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FEASIBILITY OF 5 gpm DYNACTOR/MAGNETIC SEPARATOR SYSTEM TO TREAT SPILLED HAZARDOUS MATERIALS

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FEASIBILITY OF 5 gpm DYNACTOR/MAGNETIC SEPARATOR SYSTEM TO TREAT SPILLED HAZARDOUS MATERIALS

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminents on man and the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

Pollution resulting from spills of hazardous materials is widely recognized as very damaging to the water ecosystem and to the public health and welfare. This report describes new physical-chemical treatment technology for the cleanup of waters contaminated by this source of pollution.

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ABSTRACT

Design and operating details are given for a new type of continuous flow thin-film, gas-liquid-particulate contact device called the Dynactor. The device is used as a continuous flow short-time contact reactor to effectively decontaminate water contaminated with spilled hazardous materials. The decontamination is effectively achieved by one or more processes involving oxidation, neutralization, precipitation or adsorption on powdered carbon. Contaminated water is processed by the pilot plant model Dynactor at 100 psi and at a rate of 5 gpm; stoichiometric quantities of decontaminating agents in the form of gases, liquids, slurries or powders are metered into the continuously flowing liquid configuration. The device is portable, lightweight polypropylene construction, has no moving parts, requires a pump for liquid motive power and can be scaled up to process 250 gpm of contaminated water.

Design and operating details are given for continuous flow magnetic separation to remove flocculated carbon and precipitates from the Dynactor effluent after decontamination of hazardous materials.

Experimental data on successful decontamination of heavy metals by precipitation, acids and bases by neutralization, phenol, chlorine and pesticides by powdered carbon adsorption and other selected hazardous compounds are presented.

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SECTION I

CONCLUSIONS

Under Contract No. 68-01-0123 from the Environmental Protection Agency, Industrial BIO-TEST Laboratories, Inc., and R P Industries, Inc. (subcontractor) have proven feasibility of a short contact time physical chemical treatment system consisting of a Dynactor and a magnetic separator, to process and decontaminate hazardous materials spilled in waterways. The feasibility study was directed to the decontamination of the contained spill and the contaminated waterway through a process of physical and chemical reactions carried out by a continuous flow thin-film, gas-liquid-particulate contact device (Dynactor). With this device it was shown possible to meter into the continuously flowing stream of contaminated water stoichiometric quantities of decontaminating agents in the physical form of gases, liquids, slurries and powders. These decontaminating agents interface with the contaminated water in thin-film configuration and effect decontamination during the approximate 0.2 second residence time in the Dynactor's reaction column. The decontamination was shown to be effectively achieved by one or more processes involving oxidation, neutralization, precipitation or adsorption on powdered carbon. Acids, bases, phenol, chlorine, aliphatic and aromatic hydrocarbons, cyclic and acyclic pesticides and miscellaneous hazardous substances were successfully decontaminated within the scope of the feasibility contract.

In order to separate precipitates and flocculated carbon (resulting from the decontamination process) in a continuous flow configuration, a process of magnetic separation was designed and satisfactorily demonstrated.

SECTION II

RECOMMENDATIONS

The feasibility study resulted in sufficient data, equipment performance and information to meet the design goals of the project and to recommend a Phase II study. All of the experience and data documented in this feasibility study were generated with a physical-chemical treatment system capable of processing contaminated water at the maximum rate of five (5) gallons per minute (gpm). While the 5 gpm model is a very convenient and suitably sized unit for laboratory pilot studies, useful applications in the field will require a system capable of processing at least 250 gpm. It is therefore recommended that a Dynactor and separation system be developed with a processing capacity of 250 gpm engineered in a mobile continuous flow configuration. This work should include the design, fabrication, engineering, testing and decontamination performance of the complete unit. It is also anticipated that some high rate settling columns will be necessary to initially separate the flocculated carbon and precipitates from the large volume of processed water. To complete the separation process, the solids should be further concentrated and dewatered by a suitably scaled up magnetic separation system.

It is recommended that each scaled up component of the system be tested for mechanical performance and then mounted on a single self-contained flat bed trailer equipped with a diesel powered electric generator set.

Finally, it is recommended that the total mobile system be tested against selected hazardous chemicals under simulated spill conditions.

SECTION III

INTRODUCTION

This report covers work conducted primarily during the period July 1971 through June 1972 involving a feasibility study of specific equipment for the mobile processing and decontamination of spilled hazardous materials in waterways. The work was carried out under EPA Contract No. 68-01-0123 in response to a Request for Proposal to develop new and effective methods to "Treat, Control and Monitor Spilled Hazardous Materials." Industrial BIO-TEST Laboratories, Inc., is the prime contractor responsible for program management and the chemical and analytical aspects of the decontamination studies. R P Industries, Inc., is the subcontractor responsible for equipment design, fabrication, modification and engineering evaluation.

Industry is producing and shipping an ever increasing volume and array of hazardous polluting substances which pose a constant threat of sudden discharge into the waters of the nation. Accidental spills will occur through human error or unforeseen or uncontrollable disasters and circumstances. The spills will cause varying degrees of hazard and damage in the watercourse, depending on the uses of the watercourse, type and quantity of materials spilled and their relation to the size and type of watercourse. Because of the diversity of potentially hazardous substances and persistence of materials, resulting in both immediate and long-term effects, the immediate initiation of proper countermeasures needed for flowing streams, impoundments, estuaries, and open seas will probably vary, making the type of response more diverse. In any event, the countermeasures must be selected to permit rapid application in both congested and remote areas, light in weight, easily obtainable and transportable, present limited hazards to handlers and result in no reactivity problems causing secondary pollution in the watercourses or generation of harmful sludges.

The Battelle Report (1) on "Control of Spillage of Hazardous Pollution Substances" clearly documents the fact that techniques for treating and controlling spilled hazardous materials in the aquatic environment are inadequate or nonexistent. Methods are available as a second line of defense for removing almost all water contaminants under controlled conditions and with fixed water treatment plant installations. However, most of these techniques are not satisfactory for application in the aquatic environment. The report recommended that work must be initiated in the area of control to develop new methods for containing spills before they reach surface waters, to contain contaminated waters after a spill, to decontaminate polluted water areas and to return the water in a restored condition of quality.

Our effort is directed to the decontamination of the contained spill and the contaminated waterway itself through a process of physical and chemical reactions carried out by a continuous flow, thin-film gas-liquid-particulate contact device. With this configuration, it is possible to meter into the device stoichiometric quantities of decontaminating agents in the physical form of gases, liquids, slurries and powders. The agents interface with the contaminated water in the reactor and effect decontamination during the approximate 0.2 second residence time in the reaction column. The hazardous material is decontaminated by chemical reaction processes involving oxidation, neutralization, precipitation, adsorption on activated carbon or combinations of these.

Powdered carbon containing adsorbed toxic materials and/or toxic precipitates must be removed from the reactor effluent after decontamination has been achieved. A new process that renders nonmagnetic solid materials temporarily magnetic and capable of continuous flow magnetic separation was successfully evaluated.

Chemicals representing examples of classes of hazardous materials of high ranking importance were selected for study from the Battelle Report (1). Acids, bases, phenol, chlorine, heavy metals, pesticides and water soluble fractions of fuel oil are included in this report as examples of decontamination reactions carried out with the system described.

This report documents the approach to the problem, the equipment design, decontamination experiments and results achieved.

SECTION IV

TECHNICAL APPROACH

Two basic items of equipment described herein are essential to the continuous flow decontamination processing of water contaminated with hazardous materials.

1. A thin-film gas-liquid-particulate contact device to contact the water with decontamination chemicals.

2. A moving belt continuous flow magnetic separator to remove carbon and precipitates yielding a contaminent-free effluent.

Thin-Film Contact Device

Figure 1 shows a cross sectional schematic diagram of the device named the Dynactor™, a proprietary development of R P Industries, Inc. Total weight of the unit is less than 40 pounds and stands about 7 feet in height.

