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INCINERATION SURROGATE RATIOING TECHNIQUE

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Five surrogate waste constituents, toluene, isopropanol, methyl ethyl ketone, trichloroethylene, and monochlorobenzene, were examined for destruction removal efficiency (DRE). Toluene, isopropanol, and methyl ethyl ketone were burned without auxiliary fuel; and, trichloroethylene and monochlorobenzene were burned with auxiliary fuel in an incineration tunnel. Sulfur Hexafluoride (SF_6) was used as a tracer in all experiments. The results indicate that SF_6 DRE was significantly lower than DREs of SF_6 and surrogate wastes dropped when excess air was above 100-120%. The relationship between SF_6 DRE and excess air revealed similar trends when SF_6 was injected with natural gas as fuel in the incineration tunnel and a steam plant boiler. For a given excess air value, the DREs in the boiler are lower than in the incineration tunnel.

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ABSTRACT. Five surrogate waste constituents, toluene, isopropanol, methyl ethyl ketone, trichloroethylene, and monochlorobenzene, were examined for destruction removal efficiency (DRE). Toluene, isopropanol, and methyl ethyl ketone were burned without auxiliary fuel; and, trichloroethylene and monochlorobenzene were burned with auxiliary fuel in an incineration tunnel. Sulfur Hexafluoride (SF_6) was used as a tracer in all experiments. The results indicate that SF_6 DRE was significantly lower than DREs of all five surrogate wastes. DREs of SF_6 and surrogate wastes dropped when excess air was above 100–120%. The relationship between SF_6 DRE and excess air revealed similar trends when SF_6 was injected with natural gas as fuel in the incineration tunnel and a steam plant boiler. For a given excess air value, the DREs in the boiler are lower than in the incineration tunnel.

INTRODUCTION

Current Federal Regulations Part 264·343, "Performance Standards for Hazardous Waste Incinerators," of the Environmental Protection Agency (EPA) require a 99.99% Destruction Removal Efficiency (DRE) for each waste in a hazardous waste incinerator. Test burns are expensive and testing procedures are subject to large uncertainties. Furthermore, once the unit is approved for waste incineration, there is no provision for constant exhaust monitoring to ensure effective operation. The use of tracers has been suggested to reduce the cost of test burns and to provide a means of continuously monitoring on-line units (1,4). Tracers are compounds with high thermal and chemical stability, nontoxicity and availability of sensitive detection methods.

Continuous monitoring of hazardous waste DREs when permitting incinerators or boilers as disposal units is ideal but often impractical. Feasibility of monitoring DRE by introducing SF_6 as a tracer was studied earlier at the University of Florida Combustion Laboratory (UFCL) in a natural gas turbulent diffusion flame burner (2,3). The primary goal of this research was to extend the results of earlier laboratory study to a system similar in design to small industrial boilers, similar to ones used at many Air Force installations. The laboratory environment was expected to eliminate many of the problems associated with conducting studies in a full-scale operational unit.

For experimental purposes, hazardous waste components commonly found in Air Force wastes were substituted by pure compounds and referred to as surrogates. Toluene, isopropanol, methyl ethyl ketone, trichloroethylene, and monochlorobenzene were used as surrogate wastes in this study. Nonchlorinated surrogates were burned without auxiliary fuel and even then, undetectable quantities of these components were present in the exhaust. Chlorinated surrogates had to be burned with an auxiliary fuel. Auxiliary fuel used was an isoparaffin solvent marketed by Phillips Petroleum Company as Soltrol 100. The objective of this effort was to identify surrogates or tracers suitable for use in the verification minimum waste destruction. Attempts were made to better understand the relationship of other combustion parameters to waste destruction. An incineration tunnel was constructed within UFCL to conduct experiments with gas and liquid fuels. A study of SF_6 destruction in a natural gas fired boiler at the University of Florida steam plant was also conducted to serve as a preparation for possible future extensive studies in full-scale boilers.

EXPERIMENTAL APPROACH

Experimental system consists of the following components: (a) Incineration tunnel, burner and blower and (b) Fuel, waste, and SF_6 feed system.

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The incineration tunnel is designed to simulate a 1068 K-cal/min (100 hp) firetube boiler similar to small boilers used at Air Force bases. A horizontal tunnel 3 meters long and 0.5 meter internal diameter (i.d.) consists of four water-cooled ductile iron sections. All four sections are refractory lined. Waterflow is maintained by a circulation pump and cooled through a roof-mounted radiator. The burner is an ARC Model 550 combination gas and oil burner with a minimum output rate of 125 water horsepower. Liquid atomization is accomplished by a rotating air blast atomizer. Primary air accounts for approximately 20% of combustion air and is supplied by an internal fan. Secondary air is supplied by an external blower and forced through a swirl plate to improve fuel-air mixing in the tunnel. A water manometer measures the static pressure in the air supply duct.

Figure 1A is a schematic of the fuel, waste, and SF_6 feed systems. Previously calibrated rotometers were used to measure flow rates of liquid fuel, surrogate wastes, and SF_6. The natural gas flow rate was measured at the utility supply meter. Liquid fuel was stored in 55-gallon drums and pumped to the burner via an internal burner pump. The fuel rotometer was placed between the pump and the burner. The surrogate wastes were forced from these containers by an upstream compressor and injected into the fuel line downstream of the fuel rotometer. All surrogate wastes were laboratory grade. Liquid fuel was an isoparaffin mixture with carbon numbers ranging from C_8 to C_{11}. The average carbon number of C_{10} was used for data analysis. The isoparaffin was used instead of fuel oil to avoid the possibility of fuel oil combustion products reforming in the exhaust as the wastes. Gaseous SF_6, 99.7% pure, was supplied from a pressurized cylinder. Flow rates were measured using a rotometer before injection in the fuel line near the waste injection point. A second line allowed SF_6 injection into the natural gas line.

