

CHAPTER V

RESULTS AND DISCUSSION

5.1 Determination of Temperature and Product Yield Profiles

- During the course of implementing this section of the experiments, it was found that the temperature of the feedstock entering the first distillation unit could not be raised above 150°C. There is a possibility that the bottom section of the distillation unit might be dry, resulting in a disruption of the flow feeding the second distillation unit.

- The feedstock entering the first distillation unit could not be lowered than 125°C because the level of the liquid in the bottom section of the distillation tower might be higher than the allowed level. Should it in the case that this happen, the distillation process would be disrupted due to flooding of the distillation tower.

- As the result of the above, the temperatures were increased at an increment of 5°C from 125°C to 150°C

5.1.1 The Results of Varying Feed Inlet Temperature by ASTM D86

Analysis

The products obtained from each distillation tower at a given temperature were distilled according to ASTM D86. In addition API Gravity was determined for each sample collected, which is shown in table 5.1 - 5.5.

Table 5.1 Product Yields of Rubber Solvent

Feedstock						
Temperature, °C	125	130	135	140	145	150
API						
Gravity@60°F	59.2	58.7	59.0	59.8	59.2	58.4
Sp.Gr.@60/60°F	0.7420	0.7440	0.7428	0.7397	0.7420	0.7451
Boiling Range, °C						
IBP	68.0	69.0	73.0	70.0	70.0	72.0
(%Yield@TIBP)	(0.5%)	(0.2%)	(-)	(-)	(-)	(-)
10%	80.5	80.0	81.5	79.0	77.0	80.0
(%Yield@T10)	(8.0%)	(7.5%)	(5.0%)	(-)	(13.0%)	(8.0%)
30%	86.0	85.5	85.0	83.0	83.0	84.0
50%	90.0	89.5	88.5	87.0	87.0	88.0
70%	95.5	96.0	93.0	91.0	92.0	92.5
90%	104.0	104.0	100.0	98.0	101.0	100.0
(%Yield@T90)	(77.5%)	(72.0%)	(86.0%)	(-)	(86.0%)	(86.5%)
95%	111.0	110.0	105.0	103.0	105.0	105.0
(%Yield@T95)	(89.0%)	(89.0%)	(94.0%)	(-)	(94.0%)	(94.0%)
EP	112.0	111.0	105.5	105.0	106.0	106.0
(%Yield@TEP)	(92.5%)	(92.0%)	(95.0%)	(-)	(95.0%)	(-)
Recovery, %Vol.	96.0	95.5	96.0	97.0	95.8	96.0
Loss, %Vol.	4.0	4.5	4.0	3.0	4.2	4.0

As shown in Table 5.1, the initial boiling points (IBP) of Rubber solvents were observed with increasing feed inlet temperature. However, the end points decreased with increasing feed inlet temperatures. This is probably the result of the increased temperature at the top of the column, which would result in the loss of the lower boiling point components into the products. Throughout this experiment, the reflux ratio was kept constant and the cooling rate was also kept constant. Therefore, this resulted in the reflux's inability to maintain

the temperatures at the top of the column. With increasing temperatures of the feed inlet, the specific gravities of the products were observed to increase as well.

Table 5.2 Product Yields of Straight Run Light Hydrocarbon

Feedstock Temperature, °C	125	130	135	140	145	150
API Gravity@60°F	52.5	51.8	52.4	54.7	51.9	51.6
Sp.Gr.@60/60°F	0.7690	0.7720	0.7690	0.7599	0.7715	0.7728
BoilingRange, °C						
IBP	87.0	83.0	89.0	83.0	91.0	92.0
(%Yield@TIBP)	(-)	(-)	(-)	(-)	(-)	(-)
10%	103.0	103.0	102.0	98.0	104.0	107.0
(%Yield@T10)	(-)	(5.0%)	(2.0%)	(-)	(4.0%)	(2.0%)
30%	110.0	111.0	109.5	104.0	112.0	112.0
50%	117.0	118.0	115.0	109.0	118.0	118.5
70%	124.0	126.0	121.0	115.0	125.0	126.5
90%	135.0	137.5	131.5	126.0	138.0	139.0
(%Yield@T90)	(-)	(70.0%)	(82.0%)	(-)	(72.0%)	(69.0%)
95%	142.5	146.0	137.5	135.0	145.0	147.0
(%Yield@T95)	(-)	(87.0%)	(93.5%)	(-)	(87.0%)	(86.0%)
EP	145.0	155.0	141.0	141.0	149.0	154.0
(%Yield@TEP)	(-)	(93.0%)	(96.5%)	(-)	(93.0%)	(91.5%)
Recovery, %Vol.	97.0	96.5	96.5	96.5	96.0	96.0
Loss, %Vol.	3.0	3.5	3.5	3.5	4.0	4.0