The Dynactor can be viewed as a macroscopic diffusion pump which makes use of diffusion principles in order to aspirate large volumes of air per volume of motive liquid. Liquid entering the system under a pressure of 40 to 100 pounds per square inch (typical) is atomized into thin films and droplets of average thickness or diameter less than 1/64 inch. This liquid discharge diffuses or expands into the reaction chamber causing air or gas to be aspirated by being trapped within the moving shower of films and particles. The internal configuration is constructed to maximize gas-liquid turbulence and contact throughout the length of the 6-foot long, 12-inch diameter reaction column. The resulting mixed fluid then continues to travel down the reaction column with intimate contact maintained between gas and liquid. This causes physical and chemical equilibria to occur by the time the mixed fluid exits from the reaction column into the separation reservoir.

The radial pressure transformation section is used to transform ambient or atmospheric air pressure to the partial vacuum that exists within the Dynactor. Entering air is accelerated from low velocity and atmospheric pressure to high velocity and subambient pressure as it enters the reaction column. By utilizing diffusion the Dynactor aspirates up to 4,800 standard volumes of gas per volume of motive liquid. In comparison, venturi eductors will aspirate not more than 100 volumes of gas per volume of motive liquid.

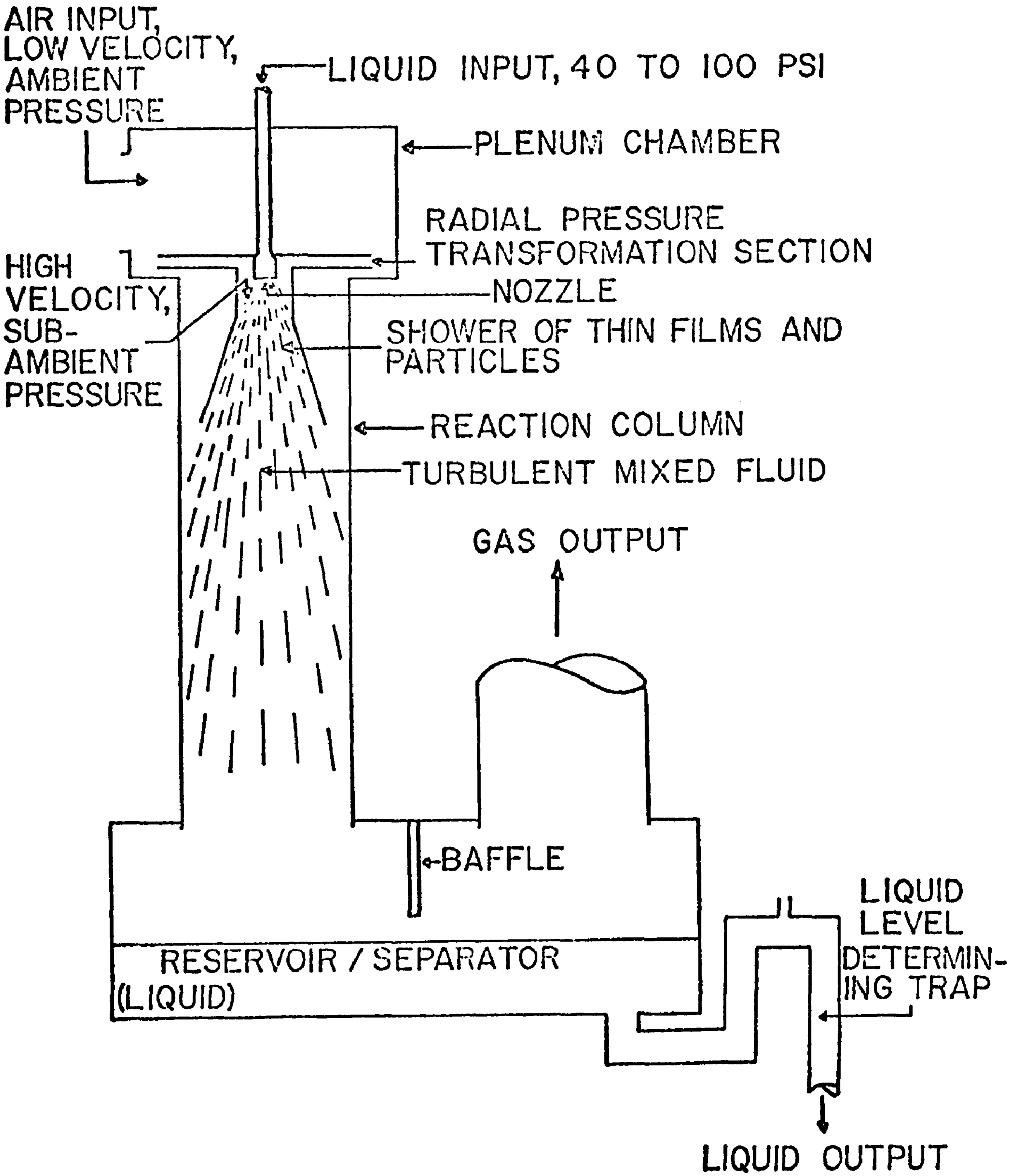

FIGURE 1. DYNACTOR DIFFUSION SYSTEM CROSS SECTIONAL VIEW

The two-stage Dynactor proposed for this study uses an input of about 5 gpm of water at 100 pounds per square inch pressure. Approximately 2,000 standard cubic feet per minute of atmospheric air is aspirated into the Dynactor and reacted with the liquid. Power requirements are 1/3 horsepower under these conditions.

The Dynactor's high speed chemical and physical reaction characteristics are due to its treatment of the flowing liquids essentially in thin-film form. Its substantially instantaneous gas transfer (oxygen, chlorine, ozone), mass transfer (reaction with activated carbon, other reagents), and heat transfer (both evaporative and conductive) are seen from the following analysis:

Thermal Conductivity (Fourier's Law)

$$Q = \frac{K\,A\,(T_2 - T_1)}{h}$$

Q = heat flow/unit time

K = thermal conductivity

T_1 = temperature at boundary 1

T_2 = temperature at boundary 2

h = layer thickness

A = area

Gas Diffusion (Mass Transfer)

$$\frac{m}{t} = \frac{B\,(d_2 - d_1 l)}{h}$$

$\frac{m}{t}$ = mass flow/unit time

B = coefficient of diffusion

d_2 = gas concentration at boundary 2

d_1 = gas concentration at boundary 1

h = layer thickness

As a consequence of their similar form, the solutions for both equations are also similar. There is obtained, therefore, from the solution of the heat-flow equation, the solution of the mass transfer equation when the dissolved gas concentration is substituted for the temperature T, and the diffusion coefficient, B, for thermal conductivity, K.

In the applicable transient heat or mass flow problem in which a layer of thickness, h, having an initial (a) temperature, or (b) gas concentration, is subjected at one boundary to a higher or lower (c) new temperature or (d) new gas concentration, the Fourier Integral analysis and solution takes the form:

$$f(h,T) \text{ or } F(h,d) = \frac{1}{\text{constant}_1}\; e^{\frac{h^2}{\text{constant}_2}}$$

It is seen that the solution involves an exponential term that includes the square of the thickness of the liquid layer as an exponent of e. Working through the mathematical details, it can be shown that a liquid layer of less than .01 inch thick reaches physical and chemical equilibrium with a contacting gas in less than 0.1 seconds.

With this configuration, it is possible to meter into the continuous flowing stream of contaminated water stoichiometric quantities of decontaminating agents in the physical form of gases, liquids, slurries and powders. The Dynactor is equipped with liquid, gas and powder metering systems. These enable lime, bicarbonate and powdered carbon, for example, to be metered by aerosolization directly into the flowing contaminated liquid and thus effect decontamination by neutralization, precipitation or adsorption. Liquid agents such as acetic acid are metered directly into the flow of contaminated water before it reaches the nozzle.

