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STRATEGY OF HUADIAN OIL SHALE COMPREHENSIVE UTILIZATION

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The estimated resources of oil shale in China are approximately two trillion tonnes, which are equivalent to eighty billion tonnes (bn.t) shale oils. This resource is next after the United States. At present, the discovered reserves of oil shale are about 32 bn.t and mainly distributed over 55 deposits located in the provinces of Jilin, Guangdong, Liaoning, etc. The discovered reserves in Jilin province are up to 17.676 bn.t, accounting for 56% of the national total amount, and distributed mainly in a few areas such as Nong'an, Qianguo, Huadian and Wangqing. The oil shales in Huadian have the best quality and are ready for exploration. In 1996, the only oil-shale-fired power plant in China, incorporating three units of 65t/h oil-shale-fired circulating fluidized-bed (CFB) boiler, was built and in operation successfully in Huadian city. To solve the problem of the shortage of petroleum energy in China, especially in Jilin province, a comprehensive utilization project of Huadian oil shales will be conducted. This paper will discuss and examine the comprehensive utilization strategy of Huadian oil shales along with Jilin's energy problems and previous oil shale exploitation and application experiences.

Jilin Province Energy Resources

Energy resources are insufficient in Jilin province, China. The average energy resource *per capita* is about 85 tonnes standard coal (tsc), only 13.2% of the national average (643 tsc *per capita*). Among the four main sources of energy, the coal reserves are approximately 2.039 bn.t (14.56 hundred million tsc), only about 0.23% of China's whole coal reserves, of which 1.08 bn.t have been consumed. In addition, the remaining 0.96 bn.t are dispersed over many small mines, so, it is impossible to build more large- and medium-size pits to increase coal production greatly. The reserves of oil and natural gas are 0.372 bn.t and 3.09 billion cubic meters, respectively,

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accounting for 4 and 0.89% of the country's whole reserves. As for these two kinds of energy resources, 10% of the oil reserves have been exploited while the natural gas reserves almost remain intact. The total capacity of hydro-power generator is 5,008.1 million watt (MW), which accounts for 65.8% of the total hydro resource. Hence, it is obvious that Jilin is an energy-deficient province.

Since the 1970s, the increasing rate of energy production has been behind the consumption in Jilin province so that the self-supply rate has been declining year by year from 98% in 1970, 79.2% in 1980, 64.5% in 1989, 50% in 1995 to only 40% in 2004. Consequently, the imported energy from other regions has inevitably increased as the following figures show: 3.999 million tsc in 1980, 6.292 million tsc in 1986, 10.628 million tsc in 1990, and more than 23 million tsc in 1995. Therefore, the energy self-supply of Jilin province has fallen short of the demand for a long time.

Jilin province is located between Liaoning and Heilongjiang provinces. Liaoning is a province of dominating heavy industry with low reserves of available energy, and its imports over 60 million tsc of energy from other provinces every year, and its degree of self-sufficiency is also less than 50%. Heilongjiang province, abundant in coal, can export some surplus to Liaoning and Jilin provinces. However, after the construction of several large-capacity pit power plants, the demand for coal has increased dramatically so the amount of exported coals has decreased considerably in recent years. Therefore, Jinlin cannot depend on Heilongjiang completely to meet its energy requirement as before.

Although Inner Mongolia Autonomous Region is abundant in coal, especially in lignite, it also cannot export the amount of energy to meet Jinlin's demand because of the on-going construction of heavy energy-consuming industries and the uneconomic features of lignite such as low heat value, high moisture and expensive long-distance transportation. Since energy shortage is common in many other regions through China due to the rapid expansion of its economy, and due to the limitation of transportation capability, it is more and more difficult to import coal from other provinces, and the amount of the energy imported cannot meet the demand. The consequence is that the gap between demand and availability is becoming larger and larger every year, and this situation has restrained the economic development severely in Jilin province [1].