The gas sampling system consisted of water cooled sampling rake, a heated sampling line, and a heated pump. A 2 micron filter was located between the sample rake and the sample line. A gas sampling pump capable of delivering 9 liters per minute, was maintained at 200°C. The continuous emission monotors (CEMs) used were a Bendix 402 hydrocarbon analyzer, a Bendix model 864 carbon dioxide analyzer, and a Teledyne model 990 CO/02 analyzer. A Perkin-Elmer model Sigma 300 gas chromatograph with both flame ionization and electron capture detectors was used for measuring waste and SF_6 exhaust concentrations on wet basis. Other CEMs required dry samples near ambient temperatures, therefore gas concentrations from the CEMs are reported on dry basis. The hydrocarbon analyzer had its own sample pump. Sample gas was supplied to the re-

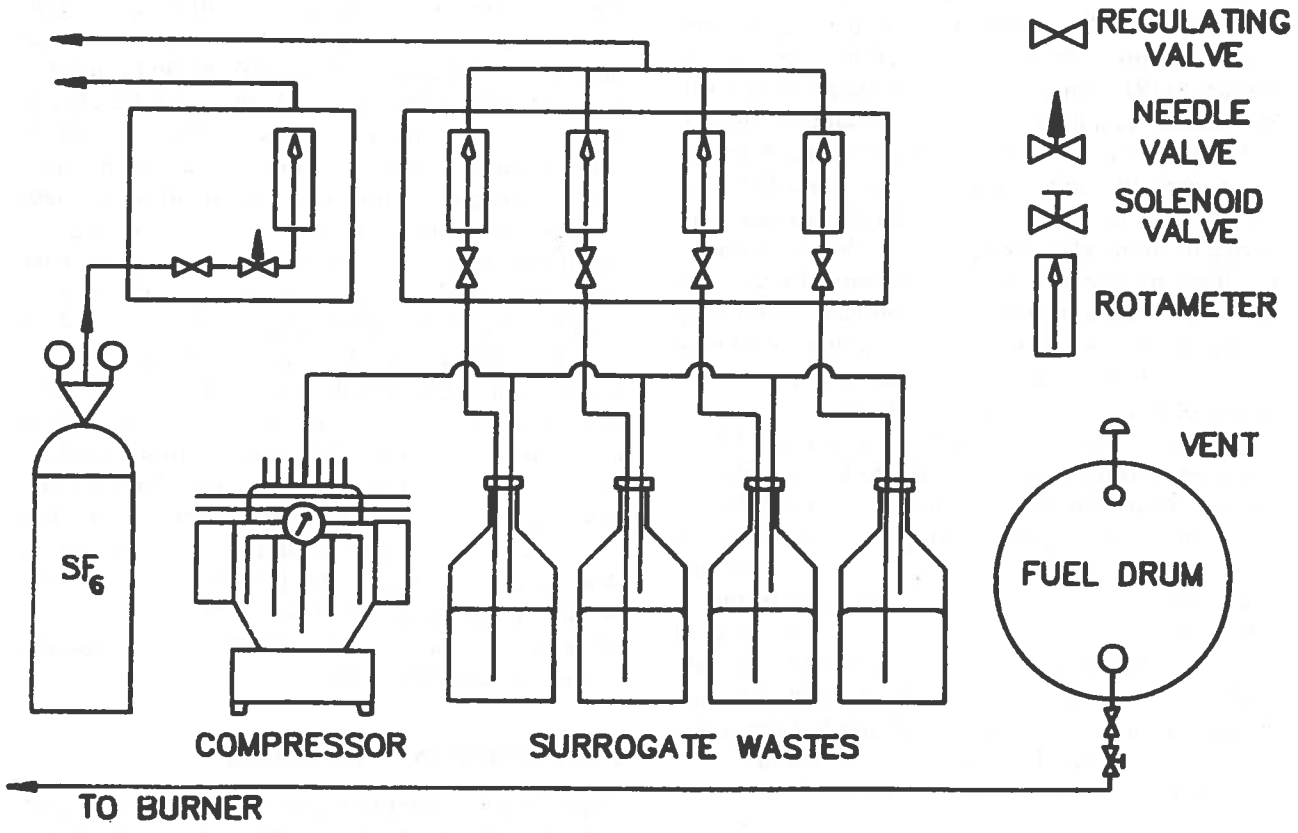

FIGURE 1A. Fuel, waste, and SF_6 injection system.

maining instruments by the main sample pump, which ran continuously. Calibration gases for each analyzer were supplied from gas cylinders. The gas chromatograph (GC) was modified to permit automatic switching between the flame ionization detector (FID) and the electron capture detector (ECD). Three automatic sampling valves were used to direct the sample onto the desired column, and for column backflushing. The FID was used for quantitative analysis of surrogate wastes and the ECD was used for quantifying SF_6 in the exhaust. A Perkin Elmer LCI-100 integrator was used for data integration detector selection, and valve switching.

Column 1 consisted of 15 cm by 0.32 cm 5% H_3PO_4 on 60/80 G(AW) Column, followed by, 30 cm by 0.3 cm 5A molecular sieve 45/60 mesh as stripper column and 4.87 meter by 0.3 cm 5A molecular sieve 45/60 mesh conditioned for 1 hour at 300°C. This set was connected to a 10 port automatic sampling valve for backflushing to vent or forward feeding to the ECD. Column 2 was installed within the GC oven and was used for hydrocarbon separation. It was a supelco 30 meter SPB-1 capillary column with 0.75 mm ID.

EXPERIMENTAL PROCEDURE

The incineration tunnel (Fig. 1B) was first heated on natural gas, then switched to Soltrol 100. Cooling water was circulated through the first two sections. Soltrol was burned over a wide range of fuel and air flows to establish background hydrocarbon concentrations. Only one surrogate waste was burned during each run. Toluene, methyl ethyl ketone, and isopropanol were undetectable when burned with auxiliary fuel. These three surrogate wastes were burned without auxiliary fuel. Even when burned without auxiliary fuel, none of these compounds could be detected in the exhaust of the tunnel. Trichloroethylene and monochlorobenzene were burned with auxiliary fuel. Thermocouple used for recording temperature in the hot zone burned out, therefore, no temperature was recorded. Waste flows ranged between 23 mL/min to 655 mL/min. Auxiliary fuel flow ranged between 0 mL/min to 448 mL/min. Air flow ranged between 0.5 m^3/min to 8.3 m^3/min. SF_6 was injected into the fuel line at 5.8 mL/min for trichloroethylene runs and 8.9 mL/min for all other surrogate wastes. The tunnel was allowed to equilibrate for at least 15 minutes before samples were taken. Carbon monoxide concentrations were above the upper range of 100 μL/L (ppm) for the CO monitor during runs 3, 6–14, 17, 18, and 20.

