# DESIGN OF A NEW OIL SHALE RETORT FOR CHINA'S FUSHUN REGION

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## ABSTRACT

Though oil shale retorting has been a well known process for over 100 years, there is still a need for improved designs. Recent attempts in the USA to process shale commercially using new technologies has either failed or the processes were not commercially economical at this time. After reviewing the disadvantages and advantages of current retort technology, a new retorting system is presented that takes advantage of fluidized bed combustion technology and removes most of the disadvantages of previous retorts. Within the coal fired fluidized bed combustor (FBC), the oil shale is processed in an array of auger-type vertical transport reactors. In reviewing oil shale deposits throughout the world, it was noted that most oil shales are of relatively low grade and that their residual carbon content is insufficient to provide all of the retorting heat; hence, either some of the product oil and gas are burned or an additional energy source is required. Since coal is often found with or nearby oil shale deposits, it was chosen as the primary heat source for the new retorting design.

The paper contains the preliminary retort design, results from the system analysis, and a summary comparison of the calculated retort performance as compared to China's Fushun retort.

## 1. INTRODUCTION

A significant challenge facing the oil shale industry today is the development of a reliable and cost efficient oil shale process. In this paper we present the preliminary design and evaluation of a new above-ground thermal retorting system. The retort was designed to take advantage of low grade coal as a thermal energy source and to efficiently process low grade shale by maximizing both oil and gas yields. The new system was designed by carefully reviewing the advantages and disadvantages of the numerous retorting systems that were developed over the past fifty years.

Today the major retorting systems are based on the principle of thermal conversion of kerogen into oil and gaseous products [Atwood, 1977; Lewis et al., 1984]. Though our new proposed retorting system is also a thermal process, we have considered as a modification to our system the recent advances in supercritical fluid extraction of shale oil; however, in this paper we will focus on the thermal processing.

As it is generally known, retorting oil shale entails heating a large mass of rock to the pyrolyzing temperature; therefore, the principal aims in any new retort design are to heat large masses of oil shale at low capital/operating cost, to maximize product recovery, and to minimize energy costs. Not surprisingly, then, retorts differ not in aim but primarily in the methods used to efficiently transfer heat to the raw shale.

Currently there are three general methods of heat transfer. The first type is where heat is transferred through a vessel wall to the shale. An early version of this type of retort was the Pumpherston retort [Atwood, 1977; Du, 1986]. In this retort, the shale flowed from the lock hopper by gravity through the retorting chamber. Steam and the oil vapors moving counter current to the shale travelled upward and out the top of the retort. Heat was supplied around the retorting chamber by burning natural gas and recycled shale gases. Since there was only one chamber the process was limited by the low heat transfer surface area. This kind of indirect heating was widely used in Scotland and in other European countries before World War II. The new process presented in this paper overcomes the problem of low heat transfer area by using a large number of vertical retorting tubes.

The second class of retort uses internal heating of the shale. There are several variations in generating the hot gases for this second generation type of retort [Du, 1986]. There are a number of examples of these retorts such as the Union, Fushun, Superior, Petrosix, Paraho, older Lurgi kiln retorts, and numerous noncommercial pilot plant retorts. Shortcomings are that a controlled particle size distribution must be maintained and that the very fine particles must be removed to permit adequate gas flow past the shale. If the hot gases are generated by burning pyrolyzed shale within the retort, as is the case in several of the designs, there is generally a loss of oil due to combustion and a dilution of the product gas. Also retorts that take advantage of internal combustion are generally more difficult to control.

The third class [Atwood, 1977; Du, 1986] is where hot solids (ceramic balls, spend shale) are mixed with the feed shale to provide the retorting heat. Examples are the Lurgi Ruhrgas and Tosco II retorts. As with the class 2 retorts, there are several variations on this type of heat transfer. Disadvantages of this method of heat transfer are the problems of circulating large amounts of inert solids to provide the necessary heat. This method does have the advantage of producing high oil yields and an undiluted product gas.

## 2. New Retorting System

The new retorting system shown schematically in Fig. 1 is a combination of two unit operations: a coal fired fluidized bed for indirect heating and an array of vertical auger-type transport reactors which carry the shale downward through the hot fluidized bed. A cut-away view of the system is illustrated in Fig. 2. The raw oil shale is fed into the hopper above the reactors. The feed is separated and flows into the vertical tube reactors. Each vertical transport reactor contains a rotating auger which controls the downward movement of the retorting oil shale. The shale is indirectly heated by combustion of the fluidized coal which surrounds the tubes. The retorted shale and the gas phase products exit from the bottom of the tubes. The outer vessel is similar to a fluidized bed