Oil Shale Resources of Jilin Province

Jilin province is abundant in oil shale (OS) mainly in Midwest regions such as Nong'an and Qianguo, and eastern regions such as Huadian and Wangqing. In the Midwest regions, the OS reserves are as high as 16.895 bn.t, accounting for 95.6% of the total reserves in this province, and are suitable for opencast mining for their simple stratigraphic configuration and shallower overburden**.** These reserves are characterized by low oil content (5.1–5.7%), low heating value (4,187 kJ/kg) and high ash content. On the contrary, OS reserves in eastern regions are about 781 million tonnes, accounting for 4.4% of the whole reserves, and suitable for underground mining and ready to be exploited firstly according to the OS developing strategy of Jilin province due to reverses' good grade, high oil content (in the range 4.4–21%, average 12%) and high heating value (average 9,630 kJ/kg), high concentration and deep bury. The characteristics of OS reserves in Jilin province are presented in Tables 1 and 2 [2].

Table 1. **Oil Shale Distribution in Jilin Province**

Distribution	Age	Layers	Thickness, m	Proved reserves, bn.t	Depth, m
Nong'an mine		2	1.2–5.5	1.408	13–100
The periphery of *Nong'an* mine	Upper	2	3–5.0	9.809	10–50
Xiaohelong mine of Nong'an	Cretaceous	2	1–4.0	0.210	10–60
Yongan mine of Nong'an		1	4.0	0.149	
Qianguo	Cretaceous	3	4–12.8	5.319	
Huadian	Tertiary	6–13	2–4.0	0.586	10–500
Wangqing	Upper Cretaceous	4	1.7–4.0	0.195	150

Table 2. **Comparisons of Oil Shale Characteristics**

Characteristic	West-Jilin	East-Jilin
Oil content, %	5.1–5.7	4.4–21
Ash, %	82.61	48.1–85.12
Volatiles, %	11.8	5.7–17.7
Moisture, %	2.74	4.44–12.23
Sulfur, %		0.54–5.02
Heating value, KJ/kg	4,186	(8,793–13,817)/9,630

Huadian city is an emerging city with 1.45 million inhabitants which is located in the southeast of Jilin province. Its main products include rubber, paper and food. Huadian OS are distributed throughout the whole Huadian basin from the north to the northeast of Huadian downtown region, and divided from west to east into three regions based on the geological structure and nature conditions, namely the Beitaizi, Dachengzi and Gonglangtou and South Miaoling regions. The mining area covers about 15 km from east to west and 4 km from north to south. The location of the OS minefield is given in Fig. 1.

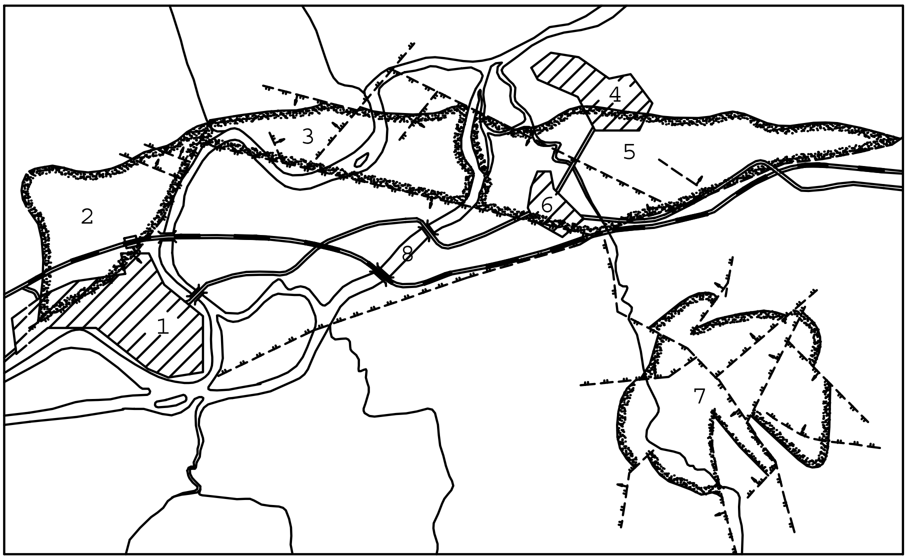

Fig. 1. Distribution of Huadian oil shale: *1* – Huadian city, *2* – Beitaizi, *3* – Dachengzi, *4* – Hongwei, *5* – Gonglangtou, *6* – Sunjia, *7* – Miaoling, *8* – Huifa River

