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MAIN FACTORS INFLUENCING EFFICIENCY OF PROCESSING LARGE PARTICLE OIL SHALE IN VERTICAL RETORTS

V. YEFIMOV
T. PURRE

Oil Shale Research Institute
Kohtla-Järve, Estonia

World-wide experience of retorting large particle oil shale demonstrates that known types of retorts are characterized by differing degrees of process efficiency. The latter depends on several factors influencing the process. In this paper an attempt in made to systematize the influence of these factors affecting, above all, the oil yield in vertical retorts. The present review, of course, does not pretend to be complete and does not consider all possible features playing a role in the process of retorting large particle shale under industrial and pilot-scale conditions. However, estimating the effect of those factors may be useful for further improvement of oil shale processing units.

The comparison of data characterizing the efficiency of thermal processing of large particle oil shale in different types of retorts usually leads to the conclusion that the design features play a decisive role in efficient operation of the retorts. It is not sufficient, however, to consider the design features only. A great deal also depends on the properties of feed shale and the operating conditions in the process.

1. Technological Properties of Feed Oil Shale

From the point of view of the retorting process efficiency the important properties are those which determine the technological behaviour of the feed shale in the retort and the heat requirements for the process of oil shale thermal decomposition. For example, organic rich oil shales, as a rule, tend to bitumenization on heating which should be carefully taken into account in developing retort designs. The tendency of different oil shales to pyrobitumen formation on heating is given in Table 1.

As is shown, kukersite as a relatively high organic oil shale, has its special place among other oil shales. Over 70 years of experience in commercial retorting of kukersite in Estonia evidences about enormous difficulties which had to be overcome during the development history of its processing. Today the optimum retort design for processing large particle kukersite is considered the use of a thin oil shale bed in the retorting chamber to avoid clogging of the retort by bitumenization, and the use of the concept of cross-current flow of the heat carrier through the shale bed.

Table 1. **Yield of Pyrobitumen on Heating Oil Shale in a Fischer Retort**

Oil shale deposits	Initial oil shale properties, dry basis			Temperature of maximum formation of pyrobitumen, °C	Pyrobitumen yield in a Fischer retort, dry basis, %
	Organic content, %	Calorific value, MJ/kg	Fisher assay oil, %		
ESTONIA					
kukersite (concentr.)	57.5	21.9	39.6	395	33.3
kukersite	36.5	14.0	24.8	395	21.6
RUSSIA					
kukersite	29.1	10.5	18.9	390	16.2
BRAZIL					
Paraiba valley deposit (papirasseo)	39.5	13.3	21.1	400	11.1
Paraiba valley deposit (pedro, lump-sized)	18.2	3.9	4.1	370	1.4
UKRAINE					
Boltysh deposit	42.0	12.7	17.5	400	8.9
SYRIA					
Senoman deposit	14.8	4.3	6.5	350	3.3

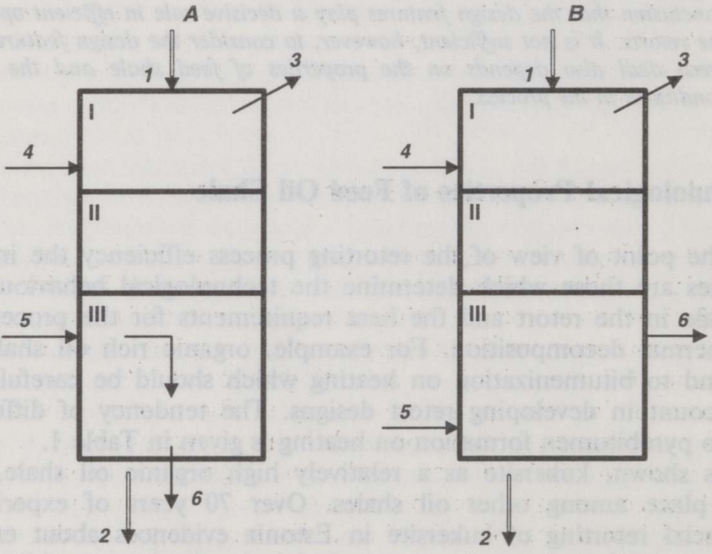

Fig. 1. Principal flow diagram of processing oil shale in retort with separate withdrawal of the vapour-and-gas mixture and the cooling gases. I - retorting zone, II - seal zone, III - cooling zone; *1* - feed shale, *2* - spent shale, *3* - oil vapours and gas, *4* - recycle gas, *5* - cooling gas, *6* - hot gas

