Research and simulation of a new shale oil recovery process

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ABSTRACT: Based on the in-depth study of current domestic shale oil recovery process, a new shale oil recovery process was developed and established. PRO/II process simulation software was used to simulate the new recovery process. Simulation results were analyzed and compared between the new recovery process and water scrubbing process. In water scrubbing process, energy can not be recovered, and 334000kg/h circulation water, 702103 kg/h cooling water and 16109 kg/h chilled water were required. However in the new recovery process, 8.1791 Mkcal/h heat could be effectively recovered and only 155000 kg/h circulation water was required. So quantity amount of water and energy consumption of pumps was significantly reduced in new recovery process. The products were also different in the two processes: in the water washing process, the products were shale oil, small amount of light oil and gas; however in the new process dry distillation gas was cut into gas, gasoline, diesel oil and heavy oil, which improved the utilization value of product

Keywords: shale oil; new recovery process; process comparison

1. Foreword

In recent years, as worldwide energy crisis and oil price rising，all countries was making effort to seek new sources of energy. So how to utilize oil shale received importance again. Obtained shale oil from oil shale by dry distillation technology has become an important alternative options, and the technology was given high attention by governments and the business community [1-2].

Shale oil recovery process in oil shale dry distillation technology affects directly the quality of products，energy consumption and environmental issues, so it is a key step in the process. In China, most of the shale oil recovery systems were referred to the water scrubbing process in the coking industry, and the shortcomings of this process is low energy recovery, large amount of recycling water, high energy consumption and so on. A new recovery process is developed in this paper. This process can efficiently recover heat from high-temperature dry distillation gas, and equipments were simpler. It can receive gas, gasoline, diesel oil and heavy oil, which improved the utilization value of product.

At present, little research has been conducted in shale oil recovery process. PRO/II[3] simulation software is used to simulate the recovery process, and an innovation shale oil recovery process is established.

2. Water scrubbing recovery process

Most of the shale oil recovery system ware referred to the washing process in the coking industry, and the process flow was shown in Figure 1.

The 490℃ dry distillation gas from dry distillation system contacted with 85℃ water in the water scrubbing tower. Mixer of shale oil, water, gas and shale oil residue left the tower was sent to gas-liquid separator. Separated gas was sent to the gas cooler, and was respectively cooled to 45℃ and 22℃ by cooling water and chilled water. Cooled gas was sent to electric tar precipitator by roots blower. In electric tar precipitator, shale oil droplet in the gas was cleaned maximally. Then the gas was sent to desulphurization system. The condensate in the gas cooler run into the condensate tank, and then a part of the condensate was pumped to the upper and lower section of the gas cooler by the circulation pump. The other part of the condensate was sent to the distillation gas pipes. Shale oil, water and shale oil residue separated left the gas-liquid separator was sent to mechanization settler .The mixer was divided into three levels in the order of shale oil, water, shale oil residue from top to bottom. After separation, water entered water circulation tank. A part of the water was sent to cool the dry distillation gas by the water pump. The excess water left the device as residual water.