Huadian OS belongs to the Early Tertiary period. The bed depth ranges from 65 to 244 m, and the total number of OS layers is of 6–26, among which 6–13 layers are suitable for exploitation [3]. The total geological reserves are approximate by 586 million tonnes, the geological reserves 506 million tonnes, and the industrial reserves 437 million tonnes, of which 54 million tonnes are in Beitaizi basin, 84 million tonnes in Dachengzi basin, 259 million tonnes in Gonglangtou basin, and 40 million tonnes in South Maoling basin.

For the whole mineral bed, the oil content varies transportation at both horizontal and vertical level. At the horizontal level, the oil content decreases gradually from west to east, reaching its peak (amount to 21%) in Beitaizi. At the vertical level, the oil content decreases gradually from top to bottom. Table 3 shows the characteristics of Huadian's OS from different deposit areas.

Table 3. **Characteristics of Huadian Oil Shale, %**

Location	Oil content	Ash	Moisture	Sulfur
Beitaizi	5.16–16.64	48.1–85.12	6.22–12.37	1.24–5.02
Dachengzi	5.32–17.23	63–79	No data	0.7–2.1
Gonglangtou	4.41–13.47	51.38–79.48	4.44–11.58	0.54–2.84

The OS mines in Beitaizi are very difficult to exploit, or shales even cannot be mined because a railroad runs across the whole mining area on the top, and there are thousands of residents living in this area. In addition, the geological structure is very complicated and some mineral beds are quite thin. The cost for exploitation in this region would be too high.

The Miaoling mining area locates on the edge of the whole OS bed. The OS, unsuitable for large-scale exploitation, can only be extracted in the way of small mines and groups of mines because of complicated geological structure, bad condition of the roof and spot distribution.

In comparison, the geological structures of OS in Dachengzi and Gonglangtou districts are simple and suitable for large-scale exploitation. The industrial OS reserves in these two districts are abundant and up to 343 million tonnes. Moreover, the OS in Dachengzi is almost undeveloped. Therefore, the comprehensive utilization project of Huadian OS will focus on these two regions.

Based on the feasibility analysis and environmental assessment, the project foresees building five large-scale mines in Dachengzi and Gonglangtou with the capacities of 1,200,000 t/a, 600,000 t/a (two mines), 450,000 t/a (two mines) as shown in Fig. 2. The total capacity is more than 3 million tonnes per year.

