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PROCESS SIMULATION OF OIL SHALE COMPREHENSIVE UTILIZATION SYSTEM BASED ON HUADIAN-TYPE RETORTING TECHNIQUE

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Abstract. *In this paper, an oil shale comprehensive utilization system based on Huadian-type retorting technique is constructed for producing shale oil, electricity, heat and construction materials. The system presented in this work aims at increasing resource utilization efficiency, improving process efficacy and reducing pollutant emission. Shale oil as a valuable product can be obtained by retorting. Meanwhile, during this process, the byproducts, retorting gas and semi-coke, not only can be used to provide sufficient energy for retorting, but can also be combusted efficiently in sequent subsystems for electricity generation and district heating. Moreover, the discharged shale ash can be used to produce construction materials. The proposed system is modeled and evaluated by the process simulation software Aspen Plus. The simulation results indicate that the scheme of oil shale comprehensive utilization has several advantages over oil shale retorting or combustion merely, and about 0.161 million t/a shale oil and 123.82 MW power can be produced in this system. Also, increasing the mass fraction of oil shale for retorting would exert a positive impact on the system's economics, which is especially important considering the rising oil prices.*

Keywords: *oil shale, Huadian-type retorting technique, comprehensive utilization, Aspen Plus.*

1. Introduction

Oil shale is commonly defined as a fine-grained sedimentary rock containing organic matter that yields substantial amounts of oil and combustible gas upon retorting [1, 2]. In China, oil shale resources total approximately 719.9 billion tons, which is equivalent to 47.6 billion tons shale oil. Of this, about 12 billion tons is recoverable. Oil shale deposits have been found in

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Jilin, Liaoning, Guandong, etc. In 1996, three 65t/h oil shale-fired CFB boiler units were built and operated successfully in Huadian city [3–6].

Oil shale can be combusted in a furnace or boiler to produce high temperature and pressure steam for electricity generation as inferior fuel. Moreover, oil shale can yield shale oil, retorting gas (combustible) and semi-coke by retorting, shale oil can be used to produce gasoline and diesel through hydrogenation. With the price of crude oil rising dramatically, shale oil production is gradually becoming profitable [7, 8]. Numerous utilization techniques have been invented for oil shale retorting or combustion, which, however, have low resource and energy utilization efficiency and can cause severe environmental pollution inevitably [9–11]. Hence, employing an advanced oil shale comprehensive utilization technology may provide a high-efficiency and environment-friendly way for oil shale industry to use this resource [12]. By now, several investigators [13–15] have carried out fundamental researches on oil shale. Others [16–19] have conducted numerous projects to research the integrated technology for oil shale comprehensive utilization.

In this paper, an oil shale comprehensive utilization system based on Huadian-type retorting technique is presented. The system includes a retorting subsystem (RS) [20], a gas and steam combined cycle subsystem (GSCCS), a semi-coke combustion and electricity generation subsystem (SCEGS) and an ash processing subsystem (APS). In this poly-generation system, various types of products such as shale oil, electricity, heat and construction materials are produced. The oil shale comprehensive utilization system is simulated in Aspen Plus in which the system mass and thermal balance can be calculated. The performance of the system is analyzed, and its optimal process parameters and conditions are determined.

2. Oil shale comprehensive utilization

2.1. Process description

An oil shale comprehensive utilization system proposed on the basis of the resource cascade utilization concept aims at improving process efficiency and reducing environmental impacts, its schematic diagram is shown in Figure 1. The system consists of RS, GSCCS, SCEGS and APS, RS can be operated successfully if other subsystems are segregated from the integrated system.

RS installs a Huadian-type retorting system using a full recycle gas heat carrier heating technology. The hot recycle gas must be heated to 600–700 °C by a semi-coke burner and a gas burner. Oil shale with high oil content is crushed to 6–50 mm particles, and conveyed to RS, the produced shale oil can be on sale directly as liquid fuel. GSCCS consists of a gas turbine and a steam turbine to utilize spare retorting gas efficiently. SCEGS is also equipped with a CFB boiler and a combined heat and power (CHP) steam turbine to utilize the low oil content and small particle oil shale, and semi-coke.

