ALL-SYNTHETIC DIESEL FUEL FROM ATHABASCA BITUMEN: PROPERTIES, TESTING AND OPERATING EXPERIENCE

by

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Syncrude Canada Ltd. operates an integrated oil sands plant in the Athabasca region in northern Alberta. Oil sand is extracted and the separated bitumen is upgraded by a combination of coking and hydrocracking processes. Distillates are hydrotreated to produce synthetic crude oil, which is shipped by pipeline to refineries for further processing and blending. Daily production of synthetic crude oil is approximately 23,850 m^3 or 150,000 bbl (1988 daily average production).

Throughout the plant, 125,000 liters/day of diesel fuel are being consumed. Heavy haulers (170 tons, 33 units) operating in the oil sands mine are major consumers, although an appreciable amount of fuel is also used to power a variety of other units. Historically, diesel fuel was purchased from commercial sources. An opportunity to reduce operating cost by substituting the purchased fuel (45 million liters/year) with a plant derived synthetic material was identified.

Typically, during the production and refining of diesel fuel, its chemical and physical properties are modified and adjusted by blending in order to meet specifications. The blending option was not available in this case where the direct use of an existing plant stream was proposed. Although several studies and tests were reported on synthetic materials of this type, more information was needed for assuring the economical and reliable operation of a large fleet under extreme temperature conditions.

Chemical, physical and ignition properties of the all-synthetic fuel were measured and compared to conventional fuels and to diesel fuel specifications. The fuel was also tested on heavy-duty diesel engine test rigs. Following this fuel evaluation study, the fuel was approved by Syncrude for use on its equipment at its oil sands plant. The switch to all-synthetic diesel fuel took place in the spring of 1988.

Properties, test results and operating experience with Athabasca bitumen derived diesel fuel will be discussed.

Results and Discussion

Athabasca bitumen is extracted from the sand matrix by the hot water process. It is then subjected to thermal cracking in fluid cokers (1). Distillate cuts are individually hydrotreated and the hydrotreated streams are blended to form synthetic crude oil (SCO) product. This is transported by pipeline to

refineries for further processing and blending. Properties of the bitumen feedstock and of the synthetic crude oil are shown in Table 1.

The stream identified for diesel fuel use is derived from a unit which prepares naphtha needed as a diluent in the extraction process. The diluent preparation unit uses a hydrotreated distillate as feed and separates the naphtha diluent. It is the bottoms stream of this distillation which was identified as a potential diesel fuel. Although a distillation residue, this stream is quite light and highly refined, due to its prior processing. It is typically blended back into the synthetic crude oil product. Hence, the proposed fuel is readily available as part of normal plant operation (Figure 1). Properties of this stream are shown in Table 2, together with those of typical commercial diesel fuels. The corresponding boiling curves are shown in Figure 2.

The boiling curve of the all-synthetic material (Figure 2) is similar to that of commercial winter diesel fuel, which is the lighter of the three seasonal fuel blends typically used in northern Alberta (Table 2). Because this stream is, in fact, a "by-product" of an existing operating unit (diluent preparation unit), it is not practical to seasonally adjust the boiling range.

Chemical and physical properties of this stream reflect its synthetic origin and its processing history. In this list, deviations from specifications or from typical values observed for conventional fuels are indicated: + indicates an advantage for the synthetic fuel. Specifically, the following properties reflect the origin: low cloud (+) and low pour points (+), low cetane number (-) and low aniline point (-). Conversely, the following properties reflect the hydrotreating severity: low values for ash, sulfur, corrosion, acidity, carbon residue and water/sediments, good color (all +) and low viscosity (+/-).

Of these properties, two are discussed in greater detail: cetane number and viscosity.

Current Canadian diesel fuel specifications (Table 3) and minimum engine manufacturer's requirements for cetane number is 40 (ASTM D613); the measured value for the all-synthetic fuel was 31-32. However, the cetane number of a fuel can be improved by doping with an ignition improver. Typically, an alkyl nitrate is used, although other compound classes were also studied (2). Response of the all-synthetic fuel to the addition of a commercial ignition improver is shown in Figure 3. A cetane number of 40 was reached by doping the synthetic fuel with approximately 0.3% ignition improver. This is in the same range as measured in an earlier study (3) with Athabasca derived diesel fuel. The proposed "1990 Canadian specifications" (4) are met by doping with only 0.15 wt% additive.