The Dynactor, much like oil or mercury diffusion vacuum pumps, has no moving parts. Since there are no constrictions, there are no zones or portions of the Dynactor on which solids or liquids tend to accumulate, thus requiring little maintenance. These units have been constructed in a wide variety of materials, including polypropylene, polyvinyl chloride, stainless steel, and mild steel. Nozzle design is such that these elements tend to be self-cleaning, further reducing maintenance requirements.

Figure 2 is a photograph of the Dynactor without the plenum chamber on the top. The liquid input tube, the air intake radial pressure transformation section and the 6-foot reaction chamber can be clearly seen. Liquids and slurries of decontaminating chemicals are metered into the input tube through the connecting valve shown at the extreme right of the input tube.

Figure 3 shows a close-up of the radial pressure transformation section which is critical to the air flow through the Dynactor. Figure 4 shows the complete Dynactor system mounted in the laboratory and includes the plenum chamber enclosing the top, the powder feed mechanism, the reservoir, and the air exhaust to the fume hood.

Figure 5 is a closeup of the plenum chamber and powder dispenser, and Figure 6 is a picture taken through the plenum chamber opening to show where the entrance of the powder dispenser is positioned in reference to the air intake baffles. Powdered carbon, for example, is aerosolized by the powder feed mechanism and sucked into the throat of the Dynactor by the air intake under the baffles of the impedence section.

Figure 7 shows the array of plumbing from the 25-gallon reservoir through the displacement pump to the nozzle section of the Dynactor. This is the laboratory 5 gpm model system used to process experimentally contaminated water from the reservoir in 100 liter batches. The data reported in Section V were obtained with this model system.