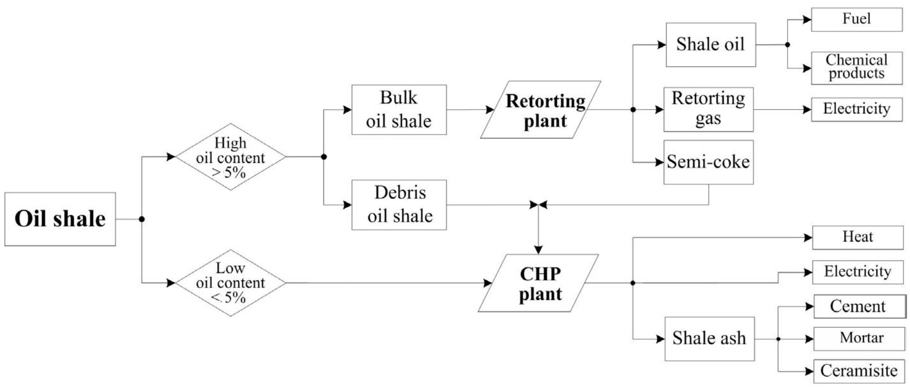

Fig. 1. Schematic diagram of the oil shale comprehensive utilization system.

Semi-coke combustion technology is a key component in oil shale comprehensive utilization. In numerous studies [21–26] the semi-coke combustion mechanism and regulation in the CFB boiler, as well as CFB boiler scaling up have been dealt with.

The purpose of integrating APS into the system is to convert shale ash to a valuable product. The shale ash, emitted from the CFB boiler in SCEGS and the semi-coke burner in RS, can be used to produce construction materials, silica and alumina, instead of being employed as mine backfill [27, 28]. In this work, in APS construction materials like shale cement, mortar and ceramisite are produced.

2.2. Huadian-type retorting technique

The Huadian-type oil shale retort reactor with a rate of 300t/d, developed by Shenyang Cheng Da Hong Sheng Energy Institute of China, employs the gas heat carrier retorting technology, and a retorting unit including six retort reactors [29, 30]. The process schematic diagram is illustrated in Figure 2.

This type technology has been employed in Jilin CDHS Energy Company in Huadian city, China. The retorting system was initially operated in 2011 with an oil shale processing capacity of 3 million tons per year, and it was the first application of this technology. It is also planned to employ this technique in an oil shale retorting project of Xinjiang, China.

Raw oil shale first flows into the crusher, then the bulk oil shale (6–50 mm) is conveyed to the oil shale tank while the debris oil shale (< 6 mm) cannot be utilized by this type of retort reactor effectively. The bulk oil shale is fed into the preheater and nearly half of moisture is driven out at a temperature between 50 and 150 °C. Then the preheated bulk oil shale falls into the retort reactor to generate shale oil and retorting gas, with the retorting temperature maintained at 450–550 °C by controlling the feeding flow of recycle gas. Numerous experiments have confirmed that the temperature for a maximum yield of shale oil is at 520 °C, above which the

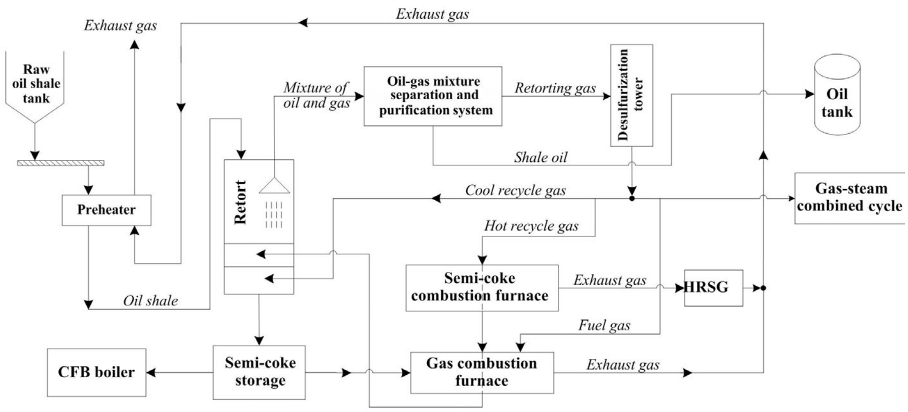

Fig. 2. Process schematic diagram of the Huadian-type oil shale retorting system.

shale oil yield would decline due to the secondary decomposition of the oil vapor. The hot recycle gas is heated to 600–700 °C by two burners (i.e. the semi-coke burner and the gas burner) and forced to flow into the retort through the middle vent to provide enough energy for an effective retorting. The cool recycle gas is conveyed directly to the retort through the lower vent to recover the sensible heat of semi-coke by cooling down to 250 °C. The oil-gas vapor mixture released from the retort and consisting of shale oil and gas (retorting and recycle gas) can be separated through the condensation process at about 40 °C.

