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SOLID OIL SHALE HEAT CARRIER TECHNOLOGY FOR OIL SHALE RETORTING

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A description is given of the oil shale retorting process by solid heat carrier technology (UTT-3000 retort at the Oil Factory of Narva Elektrijaamad AS). Data are presented of the start-up period and operation of commercial retorts and of future developments as well as of products manufactured by the Oil Factory and of the current shale oil market.

Besides processing large-particle oil shale by vertical retorts, there are two commercial retorts (UTT-3000; UTT means 'solid heat-carrier') in operation for processing fine-grained oil shale by solid heat carrier technology (in publications referred to as the *Galoter* Process).

Studies for development of the process were started over 50 years ago on OP-2 test retort in Kiviõli followed by UTT-500 experimental retort with a throughput of 500 tons per day of oil shale. It was in operation in the period of 1963–1981.

Successful studies and commercial experiments constituted the basis for a decision of construction of eleven retorts (UTT-3000) having a six times higher unit throughput rate in comparison with the UTT-500 retort. As Phase 1, by the 1980s at the Estonian Power Station two UTT-3000 retorts were constructed (The Oil Factory of *Narva Elektrijaamad* AS).

These retorts were designed for supplying the Estonian Power Station with shale oil produced from unconcentrated fine-grained (energy) oil shale.

The operating time of one retort was by design data 6800 hours per year, and simultaneous operation of two retorts was provided.

In Fig. 1 the UTT-3000 retort flow diagramm (the *Galoter* Process) is given.

The pyrolysis of dried oil shale is effected by mixing it with hot shale ash produced by combustion of oil shale semicoke (retorted oil shale). Therefore, the process is also referred to as the process with solid heat carrier.

The UTT-3000 retorts with a unit throughput rate of ~3000 tons per day of raw oil shale started operation on December 31, 1979. The leading devel-

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oping institution was the Moscow Krzhyzhanovski Power Engineering Institute (ENIN). Later, the process was subjected to substantial improvements and reconstruction by specialists of *Narva Elektrijaamad* AS.

Raw preliminary crushed oil shale is given to UTT-3000 retort by No. 2 car dumper of the Estonian Power Station. It is possible to supply oil shale also from the reserve oil shale storage of the Estonian Power Station.

Raw oil shale is transported into four measuring bins by belt conveyers. From the bins oil shale is given by box feeders to hammer crushers where it is sized to 0–25 mm. The above procedures and mechanisms are not shown in the flow diagram.

The crushed oil shale is passed by belt conveyers to raw oil shale bins arranged on the screw conveyers (flow No. 4 in the diagram).

Raw oil shale screw conveyers are equipped on the their ends with sealing chambers provided with turning trays able to reliably shut off from the atmosphere the inner space of UTT-3000 retorts maintained under excess pressure.

From the air-tight chambers of the screws the raw oil shale is poured into the inner recess of the aerofountain drier (hereinafter AFD).