Viscosity of a fuel is often linked to its lubricating properties or lubricity. The fuel injection system of a diesel engine relies on the fuel it is pumping for lubrication.

Viscosity of the material under investigation was low and similar to that of commercial winter fuel. Low viscosity is usually equated with low lubricity. However, there are reports (5, 6) indicating that this proportionality might only hold for fuels of similar origin, composition and processing history.

Therefore, it was desirable to obtain a direct, viscosity-independent measure of the lubricating properties of this material. This was done by using the "Ball on Cylinder Lubricity Evaluator" (BOCLE) test method (7, 8). Lubricity of the synthetic material was similar to that of commercial winter diesel fuel. Response of the synthetic fuel to the addition of lubricity improver was also

investigated. Lubricity of intermediate season fuel was reached by doping with approximately 50 ppm of commerical lubricity improver.

In summary, many of the properties of the all-synthetic fuel are similar to those of commercial diesel fuels, and in particular to winter diesel. In fact, only properties related to cetane number and lubricity are at variance. And, as shown, the fuel also responds well to the addition of additives, if this is desired. However, is the addition of additives needed, and what are the benefits obtained by doing so?

By definition, fuel specifications represent a body of chemical and physical properties that has proven sufficient to qualify a fuel. These correlations between chemical/physical data and engine performance are based on a database obtained with conventional fuels. Is the same set of chemical/physical data also sufficient (or is the full set indeed needed) to qualify a material of 100% synthetic origin? The significance of this issue can probably best be appreciated by considering the fact that even the specifications are subject to occasional review (4).

In the absence of a database covering operating experience with synthetic fuels, and to address the issue of actual engine performance, the properties of this fuel were reviewed with engine manufacturers. Based on these discussions, an engine durability test was performed at Detroit Diesel Corporation's test facility. In addition, dynamometer tests combined with emission measurements were also carried out. For the durability test, one cylinder bank of a 149 series heavy-duty engine was operated on synthetic fuel, whereas the other bank was run on conventional fuel. The engine was fully performance instrumented and was operated at various power settings, including elevated power output for more than 500 hours. Also, to obtain data truly indicative of the all-synthetic fuel, it had been agreed to run this test without any additive.

As part of the durability test, the engine was disassembled and its components were inspected. Overall, test results were definitely in favor of the all-synthetic fuel, in terms of operating parameters, as well as component wear. As indicated above, this test was run with no additives.

Eleven mode steady state emission tests revealed a measurable reduction in NO_x and CO for the all-synthetic fuel as compared to #2 diesel fuel. Further emission testing with the all-synthetic fuel and #1 diesel fuel on the U.S. Federal Transient Emission Test showed a 10% reduction in brake specific particulates. However, for this transient cycle test with the lighter #1 diesel fuel, the measurable reduction in NO_x and CO was nullified; indeed, the trend reversed itself and a slight increase in CO and NO_x was measured.

Since the all-synthetic fuel has very little sulfur content (0.01 wt %), the SO_2 emissions from engines burning the all-synthetic fuel were consistently lower and this was likely a contributor to the lower brake specific particulate measurement. Low sulfur content also has a beneficial impact on sulfur induced corrosion of engine components.

Brake specific fuel consumption (LB/BHP-HR) was moderately higher (2%) for the all-synthetic fuel relative to #1 diesel fuel. This is likely related to the fuel spray of the less viscous all-synthetic fuel. This hypothesis is supported by test runs on various internal injector components which yielded a greater sensitivity to these changes than did #1 diesel fuel or kerosene. However, addition of ignition improver additives may provide an offset for this slight performance loss.

In view of the extreme low temperatures (-40°C) measured at the plant site during winter, cold weather performance of any diesel fuel used at this location is of crucial significance. Two factors to be considered here are the fluidity and the ignition properties of the fuel at these temperatures. Good performance in both areas is typically associated with diverging trends in chemical composition. Indeed, n-alkanes which are thought to promote good ignition, tend to solidify and form wax particles at low temperatures.