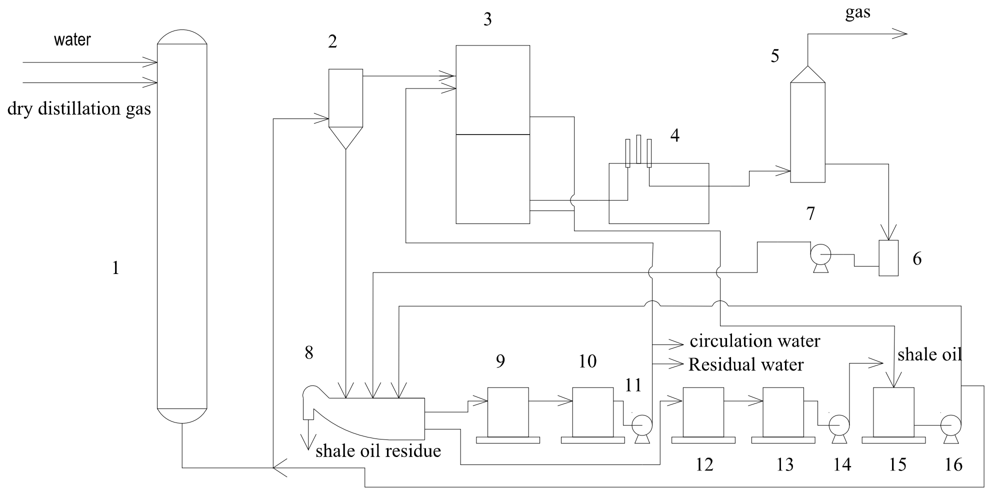

Figure 1 Water Washing Process Flow Chart

1-water washing tower；2- liquid separator；3-gas cooler；4-roots blower；5- electric tar precipitator；6- water seal tank of Electric tar precipitator ；7-pump；8- mechanization settler；9-buffer slot；10-shale oil tank；11-pump；12-hale oil tank；13-water tank；14-pump；15-condensate tank；16-pump

Shale oil was sent to the shale oil tank, and pumped to the shale oil tank farm regularly by shale oil pump. Shale oil residue separated from mechanization settler was collected by a small cart under the mechanization settler, and then sold as a fuel.

Processing capacity of dry distillation gas was 20178 kg/h, and circulation gas was 2000kg/h. Composition of dry distillation gas was shown in Table 1, composition of gas was shown in Table 2.

Table 1 Composition of dry distillation gas

Name	Content	Name	Content	Name	Content
Shale oil/g	1380	COS/ppm	105	C_2H_4/%	3.09
Light oil/g	52.6	CH_3SH/ppm	5.5	C_2H_6/%	3.72
Water/g	1253	CH_4/%	21.38	C_3H_6/%	2.30
NH_3/ppm	1200	CO/%	14.87	N_2/%	3.97
HCN/ppm	181	H_2/%	19.98	O_2/%	0.39
H_2S/g	7.23	CO_2/%	30.30		

Table 2 Composition of gas

Name	CH4/g	CO/g	H2/g	CO2/g	C2H4/g	C2H6/g	C3H6//g	N2/g	O2/g
Content/%	152.7	185.9	17.8	595.2	38.6	49.8	43.1	49.6	5.6

Utilities are as follows: recycled water is 334000 kg/h; Cooling water and chilled water for gas cooler is 702103 kg/h and 16109 kg / h.

Product of shale oil is 7262.00 kg/h, gas and light oil is 8454.13 kg/h.

3. A new recovery process

3.1. Brief introduction of the new recovery process

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Based on investigating into a large number of domestic and foreign literature, a new recovery process was established .The process was shown in Figure 2.

