Oil Shale, 2000, Vol. 17, No. 3
pp. 252-260
ISSN 0208-189X

https://doi.org/10.3176/oil.2000.3.06

THE OPTIMAL PROCESS TO UTILIZE OIL SHALE IN POWER INDUSTRY

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Creation of a power-technological complex (PTC) including plants that use solid heat-carrier and have the throughput rate 3,000 tonnes shale per day (SHC-3000) is proposed for processing oil shale from the Leningrad Deposit. Advantages of the SHC-type plant over other processes using oil shale are presented. The possibility to construct thermal power plant with a combined-cycle plant, which use liquid and gaseous fuel obtained from shale, is advanced.

Introduction

With revival of industrial potential of Russia, the country's fuel balance will change owing to gradual exhaustion of oil and gas reserves and, due to this, growth of the share of coal and gas. Supplanting oil and gas by coal and shale will lead to the application of economical and environmental requirements presented to liquid and gaseous fuels also to processes using coal and shale. To solve these problems it is necessary to develop and introduce new methods of coal and oil shale pretreatment and combustion.

Methods of thermal processing of solid fuels (coals and shales) developed by G. M. Krzhizhanovsky Power Engineering Institute (ENIN) are prospective for power and other industries.

Methods of thermal processing are based on the fact that coal and shale contain, like oil, valuable substances that are lost in the process of combustion. Therefore solid fuels, analogously to oil, should be treated not only as a fuel but also as a raw material already containing valuable matters or forming them in the process of thermal destruction.

There are several procedures for thermal processing of solid fuels (hydrogenation, gasification, etc.), but at all their advantages none of them has such wide assortment of the products obtained as pyrolysis applied in ENIN's technologies. In the process of pyrolysis the coal is converted into high-calorific solid, liquid and gaseous fuel (shale – into high-calorific liquid and gaseous fuel) and, in addition, products now imported, because of their shortage, are obtained (phenols and their derivatives, adsorbents, etc.).

At ENIN three methods (processes) of thermal processing of solid fuels have been developed, investigated and introduced on experimental and pilot scale: the *Galoter* process for oil shale; high-rate pyrolysis of coal (CHRP), and thermal contact coking of coal (CTCC). Of these three procedures the *Galoter* process, implemented at plants using solid heat-carrier (SHC) has become a commercial-scale process. CHRP and CTCC have been brought to pilot level in the towns of Tver and Ekaterinburg.

