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Preparation of Light Fuel Fractions from Heavy Vacuum Gas Oil by Thermal Cracking Reaction

Saleem Mohammed Obyed

Department of Chemical Engineering/ Collage of Engineering / Al-Nahrain University

Email:Saleem_mo71@yahoo.com

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Abstract

This work deals with thermal cracking of heavy vacuum gas oil which produced from the top of vacuum distillation unit at Al- DURA refinery, by continuous process. An experimental laboratory plant scale was constructed in laboratories of chemical engineering department, Al-Nahrain University and Baghdad University. The thermal cracking process was carried out at temperature ranges between 460-560^{o}C and atmospheric pressure with liquid hourly space velocity (LHSV) equal to 15hr^{-1}.The liquid product from thermal cracking unit was distilled by atmospheric distillation device according to ASTM D-86 in order to achieve two fractions, below 220^{o}C as a gasoline fraction and above 220^{o}C as light cycle oil (LCO).The first fraction which was below 220^{o}C was fractionated to light fractions (gasoline, kerosene and gas oil) by atmospheric distillation device. The fractions (gasoline, kerosene and gas oil) were distilled by atmospheric distillation device in order to obtained distillation curve for these fractions. Physical properties were recorded for these cuts to compare it with standard property test, in order to studying the possibilities of industrial uses. The maximum conversion of heavy vacuum gas oil was obtained by this process equal to 82 wt. % of feed at 540^{o}C.

Keywords: *light fuel, thermal cracking, heavy vacuum ,gas oil.*

1. Introduction

Vacuum gas oil is a part of petroleum hydrocarbon heavy distillate family. Vacuum distillation recovers gas oil from the residual oil; in a vacuum tower so that the boiling point temperature is reduced, this allows distillation at temperatures that are not possible in atmospheric distillation.

The thermal cracking unit is consisting of the scission of the hydrocarbon C–C bonds present in the feedstock. It is occurring when the temperature is raised (400-900) ^{o} C to a point at which the bonds that hold a molecule together are broken. Cracking reaction start to occur at a temperatures of about (315-370) ^{o} C, depending on the hydrocarbon nature of the material being cracked, feed stock type and product requirement.

Treatment in any thermal process results in the formation of gases, gasoline, middle distillate fractions (kerosene and gas oil), heavy residual fractions, and coke.

The yield, relation between the reaction product's and the properties of these products depend on many factors, but the main role is played by the composition of the feed stock, the temperature, pressure and duration of the reaction. [1]

The rate of a reaction grows with elevation of the feed stock boiling point. Feed stock containing mainly alkanes is preferable for thermal cracking plants because they decompose more readily with the formation of target products such as gas, gasoline, and middle distillate, as the same time a little coke forms.

The degree of conversion in the thermal cracking is characterized by the gasoline yield relative to the feed stock. The degree of conversion is limited by the formation of coke and gas. The coke yield grows with increasing temperature and residence time of the stock in the reaction zone. [2].

Elevation of the cracking temperature at a constant pressure and constant degree of conversion leads to an increase in the constant of light components and to a reduction in the yield of heavy fractions and coke. [3]

The feed stock consists of a large number of individual componentsso, it is impossible to predict or follow the fate of each of these components under the action of high temperatures.

The aim of this work study the thermal cracking reaction of heavy vacuum gas oil at a temperature ranges (460-560) ^{o} C and tested some major physical and chemical properties of light product fractions to compare it with standard property test, in order to studying the possibilities of industrial uses.

2. Experimental Work Materials

Heavy vacuum gas oil which produced from top of vacuum distillation unit in Al -Dura refinery was used as feedstock in this study. The properties of heavy vacuum gas oil were determined by laboratory of AL-Dura refinery, as shown in Table 1.

Table 1,
Physical and chemical properties of vacuum gas oil sample.

