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A comparison of fluidized bed pyrolysis of oil sand from Utah, USA, and Alberta, Canada

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Abstract−Characterization and thermal pyrolysis of oil sand was conducted. The experiment was performed on Circle Cliffs, Utah, U.S.A. and the results were compared with the data from Alberta, Canada. The reaction character identified by TGA was dual mode of vaporization of light hydrocarbon and thermal cracking of high molecular hydrocarbon. The pyrolysis experiment was performed in a 2 kg/h capacity fluidized bed externally heated by electricity. The process variables investigated were a temperature range of 723-923 K, fluidization gas velocity of 1.5-2 times of the minimum fluidization velocity, solid retention time of 15-30 minutes, and average particle size of 435 microns. The results of TGA and elemental analysis of bitumen provided necessary information regarding maximum liquid yield from the pyrolysis prior to pyrolysis experiment. The oil yield was maximum at 823 K. The yield of liquid was not exceeding the weight percent of maltenes in original bitumen. The optimum reaction condition should be fast vaporization of light hydrocarbon and minimizing thermal cracking of high molecular hydrocarbon. To maximize the liquid yield, fast heating and vaporization of oil sand bitumen and then the rapid removal of the vaporized product from the heating zone is recommended, i.e., operation in a fluidized bed reactor.

Keywords: Oil Sand, Circle Cliffs, Pyrolysis, Bitumen

INTRODUCTION

Oil sand, which contains 4-15% of heavy oil called bitumen, is distributed globally. It is valuable hydrocarbon source that has been neglected as primary energy source due to easy access to conventional fossil fuel such as oil and gas. The global deposit of the oil sand is considered as much as 1.7-2.5 trillion barrels [1,2]. However, even in stable supply the global political and economic issues has caused frequent fluctuation of oil prices and raised public suspicion on energy security. The search for an alternative fossil fuel has long been a pressing issue in science and engineering as well as politics and business fields.

In the United States, oil sands mines are located in the eastern part of Utah, Wyoming, and Colorado. The oil in place is estimated between 12-19 billion barrels. The oil sand deposit in Circle Cliffs, Utah, is a small county in the western USA, is known to have 590 million barrels of oil in-place and additional 1.14 billion barrels projected [1]. The oil sand reservoir in Circle Cliffs is buried in shallow beds within 50 m in depth.

Canadian Alberta oil sand deposit is the world's third largest oil sand field, after Saudi Arabia and Venezuela, covering 141 thousand square kilometers, containing 178 billion barrels. The world largest and most active mining has been in business in Canada since 1980's [2].

In-situ mining is a direct recovery method of bitumen oil which is applicable to most oil sand deposit over the world. But it is not applicable in a shallow bed deposit like the Circle Cliffs deposit. There are several above-ground upgrading technologies available for oil sand recovery of shallow bed deposit, including water, solvent extraction [3,4] and thermal processing. Among them the thermal processing of oil sand shows a few advantages over solvent or steam extraction. Thermal retorting requires no water in the process and oftentimes it can supply heat by burning a part of carbonaceous residue from the pyrolysis [5]. Thermal processing such as pyrolysis can utilize reaction mechanism of oil retorting and chain breaking together for higher oil yield. Thus, by pyrolysis, light hydrocarbon in bitumen molecule can be retorted and heavy hydrocarbon can be fractionized to lighter molecular liquid and gas. Thermal processing can be also an easy solution since it can upgrade liquid product during pyrolysis and can reduce a product's viscosity without adding diluent. It makes it easier to transport the product through pipelines.

The main issue of this work is to show the feasibility of oil sand pyrolysis as an alternative measure for current oil sand processing such as solvent extraction. Then a tool is proposed for expectation of liquid yield prior to the pyrolysis. In this study, physical characteristics of oil sand of Circle Cliffs origin were investigated. Then, a thermogravimetric study was performed to understand the characteristics of thermal reaction. Finally, a pyrolysis test in lab scale fluidized bed reactor with inert gas condition was performed to investigate the feasibility of pyrolysis reaction. The results were analyzed together and compared with previous research result of oil sand from Albert origin. Both physical analysis of bitumen and data of TGA provided a useful measure to expect liquid yield from flu-

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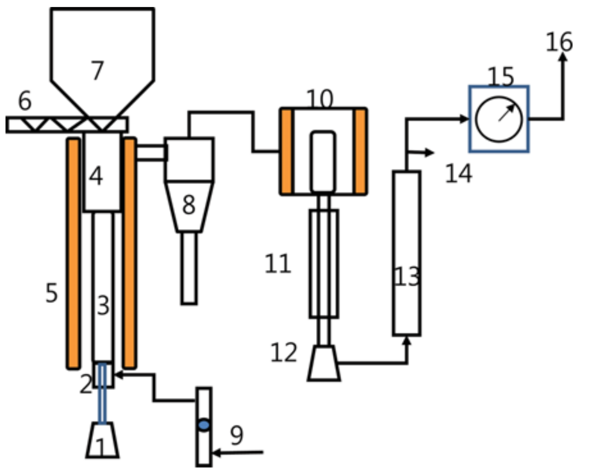

Fig. 1. Diagram of oil sand pyrolysis unit.