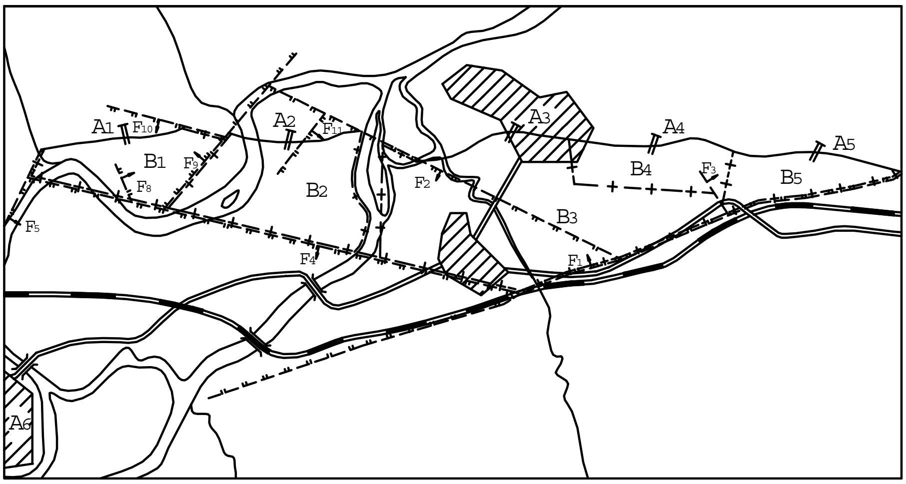

Fig. 2. Location of Huadian oil shale mining area

Review of OS Exploitation and Application

Oil shale, categorized as a solid fossil fuel, contains a high proportion of organic matter (kerogen). As one of energy resources, OS has been developed and utilized for more than one hundred years. There are two primary utilization methods: one concerns heating OS in a retorting furnace to yield gas and shale oil, which can be used directly as fuel oil or can be used to produce petroleum or diesel; the other is direct burning of OS as a fuel to generate electricity or heat [4].

Shale Oil Production

The shale oil industry in China started in 1928. In Fushun city of Liaoning province, shale oil was extracted in Fushun-type retorts. The oil shale used was detached from coal. The capacity was very low at that time. Until the foundation of the People's Republic of China in 1949, there was a rapid development of retorting technology in Fushun. By 1959, the Fushun's yearly output of shale oil accounted for 21% of the oil (including the crude and shale oil) output of whole country. However, after the 1960s, with the exploitation of the oil field in Daqing and Shengli, the crude oil production in China increased rapidly and shale oil lost in the competition due to its higher production cost. The percentage of shale oil dropped to only 3.6%.

In the mid-1980s, there were sixty sets of Fushun-type retorts in Fushun shale oil refinery, and the yearly shale oil output was 60,000 tonnes in comparison with 90,000 tonnes after another twenty sets of retorts added in the 1990s [5, 6]. The average Fischer assay and oil yield of Fushun's OS was 5.5 and 63%, respectively, and its production cost approximated 800 yuan RMB per tonne. The reason that Fushun refineries did not stop producing shale oil in the 1980s and the 1990s is that the shale is a by-product of coal mining.

Oil shale resources of Guangdong province are concentrated in Maoming city [7]. The exploitable reserves are about 5.4 bn.t. The average Fischer assay of oil shale is 6–8%, and its caloric value ranges from 3,900 to 6,200 kJ/kg. In 1955, Guangdong Province Maoming Petroleum Company was established and started to produce shale oil. By 1988, the company's annual opencast OS was 5 million tonnes with one hundred thousand tonnes shale oil output. In addition, some OS, abandoned as solid wastes when retorting, was mixed into 70 thousand tonnes cement and one million tonnes carbonate clay annually. Because 33 tonnes OS was consumed for producing one tonne shale oil, the cost reached as high as 1300 yuan RMB per tonne. Therefore the company is used to stop producing shale oil when the crude oil price is cheap.

The average Fischer assay of Huadian's OS is 12%. Dozens of sets of small-scale Fushun-type retorts have been built in Huadian city recently, and have produced shale oil successfully. Its production cost is approximately 800 yuan RMB per tonne shale oil. The current shale oil price varies from 2,000 to 2,200 yuan RMB per tonne, so a considerable amount of profit has been made.

Recently, Fushun refinery is intended to build a new plant using Taciuk advanced oil-refining technology to extend its shale oil production capacity by 200 thousand tonnes per year. In addition, Brazilian resorts will also be introduced to Longkou city of Shandong province to produce shale oil.

In summary, although shale oil industry has more than half a century history in China, the technology of production is still behind other shale oil production countries. Since the 1950s, new technology and innovation have not been made, and new generation of retorts has not been generated. There are also very little research activities in the OS.

