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Effects of magnetic field on removal of Light Non-Aqueous Phase Liquid (LNAPL) from unsaturated zone using steam injection

[1]Adegbola A. A, [2*]Abioye A. I. and [1]Yakub Y. O.

[1]*Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State*
[2]*Department of Mechanical Engineering, The Polytechnic Ibadan, Ibadan, Oyo State.*

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Corresponding Author:
aaadegbola59@lautech.edu.ng

ABSTRACT

Unsaturated zone is of great importance in providing water and nutrients that are vital to the biosphere and often the main factor controlling water movement from the land surface to the aquifer. Steam injection for remediation of porous media contaminated by LNAPLs is a potentially efficient technology. However, the need for its improvement in recovery efficiency using other methods has been a subject of continuous study. This study aimed to carry out experiments to investigate the effect of a magnetic field on the removal of LNAPLs from unsaturated zones using Steam Injection. An unsaturated zone of a sandbox of interior dimensions 110 x 74 x 8.5 cm was polluted at different periods of 0-120 s with 200 mL of Toluene. Steam injection experiment with the rate of $0.01m^3/s$ was performed to determine the recovery efficiencies of Toluene only in an unsaturated zone containing sand of porosity 0.42 and permeability of 0.001163779 cm/s with the introduction of varying magnetic field 1-3T in a step of 1T. The results for the recovery efficiency of Toluene using steam injection only was 80.30% while that of steam injection and magnetic field at 1-3 T yielded 83.70-86.60 %. The results of recovery efficiency of steam injection with magnetic field were 4.23-7.85 % higher than the result of steam injection only for LNAPL (Toluene). A combined application of steam injection with a magnetic field appreciably enhances the removal of Light Non-Aqueous Phase Liquids from an Unsaturated Zone.

INTRODUCTION

Groundwater is one of the important sources of water on our planet as it provides 36% portable water for domestic purposes, 42% for industries and 24% for agriculture (Doell and Scanlon, 2011). It is found below the surface of the earth in the soil pore space and cracks of rock formation. An aquifer is a body of rock and/or sediment that holds groundwater. Pollution of soil and groundwater by petroleum products Light Non Aqueous Phase Liquids (LNAPLs) have been recognized as one of the major environmental threats that have led to environmental degradation. The groundwater can be contaminated in different ways by different sources which are natural sources, septic systems, improper disposal of hazardous waste, landfills and impoundments, sewers, and other are pipelines, pesticides/fertilizers use, drainage wells, injection wells/floor drains, improperly constructed wells, improperly abandoned wells, active drinking water supply wells, poorly constructed irrigation wells, mining activities, and spills from stored chemicals and petroleum product such as Non-Aqueous Phase Liquids (Krishna, 2008; Zhang *et al.*, 2017).

Non-aqueous phase Liquids (NAPLs) are liquids contaminants solutions that do not dissolve in or easily mix with water, they contaminate soil and groundwater. It is classified into Dense Non-Aqueous Phase Liquids (DNAPLs) and Light Non-Aqueous Phase Liquids (LNAPLs) (Uwe, 2013).

Contamination of groundwater can result in poor drinking water quality, loss of water supply, degraded surface water system, destruction of aquatic habitats, higher cleanup costs, high costs for alternative water supplies, and health problems such as kidney failure and cancer which are life-threatening disease (Ortiz-Harnandez*et al.* 2014).

Groundwater remediation is the process that is can be used to remove pollution from soil and groundwater or to treat polluted soil and groundwater by removing the pollutants or converting them into harmless substances (Abel, 2019). During the past few years, several in situ techniques have been developed for clean up of soils contaminated by NAPLs. Existing remediation technologies include vapour extraction, radio frequency heating steam, stripping (steam injection) and biological/chemical/physical methods (Osamah, 2021). Thermal technology makes use of the application of heat to the groundwater via soil to increase the recovery efficiency of volatile and semi-volatile contaminants from the aquifer. Thermal treatment includes the use of electrical resistivity heating, steam-enhanced extraction, conductive heating, radio-frequency heating, and vitrification technologies (SEPA 2014). Among these thermal treatments steam injection is being investigated as a potential method for remediation of LNAPL contaminated soils. Some of the knowledge and techniques developed in petroleum engineering for enhanced oil recovery by steam injection are useful to the problem of steam stripping for remediation of LNAPL-contaminated soil.

