Oil Shale, Vol. 12, No. 3
pp. 247-257

ISSN 0208-198X
© 1995 Institute of Chemistry
Estonian Academy of Sciences

https://doi.org/10.3176/oil.1995.3.07

AN ANALYSIS OF THE RAS "KIVITER" ENERGY BALANCES AND DEVELOPMENT PLANS

I. ÖPIK

Estonian Academy of Sciences
Tallinn, Estonia

V. YEFIMOV

Oil Shale Research Institute
Kohtla-Järve, Estonia

The efficiency of oil shale retorting process can be raised up and, correspondingly, the production costs of oil lowered by utilization of by-products - semi-coke and gas - as a fuel for steam and power generation.

Different possible flow sheets for the RAS "Kiviter" are discussed.

The growing costs of producing oil shale for processing or for power generation, causes an unavoidable rise in the price of thermal and electric power, and also of shale oil. However, the rise in oil costs is limited by the price of the conventional heavy fuel oil imported to Estonia. Otherwise oil shale processing plants would become incapable of competing with the imported products and would become unprofitable - with all the resulting drawbacks of that condition.

On the other hand, we cannot underestimate the significant potential for producing a domestic high-quality liquid fuel. Reliance on imported supplies of fuel oil and gas to Estonia can create critical situations, especially if there is a significant increase in their world market prices. Therefore, the need to find methods for stabilizing the price of oil shale and for increasing the efficiency of oil shale thermal processing in Estonian enterprises is currently a common topic. All the possibilities for stabilizing the cost of oil shale have probably still not been implemented.

In this paper, we will confine ourselves to looking at only the possibilities for technical improvements to the retorting process for lumpy (coarse) oil shale. This approach will use the by-products of the process as a fuel in thermal power stations. As a starting point, we have analysed the efficiency of different possible flow sheets of oil shale processing for the Kiviter retorts. Modifications for oil shale processing were studied for two separate cases. One has a capacity of 1.92 million tonnes of processed shale per year (oils - 0.3 million tonnes per year) and the second a capacity of 1.6 million tonnes of shale per year (oils - 0.25 million tonnes per year). The basic data from this analysis are presented in Table 1.

The energy balances of the RAS "Kiviter" at Kohtla-Järve are given in Fig. 1 and the existing energy flow diagram - in Scheme I (Fig. 2). One can see that the sale of a part of previously purified generator gas to the Kohtla-Järve power plant, could lead to an essential rise in the efficiency of oil shale thermal processing. (This gas would already have the hydrogen sulfide removed before its use.)

Table 1. **Basic Data of Different Flow Sheets of Oil Shale Retorting in RAS "Kiviter" at Kohtla-Järve**

Raw material and products	Amount of the product per 1 tonne oil shale	Calorific value, lower, per unit		Heat content of the product, TWh	
				Retorted shale, t/a:	
		kJ	kWh	1.92	1.60
Oil shale	1000 kg	11050	3.07	5.89	4.91
Shale oil	156 kg	39560	10.99	3.30	2.75
Generator gas	450 m^3	2850	0.79	0.68	0.57
Dry semi-coke	600 kg	4120	1.145	1.32	1.10

The combustion of semi-coke in power plant boilers is of great practical interest from an efficiency standpoint. It would raise the efficiency of oil shale thermal processing in retorts. More than one million tonnes of semi-coke per year, with a heating value of 4100-4200 kJ/kg, on dry basis, are produced at the Kiviter retorts as a by-product of oil shale processing.

