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Laboratory Comparison of Trench Design Options for Recovering Spilled Oil

Renuka Fernando

*Western Michigan University*

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LABORATORY COMPARISON OF TRENCH DESIGN OPTIONS FOR RECOVERING SPILLED OIL

by

Renuka Fernando

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
December 1997
Dedicated to my loving son, Chrishan
ACKNOWLEDGMENTS

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Finally I would like to thank my husband, Menik for his encouragement and help for the preparation of this thesis and a very special thank to my little son, Chrishan for his patience during the process of writing this thesis.

Renuka Fernando
LABORATORY COMPARISON OF TRENCH DESIGN OPTIONS FOR RECOVERING SPILLED OIL

Renuka Fernando, M.S.
Western Michigan University, 1997

The research goal was to improve the performance of drainage trenches used to recover spilled oil in the subsurface. Different trench designs were compared in two laboratory experiments. The first laboratory experiment clearly demonstrates that the performance of a oil recovering drainage trench could be improved by replacing the standard gravel pack sand used around the drain pipe with mixtures of teflon and sand. The effectiveness of a downgradient impermeable 'backstop' also was studied in the first experiment.

In experiment two, four trench designs were compared: perforated drain pipe; wire-wrapped horizontal well screen; perforated sheet pile; and gravel fill with a vertical drain pipe. The horizontal well screen produced the greatest volume of oil. It had far more open area than the other three designs. The results show that the larger the open area of the drainage pipe, the greater the volume of the recovered oil. This report also demonstrates the importance of considering the other available options of drainage trenches, specially in case of deep and fluctuating water tables.
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CHAPTER I

INTRODUCTION

Statement of the Problem

Growing environmental awareness over the past decade has revealed that pollution of the subsurface is present and much more extensive than previously thought. Increased urbanization and the luxuries of modern civilization have created a need for large quantities of hazardous substances to be stored in close proximity to both ground-water resources and population centers. Petroleum in several forms, one of the more common hazardous substances, is kept in underground storage tanks at gas stations and industries at a wide variety of locations. When a leak develops in a tank, or more often the lines to a tank, detecting the leak can be very difficult. Although recent legislation in some states requires removal of a great number of leaky underground storage tanks, spills into the subsurface continue to occur. As a result of petroleum spills ground-water resources are often lost and public health and safety may become at risk.

Spilled petroleum, often gasoline, poses an environmental threat under any or all of following four conditions.
1. The liquid petroleum (free product) flows above the water table causing migration from the spill location to adjacent areas through the subsurface.

2. Liquid product exists but is immobile, trapped in the pores at residual saturation both above and below the water table. This occurs where the degree of saturation is insufficient for mobility and where water-table fluctuations have severed the free product flow paths and the product has become trapped in the pores by the surrounding water.

3. Volatilization of the product releases combustible vapors into the unsaturated zone, damaging vegetation and causing vapor accumulation in basements.

4. Some of the product dissolves in water, contaminating the ground-water with compounds such as benzene, toluene and xylene. These dissolved compounds flow with the ground-water in the saturated zone.

Rapid removal of the free product will reduce the extent of the contamination in all the conditions mentioned above. Early detection of a leak or spill is probably the most important factor in minimizing the volume of free product released. After identifying a release, appropriate steps should be taken to cut off the source such as evacuation of the storage vessel or terminating the flow for a pipeline. Upon delineation of the extent of free product contamination, appropriate wells or drainage
trenches need to be installed for monitoring and removal of the free product. The efficiency of these oil recovery wells or drainage trenches is very important for the rapid removal of the free product.

This research work was conducted in order to find out the possibility of improving the efficiency of drainage trenches currently used in the oil recovery industry. Therefore this report is focused exclusively on oil recovery drainage trenches.

Purpose of the Study

Drainage trenches or subsurface drains have been used in civil engineering for many years. They are used as a water table control measure in many disciplines of civil engineering, such as irrigation and highway engineering.

Recent developments show that there is a possibility of using drainage trenches to clean up accumulations of fluids immiscible in ground water. This method proved to be promising compared to traditional oil recovery wells since it has more contact area with the oil layer than an ordinary vertical well screen.