The purpose of remediation efforts is to remove as much of the contaminants as possible until clean-up levels are achieved. Steam Injection (SI) or Steam Enhanced Extraction (SEE) involves an injection of steam into injection wells and the recovery of mobilized groundwater, contaminants, and vapor from the recovery wells. Steam is a well-documented technology for addressing NAPL source zones in unconsolidated sub-surfaces (Davis 2008). Initially, when steam is injected into the subsurface, it gives up its latent heat of vaporization to the soil and the steam strips the volatile contaminants from the moving soil and brings them to the surface, where they are captured in a shroud or bell Jacob (2003) compared the numerical simulated result with the experimental result of removal of NAPLs from the saturated zone and confined aquifer using simulation 3D thermal with steam injection (T2VOC numerical code) in soil volume of 1.67 x 0.05 x 1 m. Thermal steam and steam injection experiment was also carried out. The issue is to remove NAPLs from the unsaturated zone using steam injection and remove NAPLs from below the water table. The field demonstration was carried out by USEPA (2007) to remediate NAPLs from an oil source contaminated area with about 12,000ibs of oil in a contaminated site 200,000-800,000 cubic yard contaminants found in the site PCE, TCE, 1,1,2-trichloroethane, carbon tetrachloride and methylene chloride in both saturated and unsaturated zone. The Steam Enhanced Extraction (SEE) was used with 68 injection wells at the center and 367 heaters. After the remediation process, both soil and groundwater were answered and about ninety (99%) of the mass of contaminants were recovered which is equal to the targeted treatment result. This demonstrates that both stream stream-enhanced extraction (SEE) with extraction well combined with thermal improve the efficiency of removing NAPLs from the contaminated site.

A magnetic field is a region or space or a vector around a bar magnet where the effect of magnetic force can be experienced of felt. The magnetic force is a force of attraction or repulsion that arises between the poles of a magnet and electrically charged moving particles. Several researches have proved that the magnetic force is capable of improving the remediation of NAPLs from both saturated and unsaturated zones using steam injection by reducing the rate of migration of NAPL in a porous media. Dare and Sasaki (2011) investigated the effect of magnetism on groundwater and pollutant movements. The effect of magnetism on the migration of kerosene, petrol and diesel was investigated by estimating the pollutant spread area for varying magnetic strength. The imposition of an external magnetic field appreciably decreases pollutant spread in an aquifer and subsequently cuts down on remediation processes. Adegbola and Dare (2018) carried out a numerical investigation of groundwater remediation using steam injection with magnetic field effect, the result demonstrates steam injection remediates contaminants from the subsurface and application of magnetic field enhanced the removal of the contaminant in the groundwater. Research shows that the presence of an applied magnetic field increases the rate of destruction of pollutant organic species by free radical oxidation but a direct interaction requires a stronger magnetic field depending on the nature of charged particles and magnetic field strength. The reservoir fluid has been shown to respond to magnetic fields. Apart from preventing the downward migration of pollutants using steam-air injection, the magnetic field can also prevent the spread of the pollutant.

Sometimes more than one remediation technology such as steam injection with air stripping, electric resistance heating with steam injection, steam injection with a magnetic field, etc may be used which may be combined or arranged in parallel or series purposely to prevent the spread of pollutant and increase the remediation efficiency of the contaminated site (Treatment Train). The objective is to use more than one remediation technique to compensate for the weakness of the other one thereby optimizing the remediation process in terms of effectiveness, and reliability. It is this objective that prompted this research work on the Effect of Magnetic Field on the Removal of Light Non-Aqueous Phase Liquid from an Unsaturated Zone using Steam Injection.