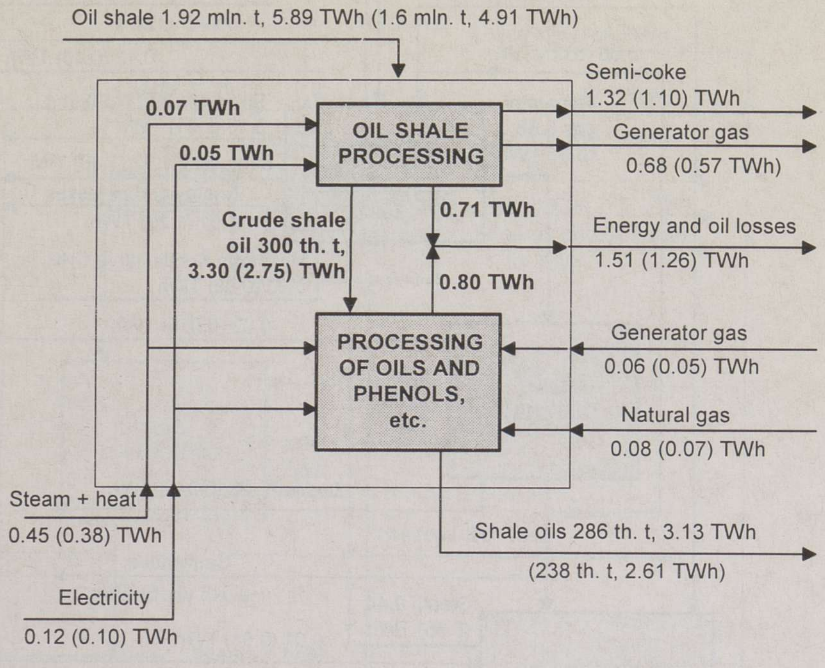
The semi-coke can be successfully combusted as a fuel in a CFB (circulated fluid-bed) boiler. This system recirculates the mineral residue (ash) from the shale. With that approach, it is possible to keep the combustion temperature constant at 850 °C. At that temperature practically all sulphur is absorbed by the minerals, and the formation of nitrogen oxides is minimal [1, 2].

The mineral residue formed during the combustion of semi-coke in a fluid-bed at 850 °C is environmentally clean and usable for neutralizing acid soils.It can be used for this purpose in Estonia. The demand for such ashes exists also in neighbouring regions [3].

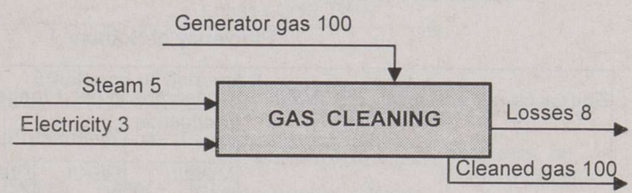
Thus, the combustion of semi-coke in fluid-bed will be effective of processing oil shale in retorts without waste. In such a case, the mineral residue will be transported to ash dumps, but the thoroughly burned mineral residue is practically harmless to the surrounding environment. In this way one of the serious factors, which limits the expansion of the oil shale processing industry in Estonia, will be eliminated.

At the present time, the utilization of semi-coke is not realized because of its high moisture content. The high percentage of water in this material (30-35) is due to the existing system of wet-ash collection (handling). Therefore, the first task for solving the problems of using semi-coke to generate thermal and electric power, is to develop equipment for discharging dry semi-coke from a retort. It must also subsequently be transported to a thermal power plant and crushed to pieces smaller than 5-10 mm.

(a) Retorts, processing of oils and phenols together with other enterprise expences (except the boilerhouse and retorting gas purification 300 th. t/a (250 th. t/a)), TWh



(b) Gas desulphurization, %



(c) Boilerhouse, %

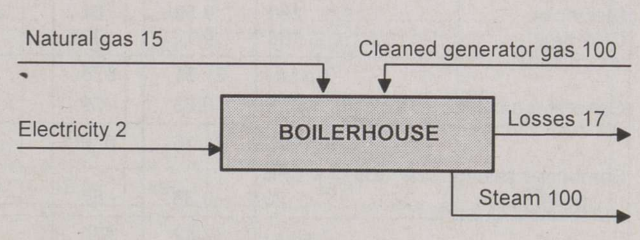
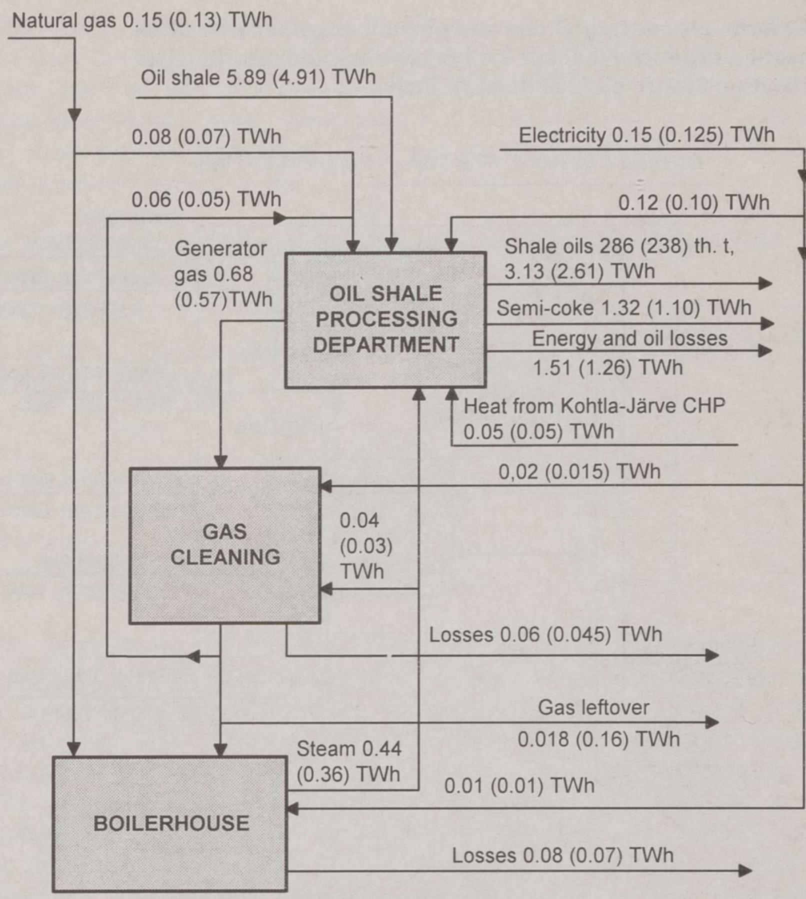