Table 2. **Development of Commercial Retort Design for Processing Large Particle Oil Shale**

Retorting process	Raw shale		Retort operating data			Oil yield	
	Moisture, %	Organic matter, %	Oil shale throughput rate, t/day	Heat carrier temperature, °C	Air consumption, m³/t	From raw oil shale, %	Of Fischer assay oil, %
Direct Heated Retorts							
ESTONIA (RAS Kiviter):							
Lengiprogaz design	9.1	32.4	92	660	500	14.4	68.0
Central heat carrier flow retort	8.6	31.0	143	810	390	15.3	72.5
Cross heat carrier flow retort:							
semicoke gasification	8.7	30.6	182	970	405	16.4	78.3
without semicoke gasification	8.4	31.8	172	960	344	17.8	83.3
U.S.A.							
Gas combustion process	0.7	15.6	5.4	500-600	109	9.8	94.2
Indirect Heated Retorts (Recycle Heat Carrier)							
ESTONIA (RAS Kiviter)							
Tunnel ovens	8.6	31.5	388	480-500	-	21.2	98
BRAZIL							
Petrosix process	5.3	16.9	1600	500-600	-	6.7	96
U.S.A.							
Union oil, retort B	0.7	15.6	3.0	500-520	-	10.4	100
JAPAN							
JOSECO retort:							
retorting Condor oil shale	8.4	-	220	590	-	58*	100
retorting Maoming oil shale	5.0	-	160	590	-	78*	102

* Litre per tonne.

