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EXPERIENCE OF IMPROVING RETORT TECHNOLOGY FOR PROCESSING LARGE PARTICLE KUKERSITE

Unlike the rock from most of the world's known oil shale deposits, the Baltic oil shale (kukersite) possesses a number of technological properties which seriously complicate its thermal processing and obtaining of high shale oil yields. These properties include bituminization of the organic matter upon heating, high carbonate content of the mineral portion, high moisture content and relatively low mechanical and thermomechanical strength [1, 2].

An acceptable process for retorting large particle kukersite has proved to be the Kiviter process where the thermal decomposition is performed in a thin oil shale bed in retorts with one or two chambers in the retorting shaft utilizing cross flow of the heat carrier gas (Fig. 1, modifications *A* and *B*) [3]. The next step in developing the retorting technology for large particle kukersite is performing the process in retorts with a circular retorting chamber. Retorts for different oil shale throughput rates are being developed (Fig. 1, modification *C*). Compared to retorts utilizing cross-current heat carrier flow, this design has a number of important advantages (Table 1) providing favourable conditions for uniform distribution of heat carrier gas and efficient heat transfer in the shale bed [4, 5].

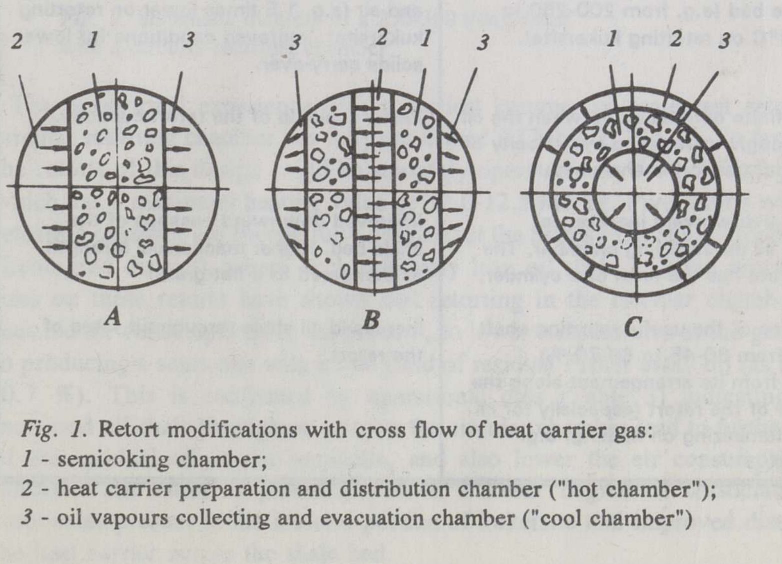

Fig. 1. Retort modifications with cross flow of heat carrier gas:
1 - semicoking chamber;
2 - heat carrier preparation and distribution chamber ("hot chamber");
3 - oil vapours collecting and evacuation chamber ("cool chamber")

Table 1. **Advantages of the modification "C" design Kiviter retort in comparison with retorts "A" and "B"**

Important design and process features	Advantages
1. Absence of cold side walls of the retorting chamber.	Elimination of problems related to the "wall effect" and to the phenomenon of the heat carrier gas passing predominantly along the side walls, and to non-uniform downward passage of the shale bed.
2. Flow of the heat carrier gas from the periphery of the circular retorting chamber towards its center.	Improved heat transfer across the whole shale bed, as the gas has higher temperatures and lower velocities at the inlet, and lower temperatures and higher velocities at the outlet.
3. Useful effect of segregation of oil shale particles according to their size at the charge: larger particles move to the periphery of the chamber towards the hotter zone, smaller ones towards the center into the zone of lower temperatures.	Favourable conditions for uniform heating of both large and small oil shale particles.
4. The bulk of oil shale rock moves through the high temperature zone.	Intensified retorting process and increased throughput rates.
5. Lower temperatures of the gas outlet resulting from improved heat transfer in the shale bed (e.g. from 200-250 to 140-160°C on retorting kukersite).	Lower specific heat consumption and, consequently, that of heat carrier gas and air (e.g. 1.5 times lower on retorting kukersite). Improved conditions for lower solids carry-over.
6. No definite correlation between the oil shale throughput rate and the velocity of heat carrier gas in the shale bed.	Easier scale-up of the retort capacity.
7. Gradual downward increase in diameter of the retorting chamber. The "cool" grate has the form of a cylinder.	Improved downward passage of the shale bed. Higher mechanical strength as compared to a flat grate.
8. Increase of the useful retorting shaft volume (from 30-45 to 60-70 %) resulting from its arrangement along the perimeter of the retort (especially for oil shales bituminizing on heating, e.g. kukersite).	Increased oil shale throughput rates of the retort.