The same principles used to design a drainage trench as a water table control measure are applicable to design a drainage trench used as a clean up measure to recover immiscible fluids. The design of drainage trench includes layout and arrangement of the drain lines, selection of
filter packing material, selection of a suitable outlet, determination of length and size of drains, and selection of good quality materials of adequate strength.

There are many factors to be considered in designing each of these parameters. Among them are water table elevation and its seasonal fluctuations, thickness and location of the oil lenses, regional groundwater flow direction and velocity, hydraulic conductivity distribution in the aquifer, avoidance of obstacles, availability of funds and so on.

In this research project two laboratory model studies were carried out in order to study the possibility of improving trench design for recovering spilled hydrocarbons.

**Introduction to Laboratory Model # 1**

The first model was designed to find out the possibility of improving the filter pack design currently used in the industry and to find out the effectiveness of using a downgradient impermeable 'back stop'.

When mobile immiscible fluids have been located in the subsurface, wells or drainage trenches are often installed to try to remove them. These are usually surrounded by coarse granular materials to admit fluids without resistance while filtering out finer aquifer particles that could ruin a pump or clog a well screen. This coarse material called gravel pack (filter pack), increases the effective diameter of the well and allows
the use of a screen with wider slots which increases yield. Since fuel spills spread laterally near the top of the water-saturated capillary fringe, the use of coarse gravel pack with its low capillary fringe provides a depression in which fuel or hydrocarbon should accumulate. Additionally, hydrocarbons accumulate preferentially in coarse lenses below the capillary fringe. That is, a gravel pack serves as a man-made coarse lens.

The standard gravel pack material recommended for water wells and currently used in oil recovery wells and trenches is a uniform, well-rounded quartz sand which is 4 to 6 times coarser than the aquifer material in the finest layer contacting the well screen or drain pipe. It would be surprising if the criteria which lead to good water well gravel pack also provided the best gravel pack for petroleum recovery wells and trenches. Petroleum recovery wells in aquifers are more complicated than water production wells because there are two fluid phases to consider. In fact, Mansur and Fouse (1984) found that oil would not enter a recovery well with a very coarse gravel pack, although it was pooled just outside the gravel pack. In a more detailed study Johnson et al. (1989) documented the accumulation of free product outside well screens for long periods before it entered the monitoring wells. This was even true in pea gravel, where capillary forces which prevent movement of product into the well are minimal. All those studies suggest the need to redesign the currently used filter pack design for oil recovery wells and drainage trenches.
Previous studies on improvement in the filter pack design of granular filters used in oil recovery wells show that a screen packed with the 50-50 volumetric mixture of Teflon (PTFE) chips and sand allows oil to enter faster and in greater quantities than a traditional standard (uniform, well rounded quartz sand which is 4-6 times coarser than the aquifer material) gravel pack material.

The first experiment was conducted in order to find out the applicability of these previous results to drainage trenches. In other words, the performance of traditional filter pack material in a drainage trench was tested against the performance of a 50 - 50 volumetric mixture of PTFE chips and sand. The filter pack performance was evaluated based upon the amount of oil recovered by each of the drainage trenches.

We also wanted to find out the effectiveness of using a downgradient impermeable 'back stop'. The downgradient impermeable back stops are used in ground water cleanup plans to prevent contamination from spreading downgradient. To study the effectiveness of using a back stop we installed an aluminum sheet at the downgradient side of the drainage trench. This was removed halfway through the experiment; then downgradient movement of contaminants was monitored.
The objectives of the second model were to compare the performance of different configurations of drainage trenches and to compare the performance of traditional flexible type plastic tubing against the slotted PVC tubing customarily used for wells.

The selected configurations of drainage trenches were: (1) Traditional perforated flexible type plastic tubing (Diameter 4 inches or 10 cm), (2) Wire-wrapped PVC tubing (Diameter 4 inches / 10 cm), (3) A drainage trench supported by two long sheet piles, and (4) A subsurface sand drain (Width 4 inches or 10 cm).

