. (water 36ℓ, detergent 12 g)
	Rinse	3.5 min. (solvent 60ℓ)		7.5 min. x twice (water 36ℓ x twice)

Demonstration Test

The optimum operating conditions for the emulsion type dry cleaning system and the superior cleaning efficiency of emulsion type dry cleaning over that of conventional dry cleaning were demonstrated in the above results. More detailed data concerning the operation of this system were derived for application to actual operation.

Table II shows the results of cleaning the clothing (with test cloths) of 100% cotton and 35% cotton and 65% polyester fabrics used generally for protective clothing, and measuring the cleaning efficiency in cleaning both materials. There is little difference in the cleaning efficiency with regard to both fabrics.

TABLE II

Results of Cleaning of Cotton and Cotton/Polyester Clothing by Emulsion Type Dry Cleaning

Material / Cleaning Efficiency (%)	Cotton/Polyester	Cotton
Standard oil-soluble soil	63.7	64.4
Standard water-soluble soil	73.0	76.5
Potassium chloride	88.9	89.3
Butyric acid	97.0	-
Radioactive crud	28.3	25.4
Radioactive ionic soil	95.6	100

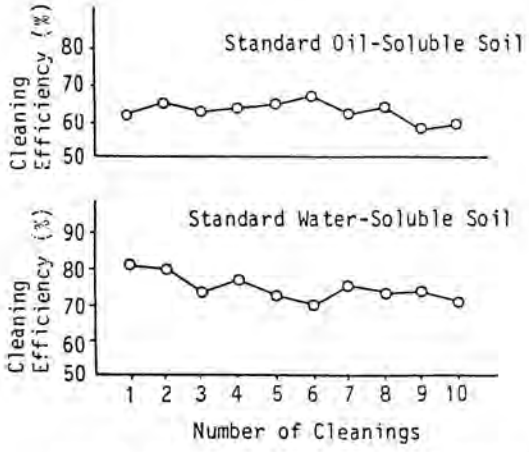


Fig. 8 Results of Cleaning by Emulsion without Distilling

In Fig. 8 the degradation of the cleaning efficiency when using an emulsion repeatedly with neither distilling it nor making-up except water is shown. From the results, i.e. that the cleaning efficiency did not drop remarkably even when the emulsion was used ten times without being distilled, it was deduced that it was possible to reduce the quantity of the emulsion being distilled and thereby decrease the loss of water and detergent.

Fig. 9 shows the transition in the quantity of the remaining soils when the clothing with oil-soluble soils which could not be removed by wet washing was cleaned repeatedly by emulsion. The results indicate that only one cleaning with the emulsion is enough to get a high cleaning efficiency.

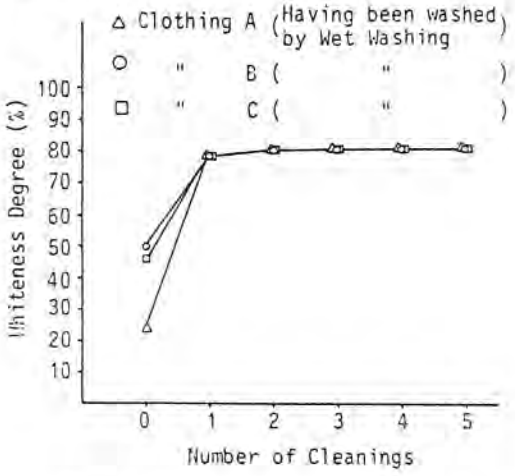


Fig. 9 Results of Repeated Cleaning

ACTUAL APPLICATIONS

Outline of Emulsion Type Dry Cleaning System

The actual emulsion type dry cleaning machine was designed based on the results of the above tests. This machine is an improved version of a conventional dry cleaning machine with an emulsion system (emulsion tank, emulsion pump, etc.) added and reinforcement of the drying capacity (In conventional commercial dry cleaning, it is not intended to dry out the water contained in the clothing.), as well as other modifications required for using it in nuclear plants.

A flow chart of the emulsion type dry cleaning system and its main specifications are shown in Fig. 10 and Table III. The clothing is put into the cleaning drum and cleaned by the emulsion (or solvent only) pumped up from the emulsion tank or solvent tank. During the cleaning process, the emulsion can be circulated between the drum and the filters. After every cleaning cycle, the emulsion or solvent used can be sent to the distiller to remove soils, surfactants and water and thus obtain pure solvent. At the end of the cleaning cycle, the water and solvent remaining in the clothing are extracted by rapid rotation of the drum.

