A Review on Technologies for Oil Shale Surface Retort

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Summary: In recent years, with the shortage of oil resources and the continuous increase in oil prices, oil shale has seized much more attention. Oil shale is a kind of important unconventional oil and gas resources. Oil shale resources are plentiful according to the proven reserves in places. And shale oil is far richer than crude oil in the world. Technology processing can be divided into two categories: surface retorting and in-situ technology. The process and equipment of surface retorting are more mature, and are still up to now, the main way to produce shale oil from oil shale. According to the variations of the particle size, the surface retorting technologies of oil shale can be notified and classified into two categories such as lump shale process and particulate shale process. The lump shale processes introduced in this article include the Fushun retorting technology, the Kiviter technology and the Petrosix technology; the particulate processes include the Gloter technology, the LR technology, the Tosco-II technology, the ATP (Alberta Taciuk Process) technology and the Enefit-280 technology. After the thorough comparison of these technologies, we can notice that, this article aim is to show off that : the particulate process that is environmentally friendly, with its low cost and high economic returns characteristics, will be the major development trend; Combined technologies of surface retorting technology and other oil producing technology should be developed; the comprehensive utilization of oil shale should be considered during the development of surface retorting technology, meanwhile the process should be harmless to the environment.

Introduction

As an unconventional energy resource, oil shale has been listed as one of the most important alternate energy source because of its rich resources and favorable characteristics [1]. Presently, the world total amount of oil shale reserved in oil shale is about 475 billion tons, more than that from oil resources which is about 300 billion tons, 4.4 times larger than the current recoverable reserves of crude oil. Through exploitation, shale oil can be obtained by using the technology of destructive distillation, fractions of gasoline and diesel can be obtained by hydrogenation which can be utilized directly in the shipbuilding industry and the auto industry. Hence, research on oil shale exploitation and utilization has gained great significance.

At present, the processing technologies for shale oil production can be divided into two categories: Surface retorting and in original technology also known as in-situ technology. Surface retorting technology transports oil shale to the surface by surface mining underground tunnel mining, crushes and screens into the required size, then transfers the crushed oil shale to the retort in order to produce shale oil, shale gas and shale char by heating and through low temperature retorting, In-situ technology directly heats oil shale from underground and converts it to shale oil or shale gas which is then transported and brought out to the surface. Among both categories, In-situ technology is still in development stage and there is no industrial application yet. So far, retorting is the main way to produce shale oil from oil shale [2].

Surface Retorting Technology

According to the variations of the particle size, the Surface retorting of oil shale can be classified into two categories: lump shale process and particulate shale process. According to the different ways of heat transfer, lump shale processing that grain size ranged 25~125mm, the main dry distillation method is gas heat carrier distillation process, while processing the particulate shale that grain size ranged 0~25mm use solid heat carrier distillation process. The major differences of them are the different methods of shale drying, the heat carrier, Semi coke processing and utilization [3].

The different oil shale retorting technologies with the lump shale process are been used around the world include Fushun retorting technology of China, the Kiviter technology of Estonia, the Petrosix technology of Brazil, etc.; The particulate shale process being used include the Gloter technology of Estonia, the LR retorting technology of Germany, the Tosco-II retorting technology of the U.S., the ATP retorting technology of Canada, the Eneifit-280 retorting technology of Estonia and Germany, and so on.

Lump Shale Process

Fushun Retorting Technology

Fushun retorting technology process is the processing method of oil shale used by the refinery of Fushun mining group. The process is shown in Fig. 1 [4].