During the segment when SF_6 was burned with natural gas in the tunnel, SF_6 was added into the fuel line at 5.8 mL/min. Fuel flow varied between 0.1 kg/min and 0.26 kg/min. Air flow rates varied between 7 kg/min and 13 kg/min. The fuel flow was varied only after the full range of air flows had been exhausted. Data were recorded from the CEMs and GC/ECD.

The final phase of the experiment was conducted at the University of Florida steam plant, boiler 5. The boiler was fueled by natural gas. Fuel flow varied between 9.6 kg/min and 19.3 kg/min. Air flows varied between 200 kg/min to 760 kg/min. Adiabatic flame temperature ranged between 1300° and 2100°C.

RESULTS

In analyzing the data, emphasis was placed on relating waste destruction removal efficiency (DRE) to data obtained from the continuous emission mon-

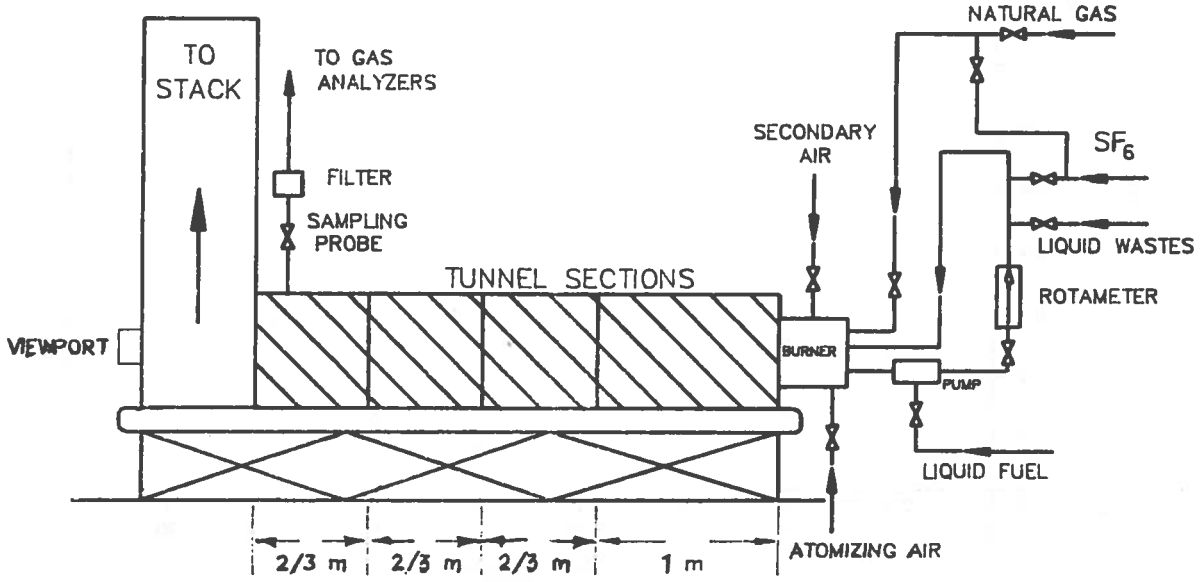

FIGURE 1B. Incineration tunnel.

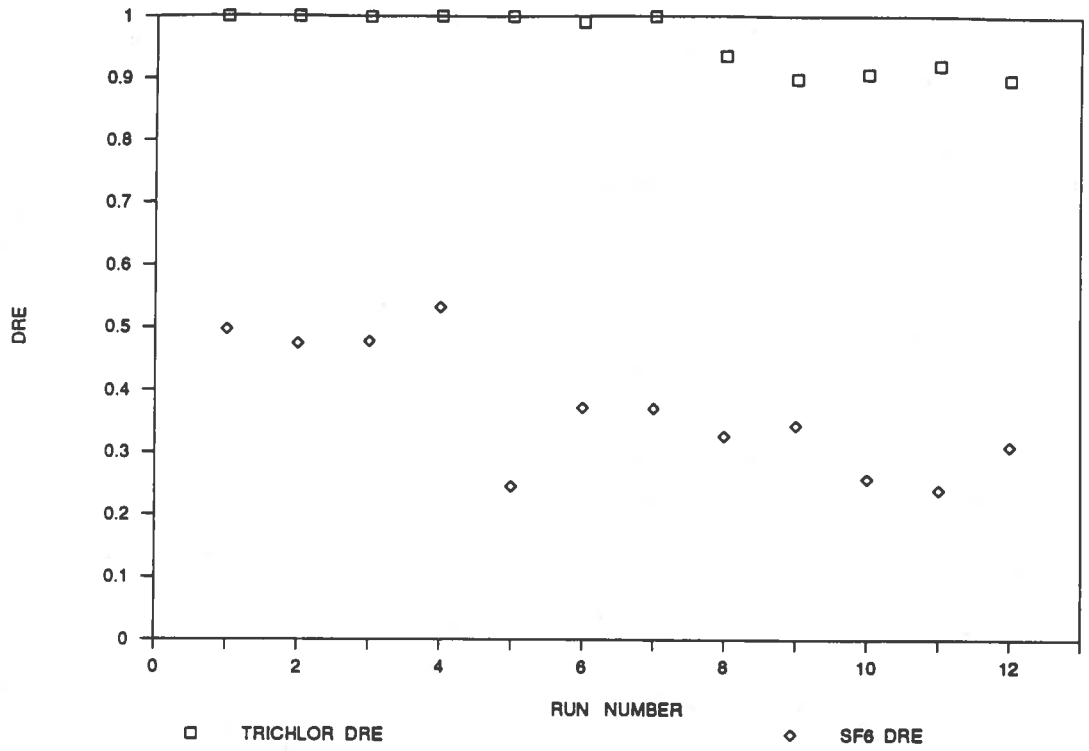

FIGURE 2. Comparison of trichloroethylene and sulfur hexafluoride DRE for liquid fuel firing in the incineration tunnel.

itors (CEMs) and to the DRE of SF_6. The relationship of excess air with waste and SF_6 DRE was also examined. The work at the steam plant generated information on the effects of excess air on SF_6 DRE in a natural gas fired industrial boiler.

The reduced data are presented in Figs. 2 to 12. Data for surrogate wastes and SF_6 in the incinerator tunnel are presented in Figs. 2 to 9. Figures 10 and 11 represent SF_6 DRE data for incineration tunnel fired with natural gas as fuel. Figure 12 represents SF_6 DRE data for steam plant boiler fired on natural gas.

