

DEVELOPMENT OF COMMUNICATION PATHS WITHIN A TAR SAND BED

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INTRODUCTION

One of the first steps to understanding in situ recovery of bitumen from the Athabasca tar sands is to fully appreciate the fact that, under reservoir conditions, the bitumen in the tar sands cannot be made to flow under the influence of any reasonable or practical pressure gradient. This fact forces a change in the traditional concepts of secondary oil field recovery and necessitates the introduction of new approaches. These approaches often require that much of our traditional thinking regarding secondary oil recovery be changed, and in some cases reversed.

If, because of its extremely high viscosity the bitumen cannot be moved ahead of a front, then, it must either be changed and then moved by a front, or it must be nibbled at from one side and the products carried away to a production point. The first approach has apparently been successfully applied by Pan American Petroleum Co. in their operations at Gregoire Lake (1). There, the tar-bearing McMurray formation is first heated to about 200 °F and then the preheated bitumen is driven to production wells by a combination of forward combustion and water flooding (COFCAW process). The second approach has been demonstrated by laboratory and field work carried out by the Shell Oil Company during the period 1956-62 (2, 3, 4, 5, 6, 7, 8, 9, 10, 11). This approach, which will be referred to as the Shell process, involves three main steps:

- (a) Drilling to the base of the McMurray formation a series of production and injection wells in some suitable pattern.
These wells are cased such that injection or production of fluids takes place only at or near the bottom of the tar-sand interval.
- (b) Achieving initial interwell communications between production and injection wells by horizontal hydraulic fracturing.
The initial communications are then developed to the point of accepting large volumes of steam without sealing. This is done by emulsifying the bitumen along the fracture path through the action of critical concentrations of sodium hydroxide and heat, forming a low-viscosity oil-in-water (o/w) emulsion which is then transported to the production well.
- (c) Injection of large quantities of steam to the well-developed communications path to achieve principal bitumen production.
This steam moves up the formation, heating and emulsifying the cold bitumen above it, and is itself condensed. The condensate and emulsified bitumen form an oil-in-water emulsion which trickles down the formation and is driven to the production wells by pressure of the injected steam.

Of these three steps, the most difficult to achieve in the field is the enlargement of interwell communications paths, particularly the development of a cold fracture path into a hot communications path which will accept large quantities of steam without sealing. At formation temperatures (~40 °F for 200-300 feet of overburden), the bitumen binds the formation sand together to form an almost brittle solid mass which fractures when subjected to a parting pressure. However, as the temperature increases, the formation softens and becomes an amorphous solid; still further heating causes the bitumen to flow as a viscous heavy crude (6 to 7 A Pt°). If steam is applied directly to a fracture path,

propped or otherwise, the formation first softens and tends to slump into the fracture and may result in sealing. Further heating causes the unemulsified bitumen to flow. This unemulsified bitumen is moved further along the fracture path where it contacts colder areas of the formation and cools to form a highly-viscous impermeable plug. This problem was recognized by Shell (6) during their experimental field work. Their solution (6, 9, 10) was to inject steam at a pressure above the pressure required to support the overburden (fracture propping pressure) but below the pressure which would propagate a vertical fracture. It was found that with this approach the injection pressure gradually rose, and from time to time it became necessary to replace the steam injection with injection of a hot solution of a critical concentration of sodium hydroxide. By repeating this cycle over a period of time, Shell were apparently able to develop hot communications paths which would accept large quantities of steam without sealing.

In pilot plant and field experiments in which we have been associated, this procedure has been less than satisfactory. Our experience has been that communications could not be maintained when using injection pressures below the vertical-fracture pressure. Use of pressures above the vertical-fracture pressure resulted in surface fractures and/or loss of fluids to high-lying relatively-permeable zones. This problem is particularly acute in areas where overburden is relatively light (e. g., 200-300 feet). To overcome these difficulties, it was suggested that initial emulsification should take place at formation temperature (i. e., cold emulsification) and that heating of the communications path take place at a rate such that all the bitumen entering the path would be emulsified. By this method the propped communications path would never become plugged with unemulsified bitumen and a low pressure process could be developed for obtaining a hot communications path through a tar sand bed.