As part of an earlier study, field tests at temperatures down to -28°C had been carried out. A variety of engines with power ratings from 200 to 870 HP were used. For low temperature tests, ignition improver (0.3 vol %) had been added. At temperatures above freezing no ignition improver was added. No non-starts were observed (9).

As part of the present study, additional startability tests at even lower temperatures were carried out at Detroit Diesel Corporation's test facility. One engine was equipped with an electronic fuel injection system (Detroit Diesel Corporation - DDEC II) and glow plug heads. A second engine of similar design, with flow plug heads but mechanical injector system was also tested.

It was shown that, at -46°C, the engine equipped with electronic injection started in 12 seconds when using the synthetic fuel with a small amount of ignition improver added to enhance the cetane number to 40 cetane. Without this ignition improver and at 32 cetane number, this all-synthetic fuel started at -43°C in 23 seconds. However, the other engine equipped with the mechanical injection system and using the 32 cetane synthetic fuel was unable to start at -4°C until small quantities of ether were injected. This engine was cranked in excess of 275 seconds with glow plug assist prior to the injection of the small amount of ether. Even with the ether injection, a considerable crank time (179 seconds) was required for the mechanical injection start.

These results can be interpreted as follows. Electronic fuel injection appears to play a significant role, at least under the conditions of this test. More work is still planned to investigate this observation. The nature of the synthetic fuel is definitely a strong contributing factor, considering that non-starts with conventional fuels are not unusual at these conditions. We feel that the unusually low pour point and cloud point (-66 and -61°C respectively), as well as the low viscosity of the all-synthetic fuel allow the fluidity and atomization into fine fuel droplets to be maintained even at these extreme temperatures, thereby ensuring fuel ignition. However, these fuel properties alone are not sufficient in some applications to provide ignition of the non additive added fuel (32 cetane), as shown by the tests with the engine equipped with a mechanical injection system.

In practical terms, the low temperature test results confirm that the synthetic fuel is an excellent blendstock, mainly because of its high fluidity at low temperature. Taken alone, without further blending or addition of ignition improvers, it is a good fuel at moderate temperatures for all the engines tested. However, its low temperature performance is affected by the type and design of the individual engines, particularly in the case of naturally aspirated low compression engines.

Almost all the engines at the Syncrude plant site have a mechanical injection system. Furthermore, the fleet includes low and high compression engines, as well as naturally aspirated and super/turbocharged engines.

On the basis of this fuel evaluation study, the all-synthetic fuel was approved by Syncrude for plant-wide use, on Syncrude owned equipment, at its oil sands

plant. The switch to synthetic fuel occurred in the spring of 1988. Throughout most of the year, the fuel is essentially used as it becomes available from the diluent preparation unit, without further processing.

Specifically, no ignition improver is added during this period. However, on the basis of the low temperature tests, the cetane number is raised during the winter months by the addition of cetane improver. Although this may not be required for all the engine types of the fleet, logistics are less complex when only one type of fuel is used at any time.

Government regulations require the addition of an approved dye. Furthermore, to prevent the build-up of static electricity, a conductivity additive is added. These materials are added together as a blend. Cost of these two additives is not a significant factor. Lubricity improver additive is not added.

Conclusions

Physical, chemical and ignition properties of an all-synthetic material derived from Athabasca bitumen were measured with respect to its use as a diesel fuel. This stream is readily available as part of the production of synthetic crude oil, and as such is not specially blended or processed for diesel fuel use.

Many properties of the synthetic fuel are similar to conventional diesel fuel, particularly to winter diesel. Cloud point and pour point show a significant advantage over conventional fuels and exceed requirements set by fuel specifications. Cetane number and viscosity are lower than for conventional fuels and specifications.

Fuel specifications were developed on the basis of operating experience with conventional fuels, whereas this is an all-synthetic fuel. In the absence of a similar database specifically addressing operating experience with synthetic fuels, performance and durability tests on heavy-duty diesel engine test rigs were carried out.