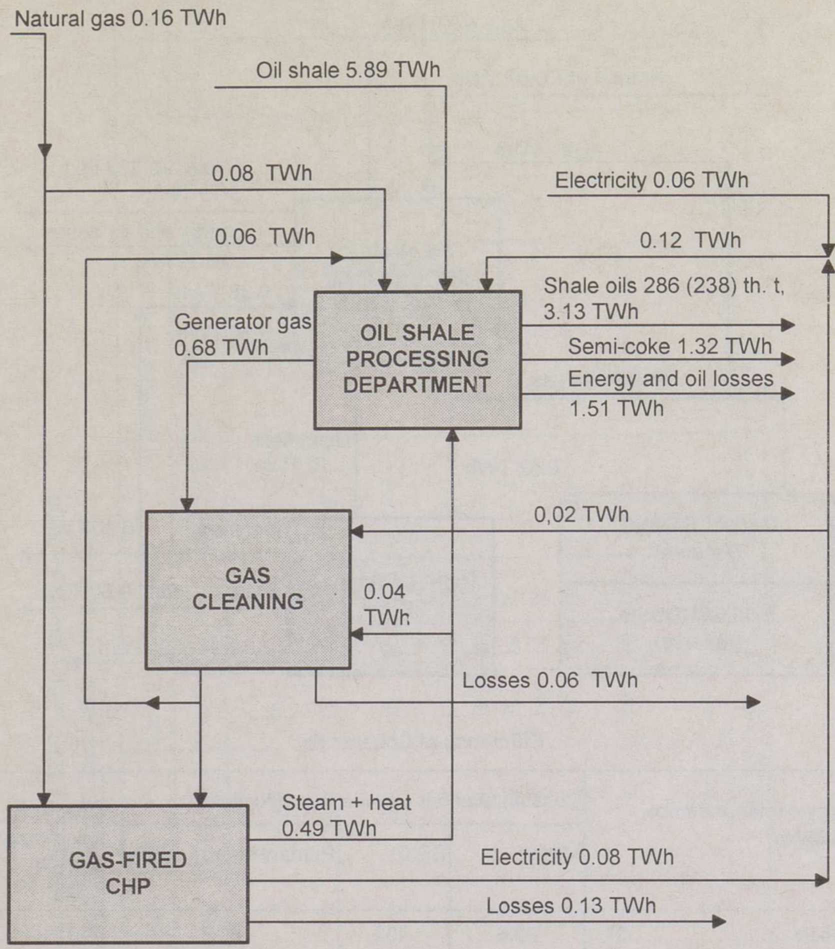
Fig. 1. RAS "Kiviter" (Kohtla-Järve) energy balances