As mentioned above, the shale oil is suitable as liquid fuel for sale. The separated gas must be divided into four streams: hot recycle gas, cool recycle gas, fuel gas (flowed to the gas burner) and spare gas (as power gas).

The semi-coke is discharged directly from the retort reactor into the semi-coke storage pool. Part of semi-coke is used as fuel coke and is fed to the semi-coke burner, while the rest of semi-coke can be utilized as power fuel in the oil shale comprehensive utilization system through the CFB boiler.

The hot recycle gas is heated first in the semi-coke burner to 400–500 °C, and then in the gas burner to 600–700 °C which can carry enough heat for retorting. The exhaust gas emits from the semi-coke burner and flows to HRSG to raise the amount of steam for daily consumption, then the gas is used to provide heat for preheating raw oil shale.

Compared to the Fushun-type oil shale retorting reactor [10], the Huadian-type oil shale retorting system has some significant advantages. First of all, both the shale oil yield rate and the heat value of retorting gas are enhanced. Additionally, the overall thermal efficiency of the retorting system is improved and the oil shale processing capacity is increased.

2.3. Characteristics of samples

The oil shale sample (OS) used in this work was obtained from Gonglangtou mine located in Huadian city of Jilin province, Northeast China. Semi-coke (SC) and shale oil (OIL) are obtained by retorting. The results of Fischer assay of OS are presented in Table 1, the properties of OS, SC and OIL are given in Table 2.

The components and properties of the recycle gas are similar with those of the retorting gas employed in the full recycle gas heat carrier heating technology for retorting, the low heat value of the retorting gas is 19.62 MJ/Nm^3.

Table 1. Fischer assay results of oil shale sample, wt%, ad

Oil	Moisture	Semi-coke	Gas and loss
11.37	3.90	80.63	4.1

Table 2. Proximate and ultimate analyses and heat value of samples

Sample	Proximate analysis, wt%				Ultimate analysis, wt%					$Q_{ad,net,p}$, $kJ \cdot kg^{-1}$
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C_{ad}	H_{ad}	O_{ad}	N_{ad}	S_{ad}	
OS	2.1	71.62	23.16	3.12	15.53	2.06	4.71	0.85	3.13	7942.37
SC	0.44	82.13	13.54	3.89	11.42	0.81	3.18	0.76	1.26	3118.45
OIL	–	–	–	–	85.7	11.41	0.70	0.28	1.91	41509.71

2.4. Process of Aspen Plus simulation flowsheet

The oil shale comprehensive utilization system proposed in this paper is simulated by the software Aspen Plus. Aspen Plus originates from the project Advanced System for Process Engineering by the Massachusetts Institute of Technology (MIT) and has been employed, in cooperation, by 55 universities since 1976. This project is supported by the DOE of US and aims at designing the third generation of process simulation system. Currently, Aspen Plus is utilized in various realms, including petroleum processing, coal gasification and carbon capture. The software is operated with the sequential modular calculation approach, and is based on the mass-heat-power balance principle. What is more, Aspen Plus can give assistance for process design and system optimization.

The simulated processes including RS, GSCCS and SCEGS are depicted in the Aspen flowsheet diagram in Figure 3. In addition, APS is calculated by a built-in FORTRAN subroutine.

