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WORLD OIL SHALE RETORTING TECHNOLOGIES

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ABSTRACT
This paper mainly describes the world's commercial oil shale retorting technologies, including lump oil shale and particulate oil shale retorting technologies. Fushun Type Retorting, Petrosix Retorting, and Kiviter Retorting are illustrated as the examples of lump oil shale retorting; Galoter Retorting and Alberta Taciuk Processing(ATP) are as the particulate oil shale retorting. Comparison of different retorting technologies are discussed.

I. Underground Retorting

Underground retorting, also called in-situ retorting, is the technology for processing oil shale in-situ underground; it is usually carried out by introducing air to burn and pyrolyze the underground oil shale layer to obtain shale oil. This process obviates the problems of mining, handling, and disposing of large quantity of material, which occurs for aboveground retorting. In-situ retorting offers the potential of recovering the deep buried oil shale. The true in-situ method is not successful, because oil shale lacks permeability, thus hindering the inflow of air and outflow of produced oil and gases, also lowering the heat transfer into the oil shale deposit. Modified in-situ retorting is a better approach, to solve the permeability problem: an upper portion of the oil shale bed is taken out to the surface by conventional mining to provide the desired void volume of the resulting underground retort; the oil shale deposit adjacent to the void portion is fractured, by using conventional explosion, to rubble which expands to the void volume. Combustion is initiated with inflow of air at the top of the shale rubble in the underground retort, with the burning front descending through the rubble bed at the rate of several meters per week. Ahead of the combustion zone, the hot combustion gas creates a pyrolysis zone , where oil shale is thermally decomposed. The shale oil produced flows to the bottom of the rubble and is pumped to the surface

In nineteen seventies, during the period of world oil crisis, different oil shale retorting technologies, including underground retorting were actively developed by oil companies. Underground retort, approximately 50m wide x50m deep x 85m high, constructed by Occidental Petroleum Co., USA, has been well operated in Colorado(Hulsebos,1988); but oil yield is not so high. Geokinetics Inc., USA, has operated a horizontal modified in-situ retort, with thin horizontal oil shale bed(about 10-25m),in Green River formation in Utah; This also involves fracturing the shale layer close to the surface with explosives and subsequently retorting the deposit horizontally. Till nineteen nineties, due to the depletion of oil price, many in-situ projects were shot down; now, although the crude oil price becomes much higher, in USA, only Shell Company is conducting in-situ oil shale retorting pilot test; Shell is trying to

freeze the retorting surrounding to diminish the leakage of shale oil vapors, however, it consumes significant power.

In general, in-situ retorting has the advantage of deviating the oil shale mining, but has the disadvantages of lower oil yield and the environmental impact to ground water by shale oil, and retorting water entrainment.

II. Aboveground Retorting

For aboveground retorting, oil shale is to be mined out. The commercial retorts have strict demand on the size range of oil shale charge. The shale excavated from mine varies greatly in size, from several mm to hundreds of mm, and even larger than 1000mm. Pretreatment of crushing and screening is necessary to meet the demands of retorting operation. Usually shale fraction is divided to lump shale and/or particulate shale, as the feed for different types of retorts.

Nowadays, almost all of the commercial retorts and the retorts in developing are the internal heating, i.e., direct heating type retorts.(the external heating, i.e., indirect heating retort is such type of retort that heat is supplied from hot medium to oil shale through a wall, this retorting type is not being employed or developed because of the small unit capacity, expensive heat transfer, and low thermal efficiency). In general, for lump shale, internal hot gas carrier is usually used for supplying heat; for particulate oil shale(less than 10mm), internal hot solid carrier is usually employed. The heat source of hot gas or hot solid carrier comes from the combustion of pyrolysis gas or retorted shale char..

Due to the low heat conductivity coefficient of lump oil shale, it takes longer time for retorting, about several hours, (because of the low heating up rate, only several degrees per minute); For particulate oil shale, due to its smaller size, the heating rate is higher, the time required for retorting the oil shale is much shorter, only about several minutes or little more than ten minutes.

