

FLUIDIZED BED COMBUSTION UNIT FOR OIL SHALE PAPER 'II'

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ABSTRACT

A fluidized bed combustion unit has been designed and installed to study the fluidized bed combustion performance using oil shale as fuel in direct burning process. It is a steel column of 18 cm inside diameter and 130 cm height fitted with a perforated plate air distributor of 611 holes, each of 1mm in diameter. Direct observation was possible by a 30 cm long sight piece.

Fluidization experiments were conducted on an oil shale test sample extracted from the El-Lajjun deposit. The pressure drop across the bed was plotted against the superficial air velocity for differently sized particles. The minimum fluidized velocity for each size was obtained. The results show a good agreement with calculated values using Ergun equation which was formulated for coal fluidized bed combustion processes, a new empirical equation was formulated to calculate the pressure drop at fluidization conditions.

Fast and safe ignition of oil shale was initiated using kerosene. Combustion temperatures ranged between 500 to 1000° C.

INTRODUCTION

Oil shale is a sedimentary rock that contains organic matter, mainly kerogen, which is a low calorific value fuel consisting mainly of volatiles and fixed carbon. Some of the organic matter can be retorted and converted into liquid fuel. It is believed that the amount of fuel contained in oil shale exceeds that of the petroleum resources [1].

Oil shale may be burned directly. The most efficient method is fluidized bed combustion. The principle of fluidization is quite simple. Air is introduced into the combustion chamber through a perforated plate at the bottom of the bed. The chamber is filled with the grains (particles) and at a certain air flow rate, the particles in the bed begin to move. The bed is brought to the ignition temperature using hot air or a burner, and the fuel is then introduced into the bed. Solid fuels, liquid and gaseous fuels can be burned in fluidized bed combustors.

Increasing attention is now given to oil shale in fluidized beds. Yavuzkurt *et al.* [1] reported on the steady state combustion of oil shale in a bubbling fluidized bed. It took about 5 – 10 min to bring the bed to a self sustainable combustion, the bed temperature being between 760 and 960° C. They found that, at this temperature range, almost all the sulfur was retained in the ashes, but the carbonate decomposition was very high, and they recommended operating at lower temperatures. Yabushita [2] recorded a combustion efficiency better than 90% when using preheated air at about 500° C.

Azzam [3] and Ahmad *et al.* [4] studied fluidized bed combustion using Jordanian oil shale. Studies on direct combustion of Jordanian oil shale was also conducted by Americans, Canadians, and Germans consultants. The studies showing that oil shale

can be burned efficiently in circulating fixed beds, but economic feasibility has not been established

The objective of the present work was to design, construct and install a laboratory scale fluidized bed combustion unit to study the fluidization and combustion of oil shale.

EXPERIMENTAL APPARATUS

The fluidized bed combustion unit is shown in Fig.1, and consists of a cylindrical steel column of 18 cm internal diameter and 168 cm in length. Air enters the unit through the distributor plate (Fig. 2) which is a steel plate of 6 mm thickness with 611 holes of 1 mm diameter. The section above the distributor is equipped with a heat exchanger. A sight glass 30 cm long and 5 cm wide is provided for direct observation. An overflow pipe is used to control the bed height at 30 cm and a drain pipe to empty the bed. Oil shale is gravity fed to the unit through a hopper fitted with a calibrated gate. The lower section is made conical to minimize expansion losses. Temperature is measured by using six chromel alumel thermocouples. Four are distributed along the bed, one at the lower section and another at the exhaust gas stack. A U-tube water manometer is used to measure the pressure drop through the bed. Air is supplied by a compressor and tank, and the air flow rate is measured by means of a rotameter.

EXPERIMENTAL SAMPLE

The oil shale sample (52 kg) extracted from the El-Lajjun deposit was crushed and screened to different sizes using ASTM standard screens. The oil shale density was measured and found to be 1720 kg/m³, and the calorific value was measured in a bomb calorimeter and found to be 1300 Kcal/kg (5442.0 kJ/kg). The ultimate analysis of the El-Lajjun oil shale, as reported by the Natural Resources Authority, as shown in table 1.