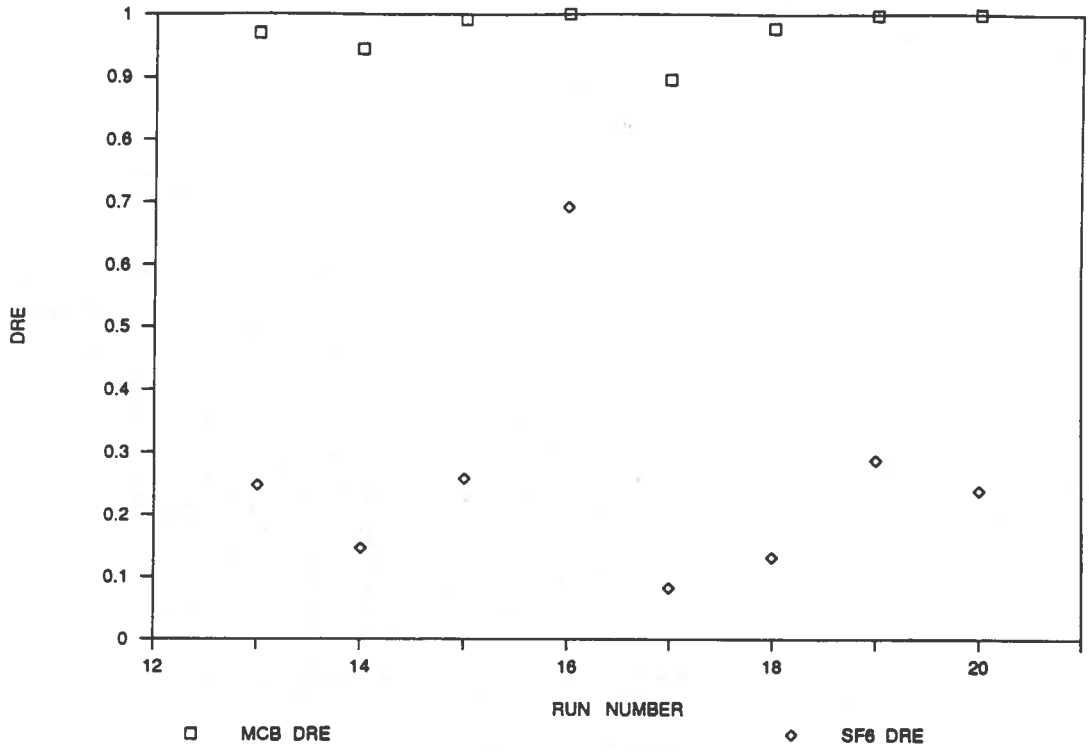

FIGURE 3. Comparison of monochlorobenzene and sulfur hexafluoride DRE for liquid fuel firing in the incineration tunnel.

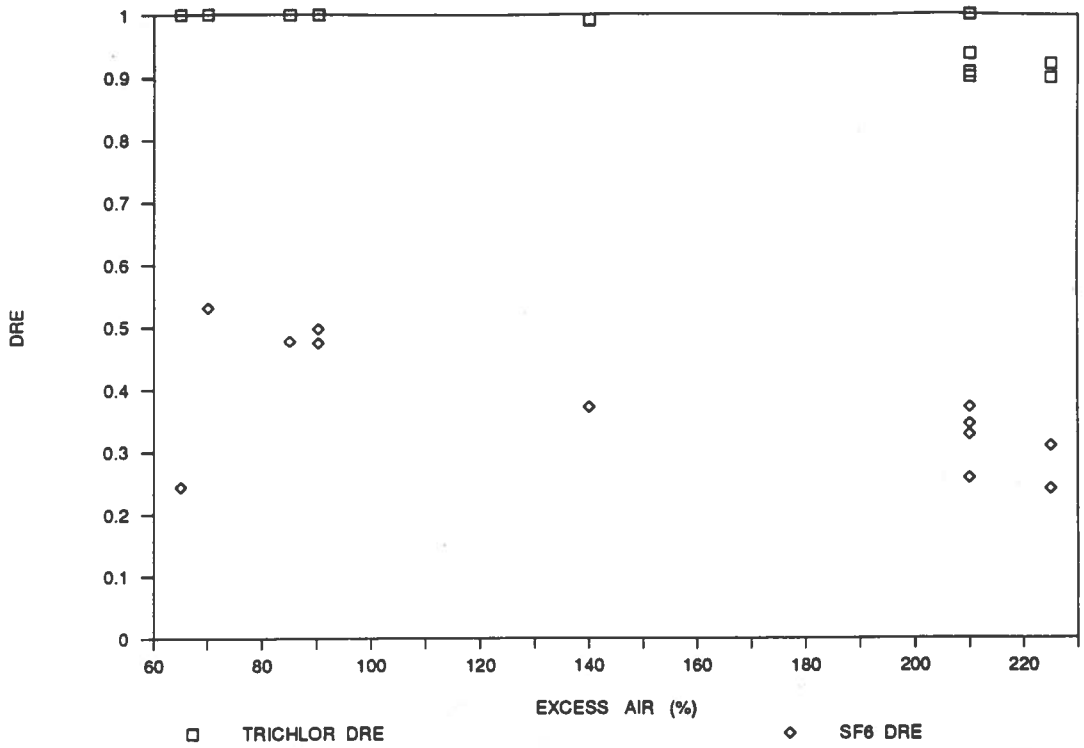

FIGURE 4. Trichloroethylene and sulfur hexafluoride DRE versus excess air for liquid fuel firing in the incineration tunnel.

