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A Simulation Approach of Characterization and Distillation Performance Assessment of Natural Gas Condensate

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ABSTRACT

This study evaluates condensate's performance as an alternate source of fuel. Also, the work explores how important system factors, such as pressure and temperature in the distillation column, affect the system efficiency under different operating conditions. Here condensate from the Kailashtila gas field has been collected and laboratory tests and simulation approaches have been performed to estimate different properties. First, the boiling point temperature is determined using ASTM D86 technique. Based on the results, we created the TBP curve; divided into its pseudo-cuts, and then estimated the physical and thermodynamic properties using DWSIM software. After that, the condensate is fed into an atmospheric and shortcut distillation unit, and the composition of the feed, distillate, and bottom products are generated, together with the pressure and temperature profile. The essential characteristics and column specifications are proposed, and the results are analyzed to observe the properties and energy consumption changes. Finally, the reliability of the study has been assessed by contrasting the outcomes from the simulation results with real field scenarios. According to the study, a distillation column with 12 trays and a height of 7 meters can produce products with specific gravities between 0.711 and 0.869 for this condensate sample. The study concludes that since medium-weight condensate can be distilled to create petroleum products like gasoline and diesel, it can be utilized as a fuel source. Changing the number of trays, column height, and feed temperature is recommended to influence the system's performance and the quality of the user-end product.

Keywords: Petroleum Refinery, Condensate, Boiling point, Pseudo-cuts, Distillation, Physical properties.

1. Introduction

A petroleum refinery processes petroleum streams to produce products like gasoline (petrol), diesel fuel, asphalt base, heating oil, kerosene, liquefied petroleum gas, and petroleum naphtha [1,2]. Crude oil is transformed into petroleum products in petroleum refineries, which is used as feedstock for producing chemicals and as fuels for heating, paving roads, power generation, and transportation [3]. In this study, the condensate performance as a substitute for crude oil in refineries has been assessed against physical and thermodynamic parameters. Natural gas condensate or natural gasoline is produced from gas fields when the reservoir pressure drops below the dew point pressure at a cri-condentherm condition. The fractionation of condensate in the fractionation column can produce products like Petrol, Diesel, Kerosene, Octane, and other hydrocarbon solvents [4,5]. Liquid hydrocarbon chains like condensate, NGL (Natural gas liquid) are considered an alternative for many gas or oil companies to increase production profitability in the face of a drop in natural gas production and an increase in the price of crude oil [6]. The precise measurements of temperature, pressure, and energy consumption are critical to assessing condensate performance as a refining feedstock because they help optimize the distillation column's performance [7]. Tangsriwong et al. compared commercial Aspen Plus and open-source software DWSIM to model chemical processes related to offshore petroleum production facilities [8] and found that these two models had consistent simulation results with real plant data.

This study employed DWSIM software to assess the energy consumption throughout the distillation process and to characterize the assay. The TBP data, molecular weight, and compositional analysis of the stream are used as input parameters.

2. Petroleum Stream Characterization

Crude oil is used as feedstock in petroleum refineries to yield petroleum products, but in recent years condensate has also served the same purpose. Regarding hydrocarbon components, pentane is the main constituent of the condensate; nevertheless, lighter hydrocarbons, like as methane, ethane, propane, and butane, or higher hydrocarbons up to C_8 may present in the gas condensate [9].

Feedstock assays are crucial to the refining process because they offer a comprehensive and in-depth study of hydrocarbon data. It also provides extensive and detailed analysis data on hydrocarbon [10]. Since the constituent composition of a petroleum stream cannot accurately reflect its composition, a distillation curve, typically characterized by small petroleum cuts or pseudo-components, is used to identify the streams [11]. The basis of a refining process is formed by pseudo components, which describe the petroleum fraction, as they are employed in calculations of the thermophysical and thermodynamic parameters of the refinery feed. The characteristics that hold the greatest significance in

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identifying the pseudo-cuts are the specific gravity and boiling point temperature. Other characteristics, such as molecular weight, critical pressure, temperature, and Watson characterization factor, are needed in the process calculation steps. Once the normal boiling point and specific gravity are established—ascertained from the TBP curve and the gravity vs volume distilled curve—one may treat the pseudo-cuts as stated [12]. As a rule of thumb, a high degree of fractionation provides precise and in-depth details about the component distribution. But fractionation cannot identify the precise components, such as aromatic, naphthene's, and paraffin; it can identify a specific number of mixture points.