Direct Combustion

The former Soviet Union was one of the earliest countries that used OS as power fuel. In 1924, Estonian OS was first used at the Tallinn Power Plant. At that time, the steam boiler with a layered firebox was a specific feature for a power plant using OS. Then, the first pulverized OS-fired steam boilers with total capacity of 65–85 t/h of steam were put into operation. A new period of the utilization of Estonian OS as power fuel began between 1959 and 1971, when the first power units were built at Baltic Thermal Power Plant with the capacity of 1,612 MW at Baltic Thermal Power Plant. At this plant there are eight turbines, each with the capacity of 100 MW, and two extractional turbines of 12 MW, which receive from eighteen boilers with the steam output of 220 t/h and four units of 200 MW from eight 320 t/h. In the years of 1969–1973, the Estonian Thermal Power Plant was put into operation with the capacity of 1,600 MW. There are eight turbines, each with the capacity of 200 MW, and eight steam boilers with the capacity of steam of 320 t/h at this plant. Above all OS was combusted by pulverized fuel combustion (PF) [8, 9].

According to the Estonia's experience, PF combustion technology has some disadvantages in burning OS:

1. Huge quantities of shale have to be pulverized.
2. PF needs additional scrubbers for desulphurizing flue gas because high combustion temperature hinders the formation of $CaSO_4$ in the combustion chamber.
3. PF leads to hard deposits on heating surfaces due to high temperatures which cause volatilization of alkalis present in the fuel and also melting of the ash.
4. NO_x emissions are high.

Therefore, fluidized-bed combustion/circulating fluidized-bed combustion (FBC/CFBC) technologies have begun to attract attentions. The Estonian Energy Company is considering CFBC technology for retrofitting its Estonian Power Plants. The Ahlstrőm Pyroflow-circulating fluidized-bed technology was selected and samples of Estonian OS have been tested in an existing Pyroflow boiler in Finland [4].

In Israel, OS has been found all over the country, and most of the exploitable deposits are concentrated in the Northern Negev. The PAMA (Energy Resources Development) Ltd of Israel started to develop direct combustion of OS using CFBC in 1981. The 1 t/h OS pilot unit was built in 1984, and the semi-commercial demonstration plant was built in 1987–1989. The fluidized-bed boiler with the capacity of 50 t/h of steam per hour was selected from Ahlstrőm Corporation. In October 1993 the board of directors of Israel Electric Corporation Ltd approved a project to build a commercial OS-fired power plant [10].

In 1965–1967, the Chinese first OS-fired pilot fluidized-bed boiler with a capacity of 14.5 t/h was installed in Maoming Petroleum Company in Guangdong province. The combustion efficiency was 90%, and heat efficiency was 77%. In 1985, additional two CFB boilers were installed in the company. These boilers were designed by Northeast Institute of Electric Power Engineering of China (NEIEP), and made by Jiangxi Boiler Plant with main parameters as follows: capacity of steam 35 tonnes per hour, the pressure of superheated steam 3.9 MPa and the temperature 450 °C.

After the 1970s, considerable efforts have been made to study the combustion technology of fluidized-bed boiler-fired Huadian OS in NEIEP. In 1974, the first and successful combustion test was conducted on a 4 t/h boiler, which showed that it is feasible to use Huadian's OS as an industrial boiler fuel. In the end of 1979, two combustion tests on bubbling fluidized-bed (BFB) boilers with capacity of 18 t/h in New China Sugar Factory were conducted, and the results showed that the boilers were stable and could meet the requirements of power generation.

In two winter periods of 1978 and 1979, more than 700 tonnes OS were fired in two BFB boilers with capacity of 10 t/h in NEIEP. In the 1980s there were several units of 4–10 t/h fluidized-bed boilers in operation firing Huadian OS whose heating value ranges from 8,374 to 12,561 kJ/kg. Combustion tests and practical use showed that the OS could be fired stably and meet the requirements of many mechanical parameters. These researches built a foundation and provided reliable data for the exploitation of Huadian's oil shale.