MATERIALS AND METHOD

Materials

This research work involved the determination of properties of the soil such as soil porosity, permeability, moisture content, and soil texture. Also, laboratory experiments using steam injection, steam injection with magnetic field 1-3 T in a sandbox of dimension 110 x75x 8.5 cm as an unsaturated zone polluted by Light Non-aqueous phase liquids (LNAPL). The pollutants used for the experiment are Toluene (LNAPL). The experiment was carried out at the New Fluid Mechanic Laboratory of the Mechanical Engineering department, LAUTECH, Ogbomoso, Oyo State.

Characterization of soil sample

Geo-technical test was performed on the soil sample (obtained in front of the chemical engineering laboratory, LAUTECH premises) to determine the identity of the soil samples used in the experiment. This test was carried out in the Geotechnical Engineering Laboratory in the Civil Engineering Department of Ladoke Akintola University of Technology, Ogbomoso, Oyo State.

Soil Porosity

Porosity is the amount of space in soil and rocks. This was measured using the procedure as follows: 100 mL of water was measured in a graduated cylinder and poured into a container. The level in the container was marked and poured back into the graduated cylinder. The container was filled with sand (soil sample) up to the mark in a container and then water was poured in a graduated cylinder into the container filled with sand until it filled up to the mark. The volume of the remaining water in the graduated cylinder was measured. The same procedure was employed with gravel (macro-porosity). Porosity was calculated using equations 1 to 3 (Fetter, 1994).

Macroporosity =

$$\frac{Pore\ space\ volume\ of\ gravel}{Total\ volume} \times 100 \qquad (1)$$

$$\text{Micro-porosity} = \frac{Pore\ space\ volume\ of\ sand}{Total\ volume} \times 100 \qquad (2)$$

$$\text{Total porosity} = \text{Macro-porosity} + \text{Microporosity} \qquad (3)$$

Soil Permeability

Soil core was filled with a soil sample which served as a hydraulic head and another soil core was placed on it and marked 5cm from the soil surface. The whole soil cores were fixed together using marking tape and were later suspended on a retort stand with a funnel fixed at it beneath with 250 ml conical flask serving as a receiver. Water was added into the whole soil cores to the fullest and the water flow was monitored for the period of five minutes. After five minutes, the receiver (conical flask) was removed and the discharged water was measured in a graduated cylinder. The process was repeated until a constant value was obtained and hydraulic conductivity was calculated using the equation (4):

$$K_T = \frac{QL}{Ath} \qquad (4)$$

Where: K_T = Hydraulic conductivity (cm/min)

L =length of specimen in centimeters
t = time for discharge in minutes
Q = volume of discharge in cm^3
(assume 1 mL = 1 cm^3)

A = cross-sectional area of permeameter (soil core) ($A = \frac{\pi}{4}$ D^2, D is the inside diameter of the permeameter (soil core) h = hydraulic head difference across length L, in cm of water

Moisture Content

Muhammed (2014) used the English Standard Institution (E.S.I) oven-drying method of English to determine the moisture content of the soil sample. A clean container of non-corrodible material with a lid was weighed and recorded. A moist soil was placed in the clean container, weighed and recorded. The lid was removed and the clean container with the moist soil was then placed in an oven for 24 hours and the temperature being maintained at 105℃ − 110 ℃. After drying, the clean container was allowed to cool in a desiccator. The lid with the clean container and the drying soil was reweighed and recorded. The moisture content was determined using Equation 5

$$M_{content} = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \qquad (5)$$

Where: M_1 = Weight of an empty clean container with lid (g)M_2 = Weight of clean container with lid + wet soil (g)M_3 = Weight of clean container with lid+ dry soil (g)

Soil Texture

Soil textural determination was done using the hydrometer method described by Bouyoucos method as described by Andres *et al* (2014). The soil sample was oven-dried and sieved. Fifty grams (50 g) was then measured for the test and ten percent (10 %) of hydrogen peroxide was added to it in a measuring cylinder. Stirred and allowed to settle for forty seconds (40 s) and a hydrometer reading was then taken. In another 2hrs, the hydrometer reading was taken again. The percentage of sand, clay and silt in the soil samples was determined using equations 6, 7 and 8, respectively. After forty seconds, the sand has settled and the hydrometer reading reflects the grams of silt + clay in 1 litre of the suspension.

