State-of-the-art technologies of oil shale thermal processing

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Abstract. Development of advanced oil shale processing technologies for production of liquid and gaseous fuels, as well as chemical raw materials, is a very topical problem. The article provides information on commercially implemented oil shale thermal processing technologies which use gaseous (Fushun, Kiviter and Petrosix) and solid (Lurgi-Ruhrgas, Tosco II, Aostra-Tasiyuk, Galoter) heat carriers. The authors note that the Galoter process implemented in plants with solid heat carriers has significant advantages compared to other processes.

1. Introduction
Oil shale (OS) is to be considered as one of the most advanced sources for production of liquid and gaseous fuels which can be used together with oil products and natural gas, and in future will completely replace them. Even while insufficient exploration of shale deposits the content of liquid hydrocarbons in them is several times in excess of the world's known oil reserves. Therefore, creation of advanced OS processing technologies to produce liquid and gaseous fuels, as well as chemical raw materials, is a very topical problem.

All processes of OS thermal treatment are based on heating initial fuel up to a certain temperature, at which maximum extraction of useful products (resin and pyrolysis gas) is achieved. The main engineering problem is to supply heat in the required quantity during a certain period of time. As a heat source gas heat carrier, solid heat carrier, liquid heat carrier, plasma heating, microwave heating, electrical heating, etc., can be used. However, in shale industry the following two thermal treatment techniques have been mainly applied: with gas heat carrier and with solid heat carrier, each having its own technological features.

2. Thermal processing of oil shale by gas heat carrier
2.1 Kiviter Process
This process, implemented in Estonia, is treatment of large-sized (25-125 mm) OS in a 1000 ton per day generator [1]. Thermal decomposition occurs in two semi-coking shafts located in parallel, separated from each other by a central (hot) chamber for preparation and distribution of heat carrier. Temperature in hot chamber of generator is maintained within the limits of 800-900°C and is ensured by supply of return gas and air in a strict ratio for burning. The Kiviter process is complicated for operation, since in one unit heating, drying and pyrolysis processes successively occur. The yield of resin in case of processing shale in generators is lower than the yield in case of semi-coking in a standard Fischer retort (~ 80%), which is explained by overheating of OS particles in some areas and their incomplete decomposition in the others.

2.2 Fushun Process
Operated in China Fushun type retorts as well as Kiviter generators are based on the use of gas heat carrier. Shale entering the retort moves in a downward direction contacting with hot gas. In semi-coking area shale temperature reaches 550°C. Semi-coke is gasified in the retort bottom at 700-800°C by mixture of air and steam vapor preheated at the expense of hot ash sensible heat. Gas-steam mixture is...
removed from top of the retort. To the middle of the retort return gas preheated in a special furnace up to 500-700°C is supplied as a heat carrier. Resin yield averages 65% of the yield in a standard Fischer retort. Shale ash is partially used for production of cement [2].

2.3 Petrosix Process

Petrosix process was developed by the national Brazilian corporation Petrobras specializing in oil extraction, refining and export. Since 1954 the corporation has been dealing with pyrolysis of Brazilian OS [3].

Petrosix process like the processes, discussed earlier, is based on application of gas heat carrier. OS with approximately 6-70 mm sized particles is supplied into top of the retort and moves under the action of its own weight through drying (200 °C), pyrolysis (480 °C) and cooling (250 °C) areas. At a pilot plant constructed in San Mateus do Sul, Brazil, resin yield reached 85-90% of the yield obtained in standard Fischer retort. Currently in San Mateus do Sul Petrosix retort with the capacity of 6200 tons of OS per day is in operation.

3. Thermal processing of oil shale by solid heat carrier

3.1. Lurgi-Ruhrgas Process

Simplified scheme of the Lurgi-Ruhrgas process [4] is shown in Fig. 1. Reactor 3 is made in the form of a screw (auger) type mixer, in which during interaction of hot solid heat carrier (650-700°C) with OS its pyrolysis occurs at the temperature of 500-540°C. OS is crushed to particles sized not more than ¼ inch (6.35 mm).

Gas-steam mixture from reactor after cleaning from solid particles in cyclone 5 is fed to condensation system 6, where it is separated into resin V, gas III and pyrogenic water IV. Flue gas after separator is injected into the second stage of scrubbing in cyclone 7, passes through heat exchanger 8 in which shale is dried to zero moisture. Final flue gas scrubbing from dry shale dust is carried out in precipitator 9. Coke-ash residue VIII having the temperature of 650-700°C from separator 2 and cyclone 7 is fed to heat exchanger 10 into which air VII is injected to create fluidized bed conditions. As a result, coke-ash residue heats air VII up to ~ 450°C for the furnace, and feed water IX converts into steam which is fed to boiler.

3.2. Tosco II Process

The name "Tosco" is the abbreviation for The Oil Shale Corporation. This process was developed by the Denver Research Institute within the period from 1956 to 1966. From 1967 to 1974 the Colony Development company, which included Tosco company, created a pilot plant with the capacity of 1000
tons of OS per day. The plant was operated in the Parachute Creek area (Colorado) of the Green River shale basin. The scheme of Tosco-II process is shown in Figure 2 [5].

![Diagram of Tosco II Process](image)

**Figure 2.** Diagram of Tosco II Process

Fine-grained shale I (~ 12 mm) enters Drier 1, from it - to separator 2 and then into rotating drum reactor 4, into which ceramic balls (~ 12 mm) heated up to 750°C in preheater 3 are simultaneously fed. Pyrolysis of OS occurs at 480°C. Balls V are separated from semi-coke in separator 5 and fed by elevator 7 to heater into which pyrolysis gas VI and air VII are injected. Semi-coke separated from the balls in separator 6, is humidified in drum cooler and removed from the plant.

