PERFORMANCE STUDY OF A SMALL-SCALE FLUIDIZED BED BOILER

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ABSTRACT

Start-up and performance of 2 MWth fluidized bed boiler burning lignite was studied at two fuel feed rates and at various air/fuel ratio. Bed warm-up operation using premixed gas (LPG+air) method indicated an optimum air velocity at $U/U_{mf} = 1.6$, which gave minimum consumption of LPG. Boiler performance in term of steam production rate and boiler thermal efficiency was found to depend on A/F ratio. The optimum thermal efficiency was found to be 85% and 70% for low (229 *kg/hr*) and high (435 *kg/hr*) fuel feed rates, respectively. Hypothesis was also given to explain the lower thermal efficiency of boiler run with high fuel feed rate.

1. INTRODUCTION

Fluidized bed combustion (FBC) has gained increasing attention during the past two decades due to its reliable combustion performance and in-situ control of released pollutants. Numerous results on various aspects of FBC ranging from laboratory-scale studies to plant trials have published in literatures [1-5]. Atmospheric fluidized bed combustion (AFBC) in particular is already an established technology and has evolved to a state of commercial operation. More than 50 companies offer fluidized bed boilers for sale in 25 countries [6]. Over 300 large-scale AFBC's in a variety of designs are in operation with capacities from 100 MWth to 490 MWth [7].

Owing to the important potential of FBC in the future, a research program has been set up to design and build a multifuel fluidized bed boiler for small-scale industrial use. The general objective of this work is to promote the use of lignite and biomass for energy generation in small industries in Thailand through the application of FBC technology. The boiler plant has now installed at Royal Food Processing Plant in Chiangrai. Plant trials are being undertaken to confirm the design and evaluate the system performance. This paper presents our results on boiler start-up and performance using lignite coal.

2. BOILER SYSTEM

The schematic diagram of the overall boiler plant is shown in Fig. 1. The boiler itself was a standard D-type water tube boiler with the bottom stoker being replaced by a fluidized bed combustion unit. The furnace had a dimension of 1.25x2.65 m^2 in cross section and contained a sand bed of 0.3 *m* in static height. This boiler was designed to produce steam at the maximum capacity and pressure of 3 *t/hr* and 10 *barg*, respectively. Detailed design of this FBC unit is given in Ref. [8]. In brief, the boiler system consisted of four major units as follows:

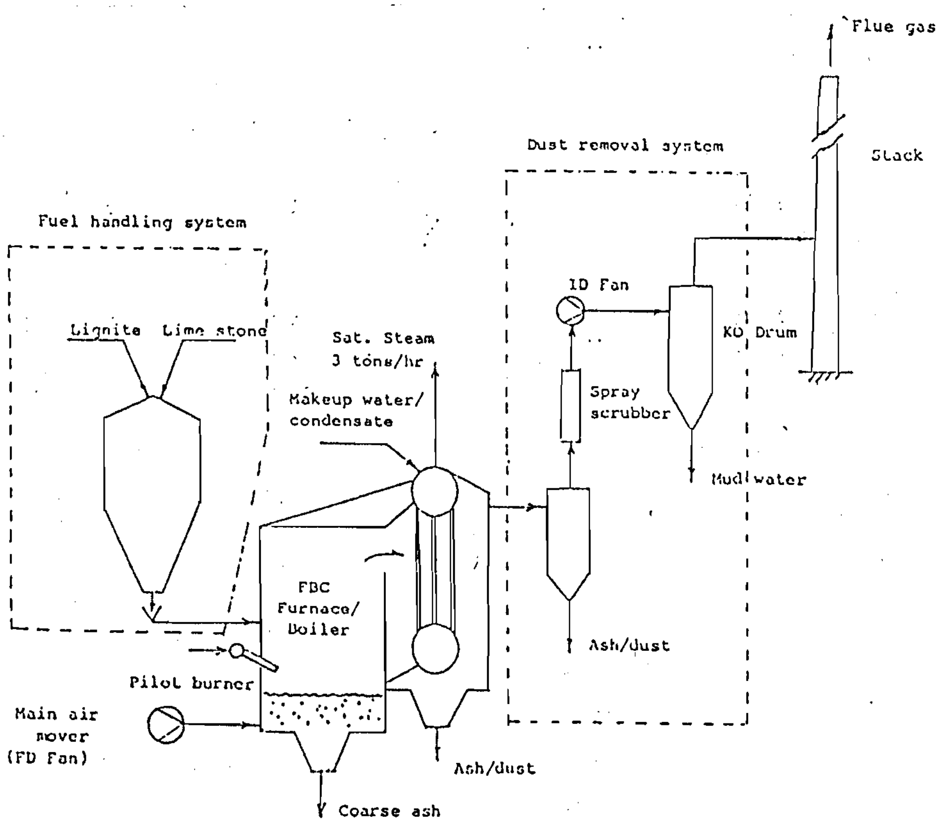


Figure 1 Schematic diagram of the fluidized bed boiler plant.

