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OIL SHALE GENERATORS* WITH CIRCULAR RETORTING CHAMBER

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СЛАНЦЕВЫЕ ГЕНЕРАТОРЫ С КОЛЬЦЕВОЙ КАМЕРОЙ ПОЛУКОКСОВАНИЯ

A decisive factor in perfecting oil shale processing technology in the generators is the improvement of heat exchange conditions in the shale bed with simultaneous reduction of specific heat consumption and, consequently, the reduction of specific air consumption of the process (without adversely affecting the degree of volatiles recovery). Increased gaseous heat carrier velocities and elevated temperatures, and also the attainment of its uniform distribution in the retorting zone make for the improvement of heat exchange conditions in the shale bed [1]. Reduced specific air consumption leads to a decrease in both the secondary pyrolisis of the volatile products and the rate of oxidation of oil shale in the reaction volume by the residual oxygen present in the gaseous heat carrier. All that makes for an increase in the oil yield in the end [2].

The reduction of specific heat consumption of the process is achieved by application of measures aimed at reducing the losses of sensible heat with oil vapours and gas and the discharged solid residue (ash or semi-coke), as well as decreasing the rate of carbonate decomposition. To these measures, first of all belong the arrangement of a cooling zone in the lower part of the generators and the reduction of the oil vapours temperature at the gas outlet [3]. As for the carbonate decomposition, the degree of this process can be lowered both by reducing the oil shale residence time in the high-temperature zone (that is achieved by increasing the shale throughput capacity of the generators), and by increasing the partial pressure of carbon dioxide in the gaseous heat carrier. The latter can be achieved by further perfection of the burner design, warranting more complete combustion of the gas, and by alternation of shale segregation structure at its charging into the generators aimed at the concentration of smaller particles mainly at the hot side of the retorting chamber [4].

The fact, that the transition from the counter-current method of semi-coking in the generators to the cross-current flow of the heat carrier (CCHC) resulted in an increase in the oil yield [5], and in a decrease in the secondary pyrolysis of the volatile products [2], evidences that the uniformity of the heat carrier distribution in the shale bed is improved. This is confirmed also by theoretical investigations [6, 7].

* In the U.S.S.R. a mode of direct heated vertical retorts for processing lump oil shale is referred to as «oil shale generators».

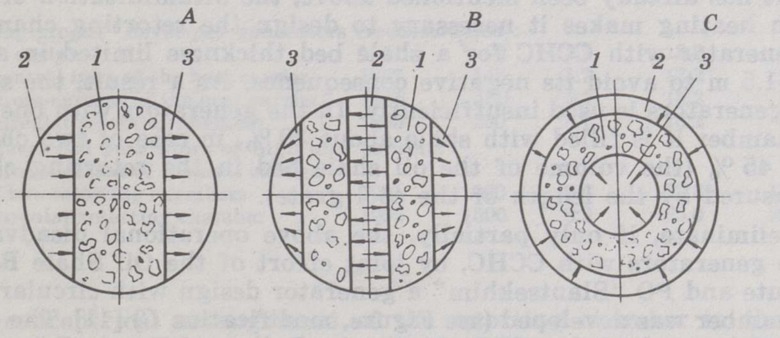
The Baltic oil shale (kukersite), as generally known, turns into a plastic state at temperatures of 350—400 °C, which limits the thickness of the bed in the retorting zone. Therefore, the transition from semi-coking of the oil shale in the counter-current of the heat carrier to the cross-current method, enabled to overcome many difficulties in the generator performance and at the same time there was a two-fold increase in the useful retorting volume. To the same extent increased the throughput rate of the generators.

Long operating experience has shown that the thickness of the shale bed in the retorting zone of the generators processing oil shale with a heating value of 13—14 MJ/kg (bomb calorimeter value on a moisture-free basis), must not exceed 1.5 m. Nevertheless, continued search for opportunities to increase the thickness of the shale bed in the retorting zone of the generators is highly important for further perfection of the generator process, as it allows:

— to reduce the specific air consumption of the process due to lower temperatures of oil vapours at the gas outlet resulting from improved uniformity of the heat-carrier distribution across the bed;

— to reduce the dust carry-over with oil vapours from the generators due to a higher filtering capacity of the bed and lower temperatures of oil vapours at the gas outlet.

Experience obtained in China is interesting in this respect [8]. When gas burners were placed inside the gasifiers of the generators, the temperature of the oil vapours was appreciably lower at the gas outlets: it dropped from 210 to 80—100 °C. Simultaneously, the specific gas yield decreased, while the oil yield, quite naturally, increased.