Pipe drains used as drainage trenches include concrete and clay tile, corrugated plastic tubing, corrugated steel pipes, slotted PVC tubing, wire-wrapped PVC or steel tubing, perforated flexible plastic tubing or other perforated conduit. Traditionally, perforated flexible plastic tubing is used in oil recovery drainage trenches. This tubing is preferred to others due to its low cost, light weight, easiness in handling and workability. But in case of a deep water table elevation it would be necessary to have a pipe with a higher structural strength to withstand high soil loads. Both corrugated steel pipes and slotted PVC tubing could withstand higher soil loads than traditional perforated flexible type tubing. The wire-wrapped PVC tubing was selected in this research project to check for its performance against
the traditional perforated flexible tubing and to allow us to determine the
effects of using drain pipes with more open area than the industry
standard. The corrugated flexible plastic drain pipe used widely today has
relatively little open area, perhaps 1 to 2%. We used Johnson wire­
wrapped PVC well screen, 4-inch (10 cm) diameter with a 20 slot (0.020
inch) opening between wires. This has an open area of 12 to 13%.

Sheet piles are used in civil engineering for many purposes. They
are used as a temporary earth retaining structure in deep excavations. It is
reasonable to assume that they could be used to recover spilled
hydrocarbons once they are perforated. If this becomes a success they
would be capable of handling deeper water tables, and/or ones with greater
fluctuations than other available subsurface drainage pipes. So, we
decided to check the performance of a drainage trench supported by
perforated sheet piles against the other available methods.

Finally a subsurface sand drain was selected to check its
performance against others because of its low material and installation
cost. A sand drain in a continuous granular pathway for fluid movement,
like an esker or utility trench backfill, which is more permeable than the
surrounding aquifer materials. These drains are also capable of handling
soil loads that would crush drain pipes. A vertical drain pipe was installed
in the sand drain to remove accumulated oil.
The performance of each of the drainage trenches was evaluated based upon the amount of oil recovered by each trench.
CHAPTER II

METHODS AND MATERIALS

Experimental Method of Laboratory Model # 1

The experiment was conducted (Figure 2) in a 135 liter glass tank (0.5 m tall by 0.9 m long by 0.3 m thick). Red Flint sand (effective size 0.35-0.45 mm) was selected as the aquifer material. The unsifted teflon was blended with an equal volume of # 30 Red Flint sand, to use as a filter pack material. The standard gravel pack material was made by blending 30% of # 20, 60% of # 30 and 10% of 0.6 - 0.65 mm Red Flint sand. This mixture satisfies the requirement of being 4-6 times coarser than the aquifer material. Table 1 and Figure 1 show that both the filter pack designs have almost the same grain size distribution.

The tank which represents an aquifer with impermeable boundaries was filled with dry sand (0.35-0.45 mm Red Flint) which was poured through a long tube. The drainage trenches, sumps and the aluminum sheets (Figure 2) were installed in the tank at predetermined depths. While continuing to fill the tank with aquifer material, the coarser granular materials (filter pack materials) were also poured into the respective gaps between the drainage trenches and aluminum sheets. All
the aluminum sheets, except the one used as a downgradient impermeable 'back stop', were pulled out when the tank was full. The tank was filled with water and then the drainage trenches were drained until an unsaturated zone appeared. A peristaltic pump was installed so that it pumped from one end of the tank (past trenches) to spill into an open trough on top of the sand at the opposite end. By doing so, a constant sloping water table was established in the tank.

Table 1

The Grain Size Distribution of Different Sands Used in the Experiment

<table>
<thead>
<tr>
<th>Sieve #</th>
<th>Slot opening (inch.)</th>
<th>Cumulative Percent retained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.35-.45</td>
<td>#20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.131</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.093</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0.065</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0.046</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0.033</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>0.023</td>
<td>35.3</td>
</tr>
<tr>
<td>35</td>
<td>0.020</td>
<td>73.8</td>
</tr>
<tr>
<td>50</td>
<td>0.012</td>
<td>99.6</td>
</tr>
</tbody>
</table>
When the water table stabilized at the target depth, blue-dyed kerosene was added into the open trough at the end of the tank. After kerosene thickness equilibrated in the tank, kerosene was pumped out simultaneously from each of the drainage trenches using two different peristaltic pumps. Sometimes more kerosene or water was added or removed to bring product thicknesses and elevations to their previous values. Since the drainage trenches, aquifer material, kerosene levels and
Figure 2. The Detailed Design of the Laboratory Model #1 (Not to Scale).
rate of pumping were all the same, the different oil recovery volumes were due to differences in the gravel packs. This procedure was repeated to check for the consistency of results.