The synthetic fuel is being used, on Syncrude owned equipment, plant-wide at Syncrude's integrated oil sands plant. Throughout most of the year, unmodified fuel is used. Only during the winter months is a higher cetane number required, particularly for naturally aspirated low compression engines. This can be achieved by addition of ignition improver.

Further studies are in progress to optimize the low temperature performance of the fuel.

Acknowledgments

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References and Notes

1. Since this study was carried out, a 40,000 bpd hydrocracker was integrated into the primary upgrading process. Fresh bitumen is fed to this hydrocracker. Distillates are routed to the hydrotreaters, whereas hydrocracker pitch is blended into the coker feed stream.

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Bitumen	
d (g/mL)	1.02
API	7.7
C (wt %)	88.3
H (wt %)	10.4
N (ppm)	5000
S (wt %)	4.5 - 5.0
Ni (ppm)	70
V (ppm)	200
Asphaltenes (C5)	17
+524°C (vol %)	59

Synthetic Crude Oil	
API Gravity (API)	31.4
Total Sulfur (wt ppm)	1500
Total Nitrogen (wt ppm)	623
99% Point (°C)	516

Naphtha (C5 - 177°C)	
API Gravity	64.4
Total Sulfur (wt ppm)	5.0
Total Nitrogen (wt ppm)	0.9

Light Gas Oil (177 - 343°C)	
API Gravity	29.8
Total Sulfur (wt ppm)	428
Total Nitrogen (wt ppm)	126

Heavy Gas Oil (343°C+)	
API Gravity (API)	18.6
Total Sulfur (wt ppm)	3430
Total Nitrogen (wt ppm)	1470

Table 1: Typical Properties of Athabasca Bitumen and of Synthetic Crude Oil

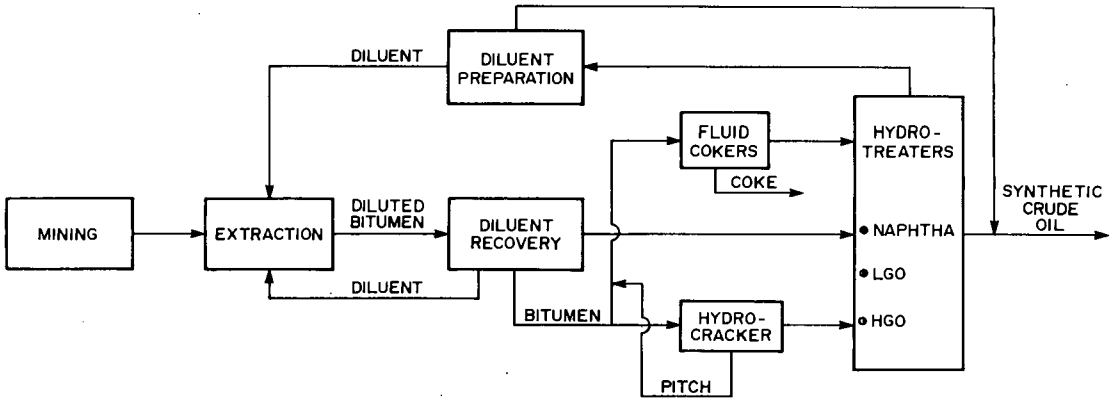
	Synthetic Diesel	Summer Diesel	Fall/Spring Diesel	Winter Diesel
d (20°C):	0.837	0.860	0.845-0.850	0.816
API:	36.8-37.8	33	35-36	42
Visc Kinemat (40°C):	1.28	2.0-4.1	1.4-2.4	1.3-2.1
Saybolt SUS (100°F):				
S wppm:	75			
Dist (D-86), IBP:	162			
10%:	174	238	215	215
50%:	199			
90%:	243	360	324	315
FBP:	278	385	338	319
Flash Point (°C):	52	45	45	45
Cloud Point (°C):	-61	0	-35	-40
Pour Point (°C):	-66	-7	-40	-45
Cetane Index:		43	43	43
Cetane Number:	31.6	40 (up to 45)	40 (up to 45)	40 (up to 45)
Aniline Point (°C):	40.6	62	57	58
Water + Sedim. (vol %):	0.00			
C-Resid, 10% bott (wt %):	0.005			
Ash (wt %):	0.00			
Copper Corrosion:	1a	0.5-1.5	0.5-1.5	0.5-1.5
Acidity (mg KOH/g):	0.00			
Color:	+14			