Toulene, isopropanol, and methyl ethyl ketone were undetectable in the exhaust even when burned without auxiliary fuel in the incinerator tunnel. The DREs were calculated based on a detection limit of 0.4ppm for GC/FID. The DREs for these three chemicals were determined to be at least 0.9999. The experiments were carried in duplicates and the results were similar in all runs. These data were not plotted. Majority of the data was collected for the two chlorinated hydrocarbons over a wide range of run conditions. Trichloroethylene and monochlorobenzene DREs ranged from 0.8963 to 0.9998. SF_6

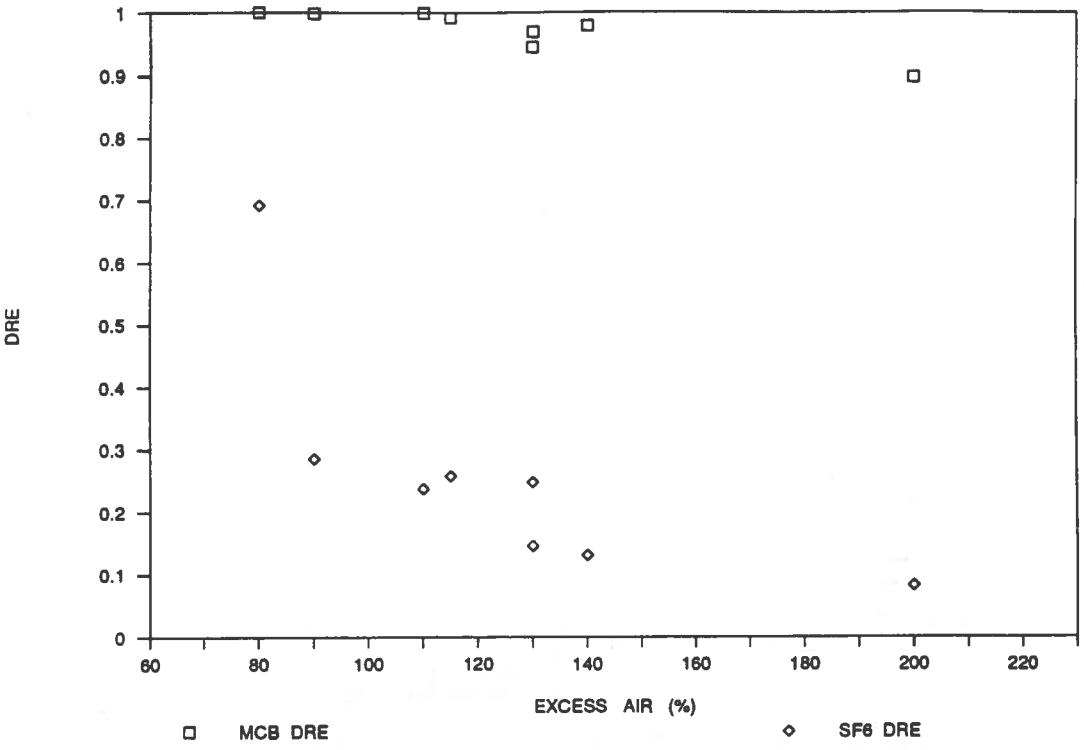

FIGURE 5. Monochlorobenzene and sulfur hexafluoride DRE versus excess air for liquid fuel firing in the incineration tunnel.

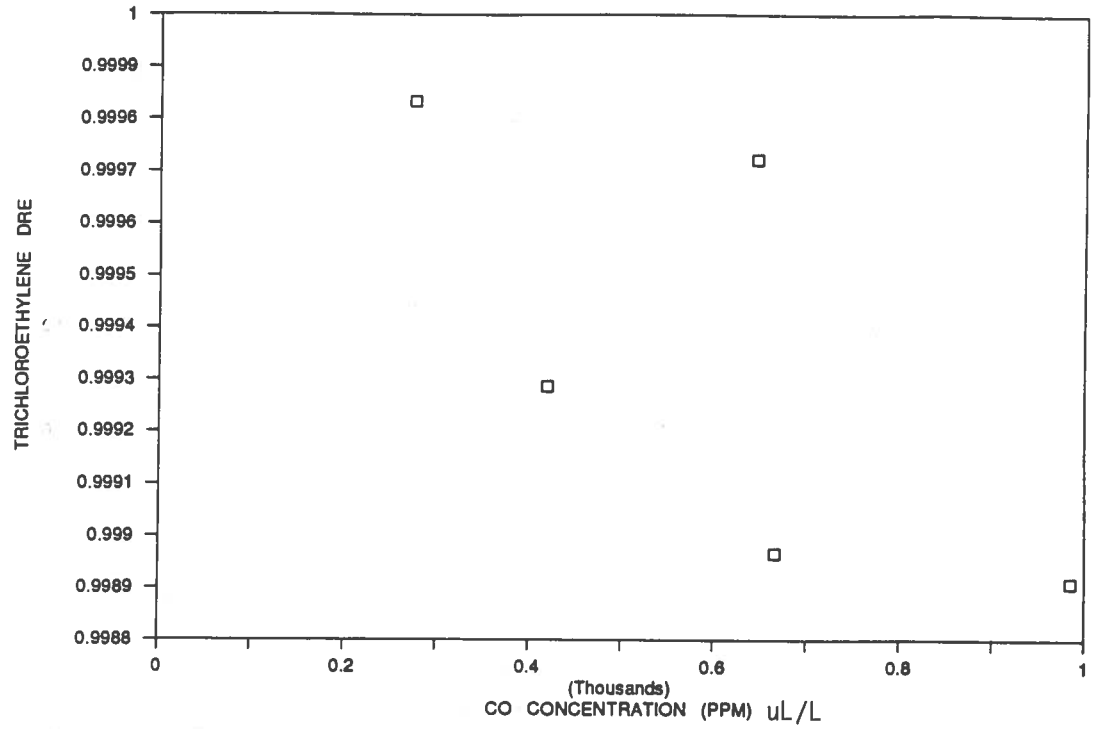

FIGURE 6. Trichloroethylene DRE versus exhaust CO concentration for liquid fuel firing in the incineration tunnel.

DREs were much lower, ranging from 0.0819 to 0.6921. Figures 2 and 3 compare the DRE of SF_6 with DREs of chlorinated surrogate wastes. In all cases, the SF_6 DRE was significantly lower than the waste DRE. This was also the case for runs with toluene and isopropanol. Data for SF_6, used with methyl ethyl ketone was not obtained, although the results should not differ from the other chemicals.