Aboveground Retorting Technologies:

USA, Russia, Estonia, Brazil, and China have developed several oil shale retorting technologies; some American large oil companies have paid much attention on the developing work, such as Union Company developed rock type retorting with the daily lump oil shale processing capacity 10,000t-the highest capacity in the world(Barnet,1982); TOSCO developed moving bed particulate retorting; but all the retorts developed by USA have not been put into long period commercial production; till now in the world, the matured commercial technologies are: Estonian Kiviter lump shale retorting, Estonian Galoter particulate oil shale retorting, Brazilian Petrosix lump shale retorting, Chinese Fushun retorting; and Australia has scaled up Canadian Taciuk particulate shale retorting, called Aostra Taciuk Processing (ATP).

III. Lump Oil Shale Retorting

III.1. Fushun GeneratorType Retorting

Similar as Estonian and Russian Generator Type Retort, Fushun type retort has been developed and utilized in commercial production for more than seventy years in Fushun,China.(He,2004;Hou,1986;Zhao,2005). The retort is of vertical cylindrical type, with outside steel plate lined with inner fire bricks; its inner diameter is about 3 m, higher than 10 m; see Figure 1. The oil shale is fed from the

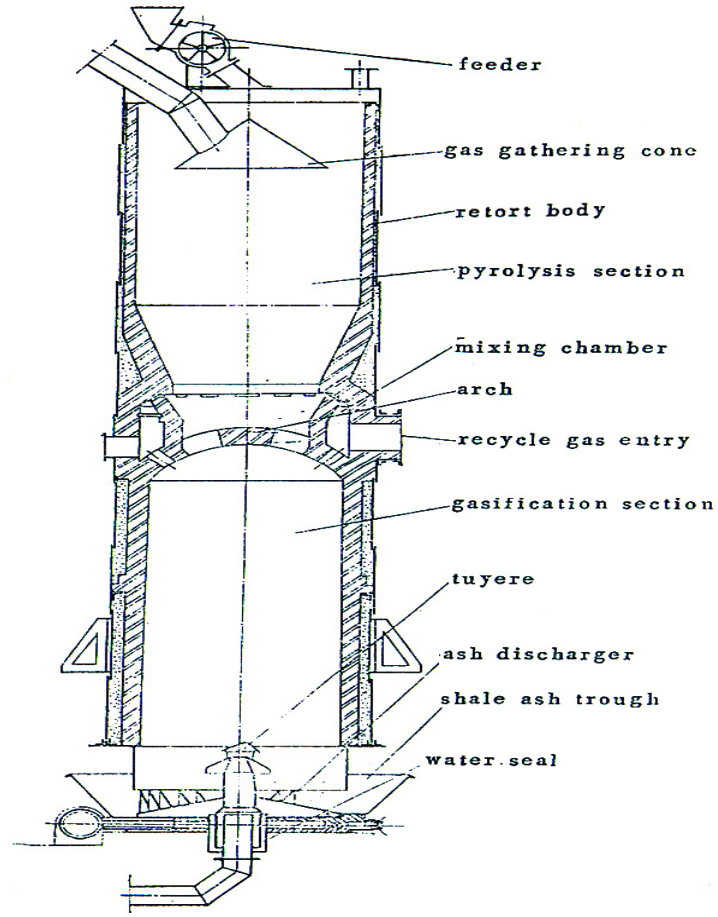


Figure 1. Fushun-type Retort

top of the retort, with the size of 10-75mm; at the upper section (pyrolysis section)of the retort, the oil shale is dried and heated by the hot ascending gaseous heat carrier, and pyrolyzed at about 500C, the oil-gaseous vapor produced exits from the top of the retort, the oil shale is converted to shale coke, and goes to the lower part(gasification section) of the retort, it is reacted with the ascending air-steam (coming from the bottom of the retort) ,it is gasified and combusted to shale ash; the air-steam react with the coke to form hot gas and flows to the upper part of the retort to heat the oil shale; at the middle of the retort a hot recirculating gas as the supplementary hot gas carrier is introduced to heat the oil shale, this recirculating gas is part of the retort exit gas, after it is cooled in condensation system(shale oil is condensed) and it is again heated in a recuperator to 500-700^{o}C, then back to the retort. The shale ash exits from the water dish at the bottom of the retort.