We also wanted to check the results under the condition of continuous (rather than intermittent) pumping since that better represents an actual cleanup plan. The oil-recovering peristaltic pumps ran for about 24 hours. Then the recovered oil and water volumes were measured. Once again the procedure was repeated for few more days to check for the consistency of the results.

We propose that the gravel pack which has the highest oil recovery rates in these simple laboratory experiments will also work best in the field at imbibing product from contaminated aquifers.

Finally, the downgradient impermeable 'back stop' was removed from the tank and the oil recovery procedure was repeated for few more days, while monitoring any downgradient movement of contaminants.

Experimental Method of Laboratory Model #2

Once again the experiment was conducted in a 135 liter glass tank (0.9m × 0.5m × 0.3m). The tank was divided into two parts using an impermeable glass sheet (Figure 3 and 4). A perforated plastic sheet, which represents a perforated sheet piling, was installed in the tank as shown in
Figure 3. This sheet was supported from collapsing against the aquarium wall by using two vertical struts.

Both sides of the tank were filled simultaneously with dry sand, (35-45, Red Flint), which represents the aquifer material, until it reached a target depth. The slotted PVC well screen and the perforated flexible plastic pipe along with their oil recovery access tubes were placed in one half of the tank. The ends of the pipes were caulked on to both the aquarium end wall and the glass sheet divider to prevent their movement and to keep the pipes free of aquifer material.

A thin aluminum sheet was installed as shown in Figure 2, to separate the sand drain compartment from the aquifer material during filling. This sheet was pulled out when the tank was full. While filling one side with aquifer material, the sand drain was also filled with # 20 Red Flint sand. A PVC tube (diameter 1 inch) with a perforated well screen about 3 inches long was installed at the middle of the sand drain to recover accumulated hydrocarbons.

The tank was filled with water and the drainage trenches were drained until an unsaturated zone appeared. After a few days it was noted that the water table had stabilized at a level just above the bottom of the pipes. At this point about 2 liters of hydrocarbon (blue dyed kerosene) was poured into each side of the tank (total of 4 liters), using a trough. The
a. Cross-Sectional View of the Tank

b. Plan View of the Tank

Figure 3. The Detailed Design of the Laboratory Model # 2 (Not to Scale).
tank was left alone until the oil layers stabilized, while noticing the apparent thickness of the oil layers at each of the drainage trenches.

After the oil layer stabilized the slotted PVC well screen was emptied using a peristaltic pump to recover hydrocarbon. The recovered oil and water volumes were measured separately and poured back into the
same side of the tank. On the same day the sand drain which was at the opposite side of the flexible drainage tube was also drained out using the same procedure. The recovered hydrocarbon and water were poured back into the same side of the tank as the sand drain and then the tank was left to allow the water and oil levels to stabilize.

The following day the oil and water recovery of the other two drains were also measured using the same procedure. Before draining the drainage trenches, the apparent thickness of hydrocarbon in each drainage trench was also noted. These experiments were repeated to verify the results by varying the order in which the drains were pumped. The results of each round of testing consistently agreed. Since the aquifer material, water table elevation and the amount of oil in each side of the drain were all the same the different oil recovery volumes were due to the differences in the drain configurations. We propose that the drain configuration which has the highest product recovery rates in these simple laboratory experiments would also work best at imbibing product from contaminated aquifers.
CHAPTER III

RESULTS AND DISCUSSION

Previous Experimental Results by Other Authors on Improvement of Filter Packs for Oil Recovery Wells

Hampton and Heuvelhorst (1990) and Hampton et al. (1991) reported the results of several gravel pack comparison studies. According to their studies, a uniform coarse gravel pack typical of water wells performed better than finer or nonuniform gravel packs. However, in other experiments they found that all gravel packs chemically treated to be water repellent outperformed the typical water well gravel packs. These experiments also showed that hydrophobic gravel packs performed better when they are closer to the aquifer grain size (that is only 2.5 times coarser). Product levels recovered much more quickly in a well with a uniform treated gravel pack about half the grain size of other coarser treated gravel pack. In an experiment focusing upon grain shape and roughness, they have found these attributes were not well correlated with gravel pack performance due to more influential confounding factors, such as subtle size and mineralogical composition differences between the packs.
Hampton et. al. (1991) analysed water in contact with chemically treated gravel packs for hazardous chemicals. Low ppb (parts per billion) levels of ethylbenzene and xylene were found, suggesting that different treatment chemicals and application methods should be tested. Therefore their subsequent experiments were focused on inherently hydrophobic materials.