Table 1. Ultimate analysis of El-Lajjun oil Shale

	Range	Average
Moisture content	(3.00 – 5.78 %)	4.39 %
Ash	(52.00 – 57.29 %)	54.68 %
CO ₂ (mineral)	(16.62 – 21.13 %)	18.88 %
Total sulfur	(2.73 – 3.5 %)	3.12 %
C	(12.96 – 16.79 %)	14.88 %
H	(1.41 – 1.87 %)	1.64 %
N	(0.34 – 0.41 %)	0.38 %
O	(1.34 – 2.40 %)	1.87 %

FLUIDIZED EXPERIMENTS

These experiments were performed to determine the minimum fluidizing velocities (U_{mf}) of different sizes of oil shale at room temperature and to inspect the quality of fluidization. For each size tested, a quantity of oil shale was introduced into the bed, the air flow rate was increased and the pressure drop through the bed was measured by the manometer; then the flow rate was decreased to measure the pressure drop in the backward direction. The pressure drop was plotted against the superficial air velocity, and the minimum fluidizing velocity (U_{mf}) was determined. A typical curve

is shown in Fig. 3. The experimentally determined U_{mf} was plotted against the particle size (Fig. 4) along with the values calculated using the procedure suggested by Kunii and Levenspiel [5]. As seen, they are in good agreement and within 10% of the calculated values.

COMBUSTION EXPERIMENTS

Many experiments were conducted to get proper combustion initiation of the oil shale. A butane gas burner inserted below the distributor was used, but the arrangement was found to be dangerous and may lead to explosion. Another butane burner introduced above the distributor did not work. Finally kerosene was used and found to provide uniform combustion of the oil shale. A small quantity of kerosene (about 0.1 liter) was mixed with 4 kg of oil shale of 1.04 mm average particle diameter and ignited inside the bed. The air flow rate was increased beyond minimum fluidization. It took about 1–2 min for the oil shale to undergo combustion, and a temperature from 600 - 1000° C was observed throughout the bed. The only method to get combustion without using kerosene is by using preheated air, which is not practical in this case.

Figure 5. shows a temperature profile along the combustor, temperature ranged from 600 – 1000° C, the highest temperature was at 30 cm above the distribution plate.

Figure 6. shows heat loss profile along the combustor, it is due to heat transfer by both convection and radiation due to high combustor temperature.

ANALYSIS AND CONCLUSIONS

A fluidized bed combustion unit has been designed, constructed and installed to study the fluidized bed combustion of oil shale. The combustor was tested and found to be capable of providing good fluidization quality and burning of Jordanian oil shale, in spite of its low calorific value. The use of kerosene to initiate oil shale combustion is a simple and safe method and requires a short time (1 – 2 min).

Ergun equation for calculating fluidized bed pressure drop is difficult to use, it requires the void volume between particles as input, which is variable with air speed, time and temperature, and not easy to calculate.

An effort in this work was made to introduce a new empirical equation to replace Ergun's and calculate the pressure drop across the fluidized bed for oil shale using bed parameters such as mean particles diameter, D , in meters, m , and bed height, L in m .

Non dimensional analysis and experimental results were used and the following equation was formulated:

$$\Delta P = f(\mu_a, \rho_a, (\rho_p - \rho_a), g, V, L, D_p). \quad (1)$$

$$\Delta P / P_B = A [\rho_a V^2 L / (\rho_p - \rho_a) g D^5] [\mu_a D_p L / \rho_a g V^3]^2 \quad (2)$$

Where: ΔP is the bed pressure drop, P_B is the barometric pressure, A is a constant and equals to 9.3×10^3 , ρ_a is air density, ρ_p is oil shale density, V air velocity, g is the gravity acceleration.

Two non dimensional numbers are used, they can be used for any two phase flow, solid and gas.

First is the number: $[\rho_a V^2 L / (\rho_p - \rho_a) g D^5]$ this represents inertia forces divided by gravitational forces, (buoyancy forces) for solid – gas two phase flow.

Second is the number: $[\mu_a D_p L / \rho_a g V^3]^2$ which represents the ratio between the viscous forces to the kinematics forces for the L height.

Both numbers are new for solid – gas two phase flow.

RECOMMENDATIONS

Additional work is needed to study the effects of the following parameters on the oil shale combustion in order to specify the optimum operating conditions: fluidizing velocity and air-fuel ratio, fuel feed rate, bed temperature and pressure, air preheat, the use of secondary air, the use of inert material inside the bed, and fly ash circulation.

