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An Experimental Investigation of Steam Distillation of Trinidad Crude Oils

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Abstract: *In steam flooding operations, oil recovery by steam distillation can be in the range of 5.0 % to 60.0 %, and there is a need for separate experimental studies and data for accurate steam flood design and predictions. Steam distillation studies were conducted on six Trinidad oil samples with gravities ranging from 11.6° to 30.6° API (American Petroleum Institute) using a locally assembled steam distillation apparatus. The experiments were performed in an 'open' (without a porous medium) cell, 91.0 cm long and 3.81 cm in diameter. The six oil samples were distilled using saturated steam at pressures ranging from 0.101 to 4.654 MPa and steam temperatures from 100 to 260 °C. The results obtained were tabulated and displayed graphically for comparison. Steam distillation yield increased significantly with an increasing saturated steam conditions for the same sample. Furthermore, for the same saturated steam conditions, steam distillation yield increased with increasing API gravity. The increase was in the range of just above 2.0 % at a steam distillation factor of 0.1 to just below 60.0 % at a steam distillation factor of 10. The results further showed that beyond a steam distillation factor of 4.0, the increase in the distillation yield was under 7.0 %. Although steam distillation yield correlated well with steam distillation factor, it cannot be correlated with API gravity because of differences in crude type which can affect the distillation process. The data obtained from this study are not available in the open literature and has important applications when performing steam flood simulation studies for Trinidad oil reservoirs. It can also be used in the testing and development of steam distillation predictive models for local and worldwide applications with steam flood simulation models and for steam flood designs.*

Keywords: *Oil, steam, steam distillation, temperature, pressure, API gravity, Trinidad*

1. Introduction

Steam distillation is a term applied to a distillation process wherein steam is in direct contact with the distilling material (Perry, 1950). Steam distillation of crude oil occurs during steam flooding of oil reservoirs and has been recognised as one of the major mechanisms responsible for high oil recovery by the steam flooding process (Duerksen and Hsueh, 1983). From steam flood studies, Farouq Ali (1968) estimated the recovery range to be about 5 to 10 % of the original oil in the case of heavy oils and as much as 60 % for light oils. Steam distillation data are therefore included in the evaluation of an oil reservoir for steam flooding, steam flood simulation studies and for the optimisation of a steam flood design. These data are best determined by experimental studies or mathematical models developed from experimental data.

The effect of steam distillation on oil recovery has been investigated experimentally in several laboratories with and without a porous media (Willman et al., 1961; Ozen and Farouq Ali, 1969; Quinones, 1971; Wu and Brown, 1975; Wu and Elder, 1980; Duerksen and Hsueh, 1983). The conclusions drawn from each study, led to modifications in apparatus design and laboratory procedures for conducting steam distillation experiments quickly and accurately and also for the development of models for predicting steam distillation yield accurately.

An early attempt to study the steam distillation process by simulating steam zone conditions was conducted by Quinones (1971). In his investigation he designed experimental techniques for studying the steam distillation effects of crude oils with and without a porous medium present. The apparatus was designed to conduct experiments under constant run temperatures and pressures using saturated steam. In his experimental procedure, the hydrocarbon was first heated to the distillation temperature as suggested by Hengstebeck (1961). Next, steam at the same distillation temperature was made to pass through the hydrocarbon until the distillation pressure was reached. The effluent vapors were condensed and collected; and their respective volumes measured. Pre-heating the hydrocarbon charge reduces the experimental time.

From the experimental runs conducted in cores, Quinones (1971) found that the steam distillation effect in a porous media is similar to that for a hydrocarbon batch and that the differences in steam distillation yields with and without a porous media were less than 4.0 %.

Wu and Brown (1975) studied the effects of porous media and process parameters on the steam distillation process. The steam distillation studies were conducted in a vertically-oriented, 91.44 cm long 7.62 cm diameter cell designed so that steam distillation tests were performed in either an open cell (without porous media) or in a packed cell (with sand). Wu and Brown (1975) plotted steam distillation yield, V_o/V_{oi} (the ratio of the collected oil condensate, V_o and initial oil volume, V_{oi}) against steam distillation correlation parameter, V_w/V_{oi} (the ratio of the collected steam condensate, V_w, and initial oil volume, V_{oi}).They observed that yields were basically independent of a porous medium (with differences in yield with and without a porous media being less than 2.0 %), steam-injection rate, and initial oil volume. However, it is necessary to select an oil volume so as to obtain measurable distillate volumes, and a steam injection rate so as to allow enough time to measure and record distillate volumes from time to time. More importantly, sufficeint time is necessary for mixing of steam and oil, so as to avoid or reduce steam channeling to a minimum.