$$\%\text{Sand} = \frac{Sample\ mass - 40\ seconds\ reading}{Sample\ mass} \times 100 \quad (6)$$

$$\%\text{Clay} = \frac{Two\ hours\ reading}{Sample\ mass} \times 100 \quad (7)$$

$$\%\text{Silt} = (100\% - \%\ sand - \%\ clay) \quad (8)$$

Tools and Equipment

The following are descriptions of some of the major tools and equipment that were used for the experiments:

Steam Boiler

A steam boiler consists of an enclosed pressure vessel where water is being heated to produce steam through a heat energy source. This steam boiler was designed in such a way that it is capable of using either charcoal, cooking gas or electricity by a 2 kW electric heater as a source of heat energy but gas was used for the work. The steam boiler is equipped with a digital temperature measuring device, pressure gauge, thermostat and pressure safety valve which are used for measuring steam temperature, and pressure and controlling the internal pressure of the boiler respectively. It is also provided with a fluid flow meter to control and measure the flow rate of the steam leaving the steam boiler to the sandbox.

Sand Box

The experiment was conducted in a sandbox. The sandbox had an interior dimension of 110 X 74 X 8.5 cm (plate 1). The sandbox was constructed from galvanized steel and a front glass panel. The glass panel was to allow for taking photographs, visual inspection and access to the sand packing. The sandbox was lagged to minimize heat loss and loss of pollutants. Steam was injected into the sandbox through the injection port. The steam from the steam boiler was superheated to 110 °C to ensure that the steam was dry. The sandbox was equipped with a temperature sensor, pressure transducer and variable electromagnetic induction device to measure temperature, and pressure and vary the magnetic field strength in the sandbox respectively. Effluent gas (steam and pollutant) left the sandbox through the extraction port located at the opposite side inlet port of the sandbox and was passed to the condenser.

Condenser

This is a device that was used to condense effluent vapour (steam and contaminant vapour) into a liquid state through cooling. The vapour was passed through a condenser.

Electromagnetic Device

An electromagnetic device was made up of coils of wires wound around a bar of iron or other ferromagnetic material. The principle of work is when electric current flows through the conductor (wire), it causes coils to generate a magnetic field that has both magnetic north and south poles. This electromagnetic device was made up of a 1.32 W DC electric motor from power sources of 0.32 A with a frequency ranging between 3.75- 6.75 HZ, and a rotational speed of 202.5 – 405 rpm. It is capable of generating variable magnetic field strength of 1-3 T which can be selected accordingly with the help of a switch and is capable of producing 3.63 Ncm torque.

Experimental Procedure for Removal LNAPL from Unsaturated Zone Using Steam

Injection

The experiment was conducted in a galvanized steel box (Sandbox) of dimensions 110 cm x 74 cm x 8.5 cm with a plain glass panel. This will allow visual access to the sand packing in the sandbox to observe the behaviours of contaminants (LNAPL). Steam was generated from the steam boiler which operates on cooking gas as its fuel and injected into the sandbox through the inlet port located at the middle of the edge of the sandbox. The steam flow rate was adjusted using a flow control valve and monitored with a flow meter and pressure gauges. The steam was injected into the sandbox and the vapor of the contaminants left the box through the outlet port and conveyed to the condenser via a metal pipe. This condenser was designed in such a way that it can be operated on a refrigerator system, using electricity to power the refrigerator, and also capable of using ice packs in case when electricity is not available. The condensate (water and contaminants) was collected into a separating funnel where the contaminant was separated from the water while the non-condensable gases flowed out of the condenser through the condenser's vent to the surrounding atmosphere. The temperature of the injected steam and extracted gases in the sandbox was measured with the thermocouple thermometer and the box was insulated during the experiment to reduce heat loss. Figure 1 shows the block diagram of the experimental setup and the schematic diagram of the experimental setup of steam injection.