1. Carbonaceous residue collector
2. Gas distributor box
3. Reactor
4. Freeboard
5. Electric heater
6. Screw feeder
7. Feed hopper
8. Cyclone
9. Fluidizing gas line
10. Metal filter
11. Water jacketed condenser
12. Liquid collector flask
13. Fabric filter packed bed
14. Gas sampling port
15. Wet test meter
16. To flare

idized bed pyrolysis.

EXPERIMENTAL

The pyrolysis experiments were performed in a vertical tube reactor with bubbling fluidized bed mode. Diagram of reactor is presented in Fig. 1 [6].

Inside diameter of reactor (3) was 0.075 m and the height was 1.7 m. The top of the reactor is connected to free board section with inner diameter of 0.15 m. Sand is filled at the bottom of the reactor forming the reaction bed. Bed material can be removed down to bottom residue collector (1). The oil sand is fed from the hopper (7) to the top of the bed by screw feeder (6). Pyrolysis product, i.e., oil mist and gas, were entrained by fluidizing gas to cyclone (8) and fines mixed with product oil and gas are removed. Fines are again removed by porous metal filter (10) next to cyclone. Liquid is collected at condenser (11) and poured into receiving flask (12). The condenser is cooled by tap water passing outside of the collecting tube. Gas and fine mist are passed through fabric filter (13), where fine mist is collected. Noncondensing gas is passed out of fabric filter, gas samples are collected (14), quantity of gas is measured (15) by wet test meter, and the remaining is vented to flare (16) to burn hydrocarbon gas. Reaction temperature was maintained by indirect heating of electric heater at preset temperature. Also, cyclone, filter are also kept at the temperature of 723 K not to proceed thermal reaction but to prevent oil condensing inside the units. Feeding was continuous with rate of 1-2 kg/h oil sand. Bed weight was kept 0.5 kg; thus, the solid retention time was arranged as 15-30 minutes. Bed material used was carbonated silica sand from previous experiment with −0.3 mm diameter. Fluidization is monitored at room temperature with glass tube with same inside diameter and length. Monitored fluidization was initiated at the gas velocity around 0.07-0.09 m/s. Nitrogen gas was used as fluidizing gas with flow rate of 140 liters/h,; around 0.15 m/s it is about 1.5-2 times of minimum fluidized bed velocity [7].

The reaction was performed with the following procedure.

Reactor was heated to the preset temperature by electric heater indirectly with bed material filled and N_2 gas flowed.

Maintaining the temperature at the set value the oil sand feed material was fed to the reactor with fixed flow rate for predetermined operation hours. Solid retention time, i.e., staying time of oil sand in the bed, is controlled by feed rate variation, i.e., θ=F/w.

Where,

Θ; Solid retention time, min

F; Feed rate, kg/min

w; Initial bed inventory, kg

The main reaction products, liquid, was collected to liquid collector flask (12). Liquid was filtered off carbonaceous particles and water then sampled for further analysis. The yield of liquid was sum of the liquid weight in liquid collector and mist collector. To condense oil mist fast, the condenser was water cooled by tap water. Carbonaceous residue, coke like product, was collected at the receiver at the bottom of the reactor during the pyrolysis reaction (1). To prevent combustion of carbonaceous residue while collecting, the collector bottle was kept air tight and nitrogen gas was purged into the bottle. Noncondensing gas was sampled at the gas sampling port (14) by gas tight syringes, then analyzed in the gas chromatograph.

After the reaction was over the heater was off and reactor was cooled to room temperature. Liquid and carbonaceous residue were analyzed after sample was collected to room temperature.

