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Filtration properties of geotextiles for heavy oil wells

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ABSTRACT: Sand production is a persistent problem in production wells located in heavy oil sand formations. With the recent development of horizontal wells in these formations, removal of the sand plugging the wells is an expensive and time consuming workover procedure. An initial research project has been conducted to evaluate needle-punched nonwoven geotextiles as filters to reduce sand flow into ambient temperature heavy oil wells. The physical, mechanical, environmental and filtration properties of selected nonwoven geotextiles were considered. This paper is limited to analyzing the measured permeability and filtration properties.

1 INTRODUCTION

Many oil wells drilled in unconsolidated heavy oil formations have problems with sand particles from the formation flowing into the well along with the oil. In some cases, when the quantity of flowing sand is significantly large, the efficiency and profitability of the well is drastically decreased. Production of the well must be shut down and the sand plugging the well removed in an expensive and time consuming "workover" procedure. Currently, sand flow in heavy oil production wells is controlled with filters such as wire wrapped screens, slotted liners, gravel and sand packs or stainless steel wool compressed between layers of a steel mesh. The stainless steel wool is similar to nonwoven geotextiles. All of the conventional techniques have had only limited success and stainless steel wool is an expensive alternative for wells at in situ temperature.

An integral design approach which included the adaptation of currently developed filter design criteria and large scale simulation tests was adopted for the evaluation of three geotextiles as filters. Simulation tests carried out in this study included normal and in plane permeability tests, filtration tests, chemical – environmental durability tests and wettability testing. However, only the results for the permeability testing and filtration testing will be discussed in this paper.

2 HEAVY OIL FORMATION SANDS

Two heavy oil formation sands, McMurray Formation sand and Lloydminister sand were used in the testing program. Their grain size distributions are shown in Figure 1. They are both very uniform sands with coefficients of uniformity less than 2 which is typical of heavy oil formations. The McMurray Formation sand is relatively clean with 2% fines (<0.074 mm) while the Lloydminister sand is finer and contains 18% fine material.

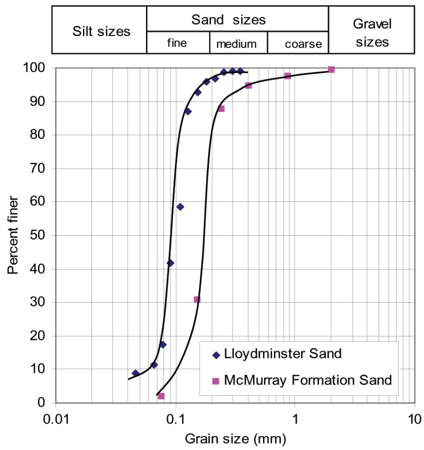

Figure 1. Grain size distribution of test sands.

3 HEAVY OIL FORMATION FLUIDS

The fluids in a heavy oil formation are the crude oil, interstitial water and gas. The heavy oil used in the testing program was a sweet, crude oil from the Lloydminister formation. The most significant property of the oil is the sensitivity of the viscosity to temperature. A decrease of about 4°C doubles the viscosity. As the flow rate varies as the viscosity, this temperature decrease would cut the flow in half. For this reason, during the tests involving oil, the temperature of the oil was carefully monitored and the tests were carried out in a temperature controlled laboratory.

4 SELECTION OF GEOTEXTILES

A total of twenty seven manufacturers in Canada, USA and Europe were contacted for product information. Only eight manufacturers produced geotextiles which fulfilled the permeability and retention criteria for filters in this application. The properties of these geotextiles were ranked according to the four categories: 1. filtration and separation efficiency; 2. flow capacity; 3. durability; and 4. stress/strain/strength behaviour. The four performance criteria are listed in the order of importance for this application, although filtration and flow capacity were ranked equally. Required minimum values for individual properties within each capacity were determined according to permeability and retention criteria for geotextile filters.

Following preliminary testing, three nonwoven geotextiles were chosen for detailed testing. Some of the properties for these geotextiles are given in Table 1. Geotextiles B and C have a needle-punched construction. Geotextile A is constructed with a scrim attached to one side of a needle-punched web. It is this construction which gives Geotextile A high strength and low elongation in the wide width strength test.

Table 1. Properties of Geotextiles.

Geotextile Properties	A	B	C
Mass (g/m^2)	800	678	322
Thickness (mm)	2.66	5.84	3.02
Porosity (%)	78	92	86
O_{95} (mm)	0.110	0.150	0.110
Puncture Strength (N)	–	1090	489
Burst Strength (MPa)	>6.33	3.32	2.79
Tear Strength (N)	6400	1112	356
Grab Strength (N)	–	2224	890
Wide Width Strength	200 kN/m	–	–
Elongation (%)	12	90	70
Polymer	polyester	polyester	polypropylene

5 HIGH CONFINING STRESS PERMEABILITY TESTS

The high confining stress permeability tests were performed on the geotextiles alone. Several layers of a geotextile with an initial total thickness of about 10 mm were used as construction of the well filters would use several layers of precompressed fabrics. The objectives of these tests were to study the influences of confining stress, hydraulic gradient and time of fabric immersion in the permeant on the permeability of the geotextiles with water and heavy oil as permeants.