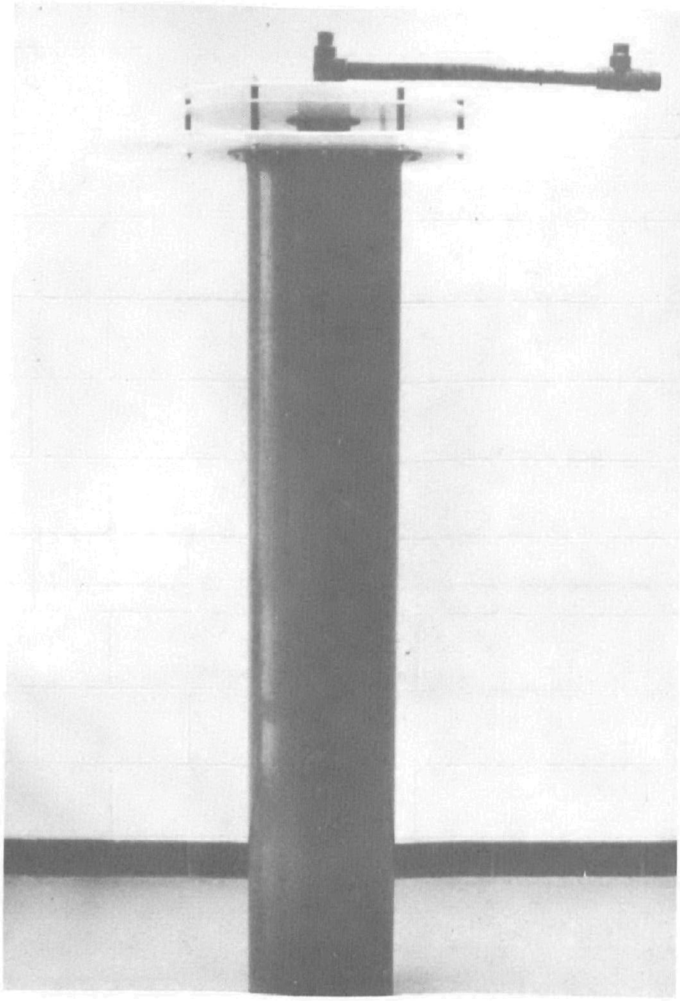

FIGURE 2. DYNACTOR MODEL 5 GPM

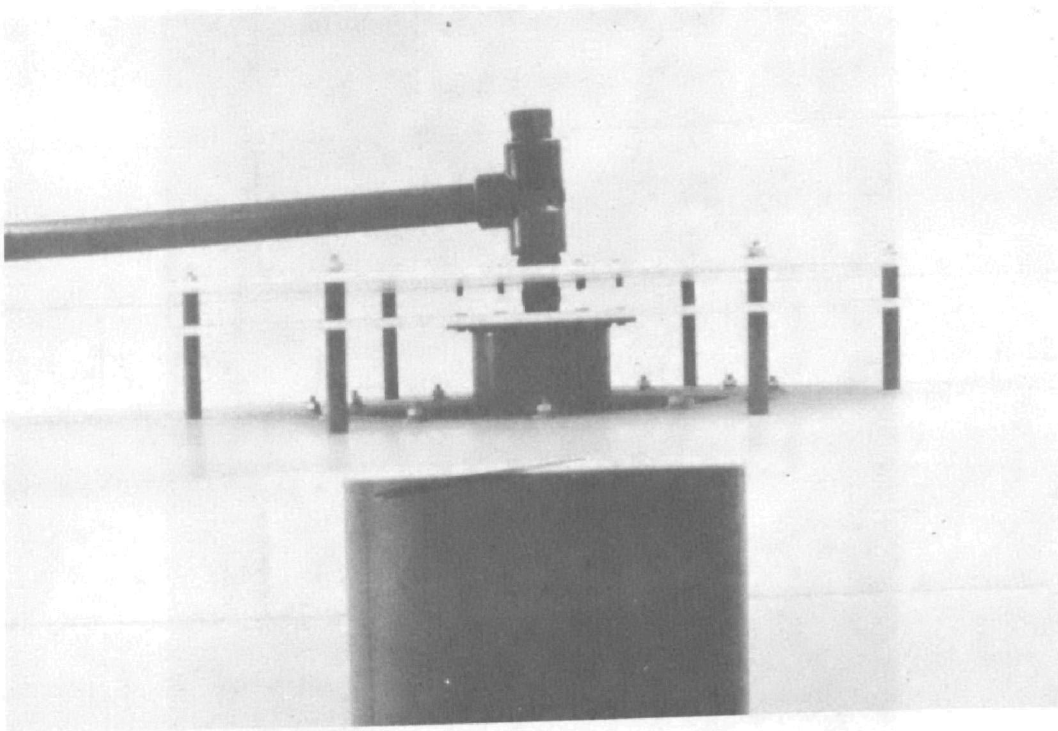

FIGURE 3. DYNACTOR RADIAL PRESSURE TRANSFORMATION SECTION

FIGURE 4. LABORATORY ASSEMBLED DYNACTOR SYSTEM

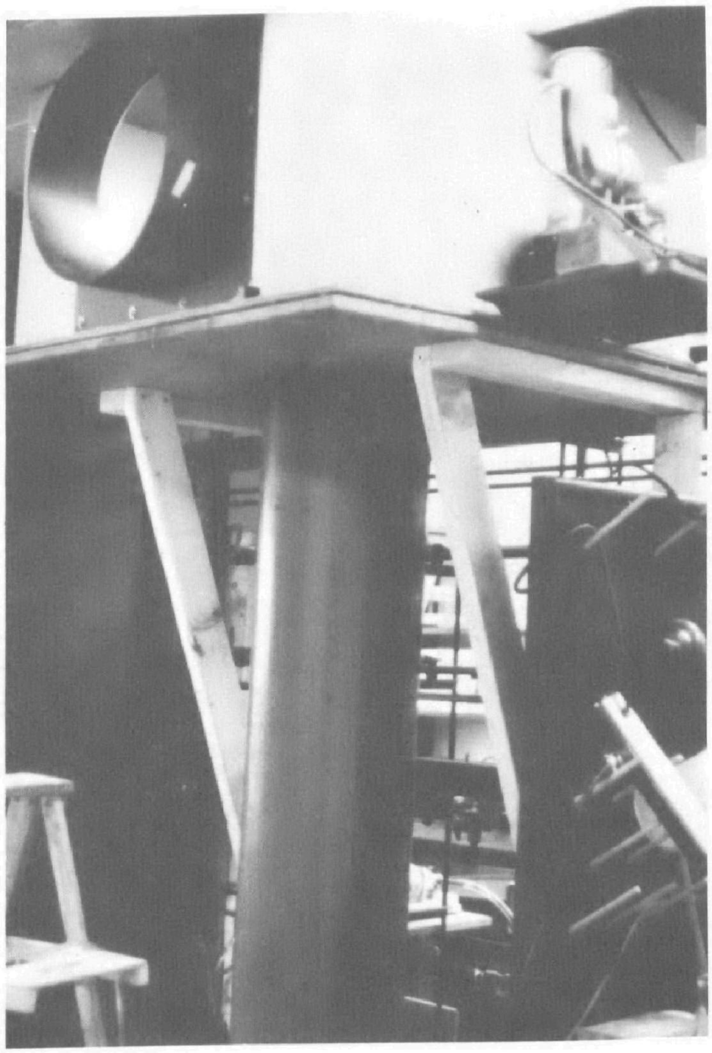

FIGURE 5. PLENUM CHAMBER AND POWDER DISPENSER

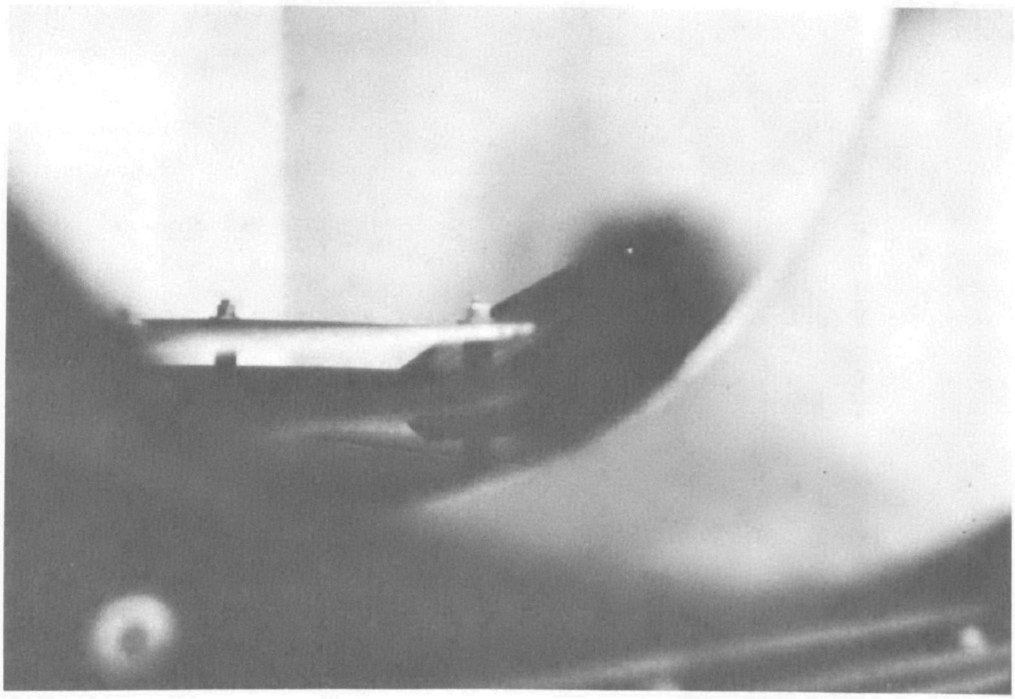

FIGURE 6. VIEW INSIDE PLENUM CHAMBER

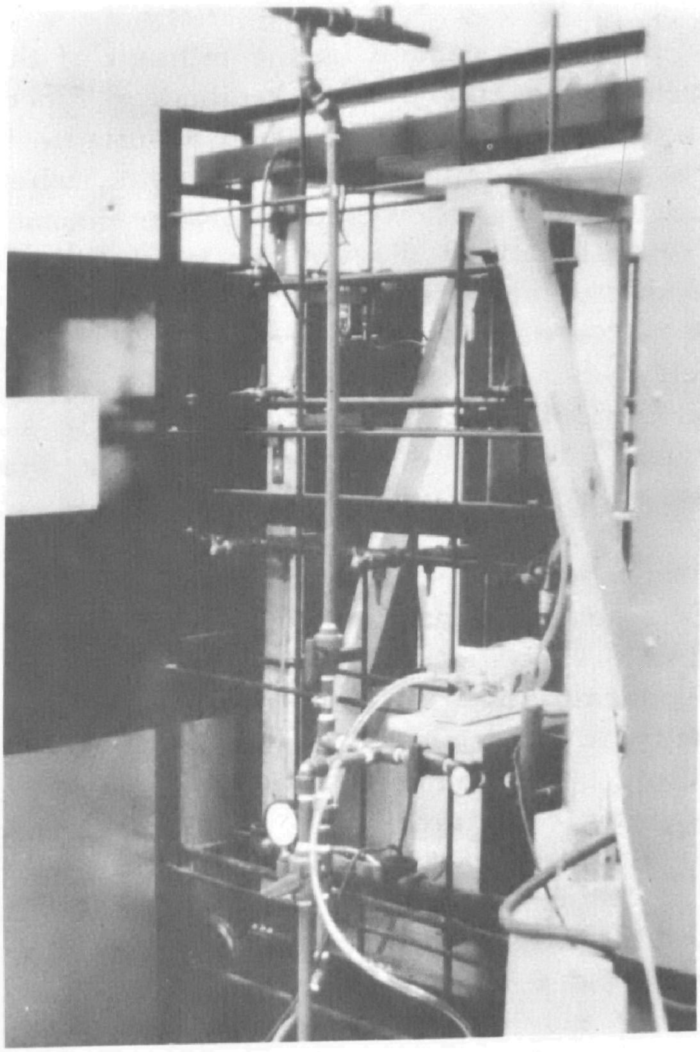

FIGURE 7. LIQUID FEED AND PUMP CONNECTIONS

Magnetic Separation Equipment

To provide a complete system for decontamination, it is essential to remove undesirable end products such as precipitates and carbon from the effluent of the Dynactor. In a mobile field configuration the decontamination of spilled hazardous materials in waterways requires a continuous flow process to remove potentially toxic precipitates, suspended solids, and spent carbon in suspension. The logistics of gravity settling tanks and cumbersome filtration devices in the field preclude their use.

Suspensions of powdered carbon in the effluent of the Dynactor were impossible to remove by conventional methods. Flocculating agents were used, and some of these produced a suitable floc within two seconds after addition of about 1 ppm. However, when the carbon floc was processed in continuous flow separators or commercial filters, the shear forces were sufficient to disrupt the lacy structure of the carbon floc and incomplete separation resulted. However, when small amounts of inexpensive magnetic oxide were added to the suspended carbon in combination with a flocculating agent, the resulting floc became magnetic and could be quantitatively removed in a continuous flow magnetic separator. The same results have been obtained with colloidal precipitates.

In order to simultaneously remove the magnetic floc of suspended solids and dewater the solids, a particular kind of magnetic separator was designed. Figure 8 shows a diagram of the continuous flow magnetic thickener/separator used to separate flocculated suspended solids containing magnetic material. Figure 9 is a photo of the actual unit capable of handling a flow of about 5 gallons per minute. Liquid effluent from the Dynactor containing activated carbon, magnetic material and a polyelectrolyte flocculating agent is allowed to flow by gravity through the orifice or "slice" of the head box under the moving Mylar belt suspended below the magnet structure. The magnetic floc of carbon or other suspended solids is attracted nearly instantaneously to the bottom side of the moving belt due to the presence of the magnet structure suspended above this element. Clarified water flows down to a sump and can be gently released back into the stream. Dewatered solids material is continuously scraped off the moving belt after the belt has passed by and away from the magnet structure. Thickened solids, carbon, and magnetic material are collected in plastic barrels and held for proper disposal of the hazardous material in question.