RESULTS AND DISCUSSION

The physical characteristic of oil sand from Circle Cliffs is rock formation, whereas that of Alberta is bitumen-coated sand grains. The oil sand from Circle cliffs was crushed to Tyler mesh 25-45 (0.7-0.3 mm) with average particle size of 435 microns before feeding to the pyrolysis reactor. Oil sand from Alberta was bitumen-coated sand grains and could be fed without further treatment. To

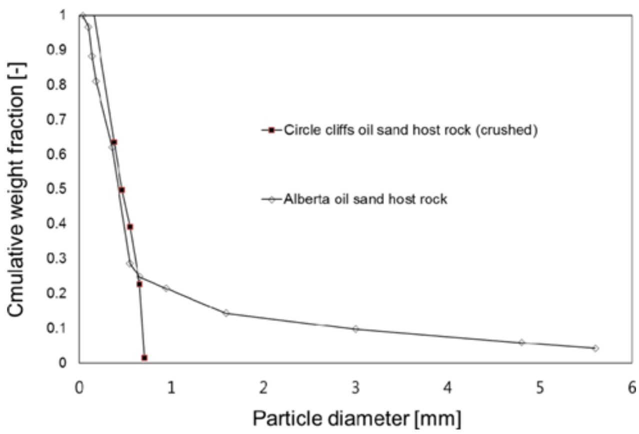

Fig. 2. Particle size distribution of oil sand host rock.

Table 1. Properties of Oil sand bitumen and pyrolysis oil

Item	Unit	Circle Cliffs		Alberta	
Bitumen content	Wt%	3.59-3.61		9.54-13.52	
Moisture	Wt%	0.3		-	
Gravity, API	-	14.3		18.5	
Elemental analysis	Wt%	Bitumen	Py. oil @823 K	Bitumen	Py. oil @773 K
C		83.3	84.0	86.1	84.5
H		9.9	8.4	6.2	11.2
N		0.4	0.4	0.3	0.2
S		4.9	5.2	5.3	4.1
O		1.5	2.0	2.1	-
Heavy metal	ppm				
Ni		59	3	72	26.3
V		164	4	203	10.6
Asphaltenes*		46.1	-	12.8	-

*Pentane insoluble fraction of bitumen

compare grain size distribution, the bitumen in Alberta oil sand was extracted and bitumen-free sand grains were sieved. The extraction was made by Soxhlet extraction method [8] using toluene as solvent; and the method is explained in the authors' previous works [6,9]. The comparison of particle size distribution for both oil san host rock is presented in Fig. 2, and both sand particle size distribution matches up to 80 weight percent.

Table 1 presents the properties of both Circle Cliffs and Alberta oil sand bitumen. The bitumen saturation of Circle Cliffs oil of 3.6% sand is relatively lean compared to that of Alberta sand of 11%, the Circle Cliffs oil sand has sand-like brown color with dryness and does not show oil on the sand grain surface, while Alberta oil sand is rich of bitumen and has the color of tar blackness with stickiness. However, both sands released a rich tar smell in storage. API gravity of Circle Cliffs bitumen is 14.3, whereas that of Alberta is 18.5, showing the density of former is higher and stiffer. Elemental analysis of both bitumen does not show significant difference showing similar chemical composition of components. The content of asphaltenes [8] in Circle Cliffs bitumen is 46%, almost four-times higher than that of Alberta of 12.8% implying less content of oily compound in the bitumen. Vanadium and nickels both are abundant in bitumen due to its biological origin [2,9], and will be toxic to catalysts in refinery process, are reduced drastically after pyrolysis.

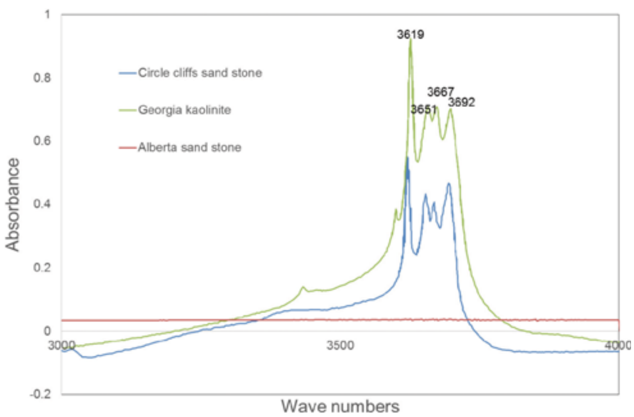

Fig. 3. Infrared spectra of oil sand host rock.

Fig. 3 shows the Infrared spectra of bitumen free oil sand host rock of Circle Cliffs and Alberta oil sand. Strong hydroxyl groups are observed at the wave number of 3,692, 3,667, 3,651 and 3,619 cm^{-1}, indicating four types of hydroxyl groups (-OH) in the Circle Cliffs oil sand host rock, probably clay like material [10]. The comparison spectrum of Georgia Kaolinite is presented as well. Circle Cliffs oil sand host rock has significant portion of kaolinite like -OH bonds that can decompose and release water during pyrolysis.