Characteristics	Value
Viscosity (40 ^{0}C)	48 C.st
Flash point (open cup)	110 ^{0}C
PH	7
Color	brown
Melting point / freezing point	>15 ^{0}C
Initial boiling point and boiling range	306-532 ^{0}C
Vapor pressure	0.01 kpa. 20 ^{0}C
Relative density	0.9
Auto-ignition temperature	>220 ^{0}C
Specific gravity	0.91

3. The Experimental Work Units

The desired quantity of HVGO(6300 ml/hr.) pumped by dosing pump at the desired flow to the evaporator. In the evaporator the feed heated to 330^{o}C, and then enters the reactor, its volume was (420 ml).

The reactor temperature was measured by thermocouples. The product discharged to the condenser section, where the condensates are collected, for all runs in various operating temperature. The uncondensed gases are collected in gas collector. The duration time for each experiment was 30 minute.

Fig. (1) Shows the fixed bed reactor unit where experiments which took place at temperature range 460-560^{o}C and liquid hour space velocity 15hr^{-1}.

Fig. (2) Shows the distillation unit of cracking liquid products which were achieved in atmospheric distillation unit which consist of heater and condenser according to (ASTM D-86) for light cuts.

Fig. 1. Photograph picture of the fixed bed reactor unit.

Fig. 2. ASTM D-86 distillation unit.

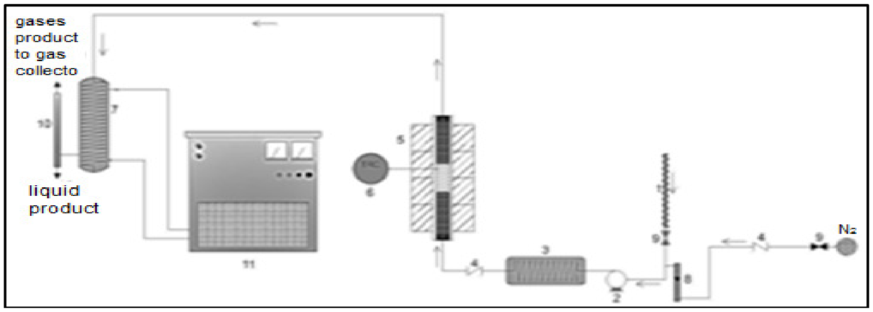

Fig. 3. Schematic flow diagram of laboratory continuous cracking unit.
1-Feed reservoir: 2- Dosing pump; 3-Preheater; 4- One way valve; 5- Reactor system; 6- Temperature controller; 7- Condenser; 8- Flow meter; 9- Control valves; 10- Separator; 11- Cooling machine.

4. Results and Discussion

4.1. Effect of Temperature on Thermal Cracking Reaction

The effect of temperature ranges (460-560)°C on the heavy vacuum gas oil conversion and the yield of gases, gasoline, light cycle oil and coke that were studied at constant liquid hour space velocity (LHSV)15hr^{1}were shown in Table 2.

Table 2,
Effect of temperature on liquid products from thermal cracking of heavy vacuum gas oil.

Temperature °C	460	500	540	560
Liquid hour space velocity hr^{-1}	15	15	15	15
Conversion wt.%	75.6	77.5	81	82
Gasoline wt.%	49	51	52	52
Light cycle oil (LCO)wt.%	24.4	22.5	19	18
Total liquid product wt.%	73.4	73.5	71	70
Coke wt.%	2	2.6	3	3.4
Gases wt.%	15	18	22	24
Residue wt.%	5.4	5.9	2	1.6
Losses	4.2	3.5	2	1

Figure 4 shows the effect of temperature ranges (460-560) ° C on the heavy vacuum gas oil conversion by thermal cracking. As shown from this figure the heavy vacuum gas oil conversion increases with increasing temperature. This may be attributed to; the increase of temperature which accelerates intermolecular motions assists the transformations of the reactants into new compounds and thus enhances the rate of chemical reaction, as mentioned also by Decroopcq [4].