3. ASTM to TBP Distillation Conversion

A TBP curve's cut point specifies how many pseudo-cuts it has; a larger cut point count aids in accurately reproducing the TBP curve. A high number of components can cause the computation time to increase even though more are needed to create a smooth property curve [13]. In this work, the Riazi/API technique and Daubert correlation are used to convert the ASTM data into TBP data. (Eq. 1 & 2)

$$TBP = a(ASTM\ D86)^b \quad (1)$$

Constants a and b are used here. TBP is computed at a specific distillation point, where the temperature is given in °R, such as 0, 10, 30, 50, 70, 90, and 95 percent points. The equations (Eq. 2) suggested by Daubert are

$$T'_{50} = A_4(T_{50})^{B4},\ T'_{30} = T'_{50} - \Delta T'_3,\ T'_{10} = T'_{30} - \Delta T'_2,\ T'_0 = T'_{10} - \Delta T'_1 \quad (2)$$

Where, $\Delta T'_i = A_i(\Delta T_i)^{B_i}$, $\Delta T_1 = T_{10} - T_o$, $\Delta T_2 = T_{30} - T_{10}$, $\Delta T_3 = T_{50} - T_{30}$, $\Delta T_5 = T_{70} - T_{50}$, $\Delta T_6 = T_{90} - T_{70}$, $\Delta T_7 = T_f - T_{90}$

The ASTM D86 and TBP temperatures, denoted by the characters T and T', are expressed in °F. The starting and ending temperatures are denoted by the subscripts 0 and f. A_i and B_i articulate the constants.

4. Condensate Sampling and Distillation Tests

Many gas reservoirs of this country like Beanibazar, Kailashtilla, Jalalabad, Bibiyana and more are producing condensate and the condensate gas ratios range between 5.31bbl/MMscf to 17.23 bbl/MMscf [14]. Here the condensate sample from the Kailashtila gas field has been taken to conduct further research. According to Hossain et al. (2019), this field's gas condensate is mostly made up of methane (85.81 wt%), ethane (6.68 wt%), propane (2.13 wt%), and trace amounts of higher hydrocarbons [15]. Mahjabin et.al. found that IBP and EP are lower in KTL condensate than other natural gas condensates [16]. Gas of Kailashtila has a very high condensate ratio in comparison to other gas fields in the Sylhet region. Md. Mizanur Rahman predicted the middle layer gas sand can deliver 19 years at 30.5 MMscfd with recovery factor of 66% which is greater than Upper Gas Sand [17]. According to the fluid's PVT parameters and reservoir characteristics, this reservoir is predicted to be a viable choice for condensate production, with productivity potential reaching 2034 [17]. The compositional data of KTL condensate generated by gas chromatograph are presented in Table 1.

Table 1 Compositional analysis of KTL condensate

Compositions	Weight%	Compositions	Weight%
N_2	0.0001	C_6(cyclo)	10.1625
CO_2	0.0001	i-C_7	6.3938
C_1	0.14	n-C_7	1.30395
C_2	0.1395	C_7(cyclo)	7.8207
C_3	1.95149	i-C_8	15.325
i-C_4	1.4129	n-C_8	1.824
n-C_4	2.725	C_8(cyclo)	1.97066
i-C_5	0.97057	n-C_9	10.24348
n-C_5	14.083	i-C_{10}	2.04585
i-C_6	2.4067	i-C_{11}	7.32566
n-C_6	1.1177	n-C_{12}	10.102
	Total		99.46466

Then, ASTM D86 test is performed to gather distillation data and ASTM D1298 to estimate density. The calculated findings of the distillation results and other properties are tabulated in Table 2.