The permeabilities were measured under six confining stresses: 1.3, 100, 500, 1300, 100U and 1.3U kPa. The letter U refers to an unloading test. The maximum confining stress of 1300 kPa was chosen as this is the approximate horizontal effective stress of a loose sand on a well casing at a depth of 1000 m in a typical heavy oil formation. Measurements of flow rate, temperature and pressure readings were taken for hydraulic gradients of 0.1, 0.25, 0.5, 1, 2.5, 5, 7.5 and 10 for each confining pressure when water was the permeant. When oil was the permeant, additional hydraulic gradients of 20 and 40 were also used and viscosity was also measured.

The system layout for the heavy oil as permeant tests is shown in Figure 2. As the volume of oil flowing through the geotextiles was small, the outflow was measured by weighing. The very high hydraulic gradients were used so larger volumes of oil would pass through the geotextiles. Temperature, density and viscosity of the heavy oil were measured at intervals throughout the test. The system layout for the water permeability tests was similar and deaired water was used as the permeant.

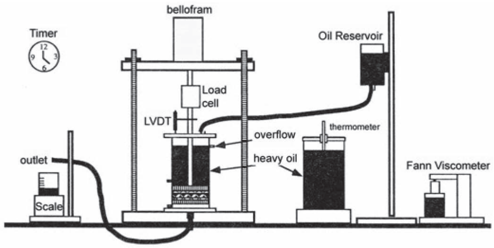

Figure 2. System layout for permeability testing with heavy oil as permeant.

The hydraulic gradient adjacent to a heavy oil well may be up to 0.5 under steady state conditions. In non steady state conditions, the in situ gradients may be as high as 5 when surge flows occur or when the permeability of the filter medium is compromised by clogging. As surge flows are not of long duration, the permeability at hydraulic gradients up to 0.5 are considered appropriate for design of well filters that do not suffer extensive clogging.

When considering the permeability of porous media, such as the sand or the geotextile, the parameter used should be only a function of the porous media not of the permeant used. For this reason, absolute permeability is used rather than hydraulic conductivity to define the permeability of the sand and the permeability of the geotextile. Absolute permeability comparisons allow the effect of the permeant on the structure of a geotextile to be evaluated. As most geotextile fibers are hydrophobic and oleophilic, the absolute permeability may vary depending on whether water or oil is the permeant.

The absolute permeability, (K) can be converted to the hydraulic conductivity (k) using the following conversion factors.

For water at 20°C:

$\mu_w = 1$ mPa · s; $\rho_w = 1000$ kg/m^3; g ~ 10 m/s^2;

K_w in μm^2 and k_w in cm/s

$$k_w = 1 \times 10^{-3}\ K_w \tag{1}$$

For Lloydminister heavy oil at 20°C: $\mu_o = 12{,}000$ mPa · s and $\rho_o = 968$ kg/m^3

$$k_o = 8.1 \times 10^{-8} K_o \tag{2}$$

Table 2 contains the results of the permeability tests at a hydraulic gradient of 0.25. There was little change in absolute permeability at higher hydraulic gradients except during the initial confining stress of 1.3 kPa in the heavy oil tests. During this initial flow period, the absolute permeability increased by 50%, 24% and 95% in Geotextiles A, B and C respectively. These increases may have been caused by the oil requiring time for flow stabilization.

Table 2. Absolute permeability of geotextiles.

Geotextile	Confining Stress kPa	Thickness mm	Water Absolute Permeability μm^2	Oil Absolute Permeability μm^2
A	1.3	9.2	213	247
(4 layers)	100	5.1	43	56
	500	3.4	23	29
	1300	2.8	15	22
	100U	3.5	23	24
	1.3U	4.3	36	39
B	1.3	9.6	175	160
(2 layers)	100	7.4	65	73
	500	6.0	27	52
	1300	5.4	20	39
	100U	6.0	23	52
	1.3U	6.9	32	68
C	1.3	8.3	290	122
(3 layers)	100	4.0	75	36
	500	2.7	33	10
	1300	2.3	22	6
	100U	2.8	28	6
	1.3U	3.9	65	10

Polyester Geotextile A is somewhat more permeable to oil than to water over its entire range of thicknesses and polyester Geotextile B is considerably more permeable to oil. Geotextile C, however, which is polypropylene is significantly more permeable to water. Chemical durability testing showed that the polypropylene fibers swell when immersed in the Lloydminister heavy oil. Swelling fibers would reduce pore sizes and result in lower permeability.

The McMurray formation sand and the Lloydminister sand have measured absolute permeabilities of 6.5 and 1.0 μm^2 respectively. All three geotextiles in their most compressed state had absolute permeabilities larger than the sands except for the permeability of Geotextile C to oil. If blinding or clogging of the geotextiles does not occur, they would not impede the flow of water or oil.