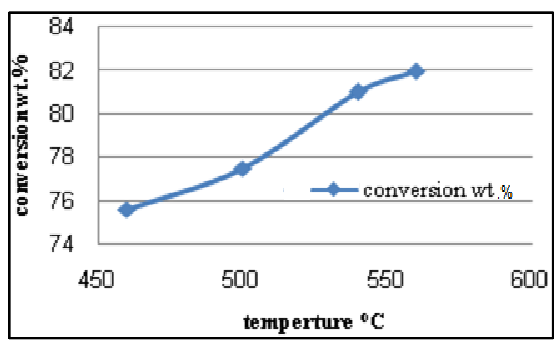

Fig. 4. Effect of temperature on conversion of thermal cracking of heavy vacuum gas oil.

Fig. (5) and fig. (6) Shows the yield of gases and gasoline respectively. The gasoline yield is chiefly affected by gas formation.

The increasing in the temperature reaction firstly increases the gasoline yield, then higher temperature gives lower gasoline yield and higher gases yield, this due to cracking gasoline itself to lighter fractions so the best temperature of thermal cracking of HVGO is 540 °C for this reason.

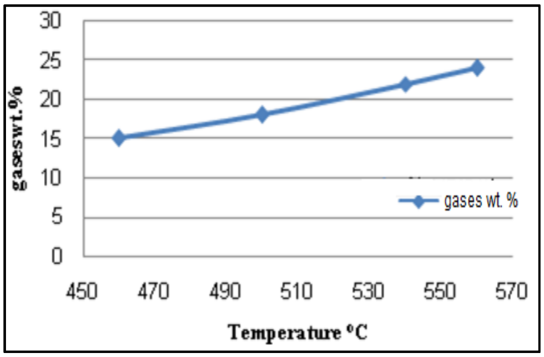

Fig. 5. Effect of temperature on gases yield by thermal cracking of HVGO.

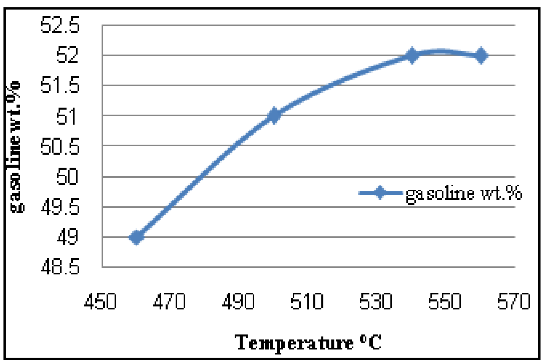

Fig. 6 .Effect of temperature on gasoline yield by thermal cracking of HVGO.

Fig.(7) and fig. (8) Shows that the yield of light cycle oil (LCO) decreases by temperature increasing and slightly increases in coke yield respectively.

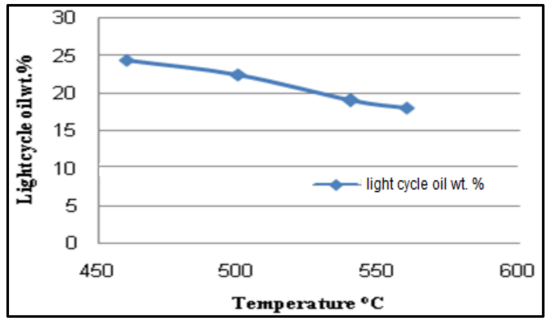

Fig. 7. Effect of temperature on light cycle oil yield by thermal cracking of HVGO.

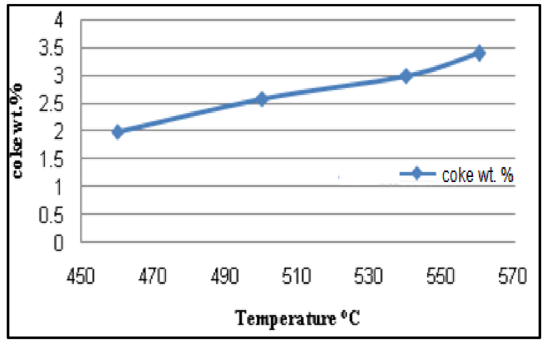

Fig. 8. Effect of temperature on coke yield by thermal cracking of HVGO.