2.1 The fuel handling system

It was designed to deliver rice hull and lignite separately. A simple magnetic shaker was used to feed lignite onto the bed surface. For rice hull, rotating table was employed to transport the fuel from a hopper to two consecutive screw feeders, by which the fuel was pushed into the bed just below the fluidizing surface.

2.2 *Air movers*

This system consists of a force-draft fan (3000 *scfm*, 40 *in.* H_2O) which was used to supply air for fluidization and combustion processes and an induced-draft fan (3500 *scfm*, -16 *in.* H_2O) which drew the combustion gas from the freeboard and maintained a negative freeboard pressure of about 1 *in.* H_2O. Air was distributed evenly into the bed via an air distributor of sparger type. This type of distributor creates a multispout cyclic motion pattern for good solid mixing within the bed.

2.3 *Emission control system*

The entrained particulates from the bed by fuel gas was controlled by a cyclone followed by a mechanically-induced spray scrubber. Also, heavy fraction of entrained particles was captured in the convective tube bank which acts as a gravity settling chamber. Sulfur dioxide level was controlled by direct addition of limestone with the fuel feed.

2.4 *Bed preheating system*

Bed preheating was achieved by a premixed gas start-up method. In this method, LPG was mixed with the fluidized air prior to distributor outlets and the mixture ignited by an over-bed pilot gas burner.

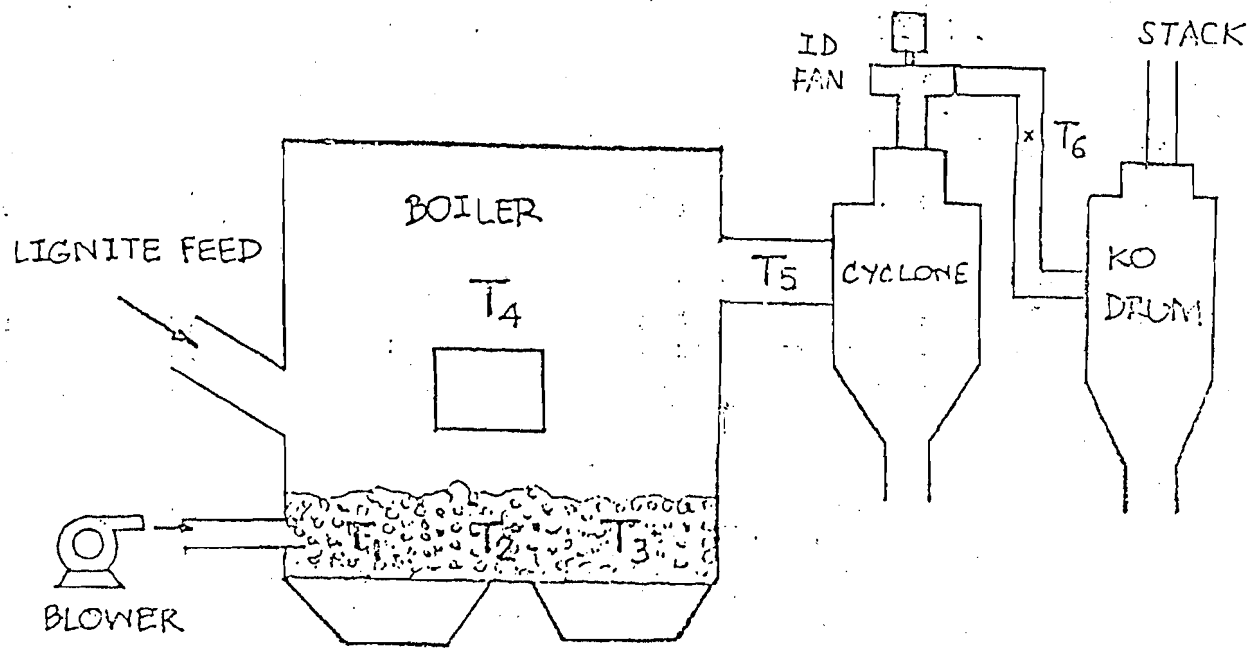
3. EXPERIMENTAL PROCEDURE

During experiments, the fluidized bed boiler was operated under no load condition i. e., steam produced was discharge to the atmosphere. Tests were carried out to collect data for start-up period and for constant air/fuel ratio operation.