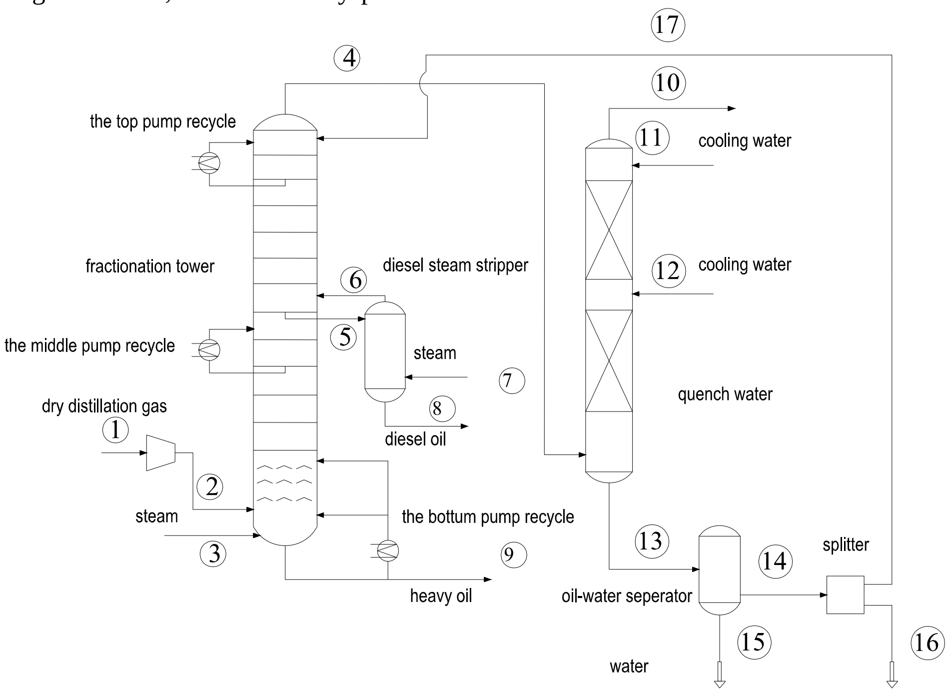

Figure 2 Flow Chart of a New Recovery Process

The feed is 460-510℃dry distillation gas with a small amount of powder. The feed got into the bottom of the fractionation tower, and contact with the cooled heavy oil from the bottom of the tower on the baffle. Overheated dry distillation oil and powder were removed. Then the saturated dry distillation gas ascended along the tower, and divided into several products. The gas left from the top of the tower. The diesel oil was draw from lateral line, and got through a diesel steam stripper to ensure that the initial boiling point of diesel met requirements. Heavy oil left from the bottom of tower.

Heat in the fractionation tower was got from the overheated state of gas. Except the product of the top left the tower in gas, the other products left the tower in liquid state. So the sensible heat and latent heat of condensate liquid products was the excess heat of the tower. Then the top pump recycle, middle pump recycle and bottom pump recycle were set to take away excess energy.

Components of the gas left the fractionating tower was water, gasoline and gas, and then run into the quench tower. In the quench tower, gas was cooled by cooling water. The temperature in the kettle of the quench tower was controlled at about 80 ℃, and the temperature in the top of the tower was about 40 ℃. The mixer of oil and water condensed in the quench tower was sent to oil-water separator. After separation a part of gasoline was cycle to the fractionation tower in order to control the endpoint of gasoline.

2.2 Raw materials

Processing capacity of dry distillation gas was 20178 kg/h, circulating gas was 2000 kg/h. Composition of dry distillation gas was shown in Table 1, and composition of gas was shown in Table 2.

2.3 Model

In this paper, PRO / II simulation software was used to simulate the process.

GS equation [3]was used to simulate of the main fractionation column, and correction of the equation was as follows: Using API[3] method to calculate the liquid density, using LK [3]method to calculate entropy and enthalpy.

SRK equation[3] was used to simulate the quench tower: using SRK mode to calculate vapor-liquid enthalpy entropy, using API method to calculate liquid density.

Table 3. Simulation results of fractionation tower

tray	temperature	pressure			flowrate（kg/h）		enthalpy
	℃	Mpa	liquid	vapor	feed	product	Mkcal/h
1	100	0.15	62241.8		3101.7L	22131.3V	-0.9581
					54741.6P	0.0W	
2	116.6	0.15	11059.7	26531.5		54741.6P	
3	131.4	0.15	11412.5	30091			
4	135.4	0.16	11346.8	30443.8			
5	137.7	0.16	11139.9	30378.1			
6	140.3	0.16	10223.5	30171.2			
7	148.2	0.16	50000.6	29254.9	587.1V		-1.4
8	172.7	0.16	13136.4	37263.6	31181.2P	31181.2P	
						2885.7L	
9	230.4	0.17	11366	34466.4			
10	266.3	0.17	11730.7	32696			
11	278.8	0.17	11524.2	33060.7			
12	285	0.17	10860.1	32854.2			
13	290.7	0.17	8922.7	32190.1			
14	302.8	0.18	67724.7	30252.7	53990.7P		-1.5
15	318.1	0.18	71603.2	35063.9			
16	335.4	0.18		38942.5	22178.0V	25196.0P	-0.7
					300.0V	53990.7P	
					25196.0P	1148.0L	

