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Remediation of contaminated media using a jet pump Part 1: Screening for significant parameters

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Abstract

New legislation is causing a change in the attitudes of industrial processes towards contamination and remediation of contaminated land, encouraging industry to remediate their contaminated sites. One new remediation option is the jet pump scrubber. Parameters that may affect the ability of a jet pump scrubber to remediate contaminated land have not been previously identified. In this study, the effect of five possible parameters of significance to the remediation process, were investigated (i.e. initial contaminant concentration, number of passes, contaminant type, motive pressure and particle size) using a full factorial screening design. For all experiments, washed oven dried silica sand was contaminated with a range of mineral oil contaminants. Samples were analysed using an ultrasonic extraction and spectrophotometric method. Contaminant removal efficiencies of up to 99.1% in the jet pump scrubber were found. Of the 30 possible parameter combinations, 15 parameter/parameter combinations were found to have a statistically significant effect on the remediation process, with the initial contaminant concentration and the number of passes in the jet pump scrubber providing the greatest effect. Therefore, future jet pump scrubber units should be designed such that contaminated media can undergo multiple passes in quick succession.

Keywords: Jet pump; Scrubber; Remediation; Contaminated land; Environmental engineering

1. Introduction

Soil and sediments have been contaminated with industrial waste since the industrial revolution. Current attitudes towards land contamination and remediation have changed, and legislation, such as the Environmental Protection and the Integrated Pollution Prevention and Control Acts, introduced into the U.K. in the 1990s, has played a significant role in encouraging industries to remediate their contaminated land sites. Despite the introduction of new legislation however, there are many contaminated sites that still require remediation [1]. Therefore, there is a real need for a simple and effective remediation process.

This paper will focus on one remediation option called soil washing (or flushing). Soil washing is predominately water and/or solvent-based, and relies on the physical and chemical differences between the contaminants, solid phase, and the wash-water to remove the contaminants from the solid phase into the liquid. Soil washing produces a "dirty" liquid phase which requires further treatment to either destroy or confine the contamination and a "clean" solid phase.

Strazisar and Seselj [2] studied the ability of a soil washing process to remove lead and zinc from contaminated soils in Slovenia. Using a simple attrition scrubber, removal percentages of up to 86% were achieved. Feng et al. [3] attempted to compare the ability of a number of different soil washing processes to remediate samples contaminated with diesel oil. Using a attrition scrubber with vertical mixing rods Feng et al. [3] achieved removal percentages of up to 97%. Bayley and Biggs [4] conducted a number of experiments using a small scale attrition scrubbing unit to remediate sand contaminated with mineral oil and found that efficiencies greater than 95% could be achieved. Bayley and Biggs [4] also investigated the relationship between a number of parameters such as temperature, attrition time, and power on the removal efficiency of the unit and demonstrated that an un-baffled attrition scrubber was very effective at remediation of contaminated sediments. Despite these studies on the efficiency of soil washing as a remediation process, the major bulk of soil washing research has been conducted on the traditional use of soil washing as a size reduction remediation process not as an actual separation of contaminants/media remediation process [5–9].

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A less traditional soil washing process is the jet pump scrubber. A jet pump scrubber has been discussed and promoted widely in literature [1,10–16]. Two of the most informative studies are by Wakefield and Tippetts [16] and Wakefield [11]. The former is a valuable insight into the operation of a jet pump scrubber using actual contaminated media and indicates that the jet pump scrubber may be very efficient at remediation of contaminated land (removal percentages of up to 99.99% are quoted). Wakefield [11] provides a detailed description of a number of jet pump scrubber setups, such as impinging jets and two stage jet pumps, and compares them with more traditional soil washing methods such as barrel washers and paddle type attrition scrubbers. In this case, Wakefield [11] concluded that a two state jet pump scrubber was the most energy efficient scrubbing process. Bayley and Biggs [1] designed, built and commissioned a Contaminated Sediment Remediation Rig (C.S.R.R.), which utilized a jet pump scrubber to remediate contaminated sands. A detailed description of the principles of a jet pump scrubber, for soil washing is also given. Initial results were promising, however a further more vigorous, defined and controlled experimental programme was recommended. Therefore, using the same C.S.R.R. as used by Bayley and Biggs [1] this paper systematically identifies key parameters and any potential interactions between key parameters that may influence the remediation efficiency of a jet pump scrubber for remediation of contaminated media.