Separation of suspended solids in a magnetic floc by the above-described magnetic separator is rapid, efficient, continuous and produces a superior water quality effluent while effecting dewatering of the removed solids.

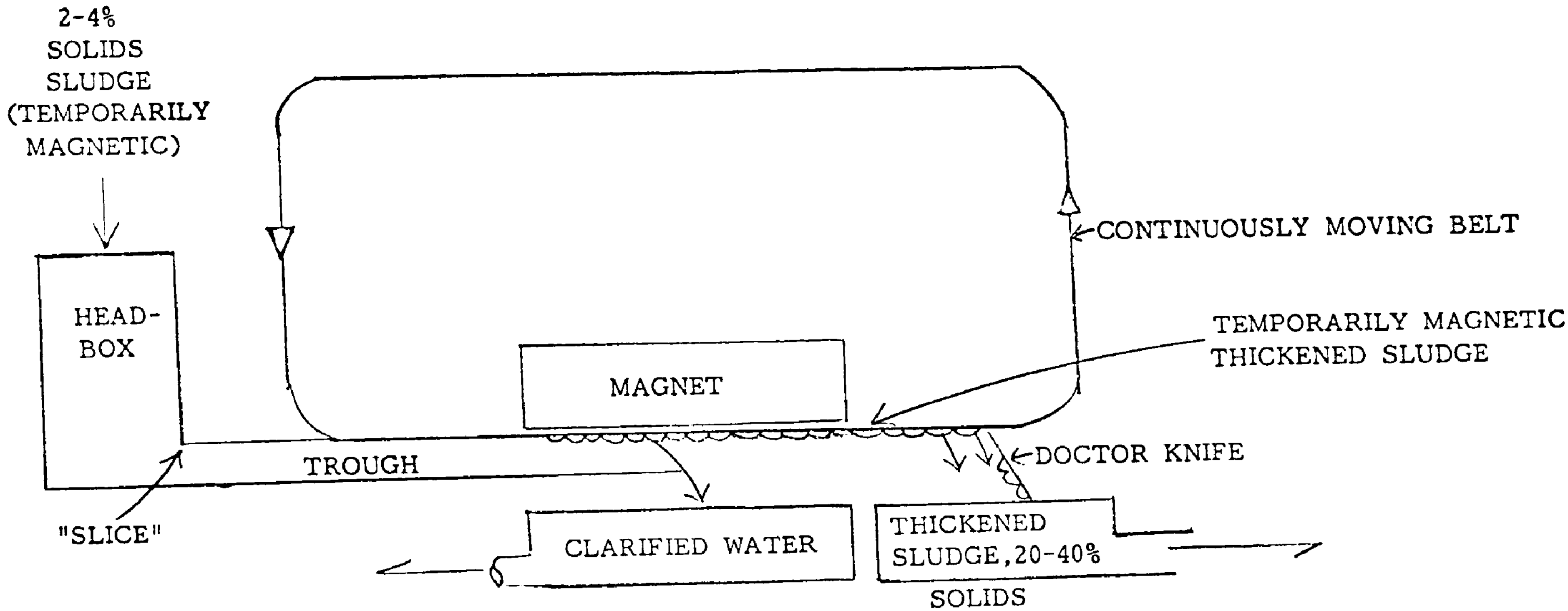

FIGURE 8. CONTINUOUS FLOW MAGNETIC THICKENER/SEPARATOR

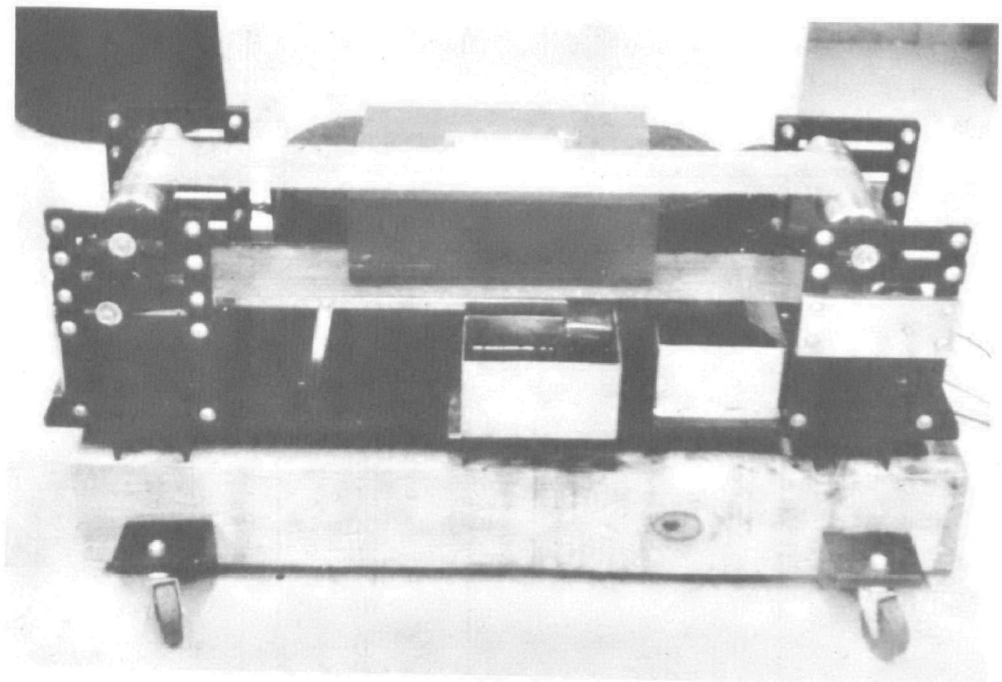

FIGURE 9. MAGNETIC SEPARATOR MODEL 5 GPM

SECTION V

EXPERIMENTAL STUDIES

The Dynactor model test system was housed in a modern chemistry laboratory equipped with hood, floor drain, safety devices and bench space for analytical work. Six Dynactors were constructed for engineering and decontamination testing. These were constructed of polypropylene and polyvinyl chloride. One complete experimental system was installed in the laboratory and consisted of (a) one 5 gpm capacity Dynactor, (b) plenum chamber, (c) sump, (d) exhaust line, (e) 25 gallon capacity reservoir, (f) a 5 gpm, 100 psi displacement pump, (g) liquid metering system, (h) turbulent mixing chamber, and (i) powder feed mechanism. These components are identifiable in Figures 4 and 7.

In operation, the 25 gallon reservoir contains water contaminated with a predetermined concentration of the selected hazardous material to simulate a spill in confined waterways. The contaminated water is then pumped through the nozzle at the top of the Dynactor at a pressure of about 100 psi. The liquid pressure can be varied from 40 to 140 psi with the model equipment producing a liquid flow rate of about 3 to 5 gpm. Since the Dynactor is equipped with liquid, gas and powder metering systems, decontaminating agents such as lime, carbonate, bicarbonate, ozone, chlorine, acetic acid, powdered carbon and other adsorbents can be metered in stoichiometric quantities into the flow of contaminated water through the Dynactor.

Insoluble precipitates formed during decontamination reactions and powdered carbon containing adsorbed toxic materials must be removed from the reactor effluent after decontamination has been achieved. Therefore, the new process, described in Section IV, that renders non-magnetic solid materials temporarily magnetic and capable of continuous magnetic separation was evaluated.

The types of decontamination reactions studied in the Dynactor system were aeration, ozonation, neutralization, precipitation and carbon adsorption. It is also possible to carry out combination reactions such as aeration, neutralization and carbon adsorption essentially simultaneously in one passage of contaminated water through the system.