For the boiler start-up experiment, the bed was first fluidized by a preselected flow rate of air. LPG (70% propane + 30% butane) was then fed and mixed with flowing air in the distributor tubes and the pilot burner ignited. The inlet LPG pressure was kept constant by a regulator to give a fixed supply rate of 65 *kg/hr* in all runs. Temperatures at various locations, as shown in Fig. 2, were monitored continuously on the charge recorder until the temperature at the bed centre (T_2) reached 350 C (at which lignite is started to batchwise feed into the bed to promote the bed warm-up). The consumption of LPG during the test was determined from the weight change of the gas cylinders.

For boiler performance tests, the bed was preheated to 350 C as outline above. Lignite was slowly added into the bed and maintained at a desired feed rate (435 and 229 *kg/hr* for this study). When the bed temperature rose up to around 600 C, the main gas supply was shut-off. Again, the in-bed and over-bed temperatures were measured until the bed temperature remained constant, usually in the range of 750-900 C depending on air/fuel ratio. Water consumption in the boiler feed water drum was noted to determine steam production rate. Flue gas was analyzed for SO_2 concentration by drawing the gas sample through a gas detector tube. Entrained particulates were captured from the gas sample on the filter paper and their sizes determined under an optical microscope. Bed temperature was also monitored during the boiler shut-off period. The purpose was to examine the rate of temperature drop due to heat loss from the system. This will effect the amount of LPG consumption during restarting the boiler, particularly when the boiler is operated on day-by-day basis.

The properties of bed and lignite used in this study are shown in Table 1 and 2, respectively.



Note:- T_1, T_2, and T_3 are measured at 15 cm above air distributor, while T_4 is 120 cm.
- Insertion length for measuring T_1-T_4 is 50 from front wall.

Figure 2 Locations of temperature measurement.

4. RESULTS AND DISCUSSION

Figure 3 shows the variation of minimum fluidizing velocity (U_{mf}) with the bed temperature. The result shows a nearly linear decrease in U_{mf} with temperature over the range 30-810 C. A reduction of about 25% in the value of U_{mf} is noted over this range.

Table 1 Bed properties

Bed material	Sand particles
Particle size, μm	104-833
Mean diameter, μm	402
Particle sphericity	0.81
Particle density, g/cm^3	2.65
Bed porosity	0.431
Static bed height, m	0.3
Minimum fluidized velocity, m/s	0.11 (33 C, 1 atm)
Terminal velocity, m/s	3.27

Table 2 Fuel properties

Fuel type	Lignite from Lee in Lampoon Province
Fuel size	minus 50 mm
Proximate analysis	
Moisture, %	26.5
Ash, %	16.6
Volatile matter, %	31.3
Fixed carbon, %	25.6
	100
Sulfur, %	1.33
Heating value, kcal/kg	4000
Ultimate analysis	
Carbon, %	39.61
Hydrogen, %	4.83
Nitrogen, %	0.45
Sulfur, %	1.33
Oxygen, %	10.78
Moisture, %	26.5
Ash, %	16.6
	100

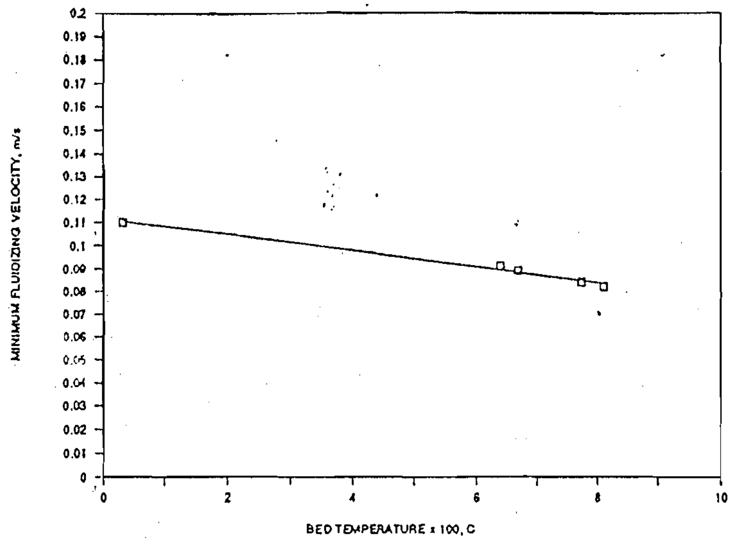


Figure 3 Effect of bed temperature on minimum fluidizing velocity.