Mineral analysis of oil sand host rock by atomic absorption method is presented in Table 2. Both oil sand host rock are silica based mineral mixtures, but that of Circle Cliffs oil sand host rock has more alumina content and it might compose kaolinite type compounds as shown in Fig. 3. Since bitumen content in the Circle Cliffs host rock is one-third that of the Alberta, the mineral content per unit weight of bitumen is thus three-times more per unit weight of bitumen. All these can have side effects on pyrolysis reaction and cause difficulties in analysis [10].

Fig. 4 Shows the comparison of Circle cliffs bitumen with that of Alberta in the temperature range of 303 to 473 K. The Circle Cliffs bitumen shows almost ten-times higher viscosity than that of Alberta, indicating the Circle bitumen is more aged and holds

Table 2. Mineral analysis of oil sand host rock

	Circle Cliffs	Alberta	Possible compound
Fe	1.2	2.39	Fe_2O_3, $FeCO_3$
Ca	8.3	2.66	$CaCO_3$
K	0.94	0.05	$KAlSi_3O_8$
Al	3.66	2.28	$Al_2Si_3(OH)_4$
As	0.014	-	-
Si	85.9	88.26	-
P	-	2.64	-

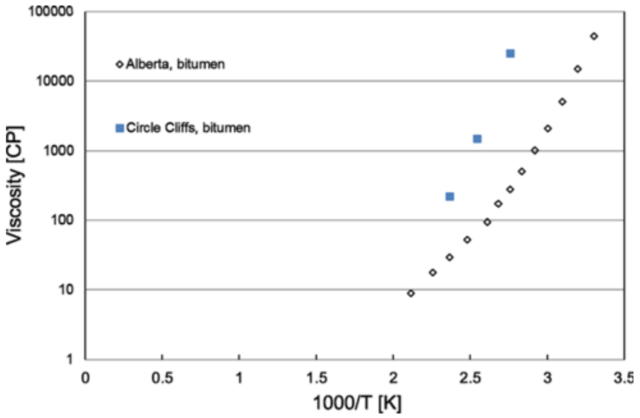

Fig. 4. Variation of viscosity of bitumen by temperature.

less of its light hydrocarbon fractions than that of Alberta.

The kinetic profile of Circle Cliffs bitumen on Circle Cliffs tar sand host mineral was studied with thermogravimetric Analyzer. To avoid mineral decomposition and its effect on thermogram, bitumen was separated from its host rock, the bitumen-free host rock was calcined 823 K for 15 hours, and the bitumen was re-saturated to host rock.

Ten weight percent of bitumen was saturated to the Circle Cliffs oil sand host rock that pores can absorb all the bitumen inside only revealing brownish colored sand surface.

Fig. 5 presents thermogram of ten percent Circle Cliffs bitumen re-saturated Circle Cliffs tar sand, non-isothermal scanning mode with the heating rate of 5, 10, 20 K/min.

Fig. 6 presents instantaneous conversion rate (DTG) of those samples. The reaction mode was dual and divided at 50 percent conversion and around 600 K. The low temperature region between 350 K and 650 K seems to be vaporization of light hydrocarbon and above 600 to 840 K seems decomposition of reaction of high molecular hydrocarbon [13-16].

The kinetic analysis was done from the data in Figs. 5, and 6 with previously presented method [6,11]. Table 3 presents the activation energy [17] of the conversion reaction of re-saturated Circle Cliffs bitumen, and it was compared with the analysis data of original Alberta oil sand. In the lower temperature reaction up 600 K the activation energy was 10-14 KJ/mol and considered to be vaporization of light hydrocarbon such as middle distillates in simulated distillation. At the higher temperature region from 600 K to 800 K it was 107 to 119 KJ/mol. In this range the decomposition reaction of higher molecular hydrocarbon such as heavy ends in simulated distillation is considered to occur [11]. The reaction mode was clearly separated by two. The values of both activation energy at vaporization and decomposition are lower than those of

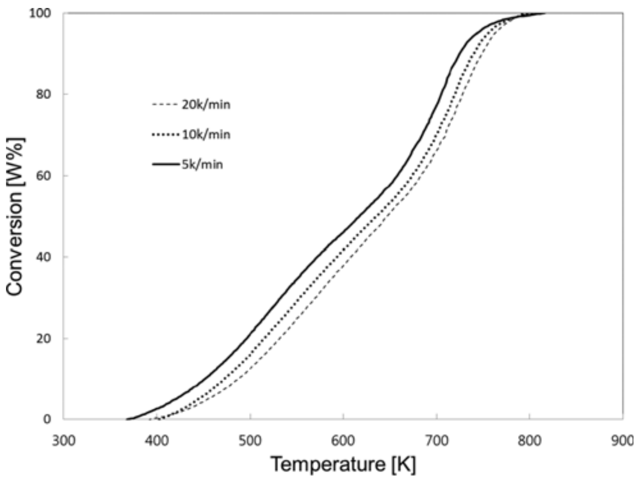

Fig. 5. Thermogram of Circle Cliffs re-saturated oil sand.