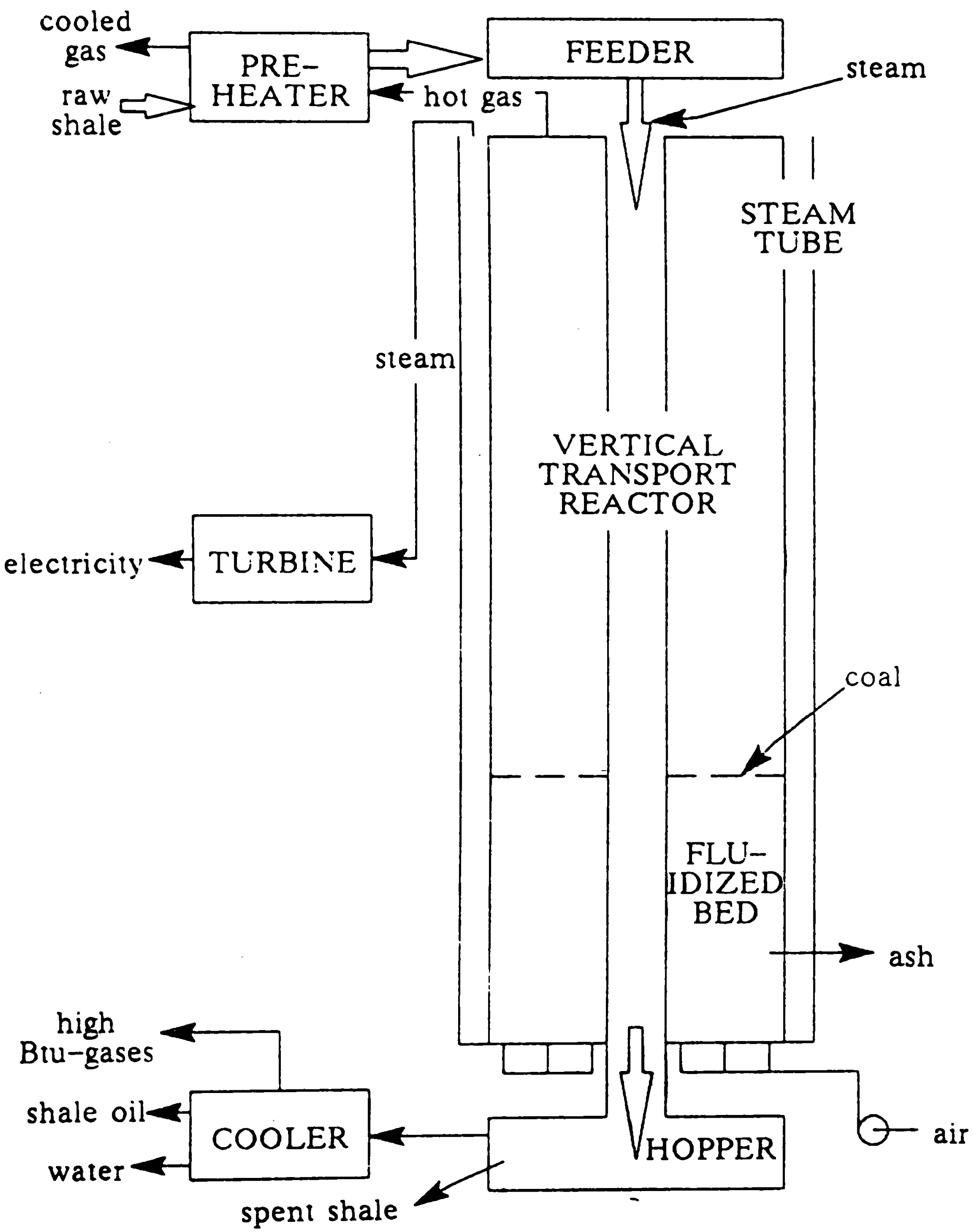


Fig. 1 - Schematic Diagram of New Retorting System.