For Straight Run Light Hydrocarbon, as shown in Table 5.2, the IBP and EP of the products were observed to increase in parallel with increasing feed inlet temperatures. This resulted in heavier and higher values of the specific gravity of the products with increasing feed inlet temperature.

Table 5.3 Product Yields of Spirit

Feedstock Temperature, °C	125	130	135	140	145	150
API Gravity@60°F	46.8	46.6	47.5	47.3	48.0	48.5
Sp.Gr.@60/60°F	0.7936	0.7945	0.7905	0.7914	0.7883	0.7861
Boiling Range, °C						
IBP	137.0	141.0	130.0	132.0	138.0	140.0
(%Yield@TIBP)	(-)	(-)	(3.0%)	(-)	(-)	(-)
10%	144.0	147.0	134.5	138.0	145.0	145.0
(%Yield@T10)	(0.1%)	(-)	(23.5%)	(-)	(-)	(-)
30%	148.0	154.0	139.0	141.0	150.0	152.0
50%	152.0	157.0	141.5	143.0	155.0	158.0
70%	156.0	161.5	144.5	147.0	160.0	163.0
90%	165.0	169.0	152.0	153.0	169.0	171.0
(%Yield@T90)	(-)	(27.0%)	(92.0%)	(-)	(43.0%)	(31.0%)
95%	170.0	175.0	158.0	158.0	174.0	176.0
(%Yield@T95)	(-)	(54.0%)	(95.0%)	(-)	(62.0%)	(50.0%)
EP	178.0	187.0	171.0	171.0	180.0	183.0
(%Yield@TEP)	(95.5%)	(93.5%)	(97.0%)	(-)	(93.0%)	(90.0%)
Recovery, %Vol.	97.5	98.8	97.0	99.0	97.5	99.0
Loss, %Vol.	2.5	1.2	3.0	1.0	2.5	1.0

For Spirit, as illustrated in Table 5.3, there would appear to be no observable trends with increasing feed inlet temperatures, EP and IBP. It is interesting to note that this product was obtained from the second column, which might suggest that the influence of the furnace is more removed for the second column than for the first tower.

Table 5.4 Product Yields of Distillate

Feedstock Temperature, °C	125	130	135	140	145	150
API	43.5	43.0	44.1	45.6	43.1	42.9
Gravity@60°F						
Sp.Gr.@60/60°F	0.8086	0.8109	0.8058	0.7990	0.8104	0.8114
Boiling Range, °C						
IBP	152.5	149.0	140.0	143.0	147.0	151.0
(%Yield@TIBP)	(-)	(-)	(1.0%)	(-)	(-)	(-)
10%	167.5	169.0	152.5	157.0	160.0	172.0
(%Yield@T10)	(1.0%)	(1.5%)	(19.0%)	(-)	(4.0%)	(2.0%)
30%	181.0	182.0	163.0	167.0	180.0	187.0
50%	195.0	195.0	177.0	176.0	194.0	201.5
70%	214.0	212.0	194.5	188.0	209.0	218.5
90%	245.0	241.0	232.0	212.0	237.0	243.0
(%Yield@T90)	(69.0%)	(70.0%)	(81.0%)	(-)	(73.0%)	(64.0%)
95%	262.0	256.0	252.0	229.0	250.0	256.0
(%Yield@T95)	(81.5%)	(83.5%)	(89.0%)	(-)	(86.0%)	(82.0%)
EP	276.0	271.0	266.0	249.0	260.0	286.0
(%Yield@TEP)	(91.0%)	(93.0%)	(94.0%)	(-)	(94.0%)	(93.0%)
Recovery, %Vol.	97.0	97.5	97.5	99.0	97.0	97.5
Loss, %Vol.	3.0	2.5	2.5	1.0	3.0	2.5