The permittivity of the geotextiles can be calculated using equations 1 and 2 and the thickness of the geotextiles. At a compressive stress of 1300 kPa, the permittivity to water for Geotextiles A, B and C is 0.054, 0.037 and 0.095 s^{-1}, respectively. Similarly, for oil, the permittivity is 6.4, 5.8 and 2.1 × 10^{-6} s^{-1}, respectively. From these comparisons, the geotextiles are fairly similar in permittivity although Geotextile C is lower for oil flow.

6 HIGH CONFINING STRESS FILTRATION TESTING

A large scale permeameter system was designed and constructed (Figure 3) in order to model the filtration conditions which exist in heavy oil wells. The permeameter cell is 130 mm in diameter and can accommodate a soil specimen up to 200 mm in height. The system can apply confining stresses up to 1300 kPa on the sand and geotextile, vary hydraulic gradients and flow velocities and accommodate water or oil as the permeant. A large number of manometer ports allow pore pressures in the sand and in the geotextile to be monitored. The equipment can produce a maximum differential fluid head of 400 kPa across the sand-filter system.

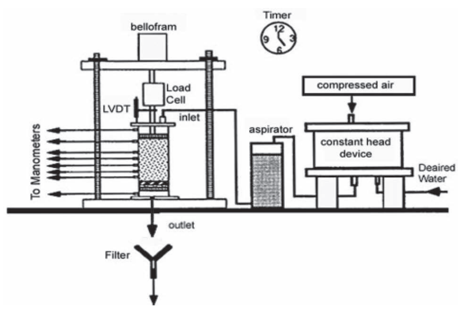

Figure 3. Schematic system setup for high confining stress sand-geotextile filtration testing.

The objectives of the filtration testing program were to understand the interaction of the sand-geotextile systems under high confining stresses and high hydraulic gradients, to determine the permeability of the geotextile fabrics under these conditions and to determine the clogging and blinding potential of the sand-geotextile systems. Multiple layers of a geotextile were tested with the McMurray Formation sands and water as the permeant under hydraulic gradients of 0.5, 1.0, 2.5, 5.0, 7.5 and 10. A confining stress of 500 kPa was chosen for these tests as 70% of the geotextiles' compression had occurred by this stress level (Table 2). Each test lasted for about 18 days as 2 to 4 days were used for each hydraulic gradient to ensure that steady state filtration conditions were reached.

Figure 4 shows the heads in the sand and geotextile for a test. The head loss at the top of the sample was caused by fines migration and blinding at the top of the sample. The difference in head between two pore pressure ports has been used to calculate the absolute permeability of the porous media between these ports (Figure 5). Small changes in measured head resulted in some scatter of the results. The sand over most of its height has an absolute permeability slightly larger than its previous measured permeability of 6.5 μm^2. The sand permeability, just above the geotextile is lower, varying form 5 to 7 μm^2 which indicates some blinding at the top of the geotextile. The absolute permeability of the geotextile varies from 4 to 7 μm^2. This is considerably lower than the absolute permeability of 23 μm^2 measured in the permeability test at a confining stress of 500 kPa (Table 2) and indicates clogging of the geotextile.

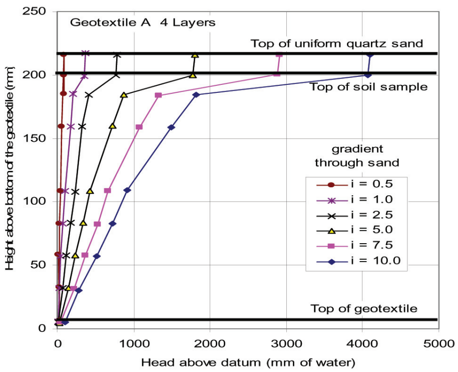

Figure 4. Head loss in the sand – geotextile system for Geotextile A in high confining stress filtration test.

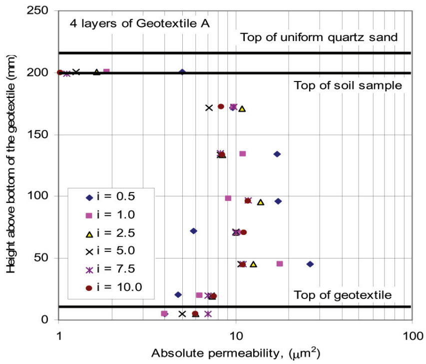

Figure 5. Absolute permeability of the sand-geotextile system for Geotextile A in high confining stress filtration test.

Geotextiles B and C showed similar clogging, both with absolute permeabilities of approximately 6 μm^2 compared to 27 and 33 μm^2 respectively in the permeability tests.

7 CONCLUSIONS

The permeability and filtration properties of three needle-punched nonwoven geotextiles were determined under high confining stresses to examine their potential to be used as filters for heavy oil wells. Polyester fabrics were more permeable to heavy oil than to water while the polypropylene fabric was considerably more permeable to water than to oil. All geotextiles showed clogging in filtration tests with the uniform, fine sand from a heavy oil formation. The clogged fabrics, however, retained a permeability similar to that of the formation sand and therefore would not significantly reduce the flow into the well.

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