20 Fushun retorts share one condensation system, i.e., the exit gas evolved from 20 Fushun retorts flows together to a collecting tube, then successively to washing tower, gas blower, and cooling tower, where shale oil is condensed; part of retort gas coming from the gas blower is introduced to the recuperator as fuel, meanwhile a part of retort gas is introduced to an another recuperator, where it is heated and recirculated to the middle of the retort as hot gas carrier for heating the oil shale in the retort; the remaining retort gas coming from the cooling

tower is introduced out of the condensation system as surplus gas.

The characteristics of Fushun retort is : the potential heat of the fixed carbon of the shale coke is partly utilized , thus high thermal efficiency is obtained, but due to the addition of air into the retort, after combustion , the nitrogen dilutes the pyrolysis gas, makes the retort-exit gas having low calorific value; further more, the excess oxygen coming to the upper part of the retort will burn out a part of the shale oil produced, thus reducing the shale oil yield greatly. The oil yield of the Fushun retort accounts for about 65% of Fisher Assay.. The daily capacity of the retort is only 100 –200 tons, Fushun type retort is suitable for small oil shale retorting plant, and for processing lean oil shale with low gas yield.

III.2. Kiviter Retorting

Estonia Kiviter retort(Sonne,2003; Yefimov,1999) is a kind of vertical cylindrical retort, having rectangular combustion chambers at the middle of upper part of the retort and also at the two sides of the middle part of the retort, see Figure 2. The combustion chambers are equipped with air and recirculating gas nozzles, the combustion takes place, and the hot combusted gas formed horizontally comes to the two pyrolysis chamber, where the oil shale fed from the top of the retort goes vertically downward and is heated by the hot combusted gas in the mode of thin layer pyrolysis, the oil-gaseous vapor horizontally escapes to the two sides of the upper part of the retort, and comes out of the retort top.