Similarly with Spirit, the IBP and EP's of the distillate did not correlate well with increasing feed inlet temperatures. As already suggested earlier, the influence of the furnace might be less for the second tower, from which the distillate solvent was obtained.

Table 5.5 Product Yields of Light Distillate

Feedstock Temperature, °C	125	130	135	140	145	150
API Gravity@60°F	38.9	40.6	39.0	39.7	39.4	39.4
Sp.Gr.@60/60°F	0.8304	0.8222	0.8299	0.8265	0.8280	0.8280
Boiling Range, °C						
IBP		181.5	179.0	155.0	167.0	174.0
(%Yield@TIBP)	175.0	(-)	(-)	(-)	(-)	(-)
10%	(-)	203.0	202.0	182.5	198.0	197.5
(%Yield@T10)	202.0	(0.1%)	(0.5%)	(-)	(3.0%)	(2.0%)
30%	(2.0%)	236.0	234.0	223.0	234.0	235.0
50%	238.0	259.5	260.5	256.0	261.0	257.5
70%	263.5	283.0	286.0	282.0	288.0	282.0
90%	287.0	328.0	325.5	329.5	333.0	326.0
(%Yield@T90)	329.5	(90.5%)	(89.8%)	(-)	(88.5%)	(91.0%)
	(90.0%)					
Recovery, %Vol.	92.5	92.1	94.1	91.75	93.0	94.7
Loss, %Vol.	7.5	7.9	5.9	8.25	7.0	5.3

As shown in Table 5.5, there would appear to be no observable trends for IBP and EP's with increasing feed inlet temperatures.

5.1.2 The Results of Varying Feed Inlet Temperature by ASTM D5443

Analysis

Products obtained from the experiments were analyzed using the PIONA method according to the procedure of ASTM D5443 - 93. The products were analyzed for the composition (by volume and weight) of saturated naphthenes, paraffin, unsaturated naphthenes, paraffin and aromatics. The results of the analyses of the products covering rubber solvent, straight run light hydrocarbon, spirit and distillate are given in table 5.6 - 5.9. Gas chromatograph analysis based on ASTM D5443 was not able to be performed on the light distillate product, due to the heavier ends of this product are above the temperature limits (200°C) required by this ASTM method. Analysis of this product would have resulted in deposition of the fraction that was above 200°C inside the column of the GC.

Table 5.6 PIONA Analysis of Rubber Solvent

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 4					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.03	0	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 5					
Saturated					
Naphthenes	0.45	0.34	0.36	0.35	0.44
Paraffin	3.00	1.66	1.45	1.40	2.04
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 6					
Saturated					
Naphthenes	9.64	9.31	11.11	10.70	11.91
Paraffin	16.23	14.64	16.53	16.33	20.16
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	5.89	5.13	6.66	5.87	7.75

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 7					
Saturated					
Naphthenes	22.42	24.13	24.50	25.65	21.36
Paraffin	20.29	21.43	23.17	24.12	20.08
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	10.39	11.09	9.98	10.00	9.27
C - 8					
Saturated					
Naphthenes	4.54	4.83	2.59	2.33	2.81
Paraffin	6.00	6.44	3.28	2.88	3.66
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0.63	0.50	0.14	0.13	0.25
C - 9					
Saturated					
Naphthenes	0.07	0.06	0	0	0
Paraffin	0.16	0.14	0	0	0.05
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 10					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.16	0.18	0.18	0.19	0.15
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0
C - 11					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.04	0.04	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

As shown in Table 5.6, the dominant component of Rubber Solvent is C₇ hydrocarbon, which consist of mainly saturated naphthene and paraffin. The range of hydrocarbon components for Rubber Solvent is from C₅ to C₁₀. In fact, from C₉ on the composition trailed off sharply.