Compared with CFB, BFB combustion technology is lower both in heat and combustion efficiency. In the end of 1992 NEIEP, Dongfang Boiler Plant and Xi'an Thermal Research Institute carried out a key science and technology research project funded by the former Department of Energy of China. At the same time, a demonstration power plant with a capacity of 18 MW (one double extractional turbine of 12 MW, another backpressure turbine of 6 MW) was begun to set up. The key apparatus was three sets of 65 t/h OS-fired CFB boiler with low solids circulation rate. Since the plant was put into operation in August 1996, it has achieved stable and reliable operation in eight years [11].

Comprehensive Utilization Strategy

In the past, shale oil had no competitive advantage against crude oil because of its high production cost. Since 2003, the crude oil price in the world market has raised over $45 per barrel. This makes the shale oil production profitable. The production cost of shale oil is about 1,000–1,500 yuan RMB for per tonne domestically, while the price of shale oil is up to 2,200–

2,400 yuan RMB per tonne, so shale oil production can bring significant profits for investors.

At present, the prevailing method of shale oil produced in China is still using traditional Fushun-type retorts. The oil yield of this method is only 63% of Fisher Assay. This is heavy energy waste and generates a lot of pollutants causing severe environmental problems. This method is not advocated. Introduction of foreign advanced retorting technology, which can make oil yield up to 90% and production cost down to around 900 yuan RMB per tonne, will result in more economic benefits. It is an effective way to develop comprehensive utilization where OS is used to extract shale oil, semi-coke is used to generate electricity and ash is used to make construction materials.

Based on foregoing discussion, Huadian government has put forward an OS comprehensive utilization project, which contains OS mining, retorting, semi-coke combustion and production of building materials. This project includes:

(1) yearly mining of 2.76 million tonnes OS;

(2) yearly shale oil yield 0.2 million tonnes;

(3) erection of a power plant with the capacity of 2 × 50 MW;

(4) production of new-type building materials including yearly output of 1.19 million tonnes cement, 3.28×10^6 cubic meters block and 2×10^6 cubic meters ceramicite, finally realizing OS processing without solid waste discharge.

This is the main strategic objective of OS development in Jilin province.

This project is strongly supported by the China Energy Conservation Investment Company and Jilin province government. In August 2003, China's International Engineering Consulting Corporation was commissioned to evaluate this project. The conclusion is "the implementation of Huadian's OS comprehensive utilization project is very important to diversify the sources of oil, renew the old industrial basis of northeast region, develop related industries, offer job opportunities and ensure society stability. The project is a good project in terms of its plentiful resources, mature technology, established market and strong ability of resisting risk". On November 13, 2003, National Development and Reform Commission of China approved the project.

In September 2004, China Energy Conservation Investment Company, Jilin Province Shulan Mine Bureau and Huadian City Hongwei Economic Development Corporation signed a joint venture agreement and decided to start in 2005.

The anticipated economic benefit is great, and the summary is as follows:

1. 2.76 million tonnes OS generated yearly with the production cost of 1.5 hundred million yuan RMB, the total sale of 1.8 hundred million yuan RMB and the total yearly profit of 30 million yuan RMB.

2. 0.2 million tonnes shale oil with total sale of 3.8 hundred million yuan RMB, total cost of 2.1 hundred million yuan RMB and total profit of 60 million yuan RMB.
3. 2 × 50 MW power plants with total electricity sale of 2.1 hundred million yuan RMB, total cost of 1.5 hundred million yuan RMB and total profit of 60 million yuan RMB.
4. New type building materials: annual cement output 2×10^6 tonnes with total sale of 3 hundred million yuan RMB and total profit of 1.34 hundred million yuan RMB, annual building block output 3.28×10^6 cubic meters with total sale of 23.8 million yuan RMB and total profit of 7.31 million yuan RMB, and annual ceramicite output 2×10^6 cubic meters with total sale of 24 million yuan RMB and total profit of 7.4 million yuan RMB.