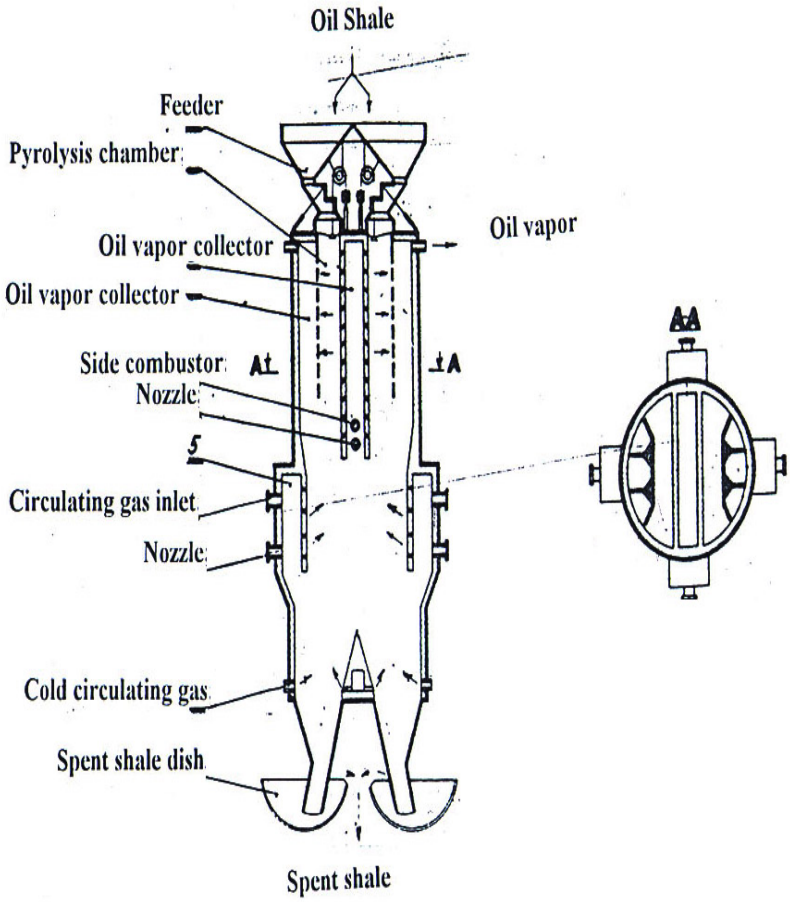


Figure 2 Kiviter Retort

The shale coke is cooled down at the lower part of the retort by the upward cooled circulating gas, and is discharged from the bottom water seal; meantime the cooled circulating gas is heated and goes upward as supplementary heat source, combined with the combusted gas for pyrolysis of feed shale. The discharged shale coke contains fixed carbon, it is not utilized in the retort, therefore the retorting thermal efficiency is not high, about 70 %, and the retort exit gas is diluted by nitrogen in air, its heating value is not high, and the Fisher assay oil yield is also not high, about 75-80%, due to the fact that air(with oxygen) introduced into the retort for combustion is in excess, and the excess oxygen burns out some shale oil produced, or mainly due to the fact that part of the shale oil produced is pyrolyzed by the hot combusted gas. The daily capacity of the retort accounts for 1000 tons oil shale with the size of 10-125mm(mainly 25-100mmm), the electricity consumption for processing one ton oil shale is about 14-18 kwh, steam(5-8 bars) 15-20 kg, and water 0.2-0.5 m^3. Two Kiviter retorts each with daily capacity of 1000t oil shale have been well operated at Estonia Viru Keemia Group(VKG), in Kohtla Yarve. This retort is suitable for medium and small shale oil plant.

III.3. Petrosix Retorting

Brazilian Petrosix technology and retort are shown in Figure 3 and Figure 4(Hohman,1992;Martignoni,2002;Sinor,2001). Petrosix retort is also a kind of vertical cylindrical retort; Petrobras Company at Sao Mateus do Sul built two large Petrosix retorts, one with inside diameter of 11 m, the other with the inside diameter of 5.5m, for processing lump oil shale 6-50 mm; the larger one with the diameter of 11 m built in 1991 has the daily capacity of processing oil shale 6200 tons, with the capital cost of 93 million USD; the smaller one with the diameter of 5.5 m built in 1981 has the daily capacity of 1600 tons, with the capital cost of 35 million USD. Petrosix retort has the upper pyrolysis section and lower shale coke cooling section. Pyrolysis temperature is about 500^oC; the retort off gas is 150^oC, it is cooled successively by cyclone, electric precipitator, and spraying tower for condensation and removal of shale oil; about 40%, 40% and 20% of shale oil are recovered from the above three equipment; part of the cooled retort gas is used as fuel in a tubular heater, part of the cooled retort gas is heated in the heater's pipes to higher than 500^oC and recirculated back to the middle of the retort as hot gas carrier for heating and pyrolyzing the oil shale feed; part of the cooled retort gas is circulated and enters into the bottom of the retort, it cools down the hot shale coke, itself is heated up and ascends into the pyrolysis section for heating the oil shale feed as supplementary heat source; the cooled shale coke is discharged from the water seals at the retort bottom. The drawback of this retort is that the potential heat of fixed carbon contained in the shale coke is not utilized, thus influencing the thermal efficiency; the advantages are: the retort capacity is high, the retort off gas has the high calorific value, due to the fact that it is not diluted by nitrogen, and moreover, the oil yield is high, reaches 85-90%of Fischer Assay(The Fischer Assay oil yield of Brazilian oil shale accounts about 8.5%.)