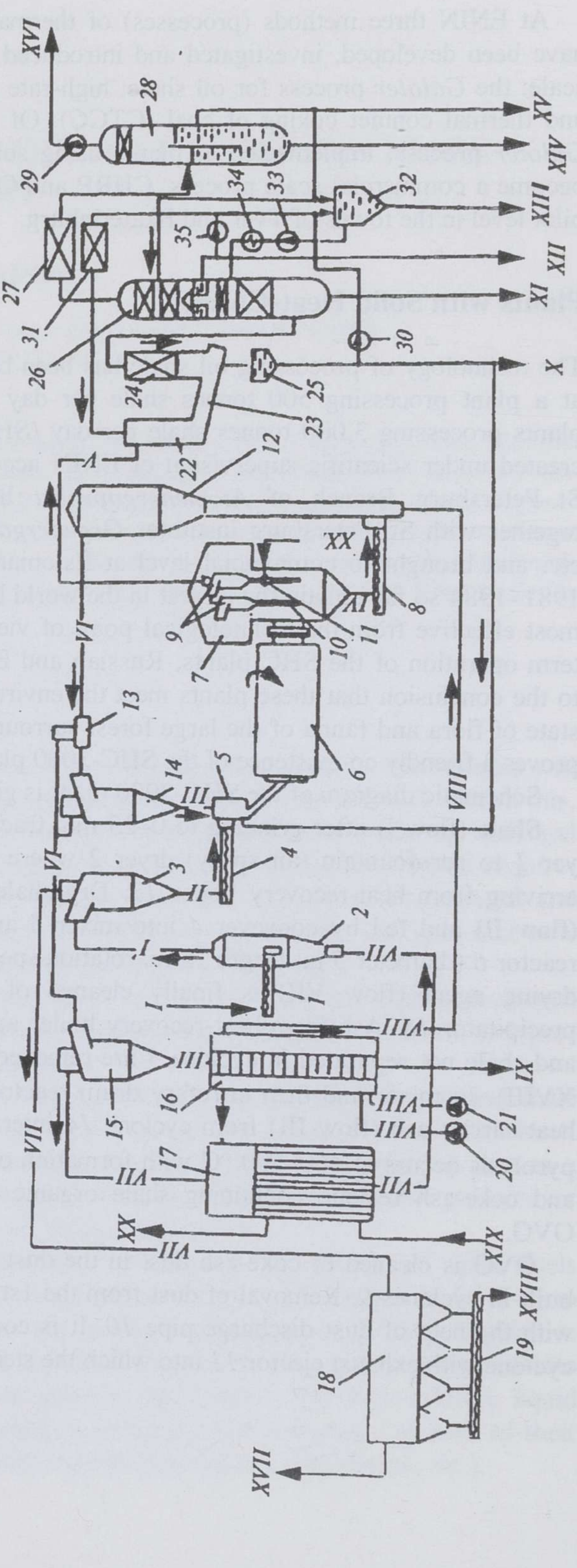
Plants with Solid Heat-Carrier

The technology of processing oil shale has been brought to commercial level at a plant processing 500 tonnes shale per day (SHC-500) and then – at plants processing 3,000 tonnes shale per day (SHC-3000). The SHC plants created under scientific supervision of ENIN according to the design of the St.-Petersburg Branch of *Atomenergoproekt* Institute (general designer) together with St.-Petersburg institutes *Orgenergostroy*, *Lengipronephtehim*, etc. and brought to commercial level at Estonian Power Plant in the years 1981–1984 so far remain the largest in the world by their production rate and most effective from the technological point of view. On the basis of a long-term operation of the SHC plants, Russian and Estonian experts have come to the conclusion that these plants meet the environmental requirements. The state of flora and fauna of the large forest surrounding Estonian Power Plant proves a friendly co-existence of the SHC-3000 plants and the environment.

Schematic diagram of the SHC-3000 plant is given in the Figure.

Shale (flow I) after grinding to 0–25 mm fraction is fed by screw conveyer *1* to aerofountain (air-spray) dryer *2* where it is dried in gas flow VII arriving from heat-recovery boiler *17*. Dry shale is entrapped in cyclone *3* (flow II) and fed by conveyer *4* into mixer *5* and then – into rotary drum reactor *6* (diameter 5 m, length 15 m, rotation speed 1 rot. per min.). Used up drying agent (flow VII) is finally cleaned of solid particles in electric precipitator *18*. Ash from heat-recovery boiler and entrapped in precipitator and shale not separated in cyclone *3* are removed by dust conveyer *19* (flow XVIII). In mixer and then in rotary drum reactor heated up to 750–800 °C heat-carrier ash (flow III) from cyclone *14* interacts with dry shale and the pyrolysis occurs at 460–500 °C with formation of oil vapors and gas (OVG) and coke-ash residue containing shale organic matter not transferred into OVG.

OVG is cleaned of coke-ash dust in the dust removal chamber *7* by two built-in cyclones *9*. Removal of dust from the 1st stage cyclone is carried out with the help of dust discharge pipe *10*. It is connected under the 2nd stage cyclone with exhaust ejector *11* into which the steam is fed (flow XX).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Schematic diagram of the SHC-3000 plant.

Equipment: *1* – raw shale screw conveyer, *2* – drier, *3* – dry shale cyclone, *4* – dry shale conveyer, *5* – mixer, *6* – rotary drum reactor, *7* – dust removal chamber, *8* – semicoke conveyer, *9* – cyclones, *10* – dust discharge pipe, *11* – dust ejector, *12* – burner, *13* –heat-carrier divider, *14* – heat-carrier cyclone, *15* – ash cyclone, *16* – ash heat-exchanger, *17* – heat-recovery boiler, *18* – electric precipitator, *19* – dust conveyers, *20* – air blower to burner, *21* – heat-recovery boiler air blower, *22* – heavy oil washing tower, *23* – gas collector, *24* – heavy oil condenser, *25* – heavy oil tank, *26* – rectification tower, *27* – gasoline and tar water cooler-condenser, *28* – separator, *29* – gas blower, *30* – heavy oil pump, *31* – heavy oil cooler, *32* – decanter, *33* – refined oil pump, *34* – heat-exchanger, *35* – gas-turbine fuel pump