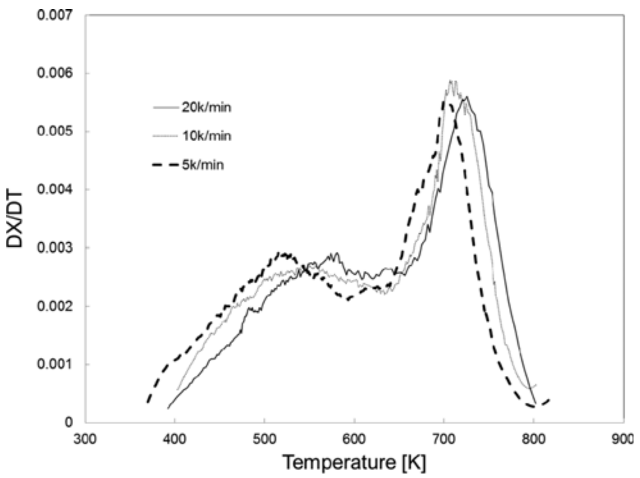

Fig. 6. Differential Thermogram of re-saturated Circle Cliffs oil sand.

Table 3. Kinetic parameters of pyrolysis of Circle Cliff and Alberta oil sands with varying heating rate in TGA [11]

Heating rate, K/min	Retorting, E, kJ/mol		Carbonaceous decomposition E, KJ/mol	
	Circle Cliffs	Alberta	Circle Cliffs	Alberta
5	10	-	119	-
10	11	20	116	246
20	14	22	107	242
40	-	23	-	146

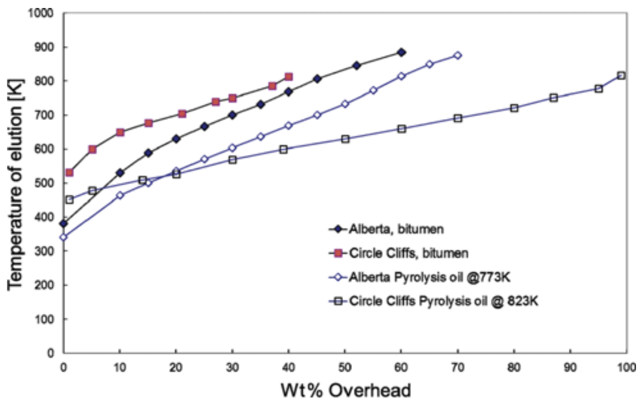

Fig. 7. Simulated distillation curves of bitumen and Fluidized bed pyrolysis product.

Table 4. Distillation cut of bitumen and pyrolysis oil from fluidized bed pyrolysis

	Circle Cliffs						Alberta		
	Bitumen	Py @723	Py @798	Py @823	Py @863	Py @873	Bitumen	Py	
Retention time, min		22	22	22	22	22		30	30
Reaction temo., K		723	798	823	863	873		733	773
−473 K	0	0.9	4.7	0.2	2.0	6.4	6.0	7.9	10.1
473-600 K	6.1	31.3	46.8	44.8	36.1	30.5	11.2	18.6	23.2
600-840 K	32.5	57.3	48.5	55.0	54.2	54.2	25.1	53.5	37.0
Residue	61.4	10.5	-	-	7.5	20.9	44.7	20	29.7

Alberta oil sand, but this might be due to re-saturation of bitumen to calcined oil sand host rock, i.e., remaining trace solvent in Circle Cliffs bitumen could weaken the bond of bitumen to host rock.

Fig. 7 presents the simulated distillation comparison of bitumen and pyrolysis products of Circle Cliffs and Alberta oil sand [6,11]. Simulated distillation curves of two bitumen samples in the figure show the difference in compositions of components between two bitumen properties. Almost 50% of Alberta bitumen was distilled by the temperature of 800 K. On the other hand, only about 40% of Circle Cliffs bitumen was distilled by the same temperature. The Circle Cliffs bitumen has higher content of heavy hydrocarbons such as asphaltenes and lower content in volatile fractions than that of Alberta. This determines the yield of the simulated distillations.