The operation data and results of the 5.5m retort: yearly operation factor 94%, retorting intensity 2750 kg/h/m^2, shale oil production 800 barrels/d, gas production 40,000 m^3/d, sulfur production 20t/d.

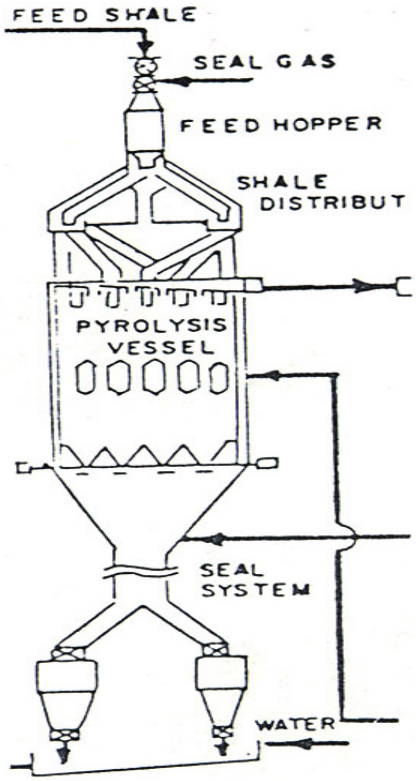


Figure 3 Petrosix Retort

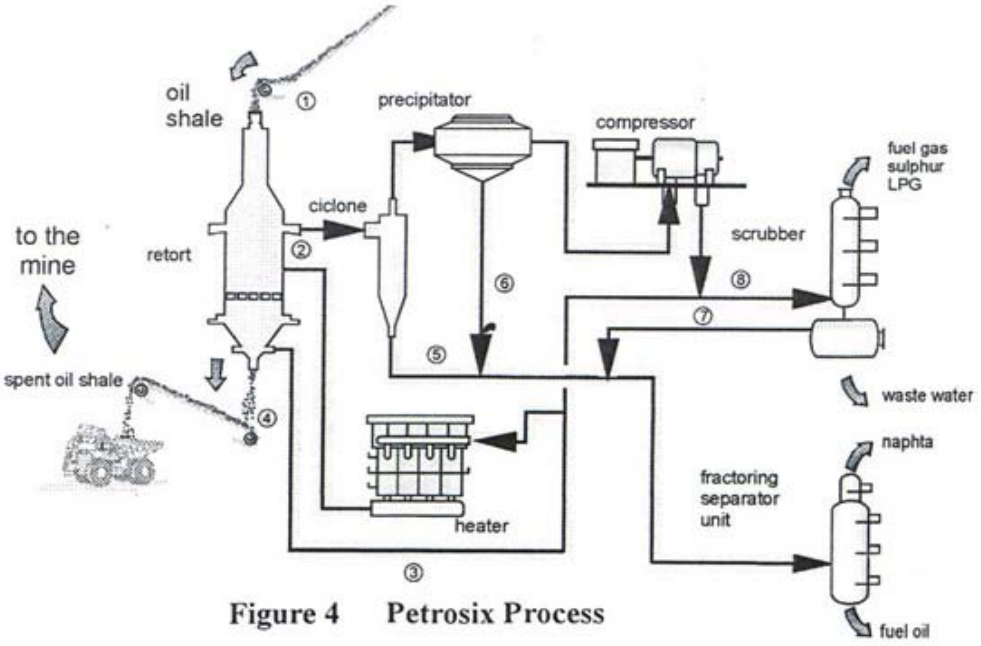


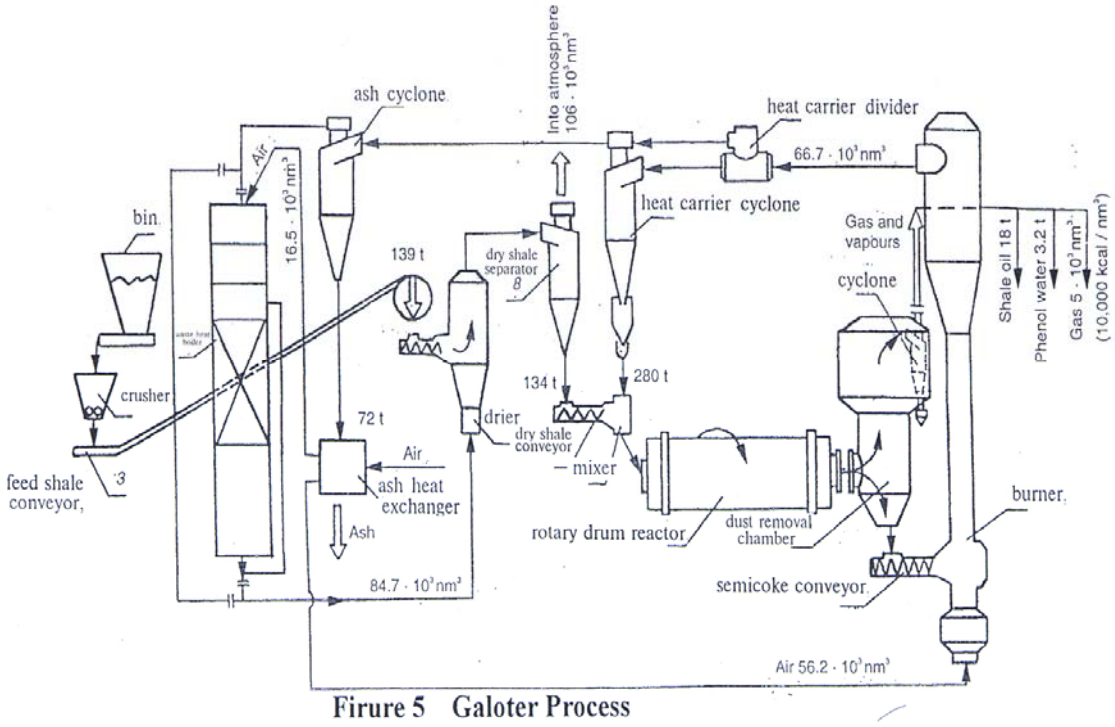
Figure 4 Petrosix Process

The operation data and results of the 11m retort: oil shale processed 6200t/d, shale oil produced 3870 barrels/d, gas produced 140,000m^3/d, LPG produced 45t/d, and sulfur produced 75t/d (The hydrogen sulfide recovered from retort gas is treated by Claus Method to produce sulfur). The production cost for one ton shale oil accounts about 10-20 USD/barrel, varying with the oil yield of the oil shale. Petrosix retort is suitable for large and middle shale oil plant.

IV. Particulate Oil Shale Retorting

IV.1 Galoter Retorting

Two Galoter solid heat carrier retorts, each with daily processing capacity of 3000t oil shale were built at Estonia Narva Power Plant(Golubev,2003;Opik,2001)The retort is a kind of horizontal, slightly declined cylindrical rotating retort, see Figure 5. The feed oil shale has the size of 0-25mm. The shale ash is used as solid heat carrier. In the horizontal cylindrical retort, the dried oil shale mixed with the hot ash carrier, and is heated to 500^{o}C, it is pyrolyzed at the interval about 20 min., shale coke is formed, it comes out from the retort with the ash into the vertical fluidized combustion chamber, where it is combusted with incoming upflowing air, shale coke is converted into shale ash, having the temperature of 700-800^{o}C, the shale ash is separated from the hot flue gas in the cyclone, and is mixed with dried oil shale, both are introduced into the retort, the dried oil shale is heated and pyrolyzed, the shale ash with the shale coke is recirculated. The hot flue gas leaving from the cyclone is introduced to the waste heat boiler and then to the fluidized drier for drying the oil shale feed.. The shale oil vapor exits from the retort, is cooled successively, thus heavy oil, light oil, naphtha fractions, and high calorific gas are obtained.