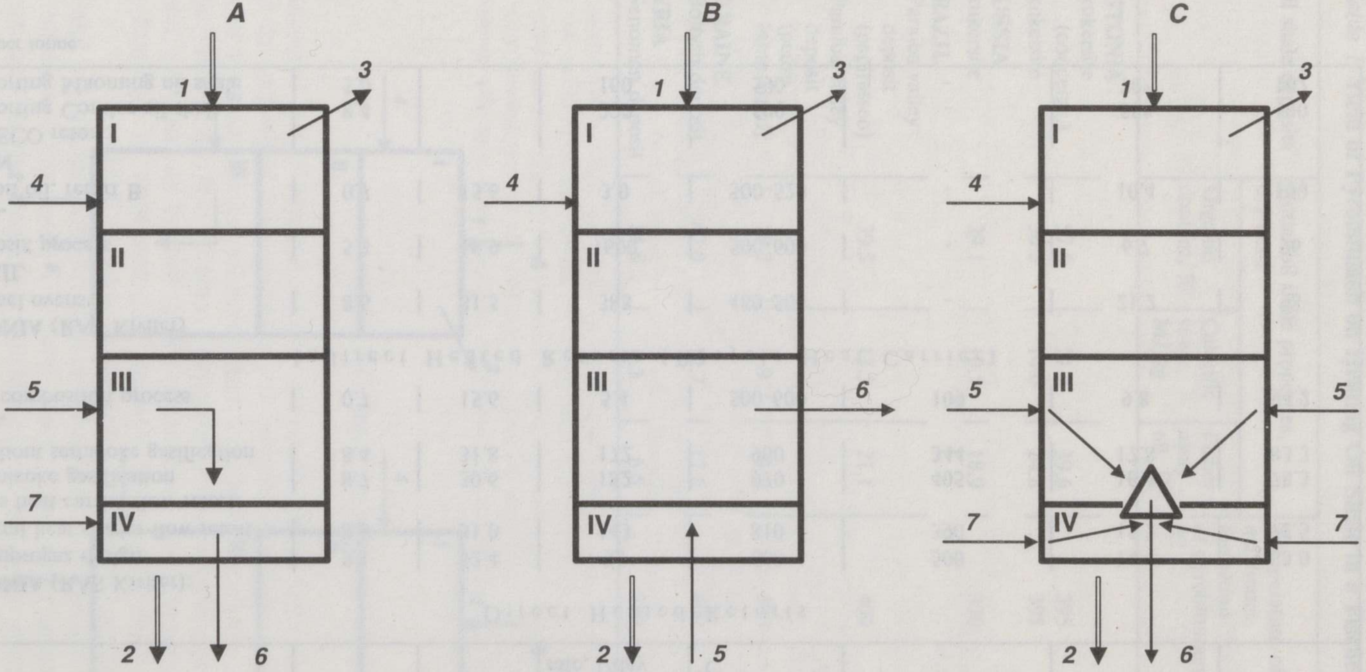

Fig. 2. Principal flow diagram of processing oil shale in retort with separate withdrawal of the vapour-and-gas mixture and gases obtained upon gasification: I - retorting zone, II - seal zone, III - gasification zone, IV - cooling zone; *1* - feed shale, *2* - spent shale, *3* - oil vapours and gas, *4* - recycle gas, *5* - oxidizing agent, *6* - gasification gas, *7* - cooling agent

It has been shown that under those conditions the optimum bed thickness for high calorific kukersite (12.5-14.0 MJ/kg) is 1.0-1.5 m, while for lower calorific kukersite rock (9.5-10 MJ/kg) the optimum range is as high as 1.5-2.0 m. However, in the existing retort design which fully meets the retorting requirements for processing bitumenizing oil shale (e.g. kukersite) the shale bed occupies max. 30-45 % of the total retort shaft volume, thus adversely affecting the throughput rate of the retort. Moreover, this is not the only disadvantage of retorting high calorific shales. It is known that the thicker the shale bed in the retort shaft, the more uniform is the distribution of heat carrier and the more effective the heat transfer in the bed, which would result in low temperatures of oil vapours in the gas outlet. In a thin shale bed, however, this is not the case and therefore it is necessary to maintain relatively high temperatures (as high as 200-250 °C) in the gas outlet, which is the cause of increased solid particles carry-over from the retort (10-12 kg per tonne of shale feed), thus deteriorating the operation of the condensation system and the raw shale oil quality.

The retorting of low calorific (lean) shales, on the other hand, is a much easier task, mostly because of the absence of the bituminization tendency. Lean shales can be processed in significantly thicker beds in the retort. The operational experience of processing lean oil shale in countercurrent heat carrier flow retorts in China and the U.S.A. has demonstrated that thick shale beds in the retort (4-5 m) enable to achieve uniform distribution of the heat carrier which leads to effective heat transfer in the bed, and makes it possible to maintain very low temperatures in the gas outlet (60-80 °C).

Very important among the technological properties of the feed oil shale is its mechanical and thermomechanical strength which determines the minimum oil shale rock particle size suitable for retorting. In case of rich shales (kukersite) relatively large particle size (25-125 mm) is required due to low mechanical strength of the shale rock which is further decreased in the process of retorting because of the dissociation of carbonates accompanied by resulting destruction of the mineral skeleton of the rock [2]. Lean oil shales possess a notably higher mechanical strength than the high organic shales which makes it possible to use smaller shale particle sizes having higher specific surface which enables to achieve higher process intensities and increased throughput rates of the retort.

For example, oil shale load over the retorting shaft cross-section on countercurrent processing of lean shales is 1100 kg/sq.m·h (particle size 10-76 mm) for Green River oil shale, and 2900 kg/sq.m·h (particle size 6-70 mm) for Irati (Brazil) oil shale. For kukersite the respective maximum load is as low as 400-500 kg/sq.m·h. Fairly low process heat requirements for the above lean oil shales (twice as low as for kukersite [3]), a high specific surface of the shale bed in the retort, determine a comparatively low heat carrier consumption for the retorting process, and consequently, enable to maintain low heat carrier temperatures in the process (500-600 °C). In the case of retorting kukersite it is not possible, because at low heat carrier temperatures the volume of the latter required for the retorting process would be enormous and lead to significantly reduced retort throughput rates (1.5-2 times lower than the usual) which is hardly feasible for commercial production.

The above indicates that the oil shale throughput rates for vertical retorts, the shale oil yield, and the solid particles carry-over from the retorts into the condensation system to a great extent depend on technological properties of the feed oil shale. In evaluation of different retorting processes and retort designs it is not always fully taken into account.