Acknowledgment:

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REFERENCES

1. Yavuzkurt, S., Gutfinger, C. and Dayan, J. *Fluidization*. John Wiley and Sons, New York, 1979, 143.
2. Yabushita, N., Development of Oil Shale Retorting Plant in Japan. Part 1, Construction of the Pilot Plant, 1987.
3. Azzam, S. M. Q., The combustion of low calorific value fuels using a fluidized bed combustor. M.Sc. Thesis, Mech. Eng. Dept., Jordan University of Science and Technology, Irbid, 1993.
4. Ahmad, N. T., et al., World Renewable Energy Congress Proceedings, reading, U.K., 11 – 16 Sept. 1994.
5. Kunii, D. and Levenspiel, O., *Fluidization Engineering*. John Wiley and sons, New York, 1969.

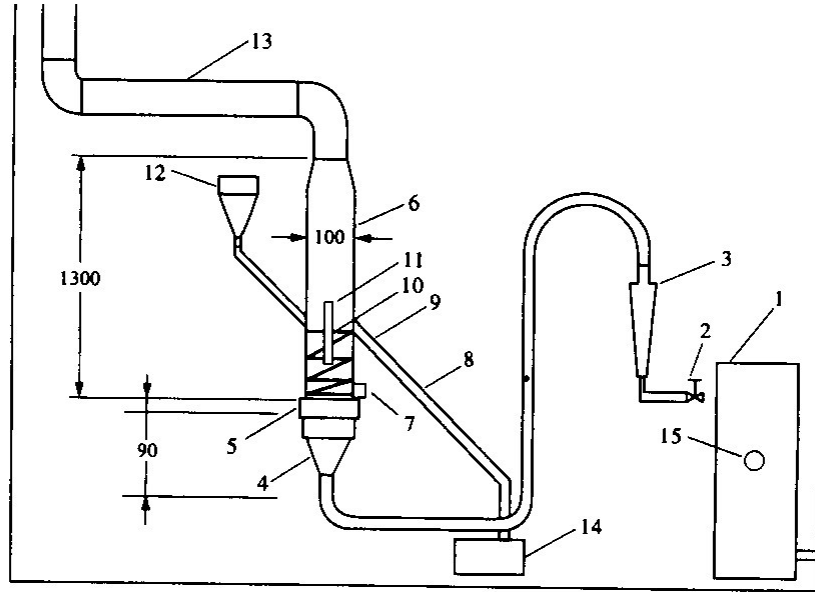
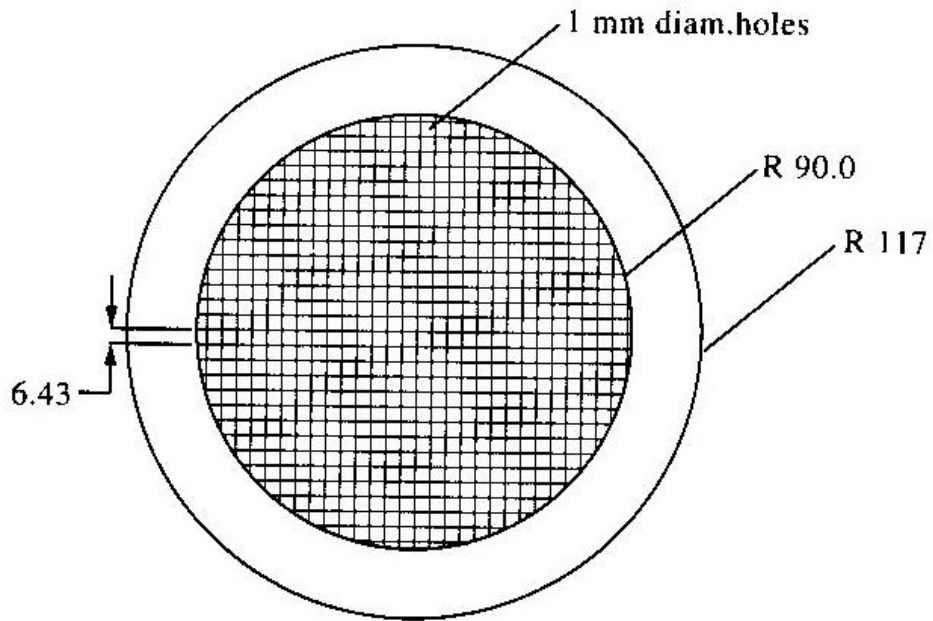


Fig. 1. Fluidized bed combustion unit: (1) air tank; (2) air valve; (3) flowmeter; (4) lower section; (5) distributor plate; (6) bed section; (7) emptying pipe; (8) overflow pipe; (9) sliding gate; (10) heat exchanger; (11) sight piece; (12) feed hopper; (13) stack; (14) ash box; (15) pressure gauge. x: Thermocouple.