Wu and Elder (1980) adopted the above experimental guidelines and conducted steam distillation studies in an open cell (without a porous media) that started with a pre-heating phase, followed by a steam injection rate of 320 cm^3 /h and using an initial oil volume of approximately 200 cm^3. Their steam distillation runs lasted between 16 and 24 hours at a steam distillation factor of 15.

Steam distillation studies in an open cell were also conducted by Duerksen and Hsueh (1983). Theycovered a wide range of varying saturated steam conditions; the minimum was at 104 °C and 0.115 MPa and the maximum was at 260 °C and 4.654 MPa. Wu and Elder (1980) and Duerksen and Hsueh (1983) obtained steam distillation yields in the range from 12.0 % to 56.0 % of the initial oil volume.

The number of steam flooding projects has been increasing worldwide during the last 10 years (Indonesia, Kuwait, Oman, the USA, Canada, Venezuela, Saudi Arabia and China), (Guntis, 2010; Vladimir and Eduardo, 2010). In Trinidad there is a heavy oil reserve of about 1.0 billion barrels on-land, of which 40 to 60 % can be recovered by steam flooding (Hosein et al., 2011). In many cases, data on the distillation process that occurs during steam flooding are not readily available for performing steam flood simulation studies. This paper describes experimental procedures for and presents results from steam distillation studies that were conducted using a locally built steam distillation apparatus.

2. Sample Selection

The oils samples were selected from wells that were drilled in the Morne L'Enfer, Cruse and Forest formations at depths ranging from 1,100 to 2,500 feet. These are the three (3) main oil-producing reservoirs located in South of Trinidad that are suitable for steam flood operations.

3. Experimental Procedures

A schematic diagram of the steam distillation apparatus for the steam distillation of Trinidad crude oils is shown in Figure 1; while Figure 2 presents a photograph. The apparatus consists of a positive displacement pump, a steam generator, a steam distillation cell, a temperature measurement and control system, a back-pressure valve and a condensing and liquid collection system. Details on the design and operational procedures have been described by Hosein and Lewis-Hosein (2012).

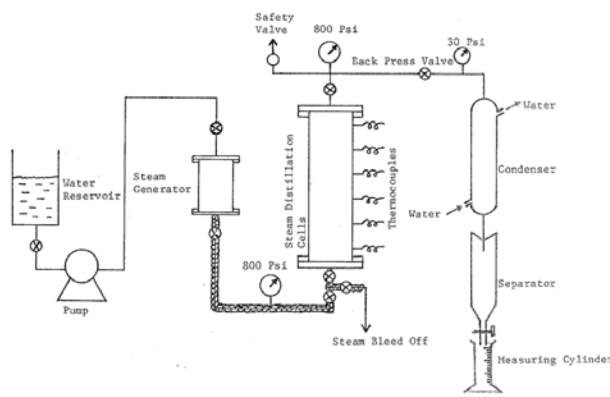

Figure 1. Schematic of Steam Distillation Apparatus

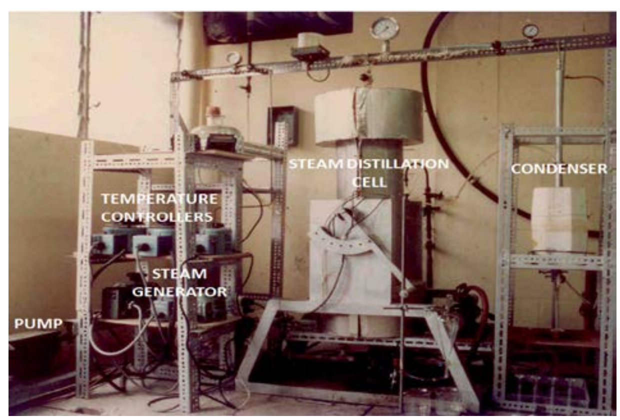

Figure 2. Steam Distillation Apparatus

The distillation runs were conducted with the cell held in a vertical position, so as to avoid steam displacement of oil during steam distillation. No porous media were used in the cell for conducting runs. As such, the difficulty of core packing before runs and core removal after runs was eliminated. Pre-heating the crude samples to the desired run temperature before injecting steam reduced experimental time considerably. A steam injection rate of 360 cm³/h allowed sufficient time to monitor and regulate constant run temperature and pressure, record distillate volumes and change measuring cylinders when filled.