Flows: I – feed shale as well as shale in drying agent flow, II – dry feed shale, III – heat-carrier (ash), IV – coke-ash residue, V – oil vapors and gas, VI – ash in flue gas flow, VII – flue gas for cleaning, VIII – air, IX – ash to be utilized, X – heavy oil, XI – middle oil, XII – gas-turbine fuel fraction, XIII – oil sludge (to mixer *5*), XIV – tar water, XV – gasoline fraction, XVI – semicoke gas and gas naphtha, XVII – treated flue gas, XVIII – ash entrapped by electric precipitator, XIX – feed water, XX – steam

Large particles of coke-ash residue fallen from drum reactor to the lower part of dust removal chamber and its pulverized fractions picked up by OVG and precipitated in cyclones (integrated flow IV) are fed by conveyer *8* to burner *12* to burn the remaining organic matter and to heat, at this expense, solid heat-carrier (ash).

Gas flow VI containing ash heated up to 750–800 °C is directed from burner to heat-carrier divider *13* where it is divided into two parts by regulating gate valve. One part of flow VI enters heat-carrier cyclone *14* where ash is separated and used as a heat-carrier (flow III). By-pass gate is positioned so that the ash precipitated in cyclone *14* ensures maintaining the temperature of shale and ash mixture in rotary drum reactor at the level of 460–500 °C. At the same time, divider performs the functions of separator by extracting large particles of heat-carrier ash from the flow. The upper part of the flow VI not introduced in cyclone *14* mixes with gas leaving cyclone. The mixed flows are cleaned of ash in cyclone *15*; the ash entrapped in it (flow III) is fed to ash heat-exchanger *16* where it heats air (flow VIII) for burner and heat-recovery boiler. Gas after cyclone *15* (flow VII) is fed into heat-recovery boiler where 4 MPa and 440 °C steam (flow XX) is generated at the cost of gas physical heat and afterburning of hydrocarbon components in burner. Gases cooled down to 500–600 °C after heat-recovery boiler (flow VII) are used as a drying agent in drier. The ash after ash heat-exchanger (flow IX) is fed to hydraulic ash-handling system or removed dry for application in agriculture and production of building materials.

OVG after cleaning of solid particles in dust removal chamber (flow V) enters heavy oil (HO) condensation unit consisting of: washing tower *22*, gas collector *23* and heavy oil condenser *24*. After condensation unit heavy oil is collected in tank *25* and delivered as a marketable product (flow X). OVG is fed into rectification tower *26* where condensation of middle oil (MO) and diesel fraction (DF) – gas-turbine fuel fraction occurs.

MO and DF are delivered as marketable products (flows XI and XII, respectively). After rectification tower OVG is fed into cooler-condenser *27* where the vapors of gasoline fraction and tar water are condensed. Condensation products are separated in separator *28* (flows XIV and XV). Semicoke gas together with the vapors of heavy hydrocarbons (gas-naphtha – flow XVI) is removed from condensation unit by gas blower *29*. In condensation unit a special tank – decanter *32* – is used to collect the mixture of heavy oil and settled-down dust (oil sludge). Oil sludge (flow XIII) is directed from decanter *32* to mixer *5* with the help of an injector. To reduce viscosity and to ensure the possibility to transport oil sludge a part of gasoline fraction from flow XV is introduced into decanter.

Advantages of the Plant with Solid Heat-Carrier

The main trait of the technology implemented at SHC-3000 plants is the possibility to process fine-grained shales (fractional composition from 0 to 13–25 mm; at mining their quantity makes about 70 %) whereas the other techniques for thermal processing of shale are designed to handle more large fractions (25–125 mm when *Kiviter*-type retorts are used, and 6.3–70.0 mm when the *Petrosix* process of *Petrobraz* company (Brazil) is used).

