**Development of an Inclined Liquid
Fluidized Bed for Tar Sand Processing**

Topical Report

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SUMMARY

An inclined liquid fluidized-bed reactor (ILFBR) system has been developed and successfully operated for 24 hours. Modifications to the previously tested ILFBR systems include incorporation of a oil fluidizing zone in the front of the fluid bed, an increase in the angle of the fluid bed to -12° (the minus sign shows that the discharge is below the horizontal level of the inlet), and reduction of the fluidizing gas velocities equal to or below the minimum fluidization velocity. These changes produced a functional bubbling slurry bed for the processing of tar sand. The produced oils and spent sand resemble the products from screw pyrolysis reactor (SPR) tests suggesting that the ILFBR system functioned similar to the SPR systems with the recycle oil pyrolysis and extraction (ROPE[®]) process. With slight modifications in the heater control and placement, the system will be ready for development of operational parameters for the surface processing of tar sand.

BACKGROUND

The Western Research Institute (WRI) is developing a processing technique and reactor systems for the surface processing of tar sand. The recycle oil pyrolysis and extraction (ROPE[®]) process consists of two pyrolysis steps for recovering initial products that will require minimal further upgrading. The first step is low-temperature (<800 °F [<427 °C]) retorting of the tar sand in the presence of recycled product oil. In the second step, the retorted tar sand is further pyrolyzed at a higher temperature (>900 °F [>482 °C]) in the absence of recycled product oil. Systems being developed for use with the ROPE[®] process are a screw pyrolysis reactor (SPR) and an inclined liquid fluidized-bed reactor (ILFBR).

Preliminary testing of the process using both 2-inch-diameter and 6-inch-diameter SPR has demonstrated the feasibility of both the process and the SPR system (Cha et al. 1987; Cha et al. 1988). The results show that the ROPE[®] process gives higher oil yields from Asphalt Ridge and Sunnyside tar sand than do other pyrolysis processes. Also, the studies show that production of lighter oils increases with increased pyrolysis temperature in the first process stage. Oil yield increased as the pyrolysis temperature increased to 750 °F (399 °C), but oil yield decreased at higher temperatures. The heteroatom content (sulfur and nitrogen) in the produced oils was lower than other pyrolysis-produced oils. Therefore, the product oils are a good feedstock for the production of transportation fuels.

The criteria for selecting a fluidized-bed reactor are reported by Merriam and Cha (1987), who identified several advantages of fluidized-bed pyrolysis systems. These advantages are high heat-transfer rates, high solids throughput, and the flexibility of the system to operate with a wide range of residence times by changing the bed angle or the fluidizing velocities. A nearly horizontal inclined bed provides plug flow for solids at a more uniform residence time and a wider range of particle sizes. Uniform residence time is attained by the vertical flow of gas or liquid through the nearly horizontally flowing solid and liquid bed. An added advantage of the fluid bed is the absence of internal moving parts.

An ILFBR system was designed and constructed based on the cold-flow model studies of Johnson and Cha (1987). The shakedown tests using this initial reactor system showed that most of the bitumen can be recovered from Asphalt Ridge tar sand. Work by Guffey and Hunter (1988) verify that the operating parameters used in the ILFBR tests permit rapid recovery of the bitumen from the tar sand and sufficient temperatures for pyrolysis of the solubilized bitumen and recycle. However, test results showed a need for

modifications to improve the operability of the reactor system. The modifications to the system consisted of changes in product collection, product oil recycle, and tar sand feed components (Johnson 1988). The operation of this modified system improved the feeding of the tar sand-recycle oil slurry and improved the recovery of entrained liquids from the fluidizing gas. Problems of solids buildup within the fluid bed remained.

This progress report contains details of the modifications and the results of shakedown tests conducted to eliminate solids buildup in the fluid. The reactor system produced as a result of this work is capable of the surface processing of tar sand and also provides an alternative system that can replace the SPR system.

DESCRIPTION OF REACTOR SYSTEM

The initial ILFBR system used in this development study, schematically shown in Figure 1, consists of a nearly horizontal (-3°) fluidized bed, 10 feet long, coupled with a 10-foot-long, 2-inch-diameter pyrolysis screw. The high temperature ($>900^\circ\text{F}$ [$>482^\circ\text{C}$]) pyrolysis screw is inclined upward at an angle of 20° . Tar sand pretreatment and recycle oil pyrolysis occur in the three sections of the fluidized bed, and recycle oil separation and residual bitumen pyrolysis occur in the pyrolysis screw. Each section of the fluidized bed has individual temperature and gas flow rate controls as well as individual gas outlets for segregating the vaporized products. This arrangement of gas injection and production ports minimizes the horizontal movement of gas and vapor.