An oil sample of volume 200 cm³ was injected from the bottom of the distillation cell using an ISCO pump. This was followed by the injection of 500 cm³ of water into the steam generator and steam line. The distillation cell and the steam generator were then heated to the same run temperature, after which water was injected continuously into the steam generator at 360 cm³ /h. The steam bleed-off valve was regulated until the run pressure and temperature were achieved with the saturated steam. The steam bleed-off valve was then closed off. With the variable transformers set to maintain a constant run pressure and temperature, the valve connecting the steam generator and steam distillation cell was opened. When the desired run temperature and pressure were achieved in the steam generator and steam distillation cell, the valve at the top of the distillation cell was opened to allow vapors to enter into the condenser, and oil and water volumes were measured. A run was terminated after a produced oil/water ratio of 0.01 cm³ has been recorded at least ten (10) times. With these experimental considerations, and following the experimental procedures outlined above, an experimental run lasted between twelve (12) to sixteen (16) hours.

4. Results and Discussion

The results obtained from the steam distillation experimental studies are shown in Tables 1 to 6. For each steam distillation test, the oil volume and steam volume that condensed were measured in 10 cm³ measuring cylinders. The American Petroleum Institute (API) gravity is a measure of how heavy or light a petroleum liquid is compared to water. Cumulative volumes of oil distilled were expressed as steam distillation yield, V_o/V_{oi} (i.e., Volume oil condensed/Original oil volume) and cumulative volumes of steam condensed were expressed as steam distillation factor, V_w/V_{oi} (i.e., Volume steam condensed/Original oil volume). Steam distillation yield by percentage (%) was then plotted against steam distillation factor in graphical form as shown in Figures 3 to 8.

During steam-flooding of an oil reservoir a steam zone is first created near the injection well. Oil; connate water; steam and hydrocarbon vapour; and a rock matrix are involved in steam distillation in the steam zone. In the steam zone, the pressure and temperature gradients are generally small indicating stable saturated steam conditions. The two (2) most important mechanisms that take place in this zone are steam distillation and steam displacement.

Table 1. Steam Distillation Experimental Results for a 11.7 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	2.20	2.65	2.70	1.90
0.25	3.10	4.00	4.95	3.80
0.50	5.15	6.50	6.95	7.25
1.00	6.95	7.95	9.00	10.55
2.00	8.20	9.55	11.45	13.95
3.00	9.30	10.65	13.00	16.15
4.00	9.80	11.40	14.05	17.65
6.00	10.55	12.50	15.25	18.70
8.00	11.20	13.30	16.50	19.92
10.00	11.50	13.80	17.45	20.80

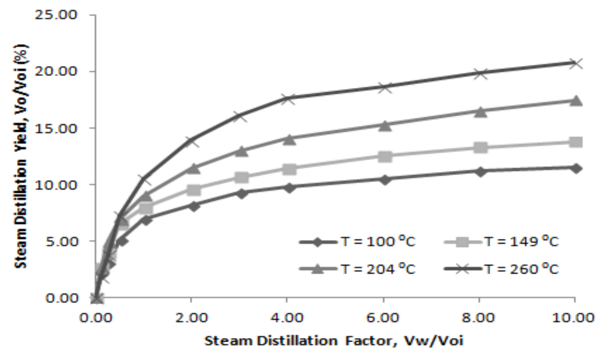

Figure 3. Correlation between Steam Distillation Yield and Steam Distillation Factor for a 11.7° API Trinidad Oil Sample

Table 2. Steam Distillation Experimental Results for a 17.2 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	3.75	5.40	3.60	3.25
0.25	7.20	8.85	7.80	8.10
0.50	9.85	10.85	10.15	11.15
1.00	11.85	13.30	13.85	14.50
2.00	14.30	16.10	17.55	19.40
3.00	16.20	19.55	21.95	24.95
4.00	18.45	21.00	25.60	28.70
6.00	19.50	22.40	27.00	30.10
8.00	20.50	24.13	28.55	32.75
10.00	20.75	25.86	30.60	34.50