Modifications of generators with cross-current flow of the heat carrier: *1* — retorting chamber; *2* — chamber for preparation and distribution of the heat carrier; *3* — chamber for collection and outlet of oil vapours

Модификации генераторов с поперечным потоком теплоносителя: *1* — камера полукоксования; *2* — камера для приготовления и распределения теплоносителя; *3* — камера для сбора и отвода парогазовой смеси

Uniform heat carrier gas distribution across the shale bed in the generators with CCHC is attained not only by employing the concept of cross-current heat carrier flow, but also by creating favourable conditions of supplying additional heat to the shale bed at the cooler side of the retorting chamber, i. e. the side from which the oil vapours are removed. It is achieved by placing additional burners in the generators. Their efficiency has already been demonstrated by operating experience over a long period of time at the "Kiviõli" shale chemical plant [9] and the 1,000 t/day generators at the PO "Slantsekhim" [4]. The experiments on a cold model of the retorting shaft of the generators with CCHC and the experience in operating the 1,000 t/day generators indicate that application of two shale feed charging mechanisms instead of one for each retorting chamber is highly efficient in attaining uniform distribution of the heat carrier across the shale bed [10].

So, there is no doubt that in the generators with CCHC (modification *A* and especially *B*, see Figure) better conditions are provided for even distribution of the heat carrier in the retorting chambers than in the generators with counter-current flow of heat carrier gas. Besides, in the generators with CCHC there is no rigid dependence of the shale throughput rate on the velocity of the heat carrier gas in the bed at a comparatively low hydraulic resistance of the retorting shaft. These advantages of the generators with CCHC become extremely important for the development of retorts with high unit throughput rates.

Further opportunities for improving the uniformity of heat carrier distribution across the bed in the retorting chamber of the generators with CCHC are limited by their design features. All disturbances in the operation of these generators (delay in the descent of the shale bed, bituminization, bridging and slagging) take place near the outer walls of the retorting chamber, where most of the gaseous heat carrier passes.

Another disadvantage of the generators with CCHC is that the shale bed has a practically equal clear cross-sectional area for both the entrance and for the removal of the heat carrier gas, which sharply impairs the heat exchange conditions on the cooler side of the retorting chamber because of lower heat carrier gas velocity and temperature.

As it has already been mentioned above, the bituminization of kukersite on heating makes it necessary to design the retorting chamber of the generator with CCHC for a shale bed thickness limited in a range of 1—1.5 m to avoid its negative consequence. As a result, the shaft of these generators is used insufficiently. In the generators with one retorting chamber it is filled with shale about 30 %, in case of two chambers about 45 % (the volume of the oil shale bed in the retorting chamber is measured by the length of the cool grate).

To eliminate, if only partially, the above operational disadvantages of the generators with CCHC, by joint effort of the Oil Shale Research Institute and PO "Slantsekhim" a generator design with circular retorting chamber was developed (see Figure, modification *C*) [11]. The concept was widely used in the 1920—30s in the Rolle and Borsig-Geissen kilns designed for semi-coking brown coals. The kilns were with external heat supply designed for processing 30—40 tonnes of coal daily. The opportunities for a scale-up of the kilns were limited and therefore no further development work was carried out.

The experience obtained over the past 5 years in semi-coking oil shale in the generators with commercial-size experimental circular retorting chambers has shown that this mode positively settles some quite complicated technical problems of perfecting the design features of the generators and of the oil shale processing technology.

Developing the generator with circular retorting chamber, we have assumed that one of the most important factors, determining the efficiency of its design, is the achievement of uniform distribution of the heat carrier and improvement of heat exchange conditions in the oil shale bed. First of all, the circular retorting chamber has no outer walls, and as a consequence, no operating difficulties accompanying oil shale processing in retorting chambers possessing outer walls. As a result, the distribution of the heat carrier in the oil shale bed improved considerably.

This was convincingly demonstrated already during the initial operations of the generators with circular retorting chambers, since the following characteristic changes took place in the generator performance:

— the residual oil content (Fisher assay oil) of the semi-coke was reduced from 2.5 to below 0.5 %;

— the temperature of oil vapours at the gas outlet decreased from 220 to 150 °C;

— the specific air consumption of the process dropped on an average from 360 to 250 m^3/t (in both cases shale processing was carried out without gasification of the semi-coke).