Efficiency of Scheme I

Energy carrier and price, EEK/MWh	Consumption per 1 tonne oil production			Efficiency, on primary energy basis, %
	MWh/t	EEK/t	Primary energy, MWh/t	
Oil shale...21	20.60	432	20.6	-
Natural gas..................................125	0.52	66	0.5	-
Electricity.....................................290	0.52	151	2.1	-
CHP heat.....................................168	0.17	29	0.2	-
Total	21.81	678	23.4	47
Generator gas leftover for sale.....62.5	- 0.63	- 39	- 0.6	-
Total	21.18	639	22.8	48
Semi-coke sale for CHP 160 MW_f CFB boiler.......................................20	- 3.36	- 67	- 3.4	-
Total	17.82	572	19.4	57

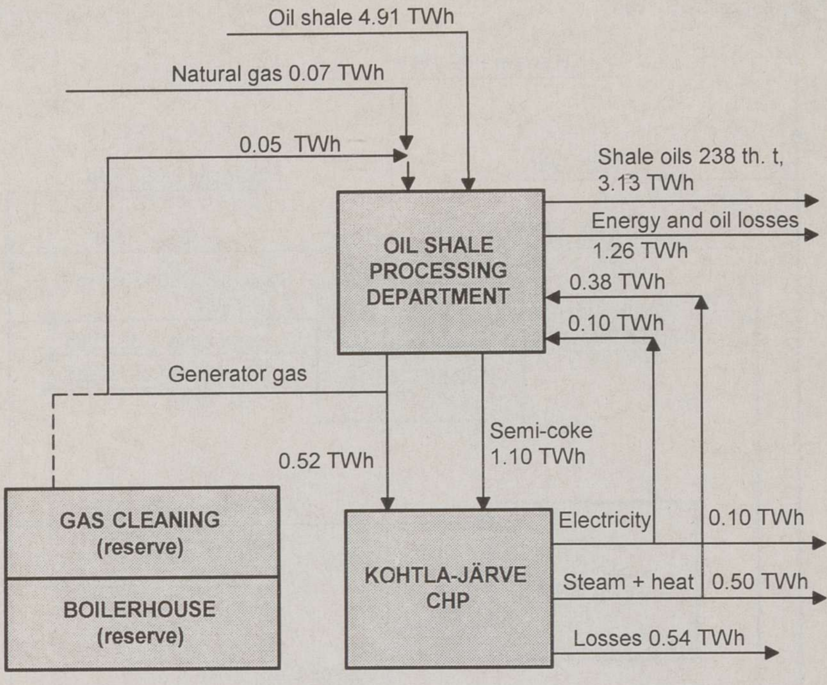
Fig. 2. Scheme I: RAS "Kiviter" (Kohtla-Järve) energy balance by existing scheme. Crude shale oil production 300 th. t/a (or 250 th. t/a)



Efficiency of Scheme II

Energy carrier and price, EEK/MWh	Consumption per 1 tonne oil production			Efficiency, on primary energy basis, %
	MWh/t	EEK/t	Primary energy, MWh/t	
Oil shale............................21	20.6	432	20.6	-
Natural gas.......................125	0.56	70	0.6	-
Electricity..........................290	0.21	60	0.8	-
Total	21.37	562	22.0	50
Semi-coke for Kohtla-Järve CHP new CFB boiler with fuel capacity 160 MW_f (50 MW_{el})............................20	- 3.36	- 67	- 3.4	-
Total	18.01	495	18.4	59

Fig. 3. Scheme II: Energy balance of RAS "Kiviter" (Kohtla-Järve) with its own gas-fired CHP (Central Heat and Power Plant). Crude shale oil production 300 th. t/a (250 th. t/a)



Efficiency of Scheme III

Energy carrier and price, EEK/MWh	Consumption per 1 tonne oil production			Efficiency, on primary energy basis, %
	MWh/t	EEK/t	Primary energy, MWh/t	
Oil shale............................21	20.6	432	20.6	-
Natural gas.....................125	0.29	36	0.3	-
Electricity (for sale).........200	- 0.42	- 84	- 1.7	-
Steam + heat (for sale)...100	- 2.1	-210	- 2.1	-
Total	18.37	174	17.1	64

Fig. 4. Scheme III: RAS "Kiviter" (Kohtla-Järve) oil shale producing complex united with Kohtla-Järve CHP. Crude shale oil production 250 th. t/a

One possible approach for the Kohtla-Järve enterprise is the use of its own power plant, fired by retort gas from which the hydrogen sulphide has been removed. This option is presented in Scheme II (Fig. 3). This kind of flow sheet for oil shale processing has already been successfully applied at the Kiviõli Oil Shale Processing Plant and Oil Shale Processing Plant in Slantsy (Leningrad district, Russia) for many years.