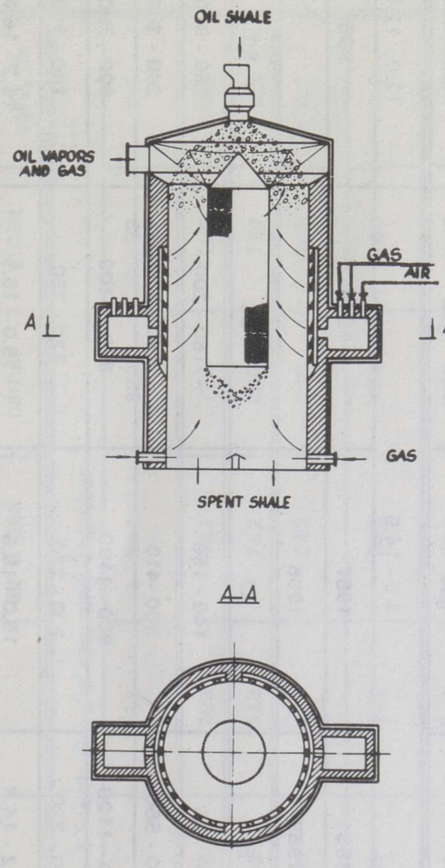

Fig. 2. Schematic diagram of a 250-300 t/day retort with a circular retorting chamber

The operational experience of the earliest commercial-scale test retorts with a circular retorting chamber has fully confirmed it (Table 2, Fig. 2). So far, however, the retorts of this design could be smoothly operated only for processing oil shale, which has a maximum heating value of 12.0-12.5 MJ/kg. Five retorts with circular retorting chamber are successfully operated at the Slantsy Oil Shale Processing Plant (Leningrad district), where such relatively lean oil shale is being processed. Test runs on these retorts have shown that retorting in the circular chamber leads to reduced air consumption for the process, to lower temperatures at the gas outlet and to producing a semicoke with a low yield of residual Fisher assay oil (as low as 0.5--0.7 %). This is confirmed by operational data (Table 3) indicating also that increased oil shale throughput rates in the circular chamber lead to further reduction of the residual oil in the semicoke, and also lower the air consumption for the process. The latter is probably due to a lower degree of dissociation of the carbonates present in the mineral portion of kukersite and improved distribution of the heat carrier across the shale bed.

The product gas from the retorts with a circular chamber has a higher heating value

Table 2. **The development of commercial retort design for processing large particle oil shale. Basic operational data**

Characteristics	Oil Shale Processing Association (Kohtla-Järve), GGS-5			Oil Shale Processing Plant (Slantsy)
	Lengiprogaz design	Retorts with central flow of heat carrier gas	Retorts with cross flow of heat carrier gas	Retorts with circular retorting chamber
Calorific value of feed shale, MJ/kg	13.5 - 14.5			12.0 - 12.5
Start-up year	1951	1957	1963	1986
Cease of operation	1959	1966	-	-
Useful volume of retorting chamber, m^3	11	23	22	50
Feed shale throughput rate, t/day	90 - 95	140 - 150	180 - 200	250 - 300
Air consumption for process, m^3/t	500 - 550	390 -410	390 - 410	240 - 260
Total consumption of air & gas, m^3/t	900 - 1100	900 - 1100	900 - 1100	600 - 700
Temperature at gas outlet, °C	200 - 220	200 - 220	220 - 250	140 - 160
Oil yield from raw shale, %	14.2 - 14.8	15.0 - 15.5	16.0 - 16.5	16.2 - 16.8*)
Oil yield of Fischer assay oil, %	65 - 68	68 - 72	74 - 78	82 - 85
Product gas, m^3/t	600 - 650	540 - 560	520 - 540	320 - 340*)
Gross calorific value of gas (incl.C_4), MJ/m^3	4.0 - 4.4	3.8 - 4.2	3.2 - 3.6	3.6 - 4.0
Process chemical efficiency, %	72 - 74	71 - 72	71 - 72	71 - 73*)