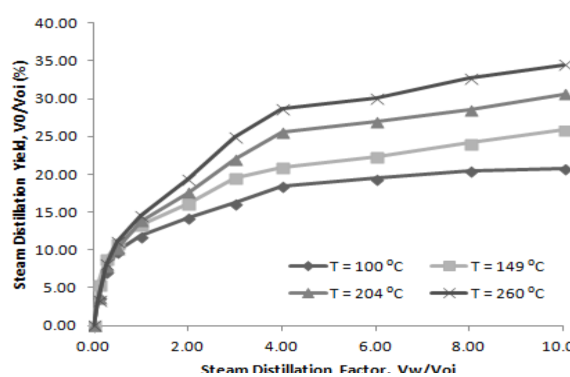

Figure 4. Correlation between Steam Distillation Yield and Steam Distillation Factor for the 17.2° API Trinidad Oil Sample

Table 3. Steam Distillation Experimental Results for a 21.3 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	4.55	5.65	5.10	4.15
0.25	8.45	9.70	9.80	8.20
0.50	10.20	11.50	11.90	10.55
1.00	12.45	14.20	15.35	16.45
2.00	16.80	18.85	20.95	23.15
3.00	18.85	21.80	26.55	29.70
4.00	20.40	23.75	29.55	32.40
6.00	21.45	25.25	31.35	36.55
8.00	22.30	27.50	32.50	37.80
10.00	23.10	28.00	33.65	39.20

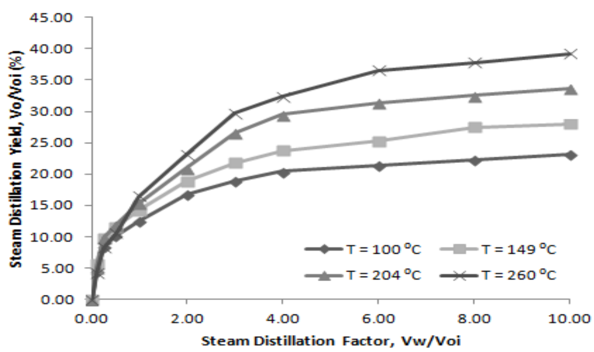

Figure 5. Correlation between Steam Distillation Yield and Steam Distillation Factor for the 21.3° API Trinidad Oil Sample

Table 4. Steam Distillation Experimental Results for a 24.8 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	4.50	6.80	4.75	4.45
0.25	8.55	9.40	9.75	9.25
0.50	12.70	13.90	14.50	15.50
1.00	15.80	18.35	19.25	22.85
2.00	19.85	22.45	25.05	30.10
3.00	22.35	25.20	30.85	36.10
4.00	24.05	27.90	33.35	39.75
6.00	25.50	30.00	36.60	42.65
8.00	26.50	31.75	39.10	44.80
10.00	27.00	32.25	40.50	46.00

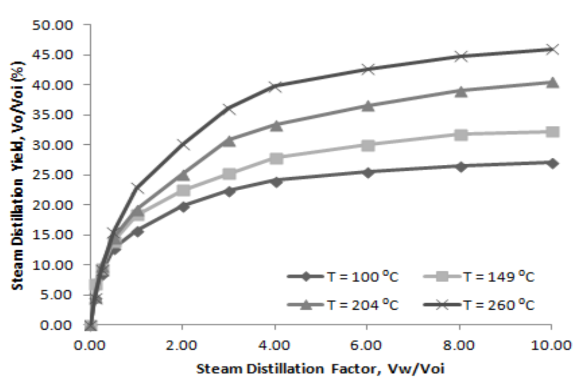

Figure 6. Correlation between Steam Distillation Yield and Steam Distillation Factor for the 24.8° API Trinidad Oil Sample

Table 5. Steam Distillation Experimental Results for a 28.0 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	8.60	9.50	7.60	5.45
0.25	12.00	12.90	13.60	10.35
0.50	15.10	16.65	18.10	19.50
1.00	19.40	20.85	23.90	29.20
2.00	22.00	24.55	29.55	38.55
3.00	25.70	28.90	36.00	44.95
4.00	27.60	31.40	38.50	47.00
6.00	28.80	33.00	40.25	48.50
8.00	29.45	34.75	42.55	49.50
10.00	30.05	36.25	44.00	50.50