Table 5.7 PIONA Analysis of Straight Run Light Hydrocarbon

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 4					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.04	0.04	0.03	0.02	0.04
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 5					
Saturated					
Naphthenes	0.12	0.11	0.09	0.08	0.10
Paraffin	0.72	0.74	0.56	0.45	0.66
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 6					
Saturated					
Naphthenes	3.21	3.10	2.93	2.57	2.80
Paraffin	3.83	3.79	3.32	2.82	3.27
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	2.08	1.94	1.79	1.53	1.81

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 7					
Saturated					
Naphthenes	12.93	12.27	13.69	13.15	12.27
Paraffin	8.86	8.51	8.93	8.47	7.98
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	8.65	7.90	9.63	9.67	8.92
C - 8					
Saturated					
Naphthenes	11.86	11.42	13.70	13.78	13.24
Paraffin	15.44	15.08	18.34	18.53	17.25
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	16.03	16.23	14.44	15.44	16.63
C - 9					
Saturated					
Naphthenes	3.88	4.04	3.10	8.51	3.61
Paraffin	6.31	10.20	5.63	2.71	8.87
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	1.30	1.80	0.69	0.78	1.03

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 10					
Saturated					
Naphthenes	2.87	0.15	1.87	0	0
Paraffin	1.54	2.32	0.90	1.08	1.18
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0.02	0	0	0
C - 11					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.23	0.24	0.29	0.33	0.26
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

Based on GC Analysis (ASTM D5443), the main component of Straight Run Light Hydrocarbon is C₈ hydrocarbon. This component consists principally of saturated naphthenes, paraffin and aromatics. The range of hydrocarbon components are from C₅ to C₁₁. However, at C₁₁ fraction, the amounts of C₁₁ hydrocarbon are small and not more than 0.5% by volume.

Table 5.8 PIONA Analysis of Spirit

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 4					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 5					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 6					
Saturated					
Naphthenes	0.02	0.02	0.08	0.02	0.07
Paraffin	0	0	0.04	0	0.04
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0.03	0.04	0.06	0.02	0.05

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 7					
Saturated					
Naphthenes	0.88	0.81	1.31	0.88	1.01
Paraffin	0.40	0.40	0.59	0.34	0.46
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0.89	0.04	1.41	0.99	1.08
C - 8					
Saturated					
Naphthenes	3.70	3.05	6.45	4.38	4.74
Paraffin	4.24	4.33	7.40	5.07	4.79
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0.05
Aromatics	14.96	11.20	26.91	16.53	19.41
C - 9					
Saturated					
Naphthenes	12.86	18.15	19.84	14.74	9.06
Paraffin	11.91	0	13.00	11.50	18.72
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	17.43	19.08	9.11	15.90	15.07

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 10					
Saturated					
Naphthenes	1.56	1.47	0.69	1.39	1.08
Paraffin	22.56	26.53	10.96	20.58	18.45
Unsaturated					
Naphthenes	0	0	0.02	0	0.02
Paraffin	0	0	0	0	0
Aromatics	1.08	1.73	0.29	0.92	0.41
C - 11					
Saturated					
Naphthenes	0.55	0.88	0	0.47	0.36
Paraffin	3.31	5.75	0.89	3.01	2.28
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

The dominant hydrocarbon component in Spirit Solvent, as shown in Table 5.8, is C₉ fraction. As with other dominant fractions, this fraction consists of principally saturated naphthenes, paraffin and C₉ aromatics. The range of hydrocarbon began with the C₆ fraction. Traces of C₄ and C₅ fraction were not observed.