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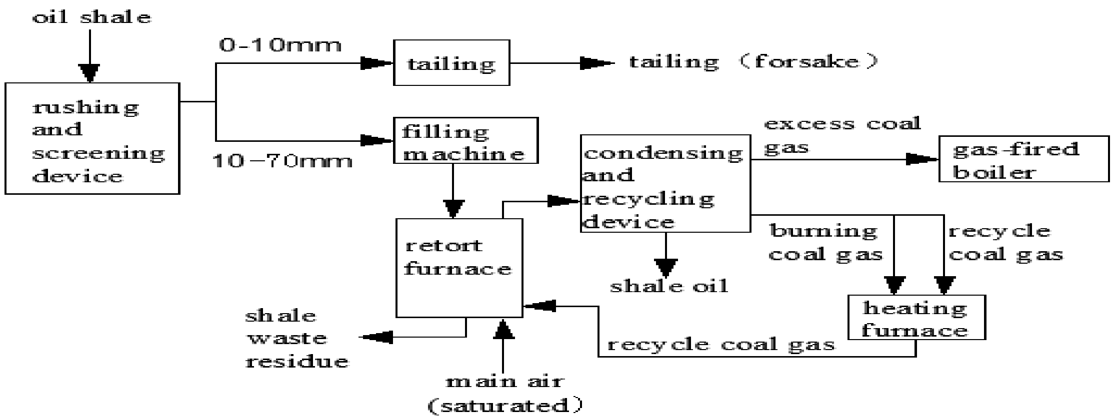


Fig. 1: Fushun retorting technology process flow diagram.

After being crushed and screened, oil shale which particle size is below 10 mm is seen as tailings, while that particle size ranged 10~75 mm is in the retort furnace [5-6]. The oil shale is dried, preheated, and retorted in the section of retorting, and then shale oil is mostly released through Pyrolysis. And remain of the shale Carbocoal will be into the gasification zone carrying out oxidation and reduction reaction with ascending saturated main bellowing air. The shale char is discharged outside of the furnace, and is transported to the storage yard with tailings, partly being reused. At the exit of the retort furnace the product of retorting, processed through condensing recovery system, can produce shale oil and dry distillation gas. Dry distillation gas is divided into three parts: one part is send to regenerative furnace for heating, as cycle coal gas of the retort furnace; another part is as the fuel of regenerative furnace; and the rest supplies for gas boiler.

The Fushun retorting technology has the advantages of simple operation and long work period. But only its flow of a single furnace is small at100t/d, resource utilization rate at 80%, the oil yield below 70%, and efficiency remain low and it is harmful to the environment. So the Fushun retorting technology is suitable for small plant processing oil shale with low oil content and gas production.

Kiviter Technology

The Kiviter retort furnace, developed by the Estonia, is a vertical and cylindrical type gas burning furnace. The structure diagram of Kiviter retort furnace is shown in Fig. 2 [7].

Air and the circulating air enter into the blast chamber from one side of the furnace, after burning, the temperature of the flue gas is between 760 °C and 800 °C [8, 9]. The flue gas enters the furnace from the lateral two parallel rectangular cross-section of the carbonization chamber, heating the top-down oil shale. In the retort furnace, the heat is provided by combustion of dry distillation gas and char. The generated oil and gas is derived by the oil and gas collecting chamber, then into the condensation system to collect the shale oil. The shale carbocoal is cooled by the cold circulation dry distillation gas from the bottom of the furnace, then it is discharged after water sealing. But this technology doesn't make full use of the latent heat of semi-coke.

The Kiviter retorting technology has the advantages of simple structure, convenient maintenance, large throughput about 1000~3000 t/d, medium investment. But in the process the loss in oil shale screening and the expenses are large, and will produce gas with low calorific value and large of carbocoal solid waste which value is about 480kg/t. So the Kiviter retorting technology is suitable for middle scale shale oil plant.

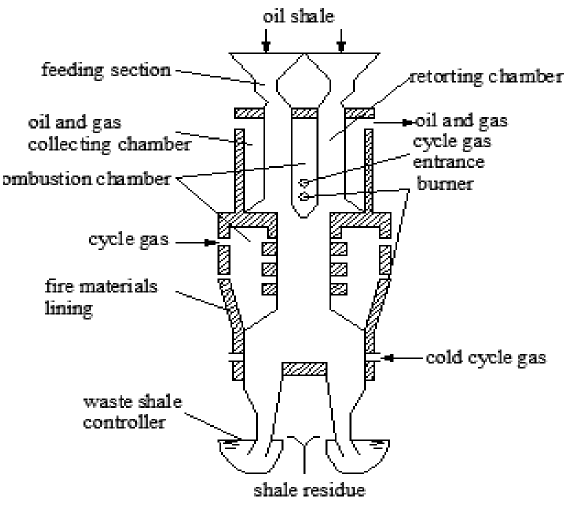


Fig. 2: Structure diagram of Kiviter retort furnace.