TABLE III

Specification of Emulsion Type Dry Cleaning System

Capacity per batch	45 kg (Garment 60 pieces)
Operating time per batch	Abt. 30 min.
Rotating speed of drum	Cleaning 30 rpm
Main dimensions	$4^W \times 2^L \times 2.8^H$ (m)
Capacity of distiller	Max. 10t/min.
Utilities	Elec., Steam, Compressed air, Detergent and Water

TABLE IV

Comparison of Quantities of the Drain from Three Washing Methods

	Wet washing	Conventional Dry Cleaning	Emulsion Type Dry Cleaning	Remarks
Facility Composition	<Wet Washer> <Drier>	Dry cleaner, <Wet Washer>, <Drier>	<Emulsion Type Dry Cleaner>	Clothing to be treated = 1500kg/day Operation Time = 10 hours/day
Quantity of Drain	$5000m^3$/year	$350m^3$/year	$110m^3$/year	Clothing to be treated = 250,000kg/year
Installation Space	$55m^2$	$70m^2$	$50m^2$	In the case of the above facility composition

After this cycle, the clothing is dried, that is, the solvent and water remaining in the clothing is volatilized and recovered in the condenser. During the drying process, air circulated by the fan through the drum and the air duct is heated in the air heater to volatilize the solvent and water in the clothing. Then it is passed through the lint-filter to remove the lint generated from the clothing, and in the condenser the volatilized gas is removed from the air. The condensed solvent and water are separated by the difference in their density, and the solvent is recovered in the solvent tank and the water is released as drain. In order to keep solvent loss as low as possible, a freezer and an activated carbon tank are used.

Actual Applications

The emulsion type dry cleaning system is being used now in one plant in Japan, though several such systems are scheduled to go into operation. It has been confirmed that clothing cleaned by the emulsion type dry cleaning system remains odorless even without periodic wet washing. Therefore the quantity of the laundry drain (radioactive liquid waste) was substantially reduced as expected (Refer to Table IV). It was demonstrated that it was possible to simplify the liquid waste disposal systems and to reduce the quantity of radioactive substances released into the environment. The utility requirements and the amount of waste from the emulsion type dry cleaning system have proved to be as expected in TABLE V and TABLE VI.

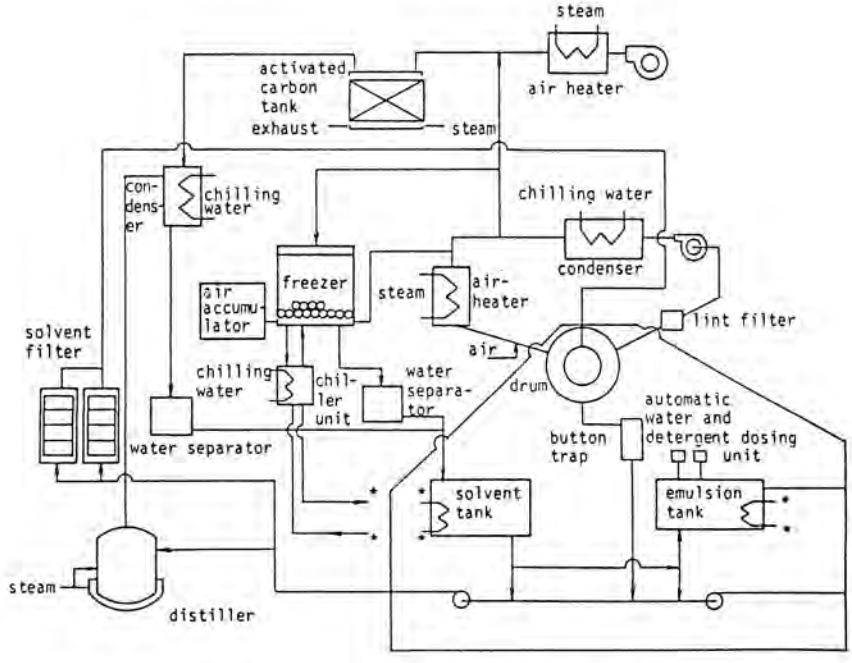


Fig. 10 System Outline of Emulsion Type Dry Cleaning System

TABLE V

Utilities of Emulsion Type Dry Cleaning System

Utility	Condition	Quantity per batch 45 kg of clothing
Electricity	AC50/60 Hz 3ø/220 V	9.3 kWh
Steam	7 kg/cm^{2}G	50 kg
Cooling water for chiller unit	Supply temp. 18 ∿ 35°C 1.5 ∿ 3.0 kg/cm^{2}G	20 m^3/h* *Being used by circulatation
Compressed air	6 ∿ 8 kg/cm^{2}G	12ℓ
Water	Demineralized water	0.8ℓ
Detergent	(Developed for emulsion)	0.1ℓ

TABLE VI

Wastes from Emulsion Type Dry Cleaning System

Waste	Quantity per 250,000 kg of clothing
Remnant in Distiller	0.2 m^3
Used Filter Element	90 elements (2.0 m^3)*
Used Activated Carbon	20 kg
Drain	110 m^3

* Dimension of element 0.34ø x 0.24ℓ (m)

CONCLUSIONS

For the purpose of developing the emulsion type dry cleaning system, detergent development tests, tests to measure cleaning efficiency, and demonstration tests were performed. From the results of these tests the optimum operating conditions for the emulsion type dry cleaning system and the superiority of emulsion type dry cleaning over conventional dry cleaning were confirmed. Furthermore, in actual application it was demonstrated that emulsion type dry cleaning is very effective as a source-oriented waste management for the substantial reduction of laundry liquid wastes in nuclear plants.