The properties of oil shale, naturally, also principally determine the physical and chemical properties of shale oil. Oil shales from the majority of deposits yield low sulphur paraffinic oil on low temperature processing (semicoking) which makes it possible to use conventional petroleum refining technologies for processing of shale oil. Oil shales from a limited number of deposits yield high sulphur oil. Kukersite from the Baltic oil shale deposit is practically the only oil shale which on thermal processing yields oil characterized by a high content of oxygen compounds.

2. Operating Conditions of Oil Shale Thermal Processing

The amount of oxygen in the reaction volume of the retorting shaft is an important factor affecting the oil yield in the process of oil shale thermal decomposition. The less oxygen enters into retorting shaft the less the reduction of the oil yield. Very important is keeping the absolute amount of oxygen entering into retorting shaft as low as possible [4], preferably not higher than 0.5 m^3 per tonne of feed shale [1].

Under the influence of oxygen the volatile products present in the reaction volume are most probably converted by the process of oxidizing pyrolysis. The main source of oxygen entering the retorting shaft is the process of semicoke gasification and burning of gas in the built-in gas burners. Therefore, the amount of oxygen in the retorting shaft may be reduced through the following procedures:

- replacement of semicoke gasification by its cooling with recycle gas;
- improvement of the gas burning process in gas burners and increasing their number;
- elevation of temperature in the gas burning zone.

An effective way to improve the currently operated retorting technology to achieve maximum shale oil yields is considered reduction of the specific consumption of air (naturally, without adversely affecting the recovery of volatiles).

To identify good solutions for retort design improvement to reduce the specific consumption of air for the retorting process further development should be directed to the following:

- improvement of heat transfer and uniform distribution of heat carrier across the shale bed resulting in lower temperatures of oil vapours and gas in the gas outlet (e.g. increasing the thickness of the oil shale bed);
- reduction of heat losses with discharged solid residue (arrangement of an enlarged cooling zone in the lower part of the retort);

- reduction of the degree of carbonates dissociation (shorter oil shale residence time in the retorting zone, housing the cooling zone in the lower part of the retort, improved distribution of heat carrier in the retorting shaft, and improved conditions for gas burning aimed at increasing the concentration of carbon dioxide and decreasing that of residual oxygen in the recycle gas).

The world-wide experience of oil shale retorting has shown that the amount of residual oxygen entering the semicoking shaft can be essentially reduced by the use of heat carrier gas circulated via special heat exchangers which is convincingly shown in Table 2.

In retorts in which the semicoke produced in the retorting process is not gasified, but only cooled in its lower part with recycle gas [5, 6], the possibilities of increasing the volume of the cooling gas are quite limited because of considerable hydraulic resistance of the semicoke bed. Therefore, instead of directing the cooling gas upwards through the whole retort, it is proposed to be taken off separately from the lower part of the retort (Fig. 1) to be heated in the heat exchanger intended for heat carrier preparation for the retorting process [7].

However, such a technological solution without gasification of the semicoke is not the best one from the point of view of incomplete utilization of the organic matter of the shale and deteriorated ecological conditions (the presence of toxic compounds in the semicoke). That is why the semicoke gasification (when semicoke is not used as a separate marketable product) has to be considered as highly useful. Anyhow, semicoke gasification must have no negative influence on the oil yield. Low calorific gasification gas which unavoidably is not free of oxygen must be excluded from entering the retorting shaft to create favourable conditions for obtaining oil yields close to the Fischer assay oil, high calorific gas, and a harmless solid retorting residue.

There are several options for the design of the lower part of the retort (Fig. 2). Case A - gasification of semicoke in the upper part of the gasifier above the cooling zone [7]. Case B - the oxidizing agent is introduced into the gasifier through the bottom of the retort. Gasification gases are removed from the upper part of the gasifier. This version has been developed and successfully put into pilot scale operation by the Japanese JOSECO Company for processing low organic oil shales [8].

Case C, developed jointly by the Oil Shale Research Institute and RAS "Kiviter" - the oxidizing agent is introduced in the upper part of the gasifier, the withdrawal of gasification gases from the point at mid-height of the gasifier, and the cooling of the solid retort residue by air or recycle gas. As demonstrated by the experience, the use of such technology results in a very low content of oil in the gasification gases - 1-2 g/m^3 against usual 8-10 g/m^3. That, in turn, essentially prolongs the normal operation of heat exchanger surfaces between cleanings. It may be expected that the introduction of the oxidizing agent under pressure into the upper part of the gasifier (approximately at the same pressure as used for the introduction of recycle heat carrier into the retorting shaft) is likely to facilitate the control of hydraulic conditions required to prevent the overflow of gasifier gases into the retorting shaft and vice versa.