Petrosix Technology

The Petrosix technology, developed by Brazil Oil Company, is a method of oil shale retorting, belongs to the gas heat carrier method. The process is shown in Fig. 3 [5].

After been crushed and screened at first the oil shale, with its particle size ranged 6.4~76 mm, enters retorting area of the retort furnace for organic thermal decomposition, heat required is from the hot gases and the cycle coal gases from waste heat recovery of shale. The hot coal gases enter from middle of the retort furnace and the cycle coal gases enter from bottom of the retort furnace. The two streams of coal gases both are generated from the process. In drying area and heating area, after devolving its heat to oil shale, the up linking coal gas is cooled and changed into condensed oil and fog, shale oil and its by-product are collected by Hydrocyclone and electrostatic oil catching device. The shale tailings and waste residues are discharged back to mine stope.

The Petrosix technology has the advantages of large throughput at 2200 t/d, high daily output 110t/d, high utilization of oil shale and oil yield both above 90%, more environmentally friendly, and self-sufficient in terms of heat. But this technology can't make full use of the oil shale whose size is less than 6.4 mm, the retort furnace is huge and it is difficult in repairing and operating. So the Petrosix technology is suitable for large scale shale oil plant.

Particulate Shale Process

Galoter Technology

The Galoter technology, developed by Estonia, is an oil shale retorting technology. This technology uses rotational tubby retorting furnace with self-produced shale ash carrier. The process is shown in Fig. 4 [10].

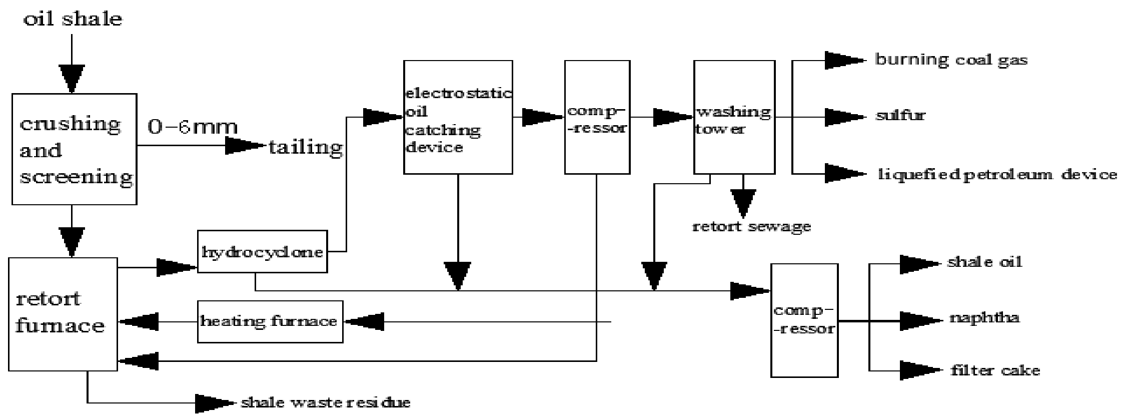
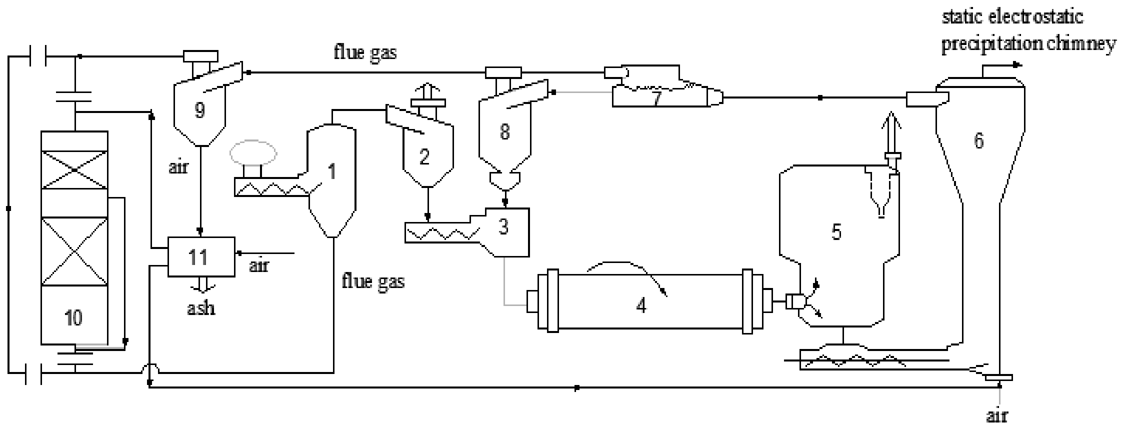