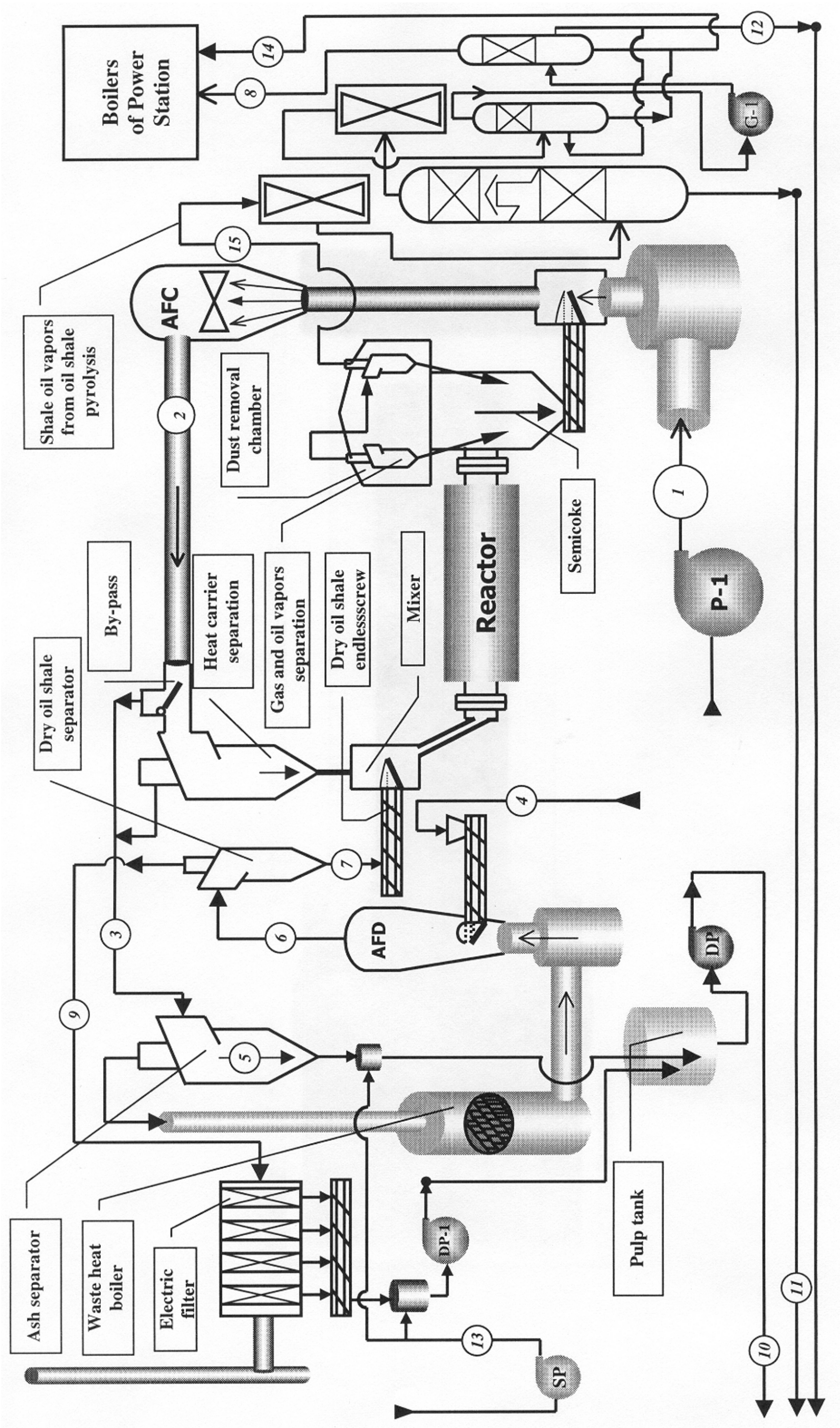
The stack gas flows at high velocity in counterflow to the oil shale moving downward. The temperature of the gas is about 590–650 ºC at the moment it meets the oil shale. As the recess in the lower part of AFD is narrower, at a certain level the moment occurs when the oil shale particles, including the largest ones, stop in the gasodynamic flow, then start moving together with the flow. The velocity of gas at the top of AFD is reduced and the large particles start moving downward again, i.e. a solid material fountain occurs. Finally, dried and to a great extent milled solid material leaves AFD as dust in gas flow at temperatures 180–165 ºC. The mix of dust and gas passes three pairs of cyclones for dry oil shale where dried fuel is separated and is given to screws of dry oil shale. The stack gas, to a great extent freed of fuel, passes to electric filter for after-cleaning and is emitted through the stack.

The dust caught by electric filter passes through an independent system of ash hydroremoval to pulp tank and is mixed with bulk of the shale ash leaving the operating UTT-3000 retort.

The material from cyclones for dry oil shale is transported by screw conveyers to air-tight screws for dry oil shale equipped also with sealing chambers with turning trays.

These mechanisms exclude or minimize flows between spaces filled respectively with stack gases and oil shale pyrolysis products. From turning trays dried oil shale is poured into the mixer recess at temperatures 110–140 ºC.

Simultaneously, from top of the mixer chamber the ash separated in heat carrier cyclones passes at 740–800 ºC through lined chutes by gravity flow.


