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## Chapter 11

# Solvent Extraction Using a Soil Agglomeration Approach

F. Weldon Meadus, Bryan D. Sparks, and A. Majid

### Introduction

The complexity and variety of contaminants found in soil has lead to the investigation of a large number of remediation technologies. Although some of these decontamination processes work well in specific cases, nearly all have limitations with respect to costs, contaminant type and soil properties. The problems associated with these technologies are further exacerbated because landfarming and landfilling are being reduced or abandoned owing to environmental concerns. Solvent and aqueous extraction or washing processes have been shown to be effective for treating many of these contaminated soils, sludges and sediments.<sup>1,2</sup> However, both extraction methods only work well on coarse material. Treatment of fine textured soils is less effective as intractable fine particulate dispersions are often formed in the liquid extraction medium.

### SESR Process

A generalized solvent extraction block diagram is shown in Figure 1. It consists of a mixing and contacting device to transfer the contaminant from the solids to the solvent. A solids-liquid separation step is next, followed by the recovery of residual solvent from the solids, by thermal drying at 110-200°C. The solvent is separated from the contaminant and recycled back to the extractor. Solids-liquid separation is the critical step for most solvent extraction processes, especially when large quantities of fines are involved (-50mm and particularly -2mm). Technical success depends on the handling of these non-settling, fine solids; typically fines have a tendency to plug separation devices such as percolation beds and filters.

The National Research Council of Canada has developed a solvent extraction process, SESR (Solvent Extraction Soil Remediation). This approach utilizes a liquid phase agglomeration technique, that improves the separation of fines from the contaminant solvent by binding them with other fine or coarse particles.<sup>3,4</sup> The contami-

nated soil is suspended in the extraction solvent and a second, or bridging liquid, selected that will preferentially wet, or absorb on the surfaces of the particulate solids, while being virtually immiscible with the slurry suspending medium. Addition of a minor amount of this bridging liquid to the solids slurry, in conjunction with suitable agitation, will result in attachment of primary particles to form aggregates. The strength of the bonding between particles results from capillary forces arising from the bridging liquid in the aggregate pores. Figure 2 illustrates the type of agglomerates formed at different levels of second liquid addition. Small amounts of water produce floc-like structures by pendular bonding; increasing the amount of water to the funicular state causes these flocs to condense forming microagglomerates; with the optimum amount of water, the system enters the capillary state, producing an agglomerate of maximum density and strength in which the internal pore volume is virtually devoid of suspending liquid. For the treatment of contaminated soil the suspending liquid is a solvent for the organic pollutant and water is the second liquid. Appropriate mixing can be obtained using rotating drums, stirred tanks or shakers of different types. Process control allows spheroidal agglomerates to be formed in a specific size range. Consequently, aggregates having good porosity for aeration and drainage can be produced. The form, strength and size of the agglomerates are primarily dependent on the size and type of soil particles, the amount of bridging liquid added and the degree and type of agitation applied.

Figure 1 General solvent extraction flow diagram

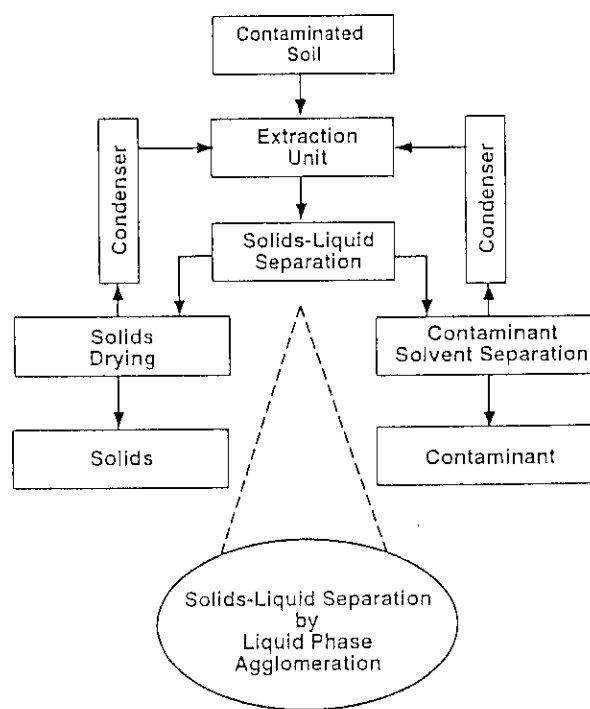


Figure 2 Agglomerates

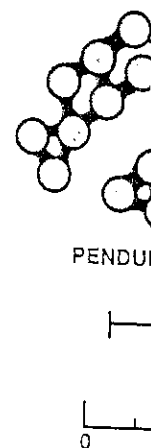


Figure 3 shows the effect of mixing time on the efficiency of extraction (mixtures molded into tablets under a 10kg load). The results show that a minimum of 10 minutes is required to produce percolation. The lower water contents in the soil correspond to only small agglomerates. At a water content of 10%, a critical level, delineate the formation of spherical agglomerates. At higher concentrations corresponding to the capillary state, shown by the formation of paste, the least retention of solvent is observed. Within the region of good fines (<45mm) content is observed, which produces progressively