3. Retort Design

It is understood from the above that there is no sense of discussing the advantages of one or another type of retort without considering specific properties of feed oil shale or the technology applied. From the point of view of design features reliable operation of the retort and possibilities of process mechanization and automatic control are the most essential factors which have to be considered.

The design of a retort intended for processing large particle shale has to guarantee even distribution of gaseous heat carrier across the retorting shaft and the minimum hydraulic resistance of its design elements.

As stated above, the use of a thick oil shale bed in the retorting shaft leads to improved uniformity of distribution of the heat carrier across it, but possibilities to do so are greatly dependent on the technological properties of the feed shale. Design of the unit, of course, has also its effect on the process. The experience of retorting kukersite has demonstrated that the distribution of gaseous heat carrier will be improved through the following procedures:

- replacing the concept of countercurrent retorting of shale with the cross flow of heat carrier gas in the retorting chamber;
- reducing segregation of oil shale particles at the charge according to lump sizes (e.g. using several charging devices and different directing mechanisms);
- arranging additional heating of the cool side of the retorting chamber in the cross-flow retort.

Retorting of shales with a low content of organic matter in retorts with the cross flow of heat carrier may turn out to be complicated and not effective due to insufficient thickness of the shale bed. In that case the well-known method of retorting in the counter-flow would give better results.

To have a relatively thin shale bed in the retorting chamber on retorting kukersite, which is rich in organic matter and has a strong tendency to bituminization, is not complicated from the point of view of design. The problem is how to avoid too high temperatures of oil vapours and gas in the gas outlet due to imperfect distribution of heat carrier and, consequently, insufficient heat exchange in a thin bed. That, in turn, has its negative effect upon the basic operational criteria of oil shale processing and contributes to carry-over of dust with vapours.

The best conditions for achieving an even distribution of heat carrier across the shale bed in vertical retorts are created when the circular retorting chamber is used [7].

Retorts with circular retorting chamber are successfully operated for processing relatively lower organic kukersite with a heating value below 12.5 MJ/kg (The yield of Fischer assay oil max. 18-20 %). Processing of richer shales in retorts with circular retorting chamber may lead to plugging of the central cylindrical grate with thermobitumen. The above discussion permits to conclude that retorts with circular retorting chamber are especially suited for retorting oil shales relatively poor in organic matter, which are found in abundance all over the world.

Consequently, retorts with cross flow of heat carrier are efficient for processing high organic oil shales or other high organic solid fuels (e.g. liptobiolith, asphaltite, brown coal, etc.), while retorts with counter-flow of heat carrier show good performance for processing low organic oil shales.

Conclusions

For efficiency estimations and comparison of different oil shale retorting processes three main factors should be taken into consideration:

1. Technological properties of feed oil shale including tendency to bituminization, mechanical and thermomechanical properties, content of carbonates and moisture. Non-bitumenizing oil shales possessing high mechanical and thermomechanical strength and a low content of carbonates and moisture are best suited for retorting.

2. Operating conditions of thermal processing should provide a residual oxygen content in the retorting zone as low as possible, not exceeding 0.5 m^3 per tonne of feed shale. The best solution to achieve it is to use for the retorting process recycle heat carrier gas preheated in heat exchangers.

For higher efficiency of retorting large particle oil shale in vertical retorts, the gas flow warmed up in the cooling zone of the retort should be drawn off separately, and directed to heat exchanger for heating the recycle heat carrier.

Further development of retorting technology for processing large particle oil shale is most likely to proceed in the direction of deep gasification of semicoke in the lower portion of the retort.

An efficient future version of the above technology provides draw-off of the retorting gases separately from the gasification gas.

3. Design of retorts should provide reliable operation, good serviceability and uniform distribution of the heat carrier across the retorting zone.

For retorting low organic oil shales (Fischer assay oil max. 18-20 %) the above requirement can be met most effectively by retorts with circular retorting chamber and the usual counter-flow retorts.

For solid fuels with a higher organic content the retort design should provide thin fuel rock bed in the retorting zone, e.g. retorts with cross flow of the heat carrier.

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