Table 2 Distillation data for KTL condensate

Volume %	ASTM °C	Daubert °C	Property	Value
0	48	11.23731	VABP	263.84
10	84	61.974034	MeABP	244.827
30	100	92.206098	K	11.43882
50	114	114.51526	SG	0.778
70	136	143.19988	MW	23.25854
90	210	218.07942	API gravity	50.37661
95	259	329.57423	υ_{210}	0.371
EP.	310	-	υ_{100}	0.679
			Density (@32(kg/L))	0.844

The ASTM distillation temperature range of 48°C to 310°C has indicated a lower IBP and longer temperature range. The average boiling point and Watson characterization factor have suggested that it is a lightweight product [13].

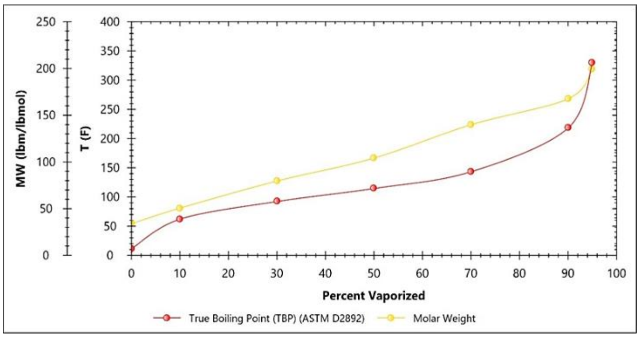

Fig. 1 TBP and Molecular Weight curve for KTL condensate

In Fig. 1**,** the variation of molecular weight and boiling point temperature with percent vaporized is displayed which assists in understanding the number of volatile components present at a particular fraction and thus aids in refining optimization. The actual boiling point (TBP) curve is created using Daubert's novel method. Next, using Peng Robinson's thermodynamic model and the obtained TBP data, DWSIM software assists in creating pseudo-cuts and their corresponding properties.

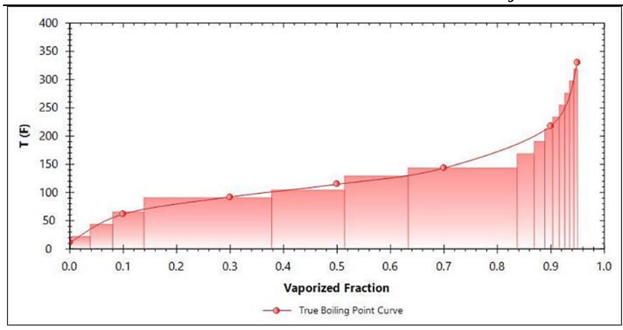

Fig. 2 TBP curve for pseudo-cuts.

Figure 2 shows the TBP curve for the pseudo-cuts that correspond to a particular temperature and for this experiment, it ranges from 11°C to 329 °C. The Critical and thermodynamic properties of the cuts are presented in Table 3.

Table 3 Critical and Thermodynamic Properties for Pseudo-cuts

Database: DWSIM			
Type: Petroleum Fraction (Pseudo-cuts**)**			
Density (Mixture)	748.05 kg/m^3	Specific Enthalpy	-1576.73 kJ/kg
Molecular Weight	8.898	Specific Entropy	-3.31011 kJ/[kg.K
Critical Temperature	440.8 K	Molar Enthalpy	-36674.8 kJ/kmol
Critical Pressure,	5346424 Pa	Molar Entropy,	-76.9932 kJ/kmol.K
Critical Volume	0.192 m^3/kmol	Thermal Conductivity	0.270447 W/[m.K]
Critical Compressibility	0.280	Kinematic Viscosity,	5.7756E-07, m^2/s
Acentric Factor	0.131	Dynamic Viscosity,	0.000432 Pa.s
Enthalpy of Formation	0.122kJ/kg	Mass Flow	127169 kg/h
Normal Boiling Point	267.54 K	Molar Flow	5467.3 kmol/h
Specific Gravity	0.711	Volumetric Flow	170 m^3/h