RESULTS AND DISCUSSION

Sodium hydroxide and other bases are ineffective in promoting the formation of oil-in-water emulsions below 60 °F. Their ability to promote emulsion formation gradually increases with temperature but does not become really effective until 90 °F or more. Athabasca tar sands, however, show considerable softening at 60 °F and will begin to weep bitumen at 90 °F. It was, therefore, important to find emulsifying agents which were more effective at the lower temperatures. It was found that a combination of sodium hydroxide and a nonionic surfactant (TX45, an octylphenoxy polyethylene oxyethanol in which the octyl group is branched and which contains about 5 moles of ethylene oxide) was effective in promoting low-temperature emulsification of the bitumen. Optimum concentrations of this surfactant and sodium hydroxide as a function of temperature are given in Table I. Using these concentrations and a gradual heating of the injected fluids, good hot communications were developed over a 100-foot interval near the base of the McMurray formation in a period of about 6 weeks. Pressures were maintained below the fracture-propping pressure. Stable emulsions were achieved, ranging in concentration from 3% for the cold emulsification up to 17% for the warmer emulsification.

Despite these encouraging results, it was of interest to find other agents which would cause more rapid emulsification at formation temperatures, which would be cheaper, and which would produce more concentrated cold-temperature emulsions. It was believed that the sodium hydroxide reacted with the acidic functional groups in the bitumen to form organic salts, and that these organic salts then acted as surface-active agents which caused emulsification of the bitumen. It was, therefore, hoped that the amount of these surface-active agents could be increased by oxidizing part of the bitumen to form more acidic groups. Several oxidizing agents were tried; ozone was the most successful.

Ozone (6% in oxygen) was passed for 2 days through a loosely-packed vertical column of Athabasca tar sand and the column eluted with water. The tar sand changed markedly in appearance, revealing many white sand grains, while the eluted material was a dark-brown color and foamed when lightly shaken. Evaporation of the eluent to dryness

yielded a material which analyzed: C, 45.3%; H, 5.5%; O, 40.6%; N, 1.4%; S, 7.2%. When stirred with water, under a microscope, the sand of the ozonized tar sands separated to form white water-wet grains, while the bitumen formed globules in the water phase. Similarly treated unozonized sands produced no noticeable change.

A 3-foot by 2-inch horizontal tube was then tightly packed with bitumen and a narrow path of 20/40-mesh Ottawa sand was placed at the bottom. Ozone (6% in oxygen) was passed through the tube for 2.5 days. The exit gas contained ~1% ozone. A 50-gram sample of the tar sand was extracted with water (500 ml) to yield a dark-brown solution which foamed when lightly shaken. A surface-tension curve versus concentration for this sample is given in Figure 1. Evaporation of the solution to dryness yielded 0.237 grams of material: C, 28.7%; H, 3.7%; O, 51.3%; N, 1.3%; S, 8.2%. A second similar 50-gram sample of tar sand was extracted with water and the resulting solution was neutralized to pH 7 with 0.1 N sodium hydroxide (41.4 cc required).

In sampling the tube, samples were taken from 4 equal-length sections along the tube, designated A, B, C and D starting from the ozone-inlet end. The bitumen was extracted from each of these samples and from a sample of unozonized tar sand (designated sample O) using toluene reflux. Elemental analyses of these bitumen samples and their molecular weights are in Table II. Standard S.A.R.A. analyses were conducted on each of the samples; thus dividing each of them into asphaltenes, resin I, resin II, saturates, and aromatics. Results of this analysis are given in Table III. Elemental analyses and molecular weights were carried out on each of the subsamples. Results are in Table IV. These analyses show that in general ozonolysis was limited to the asphaltene and resin fractions of the bitumen and resulted in a lower molecular weight and a decrease in the sulfur content. The saturates and aromatics were little affected; however, these fractions are of low molecular weight and viscosity. Thus, ozonolysis is attacking that part of the bitumen which is of highest molecular weight and viscosity and converting it into water-soluble or more hydrophylic material.