## Materials

### Flare pit sludge

Prior to the mid 1980's the sludge was removed from the flare pit. This was used for incineration, fitted to allow trans

Figure 2 Agglomerate forms

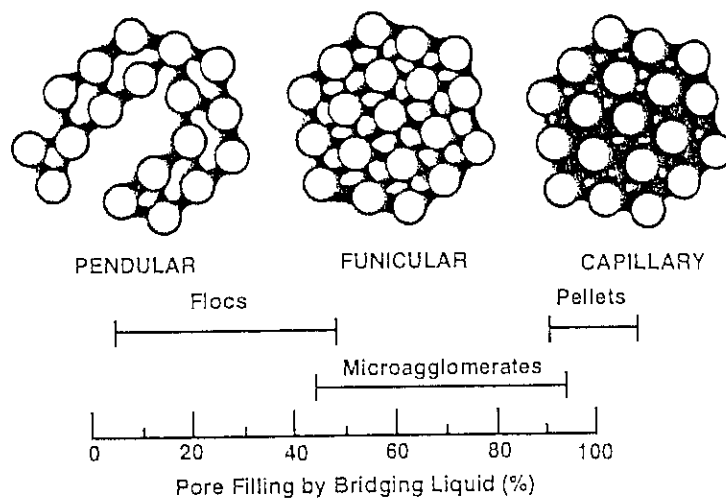


Figure 3 shows the effect of water and fines on the strength characteristics of sand mixtures molded into cylindrical pellets (13mm by 10mm, formed by compression under a 10kg load). The area ABC represents the range of water concentrations required to produce pellets, as determined in batch agglomeration experiments. At lower water contents is the region (MP) of pendular and funicular bonding where only small agglomerates or flocs are formed. When the water content reaches a critical level, delineated by AB, pellets or spherical agglomerates (SA zone) are formed. Initially, these spherical agglomerates grow larger as further water is added. Spherical agglomerates of optimum sphericity and strength are obtained at water concentrations corresponding to the maximum load and pore saturation values, the capillary state, shown by the line BD. Water levels greater than this optimum amount causes the agglomerates to become soft and misshapen (WA zone); eventually disintegration and paste formation occurs (P zone). For successful agglomeration and least retention of solvent, the water content of the agglomerate must be maintained within the region of good pellet formation ABD. No agglomerates will form if the fines (-45mm) content is less than about ten weight percent; increasing fines content produces progressively stronger agglomerates.

## Materials

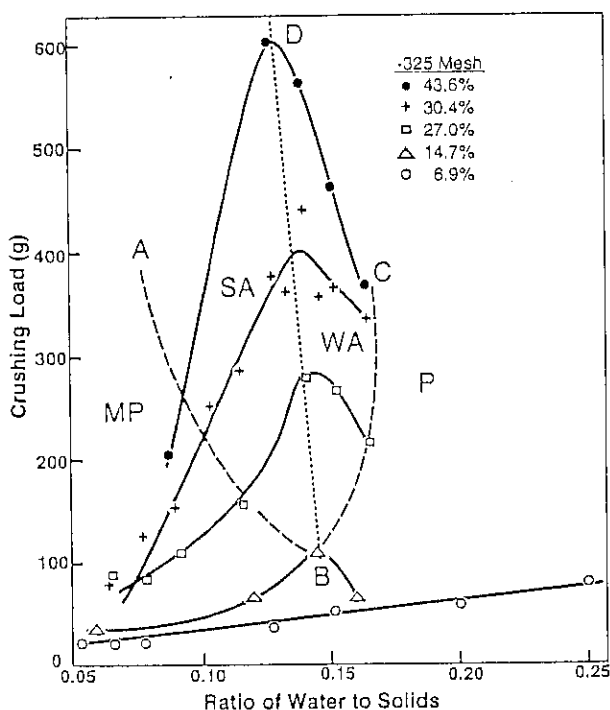
### Flare pit sludge

Prior to the mid 1980's most oil or gas wells, gas plants and refineries had some form of flare pit. This was usually an excavated area at some distance from the installation, fitted to allow transport and burning of gas or liquid petroleum. Some of these

pits were designed for emergency situations while others were intended to destroy uneconomical or waste organic contaminants. After prolonged use the soil surrounding the pits became contaminated with a wide spectrum of organic material, ranging from highly volatile organics to partially combusted heavy oils and coke-like materials. To compound the problem, flare pits were often used for burning tank bottoms and various other waste products. Also, berms built around these pits were frequently sprayed with chemical defoliants. In Canada, flare pits now require linings and open pit disposal is being discouraged. However, the legacy of tens of thousands of these pits with associated contaminated soil and partially burnt sludge remains.