Raw oil shale (FEEDSHALE) is fed into a preheater (PREHEAT), and the preheater is modeled as a heat exchanger. Then dry oil shale is transferred to the retort reactor in which the operating temperature is maintained at 520 °C, the energy required is supplied directly by the hot recycle gas (HGASRET3) and indirectly by the cool recycle gas (CGASRET2). The retort reactor is modeled by RETORT and MINRET to simulate oil shale

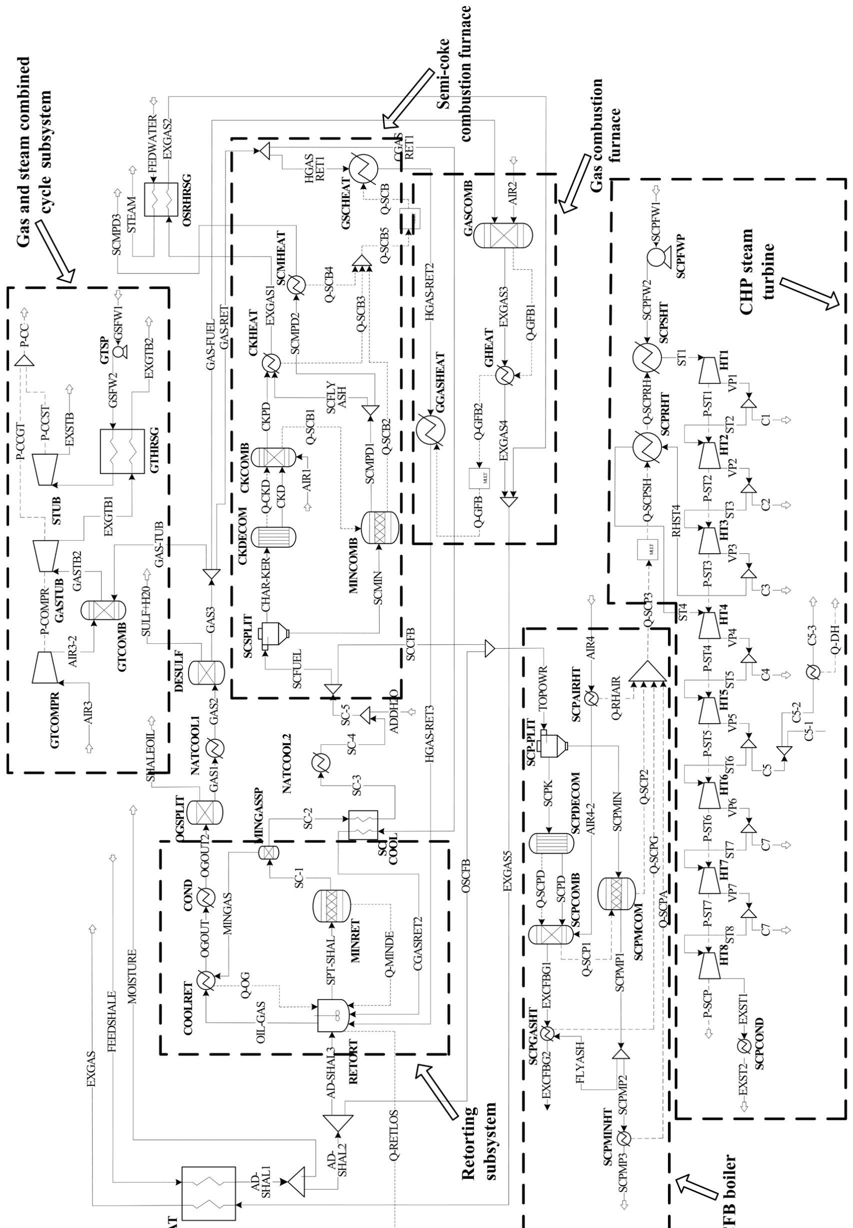

Fig. 3. Diagram of Aspen flowsheet of the oil shale comprehensive utilization system.

retorting process including kerogen pyrolysis and mineral decomposition. RETORT is specified by an external FORTRAN subroutine. The existing stream (OGOUT) from the reactor is a mixture of shale oil vapor, retorting gas and recycle gas, which is separated in two devices (COND and OGSPLIT). The gas stream (GAS3) is divided into three steams, including GAS-RET as recycle gas, GAS-FUEL as fuel gas and GAS-TUB as power gas, while the steam of GAS-RET is split into HGASRET1 and CGASRET1 for further simulation.