Table 2: Properties of Synthetic and of Commercial Diesel Fuels

Property	Fuel Type				
	Type AA	Type A	Type B	Type C	Type D
Flash point, min. °C	40	40	40	40	40
Cloud Point, max. °C	-48	-34	-23	-18	0
Pour Point, max. °C	-51	-39	-30	-24	-6
Kinematic Viscosity @ 40°C					
minimum, mm^2s^{-1}	1.2	1.3	1.4	1.4	1.4
maximum, mm^2s^{-1}	-	4.1	4.1	4.1	4.1
Distillation, 90% recovered max., °C	290	315	360	360	360
Water & Sediment, max. % vol.	0.05	0.05	0.05	0.05	0.05
Total Acid Number, max.	0.10	0.10	0.10	0.10	0.10
Sulfur, max. % mass	0.2	0.5	0.7	0.7	0.7
Copper Corrosion, 3 hrs at 100°C max.	#1	#1	#1	#1	#1
Carbon Residue (Ramsbottom) on 10% bottoms, max. % mass	0.15	0.15	0.20	0.20	0.20
Ash, max. % mass	0.01	0.01	0.01	0.01	0.01
Ignition Quality, Cetane No., min.	40	40	40	40	40

Table 3: Canadian Diesel Fuel Specifications (CAN 2-3.6-M81)

Figure 1. SIMPLIFIED DIAGRAM OF SYNCRUDE OIL SANDS PLANT



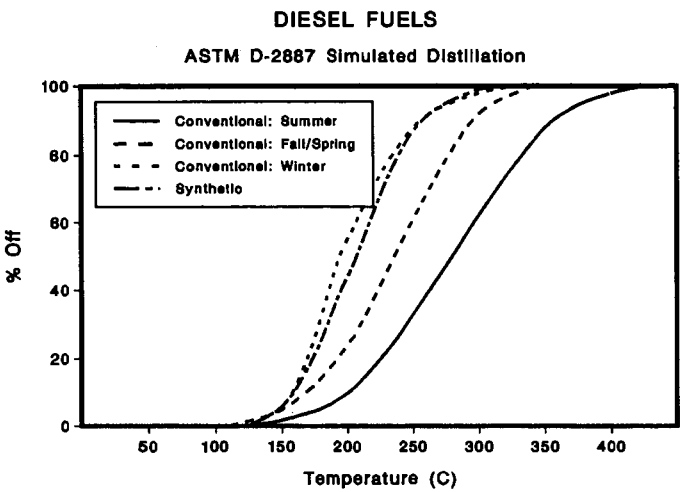


Figure 2. Boiling curves of synthetic and commercial diesel fuels.

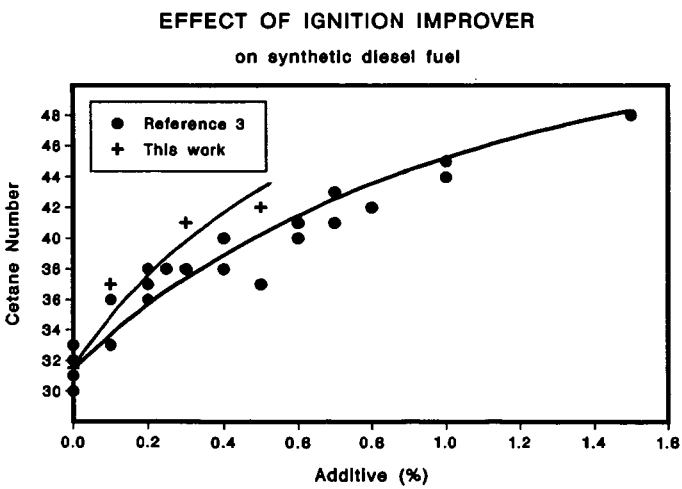


Figure 3. Effect of ignition improver on synthetic diesel fuel cetane number.