A sample of flare pit sludge material, was supplied by the Alberta Environmental Centre. The sludge was taken from a well site producing uneconomical solution gas which required flaring. The pit also contained a significant amount of wax from the disposal of pipeline de-waxing pigs.

Figure 3 Agglomerate relationship between water and fines



Contaminant analysis was carried out by exhaustive extraction with toluene in Soxhlet units fitted with Dean and Stark water separators. Results from 24 feed sub-samples gave the following average composition:  $50.9 \pm 0.8\%$  w/w solids,  $28.7 \pm 1.0\%$  w/w water and  $20.5 \pm 1.4\%$  w/w toluene solubles, by difference. The organic material had an initial boiling point of  $<50^\circ\text{C}$ ; infra-red and NMR spectra of the extract showed it to

be mainly aliphatic in nature. No aromatic compounds were found with the organics. The GC analysis showed over 320 different compounds. The limit of the apparatus. Volatiles were removed by Soxhlet extraction with methylene chloride gave a residue. The lighter vacuum fraction contained a significant amount of organic carbon contents were

#### Erskine soil

A contaminated black, clayey soil sample from an uncontaminated sample from a well site collected from surface soil of brine and crude oil from a well. Analysis showed a hydrocarbon presence of brine resulted in a 9.2N ethanol solution was

#### Other materials

Tests on other materials showed that Invert Drilling Muds contain material from a decommissioned herbicide (2,4-dichlorophenoxy) herbicide (pentachlorophenol), have a

#### Methods

In the current work, a series of organic solvents as the extractants were agitated by; (1) a commercial mixers (blender) and (3) tumblers rotating at 20% of the critical speed. This closely simulates a full scale agglomeration process is used to increase the water content. To further increase the water content, adding dryer soil or a water-soluble solvent extraction of the contaminants. The subsequent agglomeration of the material was usually washed with fresh solvent and dried at  $200^\circ\text{C}$  before being analyzed.

be mainly aliphatic in nature. The parent oil was sweet and no sulfur compounds were found with the organic contaminants. Simulated distillation gas chromatography showed over 320 different components with boiling points below 542°C, the limit of the apparatus. Vacuum distillation at 90°C to remove all light ends followed by Soxhlet extraction with methylene chloride and subsequent evaporation of the methylene chloride gave a slightly lower organic content of 19% with 7.3% being in the lighter vacuum fraction. Using a Leco CR-12 Carbon Analyzer, total and residual organic carbon contents were obtained and extractable hydrocarbon calculated.

#### Erskine soil

A contaminated black, Chernozem soil from near Erskine Alberta along with an uncontaminated sample from an adjacent site was used in these trials. Both were collected from surface soil horizons. The soil had been contaminated with a mixture of brine and crude oil from a pipeline break between the well-site and the battery. Analysis showed a hydrocarbon content of 5.6% with a high asphaltene level. The presence of brine resulted in a pH of 7.7 and an electrical conductivity of 26.8 mS/cm. The extreme water repellent condition of this soil was indicated by the fact that a 9.2N ethanol solution was needed to penetrate it in the dry state.

#### Other materials

Tests on other materials show that this approach is a promising treatment method. Invert Drilling Muds containing diesel fuel, PCB contaminated soil and waste material from a decommissioned plant that had manufactured 2,4,5-T herbicides; (2-methyl-4-chlorophenoxy) herbicides; 2,4-D herbicides and wood preservatives (primarily pentachlorophenol), have also been investigated.

#### Methods

In the current work, a series of batch-scale experiments were conducted using organic solvents as the extracting liquid and water as the bridging liquid. Samples were agitated by; (1) a complex reciprocating action (paint shaker), (2) high speed mixers (blender) and (3) tumbling in a cylindrical mill containing mild steel rods rotating at 20% of the critical speed. At a residence time of 5 minutes, the latter closely simulates a full scale process and was used for most of the test work. As the agglomeration process is water-limited it may be necessary to either increase or decrease the water content. This can be achieved by direct addition of water or by adding dryer soil or a water absorbent, such as peat moss. During processing, solvent extraction of the contaminants occurs concurrently with disaggregation and subsequent agglomeration of the soil particles. The extracted soil agglomerates were usually washed with fresh solvent to remove surface contamination and air dried at 200°C before being analyzed.