The response of temperature during bed warm-up period is illustrated in Fig. 4 . There is a measurable difference in the bed temperature T_1, T_2 and T_3 because premixed gas was admitted into the bed at one side (1/3) of the furnace area. The start-up test was performed to assess the influence of fluidizing velocity on the LPG consumption, as depicted in Fig. 5a. For air velocity varying up to twice the minimum fluidizing velocity ($U = 2U_{mf}$), there appears to be a minimum in LPG consumption (about 45 *kg*) at $U = 1.6U_{mf}$. This optimum in air velocity results

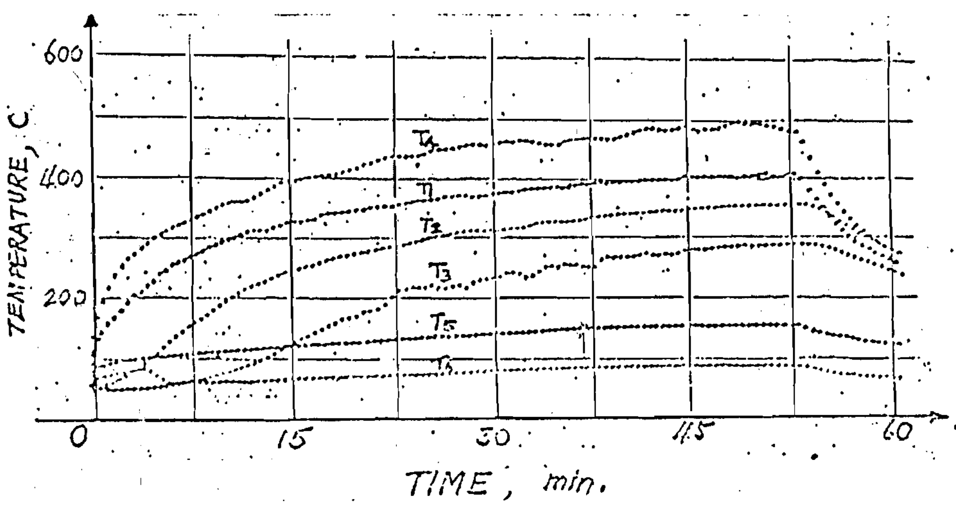
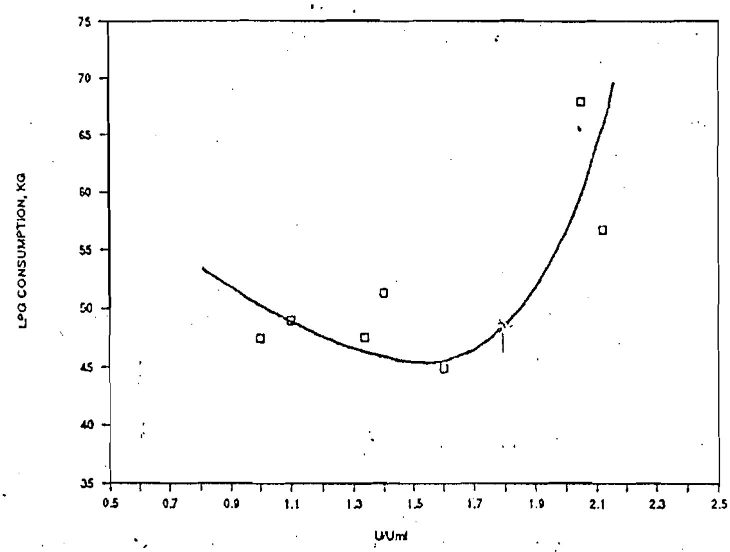
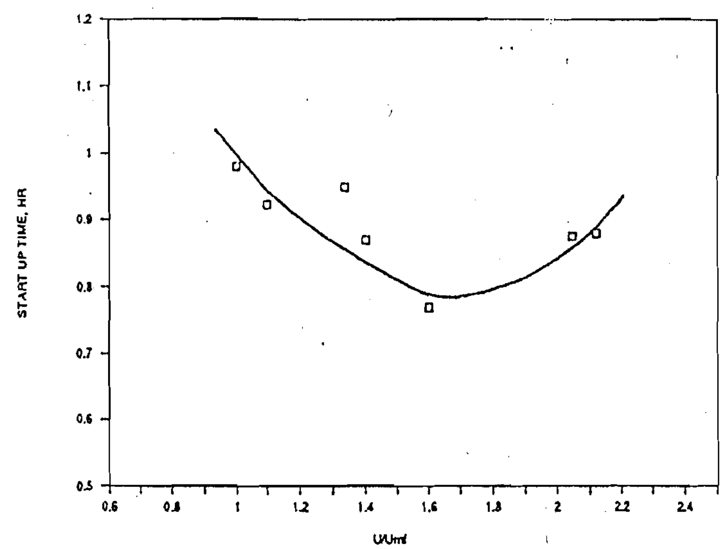