Table 5.9 PIONA Analysis of Distillate

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 4					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 5					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 6					
Saturated					
Naphthenes	0.05	0.02	0.07	0.01	0
Paraffin	0	0	0.04	0	0
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	1.26	1.36	0.96	1.17	1.34

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 7					
Saturated					
Naphthenes	0.54	0.58	0.84	0.46	0.29
Paraffin	0.25	0.25	0.39	0.20	0.12
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0.59	0.56	0.75	0.59	0.30
C - 8					
Saturated					
Naphthenes	1.43	1.31	2.36	1.46	1.00
Paraffin	1.96	1.45	2.64	1.61	0.96
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	3.93	3.67	6.55	3.82	2.95
C - 9					
Saturated					
Naphthenes	5.29	1.86	6.18	3.24	1.70
Paraffin	0	3.51	4.86	2.38	2.81
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	7.96	6.60	10.45	7.55	7.32

Feed Inlet Temperature	125°C	130°C	135°C	140°C	150°C
PIONA Analysis	% Volume				
C - 10					
Saturated					
Naphthenes	0.61	0.53	0.89	0.59	0.49
Paraffin	12.98	10.97	15.55	12.73	11.54
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	4.63	4.83	3.75	4.56	5.00
C - 11					
Saturated					
Naphthenes	1.77	1.36	1.13	1.36	1.77
Paraffin	10.86	11.85	9.20	11.57	11.15
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

The dominant hydrocarbon in distillate solvent is the C₁₀ fraction, as shown in Table 5.9. Distillate solvent hydrocarbon composition began with C₆ and ended with C₁₁. However, beset by limitation of ASTM D5443, analyses beyond C₁₁ were not possible and this product showed a hydrocarbon fraction greater than 200°C.

5.2 Determination of Feed Flowrate and Product Yield Profiles

5.2.1 The Results of Varying Feed Flowrate by ASTM D86 Analysis

The products obtained from the second distillation tower at a given feed flowrate were distilled according to ASTM D86. In addition API Gravity was determined for each sample collected, which shown in table 5.10 - 5.12.

Table 5.10 Product Yields of Straight Run Light Hydrocarbon

Feed Flowrate, GPM	41	43	45	47
API Gravity @ 60°F	50.5	50.5	50.4	49.9
Sp.Gr. @ 60/60°F	0.7775	0.7775	0.7779	0.7800
Boiling Range, °C				
IBP	100.0	100.0	98.0	107.0
(%Yield @ TIBP)	(-)	(-)	(-)	(-)
10%	111.0	111.0	112.0	116.0
(%Yield @ T10)	(12.0%)	(12.5%)	(-)	(0.3%)
20%	115.0	114.0	115.5	119.0
30%	117.5	118.0	119.0	121.5
40%	121.0	120.5	122.0	124.0
50%	124.0	124.0	125.5	123.0
60%	126.0	127.0	128.0	131.5
70%	129.0	130.0	131.5	135.5
80%	134.5	134.5	136.0	141.0
90%	141.5	141.0	143.0	151.5
(%Yield @ T90)	(91.5%)	(91.7%)	(-)	(83.0%)
95%	151.0	150.0	152.0	-
(%Yield @ T95)	(-)	(-)	(-)	(-)
EP	151.0	151.0	152.0	152.0
(%Yield @ TEP)	(-)	(-)	(-)	(-)
Recovery, %Vol.	95.0	95.0	95.0	93.0
Loss, %Vol.	5.0	5.0	5.0	7.0

See all of discussion in Chapter VIII (conclusions)

Table 5.11 Product Yields of Spirit

Feed Flowrate, GPM	41	43	45	47
API Gravity @ 60°F	44.4	45.7	45.2	43.0
Sp.Gr. @ 60/60°F	0.8044	0.7985	0.8008	0.8109
Boiling Range, °C				
IBP	149.0	147.0	154.0	155.0
(%Yield @ TIBP)	(2.5%)	(13.5%)	(-)	(-)
10%	157.5	153.0	158.5	161.0
(%Yield @ T10)	(13.0%)	(33.5%)	(-)	(0.2%)
20%	160.0	155.0	160.0	163.0
30%	163.0	158.0	161.0	164.0
40%	164.5	160.0	162.5	166.5
50%	166.0	161.5	164.0	168.0
60%	168.0	163.0	166.0	169.0
70%	170.0	165.0	168.0	171.0
80%	173.0	168.0	170.5	173.0
90%	176.0	172.0	174.0	176.5
(%Yield @ T90)	(84.0%)	(94.5%)	(-)	(83.5%)
95%	182.0	174.0	177.0	182.0
(%Yield @ T95)	(-)	(96.0%)	(-)	(84.5%)
EP	183.0	182.0	186.0	188.0
(%Yield @ TEP)	(-)	(-)	(-)	(-)
Recovery, %Vol.	96.0	97.0	98.0	98.0
Loss, %Vol.	4.0	3.0	2.0	2.0