The critical temperature and pressure of the cuts are 167 °F and 775.4 psi and the cuts have lower enthalpy and entropy compared to the reference state indicating the mixture is more stable and ordered relative to the reference state [18,19]. The study then simulates shortcut and atmospheric distillation operations to assess the system's energy consumption and distill product quality. The shortcut distillation is performed to get a preliminary idea based on empirical equations, to generate a more detailed description the atmospheric distillation is performed next.

4.1 Shortcut distillation

Shortcut distillation aims to provide insight into estimating a system's performance and needs for a given reflux ratio in the first pass. With comparatively little-known information, one can rapidly model a stream's distillation separation in this application [20].

4.1.1 Process Description

The feed is divided into 15 cuts considering the distillation temperature range, which is fed into a shortcut column. The column condition is maintained at atmospheric temperature (30°C) and the pressure is set at 0.1889 bar. The volumetric flow rate is set at 170 m^3/hour and the reflux ratio at 1.5. The pressure in the reboiler and condenser is kept at 0.1889 bar. After simulation, the minimum reflux ratio is estimated as 1.05, actual stages 15, and minimum stages 7. The calculated value for condenser and reboiler duty is 20470.3 and 22693 KW respectively and the distillate offers a denser product than the bottoms. Results are shown in Table 4.

Table 4 Shortcut Distillation Column Properties

Property	**Value**
Temperature, °C	30
Pressure, bar	0.188934
Volumetric Flow, m^3/h	170
Minimum Reflux Ratio	1.05303
Minimum Stages	7.48651
Actual Stages	14.9318
Optimal Feed Stage	4.69571
Condenser Duty, kW	20.470
Reboiler Duty, kW	22.692

4.2 Atmospheric distillation

The first significant procedure in a refinery, atmospheric distillation, often divides crude oil into its component fractions for additional processing [9]. The feed is typically introduced into the column at 350°C to 390°C and atmospheric pressure [19]. In this study, the fluid composition of the original fluid sample is used as a feedstock for distillation and, then, the operation is simulated to observe the distillate and bottom product conditions. Furthermore, the energy efficiency of the condensate duty, reboiler duty, and column are monitored. The outcomes are then examined and contrasted with actual filed data obtained from the refinery.

4.2.1 Process description

A single distillation column, a condenser for the top product, and a reboiler are used for the bottom product as seen in Fig.3. The top column pressure is maintained at 2.0 - 2.5 barg and the bottom pressure at 2.2 -2.7 barg. The feed is introduced at 360 °C at stage 6. The feed flow rate is maintained at 170 m^3/hour. The values are kept like that of the distillation process of a typical refinery. Peng Robinson equation has been selected as the thermodynamic package. The column pressure drop has been set 0.5 bar, and theoretically, 12 stages have been chosen to distillate the products.

The calculated pressure and temperature for each stage are shown in Table 5. The column height is obtained at 7000 mm from the simulation. The pressure and temperature profile is shown in Fig. 4 where the top temperature is 140 °C and the bottom is 267 °C. Each stage's temperature and pressure readings show the necessary distillation conditions for the sample to reach that stage. The data also suggests that the feed should be introduced at stage 6 and the bottoms are collected from stage 11 and the heat load of the condenser is handling a significant amount of vapor flow and energy transfer [4].