Most experiments were conducted in a 4 liter rotating contactor-mill 18 cm in diameter, containing nine 2.5 cm diameter soft iron rods as mixing media. A typical set of standard conditions is shown in Table 1. The mill was charged with contaminated soil, solvent and water and rotated at various speeds for specific times. Pre-mixing of the solids and solvent for 30 seconds was allowed before water was added. During extraction the rotation was periodically interrupted and the solution sampled, usually at 1 minute intervals, to provide data for calculation of transfer rates of the contaminant into the solvent. At the end of 5 minutes the mill charge was dumped onto a 48 mesh screen and allowed to drain for 3 minutes. The agglomerates were milled for a further 3 minutes with fresh solvent, (to simulate an extractant wash) and allowed a final drain of 3 minutes. Analysis of the solids was carried out using a Soxhlet extraction, Dean and Stark separation method. The amount of contaminant in the solutions was determined using a Spectronic 501 Spectrophotometer at a wave length of 530 nm; residual carbon was determined using a Leco CR-12 Carbon Analyzer.

Table 1 Rotating drum standard extraction conditions

Parameters	Values
Solvent	600 ml
Temperature	Ambient
Mill Speed	32% of Critical
Soil Feed	600 g
Pulp Density	50%
Total Water	17.2% of Soil
Feed Premix no added water	30 seconds

Four solvents with different polarities were selected; paraffinic (heptane); aromatic (toluene); chlorinated (trichloroethylene) and commercial naphtha (Varsol®). A solubility parameter was used to characterize each solvent. Process parameters investigated included pulp density, degree of agitation, amount of bridging liquid and the pre-mixing of solvent with soil prior to addition of agglomerating water. Parameter interactions were examined by determining relative mass transfer coefficients calculated from data on the rate of transfer of contaminant into the solvent.

## Results and Discussion

### Solubility parameter

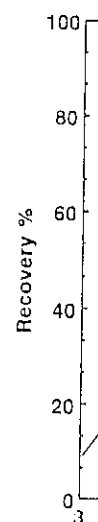
Hildebrand<sup>5</sup> has used a solubility parameter  $\delta$  to describe the solvent power of liquids:

$$\delta = \gamma^{V-1/3} \quad (1)$$

$$V = M_w / \rho$$

Where  $g$  is the surface tension and  $r$  is the liquid density. Erskine Soil and Flare Pit four solvents used. Recovery differences with respect to nature of the contaminant, such as heptane, can be self solvent effect. This can be content of the crude which is readily dissolved by chloro asphaltene precipitate and apparently low recovery of by volume, gave intermedi-

Figure 4 Recovery of c

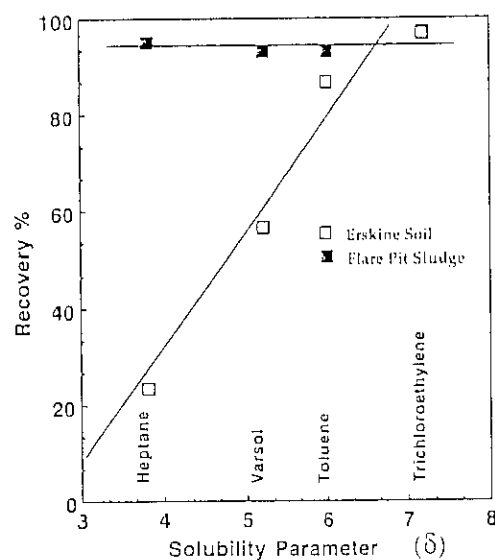


Fine particles with hydrophobic strongly bound contaminant they are not water wetted. Fil of unagglomerated material: results reflect the cleaning al

$$V = M_w / \rho \quad (2)$$

Where  $\gamma$  is the surface tension,  $V$  is the molar volume,  $M_w$  is the molecular weight and  $\rho$  is the liquid density. Figure 4 compares the recovery of contaminants from Erskine Soil and Flare Pit Sludge with respect to the solubility parameters ( $\delta$ ) of the four solvents used. Recoveries of contaminant from flare pit sludges show no major differences with respect to these solvents; this is not unexpected given the aliphatic nature of the contaminant. Consequently, a solvent with low environmental impact, such as heptane, can be selected. In the case of the Erskine soil there is a significant solvent effect. This can be attributed to the high molecular weight asphaltene content of the crude which is only sparingly soluble in paraffinic solvents but which is readily dissolved by chlorinated and aromatic solvents.<sup>6</sup> With paraffinic solvents asphaltenes precipitate and are collected with the agglomerated solids, giving an apparently low recovery of contaminant. Varsol, with an aromatic content of 12% by volume, gave intermediate results.