Table 5.12 Product Yields of Distillate

Feed Flowrate, GPM	41	43	45	47
API Gravity @ 60°F	38.2	39.0	38.9	38.0
Sp.Gr. @ 60/60°F	0.8338	0.8299	0.8304	0.8348
Boiling Range, °C				
IBP	169.5	170.0	171.0	179.0
(%Yield @ TIBP)	(0.01%)	(0.05%)	(-)	(-)
10%	180.0	177.0	177.5	181.0
(%Yield @ T10)	(0.4%)	(12.0%)	(-)	(-)
20%	182.0	179.0	180.0	183.0
30%	184.5	181.0	182.0	184.0
40%	187.0	182.5	184.5	186.5
50%	190.0	184.5	186.5	188.0
60%	192.0	186.5	190.0	190.5
70%	196.0	190.0	193.5	194.0
80%	202.0	194.0	199.0	199.0
90%	216.0	205.0	212.0	210.0
(%Yield @ T90)	(89.0%)	(93.0%)	(-)	(91.0%)
95%	231.0	220.0	233.0	226.0
(%Yield @ T95)	(95.5%)	(-)	(-)	(-)
EP	256.0	249.0	252.0	246.0
(%Yield @ TEP)	(-)	(-)	(-)	(-)
Recovery, %Vol.	98.0	97.5	97.0	98.5
Loss, %Vol.	2.0	2.5	3.0	1.5

5.2.2 The Results of Varying Feed Flowrate by ASTM D5443 Analysis

Products obtained from the experiments were analyzed using the PIONA method according to the procedure of ASTM D5443 - 93. The products were analyzed for the composition (by volume and weight) of saturated naphthenes, paraffin, unsaturated naphthenes, paraffin and aromatics. The results of the analyses of the products covering straight run light hydrocarbon, spirit and distillate are given in Table 5.13 - 5.15.

Table 5.13 PIONA Analysis of Straight Run Light Hydrocarbon

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 4				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0.01	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 5				
Saturated				
Naphthenes	0.05	0.06	0.06	0.03
Paraffin	0.21	0.25	0.25	0.12
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 6				
Saturated				
Naphthenes	1.86	1.96	1.91	1.42
Paraffin	1.56	1.71	1.68	1.11
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	1.46	1.57	1.54	1.11

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 7				
Saturated				
Naphthenes	10.01	10.09	9.64	8.49
Paraffin	5.32	5.51	5.30	4.34
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	8.18	8.18	7.78	7.00
C - 8				
Saturated				
Naphthenes	12.56	12.23	11.83	11.75
Paraffin	15.22	14.84	14.26	14.17
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	19.89	19.84	20.23	19.70
C - 9				
Saturated				
Naphthenes	5.01	5.11	12.29	5.79
Paraffin	12.09	12.26	5.58	13.40
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	2.42	2.30	2.84	4.31

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 10				
Saturated				
Naphthenes	0.62	0.71	0.83	1.04
Paraffin	3.03	2.93	3.44	5.55
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0.06	0	0.04	0.16
C - 11				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0.39	0.34	0.34	0.44
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0	0	0	0

Table 5.14 PIONA Analysis of Spirit

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 4				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 5				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 6				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0	0.01	0	0.01