Materials discharging from the fluid bed enter vertically into the lower end of the pyrolysis screw, where a continuous recycle oil-solubilized bitumen level is maintained. The two temperature zones in the pyrolysis screw permit the refluxing of recycle oil in the lower section of the screw and the pyrolysis of residual bitumen (which remains on the sand) in the upper half of the unit. Spent sand that contains coke is transferred from the pyrolysis screw to a hopper for collection and subsequent analysis.

Figure 1. Schematic for the Initial Inclined Liquid Fluidized-Bed Reactor System

After careful evaluation of the proposed changes outlined in the experimental plan, WRI determined that to completely fluidize the bed with recycle oil would require an excessive amount of solids-free oil. This excessive amount of oil will cause the bed to flood and will require the removal of solids from the recycle oil to prevent plugging of the disparger plate. Therefore, complete fluidization with the recycle oil was eliminated. The proposed change of adding an oil spray system in the disengaging area of the fluidized bed to induce coalescence of the entrained fluids and replenish the slurry liquid content was deemed applicable and was considered as a potential process modification.

Gas fluidization of the recycle oil-tar sand slurry was considered the most practical method. If the volume of gas needed to fluidize the slurry could be reduced, the amount of liquid entrained could also be reduced. In the process of reevaluating the minimum fluidization velocity for the gas fluidization of a liquid-solid system in an inclined reactor system, WRI determined that a well-mixed slurry bed can be maintained and moved through the reactor with gas velocities at or below the minimum gas fluidization velocity. This conclusion was based on (1) review of prior WRI cold-flow studies, (2) review of literature on gas fluidization of solids in liquid (Gabor et al. 1984), (3) recent studies of longitudinal-flow fluidized beds (Nilsson and Wimmerstedt 1988; Nilsson 1988), and (4) evaluation of the weeping characteristic of sieve-plate perforations (Perry 1984).

Based on the evaluation of the proposed changes to the reactor system and the evaluation of the gas fluidization velocity, WRI proposed that the first modification to the ILFBR system be in the operational sense. This is the operation of the present system at gas fluidization rates less-than-or-equal-to the minimum calculated fluidization rate and the use of a recycle oil rich slurry. Such an operational scheme will result in a well-mixed slurry bed with reduced liquid entrainment in the gas phase. The actual bed characteristics will resemble more a bubbling bed than a fully fluidized bed. The only significant mechanical modification is the increase of the bed angle from -3° to -6° to assist in the lateral slurry movement.

DISCUSSION OF TESTS

The tests conducted with the ILFBR system consisted of cold-flow tests, hot operability shakedown tests, and a process test. All tests used Asphalt Ridge tar sand and product oil from previous SPR and ILFBR ROPE[®] tests as the initial recycle oil. The shakedown tests identified problems that have been corrected. A total of two cold-flow tests, four hot shakedown tests, and a 24-hr processing test were conducted.

The cold-flow tests were conducted at ambient room temperature and used a material system of nitrogen-water-quartz sand to simulate the nitrogen-recycle oil-tar sand system. The operational parameters for the first cold-flow test were 10 lb/hr of 12- to 20-mesh sand, 30 lb/hr water, 0.5 scfm of nitrogen per fluidizing section, and a slope of -6° on the fluid bed. During this initial cold-flow test, an excessively large deposit formed in the first fluidizing zone. This suggested that the gas was not able to sustain a good fluid-sand slurry. To solve the problem, the first fluidizing zone was divided into an initial liquid fluidizing zone followed by a gas fluidizing zone. The liquid fluidizing zone was incorporated to produce a mixing zone for the solids and recycle liquid. The modified reactor system is shown in Figure 2.

The cold flow test of the modified system with the four fluidizing zones, used the same operational parameters as the initial cold flow test but with the addition of a fluidizing liquid rate. The fluidizing liquid rate was varied throughout the cold-flow test to establish the minimum rate required to produce a nearly homogeneous slurry bed. From the cold-flow test, WRI determined that a fluidizing liquid rate of approximately $44 \text{ cm}^3/\text{min}$ resulted in no appreciable solids bed being produced in the fluid bed, whereas a solids bed of increasing depth was produced as the fluidizing liquid rate was lowered.

The initial hot shakedown test used the material injection rates tested and verified in the cold flow tests. These target operational parameters were 10 lb/hr of tar sand as a 10-wt % recycle oil slurry, 30 lb/hr recycle oil (approximately $280 \text{ cm}^3/\text{min}$), 0.5 scfm of nitrogen per gas disarger section, and $44 \text{ cm}^3/\text{min}$ fluidizing oil. The entire fluidized bed was operated at 650° F (343° C). At these operating conditions, a solids plug was developed within the initial gas fluidizing section of the reactor. Analysis of the problem showed that an increase in the angle of the fluid bed along with higher recycle oil and fluidizing oil rates would assist in keeping the solids particles moving along the bed. To instrument this change, the fluid beds angle of inclination was increased from -6° to -12° .