The innocuous hydrophobic material is teflon (PTFE), which is widely accepted in the environmental community as being chemically inert. Two PTFE filter packs were compared with packs of untreated sand and with the same sand treated. One of the PTFE packs was sieved to remove the finest fraction so it would have the same grain size distribution as the sand packs. The PTFE packs outperformed by far the two sand packs. The finer PTFE pack was the most oil permeable, probably because its greater capillary attraction for kerosene led to a higher kerosene saturation. Even though the pores were smaller and the saturated permeability would be lower in the finer PTFE, its oil permeability was higher than that of the coarse PTFE at their respective oil saturations.

Thomas R. Barrett has performed laboratory tests to determine the optimum mixture of sand and teflon in gravel packs. PTFE chips were mixed with untreated sand of a similar grain size distribution. The selected percentages of PTFE chips in the four gravel packs were: 100%, 75%, 50% and 25%. The test results showed that there is a large performance
difference between 50% and 25% teflon chips, much greater than differences between 50% and 100% PTFE. Given the limited availability of PTFE chips and the possible high cost, the best mixed ratio appeared to be around 50% PTFE. This also facilitates filter packing submerged screens, because the denser sand helps push the angular PTFE chips through water-air surface, where surface tension can make the PTFE float even though it is denser than water.

Barrett and others have done another experiment to find out the possibility of using other hydrophobic filter materials than PTFE chips. They have compared three recycled plastics with an oil absorbent bentonite called Oil Dri. Polypropylene, which was recycled from auto parts manufacturing, performed slightly better than PTFE and much better than the other recycled plastic and Oil Dri. However, since the polypropylene used in this experiments was less dense than water, it limits the use of this material to prepacked screens which can be pushed below the water table. (Many plastics contain talc or other fillers which can make them denser than water.)

They concluded that the greatest performance improvements could be achieved by replacing standard gravel pack sand with finer (half as large as standard gravel pack) mixtures of teflon and sand. This conclusion was based on the data obtained from oil recovery wells.
Experimental Results on Improvement of Filter Packs for Oil Recovery Drainage Trenches

We wanted to study the applicability of those previous experimental results on improvement of filter packs used in oil recovery wells to oil recovery drainage trenches. We decided to use the same grain size distribution of both the standard filter pack and teflon filter pack. This way we could rule out any performance difference due to size variations.

The results of our experiments are given in Tables 2 and 3. Figures 5 and 6 compare the performance of teflon gravel pack against the standard gravel packs. Figure 5 illustrates that a teflon filter pack outperformed standard gravel pack under the condition of intermittent pumping. According to Table 3 and Figure 6, a teflon filter pack works even better under the condition of continuous pumping. Since this condition is more realistic under an actual cleanup plan we can expect the teflon pack to work even better in the field at imbibing product from contaminated aquifers.

The impermeable back stop which was used in model # 1 was removed half way through the experiment in order to find out the effectiveness of using it. But in this experiment we did not find any down gradient contaminants even after removing the back stop. That means, the down gradient back stop was not that useful under the conditions we
have created in our model. The contrast in pore size between the relatively coarse back fill and the finer aquifer material prevented free product migration out of the back fill. Dissolved product migration would not be prevented with or without a partially penetrating back stop.