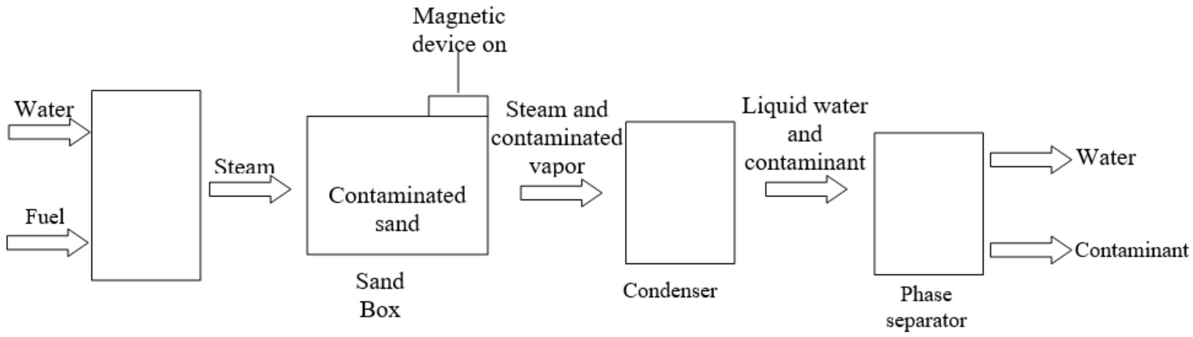

Figure 1: Block Diagram of Experimental Set up of Steam Injection

Experimental Set-up for Removal of LNAPL from Unsaturated Zone Using Steam Injection with Magnetic Effect

The experiment was conducted in a galvanized steel box (Sandbox) of dimension 110 cm x 74 cm x 8.5 cm with a plain glass panel which will allow visual access to the sand packing in the sandbox to observe the behaviours of contaminant LNAPL (Figure 2). Steam was generated from the steam boiler which operated on gas as its fuel and injected into the sandbox through the inlet port located at the middle edge of the sandbox. The steam flow rate was adjusted using a flow control valve and monitored with a flow meter and pressure gauges. A magnetic field was generated by an electromagnetic inductor which induced a magnetic field onto the metal rod perpendicularly positioned in the sandbox to the direction of flow of injecting steam. This electromagnetic device is capable of producing magnetic flux of varying values ranging from 1-3T. Steam is injected into the sandbox and the vapor of the contaminants leaves the box through the outlet port and is conveyed to the condenser via a metal pipe. This condenser was designed in such a way that it can be operated on a refrigerator system that uses electricity to power the refrigerator and is also capable of using an ice pack, in case when electricity is not available. The condensate (water and contaminants) was collected and poured into the phase separator where the contaminant was then separated from the water while the non-condensable gases flowed out of the condenser through the condenser's vent to the surrounding atmosphere. The temperature of the injected steam and extracted gases in the Sandbox was measured with the thermocouple thermometer and the box was insulated during the experiment to reduce heat loss.

Figure 1: Steam Boiler, Sand Box and Condenser Set-Up for the Experiment

Determination of Recovery Efficiency

Recovery efficiency was determined for each experiment performed using steam injection only (0 T) and steam injection with magnetic field (1-3 T) for recovery of Toluene. The volume of the contaminant recovered every thirty minutes of the experiment was recorded until no visible contaminant from the sandbox was recovered. After the whole experiment, the time taken to recover the contaminant was used as the reference time at which the recovery efficiency of both steam injection only and steam injection with the magnetic field was calculated using equation 9. The result from both methods was compared to each other to determine the most efficient method out of the two. Also, the graph of the cumulative volume of recovered contaminant (LNAPL) was plotted against time for each of the experiments performed.

$$Recovery\ Efficiency = \frac{Recovery\ volume\ of\ LNAPL\ (Contaminant)}{Initial\ volume\ of\ NAPL\ (contaminant) in\ sand\ box}\ X\ 100 \qquad (9)$$

$$\%\ Deviation = \frac{Value\ of\ steam\ injection\ by\ author - value\ of\ steam\ injection}{value\ of\ steam\ injection\ only\ by\ an\ author} \times 100 \qquad (10)$$

The experimental result of the Effect of Magnetic Field on the Removal of Non-aqueous Phase Liquid from Unsaturated Zone Using Steam Injection Only and Steam Injection with Magnetic Field was compared using descriptive and inferential statistics. The descriptive method used includes percentages while the inferential analysis used was correlation and Chi-square at 0.05 level of significance. The deviation of results was calculated with the equation 10.