Since the purpose of this project is to demonstrate feasibility of the system, only a few hazardous materials were selected that could be easily handled in the laboratory and analyzed by standard procedures. Acids, alkalies, chlorine, cyanide, phenol, lead salts, various pesticides and water saturated with fuel oil were selected for study. The major emphasis was placed on defining the types of reactions that could be carried out in the system in a continuous flow-through configuration.

Aeration

Since the Dynactor is a thin film aeration device capable of aspirating large volumes of air per volume of motive liquid, a typical flow-through experiment results in an effluent completely saturated with dissolved oxygen. Repeated experiments for oxygenation capability raised the dissolved oxygen concentration of water from initial levels of 1 ppm to 10 ppm in a single pass through the Dynactor. Supersaturation of the effluent with dissolved oxygen was always achieved. Field samples of Des Plaines, Illinois, River water containing 5 mg/liter dissolved oxygen were aerated to 9 mg/liter ($20^{o}C$) by passage through the Dynactor.

Simple, effective, continuous flow, high speed aeration of a waterway is in itself a significant contribution to water quality by increasing the dissolved oxygen content of streams, lakes, or lagoons. Many substances are toxic because they can threaten water quality by reducing the dissolved oxygen content. This can adversely affect aquatic life. There is general agreement that it is desirable to maintain high dissolved oxygen levels in water while the spilled material is being dispersed, decontaminated, and degraded aerobically.

Ozonation and Chlorination

The Dynactor used for gas experiments contains a plenum surrounding the top air intake section. The plenum has a 16-inch intake port which can be baffled to meter measured quantities of gases from compressed cylinders. The unit can also be used in a completely closed circulation system by connecting the gas outlet from the reservoir to the plenum intake port. Thus, ozone, for example, can be recirculated for optimum uptake and utilization by the thin film of water in the reaction column of the Dynactor.

Ozone was delivered to the sealed plenum of the Dynactor from a Weisbach Ozonator through a Tygon tube at rates of approximately 7 liters per minute containing approximately 15 mg O_3 per liter. Maximum absorption of ozone was demonstrated in the effluent. The conversion of potassium iodide to iodine was studied by processing 25 gallons of KI solutions through the Dynactor while bleeding measured quantities of ozone into the closed plenum. The iodine was quantitated by sodium thiosulfate titration. Complete conversion of KI to I_3 was achieved in a single pass through the Dynactor with significantly less than stoichiometric quantities of ozone.

Chlorine and oxygen can also be metered into the Dynactor for thin film gas liquid contact where needed for oxidative decontamination of hazardous materials.

Neutralization

Since the Dynactor is equipped with both a liquid metering system and a powder feed system, saturated sodium bicarbonate solutions and powdered sodium bicarbonate were individually studied as neutralizing agents for acetic and hydrochloric acids. Each form of bicarbonate effectively neutralized the acid representing the spilled hazardous material. For example, stoichiometric quantities of powdered sodium bicarbonate were aerosolized into the plenum of the Dynactor and instantly neutralized 0.01N acetic acid at a flow rate of 5 gpm at a head pressure of 100 psi. pH, titratable acidity and odor measurements were recorded on the effluent from the Dynactor to substantiate complete neutralization. Repeated experiments have been made with higher concentrations of acetic and hydrochloric acids with effective neutralization.

The successful use of powdered sodium bicarbonate, sodium carbonate and calcium hydroxide as dry neutralizing agents in the continuous flow configuration has proven the feasibility of this system for neutralizing acids and alkalies by processing the contaminated water with dry neutralizing agents.

Precipitation

Stoichiometric quantities of heavy metal precipitating chemicals such as sodium carbonate, sodium bicarbonate, lime, and sodium sulfide were metered into the system to precipitate toxic heavy metals such as lead, mercury, cadmium and zinc. The precipitating chemical agent was used in the powdered form whenever possible. For example, water containing 100 ppm of lead nitrate was pumped through the Dynactor while powdered sodium bicarbonate was aerosolized into the 5 gpm continuous flowing system. Lead carbonate precipitate was immediately observed in the effluent and a filtered sample showed 2 ppm of lead by atomic absorption analysis. Most of the toxic heavy metals can be reduced to safe levels by precipitation and removal of a highly insoluble salt.

Carbon Adsorption

Because powdered carbon treatment of contaminated water is a recognized effective countermeasure for the removal of about 80 percent of the hazardous chemicals of high ranking importance in the Battelle Report (1), significant effort has been devoted to the perfection of a process for continuous flow carbon treatment of hazardous material contaminated waters. The powdered activated carbon studied was Nuchar 190-N produced by West Virginia Paper and Pulp Company. This carbon was chosen for the initial studies because extensive data on pesticide adsorption by Nuchar 190-N was available from scientific literature(2).

Powdered activated carbon was metered into the Dynactor as a 10 percent aqueous suspension and as a dry powder. The dry powder is the preferred method of treatment for a mobile field application. Using the powder feed mechanism designed for the Dynactor, the activated carbon is aerosolized directly into the throat of the unit making intimate contact with the thin film of flowing liquid ejected from the nozzle. The wetting and dispersion of the carbon by the turbulent thin film contact is excellent at a liquid flow rate of 4 gallons per minute and a carbon metering rate of about 15 to 20 grams per minute. The adsorption of phenol, Ethion, DDT, Toxaphene and chlorine has been extensively studied and will serve as examples to demonstrate the feasibility of the Dynactor as a continuous flow carbon treatment unit for the removal of hazardous materials from contaminated water. Initial and final concentrations of phenol were assayed by gas chromatography and the pesticides by electron capture gas chromatography after concentration by extraction in hexane. Chlorine was measured by the iodometric method. The effluent from the Dynactor was immediately filtered through a 0.45 micron Millipore filter to remove the carbon and analyzed.

The results on the adsorption of phenol are shown in Figure 10. These data were obtained using a 10 percent suspension of Nuchar 190-N metered into the Dynactor; comparable data have also been obtained using powdered Nuchar 190-N aerosolized into the unit. Adsorption of phenol from the contaminated water is achieved in less than 2 minutes and greater than 90 percent removal of phenol is obtained with carbon to phenol weight ratios of about 20 to 1. Phenol adsorption as a function of initial carbon to phenol ratio is shown in Figure 11.

The adsorption of representative pesticides by Nuchar 190-N was determined experimentally in the Dynactor. Ethion, DDT, and Toxaphene were selected for study and quantitatively analyzed by electron capture gas chromatography. Multiple experiments were conducted varying the concentration of pesticide and the amount of powdered carbon.

Experimental Conditions:
3 liters 10% Nuchar 190-N metered into
5 gal/min flow rate of 25 gallons of phenol
solutions processed by Liquids Dynactor