Fig. 3: Petrosix technology process flow diagram.



1.lue gas heating shale dryer; 2.cyclone gas-solid separator;3.ash mixture feeder.
4.rotational tubby retorting furnace;5.dust chamber, 6.airflow sending combustion chamber.
7.bypass; 8.cyclone separator; 9.cyclone separator;10. waste heat boiler; 11. dust heat exchanger.

Fig. 4: Galoter process flow diagram.

The oil shale, whose particle size is 0~25 mm, is dried by the flue gases, heating up to 180 °C, it enters baffle mixture, after mixing , it goes into the rotary retort with 500 °C of retorting temperature [11-13]. The furnace lining is firebrick, retorting speed is 1 r/min, retorting time about 20 min. After 2-stage cyclone dust removal, oil gas enters condensing recovery system. Through oil washing, the temperature goes down to 300 °C, heavy oil can be gained. Then through 3-stage air cooing, the temperature goes down to 250 °C, heavy crude oil can be obtained. The heavy crude oil enters fractionating tower. At last we can get 15% light oil, 35% middle oil, and about 55% heavy oil. In addition to processing oil shale, the furnace is also a mixed processing waste rubber [14], which is now in operation.

The Galoter technology has many advantages, such as large processing capacity of single at 3330 t/d, high utilization of oil shale, high yield about 86%, high energy efficiency, fewer wastes, manageability, and harmless to environment.

LR Technology

The LR technology that German Lurgi and Ruhrgas jointly developed is a versatile solid heat carrier (using shale ash heat carrier) process. Its processing raw materials include coal, oil shale, oil sand and liquid hydrocarbons. The process is shown in Fig. 5 [15].

After been preheated to 150~210 °C, the oil shale, with its particle size below 6 mm, enters the spiral mixer, mixing shale ash coming from the heat carrier receiving tank on 650~750 °C. After the mixed material from the mixer falls into the retorting reactors for retorting, the mixed material falls to the bottom of the heating riser. But the redundant material is discharged into the fluidized bed cooler from the retorting reactors, exchanging heat with the lifting air. After been heated to about 450 °C, then into the heating riser from the bottom, the lifting air lifts the hot shale ash to the heat carrier receiving tank. Through the process of the heating riser is lifting heat shale ash, the shale carbocoal continues to release heat through and the heat carrier is heated again, then is sent into the hot carrier receiving tank. At the same time, the flue gas separates from the heat carrier and the heat carrier enters the spiral mixer, thus completing the cycle process is completed.

The LR retorting technology has the advantages of simple structure, low investment, high utilization of oil shale , high oil yield above 90%, high energy efficiency and low power consumption. But its throughput of single furnace is about 24 t/d, and the retorting process is not advanced. So it is suitable for small scale shale oil plant.

Tosco-Ⅱ Technology

The Tosco-Ⅱ technology, developed by American Tosco Company, is an oil shale retorting technology. This technology belongs to the method of gas heat carrier (using ceramic balls heat carrier), and is used to process the particulate shale. The process is shown in Fig. 6 [10].