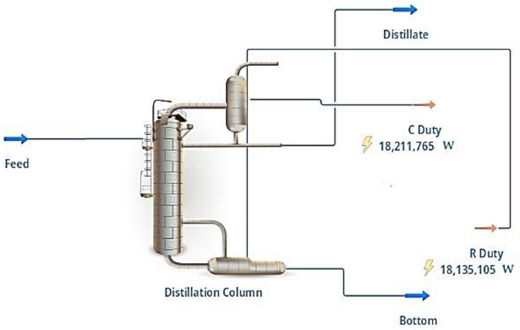

Fig. 3: Atmospheric Distillation for KTL condensate

Table 5 Property Table for Distillation Column

No. of stages	Stage Pressure	Stage Temperature
1	1.01325 bar	140.4 °C
2	1.19507 bar	130.6 °C
3	1.37689 bar	137.18 °C
4	1.5587 bar	148.57 °C
5	1.74052 bar	181.50 °C
6	1.92234 bar	222.53 °C
7	2.10416 bar	242.48 °C
8	2.2859 bar	250.8 °C
9	2.4678 bar	255.85 °C
10	2.6496 bar	259.83 °C
11	2.83143 bar	263.42 °C
12	3.01325 bar	266.77 °C
Number of Stages		12
Stream 'Feed' Stage Index		6
Stream 'Bottom' Stage Index		11
Estimated Height, mm		7000
Estimated Diameter, mm		5,902
Condenser Pressure Drop		0.5
Column Pressure Drop, bar		2
Condenser Duty, kW		1.82118E+4
Reboiler Duty, kW		-1.81351E+4

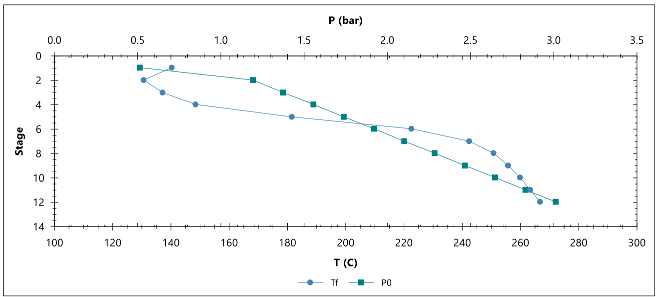

Fig. 4 Temperature and pressure profile inside the distillation column

5. Result analysis

The feed after distillation yields two material streams: distillate and bottom (Appendix A). The specific enthalpy and entropy at the distillation column are determined to be 659.28 kJ/kg and 1.275 kJ/kg.K. The density of the distillate and bottoms are 596.905 kg/m^3 and 541.596 kg/m^3. While n-C_{12} is the main ingredient in the bottom yield, n-C_8 is the main ingredient in the distillate and feed. According to the simulation results, high-temperature heating of the feed results in a lighter distillate product. The findings also indicate that a heavy product with carbon number C_{12} is dominant at the bottom and n-C_8 or a product with specific gravity of 0.74, dominates at the top. The results are then compared with real field data and presented in Appendix B.

The analysis shows that the sample under investigation is a sulfur-free medium-weight condensate according to its specific weight and compositional data [13,16]. A 7 m tall distillation column with one condenser, one reboiler, and 12 trays is advised to distill this condensate. The product obtained after atmospheric distillation has a specific gravity between 0.711 and 0.869, with n-C_8 being the main component in the feed and n-C_{12} at the bottom. The power consumption rate for the condenser is 20kW about the same as ERL [19]. The thermodynamic properties indicate that the system is stable under given conditions. Because light goods vaporize at low temperatures, this condensate type can produce distillate products quickly, but it also carries the danger of losing light products [20-21]. The findings suggest that the sample can be used to yield products like gasoline, octane, and diesel, according to the compositional analysis, specific gravity measurements and real field data comparison. The height, number of trays, and temperature can be modified to optimize the product quality and system efficiency.

6. Conclusion

The study attempts to evaluate condensate's performance and viability as a fuel source. Its conclusions are reached by combining theoretical and simulation techniques, and its uniqueness is confirmed by comparing the results to field data collected in the real world. The results imply that petroleum products can be produced from medium-weight condensate, reducing reliance on crude oil. The distillation unit's design is essential for maximizing output from condensate because the design also affects the power consumption rate and, consequently, expenses.