Figures 4 and 5 show the DREs plotted against excess air. For the wastes, a sharp drop in DRE is observed for excess air above 100–120%. SF_6 DRE also decreases with increased excess air. Similar

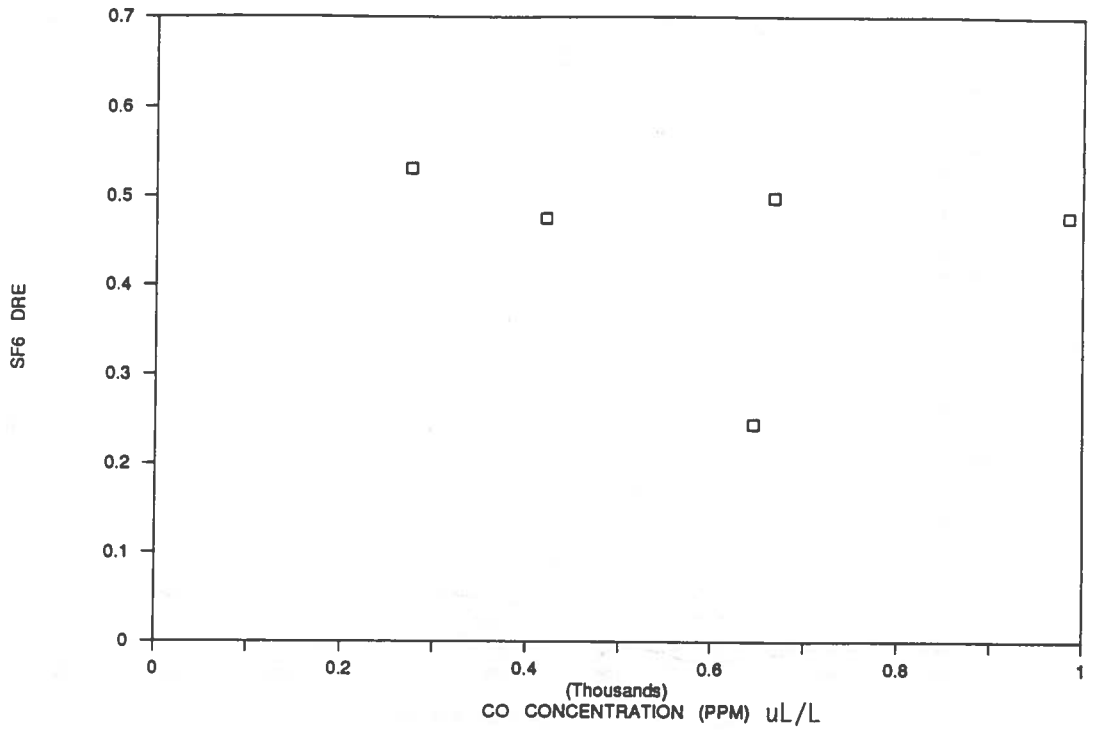

FIGURE 7. Sulfur hexafluoride DRE versus exhaust CO concentration for liquid fuel firing with trichloroethylene in the incineration tunnel.

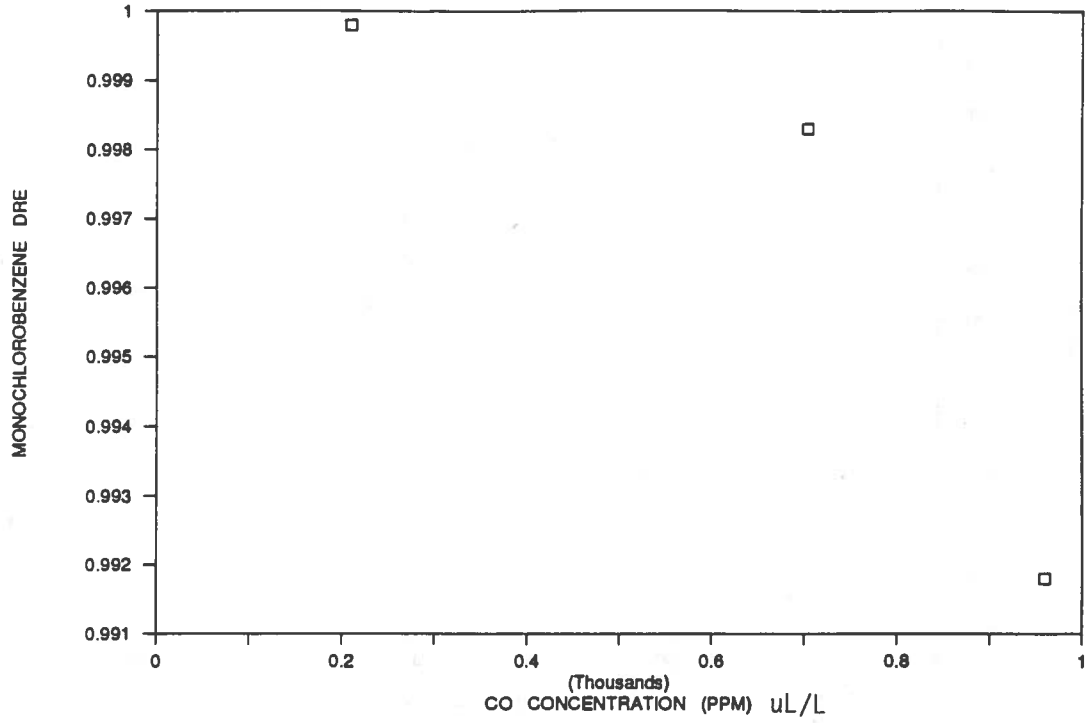

FIGURE 8. Monochlorobenzene DRE versus exhaust CO concentration for liquid fuel firing with trichloroethylene in the incineration tunnel.

trends are seen when DREs are plotted against O_2 concentration.

Figures 6 through 9 show the DREs of the wastes and SF_6 plotted against the exhaust CO concentration (dry basis). Many of the CO measurements were above the maximum range of CO analyzer. CO in the exhaust is an indication of inefficient combustion, often related to poor mixing, poor atomization, or reaction quenching as a result of insufficient energy to complete the oxidation of CO to CO_2. During this experiment, it is likely that all three of these played a role in causing high CO concentrations. Only those