A second 3-foot by 2-inch horizontal tube was packed, and ozone (6% in oxygen) was passed through for 7 days (80% of the ozone was still being absorbed by the cell after 7 days). Distilled water (20 ml/hour) and ozone (6% in oxygen) were then passed through the tube for 6 days. Examination of the cell disclosed areas around the sand path and extending out around the surface of the cell which had been largely depleted of bitumen, leaving clean white sand. The initial effluent from the cell (first day's effluent after commencing water injection) was an amber color (pH 1.35) and contained about 6% water-soluble organic material. This material exhibited a surface-tension curve as given in Figure 2. The surface tension of the neutralized material as a function of concentration is also given in Figure 2. Approximately 9.5% of the bitumen originally in the cell was removed during the 6 days of water injection.

The test cell was reassembled and a solution of 0.2% sodium hydroxide was passed through the cell for 14 days (20 cc/hour). An additional 8.7% of the bitumen in the cell was removed during this period. Most of the cell effluent which was collected during the first 6 days of water injection was neutralized to pH 7, and this material was recycled through the cell 6 times. This procedure removed a further 2% of the bitumen from the cell, for a total bitumen recovery of 20.2%. When the cell was opened and the tar sand examined it became evident that the whole cross section of the tube had been affected to some extent by the combination of ozonolysis, distilled-water flush, sodium hydroxide-solution flush, and neutralized-effluent recycle, but in some areas the bitumen had been extensively removed, especially near the original sand path and extending around the glass surface.

These results indicate that ozone readily reacts with bitumen at formation temperatures (40 °F) to form water-soluble highly-oxygenated materials which have surface-active properties in both acid form and as neutralized salts. Passing of water through an ozonized formation of tar sands results in removal of part of the bitumen; in some areas this removal is extensive while in other areas it is minor. When 0.2% sodium hydroxide

solution is passed through such a bed, more bitumen is removed and the highly-depleted areas are extended. It is our intention to in future test a pilot-plant simulation of field conditions for this process to determine whether the combination of ozonolysis, water flush, 0.2% sodium hydroxide flush, and gradual heating can be used for the low-pressure development of a cold propped fracture into a hot communications path which will accept steam without sealing.

CONCLUSIONS

It has been demonstrated in the field and in the laboratory that by using a combination of nonionic surfactant and base (sodium hydroxide), and using pressures substantially below the propping pressure, a cold propped fracture path can be developed into a zone that will accept large volumes of steam without sealing. It has been further demonstrated in the laboratory that ozone will readily react with bitumen at formation temperatures, to form highly-oxygenated water-soluble surface-active agents. Therefore, it is anticipated that ozone together with water and/or dilute basic solutions can be used at low pressures to expand a propped fracture path into a hot communications path which will accept steam without sealing.

REFERENCES

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- (7) T. M. Doscher, et. al, Oil Recovery from Tar Sands, U.S. patent 2,882,973, issued April 21, 1959.
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TABLE I

Optimum Concentrations of TX45 and NaOH
as a Function of Temperature

Temperature (°F)	TX45 Concentration (%)	NaOH Concentration (%)
40 - 60	0.4	0.2
60 - 70	0.2	0.2
70 - 80	0.2	0.15
80 - 100	0.1	0.15
100 - 120	0.1	0.1
120 - 200	nil	0.1
>200	nil	nil

TABLE II

Analysis of Unozonized and Partly-Ozonozed Bitumen

Sample	Carbon (%)	Hydrogen (%)	Oxygen (%)	Sulfur (%)	Nitrogen (%)	Ash (%)	Molecular Weight
O	81.82	10.37	0.78	5.17	1.23	-	1448
A	81.63	9.98	2.18	4.02	1.28	1.11	668
B	81.71	10.62	2.25	3.97	0.88	0.92	625
C	81.66	10.67	2.37	3.95	0.71	-	634
D	81.44	10.55	2.25	4.30	1.05	1.05	641