The semi-coke (SC5) discharged from the retort reactor is divided into two streams (SCFUEL and SCCFB) by a splitter, and conveyed to a semi-coke burner in RS and a CFB boiler in SCEGS for combustion, respectively. The semi-coke burner is modeled by three reactors (CKDECOM, CKCOMB and MINCOMB) and three heaters. The CFB boiler used to combust the rest of semi-coke and debris oil shale is simulated by three reactors (SCPDECOM, SCPCOM and SCPMCOM) and some heaters as well. The heat generated by the semi-coke burner and CFB boiler is transmitted by two heat streams (Q-SCB and Q-SCPSH) to two heaters (GSCHEAT and SCPRHT), respectively. Fuel gas (GAS-FUEL) is conveyed to and combusted in the gas burner (GASCOMB), the combustion heat carried by heat stream Q-GFB to GGASHEAT, is modeled as a heater, for heating hot recycle gas.

The turbine (e.g. a gas turbine and a steam turbine) can be modeled using the compressor model. Power gas (GAS-TUB) is burned in the gas combustor (GTCOMB) to obtain a high temperature gas stream (GASTB2) above 1200 °C at 1.5 MPa to drive the gas turbine (GASTUB) for generating electricity, the exhaust flows to HRSG (GTHRSG) to raise the amount of steam for driving the steam turbine (STUB) for electricity generation totally accumulated in the power stream P-CC. The steam generated by the CFB boiler is transferred to a multistage CHP turbine which is modeled by eight turbine stages. Output is for both electricity generation (P-SCP) and district heating (Q-DH).

2.5. Assumptions

The RK-SOAVE is chosen as a global property method. According to the experiments, all the devices of the system are operated under atmospheric or slightly sub-atmospheric conditions. The oil shale comprehensive utilization system is simulated on the basis of some simplifying assumptions as retorting and combustion are complex chemical reaction processes. The assumptions are as follows:

(1) The yields of oil and gas from the retort are based on the experimental data, the oil and gas yield of the Huadian-type retorting system to Fischer assay is 80% and there is no mass loss in the retorting process.
(2) The shale oil obtained from retorting is a complex compound and is described by $C_{21}H_{36}$ [31].
(3) All reactions in the process reach their chemical equilibrium and the equipment is operated steadily.

(4) Heating rate and mineral composition do not exert any influence on oil shale retorting.
(5) The fraction of debris oil shale to raw oil shale is 20%. This material is used for direct combustion in the CFB boiler.

The input parameters for the simulation of some devices are specified under original design conditions. The oil shale processing rate is about 2.6 million t/a (i.e. at a feeding rate of 100 kg/s) and the annual running time of the system is 7200 h (4320 h in winter). The operation parameters of the devices are given in Table 3.

Table 3. Operation parameters of system devices

Device	Operation parameter	Value
Retort	Temperature, °C	520
	Pressure, MPa	0.1013
Semi-coke burner	Temperature, °C	820
	Pressure, MPa	0.1013
	Efficiency, %	75
Gas burner	Temperature, °C	1000
	Pressure, MPa	0.1013
	Efficiency, %	75
Gas-steam combined cycle	Pressure ratio	15
	Furnace temperature, °C	1200
	Steam temperature, °C	520
	Steam pressure, MPa	8.83
CFB boiler	Temperature, °C	820
	Pressure, MPa	0.1013
	Flue gas temperature, °C	150
	Slag temperature, °C	600
	Fly ash content, %	50
	Steam temperature, °C	535
	Steam pressure, MPa	13.24
	Efficiency, %	85

2.6. System evaluation

The total energy efficiency η_e, the system annual revenue I_t and the system annual profit p_t' are used to evaluate the performance of the oil shale comprehensive utilization system as follows:

$$\eta_e = \frac{LHV_{oil} \cdot f_{oil} + P_{CC} \cdot T + P_{SC} \cdot T + Q_{DH}}{LHV_{OS} \cdot f_{OS}} \quad (1)$$

$$I_T = \sum I_i \quad (2)$$

$$p_t' = \sum p_i' \quad (3)$$

where LHV_{OS} is the low heat value of shale oil, kJ/kg; P_{CC} is the power generated by GSCCS, kW; P_{SC} is the average power generated by the CHP steam turbine between the district heating period and non-heating period, kW; Q_{DH} is the heat output in the district heating period, kJ; T is the running time, h (e.g. 7200 h); f_{os} and f_{oil} are the oil shale feeding flow and shale oil yielding flow, respectively, kg/s; I_T and I_i are the annual revenue of the whole system and each subsystem, respectively, yuan RMB; p_t' and p_i' are the annual profit of the whole system and each subsystem, respectively, yuan RMB. Material and product prices are listed in Table 4.