Firure 5 Galoter Process

Galoter retort has the daily capacity of 3000 tons oil shale, technological chemical efficiency accounts for 73-78%, with the electrical consumption of 4400 kw, oil yield reaches 85-90 % of Fisher Assay, retort gas yield accounts for 48m^3/t ,with the heating value 46000kj/m^3, containing light olefins 30% , it may be used for producing petrochemicals or as town gas; besides the oil shale as feed, the waste rubber(30x30mm) can also be mixed with oil shale as feed(Senchugov,1997) This retorting technology is complex, having more equipment and machines, the operation is not easy, Estonia and Russia have spent much money and time for developing ; more than 50 years for scaling up from laboratory to pilot plant and at last to

the commercial scale. Now it is in commercial production. In recent years, the yearly retort's operation time accounts for about 6200 hours, with the oil shale yearly about 769,000t processed and shale oil about 84,500t produced.

IV.2. Taciuk Retorting

Alberta Taciuk Process(ATP) is named for its inventor, engineer William Taciuk of UMATAC Industrial Processes, a Division of UMA Engineering, Ltd., in Canada. A portable Taciuk processor was built with the capacity of 240 tons per day, The Taciuk process was originally developed for pyrolysis of tar sand, but was also suitable for treating oil shale and remediation of hydrocarbon-bearing wastes.

In 1999, Australian SPP Company utilized Taciuk technology, scaled up the Taciuk retort and built a plant at Stuart, Australia, with the daily capacity of retorting 6000 tons oil shale, spending investment 170 million USD. It was designed for producing shale oil 640 tons per day, with the production cost 70 USD / ton shale oil.(Schmidt，2002；Schmidt，2003；Sinor,2001;Taciuk,2002)

SPP-Taciuk retort is a kind of horizontal (slightly inclined) cylindrical, rotating retort, with the diameter of 8 m, and 60 m length; see Figure 6. The oil shale with the size of 0-25mm is fed into the drying zone of the retort, where it is preheated and dried indirectly by hot shale ash and hot flue gas; then moved to pyrolysis zone, where it is mixed with hot shale ash and heated to about 550^{o}C, and converted to shale coke with the evolution of shale oil vapor; the shale coke(mixed with ash) comes to the combustion zone , where the air is added and the coke is burnt to form shale ash with the temperature of about 800^{o}C, part of ash,acting as hot solid carrier, is recycled to the pyrolysis zone for pyrolyzing the dried oil shale, another part of ash comes through the cooling zone to the exit. The shale oil vapor evolved from pyrolysis zone is cooled externally, condensed product oil is recovered and fractionated, to produce light naptha and light fuel oil, meanwhile high calorific gas is also obtained; the light naphtha is hydrotreated to produce ultra low sulfur gasoline fraction. The oil yield is designed about 85-90% of Fisher Assay. The retort is at the trail stage; the products, ultra low sulfur gasoline fraction and light fuel oil are both sold in 2003 at the price of A $ 60 per barrel.

In 2003, the retort was operated at 60% of plant availability; 629,000 bbl shale oil were produced, with the oil yield on 82% of Fischer Assay(shale oil Fischer Assay yield: 181 liters/ton on dry basis); and with the shale feed rate:3790 t/d in Jan.2003; and 4460 t/d in Dec.2003.(McFarland, 2003; McFarland,2004).

In 2004, the retort was operated for half year, then SPP sold the ATP retorting plant with its oil shale reserves to an US company-Queensland Energy Resources Limited(QERL). Since 2005, QERL has shut down the operation.