3.3. AASTRA-Tasiuk Process

AAASTRA-Tasiuk Process (ATP) was invented by William Tasiuk (Canada) [6] and jointly developed by two Canadian companies: Alberta Oil Sands Technology & Research Aforeti and Yumatek Industrial Process. Based on the studies conducted between 1997 and 1999, in Queensland state (Australia) a commercial ATP Plant with the capacity of 5000 ton OS per day was constructed.

Extracted in a quarry by open pit mining OS was fed to ATP processor, consisting of two concentric tubes, rigidly connected to each other, rotating at a speed of about 4 rpm [6-7]. Scheme of flows in ATP processor is given in Fig.3.

Processor by special devices, not shown in Fig. 3, is divided into four zones: heating, reaction, combustion and cooling. Heated OS is fed into reaction zone, where, when interacting with ash at 600-750°C its pyrolysis occurs with formation of vapor-gas mixture and semi-coke. Semi-coke enters combustion zone. Ash formed during combustion of semi-coke is divided into two flows: the first one is forwarded to reaction zone as a solid heat carrier, and the second one- to OS heating zone. Ash (spent shale) is removed from processor into humidifier.

![Diagram of ATP Processor](image)

**Figure 3.** Aostra-Tasiyuk Process diagram

In late 2004, due to difficulties in operation and ecological imperfection this facility in Queensland was stopped. During this period Chinese company Fushun Mining Group, engaged in processing of large-sized shale in Fushun type retorts, actively searched for the ways to utilize shale fines.
formed during production of OS. Within the period from 2006 to 2010, the second ATP Plant was
constructed almost repeating technical characteristics of the first plant. According to the data [7], the ATP
Plant Fushun was put in operation in 2013, and in 2015 reached 80% of the design capacity and was
continuously operated during 115 days.

3.4. Galoter process

In the late 1940s at the G.M. Krzhizhanovsky Power Engineering Institute Principal Diagram of the
Galoter Process was developed. The process was named after the research team leader I. Galynker, whose
name was combined with the word "thermal". Galoter Process was implemented in a plant using solid
heat carrier (UTT*). Development of the UTT optimal version was carried out in the following sequence:
a pilot plant at the Ilmarine Plant in Tallinn with 100 kg/h capacity (1950-1955); UTT-200 Pilot Plant
(200 tons of OS per day, 1953-1962); UTT-500 commercial Plant (500 tons of OS per day, 1962-1981).
UTT-200 and UTT-500 Plants were constructed in the territory of Shale Processing & Chemicals Plant in
Kiviõli (Estonia).

Two UTT-3000 plants were constructed on site of the Estonian GRES with OS capacity 3000 ton/day
each. The first UTT-3000 Plant was constructed in 1980, the second one - in 1984. Both plants have been
operated at the design parameters until now. Shale gas produced in them is burnt in furnaces of the
Estonian PP power boilers, and shale oil is sold to heating plants and power plants in Latvia and Estonia.
The Galoter process is based on the concept of heating fine-grained shale by a solid heat carrier - ash,
formed in the process of semi-coke combustion in fluidized furnace. UTT Schematic Diagram is given in
Figure 4.

OS is fed to fluidized drier 1, where gas enters from cyclone 6, ensuring almost complete removal of
moisture from OS. Dry shale is caught in cyclone 2 and fed to reactor 3 together with heat carrier-ash
from cyclone 5. As the result of pyrolysis in reactor 3 destruction of OS occurs separating it into two
phases - gas-steam mixture and coke-ash residue. Gas-steam mixture is cleaned off large solid particles
in dust settling chamber 7 and sent to condensation section where heavy, middle, light and gasoline
fractions of the resin, pyrogenic water and gas are extracted from it. Coke-ash residue is settled in dust
settling chamber and then organic substances remained in it, are combusted in fluidized furnace 4. Ash, formed
after combustion of coke-ash residue, is separated in cyclone 5 and used as a solid heat carrier.

Major characteristic of the process implemented in UTT plants is the possibility to pyrolyze fine-
grained shale (particles sized from 0 to 25 mm, the amount of which in the production is about 70%),
whereas the above shale thermal treatment processes are designed for coarse-grained shale (particles sized
25 - 125 mm for Kiviter type generators and 6.3 - 70 mm for Petrosix process). Pollutant free high-
calorific fuels - liquid one with calorific value of about 40-41 MJ kg and gaseous one with combustion
heat of about 42 MJ/kg (48 MJ/kg) - are produced in the UTT plants from shales with calorific value of
7.8 - 8.4 MJ/kg Nm³). UTT type units can be used for shale not only of any size (for large particles – after
crushing to 0-25 mm), but practically of any combustion heat, including low-calorie shales with

![Figure 4. Diagram of the plant using solid heat carrier](image-url)
combustion heat to 2.9 MJ/kg (700 kcal/kg). In case OS has lower combustion heat supply of additional fuel to ensure thermal balance of pyrolysis process will be required. Remaining advantages of the Galoter process are set forth in [8] and are not repeated here.

Below table lists the main process parameters of OS thermal treatment processes described in the article.

**Table.** Process parameters of oil shale thermal treatment

| Parameter                  | Gas Heat Carrier | Solid Heat Carrier |
|----------------------------|------------------|--------------------|
|                            | Kiviter          | Fushun             |
| Capacity, ton/hour         | 42               | 10                 |
| Shale size, mm             | 25 - 125         | 10 - 75            |
| Heat Carrier               |                  |                    |
| Process temperature, °C    | 800-900          | 550                |
| Process duration, min      | > 60             | > 60               |
| Resin yield (of Fischer Retort), % | 80          | 65                 |

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