Table 1. **Basic characteristics of the generators of different design**

Таблица 1. **Основные параметры генераторов разной конструкции**

Design mode	Start-up year	Throughput capacity, t/day	Outer diameter of the retort vessel, m	The height of the vessel from the zero mark to the charging devices, m	Useful volume of the retorting chamber, m^3
The "Lengiprogas" developed generators (reconstructed):					
initial design	1951	90	3.7	13.2	11
with central inlet of the heat carrier	1957	145	3.7	13.2	23
with cross-current of the heat carrier	1956	180	3.7	13.2	22
with circular retorting chamber	1985	250	3.7	13.2	50
Newly developed generators of high unit capacity:					
with cross-current of the heat carrier and two retorting chambers	1981	1000	9.6	22.8	180
with circular retorting chamber	1995	1500	8.3	25.0	280

The concentrical arrangement of the retorting chamber in the generator guarantees, as it can be seen from Table 1, the opportunity of a considerable enlargement of the useful volume of the retorting shaft, while the small thickness of the bed is retained. The latter is very important in case of processing organic rich kukersite, which easily bituminizes when heated. An insignificant increase in the diameter of the generator of this design leads to a considerable expansion of the useful volume of the retorting shaft, which reaches 70—80 % of the whole shaft volume. That is about 1.5—2 times greater than in the generators with CCHC. So it is no mere chance that in some generators with circular retorting chambers (e. g. at the "Slantsy" shale processing plant, where the oil shale has a low degree of upgrading and a heating value of 12.0—12.5 MJ/kg) the throughput capacity reaches 260—280 t/day of shale, instead of 150—180 t/day in generators with CCHC.

As for the 1,000 t/day generators with CCHC, the designed useful volume of the retorting chamber can ensure higher throughput rates than initially projected. This, however, could not be attained so far due to a design related high hydraulic resistance of the generator and that of the oil shale bed. For example, the hydraulic resistance in the retorting chamber reaches the level of 2450—2950 Pa. As our calculations have shown, about 80 % of the resistance is due to the design of the hot grates [12]. The 200 t/day generators, on the other hand, have a hydraulic pressure of the retorting chamber not exceeding 980 Pa. This specific feature of the generators is explained by the fact that when the 1,000 t/day generators were developed, the hot grate had to be of complicated design to ensure its mechanical strength. In generators with circular retorting chambers there is no need for such design, as the grate is arranged concentrically in the retort vessel and coincides with the refractory lining. In this case the hydraulic resistance of the retorting chamber proves to be even lower, and the throughput capacity higher than it was provided in the project.

When the circular chamber is used for semi-coking, favourable conditions for intensifying heat exchange in the shale bed are created, especially at its cooler side. When the heat carrier gas passes from the periphery of the chamber to its center, the inevitable decrease in its temperature and volume 1.5—2.0 times is accompanied by a similar increase in its velocity. As a result, heat exchange is equalized throughout the bed in the retorting chamber. It is also important for satisfactory heating of the retorting chamber that the bulk of the oil shale were located at the hot side of the chamber.

A decrease in the oil vapours temperature at the gas outlet from 220 to 150 °C in the generators with circular retorting chambers becomes possible thanks to a more uniform distribution of the heat carrier gas across the shale bed and the improvement of heat exchange conditions between the gas flow and the oil shale in the retorting shaft, as compared to the 200 t/day generators with CCHC. Lower temperatures create conditions for a considerable reduction in dust carry-over with oil vapours. Direct measurements at the GGS-5 of the PO "Slantsekhim" have shown that by reducing the temperature of oil vapours at the gas outlet from 200 to 150 °C, the dust carry-over decreases twice.

Because of the lower specific air consumption in the generators with circular retorting chamber, a lower yield of generator gas should be anticipated. This has not been measured in practice so far, as there was no opportunity to test the new design of the generator by connecting it to a separate condensation system. According to approximate calculations, the specific yield of product gas in the generators with circular retorting chambers should be on the level of 300—350 m^3/t under the conditions existing at the PO "Slantsekhim" (instead of 430—460 m^3/t in the 1,000 t/day generators, operating also without gasification the semi-coke).

It is very important that in the generators with circular retorting chambers the specific consumption of the recycle gas in the process also decreases considerably. As it can be seen from Table 2, the total specific consumption of air and gas in the process makes up 600—700 instead of the usual 1,000—1,100 m^3/t. At the same time, the load on the condensation system of the plant also decreases. This means that without extra expenditures on its enlargement, the throughput capacity of the generators can be increased by approximately 30 %.