Figure 4 Recovery of contaminant as a function of solubility parameter

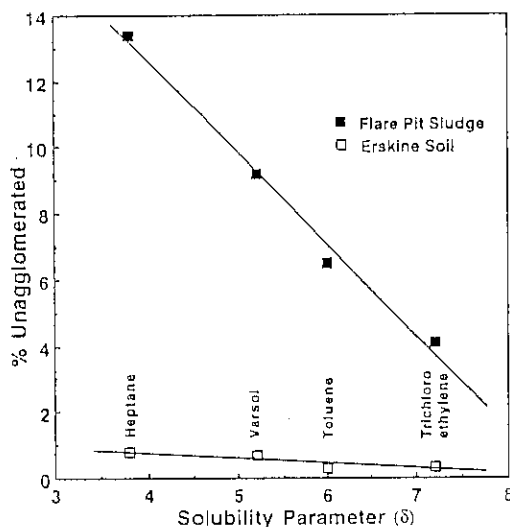


Fine particles with hydrophobic surfaces such as coal, coke and those coated with strongly bound contaminant will tend to remain suspended in the solvent because they are not water wetted. Figure 5 shows the effect of solvent power on the amount of unagglomerated material for both flare pit sludge and Erskine soil. Again these results reflect the cleaning ability of various solvents for removal of adsorbed con-



taminants. In the case of flare pit sludge, heptane resulted in the agglomeration of significantly less solids than for the trichloroethylene test, but was only marginally worse for Erskine soil. The observed differences can be attributed to the fact that the flare pit sludge contains a considerable amount of surface bound contaminant not extracted by weak solvents. Also, unlike Erskine soil, flare pit sludge contains insoluble coke-like material. This is reflected in the amount of unagglomerated solids shown for the two samples when treated with trichloroethylene. Contaminants are removed, either by dissolution, or selectively as a surface coating on fine, hydrophobic solids rejected from the water wetted agglomerates. Consequently, a high recovery of contaminant can be obtained even when strongly bound organic material is not removed from particle surfaces.

Figure 5 Unagglomerated solids as a function of solubility parameter



### Mass transfer

The extraction behavior exhibited in these tests is typical of mass transfer controlled processes. However, equilibrium considerations often become limiting factors.<sup>7</sup> Several mass transfer models were considered for application in this work. One, by Phillips et al.,<sup>8</sup> was selected as the most appropriate. This model was originally formulated for application to the solvent extraction of bitumen from oil sands. Because oil sand is a combination of bitumen with sand, silt and clay, it may be considered analogous to a petroleum contaminated soil and consequently the application should be valid. It provides an effective way to test extraction parameters by reference to a set of standard conditions.

Phillips' distributed-radius extraction process in stirred tanks essentially spherical in shape but diminish in size. The process is controlled by mass transfer and the following relationship, e

$$K_s / K_t = \phi_s C_{\max s} V$$

where  $K$  is the relative over standard set of conditions and  $C$  is the contaminant concentration.  $\phi$  is  $(1-h)$  integrated with respect to integration limits, for this standard conditions

Although Phillips' model was linear for concentrated solutions, it is still relevant in other cases of comparing the effectiveness of using a single parameter, the

Calculated values for this relationship have been determined for a number of coefficients,  $K_s$ , and degree of extraction. The results shown in Figure 6 are typical for a variety of standard conditions used for Erskine soil.

Figure 7 demonstrates the use of the model to determine the interaction of operating conditions on pulp-density, defined as the weight of the total slurry in the extraction. This figure shows that increasing the pulp density. Working with stirred reactors, particle-particle interaction of results in more particle abrasion and transfer of contaminant.

In the rotating mill, agglomerate tumbling rod charge and end rotation. Figure 8 shows that caused a slight reduction in the rate of agglomeration. It can be concluded, over the range of conditions, that the agglomeration rate to increase, re

Phillips' distributed-radius mass transfer model has been applied to a solvent extraction process in stirred tanks. This model assumes that sand-bitumen aggregates are essentially spherical in shape and that during the extraction process they remain spherical but diminish in size. The model postulates that extraction in dilute solutions is controlled by mass transfer at the solvent-bitumen interface. Phillips has developed the following relationship, equation 3, for the comparison of test parameters:

$$K_s / K_a = \phi_s C_{\max s} V_s / \phi_a C_{\max a} V_a \quad (3)$$

where  $K$  is the relative overall mass transfer coefficient, (subscript  $s$  represents a standard set of conditions and subscript  $a$  the comparative set);  $C_{\max}$  is the maximum contaminant concentration possible;  $V$  represents the average volume of solvent and  $f$  is  $(1-h)$  integrated with respect to time, where  $h$  is the degree of extraction. The integration limits, for this study were 0 and 5 minutes, corresponding to the experimental conditions.

Although Phillips' model was designed strictly for dilute solutions, it becomes non-linear for concentrated solutions, he argues that the qualitative features of the equation are still relevant in other cases. It has been used in this work to provide a means of comparing the effectiveness of contaminant extraction under different conditions using a single parameter, the relative mass transfer coefficient  $K_s/K_a$ .