Table 4. Simulation results of quench tower

Tray	Temperature	Pressure			Flowrate（kg/h）	
	℃	Mpa	Liquid	Vapor	Feed	Product
1	36.2	0.12	65017.2		65000.0W	10560.8V
2	37.1	0.12	65100.9	10578.1		
3	40.8	0.12	65455.2	10662.5		
4	51.9	0.12	155442.1	11017.5	90000.0W	
5	51.9	0.12	155444.8	11003		
6	52	0.12	155474.1	11005.6		
7	52.7	0.12	155736.5	11035		
8	55.6	0.12	156917.1	11297.5		
9	64.9	0.12	160553.6	12477.9		
10	79.2	0.12		16114.4	22132.7V	166572.0L

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Table 5. Products

Stream Name	Diesel oil	Heavy oil	Gas	Gasoline
ASTM D86				
IBP	200.00	275.41	-251.10	86.43
5%	211.12	379.01	-251.10	145.05
10%	212.98	386.27	-196.71	156.76
30%	217.82	408.49	-159.50	177.74
50%	251.11	432.51	-87.01	185.51
70%	290.12	475.34	-72.80	190.16
90%	343.44	559.23	93.66	196.25
95%	354.87	574.96	128.21	200.89
EBP	365.64	586.52	171.47	204.45
Temperature，℃	177.23	335.43	36.19	84.16
Pressure(a),Mpa	0.22	0.18	0.12	0.12
Total Mass Rate，kg/h	2569.19	1148.02	10560.59	1609.71

2.4 Simulation results

Simulation results of the new recovery process were shown in Table 3, 4 and 5.

As shown in table 3, the top pump recycle took away heat of 0.9581 Mkcal/h, middle pump recycle took away heat of 1.4Mkcal/h and bottom pump recycle took away heat of 2.2 Mkcal/h. Temperature of diesel oil draw was 172 ℃, and it could be used to heat materials or generate stream. The temperature of heavy oil was 335℃, and it could be used to generate high-temperature steam. The total recovered heat was 45581Mkcal/h.

We can see from table 4, the gas left the fractionating tower got into the quench tower. Temperature of cooling water in the top was 36℃, and flowrate was 65000 kg/h. Temperature of cooling water in the middle was 60℃, and flowrate was 90000 kg/h. The mixer of oil and water condensed in the quench tower was sent to oil-water separator. After separation, water was cooled to 60℃, and recovery energy of 3.6456 Mkcal/h. A part of water recycle to the middle of quench tower, and the other part of water recycle to the top of quench tower after cooled to 36℃.

The products were shown in table 5. Material balance and energy balance of fractionation tower and quench tower was shown in table 6.

Table 6. Material balance and energy balance

Type	Stream	Phase	Flowrate	Enthalpy
			Kg/h	Mkcal/h
In	2	Vapor	22178	10.579
In	3	Liquid	300	0.198
In	7	Vapor	270.531	0.211
Out	8	Liquid	2569.15	0.182
Out	9	Liquid	1148.019	0.167
Out	10	Vapor	10560.587	0.963

Out	18	Liquid	6862.25	0.543
Out	16	Liquid	1609.711	0.051
Pump recycle1（tray）	draw：16	back：16		0.7
Pump recycle2（tray）	draw：16	back：14		1.5
Pump recycle3（tray）	draw：10	back：9		1.4
Pump recycle4（tray）	draw：2	back：1		0.9581
Cooler 1	Temperature	60		3.3015
Cooler 1	Temperature	36		1.3029
Material balance,（In-out）			-1.186	
energy balance,（In-out）				-0.0805

3. Comparison of the new recovery process and water scrubbing process

Currently most of the shale oil recovery systems were referred to the water scrubbing process in the coking industry, and little research has been conducted in shale oil recovery process. In this paper, a new shale oil recovery process was established, and the comparison was made between the two different processes as follow.