Since the generators with circular retorting chambers ensure an appreciable decrease in the specific air consumption for the process, and a reduction in oil losses with spent shale demonstrating the lowest values of these characteristics in comparison with other types of generators,

Table 2. **Basic operating conditions of processing lump shale (heating value 13—14 MJ/kg) in the generators without gasification of the semi-coke**

Таблица 2. **Основные технологические параметры переработки кускового сланца (Q^d_δ 13—14 МДж/кг) в генераторах на режиме без газификации полукокса**

Date of experiment	Through-put capacity, t/day	Temperature, °C		Specific consumption in the process, m^3/t			Residual content of oil in the semi-coke (Fischer assay oil), %
		of the heat carrier	in the gas outlet	air	gas	total	
Generator No. 7 with cross-current of the heat carrier GGS-5 (modification *A*) [13]							
March 22—28, 1962	142	743	223	314	616	930	4.71
March 30—April 5, 1962	110	729	223	297	614	911	4.42
March 18—24, 1962	155	695	227	300	633	933	4.98
March 7—13, 1963	140	838	283	324	733	1132	1.67
January 29—February 4, 1964	158	993	235	384	620	1004	2.40
March 5—13, 1965	172	960	228	344	739	1083	0.90
June 16—20, 1969	161	875	235	367	732	1099	—
February 10—17, 1971	171	988	228	377	598	975	1.30
1,000 t/day generators (modification *B*)							
1988, GGS-5	944	900	230	332	793	1125	1.5
1989 „	950	900	230	352	788	1140	1.8
1988 GGS-6	963	900	230	368	613	981	0.9
1989 „	950	900	230	373	611	984	0.9
Generators with circular retorting chambers; PO “Slantsekhim” (modification *C*)							
GGS-5, generator No. 8							
March—April, 1985	240	775	168	246	408	654	0.4
“Slantsy” shale processing plant, generator No. 6							
January 4—February 6, 1986	250	900	179	216	437	653	1.6
Generator No. 17							
August—November 1986	235	784	180	251	438	689	0.5
“Kiviõli” shale chemical plant, generator No. 2							
October 1986—March 1987	241	850	171	209	486	595	0.5

the new design should ensure the highest oil yield. The new generators have proved to be most effective retorting poorly enriched oil shale (with a heating value below 12.0—12.5 MJ/kg at the "Slantsy" plant and 9—10 MJ/kg at the "Kiviõli" plant). But when the retorts at the "Kiviõli" plant were transferred to processing oil shale rich in organic material with a heating value of 15—16 MJ/kg and possessing, moreover, a comparatively low thermo-mechanical strength, the generator with circular retorting chamber could not be normally operated so far. Because of heavy clogging of the under-arch space and the central grate, the generator had to be remodelled by returning to the previous design with cross-current heat carrier flow.

As it has been pointed out above, the development of retorts of high unit capacity with counter-current flow of heat carrier gas for semi-coking lump shale meets serious technical problems because of:

— a rigid connection between the speed of descent of the shale in the retorting shaft and the velocity of the gaseous heat carrier;

— an inevitable increase in the velocity of gaseous heat carrier in the bed and, as a consequence, increase in the dust carry-over into the condensation system with oil vapours;

— deterioration of the uniformity of distribution of the heat carrier gas across the shale bed due to the necessity of increasing the diameter of the retort (in order to reduce dust entrainment with oil vapours).

The absence of rigid connection between the shale throughput capacity of the retort and the velocity of the heat carrier in the shale bed, becomes the determining advantage of the generators with circular retorting chambers to be developed as high capacity units. In this case there is no need for designing retorts with large diameter (11—18 m, for example, in case of the counter-current flow of heat carrier). The otherwise insurmountable difficulties in ensuring even distribution of the heat carrier across the shale bed no longer exist. The useful volume of the retorting chamber can be increased by increasing its height.

Higher throughput rates are achieved not only by increasing the dimensions of the retort, but also by means of better operational procedures. Therefore the generators with circular retorting chambers, when compared to the retorts, where the oil shale is processed in the counter-current, are more compact, with smaller dimensions.

In designs of the generators with circular retorting chambers for throughput rates as high as 1,500 tonnes of shale per day, for the first time in practice a negligible widening of the chamber downwards is provided. This creates good conditions for uniform downward passage of the shale in the retort. The use of four charging devices for one retorting shaft should ensure a fairly even shale particle size distribution, and consequently, an even distribution of the heat carrier across the shale bed. This has been confirmed by the investigations on cold models of the generators of different design mode and by the operational experience of the 1,000 t/day generator [10, 14].