2. Key parameters

The current literature on soil washing and the jet pump process was used to identify five key parameters that are considered to have an important effect on the ability of the jet pump to remediate contaminated media. Each of these parameters are discussed in turn, highlighting what previous research has been conducted on these parameters, and why these parameters are considered to be significant.

2.1. Contaminant concentration

A key driver for conducting studies to clean up contaminated media is the level of contamination. When considering the level of contamination it is also important to consider the type of attachment between the contaminant and the media. For example, if there are X sites per particle on which contaminants can attach, then the number of contaminants that can attach to the particle surface is also X. If the number of contaminants is increased by ΔX to $X+\Delta X$, then there are ΔX contaminants that are not directly bonded to the particle surface. These ΔX contaminants are assumed to attach to the X contaminants that are themselves attached directly to the particle surface (Fig. 1). The ΔX contaminants should be easier to remove than the X contaminant, as they are not directly bonded to the surface of the particles. It follows therefore, that as the contamination level increases, there will be a greater amount of contaminant that is not directly bonded to the particle (i.e. an increase in ΔX), for any given particle. Hence, it is hypothesised that a greater total percentage of contaminants will be removed from the media at higher contaminant concentrations, than at lower concentrations, due to the increase in ΔX.

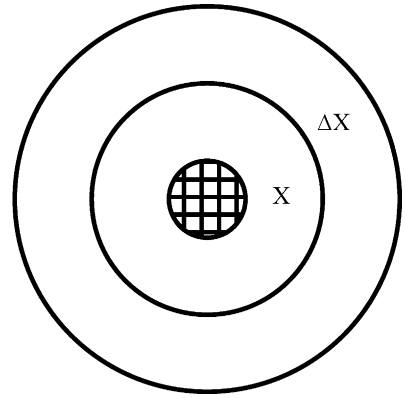

Fig. 1. Two layer surface model of contamination on a solid particle.

2.2. Contaminated media particle size

Feng et al. [3], using a jet reactor, showed that contaminated media with a larger particle size was easier to remediate than media with a smaller particle size. In this case, sand of three different particle sizes, with an average particle size of 0.1, 0.3, and 0.5 mm, were contaminated with 5 wt.% diesel. This observation was due to the greater surface area to mass ratio for the media with a smaller average particle size compared to that of the larger particles. The contaminants attached to the particle surface (i.e. X contaminants described above and Fig. 1) will be harder to remediate, using the scrubbing action of the jet pump, than contaminants not attached to the surface (i.e. ΔX). So it is hypothesised that the media with a smaller average particle size, and hence, larger surface area ratio should be harder to remediate, as more contaminants are tightly sequestered to the particles surface than media with a bigger particulate size and a smaller surface area ratio.

2.3. Contaminant type

The more hydrophobic and the more viscous the contaminant is, the harder it will be to remove from the solid phase into the liquid phase due to the greater required impact energy needed to dislodge the contaminant from the particle. Therefore, hydrocarbons with a lower Relative Molecular Mass (R.M.M.), which are less viscous, should be easer to remove than hydrocarbons with a higher R.M.M. Bayley and Biggs [4] showed that using a paddle type scrubber, there was a considerable difference in the remediation efficiency between silica sands contaminated with mineral oil or bees wax (80.2% and 16.8 % removal efficiencies, respectively). Thorvaldsen and Wakefield [13] also showed that that increasing the carbon chain length of the contaminant reduced the final removal efficiencies in a jet pump scrubber.

2.4. Motive flow pressure

Attrition scrubbing relies on the fact that during an impact involving a particle, there is sufficient energy in the impact to