Boilers of Power Station
Shale oil vapors from oil shale pyrolysis
AFC
Dust removal chamber
Heat carrier separation
Gas and oil vapors separation
Dry oil shale endlessscrew
Mixer
Reactor
Semicoke
By-pass
Dry oil shale separator
P-1
G-1
AFD
DP
DP-1
SP
Ash separator
Waste heat boiler
Electric filter
Pulp tank
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2
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Fig. 1. Short description of oil shale processing technology by UTT-3000 retort (the *Galoter* process).

Abbreviations:
Reactor – drum reactor for oil shale pyrolysis; Boilers of Power Station– boilers of the Estonian Power Station; AFC – aerofountain combustor of the retort; AFD – aerofountain dryer; P-1 – centrifugal air blower; DP – dredger pump; DP-1 – small dredger pump of electric filters; SP – pump for settled recycle water; G-1 – centrifugal gas blower

Principal material flows in flow diagram of the UTT-3000 retort:
1 – compressed air given to the retort; *2* – solid heat carrier mixture with stack gas after combustion of semicoke in AFC; *3* – mixture of ash and stack gas after separation of solid heat carrier required for oil shale pyrolysis process; *4* – raw oil shale to pyrolysis in the retort; *5* – ash separated by 1st, 2nd and 3rd stage ash cyclones; *6* – dried oil shale mixture with stack gas after AFD; *7* – dried oil shale separated by 1st, 2nd and 3rd stage cyclones prior to entering the system of dry oil shale screw conveyers; *8* – retort gas given to firing in power station boilers; *9* – stack gas to electric filter for final purification; *10* – ash pulp of the retort to No. 4 dredger unit of the power station; *11* – shale oils to fuel storage of the oil factory; *12* – oil shale gasoline separated from water to storage of the oil factory; *13* – settled recycle water to washing facilities of ash hydroremoval system of the retort; *14* – retort phenol water to incineration in power station boilers; *15* – oil vapors after cleaning to condensation system

The weight balance ratio between ash and dry oil shale is in the range of 2.8–3 to 1. Simultaneously, into the mixer chamber the following wastes are sprayed: oil wastes with impurities, fusses formed in the process of obtaining marketable products and part of the heavy oil fraction used in the system of the cleaning of oil vapors. In the mixer the first contact between the two solid materials takes place. Practically momentarily, because of a high heat capacity of the media present, in contact points of hot ash with organic material the release of gas from pyrolyzable products occurs, and the whole mass of the disperse material becomes highly mobile (fluidization).

Then the "fluidized" material moves through an inclined chute into the reactor. In the rotary reactor drum homogenization of temperatures takes place between hot ash and the pyrolyzable organic material, such as oil shale, fusses and heavy oil. The residence time of the solid material in the reactor totals to 14–16 min. The ratio of the heat carrier to pyrolyzable organic material is controlled by the position of aerodynamic tray arranged in the heat carrier by-pass. The adjustment is controlled by the temperature of oil vapors at the inlet into the cleaning cyclones. The pyrolysis products (retorting products) leave the reactor at 470–490 ºC and enter the dust removal chamber for preliminary cleaning of the gas phase from solid material by gravity.

From this moment the solid material, irrespective of its origin is referred to as 'semicoke'. The gas phase, however, has a high concentration of finely dispersed ash, and to still greater extent that of soot. To clean the oil vapors from solid products, a special high-efficiency two-stage system of cleaning cyclones is applied using forced suction of the dust-laden flow from the 2nd stage cyclone. The dust separated by cyclones for oil vapors is discharged into the lower parts of the dust removal chamber. Then the oil vapors are once more radically cleaned from ultradispersed particles by condensing part of heavy oil in a special wet cleaning system.

The cleaned oil vapors are fed to a rectification column for production of the middle-heavy shale oil fraction and the kerosene-solar oil fraction ("gas turbine fuel"), then in a cooler gasoline and water vapors are condensed, the retort gas is compressed by gas blowers, and after cleaning once more from condensed compounds, is directed as fuel for the energy boilers of the Power Station. The solid pyrolysis residue (semicoke) is collected in the lower part of the dust removal chamber and is taken off by semicoke screw conveyer. The latter is also equipped with a sealing chamber with a turning tray which prevents the ingress of air oxygen to heated (~490 ºC) hydrocarbon products of oil vapors in the dust removal chamber.