Table 4. Material and product prices per unit*

	Oil shale, yuan RMB/t	Shale oil, yuan RMB/t	Electricity, yuan RMB/kWh	Heat, yuan RMB/GJ
Price	120	5000	0.4	40

3. Results and discussion

3.1. Process simulation results

The oil shale comprehensive utilization system is constructed based on Huadian-type oil shale retorting technique and integrated with some subsystems as well. The Aspen Plus simulator is used to simulate the system. The hot recycle gas is heated in the semi-coke burner and then in the gas combustion burner to 500 °C and 600 °C (denoted by 500/600 °C), respectively, to provide sufficient heat for retorting. The process simulation results are given in Table 5.

Table 5. Process simulation results for material streams of the retorting subsystem

Material stream	Temperature, °C	Mass flow, $kg \cdot s^{-1}$	Substream component mass flow, $kg \cdot s^{-1}$					
			Water	Kerogen	Char	Mineral/ash	Oil	Gas
FEED-SHALE	25	100	15.13	15.85	–	69.02	–	–
SHALEOIL	50	6.21	–	–	–	–	6.21	–
GAS3	35	107.56	–	–	–	–	–	107.56
GAS-FUEL	35	1.17	–	–	–	–	–	1.17
GAS-TUB	35	1.23	–	–	–	–	–	1.23
HGASRET3	600	24.66	–	–	–	–	–	24.66
CGASRET1	35	30.81	–	–	–	–	–	30.81
SC5	50	61.65	3.81	2.37	2.24	53.23	–	–
SCFUEL	50	14.88	0.92	0.57	0.54	12.85	–	–
SCCFB	50	46.77	2.89	1.80	1.70	40.38	–	–
TOPOWER	60	65.44	4.58	4.97	1.70	54.19	–	–
EXGAS	75	48.06	2.33	–	–	2.89	–	45.73

Under the condition of 500/600 °C, the heat loss for oil-gas vapor condensation from the system is 29916 kW, which is about 35% of the input

* 1 CNY = 0.1633 USD, calc from the ECB's exchange rates at 21.08.2013 (Ed.)

heat in the retort reactor. The production simulation results for power and heat streams are presented in Table 6.

Table 6. Production simulation results for power and heat streams of the system

Subsystem	Stream		Power, kW	Heat, kW
GSCCS	P-CCGT	Gas turbine power	9088.39	–
	P-CCST	Steam turbine power	3542.73	–
	P-CC	Total combined cycle power	12631.12	–
SCEGS	P-SCP*	CHP turbine power	119640.16	–
	P-SCP**	CHP turbine power	105553.6	–
	Q-DH**	District heating power	–	76528.53

* in the district heating period
** in the non-heating period

3.2. Energy efficiency and economic performance of the comprehensive utilization system

The oil shale retorting subsystem is a core part of the comprehensive utilization system. In the conditions of rising crude oil price and considering the social aspect, it is reasonable to maintain production of shale oil as liquid fuel. The retorting by-product is further utilized in subsequent subsystems. As shown in Figure 4, the total energy efficiency of the comprehensive system is 69.92%, which is 1.87 times that of oil shale retorting only (with the efficiency of 39.34%).

The products of the system, including shale oil, electricity, heat and construction materials, and the annual product output and revenue of subsystems are given in Table 7. The annual shale ash output of the system amounts to 1.6 million tons, the backfill proportion is 40%. This means that about 0.96 million tons of shale ash may be used to produce 1.12 million tons of shale cement, 0.508 million m^3 mortar and 0.225 million m^3 ceramisite in APS. The predicted annual revenue and profit are 0.412 billion yuan RMB and 0.104 billion yuan RMB, respectively.

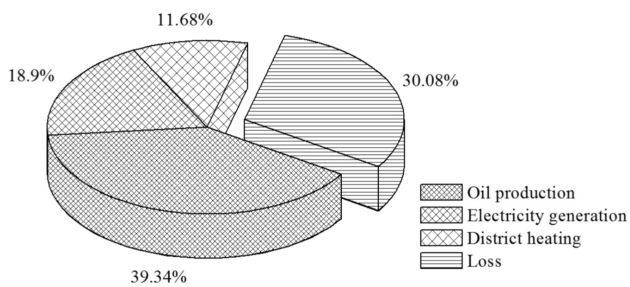

Fig. 4. Energy efficiency of each subsystem in the oil shale comprehensive utilization system.