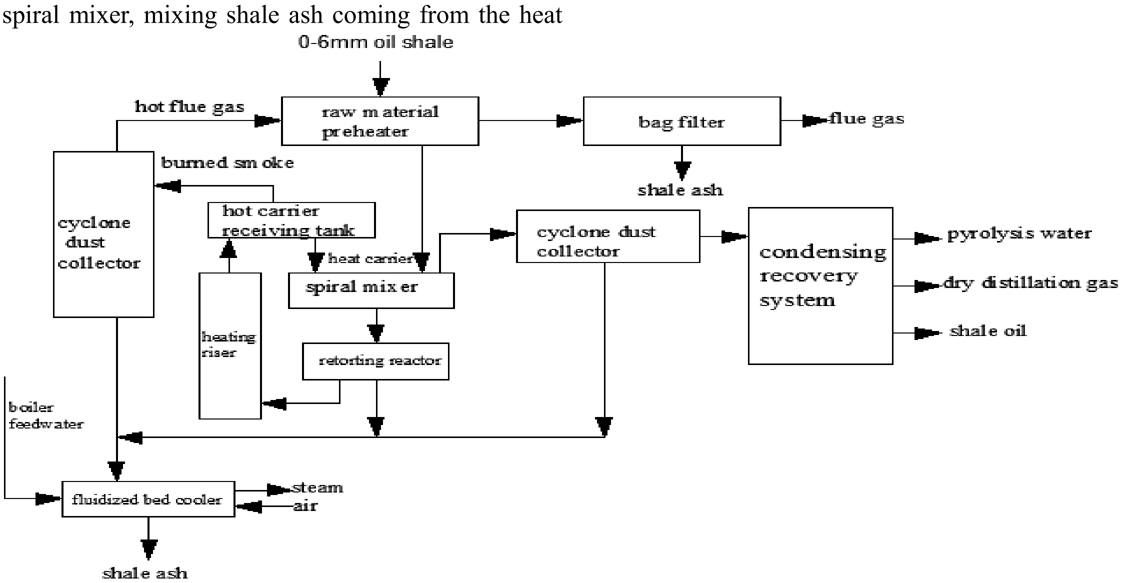


Fig. 5: LR technology process flow diagram.

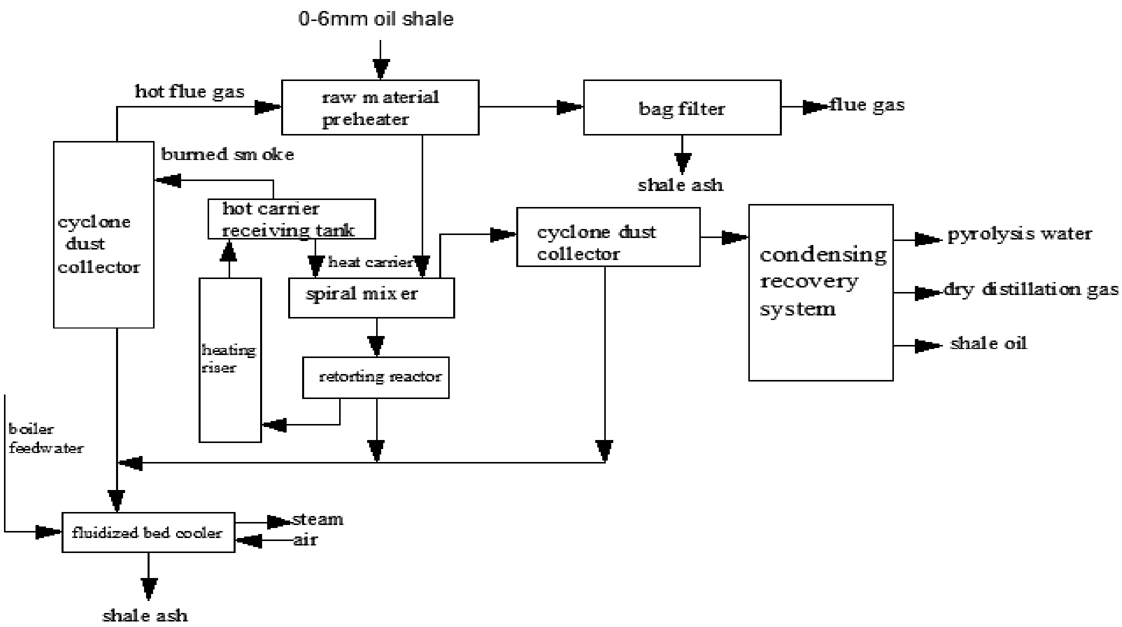


Fig. 6: Tosco-II technology process flow diagram.