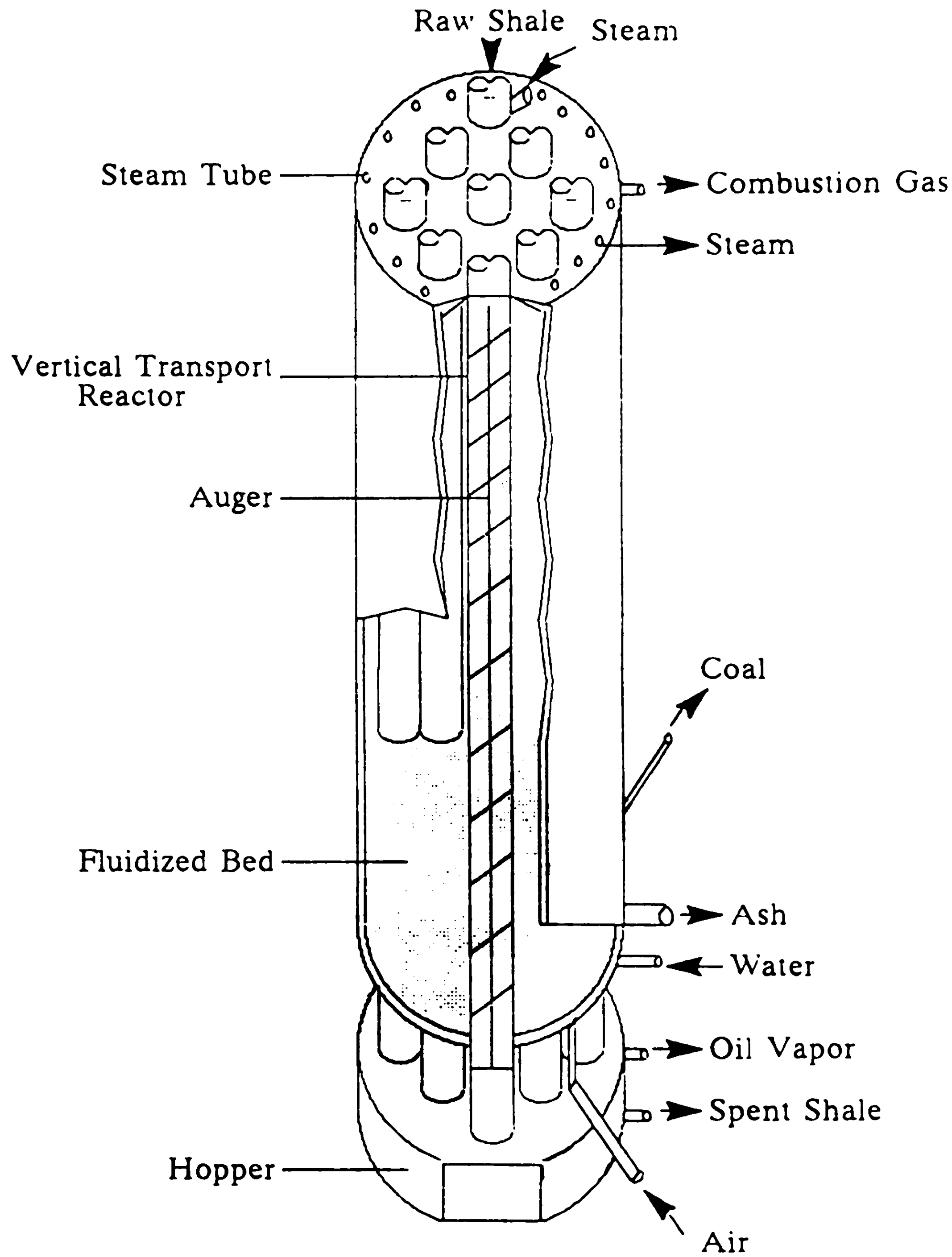


Fig. 2 - Cut-Away View of New Retort.

coal combustion steam boiler and, in fact, some of the tubes, perhaps those at the wall, could be used for steam generation.

Development of fluidized-bed boilers began in the early 1960s. Fluidized-bed boilers offer advantages in $SO_2$ removal using calcium carbonate, in higher heat transfer (2-5 times greater), in the use of low grade coal/fuels, in lower operating temperatures, in lower grinding costs for the coal, and in a 12 to 20 % lower capital cost. Today this technology is commercially available. Examples are the 20 MWe pilot plant at TVA's Shawnee power plant in Kentucky and the installation in 1984 of two fluidized-bed boilers in China. Du, 1986 in his analysis of the new retorting system carefully reviewed the extensive fluidized bed combustor literature [Cooper, B. R., and W. A. Ellingson. 1984; Howard, 1983; Skinner, 1971; Ehrlich, 1975; Squires, 1982; Jahnig, et al., 1980; Kunii and Levenspiel, 1969; Datta, et al., 1985, Kiang, K. D. et al., 1976] and from the literature determined the size of typically available commercial units. He chose as typical values the following fluidized bed design parameters. From these parameters, the number and size of the internal vertical transport tubes were calculated.

Table I. Design Parameters for a Typical Fluidized Bed Combustor

| | |
|---|---|
| OUTPUT | 30 MW |
| BED TEMPERATURE | 800-850 °C |
| BED DIAMETER | 5 m |
| BED DEPTH | 1.4 m |
| TOTAL HEIGHT | 10 m |
| COAL SIZE | < 8 mm |
| SPACING BETWEEN TUBE SURFACES | 50 mm |
| HEAT TRANSFER COEFFICIENT IN DENSE PHASE | 200 $w/m^2/^oC$ |
| HEAT TRANSFER COEFFICIENT IN DILUTE PHASE | 17 $w/m^2/^oC$ |
| VERTICAL TUBE ARRANGEMENT | TRIANGULAR PITCH |

The next step was to determine the effect of tube diameter on the overall oil shale throughput of the system. Design information for the throughput of the auger-type reactors was provided by KWS Manufacturing Co. Inc., 1984. The rate of heat transfer from the fluidized bed into the vertical tubes proved to be the limiting factor, thus setting the solids feed rate since the exiting shale must be heated to about 550 °C for complete pyrolysis. Oil shale throughputs were calculated for the following set of conditions. The design conditions and resulting maximum throughputs are given in Table II.