The total investment of the project is expected to be 2.75 billion yuan RMB, anticipated yearly sale and profit are 1.118 billion yuan RMB and 4.79 hundred million yuan RMB respectively. The payback period of the investment is estimated to be less than seven years.

The success in developing semi-coke burning technology is the key to the success of the whole project. CFB, an advanced clean coal technology with its virtues of wide fuel flexibility, high efficiency and low pollution will play the most important role in the project.

Conclusions

Comprehensive and systematic utilization of OS is very important in energy production and therefore economic development in China. A key OS utilization project, the comprehensive exploitation of Huadian's OS in Jilin Province, China, is analyzed and assessed in this paper. Some key points and conclusions are as follows:

1. Jilin province has abundant reserves of OS, which accounts for 56% of the country's whole reserves. Moreover, the OS in Huadian city has high quality and should be exploited with high priority.
2. Three units of 65 t/h CFB boilers in Huadian power plant are the biggest CFB boilers in the world combusting oil shale. These boilers have been in stable operation for eight years and provided a lot of practices and reliable data for the further development of large-scale construction of OS in circulating fluidized-bed boilers.
3. Comprehensive utilization of Huadian OS – oil shale mining, retorting, semi-coke combustion and production of building materials on ash basis includes:
   i. yearly mining of 2.76 million tonnes of OS;
   ii. yearly shale oil yield 0.2 million tonnes;
   iii. erection of a power plant with the capacity of 2 × 50 MW;

iv. production of new-type building materials including yearly output of 1.19 million tonnes cement, 3.28×10^6 cubic meters block and 2×10^6 cubic meters ceramicite. The overall objective is to utilize OS in a comprehensive process without producing solid wastes.

4. Employment of CFB boiler for combustion of semi-coke derived from OS retort is the key for the success of this comprehensive utilization project.

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REFERENCES

1. Energy Status Analysis of Jilin Province : Report of Northeast China Institute of Electric Power Engineering. – Jilin, 1999 [in Chinese].
2. Construction Layout of Huadian Oil Shale Mining : Feasibility Report of Jilin Coal Design Institute. – Jilin, 1997 [in Chinese].
3. *Dehong, P., Jialin, Q.* Oil shale activities in China // Oil Shale. 1991. Vol. 8, No. 2. P. 97–105.
4. *Holopainen, H.* Experience of oil shale combustion in Ahlstrom pyroflow CFB-boiler // Oil Shale. 1991. Vol. 8, No. 3. P. 194–209.
5. *Xigui, W., Guizhen, H.* Technical features of Fushun-type retort today // Proc. Inter. Conf. on Oil Shale and Shale Oil, Beijing, China, 1988. P. 409–414.
6. *Qian, J., Wang, J., Li, S.* Oil shale development in China // Oil Shale. 2003. Vol. 20, No. 3 Special. P. 356–359.
7. *Yihe, L.* Oil shale retorting technology in Maoming // Proc. Inter. Conf. on Oil Shale and Shale Oil, Beijing, China, 1988. P. 415–423.
8. *Ots, A.* Utilisation of Estonian oil shale at thermal power plant // Proc. Inter. Conf. on Oil Shale and Shale Oil, Beijing, China, 1988. P. 650–657.
9. *Ots, A.* Formation of air-polluting compounds while burning oil shale // Oil Shale. 1992. Vol. 9, No. 1. P. 63–75.
10. *Schaal, M., Podshivalov, V., Wohlfarth, A., Schwartz, M.* FBC to burn oil shale in the northern Negev // Modern Power Systems. 1994. No. 9. P. 25–28
11. *Qing, W., Zhijin, H., Jian, S., Yunkun, Q*. Operating performance analysis of an oil shale-fired circulating fluidized-bed boiler of the highest capacity currently in operation in China // J. of Engineering for Thermal Energy & Power. 2001. Vol. 16, No. 5. P. 513–516 [in Chinese].

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