TABLE III

S.A.R.A. Analysis of Unozonized and Partly-Ozonized Bitumen

Sample	Asphaltenes (%)	Resins I (%)	Resins II (%)	Saturates (%)	Aromatics (%)
O	21.8	42.3	4.2	15.9	14.3
A	24.7	43.9	4.3	13.3	10.6
B	25.3	42.1	4.0	18.4	8.8
C	25.8	39.5	2.5	20.0	9.0
D	24.5	44.8	2.6	18.7	6.7

TABLE IV

Analysis of Unozone and Partly-Ozone Bitumens
After S. A. R. A. Analysis

Sample	Carbon (%)	Hydrogen (%)	Oxygen (%)	Sulfur (%)	Nitrogen (%)	Ash (%)	Molecular Weight
Asphaltenes:							
O	78.84	7.83	3.03	8.48	1.34	0.64	4797
A	77.60	7.90	4.11	7.88	1.81	0.79	4722
B	76.86	7.74	4.88	7.68	0.82	1.88	-
C	76.87	7.65	4.90	7.75	0.90	1.80	-
D	77.38	7.88	4.44	7.71	0.89	1.53	3493
Resins I:							
O	76.89	9.72	3.97	5.48	0.73	1.01	727
A	77.27	9.48	4.23	4.77	0.77	1.31	731
B	78.53	9.73	6.05	4.65	0.25	-	563
C	78.71	9.63	6.05	4.71	0.26	-	590
D	78.67	9.73	5.97	4.64	0.17	-	617
Resins II:							
O	76.31	9.44	4.44	2.30	0.30	2.17	-
A	77.47	9.89	6.03	1.17	1.17	1.15	-
B	78.99	10.50	7.84	1.96	0.18	-	-
C	79.37	9.53	9.07	1.62	0.21	-	-
D	79.17	10.63	8.00	1.71	0.19	-	-
Saturates:							
O	85.81	13.31	0.17	0.28	0.45	-	454
A	85.92	13.34	0.14	0.27	0.41	-	433
B	86.31	13.03	0.08	0.26	0.18	-	397
C	86.57	12.88	0.22	0.36	0.21	-	395
D	86.28	13.10	0.15	0.25	0.13	-	412
Aromatics:							
O	85.13	10.33	0.27	3.63	0.59	-	398
A	84.94	10.25	0.19	3.75	0.64	-	397
B	85.33	10.61	0.45	3.13	0.15	-	390
C	85.30	10.45	0.48	-	0.16	-	373
D	85.29	10.48	0.50	3.22	0.26	-	379

FIGURE 1 - Surface Tension of Water Soluble Fraction of Ozonized Bitumen

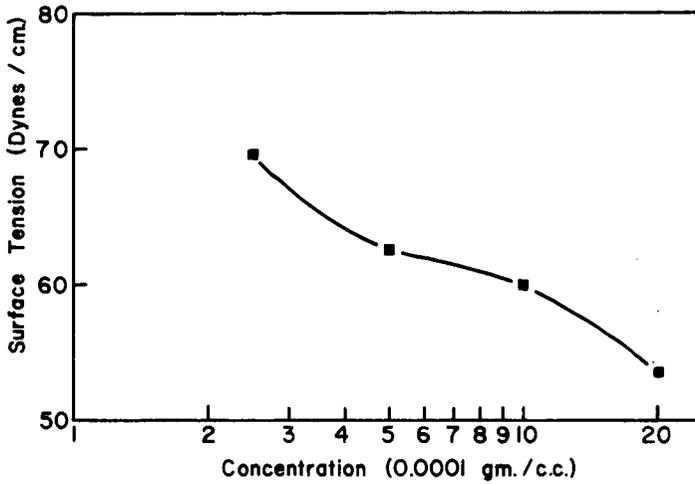


FIGURE 2 - Surface Tension of Water Soluble Ozonized Bitumen