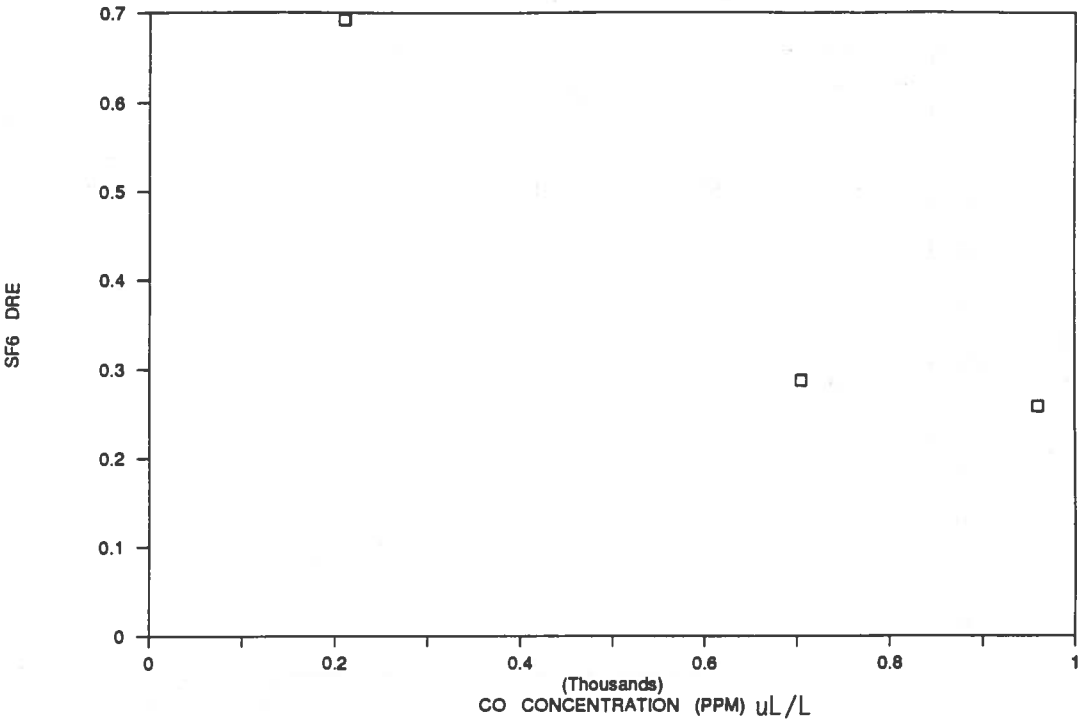

FIGURE 9. Sulfur hexafluoride DRE versus exhaust CO concentration for liquid fuel firing with monochlorobenzene in the incineration tunnel.

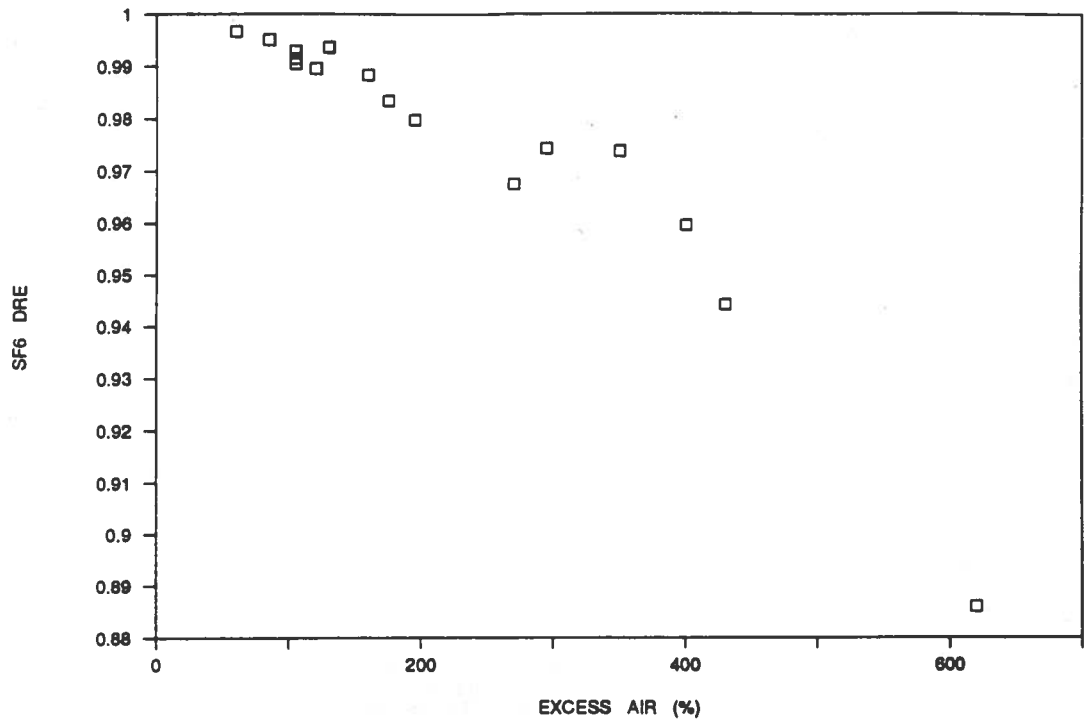

FIGURE 10. Sulfur hexafluoride DRE versus excess air in the incineration tunnel fired on natural gas.

values within the range of CO analyzer are plotted. A trend of lower DREs with increased CO concentration is evident, although there were too few data points plotted to draw definite conclusions. The high DREs of toluene, methyl ethyl ketone, and isopropanol were accompanied by relatively low CO and unburned hydrocarbon concentrations.

The reduced data from the natural gas runs in the incineration tunnel and steam plant boiler are presented in Figs. 10 through 12. Data from the CEMs were only obtained from the runs in the incineration tunnel and are presented in Figs. 10 and 11. Figure 11 shows no strong correlation of exhaust CO with SF_6 DRE, although a trend of reduced DRE at higher CO concentrations was observed. Figures 10 and 12 show SF_6 DRE plotted against excess air in the in-