The liquid product of fluidized bed pyrolysis, both Circle Cliffs and Alberta oil sand at various reaction temperature are presented in Table 4. The result shows improved mobility of liquid products, i.e., increased fraction of volatiles by pyrolysis, compared to its original bitumen. The eluted fraction of bitumen up to 473 K is equivalent to naphtha cut in petroleum refinery process [14]. That is equivalent to the boiling point of n-undecane (C11). The naphtha cut of the Circle Cliffs oil sand bitumen is about 0% and that of pyrolysis oil is 0.2-4.7%. The naphtha cut of pyrolysis product from Alberta oil sand bitumen is 6% and that of the pyrolysis oil is 8-10%. The elution temperature range between 473 and 600 K is considered to be the range of middle distillates similar to Diesel oil. The end cut of middle distillates are n-C18. The middle distillates cut of the Circle Cliffs' bitumen is 6%, and that of pyrolysis oil is 32-47%. For the Alberta oil sand, the cut from bitumen is 11%, and that of pyrolysis oil is 19-23%. From 600 K up to 840 K almost all the volatile components are eluted, is called heavy ends, and is up to n-C44. Both pyrolysis product oil showed increased proportion of heavy ends than that of bitumen.

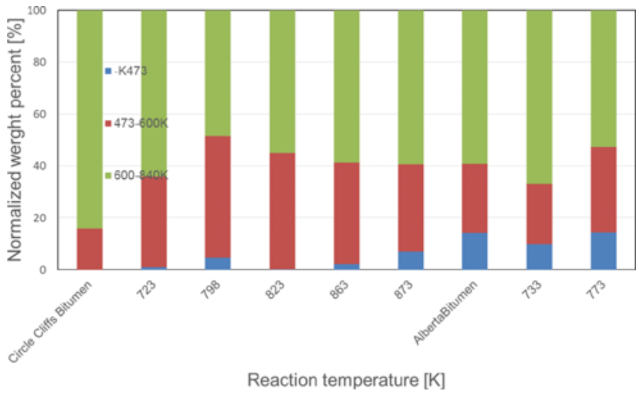

Fig. 8. Normalized distribution of boiling point cut in liquid product.

Since, asphaltenes are originally solid material and it is difficult to yield liquid oil during pyrolysis rather than producing gas and carbonaceous material. Most liquid yield can be expected from vaporization of light hydrocarbon (naphtha and middle distillates) and thermal cracking of high molecular hydrocarbons (heavy ends). The product generally has increased middle distillates and reduced heavy ends to its bitumen properties. We normalized the result of Table 4 to 840 K cut and presented in Fig. 8.

Table 5 presents the products yield from fluidized bed pyrolysis of both Circle Cliffs and Alberta oil sand. In the reaction temperature range the yield of carbonaceous residue is similar to the asphaltenes (toluene soluble) content in bitumen. Thus, the oil and

Table 5. Pyrolysis yield of oil sand

Source	Circle Cliffs				Alberta
T, K	773	798	823	873	773
Retention time, min	15-30	15-30	15-30	15-30	30
Oil, wt%	17.3-32.1	20-29.8	23.2-35.9	16.9-30.0	74.5
Gas, wt%	28.5-40.2	35.8-42.0	20.1-54.6	25.8-45.3	13.3
CO_2, wt%	5.2-5.6	5.7-11.6	7.1-9.0	12.3-29.9	-
Carbonaceous residue, wt%	39.4-42.5	33.8-38	33.5-51.7	37.4-44.2	12.2
Water*, wt%	22.1-30.0	23.5-	17.3-29.5	39.2-44.2	-

*Water and CO_2 yield based on bitumen content gas yield were similar to 100 percent-asphaltenes percent (maltenes or pentane soluble).

Asphaltenes are a multi-ring aromatic compound which is pentane insoluble and composes carbonaceous compounds in bitumen. In pyrolysis condition, it will decompose to gas and carbonaceous residue. Whereas, maltenes are pentane soluble light and mid-molecular hydrocarbon and it will either vaporize during the reaction or decompose to lighter molecules [14]. The maximum oil and gas yield is about 100 percent minus asphaltenes percent, which is the content of maltenes [16]. At higher temperature, thermal cracking will overlap the vaporization and will produce higher gas yield. A similar trend appears in the pyrolysis of Alberta oil sand [6,11,12]. As shown in Table 4 and Fig. 8, secondary cracking reaction in pyrolysis is significant enough to change oil properties, increasing light fractions compared to bitumen. But the total weight of liquid is always limited to maltenes content in bitumen.