RESULTS AND DISCUSSION

Results of Soil Geophysical Test

The result of the soil geophysical test of the soil sample collected in front of the chemical engineering laboratory, Ladoke Akintola University of Technology, Ogbomoso, Oyo state to determine the Effects of Magnetic Field on Removal of Non-Aqueous Phase Liquid from Unsaturated Zone using Steam Injection. The results of the soil moisture content, permeability, soil texture, porosity, and soil grain size are as follows. From the first experiment, the masses of the cups with wet soil for the two samples were 46.3g and 77.5g respectively, after drying in the oven the masses were reduced to 45.0g and 73.4g respectively as a result of loss in weight due to evaporation of water in the soil which means the mass of water content in the soil are 1.3g (8.33 %) and 4.1g (9.60 %) of the total mass of the first and second soil samples respectively. The average moisture content of the soil was 9.0 per cent. The result shows that the soil was moist soil which was because soil the sample was collected during the rainy season. The quantity of clay, silt and sand distribution in the soil sample was measured from the triangle of soil texture.

Table 1: Result of Soil Moisture Content Test

S/N	Description	1st Result	2nd Result
1	Container No (cup no)	243	345
2	Mass of cup (g)	29.40	30.70
3	Mass of dry soil (g)	15.60	42.70
4	Mass of cup + wet soil (g)	46.30	77.50
5	Mass of cup + dry soil (g)	45.00	73.40
6	Mass of water (g)	1.30	4.10
7	Water content (%)	8.33	9.60
	Average water content (%)	**9.0**	

Table 2: Properties of Soil Sample Used for Experiment

S/N	Parameter	Value of the Result
1	Sand color	Light brown
2	Sample area (cm^3)	86.6250
3	Sample length (cm)	12.5000
4	Bulk Density (g/cm^3)	1.7600
5	Moisture content (%)	9.000
6	Dry density (g/cm^3)	1.6200
7	Specific Gravity	2.6000
8	Void ratio	0.0044
9	Porosity	0.42
10	Manometer Area	1.0000
11	Soil texture: sand, clay, silt (%)	64.5, 11.4, 24.1
12	Hydraulic constant (cm/s)	0.001163779

From the result, the percentages of sand silt and clay content in the soil sample obtained were 82.68 %, 11.24 % and 6.08 % respectively which makes the soil samples used to be classified as sand silt (Tables 1 and 2).

It takes water 60 s to flow through 9.7 cm of the soil column, 15.0 cm in 120 s and after 180 s the water flows through 19cm of soil core while it takes water 240 s and 300 s to pass through 21 cm and 22.4 cm of the soil core respectively. It was noticed that the flow rate of water through the soil core is reducing down the soil core which might be a result of an increase in resistance of the soil core to the water as the soil pack increases. After the calculation, the hydraulic conductivity (Kt) of the soil sample was 0.001163779cm/s.Other properties of the soil sample used for the experimental investigation are dry density, bulk density, specific gravity, void ratio, and porosity are 1.62 g/cm^3, 1.76 g/cm^3, 2.6, 0.0044 and 0.00442 respectively.

Result of Effect of Magnetic Field on Removal LNAPL (Toluene) from Unsaturated Zone Using Steam Injection

From Table 1, the cumulative recovered volumes of contaminant (Toluene) after treating with steam injection only for another 30, 60, 90 and 120 minutes of remediation process were 25.6, 82.6, 155.4, and 160.6 mL respectively out of 200 mL total initial volume of contaminant (toluene) in the sandbox were recovered. The calculated recovery efficiency for the same respective treatment time was 12.80, 41.30, 77.70 and 80.30% respectively.