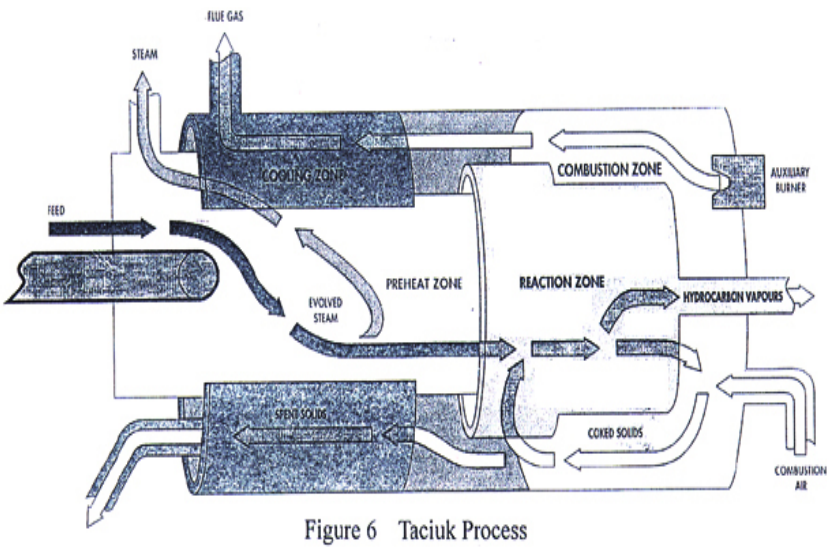


Figure 6 Taciuk Process

V. Comparison of world oil shale commercial retorting technologies

World's current oil shale commercial retorting technologies are listed and compared as shown in Table 1(Qian,2002).

Table 1 Comparison of World's Commercial Oil Shale Retort Technologies

Retort	Chinese Generator	Kiviter	Galoter	Petrosix	Alberta Taciuk
Company	Fushun Shale Oil	Viru Keemia	Narva Power	Petrobras	SPP
Country	China	Estonia	Estonia	Brazil	Australia
Location	Fushun	Kohtla Jarve	Narva	Sao Mateus do Sul	Stuart
Oil Shale T/d	100	1,000	3,000	6200/ 1600	6,000
Size,mm	10-75	10-125	0-25	6-50	0-25
Configu-ration	Vertical Cylindri.	Vertical Cylindri.	Horiz. Cylindri.	Vertical Cylindri.	Horiz. Cylindri
Process Heat. .. Carrier	Shale Pyro. Coke Gasi Gas	Shale Pyro. Coke Cool Gas	Shale Pyro Coke Comb Ash	Shale Pyro CokeCool Gas	ShalePyro CokeComb Ash
Oil Yield ,% Fisher Assay	65	75-80	85-90	90	85-90
Products	FuelOil Low Cal Gas Ash Gas Coke	FuelOil Chemi-cals Low Cal. Gas Ash	FuelOil Chemi-Naphtha cals HighCal. Gas Coke	FuelOil Naphtha Sulfur HighCal. HighCal. Gas Ash	Low S Light Fuel Oil

VI. Discussion and Conclusion

1. In-situ retorting has been developed in past decades, but now only Shell is conducting pilot trial.
2. Above ground retorting technologies may be classified to lump oil shale retorting and particulate oil shale retorting.
3. Chinese, Russian and Estonian Generator type lump shale retort is of small capacity with low oil yield on Fisher Assay, is not advanced , but suitable for small plant due to its low investment.
4. Estonian Kiviter lump shale retort is of middle capacity, with middle oil yield, its investment is relatively not high, it is suitable for medium scale plant.
5. Estonian Galoter particulate shale retort is of large capacity, with high oil yield on Fisher Assay, and producing high calorific gas, but its construction is rather complex, and maintenance are expensive, it is suitable for large scale plant.
6. Brazilian Petrosix lump shale retort is of large and very large capacity, with high oil yield and producing high calorific gas, its investment is costly, it is suitable for medium and large scale plant.
7. Australian SPP-Alberta Taciuk particulate shale retort is of very large capacity, with high oil yield on Fisher Assay, and producing high calorific gas, the light naphtha is upgraded to produce ultra low sulfur gasoline fraction, its investment is costly, it is going to normal operation and is suitable for large and medium scale plant.

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