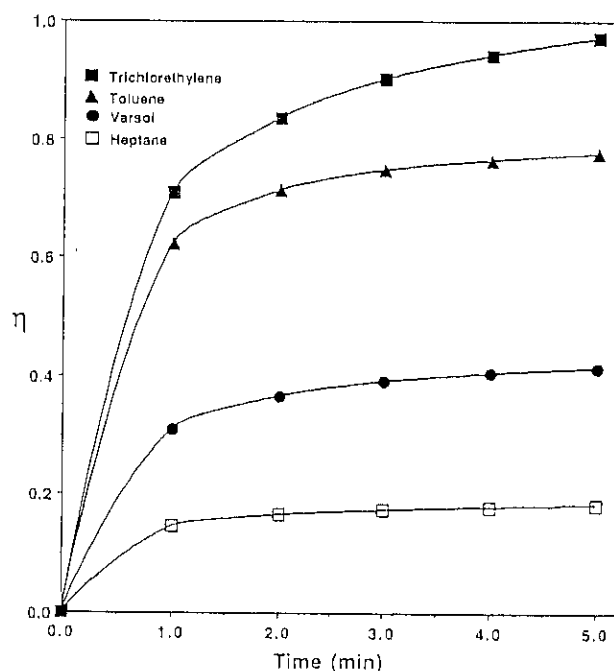
Calculated values for this relative mass transfer coefficient (based on Eqn. 3) have been determined for a number of operating conditions. The standard mass transfer coefficient,  $K_s$ , and degree of extraction,  $h$ , were calculated using the experimental procedure and conditions shown in Table 1. The extraction profiles shown in Figure 6 are typical for a variety of solvents. The curve for toluene represents the standard conditions used for Erskine soil as the test material.

Figure 7 demonstrates the use of the relative mass transfer coefficient  $K_s/K_a$  to determine the interaction of operating parameters on the rate of extraction. The effect of pulp-density, defined as the weight of agglomerates (solids plus water) as a percentage of the total slurry in the extraction/agglomeration mill, is illustrative of this type of analysis. This figure shows that an improvement in extraction rate is obtained by increasing the pulp density. These data are consistent with those found by Phillips, working with stirred reactors. He attributes this type of improvement to greater particle-particle interaction obtained at the higher pulp densities. This interaction results in more particle abrasion and breakdown of aggregates and thus better mass transfer of contaminant.

In the rotating mill, agglomeration is retarded by destructive forces, caused by the tumbling rod charge and encouraged by constructive forces attributable to the mill rotation. Figure 8 shows that for Erskine soil, an increase in mill rotation speed caused a slight reduction in the mass transfer rate of the contaminant. Hence we can conclude, over the range studied, that increasing the mill speed causes the agglomeration rate to increase, reducing the exposure of contaminant to extraction by

the solvent. Also, less scouring of the individual particle surfaces will occur. This is contrary to observations found by Phillips for stirred reactors where an increase in stirrer speed resulted in break-down of aggregates and better extraction. However, other authors<sup>9</sup> have reported only a weak dependency on stirrer speed, providing that the speed is in excess of that required to suspend all solids. Phillips concluded that solvent type and stirrer speed were the most important parameters with particle-particle interaction being a secondary effect. Our studies have also shown that extraction temperature and pre-loading of the solvent with a small amount of contaminant are parameters that improve extraction rates.

Figure 6 Standard extraction profiles for various solvents



### Agglomerate size and strength

The Erskine sample was obtained from an agricultural area. One of our major goals was to remediate this soil to a point where it could be returned to productive use. Therefore, it was necessary to produce restored soil having chemical and physical characteristics that would allow for safe crop growth. Bloch Decay and Cross Polarization Magic Angle  $^{13}\text{C}$  NMR studies demonstrated that the contaminants could be removed, by an appropriate solvent, without unduly affecting the indigenous humic matter necessary for healthy soil.<sup>10</sup>

Figure 7 Relative mass t

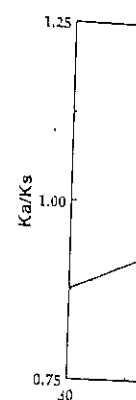
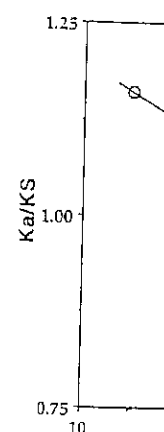


Figure 8 Relative mass tr



Natural aggregation occurs in filters that are physically discrete, particularly the macro porosity, while maintaining free moisture while maintaining free most natural aggregates. However, reaggregating the soil, into round vent extraction of the contaminants by process variable control to give nature. Figure 9 shows the parti