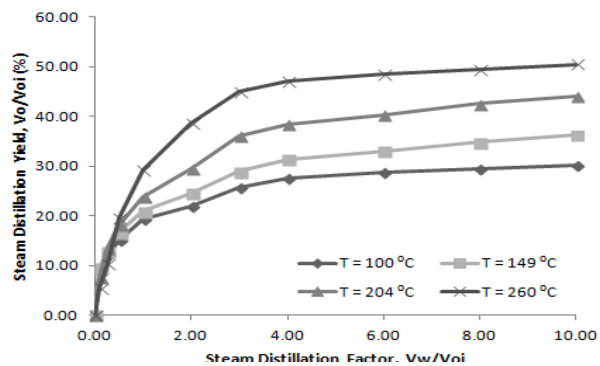

Figure 7. Correlation between Steam Distillation Yield and Steam Distillation Factor for the 28.0° API Trinidad Oil Sample

Table 6. Steam Distillation Experimental Results for a 36.6 °API Trinidad Oil Sample

Steam Distillation Factor, V_w/V_{oi} (Dimensionless)	Steam Distillation Yield, V_o/V_{oi} (%) at Various Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
0.10	13.00	12.85	12.25	11.85
0.25	17.15	17.95	17.55	16.90
0.50	21.35	23.75	23.45	24.60
1.00	25.05	27.05	30.55	33.10
2.00	28.75	30.70	36.10	41.55
3.00	31.65	34.90	41.15	49.70
4.00	33.05	37.25	44.50	53.90
6.00	34.90	38.55	47.05	56.05
8.00	36.25	39.50	48.50	57.25
10.00	36.50	40.25	49.00	58.75

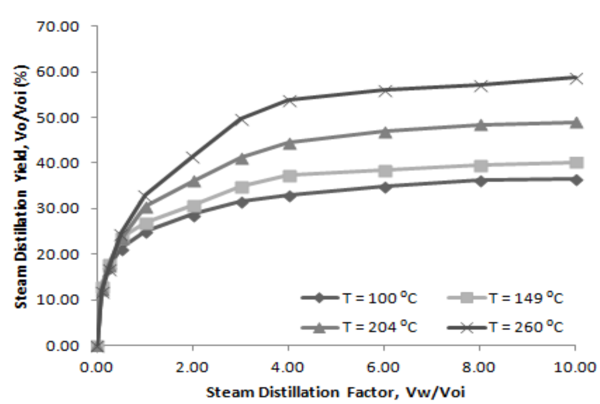

Figure 8. Correlation between Steam Distillation Yield and Steam Distillation Factor for the 30.6° API Trinidad Oil Sample

The presence of the steam vapour in the steam zone with the heated oil and hot connate water induces vaporisation of the light oil fractions and connate water. These oil and water vapours are displaced downstream by the incoming steam which condenses further down the reservoir.

Wu and Brown (1975) stated that changes in saturated steam conditions have insignificant effects on steam distillation yields. By simulating this "chipping effect", that takes place in the steam zone during steam flooding, the results from this study showed that for the same sample, steam distillation yield increased significantly with an increase in saturated steam conditions. Furthermore, for the same saturated steam conditions, steam distillation yield increased with increasing API gravity, ranging from 2.0% for the lowest API and lowest steam conditions to just below 60% for the highest API and highest steam conditions studied. The experiments conducted by Wu and Brown (1975) showed that steam distillation yields were independent of the presence of a rock matrix. As such, steam distillation studies conducted by Wu and Elder (1980) and this study did not employ porous media, so as to reduce the effort and experimental time required for each test.

The results from this study were similar to the recovery range of 5.0 % to 60.0 % reported by Farouq Ali (1968), Wu and Elder (1980) and Duerksen and Hsueh (1983). The results further show that for steam distillation factors higher than 4, the increase in the steam distillation yield was under 10.0% (under 3% for the lowest API and lowest steam conditions studied and under 7% for the highest API and highest steam conditions studied). The increases in steam distillation yield with API gravity for a steam distillation factor of 4.0 are shown in Table 7.