*) Calculated figures in Tables 2 and 4 (direct measuring being impossible, because of lack of separate condensing system).

Table 3. **Basic operating conditions of processing large particle oil shale at the Slantsy Oil Shale Processing Plant**

Test run No.	Period of test run	Feed shale throughput rate, t/day	Consumption for process, m^3/t			Temperature, °C		Fischer assay oil yield from semi-coke, %
			Air	Gas	Total air & gas	Heat carrier	Gas outlet	
Retort No. 17 with circular retorting chamber								
1.	6.03-5.07 1989	271	231	313	544	830	153	0.3
2.	28-29.08.86	262	230	203	433	755	165	0.2
3.	Oct. 1986	243	259	523	782	800	170	0.5
4.	12.05-5.07 1989	239	259	381	640	828	155	0.7
5.	Aug.-Nov. 1986	235	251	438	689	784	180	0.5
6.	16-19.07.89	223	288	509	797	847	146	1.2
7.	Aug. 1986	205	346	431	777	820	156	-
Commercial Retort Facility								
	1988	153	285	321	604	818	189	2.6
	1989	171	278	315	588	836	191	2.5
	1990	173	281	334	615	828	192	2.7

than the gas produced by retorts of other types (Table 4). The yield of hydrogen calculated on the initial oil shale or its organic matter is appreciably lower than at the commercial retorts in operation, which can be explained by a lower degree of volatiles pyrolysis in the circular chamber [6]. Thus the higher heating value of the gas can be attributed to a lower nitrogen concentration owing to reduced air consumption for the process.

Since retorting in circular chambers is marked by appreciable reduction of air consumption with a simultaneous reduction of residual oil in the semicoke, the yield of product oil should be consequently higher. According to calculations [6], it is as high as 85% of Fischer assay oil.

The operational experience at the Slantsy Oil Shale Processing Plant indicates that compared to retorts with cross flow of heat carrier, the solids carry-over with oil vapours from the retort with a circular retorting chamber is 2-3 times lower. This is due to favourable conditions of maintaining an effective filtering oil shale bed in the retorting shaft.

It should be noted that because of the specific design features of the circular retorting chamber, it is not easy to realize its advantages by reconstructing the existing small size 200 tonne-per-day retorts. The problems of creating high unit capacity retorts are much simpler because of large dimensions of the retort. With due consideration of the operational experience of the 1,000 tonne-per-day retorts and the earliest commercial-scale retorts with a circular chamber, high capacity retorts of the latter type were designed for GGS-7 of the Oil Shale Processing Association (Kohtla-Järve). The installation includes four retorts with a throughput rate of 1,500 t/day each. A number of novel design features were introduced to improve the efficiency of oil shale processing in these retorts. For example, to ensure uniform and stable passage of the shale through the retort, its inner diameter gradually increases downward. This simple idea had never been realized in oil shale retorts so far.

As the process of semicoking takes place in an oil shale bed, where the heat carrier gas passes the larger particle portion of the bed first with subsequent flow through its smaller particle portion towards the retort center, favourable conditions are created for removing the solids from the oil vapours. It is expected to keep the temperature at the gas outlets of the GGS-7 retorts on a low level (100-150 °C). The design of the cylindrical grate in the retort center has been improved to reduce the tendency of getting jammed.

The operational experience of the circular retorting chambers also reveals their high sensitivity to lasting breaks in operation of the discharge mechanisms. In such cases, as a result of jamming the cylindrical grate with thermobitumen and deterioration of uniform downward passage of the shale bed, the normal operation is disturbed. The behavior of the large size retorts designed for GGS-7 differing by design significantly from small 200 tonne-per-day retorts will be revealed only after their start-up.