When SHC-type plants are applied, environmentally friendly high-calorific fuels – liquid (combustion heat 38–40 MJ/kg) and gaseous ones (combustion heat 41–42 MJ/kg) are obtained. The SHC-type plants can be applied for shale not only of any fractional composition but also practically of any combustion heat including low-calorific shale with combustion heat to 2.9 MJ/kg (≈700 kcal/kg).

Besides the advantages listed above (possibility to process shale of any fractional composition and quality as well as high unit capacity), the SHC-type plants have the following additional ones:

- Only solid phases (dried shale and ash) enter the reactor due to separation of processes of shale pyrolysis (in drum-type reactor) and solid heat-carrier (ash) preparation (in burner of aerospouting type). Therefore pyrolysis gas contains neither oxygen nor nitrogen from the free air and due to this its combustion heat is 2.5–3.0 times higher than this value for foreign plants. Thus, pyrolysis gas combustion heat is 48.4 MJ/m^3 (11,560 kcal/m^3) or 42.2 MJ/kg (10,080 kcal/kg) when Leningrad Deposit shale is processed at the SHC-type plants.
- Obtained at the SHC-type plants gas is a marketable product – a fuel for gas turbines, whereas the majority shale-processing plants use gas in the process – it is fed into reactor.
- Application of ash instead of gas for pyrolysis increases the efficiency of the SHC-type plants up to 84–89 %, whereas the efficiency of foreign plants is not higher than 65 %.
- Due to the application at SHC-type plants of fundamentally new designs for dust removal from OVG cleaning cyclones, their total effectiveness reaches 99.5 %. Owing to this the dust content even of oil shale heavy fractions does not exceed 1.0–1.5 %.

Worn-out tires in the mixture with shale have been processed during several years at SHC-3000 plants of Estonian Power Plant [1]. Processing of soils impregnated with oil products being the result of accidents at refineries and transportation of oil products in tankers and tank cars is also possible from the technical point of view and is confirmed by practice.

Motivation of the Expediency to Apply Plants Using Solid Heat-Carrier for Processing Leningrad Deposit Oil Shale

According to the works performed by ENIN and St.-Petersburg institutes *Atomenergoproject* and *Giproshaht*, the following was established.

At present the only Russian industrial shale-mining enterprise (OJSC *Leningradslanets*) situated in the town of Slantsy, Leningrad Region, experiences considerable difficulties in marketing shale. On the basis of the explored deposits, OJSC *Leningradslanets* planned to construct new *Kirovskaya* mine and *Mezhdurech'ye* open pit with total output of 6 million tonnes shale per year. Potential of industrial reserves of the Leningrad Deposit is sufficient to provide mining of 10 million tonnes shale per year.

Since the beginning of 1999 only one mine belonging to OJSC *Leningradslanetz* – the *Leningradskaya* mine – has been in operation. At the designed 3.7 million tonnes annual output, only 2.5 million tonnes per year are mined. At 3 million tonnes annual mining, the industrial reserves of the *Leningradskaya* mine will suffice for 37 years [2]. As before the reforms, the bulk of the shale mined (about 2 million tonnes per year) is sent now by OJSC *Leningradslanetz* to Estonia to Baltic Power Plant.

To involve the Leningrad Deposit shale into the fuel balance of Russia, OJSC *ENIN* and St.-Petersburg *Atomenergoproject* Institute have investigated the possibility to include shale in power capacities of Russia. Specific properties of shale do not allow burning it in boilers designed for coal. Experience at Estonian power plants (Estonian, Baltic, etc.) has shown that combustion of shale is not effective from the economic point of view even in the boilers designed specially for this fuel as specific properties of shale ash lead to contamination and abrasive wear of heating surfaces. Specific consumption of shale at TTP is not less than 408 g coal equivalent/kW h.

The optimal option to use the Leningrad Deposit shale in power industry should be its pyrolysis in plants using solid heat-carrier – SHC-3000 plants – with subsequent use of liquid and gaseous fuel yielded from shale at thermal power plants (TPPs).

To be convinced that the suggested method of utilization of oil shale is optimal, the possibility of long-term storage of the liquid fuel obtained from shale should be taken into account. The mass of this liquid fuel is 2.5–3 times more than that of gas obtained from shale. Therein lies the advantage of the pyrolysis process compared with gasification of solid fuels where the only marketable product is low-calorific gas that cannot be stored.