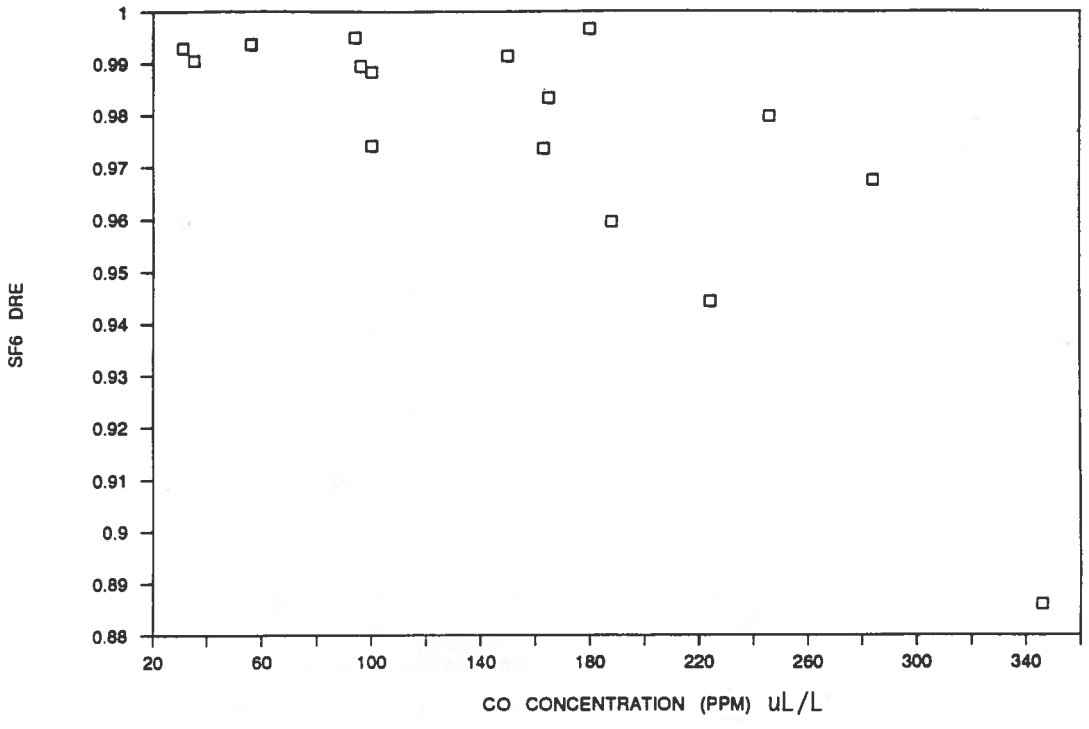

FIGURE 11. Sulfur hexafluoride DRE versus exhaust CO concentration in the incineration tunnel fired on natural gas.

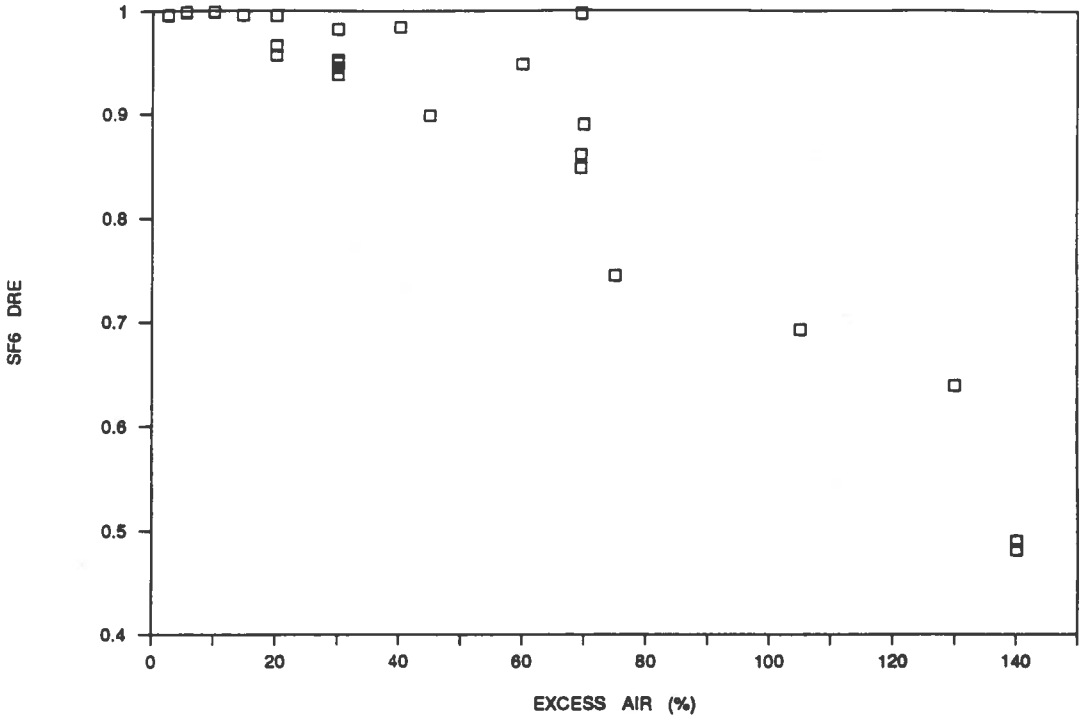

FIGURE 12. Sulfur hexafluoride DRE versus excess air in the steam plant boiler fired on natural gas.

cineration tunnel and the boiler. For both systems, DRE falls with increased excess air. Increased exhaust concentrations of O_2 and unburned hydrocarbons are indicative of reduced SF_6 DRE. For a given excess of air value, the DREs in the boiler are lower than in the tunnel. This is explained by the fact that the boiler was producing steam, therefore transferring energy in the boiler to waterwalls. While in the tunnel, the water flow through the last two sections was shut off, therefore, extra energy was available in the tunnel to burn wastes and SF_6.

CONCLUSIONS

For all the experimental runs from which data were obtained, the DREs of toluene, methyl ethyl ketone isopropanol, trichloroethylene and monochlorobenzene were greater than the DREs of SF_6. This indicates that SF_6 is more difficult to destroy than the surrogate wastes tested in this study. This supports the contention that SF_6 would be a reasonable tracer to use in the incineration process for several reasons. SF_6 is neither found in waste streams nor is it the by-product of combustion reactions. It is easy to detect at low parts per billion (nL/L) levels and with near real-time techniques. A potential disadvantage of a gas phase tracer, such as SF_6, is that it can't predict atomization characteristics of an injection nozzle. SF_6 DRE data for the incineration tunnel, when fired with liquid fuel, is considerably different from the data obtained when the same tunnel was fired with natural gas. Previous work done at UFCL (3) for SF_6 as tracer and benzene and trichloroethylene surrogate wastes in a natural gas burner did show SF_6 DREs lower than surrogate waste. The difference was not as large as that obtained in the incineration tunnel fired with liquid fuel plotted in Figs. 2 and 3. This study, although not complete, does indicate utility of SF_6 to monitor boiler operations when it is cofired with waste solvents. If approved by the regulatory agencies, this would be a convenient technique for monitoring combustor operations almost continuously, at relatively low costs. The majority of Air Force bases have boilers that can be utilized for periodic on-site destruction of very small quantities of solvents.

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