At present the construction of GGS-7 (Fig. 3) has been suspended due to investment problems, which means that no start-up and operational experience of high capacity circular retorting chambers will be available in the near future. At the same time, such information would be of great interest for commercial utilization of oil shale deposits other than kukersite. It has been estimated that the dimensions of retorts designed for the GGS-7 to retort 1,500 tonnes per day of kukersite, are sufficient to house retorts of the same type with a much higher throughput rate for processing lean oil shales.

Table 4. **Yield and characteristics of product gas at the Slantsy Oil Shale Processing Plant**

Test run No.	Product gas yield, m^3/t	Composition of gas, vol. %							Gross calorific value (incl C_4), MJ/m^3	Yield of hydrogen, m^3/t	
		$CO_2 + H_2S$	C_nH_m	O_2	CO	H_2	CH_4	N_2		from oil shale	from organic matter
Retort No.17 with circular retorting chamber											
1.	298	19.4	1.5	0.7	5.2	9.0	3.2	61.0	3.77	26.8	88
2.	298	20.1	1.4	0.7	4.9	8.2	3.2	61.9	3.39	24.4	81
3.	326	18.5	1.3	0.6	6.6	7.7	2.5	62.8	3.64	25.9	85
4.	340	19.0	1.5	0.7	5.5	9.5	3.5	60.3	3.98	32.0	105
5.	325	-	-	-	-	-	-	-	-	-	-
6.	368	18.3	1.2	0.7	7.3	8.8	2.1	61.6	3.39	33.0	108
7.	446	-	-	-	-	-	-	-	-	-	-
Commercial Retort Facility											
1988	438	17.3	1.0	1.7	4.6	8.6	1.9	64.9	3.10	37.7	124
1989	425	18.1	1.0	1.5	4.6	8.2	1.8	64.8	2.97	34.8	115
1990	454	17.7	1.0	1.6	4.6	8.1	1.8	65.2	2.89	36.8	121

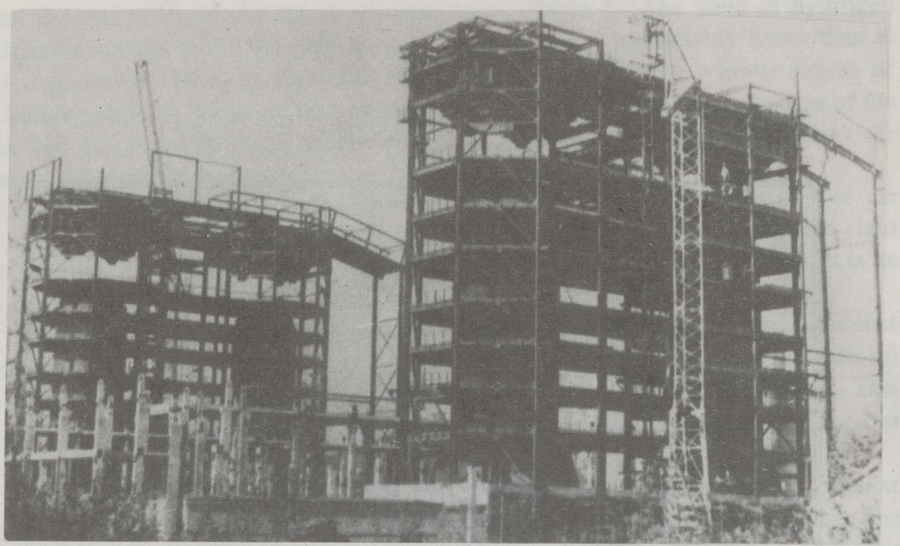

Fig. 3. General view of the retorting station (GGS-7) comprising four 1,500 tonne-per-day retorts while under construction