During the process, oil shale is crushed to less than 12.7mm in particle size, and then is dried and preheated to 260 °C. After that, it is sent to the rotational tubby retorting furnace with ceramic balls. The balls with the diameter of 12.7mm and 680 °C of temperature are from the heater. When the retort furnace rotates, heat is transferred between the balls and the oil shale. And the process of destructive distillation would begin when oil shale is heated to 480 °C. Dust carried by the oil and gas will be removed by the separator. And oil and gas will then be sent in the separation tower, divided into coal gas, naphtha, distillate, and other components. The recovery ratio is above 90% of Fisher Assay shale oil yield rate.

The Tosco-II technology has the advantages of 100% oil yield, great utilization of 100% oil shale and high energy efficiency. The devices are complex and they are difficult in repairing; the investment and maintenance expenses are high because of the utilization of ceramic balls; this technology doesn't use the latent heat of semi-coke; the oil sludge in oil product is big. So the Tosco-II technology is suitable for middle scale shale oil plant.

ATP Technology

The ATP retorting technology introduced from Canada belongs to the method of solid gas heat carrier (using shale ash heat carrier). The process is shown in Fig. 7 [16].

After being dried by the rotary dryer, the oil shale, whose particle size is below 25 mm, passes through in turn the preheating zone, retorting zone and combustion zone successively [17]. The reverse flow of hot oil shale waste residues outside the inner cylinder transfers heat to the oil shale in inner cylinder by cylinder wall. In preheating zone, the shale is heated to about 250 °C and the free water in oil shale is expulsed by turning into steam [18]. In retorting zone, oil shale and shale which are partially burnt returning from the combustion mixture and the temperature of the mixture rises to 500 °C, then the Kerogen Thermal Decomposition becomes the hydrocarbon gas, and then enters the oil recovery plant through pipeline. After retorting, the oil shale waste residues enters to the combustion zone, contacting with air, burning the carbon residue will be burning , and the temperature should be controlled at the level of 500 °C. After combustion oil shale is divided into two parts. The one part returns to the retorting zone and provides heat for oil shale carbonization and Pyrolysis correspond; the other part is put into the outer cylinder, reverse flows with the oil shale in inner cylinder, and transfers heat to shale in the preheating zone.

The ATP technology has the advantages of large throughput at 600 t/d, high daily output at 600 t/d, high utilization of 100% oil shale, 95%oil yield, self-sufficient in terms of heat, and it is environmentally friendly. But the devices are complex and it is difficult in repairing. In addition the work period is short. So the ATP technology is suitable for large and middle scale shale oil plants [19].

Enefit-280 Technology

The Enefit-280 technology that Eesti Energia AS and Outotec jointly developed in 2008 is called Enefit process. This technology is an upgrade based on the Gloter technology. It combines the Gloter technology with the circulating fluidized bed technology. The process is shown in Fig. 8 [20].

Oil shale particles mixed with oil shale ash is as the mixing process of the traditional Gloter technology. The mixtures are fluidized by cycle gas [21]. Shale thermal decomposition conducts in the rotational tubby retorting furnace and finishes in the char separation chamber. Char and dry distillation gas burn in circulating fluidized bed [22].

Compared with the traditional technologies, this technology has many advantages. The char combustion is more complete; the Fisher Assay oil yield is high; the throughput is large; no use of moving components in retorting zone, it increases the ability of continuous operation; combing the Gloter technology and the Outotec circulating fluidized bed technology, the oil shale processing power has improved two times and the process has the characteristics of shale complete combustion and high thermal efficiency; the generated heat is used to generate steam for power plants; the shale ash doesn't include organic compounds, allowing to backfill and reuse; the generated exhaust emissions meet the European standards.

Process Comparison

Detailed comparison of the oil shale surface retorting technologies is shown in Table-1.