Figure 7 Relative mass transfer coefficient as a function of pulp density

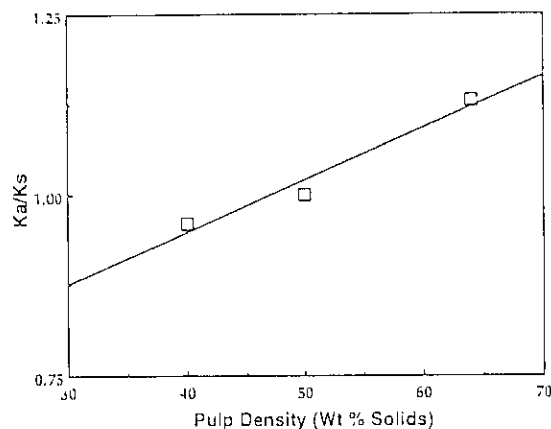
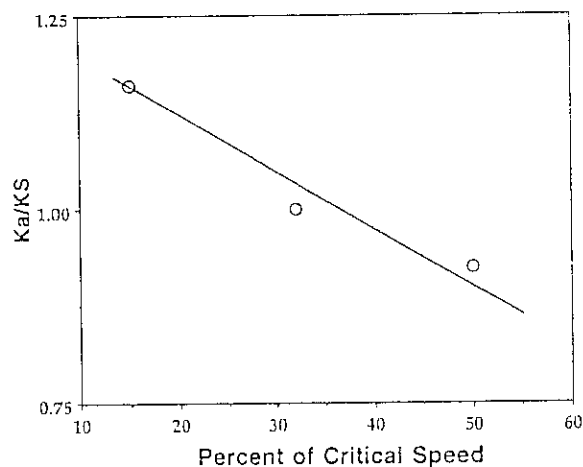


Figure 8 Relative mass transfer coefficient as a function of critical speed



Natural aggregation occurs in fine textured soil to give relatively stable particle clusters that are physically discrete units.<sup>11</sup> This process increases soil porosity, particularly the macro porosity, which is characterized by the ability of the soil to retain moisture while maintaining free drainage. Solvent extraction and milling destroys most natural aggregates. However, the SESR process overcomes this problem by reaggregating the soil, into roughly spherical agglomerates, concurrently with solvent extraction of the contaminant. The size of the agglomerates can be manipulated by process variable control to give a narrow size distribution, similar to that found in nature. Figure 9 shows the particle size distribution for the clean, dispersed Erskine

soil; the median size is about 30  $\mu\text{m}$ . The natural soil aggregate diameter averages about 1 mm; agglomerates from the extraction process have a narrower size range, but still average 1 mm in diameter. These soil agglomerates were found to be three times more stable than similar sized aggregates separated from an uncontaminated sample of the same soil. This difference is illustrated by Figure 10 where aggregate and agglomerate stability were measured by wet sieving in a standard apparatus.

Figure 9 Size distribution for soil aggregates and agglomerates

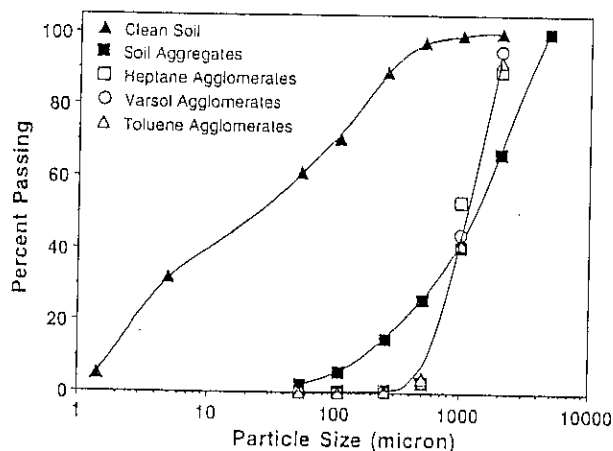
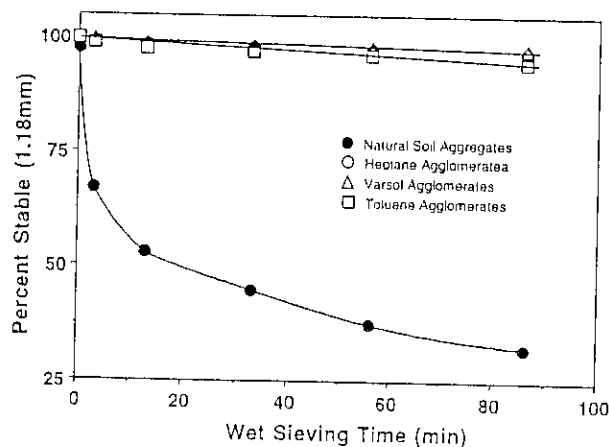


Figure 10 Stability of soil aggregates and natural aggregates



After agglomeration the soil remaining agglomerates was carried out by percolation. Leaching of the salt was rapid. The result of the stability of the artificial salts during agglomerate drying motion. The improved strength of soil process optimization of the large particles into densely packed entire agglomerates. For Erskine soil a large role in agglomerate stability.