As a rule the majority of the world's oil shale deposits are represented by leaner shales, which can be retorted without technological difficulties characteristic to kukersite. This is confirmed by rather short experience gained in the People's Republic of China so far. Since mid-1991 a small capacity retort is in operation at a plant of the Maoming Petroleum Chemical Company to process the local oil shale in a circular retorting chamber. The retort reconstructed according to recommendations by the Oil Shale Research Institute and the Oil Shale Processing Association (Kohtla-Järve) has a throughput of 150 tonnes per day. The shale processed is characterized by 17% moisture, by a heating value of 7,500 kJ/kg and a Fischer assay oil of 8%. Since the retort is connected to a separate condensation system, it has become possible for the first time to directly measure the yield of oil from a circular retorting chamber and thus evaluate the effectiveness of this design. The plant yield of oil increased from 60-65 to 75-80 % of Fischer assay oil, reaching at times 83-85 %.

Over the past decade the development of retorting techniques has been directed to creating automated high capacity retorting units with improved technological procedures. The results show a significant increase in unit throughput rates of the retorts (from 35 to 1,000 tonnes per day). At the same time, however, the oil yield showed only a slight increase. The oil yield of the Fischer assay oil increased from 65-68 to 74-78 %. This was because the technological problems arising from retort upscaling are complicated by difficulties in ensuring even distribution of the heat carrier gas across the shale bed, and the uniform downward passage of the latter in the retort.

Theoretical research and operational experience have shown that the oil yield is negatively influenced by the presence of oxygen in the gaseous heat carrier [7-9], and that there is a direct relationship between the consumption of air for the process and the oil yield. To attain normal oil yields, the concentration of oxygen in the retorting chamber should not exceed 0.5 m^3 per tonne of feed shale [6]. Most of the oxygen present in the retorting chamber comes from the gasification zone as a result of unsatisfactory semicoke gasification procedures [7]. It can be seen in Table 2 that lowering the intensity of the gasification leads to increased oil yields. By replacing the gasification process with cooling of the semicoke with recycle gas, the concentration of oxygen in the retorting chamber is sharply reduced. Another source of oxygen to the retorting chamber is the flue gas from the built-in gas burners in the retort, which can be eliminated by introducing improved gas burner designs.

As was noted above, significant research effort has been directed to lowering the oxygen concentration in the retorting chamber by reducing the consumption of air for the process. This can be attained by reducing the sensible heat losses with spent shale (by cooling it with recycle gas or air), and with oil vapours by bringing down their temperature by increasing the height of the shale bed and improving the uniformity of heat carrier distribution across it. Another factor contributing to the reduction of air consumption is operating the retorting process at a lower degree of carbonates dissociation. The air consumption can be reduced also by a more complete utilization of oxygen in the gas burners of the retorts. The lowest air consumption for the retorting process has been attained in retorts with a circular retorting chamber (Table 2) which evidences of improved process procedures in this retort modification.

The best solution for the problem of reducing oxygen to the retorting chamber is the use of recycled gaseous heat carrier heated in separate heat exchangers. This has been proved by long operation of the tunnel ovens in Estonia, and also by experience gained by Petrosix, Unocal, JOSECO, etc. elsewhere. The method is a radical solution for producing practically oxygen-free heat carrier gas.

The advances in developing high unit capacity retorts over the past decade are the result of replacing the semicoke gasification by cooling it with recycle gas. However, this is not an optimal solution from the point of view of environment protection and of the complete utilization of residual carbon of the semicoke. The semicoke discharged from the retort has a higher concentration of toxic substances (water soluble sulphides, benz(a)pyrene, volatile phenols, etc.) than the spent shale (ash) from the process of deep semicoke gasification. The gasification process, however, is practically impossible to be introduced in the retorts at present in operation because of unavoidable inflow of significant amounts of oxygen into the retorting chamber, and difficulties in process control. For this reason for the retorts in operation (and for those designed for GGS-7) which are designed for retorting without semicoke gasification, additional separate facilities must be provided for burning the semicoke. Designs of such facilities are known in the world practice (JOSECO, Petrosix, etc.).