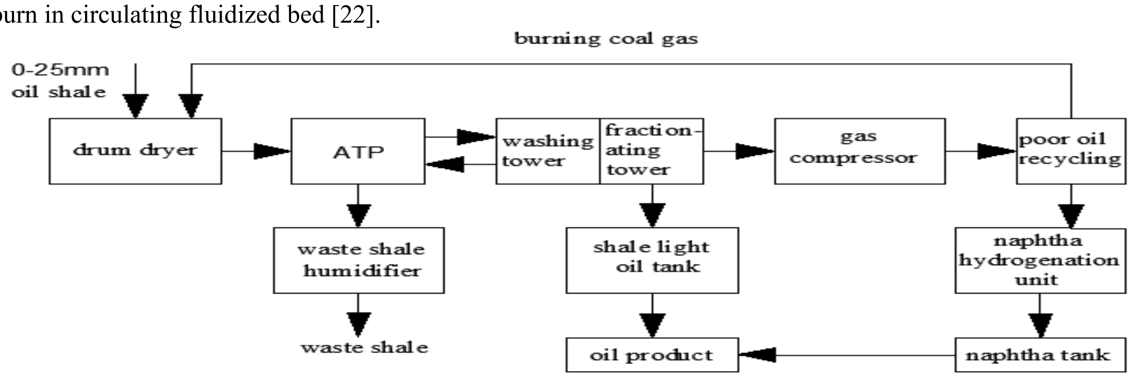
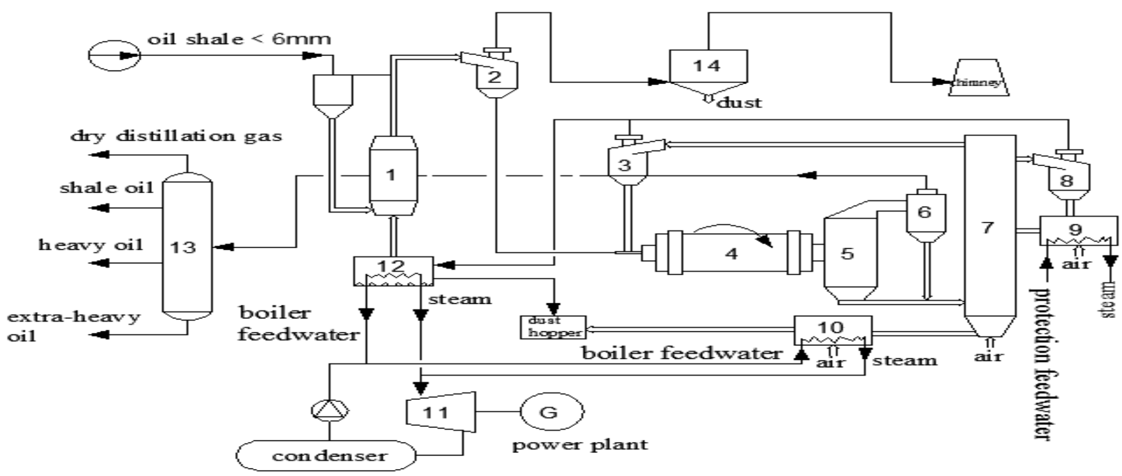


Fig. 7: Petrosix technology process flow diagram.



1.venturi dryer; 2.oil shale cyclone separator; 3.heat carrieer cyclone separator;4. rotational tubby retorting furnace; 5.dust chamber; 6.dust cyclone separator;7.circulating fluidized bed boiler; 8.shale ash cyclone separator:9.circulation condenser: 10.fluidized bed cooler:11.steam turbine: 12.waste heat boiler; 13.condensing recovery system 14. electrostatic precipitator;

Fig. 8 Enefit-280 technology process flow diagram.

Table-1: Comparison of the oil shale surface retorting technologies.