Fig. (9) Shows the thermal cracking products distribution at different temperatures ranges (460 – 560) °C and constant LHSV.

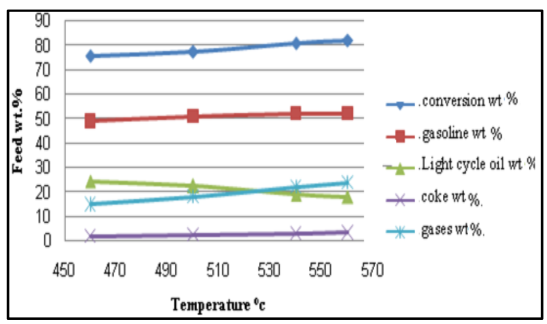

Fig. 9. Effect of temperature on thermal cracking products yield from HVGO.

The increasing in the reaction temperature firstly increases the gasoline yield then higher 560 °C temperature gives lower gasoline yield and higher gases yield**,** (figures 6 and figure 5). Since the conversion increases with temperature increasing, the light cycle oil decreases by temperature increasing at constant LHSV as shown from figure 7. And slightly decreases in coke yield (figure 8).

Clear pictures for thermal cracking products distribution at different temperatures ranges 480 - 540 ºC and constant LHSV were presented at figure 9.

The above results agreed with those obtained by Reagan [5].

4.2. The atmospheric distillation results

4.2.1. Heavy Vacuum Gas Oil

The results of atmospheric distillation for heavy vacuum gas oil and true boiling point distillation (TBP)were tabulated in table 3 which used to calculate some physical properties after calculate the mean average boiling point .

Table 3
Results of ASTMD-86 and TBP distillation for heavy vacuum gas oil.

Volume%	ASTM D-86 (^{o}C)	ASTM D-86 (^{o}R)	T.B.P (^{o}R)	T.B.P (^{o}C)
0	90	654	606	63
5	250	942	948	253
10	270	978	959	259
15	276	989	978	270
20	280	996	996	280
25	300	1032	1040	296
30	306	1043	1040	304
35	310	1050	1051	310
40	316	1061	1065	318
45	320	1068	1073	322
50	322	1072	1080	327
55	326	1079	1090	332
60	330	1086	1103	339
65	332	1090	1107	342
70	336	1097	1118	348
75	336	1097	1127	352
80	338	1100	1137	358
85	344	1111	1145	362
90	350	1122	1150	365
95	365	1149	1181	383
100	370	1158	1194	390

4.2.2. Light Fractions

The results of atmospheric distillation for light fractions (gasoline, kerosene and gas oil) according to ASTM–D86were tabulated in table 4which used to calculate some physical properties after calculate the mean average boiling point for any fraction.

Table 4,
Results of ASTM D-86 distillation for (gasoline, kerosene and gas oil)

Volume %	ASTM D-86 (^{o}C) gasoline	ASTM D-86 (^{o}C) kerosen	ASTM D-8 (^{o}C) gas oil
Initial boiling point	44	135	195
5	57	170	215
10	63	178	230
20	73	176	247
30	82	190	259
40	92	197	262
50	103	205	279
60	116	210	289
70	130	216	299
80	150	228	309
90	180	241	329
95	195	258	

5. The Physical and Chemical Properties of Fractions

Table 5 shows the properties for light fractionswhich were produced from distillation of liquid thermal cracking for heavy vacuum gas oil, to compared it with standard property for the same fraction, in order to possibility commercial uses these fractions.

Table 5,
The results of physical properties for (gasoline, kerosene and gas oil).