Table II. Vertical Reactor Design Parameters and Throughput

| | |
|---|---|
| TUBE LENGTH | 10 m |
| RANGE OF TUBE DIAMETERS | 10-46 cm |
| TUBE/PARTICLE DIAMETER | 6/1 |
| INLET SHALE TEMPERATURE | 100 °C |
| OUTLET TEMPERATURE OF LARGEST PARTICLE | 550 °C |
| RANGE OF RESULTING SOLIDS FLOW RATES | 7-3250 tons/day |

The total number of tubes in the 5 m diameter FBC was based on a triangular packing geometry and a 50 mm spacing between tubes. The number of tubes and the resulting shale throughput increased with decreasing tube diameter thus reflecting the basic heat transfer limiting nature of the system. The resulting system throughput, tube number, particle residence time and total tube heat transfer area are given in Table III as a function of tube diameter [Du, 1986].

Table III. Design Results as a Function of Tube Diameter

| | Diameters | | |
|---|---|---|---|
| | 10 cm | 20 cm | 35 cm |
| Throughput (tons/day) | 185 | 65 | 35 |
| Number of Tubes | 962 | 329 | 128 |
| Residence Time (hours) | 1.8 | 7.2 | 22.1 |
| Heat Transfer Area ($m^2$) | 3070 | 2010 | 1430 |

These result were next compared to China's Fushun retort in order to assess the viability of this design.

## 3. Evaluation

China's Fushun retort was chosen for comparison with our system because the Fushun retort has been in commercial operation for over fifty years, because there was available operating and design data, and because at the time of this study China was interested in modern oil shale processing technology. The following areas of comparison were investigated: heat transfer limitations, residence time, throughput, feed size distribution, oil yield, heating value of product gases.

Information on Fushun retort was obtained from Du, 1986 and Huo, 1984. A general comparison of the new retorting system to the Fushun retort is presented in Table IV.

Table IV. Comparison to China's Fushun Retort

| Parameters | New System | Fushun |
|---|---|---|
| Heat Transfer Limitation | Reactor Wall Area | Particle Size |
| Shale Residence Time (hours) | 1.8-22.1 | 18 |
| Throughput (tons/day) | 26-187 | 200 |
| Feed Size (mm) | 0-60 | 8-75 |
| Oil Yield (% of Fisher Assay) | 100% | 65-70% |
| Heating Value of Gas (kcal/nm$^3$) | 10,000 | 1,000 |

The two systems were comparable in throughput with the advantages for the new system in a higher oil yield, in a higher heating value gas product, and in higher overall energy efficiency. The advantages in the new retorting system of using low grade coal for heat and the retort's ability to process fines should also have a positive and significant impact on overall operating costs. Disadvantages are higher capital costs for about the same throughput of shale. Also, the new system may be limited in further scale-up because of limitations in scaling up fluidized bed combustors, hence increased unit size may not be possible.

## 4. Conclusions

A new oil shale retorting system was presented which takes advantage of fluidized bed coal combustion as the heat source. The new system provides numerous advantages over older retorts. These include

1. Well established fluidized bed combustion (FBC) technology.
2. High yields of oil and nondilution of the product gas.
3. No combustion losses of oil/gas products. (Indirect Heating)
5. Ease of scale-up to commercial size since the retort is based on FBC.
6. Treatment of fines as well as particles up to about 2 inches in diameter.
7. Good control of solids transport and residence time.
8. Uses low grade coal and pyrolyzed shale as a heat source.
9. Produce steam for electrical and processing requirements.
10. Ease of startup, shut down, and process control.

When compared to the Fushun retort, the new system will give about 36% higher overall oil yields due to separation of combustion and pyrolysis and to the treatment of the fine particles. Also the Also, the proposed system will produce a product that is about 10 times higher in heating value as compared to the Fushun retorts. Estimated throughputs of 200 tons/day compare favorably to the Fushun retort. Capital and operating costs for the new system are estimated to be higher but we believe are more than justified by higher oil yields, higher product gas quality, and the generation of process steam within the retorts.

Design calculations by Du, 1986 were based on a 30 MW fluidized bed combustion unit with an array of vertical reactors. The optimal vertical tube reactor diameter appeared to be about 10 cm. For this diameter tube, a single retort would require approximately 950 vertical reactors. This rather large number of required vertical tubes was necessary to provide sufficient heat transfer area in order to achieve reasonable oil shale throughput.

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