Dimensions are in mm

Fig. 2. Distributor plate.

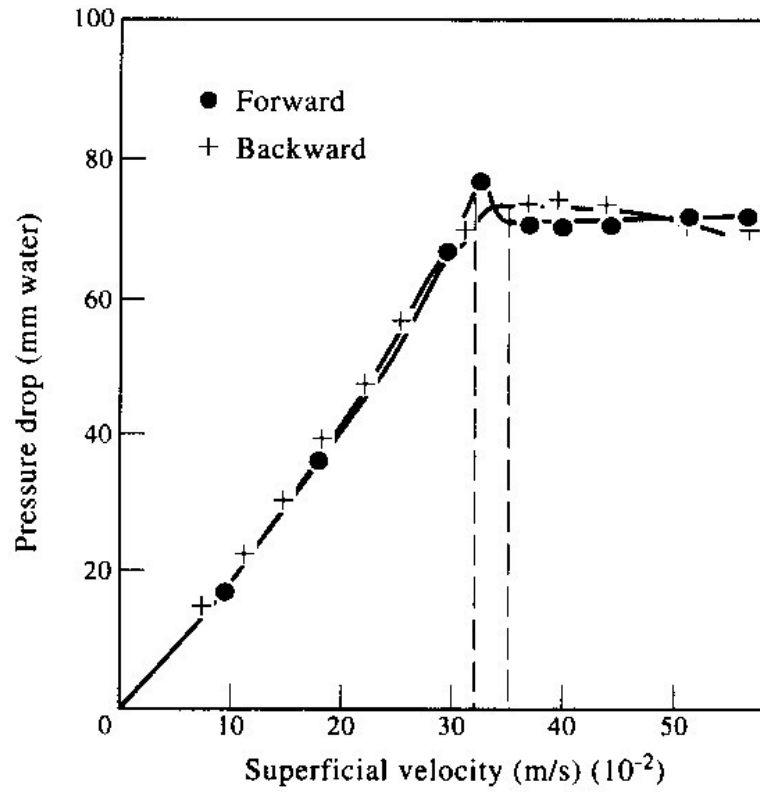


Fig. 3. Fluidization curve for 0.86 mm and 1.7 kg oil shale sample.