The efficiency of oil shale retorting process can be raised up to 60 %, and, correspondingly, the production cost of one tonne of oil lowered from 562 down to 495 kroons by selling some part of semi-coke to Kohtla-Järve Heat and Power Plant. There it will be burned in a new CFB boiler (see Scheme II - Fig. 3).

Table 2. **Investments (by RAS "Kiviter" (Kohtla-Järve) and local CHP) before the Year 2000 (Investments are approximate, especially the part of semi-coke dry separation and transport)**

Name	Investment, mln. EEK*			Credit		Annuity		Annuity for Scheme No.**						
	Amount	Ready	To be done	Years	%	%	Mln. EEK	I^a	I^b	I^c	II^a	II^b	III^a	III^b
1. 50 MW_{el} unit with CFB boilers included semi- coke handling and transport	1000	0	1000	15	8	11.7	117	-	-	-	-	-	117	-
2. CFB boiler 160 Mw_f for existing Kohtla-Järve CHP	400	0	400	15	8	11.7	46	-	-	-	-	-	-	46
3. Semi-coke handling and transport if financed separately	100	0	100	10	10	16.3	16.3	-	-	16.3	-	16.3	-	16.3
4. RAS "Kiviter" 10 MW steam turbine and gas-fired boiler	87	24	63	10	10	16.3	10.3	-	-	-	10.3	10.3	-	-
5. New semi-coke dumps	96	45	51	10	10	16.3	8.3	8.3	8.3	-	8.3	-	-	-
6. New gas desulphurization	42	0	42	10	10	16.3	6.8	6.8	6.8	6.8	6.8	6.8	-	-
7. Water cleaning systems and handling	54	18	36	10	10	16.3	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
8. Sludge utilization	13	0	13	10	10	16.3	2.1	2.1	2.1	-	2.1	-	-	-
9. Generator gas pipe to Kohtla-Järve CHP	2	0	2	10	10	16.3	0.3	-	0.3	0.3	-	-	0.3	0.3
10. Reconstructions of retorts to rise the total capacity of oil production to level 300 th. t/a	10	2	8	10	10	16.3	1.3	1.3	1.3	1.3	1.3	1.3	-	-
Annuity, total, mln. EEK								24.5	24.8	30.3	34.7	40.6	123.2	68.5

* 1 EEK = 0.09 US$.

** For Scheme numbers see Table 3.

The best results are expected if oil shale processing units and the power plant are located at the same enterprise. Not only shale oil, but also thermal and electric power (which is produced from the combustion of semi-coke and gas) are the main products of an enterprise like this. This can be seen in the Scheme III (Fig. 4). When the semi-coke and gas are co-fired in the CFB boilers, with partial recycle of the mineral residue, there is no need to remove the hydrogen sulphide from the gas separately.

In the case of rising oil shale prices, the production of thermal and electric power, according to the approach described in Scheme III, enables one not only to compensate for increasing expenses of oil production but to reduce them from 495-639 down to 174 kroons per tonne (a rise in oil shale price also leads to an increase in the thermal and electric power prices, since they are sold by the enterprise as goods).

Presumable investments and revenue from building new facilities, as well as income from the accepted scheme for oil shale thermal processing are given in Table 2. Using these data, the investments required for implementing every one of the proposed schemes are evaluated and presented in Table 3.

Table 3. **Total Investments and Annuity (based on the data from Table 2)**

Scheme	Mln. EEK	
	Investment	Annuity
I^a - existing	150	24.5
I^b - same + gas pipeline	152	24.8
I^c - same, as previous + semi-coke dry transport	186	30.3
II^a - own gas-fired CHP	213	34.7
II^b - same + coke transport	249	40.6
III^a - joining with a new 50 MW_{el} power unit	1056	123
III^b - new CFB boilers at Kohtla- Järve CHP	556	68.5

In Table 4 the total costs of raw materials, thermal and electric power, natural gas and revenues per tonne of shale oil are given. As seen from these data, in the case of Scheme III the share of raw material and energy in total costs is sharply reduced (from 70-80 down to 23-48 %) despite an unavoidable rise in their price. Consequently, in that case the costs of raw materials and energy consumption essentially have a smaller effect on the total costs. Even when the price of oil shale and thermal and electric power double, the total costs of oil production increase only 20-30 %, as is seen in Table 5 (natural gas is excluded from this analysis since its price is not influenced by rises in prices of oil shale).