The semicoke is poured by turning tray of the sealing chamber of semicoke screw conveyer to the speed-up zone of the aerofountain combustor (hereinafter referred to as AFC). High-velocity air flow, generated by a high-capacity centrifugal blower, passes through the shaft of the speed-up zone of AFC. The semicoke is carried by the high-speed air into AFC. Approximately at mid-height of the speed-up shaft the semicoke undergoes selfignition. From the speed up part of the shaft the burning semicoke mixed with air and stack gases passes into the expanded top where the solid material starts spouting (fountaining). To intensify the combustion process of the low-calorific semicoke and reduce the size of AFC, in the center of furnace a swirler is arranged. The combustion process of the semicoke takes place at temperatures of 760–810 ºC and α_{air} = 0.95–0.89, i.e. at air shortage. Increase of the ratio air/semicoke is barred by the combustion temperature. At temperature exceeding 870 ºC fusion of the ash takes place.

The combusted semicoke leaves AFC as ash and passes into heat-carrier separation system, including the heat carrier by-pass and two parallel heat-carrier separation cyclones. The excess ash is removed from the heat-carrier separation system carried by stack gas and passes three pairs of ash cyclones in succession. The separated ash is moved to washing facilities of the ash-removal system, and then into pulp tank which serves at the same time as hydroseal against excess pressure in the UTT-3000 retort.

As washing water, the settled circulation water of the ash hydroremoval system of the Power Station is used. The temperature of stack gas is in the range of 740–800 ºC. The heat contained in stack gas exceeds that required for drying raw oil shale. The presence of 6.50–1.35 vol.% of combustible compounds and a surplus of sensible heat in the gas make it possible to include a waste-heat boiler into the complex of UTT-3000 retort, including afterburning of stack gas, prior to introducing the gases into AFD. The surplus of heat is not easily controlled by operating conditions of the waste-heat boiler, therefore the accurate control of the temperature of the mixture of dust and gas at the outlet from AFD and, consequently, of the conditions of drying oil shale are effected by spraying circulation water into the neck of the dryer.

The ash separated by ash cyclones and the ash carry-over caught by electric filters consisting of a mix of fine fractions of the same ash and fines of dried oil shale are contacted in washing facilities of the UTT-3000 retort and joined in the pulp tank and directed for mixing with alkaline ash aqueous suspension originating from firing oil shale in the boilers of the Power Station. Over the inclined surface of the ash disposal area solids of the suspension are settled into sediment, while the settled water is recycled to washing facilities of the Power Station boilers and UTT-3000 retort. Thus the cycle of recycle water of the ash hydroremoval system is closed. Along with solid wastes and water from ash hydroremoval system the wastes of oil shale processing at the Oil Factory include: emissions of stack gas into the atmosphere, retort (phenol) water originating from shale oil condensation system, and surface waters from technological sites of the factory.

The phenol water totaling to 2–3 tons per hour from one operating UTT-3000 retort is given to incineration through nozzles arranged in oil-shale-fired boiler of the Power Station.

The surface waters collected in regularly controllable intermediate tanks are given to ash disposal area. Simultaneously, there is an emergency discharge from the intermediate tanks into a pipe leading to phenol water incineration in boilers. The introduction of UTT-3000 retorts was carried out in two phases. Phase 1 included start-up and technology development (Table 1).

Table 1. **Basic Operating Data of the Retorts in the Period of 1980–1986**

Year	Feed oil shale, thousand tons	Shale oil, thousand tons	Operating time, hours
1980	4	0.3	61
1981	16	1.4	130
1982	51	5.7	379
1983	25	3.0	172
1984	77	9.7	634
1985	87	11	762
1986	128	15.2	1036

Phase 2 of technology development began since 1987 and was concerned with reliability of operation of the retorts (Table 2).