It was observed that, within the first thirty minutes of commencement of the process, the recovery rate was very small so as well as the recovery efficiency too when comparing it with that of thirty to ninety minutes. This was because the injected steam lost its latent heat to raise the temperature of the sandbox from room temperature to temperature enough to vaporize the water and the NAPL and there was an increase in recovery volume of NAPL(Toluene) between thirty minutes to ninety minutes of steaming which also increase the recovery efficiency because the temperature of the sandbox at this period was sufficient to vaporize the NAPL (Toluene). However, there was a reduction in recovery volume of NAPL between ninety minutes and one-twenty minutes of the process. This might be a result of a reduction in the concentration of NAPL(Toluene) in the sandbox or some of the NAPLs were lost through evaporation to the surroundings and were unable to be recovered.

The increase in the amount of toluene recovered was attributed to the temperature of NAPLs which vaporized at a temperature usually less than one hundred Celsius (Kaslusky and Udell 2002). As the temperature increases the vapor pressure also increases which reduces the viscosity of the toluene in the soil pores and causes the toluene to vaporize and this leads to an increase in toluene recovered from the soil.

Unsaturated Zone using Steam Injection

The result of total cumulative volume and recovery efficiency of Light Non-Aqueous Phase Liquid (toluene) from an unsaturated zone (sandbox) after remediation of the contaminated soil with steam injection and a combination of steam injection and magnetic field strength (1-3 T) at steam injection flow rate of 0.01 m^3/s for 120 minutes are as follows:

Table 3: Result of Recovery Efficiency of Removal of LNAPL (Toluene)

Time(minute)	Recovery Efficiency at 0T (%) (S.I. only)	Recovery Efficiency at 1T (%)	Recovery Efficiency at 2T (%)	Recovery Efficiency at 3T (%)
0	0	**0**	0	0
30	12.80	12.9	14.80	15.10
60	41.30	43.95	47.45	48.80
90	77.70	82.10	84.80	85.85
120	80.30	83.70	85.85	86.60

Table 3 shows the experimental result of removal of LNAPL (Toluene) from the unsaturated zone using steam injection only at 0.01 m^3/s after steaming for 120 minutes was 80.30 % while steam injection with magnetic field 1-3 T yielded 83.70-86.60 %.

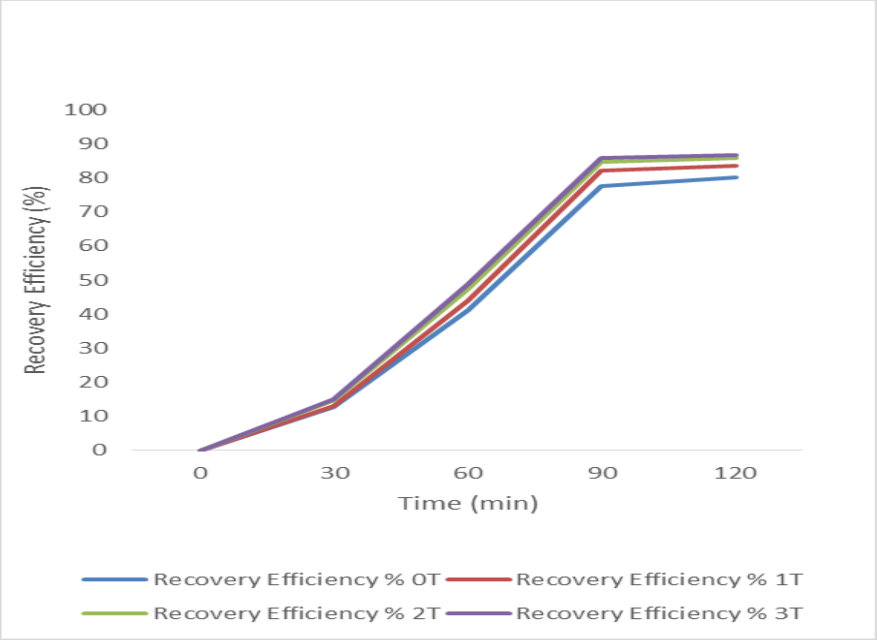

Figure 3: Recovery Efficiency of NAPL (Toluene) from Sand Box using Steam Injection only and Steam Injection with Magnetic Field (1 -3 T)

The result of steam injection only for the removal of Toluene was in agreement with the result of work done by Muhammed*et al.* (2014) with a deviation of 0.38 % and the result of recovery efficiency of steam injection with magnetic field was 4.23-7.85 % higher than the result of steam injection only. Comparing the Experimental Result on Removal of LNAPL (Toluene) from Unsaturated Zone using Steam Injection Only and Steam Injection with Magnetic Fields.