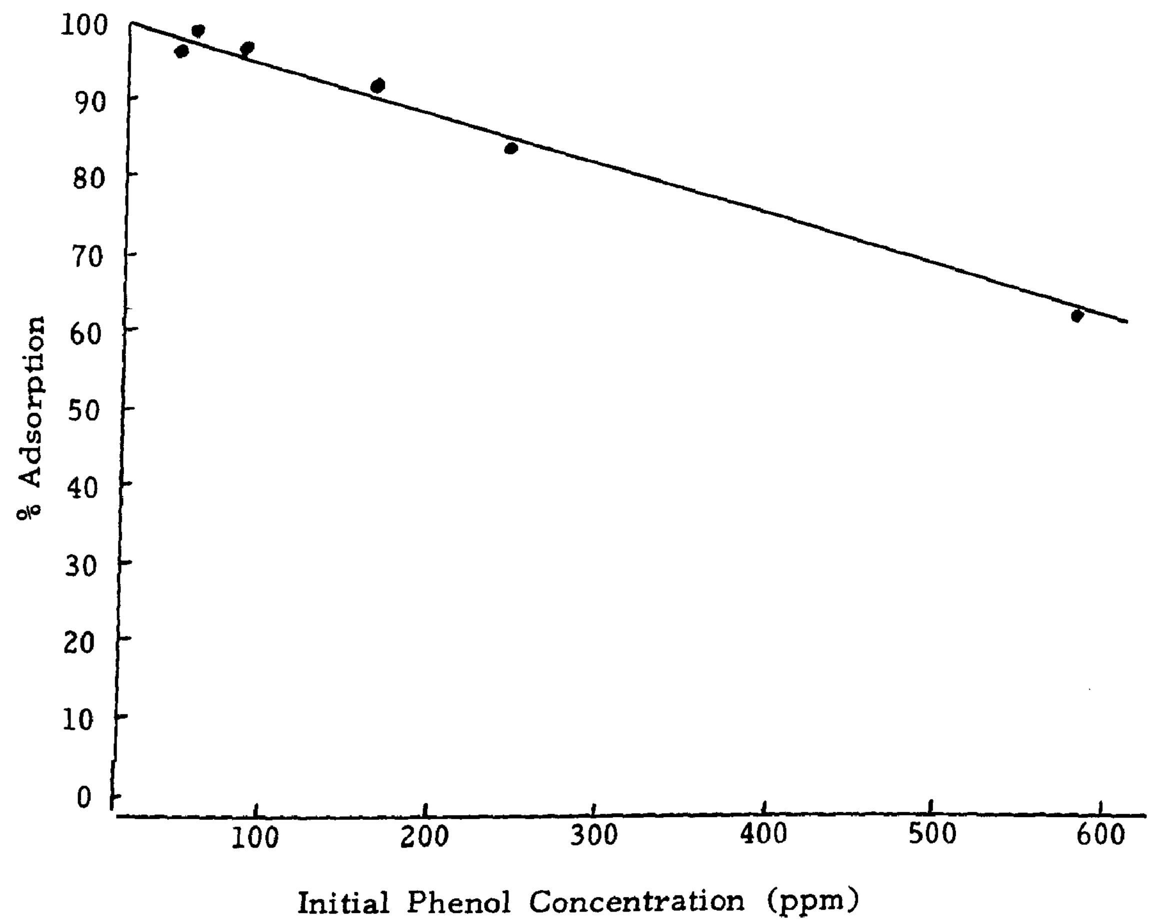

FIGURE 10. PHENOL ADSORPTION VS. INITIAL PHENOL CONCENTRATION

Carbon = Nuchar 190-N processed as a 10% slurry through Liquids Dynactor

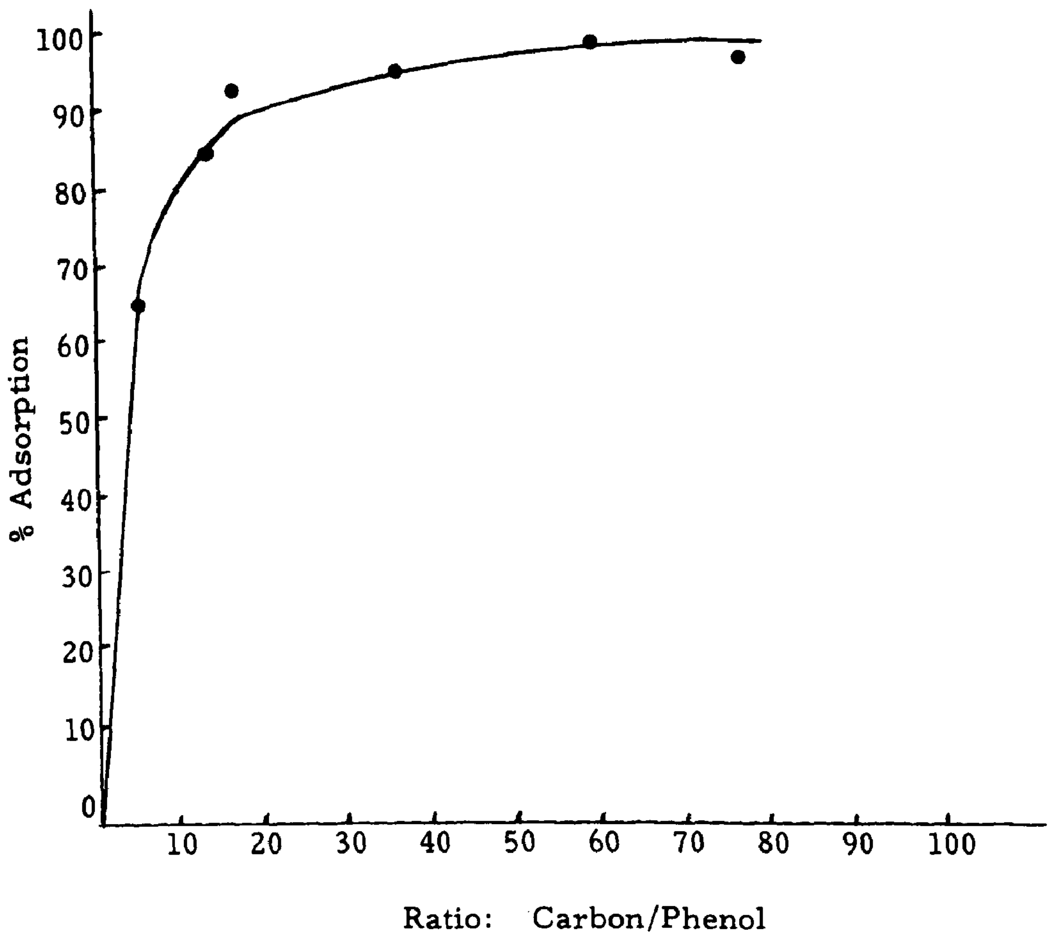

FIGURE 11. PHENOL ADSORPTION AS A FUNCTION OF INITIAL CARBON TO PHENOL RATIO

The carbon was aerosolized into the Dynactor by the powder feed mechanism and the pesticide contaminated water was pumped through the system at about 100 psi and a flow rate of 4 gpm. The carbon was separated from the Dynactor effluent by Millipore filtration immediately upon collection. Table 1 shows the adsorption data obtained for each of the pesticides. The system worked well in removing greater than 99 percent of the initial pesticide concentration, leaving only parts per billion concentration in the effluent.

Pesticides in general present particular problems when spilled in waterways. Initial concentrations of soluble pesticides are usually very low (1 to 10 ppm), but toxicity to fish and other organisms can be substantial at 0.05 ppm and less (3). It appears advisable to use excessive ratios of carbon to pesticide in order to obtain an effluent having a safe pesticide level. Since initial concentrations of pesticides are likely to be in the 1 to 10 ppm range because of limited solubility, the total quantity of carbon required is not great even at excessive ratios.

Several chlorine removal experiments were conducted using Nuchar 190-N processed by the Dynactor system. The chlorine concentration before and after removal was measured by the iodometric method. Chlorine was diffused into the 25 gallon reservoir from a compressed cylinder of chlorine. Table 2 shows the results of the chlorine adsorption experiments. Chlorine is easily removed by the short time contact with powdered carbon in the Dynactor. Relatively small quantities of carbon are needed to effect 99 percent removal of chlorine from contaminated water.

Very preliminary experiments were made on removal of water soluble components of No. 2 fuel oil by treatment in the Dynactor with powdered carbon (Nuchar 190-N). Water was saturated with fuel oil by mixing overnight and allowed to separate. The water soluble fraction was drawn off and this was processed in the Dynactor using powdered carbon in the powder feed unit. Initial and final COD measurements were used as a semiquantitative guide to removal of water soluble hydrocarbons. Perception of fuel oil odor after treatment was also used as a sensitive index of removal. Results obtained are shown in Table 3. The data indicate that about 200 mg/liter of carbon will remove essentially all of the water soluble hydrocarbons from fuel oil. More quantitative work will be required to establish carbon quantities for less than saturated solutions.