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 7				
Saturated				
Naphthenes	0.18	0.26	0.12	0.20
Paraffin	0.06	0.13	0.04	0.07
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0.22	0.31	0.16	0.23
C - 8				
Saturated				
Naphthenes	1.16	1.74	1.02	1.00
Paraffin	1.19	1.78	1.72	1.05
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	5.85	9.22	5.94	4.46
C - 9				
Saturated				
Naphthenes	4.73	6.73	4.94	4.01
Paraffin	8.21	12.53	9.38	6.58
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	23.73	21.74	24.38	24.69

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 10				
Saturated				
Naphthenes	9.54	9.40	9.97	9.75
Paraffin	22.87	22.07	24.54	23.98
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	9.26	5.15	6.75	9.80
C - 11				
Saturated				
Naphthenes	2.58	1.90	2.38	2.80
Paraffin	7.56	5.09	6.34	8.34
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0	0	0	0

Table 5.15 PIONA Analysis of Distillate

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 4				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 5				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
C - 6				
Saturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0	0	0	0

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 7				
Saturated				
Naphthenes	0.06	0.12	0.07	0.06
Paraffin	0	0.05	0	0
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0.07	0.13	0.08	0.07
C - 8				
Saturated				
Naphthenes	0.25	0.37	0.28	0.24
Paraffin	0.35	0.54	0.28	0.29
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	1.02	1.35	1.17	0.99
C - 9				
Saturated				
Naphthenes	0.76	0.96	0.86	0.60
Paraffin	1.14	1.53	1.27	1.06
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	13.57	16.69	15.72	13.55

Feed Flowrate (GPM)	41	43	45	47
PIONA Analysis	%Volume			
C - 10				
Saturated				
Naphthenes	0.36	5.52	0.37	2.54
Paraffin	12.31	10.96	14.73	10.12
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	25.48	24.57	25.06	25.30
C - 11				
Saturated				
Naphthenes	0.89	3.25	0.95	0.98
Paraffin	13.28	12.38	13.91	14.19
Unsaturated				
Naphthenes	0	0	0	0
Paraffin	0	0	0	0
Aromatics	0	0	0	0

5.3 The Results of Experiment from ASTM D5443 by measure Feed Inlet Temperature versus Time

Products obtained from the experiments were analyzed using the PIONA method according to the procedure of ASTM D5443 - 93. The products were analyzed for the composition (by volume and weight) of saturated naphthenes, paraffin, unsaturated naphthenes, paraffin and aromatics. The results of the analyses of straight run light hydrocarbon which are drawn from the top of the second column by adjusting the Feed Inlet Temperature from 140°C to 150°C and are measured every 30 minutes until the process has reached the steady state at 120 minutes. The result shown in Table 5.16.

Table 5.16 PIONA Analysis of Straight Run Light Hydrocarbon

Time (Minutes)	0	30	60	90	120
PIONA Analysis	% Volume				
C - 4					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.04	0.03	0.04	0.03	0.05
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 5					
Saturated					
Naphthenes	0.10	0.09	0.10	0.10	0.12
Paraffin	0.63	0.58	0.63	0.67	0.83
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
C - 6					
Saturated					
Naphthenes	2.78	2.63	2.75	2.90	3.24
Paraffin	3.19	3.01	3.17	3.39	3.88
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	1.82	1.69	1.79	1.90	2.08

Time (Minutes)	0	30	60	90	120
PIONA Analysis	% Volume				
C - 7					
Saturated					
Naphthenes	12.81	12.24	12.36	13.02	13.90
Paraffin	8.17	7.71	7.95	8.37	9.14
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	9.68	9.17	9.17	9.67	10.05
C - 8					
Saturated					
Naphthenes	13.99	13.81	13.50	14.06	13.85
Paraffin	18.36	18.09	17.74	18.65	18.47
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0.05
Aromatics	15.88	16.62	16.43	15.45	14.25
C - 9					
Saturated					
Naphthenes	3.12	3.45	3.27	2.86	7.46
Paraffin	7.93	8.60	8.57	7.55	1.53
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0.65	0.85	0.92	0.54	0.38