The yield of carbonaceous residue will be larger in Circle Cliffs oil sand than that of Alberta oil sand, since the original content of asphaltenes in Cicle Cliff's bitumen is about three times of that of Alberta oil sand.

The CO_2 yield in Circle Cliffs oil sand is considered to be dissociation of mineral carbonates in oil sand matrix, such as Ca and Fe. The CO_2 was not detected in pyrolysis gas of Alberta oil sand.

Circle Cliffs oil sand contains about 0.3% moisture which is released during solvent extraction. Initial 0.3% of moisture is considered to be connate water fraction absorbed to oil sand host rock. This is about 8% of weight of bitumen. However, in pyrolysis 22-34% of water yield compared to bitumen weight was obtained. The extra yield of moisture in pyrolysis product is considered from the breakage of -OH bonding of oil sand host rock as seen in Fig. 3. The Alberta oil sand did not produce detectable amount of water during pyrolysis.

Another significant character in Circle Cliffs oil sand pyrolysis is yield of carbon dioxide (CO_2). Considering the pyrolysis is no oxygen reaction, the yield of carbon dioxide is from oxidation of bitumen by mineral oxide or at high temperature of 873 K decomposition of mineral carbonates. Alberta oil sand did not produce carbon dioxide either.

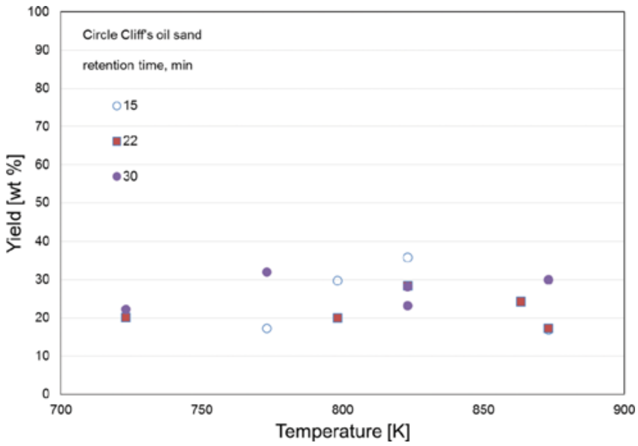

Fig. 9. Effect of reactor temperature on oil yield from fluidized bed pyrolysis of Circle Cliff's oil sand.

Fig. 9, Fig. 1, and Fig. 11 are presentations of the yield of oil, gas, carbonaceous residue (char like material) from the fluidized by pyrolysis of Circle Cliffs oil sand according to temperature and solid retention time, respectively.

In Fig. 8, the effect of solid retention time in oil yield is not conspicuous, but in general in lab scale experiment with short retention time means high feeding rate causing cooling down of reaction environment and suppressing further pyrolysis after retorting. This can result in higher liquid yield of the process and continues as long as the reaction mode is stable. At 823 K and at the retention time of 15 minutes the oil yield was maximum. This means there is a condition of optimum heat input that can vaporize light hydrocarbon yet minimized secondary cracking.

In Fig. 10, same as Fig. 9 the effect of retention time is not clear, but the yield of gas increases as reaction temperature increases, implying increased thermal cracking of bitumen at higher temperature resulting increased gas yield. Also, asphaltenes in bitumen also crack releasing more gas at higher temperature. The result is consistent with the result of previous researchers [6,12,15, 18,19].

In Fig. 11 the yield of carbonaceous residue is calculated as 100% - oil yield % - gas yield %. As in previous figures of Fig. 8

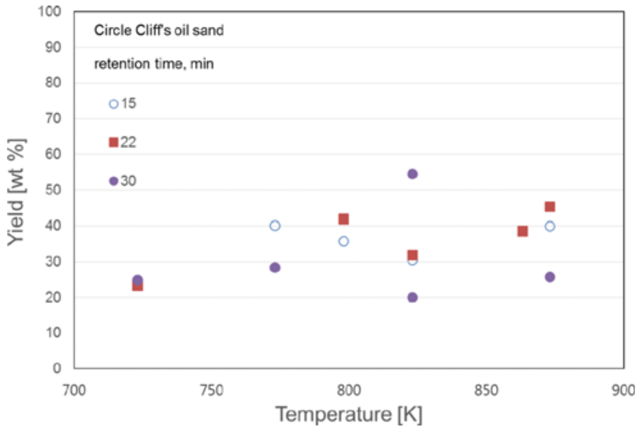

Fig. 10. Effect of reactor temperature on gas yield from fluidized bed pyrolysis of Circle Cliff's oil sand.