Property		Type of fraction which were produced from liquid thermal cracking of VGO			standard property for fraction		
		gasoline	kerosene	Gas oil	gasoline	kerosene	gasoil
Specific gravity.		0.77	0.81	0.85	0.72-0.77	0.77-0.82	0.82-0.86
API gravity.		85	48	44	50-60	40-50	35-45
T_b (ºR)		640	870	975			
K-index		12	12.2	12.3	11-13	11-13	11-13
Molecular weight.		93	167	214	115	170	225
Flash point(ºk)		300	310	325	Min.327	Min.315	Min.305
Diesel Index.		90	61	73			
Aniline point (ºC)		67	70	72	60	65	70
Viscosity at 100 ºF (Cst.)		0.5139	1.3238	2.511	0.6	1.6	Max.5.6
refractive index	Experimental	1.4104	1.435	1.4456			
	Empirical	1.4395	1.456	1.4877			
Pour point (ºk)		165	246	218	Max.264	Min.220	Min.160
Smoke point (mm)			23			Min.21	

6. Conclusion

1- It was concluded that the possibility produced of light fractions (gasoline, kerosene, gas oil) from heavy vacuum gas oil by thermal cracking process at different temperatures and constant space velocity at atmospheric pressure.
2- It was concluded that the heavy vacuum gas oil conversion increases with increasing the temperatures of thermal cracking.
3- Possibilty uses these light fractions for internal combustion engine or for domestic usesand diesel fuel.

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تحضير مقاطع وقود خفيفة من زيت الغاز الفراغي الثقيل بواسطة تفاعل التكسير الحراري

سليم محمد عبيد
قسم الهندسة الكيمياوية/ كلية الهندسة/ جامعة النهرين
البريد الالكتروني: Saleem_mo71@yahoo.com

الخلاصة

يتناول هذا البحث التكسير الحراري لزيت الغاز الفراغي الثقيل الذي ينتج من الجزء العلوي من وحدة التقطير الفراغي في مصفاة الدورة، عن طريق عملية تكسير حراري مستمرة.- تم تصميم وتنفيذ منظومة مختبريه تجريبية في مختبرات قسم الهندسة الكيميائية في جامعة النهرين وجامعة بغداد. وقد أجريت عملية التكسير الحراري في معدل درجة حرارة تتراوح بين ٤٦٠-٥٦٠ ^oC والضغط الجوي الاعتيادي مع سرعة الفضائية (LHSV) تساوي ١٥ $^{-1}$سا. - تم تقطير السائل المنتج من وحدة التكسير الحراري بوساطة جهاز التقطير الجوي طبقا للمواصفة ASTM D-86 من أجل تحقيق مقطعين، تحت ٢٢٠ ْم بوصفه مقطعا للبنزين وفوق ٢٢٠ ْم بوصفه زيتا خفيفا مدور (LCO).- تم تقطير الجزء الأول الذي كان تحت ٢٢٠ ْم إلى المقاطع الخفيفة (البنزين والكيروسين وزيت الغاز) عن طريق جهاز التقطير الجوي. - كذلك تم تقطير المقطر لمقاطع (البنزين والكيروسين وزيت الغاز) من خلال جهاز التقطير الجوي من أجل رسم منحنى التقطير الذي تم الحصول عليه لهذه المقاطع وذلك لحساب معدل درجة الغليان لهذه المقاطع. حساب بعض الخصائص والمواصفات الفيزيائية والكيميائية المهمة مثل (متوسط درجة الغليان، الوزن النوعي، نقطة الوميض، نقطة الأنيلين، نقطة الدخان، الوزن الجزيئي) وذلك لمقارنتها مع المواصفات القياسية التجارية من أجل دراسة إمكانيات الاستخدامات الصناعية. تم الحصول على أقصى قدر من تحويل زيت الغاز الثقيل الفراغي من هذه العملية يصل إلى ٨٢ بالوزن. ٪ عند٥٤٠. ْم