Table 2

The Oil Recovery Test Results of Standard and Teflon Gravel Packs Under Intermittent Pumping Condition

<table>
<thead>
<tr>
<th>Date</th>
<th>Oil recovery (mL)</th>
<th>50/50 mixture of # 30, Red Flint and unsifted teflon</th>
<th>Mixture of 30% # 20 and 60% # 30 and 10% 60-.65, of Red Flint sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/12/96</td>
<td>200</td>
<td></td>
<td>147</td>
</tr>
<tr>
<td>3/13/96</td>
<td>173</td>
<td></td>
<td>145</td>
</tr>
<tr>
<td>3/14/96</td>
<td>170</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>3/15/96</td>
<td>191</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>3/18/96</td>
<td>150</td>
<td></td>
<td>141</td>
</tr>
</tbody>
</table>

Table 2 shows the results of experiment # 1 for intermittent pumping condition (Duration of pumping is about 5 minutes and rest period is about 24 hours).
Table 3

The Oil Recovery Test Results of Standard and Teflon Gravel Packs for Continuous Pumping

<table>
<thead>
<tr>
<th>Date</th>
<th>Oil recovery (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50/50 mixture of</td>
</tr>
<tr>
<td></td>
<td>#30, Red Flint</td>
</tr>
<tr>
<td></td>
<td>and unsifted teflon</td>
</tr>
<tr>
<td></td>
<td>and 60% #30</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3/19/96</td>
<td>155</td>
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<tr>
<td>3/20/96</td>
<td>57</td>
</tr>
<tr>
<td>3/22/96</td>
<td>190</td>
</tr>
<tr>
<td>3/23/96</td>
<td>81</td>
</tr>
<tr>
<td>3/25/96</td>
<td>30</td>
</tr>
<tr>
<td>3/26/96</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3 shows the results of experiment #1 for continuous pumping condition (Duration of pumping is about 24 hours).

Experimental Results on Effectiveness of Down Gradient Impermeable 'Back Stop'

In real field applications, such a partially penetrating wall at the downgradient edge of a trench could be helpful or harmful. It could be
helpful if the product removal system in a trench failed, allowing product to accumulate in the trench and possibly into the aquifer downgradient from the trench. The back stop is intended to prevent product movement into the aquifers. A partially penetrating cutoff wall could be harmful if it penetrated too deep, thereby isolating the trench area from the overall groundwater flow pattern. If that happens the trench fails to remove product from the contaminated aquifer because the flow system stagnates.
Experimental Results of the Model # 2

The objective of this experiment was to compare the performance of different types of drainage trenches. The results of the experiment are given in Tables 4 and 5 and Figures 7 and 8. According to Table 5 the results of each round of testing consistently agreed. All the other configurations of drainage trenches outperformed the perforated flexible
plastic drain pipe, which is currently the standard used in the oil recovery industry. The highest volume of oil was recovered from wire-wrapped PVC well screen used instead of flexible drain pipe. The sand drain which has several advantages over the perforated flexible plastic tubing performed slightly better. The performance of a drainage trench supported by sheet piling was also quite promising.

Implications for Future Studies

The results of our experiment gave us some implications for future studies. The previous experimental results on improvement of filter pack materials used in oil recovery wells show that the best performance improvement could be achieved by replacing standard filter pack material by finer (1/2 as large as) mixtures of teflon and sand. Now that we know those experimental results are also applicable to oil recovery drainage trenches we could check the performance improvement we could achieve by replacing the teflon filter pack material used in our experiment by a finer mixture of teflon and sand.

According to our laboratory results the downgradient impermeable back stop used in our experiment was not that useful under the conditions we have created in our model. But we know that under different circumstances a down gradient back stop could be extremely useful.
Table 4

Apparent Thickness of Oil Layers at Different Drain Locations

<table>
<thead>
<tr>
<th>Date</th>
<th>Apparent thickness of the oil layer (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slotted PVC well screen</td>
</tr>
<tr>
<td>06/03/96</td>
<td>3.3</td>
</tr>
<tr>
<td>06/05/96</td>
<td>2.5</td>
</tr>
<tr>
<td>06/06/96</td>
<td>2.4</td>
</tr>
<tr>
<td>06/09/96</td>
<td>2.5</td>
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<tr>
<td>06/10/96</td>
<td>2.8</td>
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<tr>
<td>06/12/96</td>
<td>2.7</td>
</tr>
<tr>
<td>Average thickness</td>
<td>2.7</td>
</tr>
<tr>
<td>% Average deviation</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 4 shows the results of experiment # 2 for intermittent pumping condition (Duration of pumping is about 5 minutes, rest period is about 24 hours). Therefore it is worthwhile to study the effectiveness of having a downgradient back stop under different ground water flow velocities and different oil recovery rates.
Table 5