Table 7. Annual product output and economic efficiency of subsystems

Product	RS	GSCCS	SCEGS	APS	Total
Shale oil, million t	0.161	—	—	—	0.161
Electricity, billion kWh	—	0.091	0.801	—	0.892
Heat, million GJ	—	—	1.191	—	1.191
Cement, million t	—	—	—	1.123	1.123
Mortar, million m^3	—	—	—	0.509	0.509
Ceramisite, million m^3	—	—	—	0.225	0.225
Revenue, billion yuan RMB/a	0.805	0.036	0.368	0.412	1.621
Profit, billion yuan RMB/a	0.483	0.022	0.226	0.104	0.835

The annual shale oil production is 0.161 million tons, the annual revenue and profit are 0.805 billion yuan RMB and 0.483 billion yuan RMB, respectively. With semi-coke and gas combusted for electricity generation and district heating, the annual revenue and profit can rise to respectively 1.209 billion yuan RMB and 0.731 billion yuan RMB. This increases the revenue and profit by 50.19% and 51.35%, respectively. The revenue and profit can rise further to 1.621 and 0.835 billion yuan RMB per year, respectively, if integrating the ash processing subsystem with oil shale and power generation.

3.3. Effect of the mass fraction of oil shale for retorting

The fluctuation of world crude oil price is influenced by the international economy and security situation, while in China the price of electricity and heat can be kept relatively stable. Adjusting the mass fraction of oil shale sent for retorting appropriately can be used to optimize the overall profits with oil price variation. This is demonstrated in Figure 5 by changing the mass fraction of oil shale for retorting from 80% to 0% along with the oil price swinging from 2000 to 5000 yuan RMB/t.

The cost of electricity generation and district heating is relatively low compared with coal-based generation as the prices of oil shale and semi-coke are lower. Raising the mass fraction of oil shale for retorting can increase the profit of the system in the period of high oil price. RS can maintain financial balance when shale oil price is 2000 yuan RMB/t, while the profit of the whole system is 0.351 billion yuan RMB/a. Keeping the price of electricity and heat stable, 3150 yuan RMB/t is the critical oil price for the system, while increasing the mass fraction of oil shale for retorting will be more profitable if oil price is higher than 3150 yuan RMB/t. The oil shale comprehensive utilization system is profitable even it is not advantageous for oil shale retorting as oil price is lower than the cost. So, a proper strategy for oil shale industry employing the oil shale comprehensive utilization system can avoid the influence of economic depression temporarily or during a relatively long period.

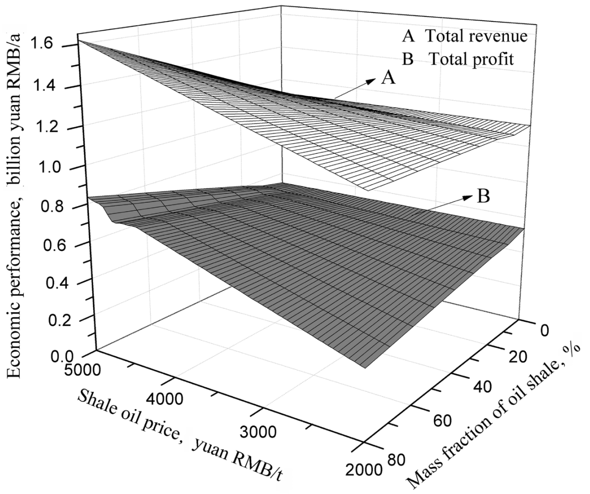

Fig. 5. Effect of the mass fraction of oil shale for retorting on the system economic performance.

3.4. Comparison between different oil shale utilization modes

Retorting to yield shale oil or combustion for electricity generation is the traditional method to utilize oil shale. One has to ask whether integrating various subsystems is a wise way to achieve a highly efficient utilization of this resource. To study impacts of changes, a comparison is drawn between the following five oil shale utilization systems:

case A – combusting oil shale for generating electricity;
case B – combusting oil shale for electricity generation and district heating;
case C – retorting oil shale for yielding shale oil;
case D – retorting oil shale and combusting semi-coke for yielding shale oil and generating electricity;
case E – retorting oil shale and combusting semi-coke for yielding shale oil, generating electricity and heat for district heating.