Figure 1 shows the recovery efficiency of steam injection with a magnet on the removal of non-aqueous phase liquid from an unsaturated zone at different times (30, 60, 90, and 120 minutes) for steam injection only and steam injection with magnetic field 1-3 T. From the figure 1 on treating the Toluene in the sandbox with Steam Injection only, the recovery efficiency obtained for the steaming time of 120 minutes was 80.30 % which was in lined with the work done by Mohammad *et al* (2014) with a deviation of 0.38 % while treating the contaminant (Toluene) for the same period with steam injection with the magnetic field of 1-3 T, the recovery efficiency was 83.7 %-86.60 %. This shows that the more the steaming time and magnetic field the more the recovery efficiency of the remediation process at a constant steam injection flow rate of 0.01cm^3/s. The surge in recovery efficiency of the remediation process was attributed to the decrease in the amount of contaminant (Toluene) in the sandbox after the remediation process.

The soil type may influence the process of exit of Toluene considering the porosity of the soil which allowed the persistent penetration of steam into the soil and in turn aided Toluene to vaporize and desorb from the soil particles. Sleep and McClure (2001) described volatile organic compounds as those compounds that vaporize at a temperature usually less than 100℃. The more the steam is injected into the soil in the sandbox the more the Toluene vaporize from it because of its nature of volatility and this leads to the reduction in Toluene and which eventually increases the recovery efficiency of the remediation process. It was also observed that the recovery efficiency of toluene in the sandbox when treated with steam injection with magnetic field 1-3T is higher than the one treated with steam injection only by 4.23-7.85 %. This was because the magnetic field increases the rate of evaporation of NAPLs (Toluene) by reducing the strength of Van der Waals force which results in a reduction in viscosity of Toluene and eventually increases the recovery rate of NAPL (Toluene) in the sandbox. Table 3 shows the observed and expected recovered volume of toluene for steam injection with magnetic field 1-3 T respectively. The calculated value of Chi-square (0.921) was less than the critical value (16.92) at nine degrees of freedom at a 0.05 level of significance.

Table 3: Effects of Magnetic Field on Removal of Light Non-Aqueous Phase Liquid (Toluene) from unsaturated zone using steam injection only and steam injection with magnetic field 1-3 T.

Time (minute)	**Volume Recovered at 0 T**	**Volume Recovered at 1 T**	**Volume Recovered at 2 T**	**Volume Recovered at 3 T**	**Total**
0.0	0	0	0	0	0
30.0	26.516	27.64	28.349	28.6	111.1
60.0	60.121	62.67	64.276	64.84	251.9
90.0	71.099	74.11	76.013	76.68	297.9
120.0	2.864	2.985	3.062	3.089	12
Total	160.6	167.4	171.7	173.2	672.9
X^2 Value					
P=	**0.921**				

CONCLUSIONS

The study has been able to determine the effect of magnetic field on the removal of Light Non-Aqueous Phase Liquid from unsaturated zone using steam injection only and steam injection with magnetic field 1-3 T. And also, to compare the remediation processes. The following conclusions were drawn from the research work.

The experimental result for the recovery efficiency of Light Non-Aqueous Phase Liquid (Toluene) using steam injection only at 0.01m^3/s was 80.30%. Steam injection for remediation of porous media contaminated by LNAPL is an efficient technology.

The experimental result for the recovery efficiency of light non-aqueous phase liquid (Toluene) while steam injection of 0.01m^3/s and magnetic field 1-3 T yielded 83.70-86.60%. The better recovery efficiency of toluene was obtained from Steam injection with a magnetic field than from steam injection only.

The recovery efficiency of LNAPL (Toluene) in the sandbox treated with steam injection and magnetic field 1-3 T is higher than the one treated with steam injection only by 4.23-7.85%. The study therefore concluded that steam injection removed LNAPLs (Toluene) from the unsaturated zone and magnetic field with steam injection improved the recovery rate of LNAPL

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