Particle size	Technology	Developmental State	Retorting Device	Range of Particle Size /mm	Heat Carrier	Throughput /(t·d^{-1})	Oil Yield /%	Equipment Structure and Maintenance Operation	Investment and Operation Cost
	Fushun retorting technology	China	Vertical cylindrical	10 ~ 75	cycle coal gas	100	70 ~ 75	simple structure, convenient repairing, simple operation	low
lump shale process	Kiviter	Estonia	Vertical cylindrical	25 ~ 125	cycle coal gas	1000 ~ 3000	75 ~ 80	Simple structure, convenient repairing	middle
	Petrosix	Brazil	Straight tube	6 ~ 76	cycle coal gas	2200 ~ 8000	90	complex structure, maintenance and operation relatively difficult	relativey high
	Galoter	Estonia	rotating cylinder	Less than 25	shale ash	3000	85 ~ 90	complex structure, maintenance and operation relatively difficult	relativey high
	LR	Germany	double drum blade	Less than 6	shale ash	24	close to 100	Simple structure	low
Particulate shale process	Tosco-Ⅱ	American	rotary drum	Less than 12.7	Special Ceramic Ball	900	close to 100	complex structure, maintenance and operation relatively difficult	relativey high
	ATP	Canada	level rotary cylinder	Less than 25	shale ash	6000	95	Simple structure, convenient repairing, simple operation	middle
	Enefit-280	Estonia and Germany	horizontal cylinder	Less than 6	shale ash	6700	~ 90	complex structure, maintenance and operation relatively difficult	relativey high

The commonness of the above surface retorting technologies and their respective characteristics are summarized as follows:

1. Oil yield of the particulate shale process is about 100%, universally higher than the lump shale process.
2. The Fushun retorting technology and the LR retorting technology has some similar points such as small treatment capacity, lower investment, simple structure and operation, and convenient maintenance. They are suitable for small scale shale oil plant.
3. The Kiviter technology has the following characteristics: large throughput, low oil yield, low investment. So it is suitable for middle scale shale oil plant; the Tosco-□ technology, high oil yield, complex equipment, higher investment. So it is also suitable for middle scale shale oil plant.
4. The Petrosix technology has the following characteristics: large throughput, high oil yield, better environmental protection, by-product high calorific value gas, mature furnace type. So it is suitable for large scale oil shale plant.
5. The ATP technology has the following characteristics: large throughput, being able to process particulate oil shale, high oil yield, by-product high calorific value gas, complex equipment, high investment. So it is suitable for large and middle scale oil shale plant.
6. The Gloter technology and the Enefit-280 technology have the same essence, which belongs to solid heat carrier distillation process. They have the following characteristics: large throughput or flow, high oil yield, relatively complex construction, high maintenance cost. They are suitable for large scale oil shale plant. The oil shale processing power of the Enefit-280 technology is two times of the Gloter technology, and the Enefit-280 technology is better for environmental protection and it is more efficient. Now this technology is one of the best retorting technologies in the world [23, 24].

Conclusion

1. Compared with the lump shale process, the particulate shale process has advantages such as low processing particle size, better utilization of oil shale, higher oil yield and better for environmental protection. Instead the lump shale process which has been developed for a long time ago has some advantages, like mature technology, relatively simple process and low investment. So the lump process can't be replaced in short while.
2. Trend of the oil shale retorting technology:

a. Continuously optimize the process flow, increase throughput of single furnace, reduce cost and improve economic benefit.

b. Develop combined processes of the surface retorting technology or other producing technologies of oil, such as combining the solid gas heat carrier process with the gas heat carrier process, combining the solid heat carrier process with the circulating fluidized bed process.

c. The development of oil shale surface retorting technology needs to be combined with oil shale comprehensive optimized utilization method [25, 26]. Through the method of comprehensive and optimized utilization of oil shale, we need to develop circular economy. After crushing, oil shale char, generated in retorting furnace, mix with particle fine slag, wasted in oil refining process. The heat is generated from combustion changes into steam, which is divided into two parts. One part is used as external supply refrigerant and the other part is used to drive steam turbine for power generation. The ash residue generated from combustion can be used as raw material of cement, haydite and building blocks. This can improve the added value of oil shale and Increase the ability of market competition.

d. Because the surrounding environment is endangered in the process of oil shale retorting, processing and utilization [27-30], in the development of oil shale retorting technologies at the same time must be attached great importance to environmental protection. A complete technology of oil shale retorting must include a high-efficiency deducting technology, a shale wastewater processing technology and a shale ash residue effective utilization technology.

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