3.1 Equipments

The main equipments of water scrubbing process included water scrubbing tower, gas cooler, electric tar and so on. Water scrubbing process was mainly referred to water scrubbing process in the coking industry, which was learnt from the former Soviet Union in the sixties of last century. During several decades, little change was made for the process, and most of the process were designed based on experience. So process and equipment of water scrubbing process were so backward.

However, the main equipment of new recovery process were oil washing tower, quench tower, and so on. The equipment were much simple than that of water scrubbing process. The new process combined with a number of different processes, and equipments and process were advanced after decades of continuous development.

3.2 Energy Recovery

In water scrubbing process, 490 ℃ dry distillation gas contacted with plenty of 85 ℃hot water in water scrubbing tower. Gas was cooled to 90℃, and was sent to the gas cooler. Mixture of oil and water was sent to oil-water separator. After separation, water was recycled to water scrubbing tower by pump. So the energy of dry distillation gas was taken away by circulation water. The temperature of circulation water left the water washing tower was 92℃, and the energy utilization of the circulation water was limited or not available. Therefore, the energy of dry distillation gas was not recovered efficiently.

In the new recovery process, the top pump recycle, middle pump recycle and bottom pump recycle were set to take away excess energy of the tower. The top pump recycle took away heat of 0.9581 Mkcal/h, middle pump recycle took away heat of 1.4Mkcal/h and bottom pump took away heat of 2.2 Mkcal/h. In addition to pump recycle, the energy of high-temperature flow left the fractionation tower could also be fully utilized. Temperature of diesel oil draw was 172 ℃, and it could be used to heat materials or generate stream. The temperature of heavy oil was 335℃, and it could be used to generate high-temperature steam. The total recovered heat was 45581Mkcal/h.The gas from the fractionating tower got into the quench tower. The mixer of oil and water from the bottom of quench tower was sent to oil-water separator. After separation water was cooled to 60 ℃, and recovery energy of 3.6456 Mkcal/h. A part of water recycle to the middle of quench tower, and the other part of water recycle to the top of quench tower after cooled to 36℃.The total energy recovery in new recovery process was 8.1791 Mkcal/h. So the energy recovery efficiency is better than that in the water

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scrubbing process.

3.3Water consumption

In water scrubbing process, large amount of circulation water was used to cool high-temperature dry distillation gas. As shown in this paper, the amount of circulation water was 334t / h. Cooling water used in gas cooler was 702103 kg/h and 16109kg /h. So the amount of circulation water and energy consumption of the pump was great.

In the new recovery process, only 155000t/h circulation water was required in quench tower. The consumption of water and energy consumption of pump reduced significantly.

3.4 Products

In the new recovery process, oil gas was cut in gas, gasoline, diesel oil and heavy oil, but in the water scrubbing process, the product was shale oil, small amount of light oil and gas.

To conclude, the new recovery process is better than water scrubbing process, and it will be the development direction of shale oil recovery process in the future.

4. Conclusions

(1) A new shale oil recovery process was established based on the in-depth study of shale oil recovery process. PRO/II process simulation software was used to simulate the new recovery process.

(2) The main equipments of water washing process include water scrubbing tower, gas cooler, electric tar and so on. The main equipments of oil washing process are oil washing tower, quench tower, absorption tower and so on. Equipments and process are much more advanced than water washing process.

(3) In the water washing process, energy of overheated dry distillation gas was not recovered efficiently. However in the oil washing process, the total recovered energy was 8.1791 Mkcal/h. The heat could be used to heat materials or generate steam.

(4) In the water scrubbing process, the amount of circulation water was 334t/h, and cooling water used in gas cooler was 702103 kg/h and 16109kg /h. In the new washing process, circulation water required was 155000t/h. So the water and energy consumption of pump reduced significantly.

(5) In the water scrubbing process, the products were shale oil, small amount of light oil and gas. But in the new recovery process, dry distillation gas was cut in gas, gasoline, diesel oil and heavy oil.\

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