Table 6. Steam Distillation Experimental Results at a Steam Distillation Factor of 4.0 for Trinidad Oil Samples with API Gravities from 11.7 to 30.6

Oil Gravity API	Steam Distillation Yield, V_o/V_{oi} (%) at Steam Distillation Factor = 4, forvarious Saturated Steam Temperature, T and Pressure, P			
	T = 100°C P = 0.101 Mpa	T = 149°C P = 0.448 Mpa	T = 204°C P = 1.689 Mpa	T = 260°C P = 4.654 Mpa
11.70	9.80	11.40	14.05	17.65
17.20	18.45	21.00	25.60	28.70
21.30	20.40	23.75	29.55	32.40
24.80	24.05	27.90	33.35	39.75
28.00	27.60	31.40	38.50	47.00
30.60	33.05	37.25	44.50	53.90

Although steam distillation yield correlated well with steam distillation factor, it cannot be correlated with API gravity. From experimental studies, Wu and Brown (1975) observed a lower steam distillation yield for a 36.0° API oil than for a 26.0° API oil. This unexpected behavior resulted because of differences in wax content. In this study, the wax content of the crude samples investigated was not determined.

Preliminary studies show that for steam distillation factors ≥ 0.5, the empirical steam distillation model by Rhee and Doscher (1980) can be used to predict the experimental steam distillation yields obtained in this study. The differences between the predicted and experimental values observed were less than ± 10.0 %.

5. Conclusions

This study presents a comprehensive analysis of steam distillation for crude oils systems in Trinidad. The paper also includes a procedure for conducting steam distillation experiments.

For the oil samples studied, steam distillation yield increased significantly from 2.0% to just below 60% with increasing saturated steam conditions from 100 °C and 0.101 MPa to 260 °C and 4.654 MPa).

It was found that steam distillation yield did not increase higher than 7.0 % at steam distillation factors higher than 4.0. For the oil samples studied steam distillation yield increased with API gravity. Moreover, steam distillation yield correlated well with steam distillation factor.

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References:

Duerksen, J. H. and Hsueh, L. (1983), "Steam distillation of crude oils", *Journal of Petroleum Science and Engineering*, Vol.23, No.2, pp.265-271.

Farouk Ali, S.M. Jr. (1968), "Practical consideration in steamflooding", *Producers Monthly*, Vol.32, No.l, pp.13-16.

Guntis, M. (2010), "Special report: EOR/Heavy oil survey: CO_2 miscible, steam dominate enhanced oil recovery processes", *Oil and Gas Journal*, Vol.109, No.36, September, pp.62-69.

Hengstebeck, R.J. (1961), *Distillation: Principles and Design Procedures*, Reinhold Publishing, New York

Hosein, R. and Lewis-Hosein, R. (2012), "Design and operational procedures for a locally made steam distillation apparatus", *Advances in Petroleum Exploration and Development*, Vol.4, No.2, pp.1-7.

Hosein, R., Bertrand, W. and Dawe, R. (2011), "Heavy oil recovery in Trinidad and Tobago by steam injection: Past, present and future (Trinidad EOR-1)", *Oil and Gas Journal*, Vol.109, No.36, September, pp.62-69.

Ozen, A.S. and Farouq Ali, S.M.Jr. (1969), "An investigation of the recovery of the Bradford crude by steam injection", *The Journal of Petroleum Technology*, Vol.2l, No.6, pp.692-698.

Perry, J. H. (1950), *Chemical Engineers' Handbook*, Third Edition, McGraw-Hill Book, New York

Quinones-Martinez, O.A. (1971), *Steam Distillation*, (*Unpublished Master's thesis)*, Department of Petroleum and Natural Gas Engineering, The Pennsylvania State University, USA.

Rhee, S.W. and Doscher, T.M. (1980), "A method for predicting oil recovery by steamflooding including the effects of distillation and gravity override", *Journal of Petroleum Science and Engineering*, Vol.20, No.4, pp.249-266.

Vladimir, A. and Eduardo, M. (2010), "Enhanced oil recovery: An update review", *Energies*, August, pp.1529-1575; doi:10.3390/en3091529.

Wu, C.H. and Brown, A. (1975), "A laboratory study on steam distillation in porous media", Paper presented at the 1975 *SPE Annual Technical Conference and Exhibition*, Dallas, Texas, September 28 to October 1.

Wu, C.H. and Elder, R.B. (1980), *Crude Oil Steam Distillation in Steam flooding*, U.S. Department of Energy, Colorado

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