Table 2. **Dynamics of Increase in Reliability of Operation of the Retorts in the Period of 1992–2001**

Year	Feed oil shale, thousand tons	Shale oil, thousand tons	Gas, million m^3	Operating time, hours
1992	309	38,5	–	2982
1993	503	65,9	–	4433
1994	564	71,3	19,2	5445
1995	511	62,1	19,1	4962
1996	546	69,9	21	5197
1997	609	78,9	22,2	5651
1998	509	65,3	19,5	5000
1999	488	59,9	16,6	4370
2000	687	77,5	22	5887
2001	769	84,5	26,6	6177

During the introduction period the following results of Phase 2 in improvement of technology were reached:

1. Over 22 years more than 50% of the equipment was reconstructed by *Narva Elektrijaamad* AS.
2. Continuous operation was reached of one retort in accordance with design operating conditions (six months in 2002).
3. Simultaneous operation of two retorts was tested (continuous operation for eight consecutive days in 2002).

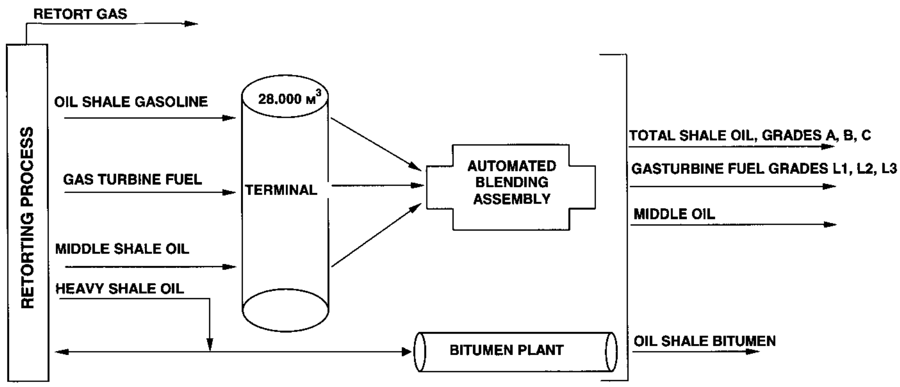

Fig. 2. Marketable fuels produced by the oil factory

Marketable Items in the Production List by the Oil Factory

The products are shown in Fig. 2. The condensation system of the retorts is able to separately produce heavy oil, middle oil, gas turbine fuel and gasoline which, with the exception of heavy oil, are pumped to the factory storage (terminal) for producing on their basis of total oil A, B and C, gas turbine fuel L1, L2 and L3, and middle oil. The heavy oil is either recycled to the process or passed to the bitumen plant for producing oil shale bitumen.

FurtherActivities by the Oil Factory of *Narva Elektrijaamad* AS

1. Increase in production efficiency
2. Balance tests of the retorts scheduled for 2002–2003
3. Increase of shale oil production in 2003 to 105000 tons
4. Continuation of effective measures for reduction of harmful impact on the environment
5. Purification of stack gases during start-up operations
6. Realization of requirements connected with the accession of Estonia to the European Union. Organization of an excise storage. Registration of marketable products in the list of chemicals of EU

Conclusions

1. Phase 1 of operations included start-up, operating and development of technology.
2. Phase 2 of technology development since 1987 was concerned with increase in reliability of operation of the retorts.
3. Advantages of the technology were demonstrated:
   - Environmentally friendly. In the solid residue (ash) the concentration of organic substances is below 1%.
   - Economically efficient resource saving technology. Unconcentrated oil shale feed is used with particle sizes 0–25 mm and a heating value of 2000 kcal/kg.

– Has a high efficiency. The chemical efficiency is up to 80%.
– High quality of products. The shale oil has a low water and impurities content, the retort gas has a high calorific value.
– High retort unit throughput. In an average it reaches 3300 tons per day of oil shale.
– The retort is able to process technical rubber waste and petroleum wastes.

4. The process for retorting oil shale fines operated by the Oil Factory of *Narva Elektrijaamad* AS demonstrated that the advantageous prototype retort is suitable for introduction of new productions by processing Baltic oil shale and oil shales of other world deposits.

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