As for new processes being developed for oil shale retorting, it would be feasible to house both the retorting and gasification zones in one retort vessel in a manner which eliminates the negative influence of the gasification process upon the retorting efficiency. The use of the retorts designed for processing oil shale without gasification is fully justified in case of producing semicoke as a market item, or when semicoke is readily fused into ash-slag in the gasification process. In the retorts without semicoke gasification where the latter is cooled by recycle gas, the possibilities of increasing the gas flow for the cooling process are limited because of increased hydraulic resistance of the shale bed. As a rule, the consumption of recycle gas for cooling the semicoke does not exceed 400-500 m^3 per tonne of feed shale, which does not allow to effectively use the sensible heat of the semicoke. As a result, the latter can be cooled only to a temperature level of 200-250 °C.

To increase the efficiency of processing oil shale in vertical retorts, the Oil Shale Research Institute and the Oil Shale Processing Association have developed a proposal for taking out the recycle gas separately from the cooling zone, and use it, for example, in heat exchangers to heat the recycled heat carrier used in the retorting process [10]. This enables to raise the volume of recycle gas used in the cooling zone to 600-800 m^3 per tonne of feed shale, and, consequently, to cool the semicoke down to 50-150 °C.

It would be feasible to design the semicoke gasification zone above the cooling zone in the lower part of the retort. In this case it would be possible to use air as a cooling agent for gasified spent shale (ash) discharged from the retort. As a result, the possibility of passing the low calorific oxygen-containing gasification gas into the retorting zone is completely excluded. Thus favourable conditions are provided for attaining oil yields close to Fischer assay oil. Simultaneously high calorific gas and a low-toxic solid residue are produced.

Research and development is successfully under way in this direction in Japan by JOSECO [11]. The high efficiency of performing the processes of oil shale retorting and semicoke gasification separately in the retort vessel has been proved in a 250 tonne-per-day experimental oil shale retorting plant in Japan. The retort was designed to process low organic shales. In the test runs oil yields close to those of Fischer assay were obtained.

Conclusions

1. For low temperature processing of Baltic oil shale (kukersite) which has a number of specific technological properties, the most widely used is the Kiviter process. It has been developed for processing large particle shale in retorts designed with one or two chambers in the retorting shaft and using the concept of cross-flow of the gaseous heat carrier. The Kiviter retorts is operation have throughput rates of 180--200 and 900-1,000 tonnes per day respectively. Introduction of the cross flow Kiviter retorts enabled to increase the oil yield from 65-68 to 74-78 % of Fischer assay oil.

2. For further development of retorting techniques for low temperature processing of large particle shale a novel retort design with a circular retorting chamber has been proposed to obtain oil yields as high as 85 % of Fischer assay oil. The first commercial-scale experimental retorts with a throughput of 250-300 tonnes per day of feed shale demonstrated smooth operation on low upgraded kukersite with a heating value of max. 12.0-12.5 MJ/kg (bomb calorimeter value).

The construction of an installation of four 1,500 tonne-per-day retorts with circular retorting chambers (GGS-7) has been suspended due to investment problems. Taking into consideration that the novel high-unit-capacity retort design has a number of undeniable advantages in comparison to known retorts in operation for oil shale low--temperature processing, and it is of practical interest for commercial retorting of low organic shales, it would be expedient to find means for completion of the GGS-7 without further delay.

3. Taking into account the continous increase in kukersite price and operational difficulties experienced by retorting relatively high-organic oil shale in circular chambers, it is necessary to consider the feasibility of lowering the degree of upgrading the feed shale.

4. To increase the efficiency of processing large particle kukersite in vertical retorts without semicoke gasification, it is recommended to take the portion of gas which has passed the cooling zone, as a separate flow into heat exchangers, and use it there for heating the recycle heat carrier passing into the retorting chamber. In cases when the use of the gasification process is possible, and no slagging of the semicoke occurs in the gasification zone, the latter should be arranged above the cooling zone in the retort.

Since the above design concept is a good basis for developing efficient retorting techniques for large particle oil shale, it would be timely and feasible to build a commercial-scale experimental retort on the site of an oil shale processing plant in the Baltic basin for developing sound technologies for low-temperature processing of kukersite with due consideration of its technological properties.

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