Some preliminary work was also completed on carbon removal of oil in water emulsions. Oil in water emulsions was produced from No. 2 fuel oil in a mechanical homogenizer; 5, 2.5, 1.0, 0.5 and 0.1 percent oil to water ratios were prepared. Varying amounts of powdered

TABLE 1

Adsorption of Pesticides in Dynactor System
Using Powdered Activated Carbon

Pesticides	Init. Pest. Conc. (ppm)	Final Pest. Conc. (ppb)	Carbon (mg/l)	% Removal	C/Pest. Ratio
Ethion	18	11	1600	99.9	89
Ethion	13	28	100	99.8	8
Ethion	8.5	4	1000	99.9	118
Ethion	5	4	750	99.9	150
Ethion	1.6	6	200	99.6	125
DDT	2.00	17	500	99.2	250
DDT	1.00	0.65	700	99.9	700
DDT	0.45	0.49	1000	99.9	2200
DDT	0.19	0.75	600	99.6	3200
DDT	0.098	0.40	600	99.6	6000
Toxaphene	1.1	2.5	700	99.8	650

TABLE 2

Adsorption of Chlorine in Dynactor System
Using Powdered Activated Carbon

Initial Cl_2 Conc. mg/l	Final Effluent Conc. mg/l	Carbon Used mg/l	% Removal	C/Cl_2 Ratio
123	0.01	1500	99.99	12.0
162	0.01	1300	99.99	8.0
214	0.57	800	99.7	3.7
278	6.57	700	97.6	2.5
0.61 Tap Water		-	-	-

TABLE 3

Removal of Water Soluble Components
Fuel Oil No. 2 - Carbon Adsorption
Dynactor Processed

Initial C.O.D.	C.O.D.	Carbon Used mg/l
296	15	1500
43	3.5	1500
11	0	1500

Tap Water C.O.D. - 5.9

Mg Carbon/l	Removal of Odor
1500	Yes
1000	Yes
500	Yes
250	Yes
200	Yes
100	Faint Trace

powdered carbon were used in the Dynactor to establish an effective ratio of carbon to oil emulsion for the removal of emulsified oil. Turbidity and odor measurements were made before and after carbon treatment as indices of removal. The results are shown in Table 4. It appears that a carbon to oil ratio of about 2 to 1 will remove essentially all of the fuel oil and water soluble components from emulsions up to 5 percent. Higher concentrations were not tested and quantitative analytical studies not conducted within the scope of this program. These experiments with oil are preliminary in nature and are intended to examine the feasibility of carbon removal of components of oil in water by Dynactor processing.

Magnetic Separation of Carbon

To provide a complete system for decontamination of hazardous materials, it is necessary to remove undesirable end products from the effluent of the Dynactor such as precipitates and spent carbon. The program originally proposed, in Contract 68-01-0123, the development of a static sealed centrifuge designed as a Solids Statifuge to remove solids and a Gas Statifuge to remove gases. Both of these units were designed, fabricated and tested in accordance with the contract. The Gas Statifuge failed to effectively remove dissolved gases from decontamination reactions and was therefore not further tested.

Exhaustive testing of the Solids Statifuge yielded only about 75 percent removal of the flocculated carbon from the aqueous effluent of the Dynactor after activated carbon had been used to adsorb toxic materials processed in the system. The reason for this limited carbon removal by the Statifuge is the use of finely divided powdered activated carbon which must be flocculated from suspension prior to removal. The flocculated carbon is lacy in physical structure, and hence, very fragile and easily redispersed. The shear forces of the Statifuge break up part of the flocculated carbon and some of the dispersed carbon particles escape removal and appear in the effluent from the Statifuge. Such an effluent would not meet water quality standards, and therefore, another method of carbon removal was considered essential to the program. It is important to realize that for the Dynactor system to perform in a mobile field configuration, the entire decontamination process, including removal of the carbon, must perform on a continuous flow basis without the need for large settling tanks or columns.

Substantial efforts were expended to find a satisfactory continuous flow carbon separation method suitable for field use. Separation was studied in commercial cyclone separators, commercial continuous flow centrifuges, commercial filters and finally a magnetic separator. Cyclones, centrifuges and filters yielded only partial removal. but magnetic separation gave essentially 99 percent removal of the flocculated carbon. Twenty-five percent magnetic material in the form of finely divided iron oxide

TABLE 4

Removal of Oil in Water Emulsions
Carbon Adsorption - Dynactor Processed

Carbon/Oil Ratio	% Odor Removed	% Turbidity Removed
0.1	50	10
0.2	50	20
0.5	80	30
0.7	85	60
1.0	100	85
1.5	100	95
2.0	100	100

is added to the powdered carbon used to feed into the Dynactor for the adsorption of toxic materials; 2 ppm of a polyelectrolyte flocculating agent (Nalco 8173) is added to the suspended carbon in the effluent from the Dynactor, and the magnetic particles are trapped in the lacy floc.

In order to simultaneously remove the magnetic floc of suspended solids and dewater the solids, the magnetic separator described in Section IV was used.

The decontamination of hazardous material spills often results in the formation of fine colloidal precipitates such as heavy metal carbonates and sulfides. These fine precipitates are difficult to remove by settling or filtration. Magnetic separation studies were applied to the separation of lead carbonate. Magnetic iron oxide can be added to the sodium bicarbonate prior to the formation of lead carbonate precipitate or after the colloidal lead carbonate precipitate has been formed. Amounts of magnetic material required are about three times the amount of lead carbonate precipitate. A polelectrolyte flocculating agent such as Nalco 8173 is added to the suspended precipitate at a concentration of 2 to 3 ppm and mixed for 10 seconds; the magnetic floc formed is then readily removed by passing through the magnetic separator.

Although magnetic separation studies were limited to carbon and lead carbonate, it is anticipated that all types of suspended solids can be removed from water by the magnetic separation process described. Optimum proportions of flocculating agent and magnetic material may vary with the amount and type of suspended solids present, but the basic principle appears applicable.

SECTION VI

REFERENCES

1. Dawson, G. W., A. J. Shuckrow, and W. H. Swift, Control of Spillage of Hazardous Polluting Substances, Battelle Memorial Institute, FWQA 15090 FOZ, October 1970.

2. Schwartz, Jr., Henry G., Adsorption of Selected Pesticides on Activated Carbon and Mineral Surfaces, Environmental Science and Toxicology 1, 332-337, 1967.

3. McKee, J. E., H. W. Wolf, Water Quality Criteria, 2nd Ed., Resources Agency of California, 1963.

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16. ABSTRACT

Design and operating details are given for a new type of continuous flow thin-film, gas-liquid-particulate contact device called the Dynactor. The device is used as a continuous flow short-time contact reactor to effectively decontaminate water contaminated with spilled hazardous materials. The decontamination is effectively achieved by one or more processes involving oxidation, neutralization, precipitation or adsorption on powdered carbon. Contaminated water is processed by the pilot plant model Dynactor at 100 psi and at a rate of 5 gpm; stoichiometric quantities of decontaminating agents in the form of gases, liquids, slurries or powders are metered into the continuously flowing liquid configuration. The device is portable, lightweight polypropylene construction, has no moving parts, requires a pump for liquid motive power and can be scaled up to process 250 gpm of contaminated water.

Design and operating details are given for continuous flow magnetic separation to remove flocculated carbon and precipitates from the Dynactor effluent after decontamination of hazardous materials.

Experimental data on successful decontamination of heavy metals by precipitation, acids and bases by neutralization, phenol, chlorine and pesticides by powdered carbon adsorption and other selected hazardous compounds are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

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*Water treatment, *Decontamination, *Magnetic separators, *Activated carbon treatment, Water pollution, Chemical removal (water treatment), Separation, Neutralizing, Precipitation (chemistry)	Hazardous materials spill cleanup, Hazardous materials spill control, Hazardous polluting substance spills, Hazardous chemical spills, Dynamic reactor, Dynactor	13B

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