Conclusions

The method of semi-coking oil shale in the circular retorting chamber makes it possible to ensure a more uniform distribution of the heat carrier gas across the shale bed, than in the vertically placed retorting chambers with cross-current heat carrier flow, and in the generators using the counter-current method of heat exchange. This also ensures the most favourable conditions for effective heat transfer in the retort-

ing chamber from the gas flow to the shale bed due to the following factors:
— absence of the lateral outer walls in the retorting chamber;
— the concentrical arrangement of the retorting chamber and the passage of the gaseous heat carrier through the shale bed from the periphery of the retort to its center;
— the bulk of the oil shale charged passes through the hot part of the retorting chamber (i. e. on the side of inlet of the gaseous heat carrier into the shale bed).

As a result, processing the oil shale (kukersite) in the generators with circular retorting chambers leads to a decrease in the temperature of oil vapours at the gas outlet on an average from 220 to 150 °C and the reduction of the specific air consumption for the process — from 360 to 250 m^3/t. According to the calculated data, it ensures an increase in oil yield from 78 to 84 % of the Fischer assay oil.

The application of the circular retorting chamber in the generators, creates conditions for increased unit throughput rates of the retorts 1.5—2.0 times with a simultaneous increase in the oil yield. For processing oil shales rich in organic material, which readily bitumenize, retorts for a throughput of 1,500 tonnes per day have been developed and are already under construction at the PO "Slantsekhim". Project designs for the leaner shales can be developed for throughput rates in excess of 5,000—6,000 tonnes per day. The retorts will have a comparatively small diameter and a simpler design than the 1,000 t/day generators being now in operation.

РЕЗЮМЕ

На генераторах с поперечным потоком теплоносителя (ППТ) и, особенно, с двумя камерами полукоксования (рисунок, модификация *В*) обеспечиваются лучшие условия для равномерного распределения теплоносителя в камере полукоксования, чем на генераторах с использованием противоточного метода полукоксования. Дальнейшие возможности улучшить равномерность распределения теплоносителя в слое камеры полукоксования генераторов с ППТ ограничиваются их конструктивными особенностями. Все нарушения в работе этих генераторов (задержка схода материала, битуминизация, шлакование, образование настылей и т. д.) происходят в основном у боковых торцевых стенок камеры полукоксования, где преимущественно проходит газовый теплоноситель.

Другим принципиальным недостатком генераторов с ППТ является практически одинаковое живое сечение слоя в камере полукоксования как на входе в него газового теплоносителя, так и на выходе. В результате на холодной стороне камеры полукоксования в слое резко ухудшаются условия теплообмена вследствие снижения одновременно скорости теплоносителя и его температуры. Кроме того, из-за битуминизации сланца толщину слоя в камере полукоксования приходится поддерживать в пределах 1,0—1,5 м. В результате шахта полукоксования генераторов используется неудовлетворительно — она заполнена сланцем лишь на 30—45 %.

Для устранения, хотя бы частичного, указанных недостатков в работе генераторов с ППТ специалистами НИИсланцев и ПО «Сланцехим» в Кохтла-Ярве (Эстония) предложена конструкция генератора с кольцевой камерой полукоксования (рисунок, модификация *С*). Уже первые испытания этой конструкции на сланцеперерабатывающих предприятиях показали, что на генераторах действительно улучшились условия теплообмена в шахте полукоксования. Об этом свидетельствуют характерные изменения в работе агрегатов:

— остаточное содержание смолы в выгружаемом полукоксе уменьшилось с 2,5 до 0,5 % и менее;
— температура парогазовой смеси в газосливе понизилась с 220 до 150 °С;
— удельный расход воздуха на процесс уменьшился в среднем с 360 до 250 м^3/т.

Концентричное же размещение камеры полукоксования в генераторе позволило увеличить полезный объем шахты полукоксования генераторов с ППТ в 1,5—2,0 раза (табл. 1). В результате пропускная способность генераторов по сланцу возросла в среднем со 160 до 240 т/сут. Расчетный выход смолы возрос при этом примерно на 10 % относительных. Очень важно, что на генераторах с кольцевой камерой полукоксования заметно снизился суммарный удельный расход воздуха и газа на процесс — он составил 600—700 вместо обычных 1000—1100 м^3/т (табл. 2). Новые генераторы проявили себя с хорошей стороны при переработке в первую очередь малообогащенного сланца (с удельной теплотой сгорания не выше уровня 10—12 МДж/кг).

Для сравнительно богатого органической массой и битуминизирующегося сланца-кукерсита уже разработаны и сооружаются в ПО «Сланцехим» агрегаты на 1500 тонн сланца в сутки, а для «бедных» сланцев могут быть спроектированы агрегаты на 5000—6000 т/сут и более.

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