That is way the Scheme III seems to be the most acceptable especially under conditions of constantly rising oil shale prices. But in order to implement this approach, a careful study and experimental testing is needed.

Table 4. **Cost of Raw Material and Energy and Annuity on 1 Tonne Shale Oil**

Scheme*	Oil, production th. t/a	EEK/t			%		
		Raw mat. & energy	Annuity	Total	Raw mat. & energy	Annuity	Total
I[a]	286	678	86	764	89	11	100
I[b]	286	639	87	726	88	12	100
I[c]	286	572	106	678	84	16	100
II[a]	286	562	121	683	82	18	100
II[b]	286	495	142	637	78	22	100
III[a]	238	174	517	691	25	75	100
III[b]	238	174	288	462	38	62	100

* For Scheme numbers see Table 3.

Table 5. **Increase in Oil Shale, Energy and Capital Costs if Oil Shale and Electric Power Prices Are Doubled**

Scheme*	Costs, EEK per 1 tonne shale oil			Rise, %
	Oil shale, energy, and annuity by present prices	Additional for oil shale and electric power	(2) + (3)	
(1)	(2)	(3)	(4)	(5)
I[a]	764	612	1375	80
I[b]	726	573	1299	79
I[c]	678	506	1184	75
II[a]	683	492	1175	72
II[b]	637	425	1062	67
III[a]	691	138	829	20
III[b]	462	138	600	30

* For Scheme numbers see Table 3.

In the opinion of authors, the best conditions for testing and elaborating this complex flow sheet exists at the smaller oil shale processing plant at Kiviõli (belongs to RAS "Kiviter" now).

In Kiviõli, the thermal power station belongs to the processing plant, and that simplifies the solution of many organizational and technical problems. The retorts' department and the thermal power station are located side by side, having a number of common communications.

Previous calculations (based on heating values) have shown, that semi-coke can be substituted for oil shale, which is currently combusted in three boilers of the thermal power plant (Scheme IV - Fig. 5). The other two boilers consume the retort gas. If gas and semi-coke are co-fired in a CFB boiler, the emission of SO_2 into air can be totally reduced.

If an increase in the production of thermal and electric power is needed, then semi-coke can be enriched with oil shale screenings. But then the problem of how to use the overproduced thermal power, especially during the summer time, has to be solved.