Time (Minutes)	0	30	60	90	120
PIONA Analysis	% Volume				
C - 10					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.50	1.00	1.27	0.50	0.40
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0
C - 11					
Saturated					
Naphthenes	0	0	0	0	0
Paraffin	0.26	0.31	0.30	0.27	0.28
Unsaturated					
Naphthenes	0	0	0	0	0
Paraffin	0	0	0	0	0
Aromatics	0	0	0	0	0

5.4 The Results of the Experiment from ASTM D5443 by Varying Reflux Feed Rate

Products obtained from the experiments were analyzed using the PIONA method according to the procedure of ASTM D5443 - 93. The products were analyzed for the composition (by volume and weight) of saturated naphthenes, paraffin, unsaturated naphthenes, paraffin and aromatics. The experiments were controlled by changing the speed of the motor of the reflux feed rate pump on the top of the column, which can be measured from the top temperature for control of the product qualities. The results of the analyzes of the products covering Straight Run Light Hydrocarbon, Spirit and Distillate are given in Table 5.17 - 5.19.

Table 5.17 PIONA Analysis of Straight Run Light Hydrocarbon

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 4			
Saturated			
Naphthenes	0	0	0
Paraffin	0.02	0.02	0.03
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 5			
Saturated			
Naphthenes	0.12	0.09	0.12
Paraffin	0.42	0.33	0.43
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 6			
Saturated			
Naphthenes	3.00	2.38	3.05
Paraffin	2.49	1.90	2.47
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	2.73	2.16	2.74

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 7			
Saturated			
Naphthenes	14.39	11.90	14.92
Paraffin	7.35	5.99	7.57
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	12.02	10.02	12.38
C - 8			
Saturated			
Naphthenes	13.71	13.73	14.36
Paraffin	16.51	16.03	17.40
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	13.08	16.96	12.87
C - 9			
Saturated			
Naphthenes	2.73	8.96	6.66
Paraffin	6.49	2.76	1.42
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	1.71	2.40	1.05

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 10			
Saturated			
Naphthenes	0.88	1.25	0.77
Paraffin	1.96	2.67	1.35
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0.04	0.08	0.04
C - 11			
Saturated			
Naphthenes	0	0	0
Paraffin	0.22	0.26	0.31
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0	0	0

Table 5.18 PIONA Analysis of Spirit

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 4			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 5			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 6			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0	0	0

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 7			
Saturated			
Naphthenes	0.10	0.10	0.12
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0.12	0.12	0.16
C - 8			
Saturated			
Naphthenes	0.86	0.91	1.12
Paraffin	0.76	0.81	1.00
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	4.15	4.80	5.08
C - 9			
Saturated			
Naphthenes	4.03	4.82	3.10
Paraffin	3.10	3.55	4.82
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	22.59	22.63	21.85

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 10			
Saturated			
Naphthenes	16.00	17.29	15.99
Paraffin	15.20	14.33	14.65
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	9.88	9.36	9.96
C - 11			
Saturated			
Naphthenes	0.82	1.16	0.76
Paraffin	13.84	13.10	13.40
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0	0	0

Table 5.19 PIONA Analysis of Distillate

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 4			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 5			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
C - 6			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0	0	0

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 7			
Saturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0.03	0	0.02
C - 8			
Saturated			
Naphthenes	0.08	0	0.06
Paraffin	0.04	0	0
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0.40	0.26	0.35
C - 9			
Saturated			
Naphthenes	0.28	0.21	0.25
Paraffin	0.35	0.23	0.31
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	6.55	5.81	6.19

Reflux Motor (RPM)	3000	2900	2780
Top Column Temperature, °C	100	105	108
PIONA Analysis	% Volume		
C - 10			
Saturated			
Naphthenes	2.00	1.80	1.97
Paraffin	4.79	3.99	4.46
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	11.29	10.87	10.85
C - 11			
Saturated			
Naphthenes	0.30	0.25	0.27
Paraffin	10.73	9.87	9.94
Unsaturated			
Naphthenes	0	0	0
Paraffin	0	0	0
Aromatics	0	0	0