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NOMENCLATURE

KTL	: Kailashtila
TBP	: True Boiling Point
ABP	: Average Boiling Point
VABP	: Volume Average Boiling Point
IBP	: Initial Boiling Point
EP	: Endpoint
SG	: Specific Gravity
LDO	: Light Disel Oil
MeABP	: Mean Average Boiling Point
SC	: Shortcut Column
ADU	: Atmospheric Distillation Unit
GC	: Gas Chromatography
MW	: Molecular Weight
ERL	: Eastern Refinery Limited
ALC	: Arabian Light Crude
JBO	: Jute Batching Oil
HSD	: High-Speed Diesel
HSFO	: High-Sulfur Fuel Oil

Appendix A

Property	**Feed**	**Distillate**	**Bottom**	**Component**	**Mixture Molar Fraction**		
					Feed	Distillate	Bottom
Temperature, °C	360	140.401	266.773	N_2	1.01859E-09	1.01859E-09	7.802E-25
Pressure, bar	51.239	0.51325	3.01325	CO_2	1.01859E-09	1.01859E-09	5.859E-23
Mass Flow, kg/h	3.73758E+08	3.73758E+08	56061.2	C_1	1.42603E-06	1.42603E-06	1.152E-20
Volumetric Flow, m3/h	170	626.160	103.511	C_2	1.42093E-06	1.42093E-06	3.496E-19
Density (Mixture), kg/m^3	2198.5	596.905	541.596	C_3	1.98777E-05	1.98777E-05	6.687E-17
Specific Enthalpy (Mixture), kJ/kg	659.277	-79.1447	283.917	N-C_4	2.77566E-05	2.77566E-05	1.269E-15
				N-C_5	0.000143448	0.000143448	7.826E-14
Specific Entropy kJ/[kg.K]	1.27574	-0.11331	0.766778	N-C_6	0.00235315	0.00235315	1.609E-11
				N-C_7	0.0467066	0.0467066	9.576E-09
Thermal Conductivity (Mixture), W/[m.K]	0.0351278	0.0935374	0.083056	N-C_8	**0.950316**	**0.950316**	2.321E-05
				N-C_9	0.000104339	0.000104339	3.981E-07
Molecular Weight Mixture), kg/kmol	113.504	113.504	170.248	N-C_{10}	2.08388E-05	2.08388E-05	1.234E-05
				N-C_{11}	7.46185E-05	7.46185E-05	0.006038
				N-C_{12}	0.000102898	0.000102898	**0.993926**
				iC_4	1.43917E-05	1.43917E-05	3.459E-16
				iC_5	9.88614E-06	9.88614E-06	3.450E-15
				Benzene	0.000103514	0.000103514	1.087E-12
				Toluene	1.06321E-08	1.06321E-08	6.551E-15

Appendix B

Property	KTL condensate	Partex Petro Ltd**.**	ERL.
SG	0.778	0.7522 (Imported condensate)	0.858(ALC) 0.828 (Murban)
Feed Temperature	360°C (ADU)	60-70°C (ADU)	366°C (ADU)
No. of trays	12	37	33
Feed flow rate m^3/h	170	50	180-220
Product	C_1- C_{7+} Specific gravity: 0.711-0.869 Major constituent: N-C_8 (feed) N-C_{12} (bottom)	LPG (4.7%), Light Naphtha (26.4%), Reformate (55.5%), JET fuel (1.3%), Diesel (12.1%), Octane and petrol	LPG, SBP, petrol, octane, naptha, kerosene, mineral turpentine, Aviation fuel, JBO, HSD, LSDO, LDO, HSFO, LSFO, Bitumen
Temperature at top and bottom, ˚C	140 & 267	85-90 & 272-275	127-134 & 360-362
Column height, m	7	3.4	26
Condenser duty	20 kW (SC) 18 kW (ADU)	-	Aero condenser (8) 8*30=240 kW
Total Sulfur content	0 % (GC)	0.25 (ASTM D 4294)	1.8 (ALC) 0.74 (Murban)