After brine removal the remediated soil was tested using: (1) recontaminated soil to establish native flora and fauna. (2) contaminated surface soil from the spill. (3) extracted soil were nearly as large as natural soil in cleaned and uncontaminated soil. The chamber provided a nearly optimum environment in the contaminated soil and

#### Remediation of chlorinated organics

Single stage preliminary experiments were conducted using two other materials: transformer oil spill and two, a waste material that had manufactured chlorinated hydrocarbons. These are shown in table 2. Even though more than one extraction step, it is apparent that these contaminants to accept; as preliminary; further test work is in

#### Conclusions

It has been demonstrated that fine tailings are a critical parameter. By understanding the physical characteristics suitable for using steps prior to returning the soil to

After agglomeration the soil remained saline. Leaching of these brine contaminated agglomerates was carried out by percolation through a packed bed of agglomerated soil. Leaching of the salt was rapid because the narrow size distribution of the aggregates resulted in a high permeability that was maintained during leaching as a result of the stability of the artificial aggregates. Also, efflorescence of water soluble salts during agglomerate drying made them readily accessible to the leaching solution. The improved strength of soil agglomerates is derived predominantly from the process optimization of the large surface tension forces which then draw the soil particles into densely packed entities; in this respect finer particles give stronger agglomerates. For Erskine soil a high humic content (4.5 w/w%) may also play a role in agglomerate stability.

After brine removal the remediated soil was evaluated by using it to grow field peas. Tests were conducted using: (1) remediated soil inoculated with 1% uncontaminated soil to establish native flora and fauna; (2) untreated, contaminated soil; (3) uncontaminated surface soil from the spill site. After six weeks, field peas growing on extracted soil were nearly as large as those growing on uncontaminated soil; germination in cleaned and uncontaminated soil was 100 percent. Although the growth chamber provided a nearly optimum growing environment, only one pea seed germinated in the contaminated soil and its growth was poor.

#### Remediation of chlorinated organics

Single stage preliminary experiments, using shaking and blending methods, were conducted using two other materials; one, a soil contaminated with PCB from a transformer oil spill and two, a waste sludge material from a decommissioned plant that had manufactured chlorinated herbicides and wood preservatives. The results are shown in table 2. Even though more than 90% of all contaminants were removed in one extraction step, it is apparent that a multistage process will be required to reduce these contaminants to acceptable levels. These results should be considered as preliminary; further test work is in progress.

#### Conclusions

It has been demonstrated that fine textured soil can be remediated using the SESR Process and that relative mass transfer coefficients can be calculated to determine critical parameters. By understanding the agglomeration process it is possible to reduce substantially the entrapped residual solvent and to form agglomerates with physical characteristics suitable for subsequent leaching and bioremediation polishing steps prior to returning the soil to the environment.

Table 2 Summary of results for remediation of soils contaminated with chlorinated organics

Sample	Particle Size			Contaminant	Concentration	Recovery %
	<2 $\mu$ m	2-50 $\mu$ m	>50 $\mu$ m			
Flare Pit Sludge	1.7	24.6	73.7	Hydrocarbons	25 w/w%	96+
PCB Soil	<1.0	7.3	91.7	Aroclor 1016	14,100 ppm	94
Pond Sludge	14-41	21-38	31-65	Dioxin	30 ppm	93+
				2,4 Dichlorophenol	1,035 ppm	93+
				2,4,6 Trichlorophenol	116 ppm	93+
				Pentachlorophenol	421 ppm	93+
Erskine Soil	34	27	39	Crude Oil Residue	5.6 w/w%	96+

## Acknowledgement

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## The Role of Hydroxyl Radicals in The Advanced Oxidation Processes

C.H. Kuo, 1

### Abstract

This research investigates kinetics between dissolved ozone and a stopped-flow spectrophotometer. The initial ratio of the molar concentration of hydroxyl ion to ozone is less than 30. At lower ratios, the rate is independent of the concentration of hydroxyl ion. At a concentration of 11.0 at 25°C examined, the decay rate equation derived on the basis of the hydroxyl radical by the oxidants, and the rate of oxidation of a pollutant, the rate of conduct the peroxone process is in excess to enhance the destruct

### Introduction

The decontamination of drinking water. Recent applications include irradiation during the ozonation [9]. The result in faster rates of pollutant degradation process, and complete conversion.

The peroxone process, one of the most efficient oxidation of gaseous ozone and liquid phase oxidize contaminants in the solid phase molecules into the interface between

123  
~~122~~

# EMERGING TECHNOLOGIES IN HAZARDOUS WASTE MANAGEMENT VI

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