The five utilization systems can be simulated by the modified Aspen flowsheet. All the cases maintain the oil shale processing capacity of 2.6 million t/a, while the above-mentioned ash processing subsystem (i.e. production of 1.12 million tons of shale cement, 0.508 million m^3 mortar and 0.225 million m^3 ceramisite per year) is integrated into each system. The comparison of these different utilization modes is depicted in Figure 6.

As shown in Figure 6, the total energy efficiency, revenue and profit of these systems increase from case A to case E, while the energy efficiency of case B is relatively high as the district heating unit can utilize the latent heat of steam.

The energy efficiency of case A is 34.85%, total revenue is 1.069 billion yuan RMB/a and profit is 0.499 billion yuan RMB/a. Case B is constructed on the basis of case A and the district heating subsystem is added. The energy

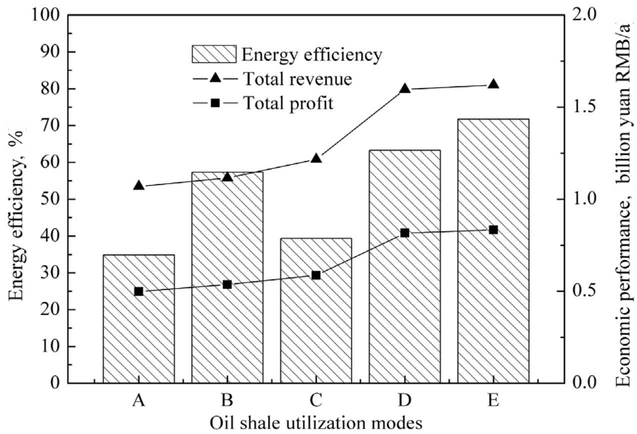

Fig. 6. Total energy efficiency and revenue of different oil shale utilization systems.

efficiency of B can be raised to 57.29% even though the revenue has not increased significantly. The utilization mode of case C, retorting oil shale for yielding shale oil directly, is opposite to case A and case B. The energy efficiency of case C is 39.34%, total revenue is 1.216 billion yuan RMB/a and total profit 0.587 billion yuan RMB/a, which is a rise by 12.88%, 13.75% and 17.64% compared to case A, respectively. Case D's energy efficiency, total revenue and total profit are significantly higher than those of case C as SCEGS is added and the semi-coke is free for generating electricity. The oil shale comprehensive utilization system proposed in this paper, i.e. case E, is a poly-generation system whose energy efficiency is 69.92%, total revenue 1.621 billion yuan RMB/a and total profit 0.834 billion yuan RMB/a, which shows improvement by 100.63%, 51.64% and 67.13% over the figures of case A, respectively, and by 77.73%, 33.31% and 42.08% over those of case C, respectively.

As comparison shows, the advantage of case E over the other cases is obvious. At the same time, issues such as increased investment requirements and complications of the developed system yet exist. However, the authors expect that the experience gained in oil shale retorting and oil shale combustion, together with further research by related universities and institutes will contribute to the profitable operation of such a comprehensive system.

4. Conclusions

In this paper, the oil shale comprehensive utilization system based on Huadian-type oil shale retorting technique is presented as simulated in Aspen Plus. The mass and heat balance of the system is calculated using Aspen Plus, with subsequent analysis to demonstrate its efficiency under various scenarios. The following conclusions can be drawn from the results:

(1) Compared with simple oil shale retorting or combustion, comprehensive utilization will increase energy efficiency and minimize environmental pollution.
(2) Constructing an oil shale poly-generation system and developing oil shale recycle utilisation will take full advantage of the oil shale resource to yield shale oil and produce various by-products, and increase the economic benefit of the system.
(3) According to the process simulation, the comprehensive system at a scale of 2.6 million t/a will produce 0.161 billion tons shale oil, 0.892 billion kWh electricity, 1.19 million GJ heat, and various construction materials. The revenue and profit of the system may amount to 1.621 billion yuan RMB/a and 0.835 billion yuan RMB/a, respectively.
(4) Utilizing oil shale comprehensively not only decreases the influence of international oil price fluctuation, but maximizes the profit by adjusting the oil shale mass fraction for retorting and combustion.

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