The Oil Recovery Volumes of Selected Drain Configurations

<table>
<thead>
<tr>
<th>Date</th>
<th>Slotted PVC well screen</th>
<th>Perforated flexible drain pipe</th>
<th>Sand drain</th>
<th>Perforated sheet piling</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/03/96</td>
<td>1403</td>
<td>*</td>
<td>685</td>
<td>*</td>
</tr>
<tr>
<td>06/05/96</td>
<td>*</td>
<td>505</td>
<td>*</td>
<td>815</td>
</tr>
<tr>
<td>06/06/96</td>
<td>1420</td>
<td>*</td>
<td>720</td>
<td>*</td>
</tr>
<tr>
<td>06/09/96</td>
<td>*</td>
<td>510</td>
<td>*</td>
<td>790</td>
</tr>
<tr>
<td>06/10/96</td>
<td>1400</td>
<td>*</td>
<td>580</td>
<td>*</td>
</tr>
<tr>
<td>06/12/96</td>
<td>*</td>
<td>605</td>
<td>*</td>
<td>710</td>
</tr>
<tr>
<td>Average</td>
<td>1408</td>
<td>540</td>
<td>662</td>
<td>772</td>
</tr>
<tr>
<td>% Average</td>
<td>0.6</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

* The drains were not tested on these days.

We could also combine the results of both the experiments to check the possibility of having a better performance improvement by replacing the filling material used in our sand drain of model # 2 by a finer mixture of teflon and sand.
Figure 7. Average Apparent Thickness at Different Drain Locations.

The efficiency of the drainage trench should not be the only deciding criteria on selecting best suitable drainage configuration. One of the most important factors among the others is the cost involved with material, installation and maintenance. Therefore it is worthwhile to do a cost analysis for the different configurations of drainage trenches before making a final decision.
Figure 8. Recovered Volume of Oil of Different Drain Configuration.
CHAPTER IV

CONCLUSIONS

Model # 1

The experimental results of model # 1 confirm that previous experiments on improvement of filter packs used in oil recovery wells are also applicable to oil recovery drainage trenches. That is, the teflon filter pack outperformed the standard gravel pack under both conditions of intermittent and continuous pumping.

The use of hydrophobic filter packs provides two distinct advantages over using conventional filter packs. In locations where produced thicknesses are not great the product may not acquire enough pressure (positive) to move laterally into the larger pores of a filter pack or a well (gravity drainage).

Hydrophilic (conventional) filter packs do not exert a significant capillary (suction) pressure on the product and product may never enter the well. Hydrophobic filter packs are wetted by the product and therefore exert a capillary (suction) pressure on the product drawing it to the well.

The other significant advantage of using hydrophobic materials as filter packs is the increase in the rate of production from hydrocarbon recovery drainage trenches.
Mixing the hydrophobic filter pack with hydrophilic sand provides many advantages over exclusively hydrophobic filter pack. The most practical advantage is that hydrophobic materials are expensive and standard filter-pack (sand) is inexpensive. Mixing the materials provides enhanced hydrocarbon production at a reduced cost relative to a 100% hydrophobic filter-pack. Use of sand also ensures a more uniform placement of the hydrophobic material. Mixing also avoids sorting of material during emplacement of filter-pack due to the lower density of teflon (2.05 gm/cc).

Another benefit of mixing the material is the ability to shift the grain size distribution. As the size of the hydrophobic material may not be readily changed, mixing it with an appropriate standard sand may shift the grain size distribution curve to match the design criteria for a given application.

The results of part 2 model # 1 (effectiveness of downgradient impermeable backstop) concludes that further investigation is required to find out the effectiveness of downgradient backstop under different groundwater flow velocities and oil recovery rates.

Model # 2

The results of model # 2 show that the open area of the drainage pipe plays an important role in the effectiveness of a drainage trench. The
results clearly indicate that the drainage trench made out of Johnson wire-wrapped PVC well screen (open area 12 to 13 %) outperformed the drainage trench made out of flexible plastic drain pipe (open area 2 %). That is, the larger the open area, the greater the volume of recovered oil.

The results also show that it is worthwhile to consider the other available options of drainage trenches especially in cases of deep and fluctuating water table conditions.
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