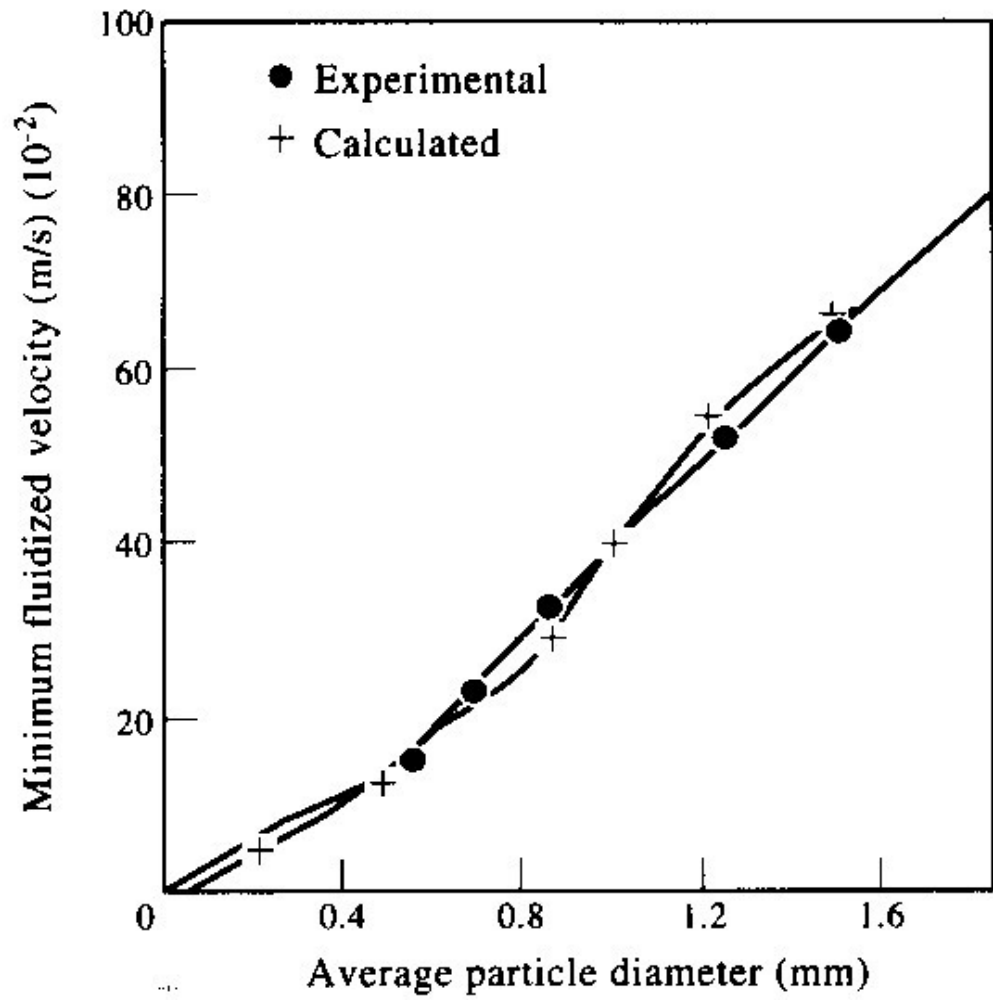


Fig. 4. Minimum fluidizing velocity *vs.* particle diameter

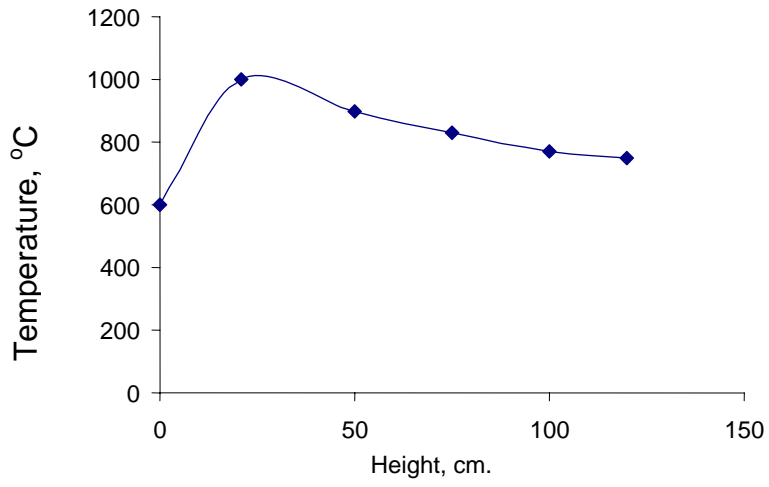


FIG. 5 Temperature profile

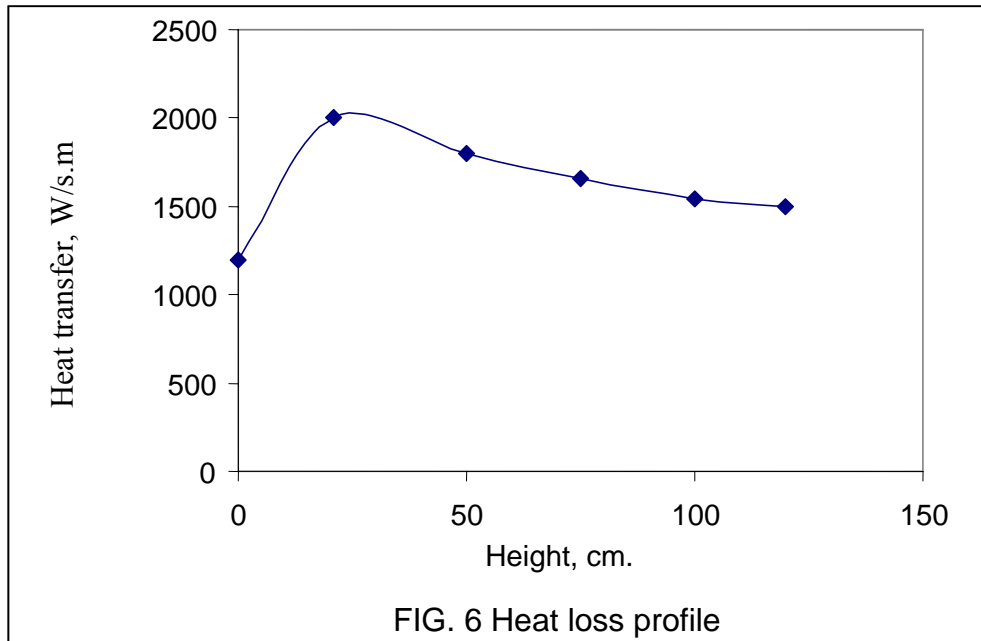


FIG. 6 Heat loss profile