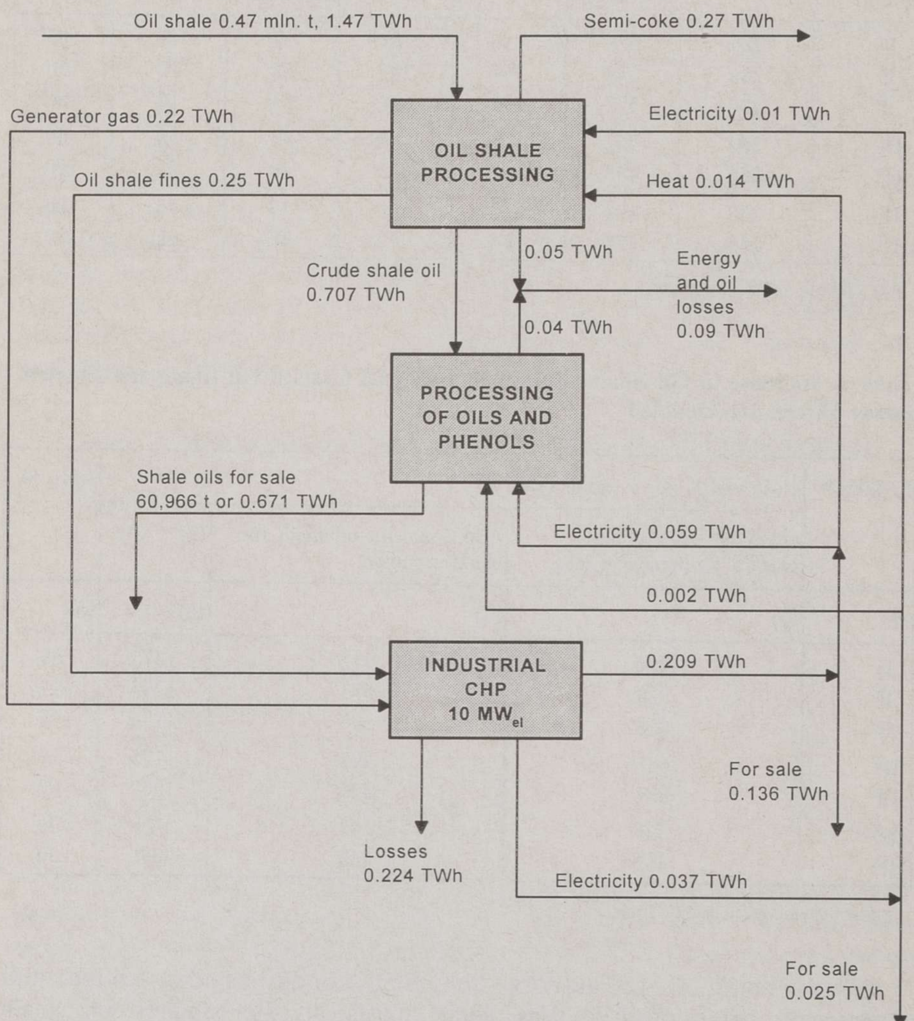


Fig. 5. Scheme IV: RAS "Kiviter" annual energy balance at Kiviõli Oil Shale Processing Plant

Conclusion

The process in Scheme III is very attractive: a complex energy system connecting the oil shale processing plant and the Central Heat and Power

Plant in the town of Kohtla-Järve. The scheme is worth having a consulting company prepare a feasibility study.

Reasons

1. Kohtla-Järve Central Heat and Power Plant needs renewal and installation of a fluid-bed boiler before the year 2000. By the end of the century the CHP will have been in operation for 52 years. Its electrical capacity has dropped from 56 to 39 MW. The present thermal capacity is 535 MW. In 1993, 0.56 TWh of thermal energy was produced, of which steam comprised 0.21 TWh.

2. The semi-coke from oil factories, which has not been used previously, is the best fuel for CFB boilers.

3. The total cost for oil shale, energy and investments per 1 tonne of oil according to the Schemes II and III (Figs. 3 and 4) are almost equal. In case of Scheme III the investments are 2-3 times higher than the costs for oil shale and energy. This fact will guarantee a stable price for oil in spite of lasting inflation, because the equivalent rise in sold electricity and thermal energy prices will compensate for the rise in oil shale price.

4. The companies, who are interested in building power plants, can presumably guarantee favourable credits.

5. Implementation of an experimental test program, which would simulate the Scheme III, would be expedient at the Kiviõli Oil Shale Processing Plant.

REFERENCES

1. *Holopainen H.* Experience of oil shale combustion in Ahlstrom pyroflow CFB boiler // Oil Shale. 1991. V. 8, No. 3. P. 194-209.
2. *Öpik I.*. The Chatham CFB boiler for a wide spectrum of fuels and some problems of Estonian oil shale combustion in CFB systems // Oil Shale. 1995. V. 12, No. 2. P. 179-184.
3. *Kikas H.* Mineral matter of kukersite oil shale and its utilization [in Russian, with English summary] // Oil Shale. 1988. V. 5, No. 1. P. 179-184.

Received April 19, 1995

OIL SHALE CONSUMPTION QUANTITIES IN ESTONIA, 1994

(Compiled by Ilmar Öpik. July 20, 1995)

Consumption branch for oil shale	Technological grade		Power plant grade		Importation from Russia**		Total			
	CV, lower value, MWh/t (GJ/t)								Wt, %	CV, %
	3.19 (11.5)		2.40 (8.65)		2.27 (8.17)		2.53 (9.10)			
	Mt	TWh	Mt	TWh	Mt	TWh	Mt	TWh		
Power and central heat supply	0.47	1.50	10.91	26.18	1.65	3.75	13.03	31.43*	81.2	77.5
Chemical processing	2.04	6.51	0.57	1.37	-	-	2.61	7.88	16.3	19.4
Cement industry	0.33	1.05	0.04	0.10	-	-	0.37	1.15	2.3	2.8
Others	0.02	0.06	0.02	0.05	-	-	0.04	0.11	0.2	0.3
Total	2.86	9.12	11.54	27.70	1.65	3.75	16.05	40.57	100.0	100.0
Wt, %	17.8	-	71.9	-	10.3	-	100.0	-	-	-
CV,%	-	22.5	-	68.3	-	9.2	-	100.0	-	-

* Included 3.03 TWh for associated heat supply.

** Excluded for SILMET Heat and Power Plant.