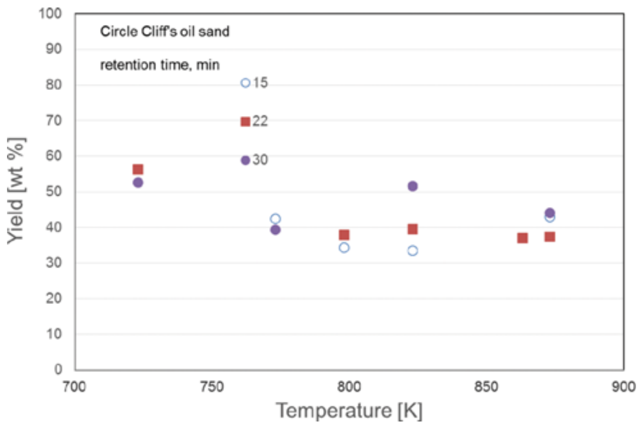

Fig. 11. Effect of reactor temperature on yield of carbonaceous residue from fluidized bed pyrolysis of Circle Cliff's oil sand.

and Fig. 9, the effect of solid retention time is not conspicuous; however, the yield of carbonaceous residue slightly decreases as the reactor temperature increases, implying not only thermal crack of heavy end cuts (in simulated distillation and thermogram), but also cracking of asphaltenes occurs and produces more gas at higher temperature, reducing carbonaceous residue.

The pyrolysis result of the Circle Cliffs and Alberta oil sand both show the maximum yield of oil is limited to the amount of maltenes shown in simulated distillation, i.e., Circle Cliffs 55%, Alberta 83% from bitumen analysis [6]. Thus, the result of physical analysis of bitumen and non-isothermal TGA data is applicable to anticipate the maximum yield of liquid in fluidized bed pyrolysis.

In optimum reaction condition to maximize liquid yield we expect to retort all naphtha and middle distillates (less than 600 K cut) and minimize cracking of heavy end cuts (600 to 840 K) in bitumen.

For fast vaporization the rapid heating of fluidized bed is advantageous since it provides large heated sand bed, which can provide a large amount of heat and good mixing. To suppress cracking it is important to reduce oil sand holdup time in the reaction zone and remove vaporized product rapidly from the reaction zone. To do this, increasing sweeping gas velocity and cooling down the system other than reactor body will be necessary. The previous vacuum pyrolysis study [12] was claimed to be effective for increased oil yield, removing product oil to colder condensing region fast by applying suction process, suppressing further cracking in hot reactor zone.

Fluidized bed reaction has advantage to provide heat in fast heating mode enhancing retorting reaction. When products are eluted they can be removed rapidly by fluidizing gas outside of the reaction zone suppressing secondary reaction. Thus, in fluidized bed pyrolysis the vaporization can be maximized and cracking can be minimized compared to any other continuous reactor system.

CONCLUSIONS

The fluidized bed pyrolysis of Circle Cliffs oil sand was investigated to identify feasibility of thermal processing of the oil sand.

- The Circle Cliffs oil sand is lean saturated (~3.6%) rock formation. The host rock contains clay-like compound which releases water during pyrolysis. The host rock contains more calcium, potassium and alumina content than that of the Alberta oil sand. Since bitumen saturation is one-third of that of the Alberta oil sand, content of calcium per bitumen is nine-times, iron is 1.5-times more than that of the Alberta oil sand. These mineral compounds are considered to be the cause of carbon dioxide release during pyrolysis.
- Thermogram of the re-saturated Circle Cliffs oil sand showed dual reaction mode, one the retorting of light hydrocarbon and the other high molecule hydrocarbon decomposition. Simulated distillation and thermogram showed middle distillates vaporize and heavy ends cracks during pyrolysis.
- To optimize oil yield fast retorting of bitumen and rapid cool down of the product to minimize further cracking is recommended.
- The pyrolysis yield of oil was maximum at 823 K. The heat provided at this condition is optimum for vaporization of light hydrocarbon but minimum for secondary cracking. As the reaction temperature increases the yield of gas increased, and the yield of carbonaceous residue slightly decreased, indicating increased secondary cracking at higher temperature. The oil product changed its property to increased lighter fractions, indicating significant thermal cracking during pyrolysis.
- The fluidized bed retorting is one of the optimum measure since it can vaporize light part of bitumen fast and remove product swiftly out of the reaction zone by fluidizing gas minimizing thermal cracking of oil composition.

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