Figure 2. Schematic for the Modified Inclined Liquid Fluidized-Bed Reactor System

The next three hot shakedown tests were conducted with the -12° inclined fluid bed. The tar sand slurry feedrate, the fluidizing gas flow rates, and reactor temperatures were maintained at the same settings as in the first hot shakedown test. The operational parameters of recycle oil rate and fluidizing oil rate were varied to produce the desired conditions. Recycle oil rates up to $560 \text{ cm}^3/\text{min}$ and fluidizing oil rates up to $200 \text{ cm}^3/\text{min}$ were tested. At the upper end of the oil rates, there was excessive sand carryover into the recycle oil tank in the transition section between the fluid bed and the pyrolysis screw. As the oil rates were decreased, the sand carryover decreased. Conditions of $280 \text{ cm}^3/\text{min}$ for the recycle oil and $150 \text{ cm}^3/\text{min}$ for the fluidizing oil are optimal for minimizing the sand carryover while still maintaining only a trace of a solids bed within the fluid bed.

The selected operational parameters for the process test were those identified in the shakedown tests and prior 2-inch-diameter SPR tests as producing the best oil yield-oil quality combination. The actual operating conditions varied from the target conditions in the process test. The fluidized-bed reactor angle was set at -12° . Feed for the test was to be 11 lb/hr of a slurry composed of 10.0 lb of tar sand to 1.0 lb of recycle oil with the recycle oil content increased to approximately a 5:1 weight ratio of recycle oil to tar sand by the time the slurry exits the oil fluidizing section. The three gas fluidization sections were to have nitrogen rates of 0.5 scfm per section and operating temperatures of approximately 650, 700, and 750 °F (343, 371, and 399 °C), increasing from the inlet to the outlet of the fluid bed. The liquid fluidizing zone oil rate was set at $150 \text{ cm}^3/\text{min}$ and a temperature of 650 °F (343 °C). The recycle oil reflux zone and the residual bitumen pyrolysis (high temperature) zone were to be operated at 750 and 975 °F (399 and 524 °C), respectively. The modified reactor system was to operate for 24 hours.

The process test was conducted at essentially constant conditions for 24 hours. However, as previously stated, some of the actual operating conditions varied from the target conditions. Parameters that met target conditions include the rates of the recycle oil and the fluidizing oil, and the rates and temperatures for the fluidizing gas. The tar sand feed rate for the test averaged only 6.8 lb/hr for a recycle oil-to-tar sand ratio of 8.5:1. The temperatures of the overhead region in the three zones of the fluid bed were 200 to 250 °F (93 to 121 °C) lower than the desired temperatures. The pyrolysis screw temperatures were satisfactory in the lower section but varied from 850 to over 1000 °F (454 to 538 °C) across the upper portion.

The overall material balance for the 24-hr process test was 100.1% (Table 1). The lower fluidized-bed temperatures produced less light oils and more heavy

oil. Because of the nature of this test, no analysis of the produced oils was conducted. The spent sand carried from the pyrolysis screw had a coke content of 1.71 wt % compared with the 1.22 wt % coke content produced during SPR tests. These coke levels show that the oil yield from the ILFBR was slightly less than the yield from the SPR. However, if the temperatures of the ILFBR were raised to match those of the first pyrolysis screw of the SPR, the oil yield for the two reactor systems should be comparable. From an operational standpoint, the process test was a success even though some of the process temperatures were not in line with projected values. Slight modifications in heater control and placement will eliminate temperature problems and produce a higher content of lighter oils.

Table 1. Overall Material Balance, lb

<u>IN</u>	
Slurry	
Tar Sand	170.2
Recycle Oil	18.9
Recycle Oil	<u>368.4</u>
Total In	557.5
<u>OUT</u>	
Slurry	8.4
Materials Remaining in System	14.0
Reacted Sand	138.7
Oil	
ILFBR Products	95.6
Recycle Oil	<u>301.2</u>
Total Out	557.9

CONCLUSIONS AND RECOMMENDATIONS

The modified ILFBR system, shown in Figure 2, was successfully operated for 24 hours without any significant problems. The sand produced from the pyrolysis screw had a light coke coating showing that the ROPE[®] process functioned in the ILFBR system as it has in the SPR systems. With slight modifications in the control and placement of the heaters, the system will be ready to operate for the development of operational parameters for the surface processing of tar sand.

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