St.-Petersburg *Atomenergoproject* and *Giproshaht* institutes under the scientific guidance of ENIN have developed the feasibility report based on the data of a long-term operation of the SHC-3000 plants at Estonian Power Plant. It has been proved that the following marketable production can be yielded while processing 2.5 million tonnes of the Leningrad Deposit shale per year at a power-technological complex (PTC) consisting of three SHC-3000 plants:

- Shale oil with combustion heat not below 38 MJ/kg (9,080 kcal/kg) – a substitute for high-quality residual oil – amounting 350 thousand tonnes per year.
- Synthetic gas with combustion heat 48.4 MJ/m^3 (11,560 kcal/m^3) or 42.2 MJ/kg (10,080 kcal/kg) – gas turbine and boiler fuel – amounting 89.0 million m^3 per year.

Heat-recovery boilers being a part of SHC-3000 plants generate steam (4 MPa, 440 °C) that is utilized in 12-MW turbines PT-12-3,4/1. Electric and thermal power generated is enough to cover auxiliary needs of the mine and PTC making them independent of power producers and prices.

In the case of combustion of all products obtained at power-technological complex it is possible to create a 380-MW thermal power plant including 180 MW – in combined-cycle plant (120 MW from it – in gas-turbine plant).

Construction of TPP with combined-cycle plant (CCP) is very important for the North-West of Russia because in this region thermal power plants and nuclear power plants designed for base-load operation and cogeneration plants designed to operate according to heat load curve were constructed. Therefore the creation of TPP with CCP will allow compensating the variable part of the load curve [3] at the expense of good maneuverability of CCP.

To reduce the start-up investment into the feasibility study it was proposed to create a PTC in two stages:

- The first stage with sales of shale oil and combustion of synthetic gas at TPP of the shale processing plant – JSC *SPZ Slantsy*. Feasibility study estimates capital investments for the 1st stage of the PTC to be US$ 112.5 million.
- The second stage with construction of 380-MW TPP including 180-MW CCP. Such TPP costs about US$ 90 million.

Industrial site for construction of PTC in the town of Slantsy is selected. It is co-ordinated with the government of Leningrad Region and approved by the Ministry of Fuel and Power of the Russian Federation.

There exists a possibility to increase the efficiency of PTC at the cost by processing shale together with organic-containing wastes including worn-out tires, grounds impregnated with oil products, etc. Commercial tests made at the SHC-3000 plants of Estonian Power Plant have shown that the maximum proportion of the waste to shale makes 1 to 10, i.e. it is possible to process up to 250,000 tonnes wastes annually. This will allow to yield up to 100,000 tonnes oil very close by its quality to shale oil and to solve the problem of waste reclamation.

Moreover, the possibility to use ash obtained during processing of shale for production of building materials and in agriculture to lime soils and raise the productivity is commercially tested.

At present the problem of financing the 1st stage of PTC is being solved with possible attraction of foreign investors and basing on the Federal Law "Agreements on Distribution of Production". By the Act of the Leningrad Region Government the Leningrad Shale Deposit is assigned to the objects whose right of use is granted on the basis of the Federal Law.

Conclusions

Feasibility and economic expediency of creating PTC for thermal processing of the Leningrad Deposit shale on the basis of the SHC-3000 plants can be supported by the following factors:

- Available industrial shale reserves of only *Leningradskaya* mine will ensure the operation of PTC in the course of 37 years.
- There are specialists dealing with mining and thermal processing of shale in the town of Slantsy as well as the necessary infrastructure including the territory for construction of PTC, motorroad and railroad, etc.
- Long-term experience of SHC-3000 plants operation at Estonian Power Plant proved their cost efficiency and ecological friendliness.
- Electric and thermal power is generated at the PTC alongside with liquid and gaseous fuels that makes the mine and PTC independent of power producers and prices for energy carriers.
- Application of the Federal Law "Agreements on Distribution of Production" provides economic incentives for solution of financing problems with attraction of foreign investors.
- The SHC-3000-type plants can be used for shale of practically any deposit both in Russia and abroad.

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Received November 11, 1999