Figure 4 Temperatures inside the fluidized bed furnace during warm-up as a function of time.

from the counter effects of less particle mixing and high heat loss with combustion gas as air velocity is increasing. Fig. 5b shows the warm-up time plotted against U/U_{mf}. Again, the optimum air velocity gave least time (0.77 hr) in heating up the bed to the required temperature of 350 C.



(a)



(b)

Figure 5 Effect of fluidizing air velocity on (a) LPG consumption and (b) start-up time.

Figure 6 indicates typical temperature responses for various periods of boiler operation. They include bed preheating with LPG (period I), period of increasing coal feed (II), period of constant coal feed (III), and boiler stopping period (IV). It took about one and a haft hour to bring the bed temperature up to 850 C. Over these periods (I & II) it is noticed that the freeboard temperature (T_4) was higher than the bed temperature (T_1, T_2 and T_3), indicating a significant over bed combustion of LPG and evolved volatile matters. Period III, in which LPG was shut-off, shows a uniform temperatures in the dense bed and freeboard regions, indicating efficient burning of volatile matter and char in the bed at this high bed temperature. Period IV shows that when the boiler was shut-off the bed temperature dropped to about 400 C within 10 hours. After resupplying the coal into the bed, the boiler was brought into operation without using LPG for bed warm-up. This shows a high thermal storing capacity of the bed, and thus the preheating time is significantly reduced when the boiler is operated on a day-by day basis.

The boiler performance was assessed in term of steam production capacity and boiler thermal efficiency at fuel feed rates of 435 and 229 *kg/hr* and at varying air/fuel ratio (A/F). Figures 7a and 7b showed the results. Figure 7c shows corresponding bed temperature under the same condition. It should be noted that in running the tests no attempt was made to control the bed temperature once the steady state condition had been attained. In this work, bed temperature varied from 750-900 C, depending on the running conditions.

The results obtained shows that A/F ratio had an important effect on the boiler performance. For each fuel rate, there exists an optimum A/F ratio which gives maximum output and efficiency. As expected, the steam production rate increases with fuel supply rate (Fig. 7a). However, Fig. 7b indicates a higher boiler efficiency for condition run at lower fuel rate. The drop in boiler performance is also observed at A/F ratio smaller than the stoichiometric ratio of 5.8 for the case of high fuel feed rate. The possible explanation to this behavior could be as follows. Increasing air flow rate through the bed would increase rate of oxygen transfer to coal particle surface, hence increasing heat generation rate. However, high air velocity would also promote heat loss from the combustion zone. As a result, at sufficiently high air flow rate, the rate of heat loss exceeds the heat generation rate from the combustion process resulting in a drop in bed temperature (Fig. 7c) and hence thermal efficiency. This effect is more pronounced for high fuel feed rate since more air has to be used for a given A/F ratio. If smaller fuel size is used at this fuel feed rate, say particle top size of 10 *mm*, we would expect an improved thermal efficiency and higher bed temperature due to increase surface area of fuel particles and hence burning rate.

The emission level of sulfur dioxide was found to be less than 100 *ppm* for the coal and under the conditions tested. The emission standard set by the National Environmental Board (NEB) is limited at 400 *ppm*. Particle size of entrained dust detected at the stack outlet was found to be in the range 1-5 μm. Particulate concentration was not determined in this work.

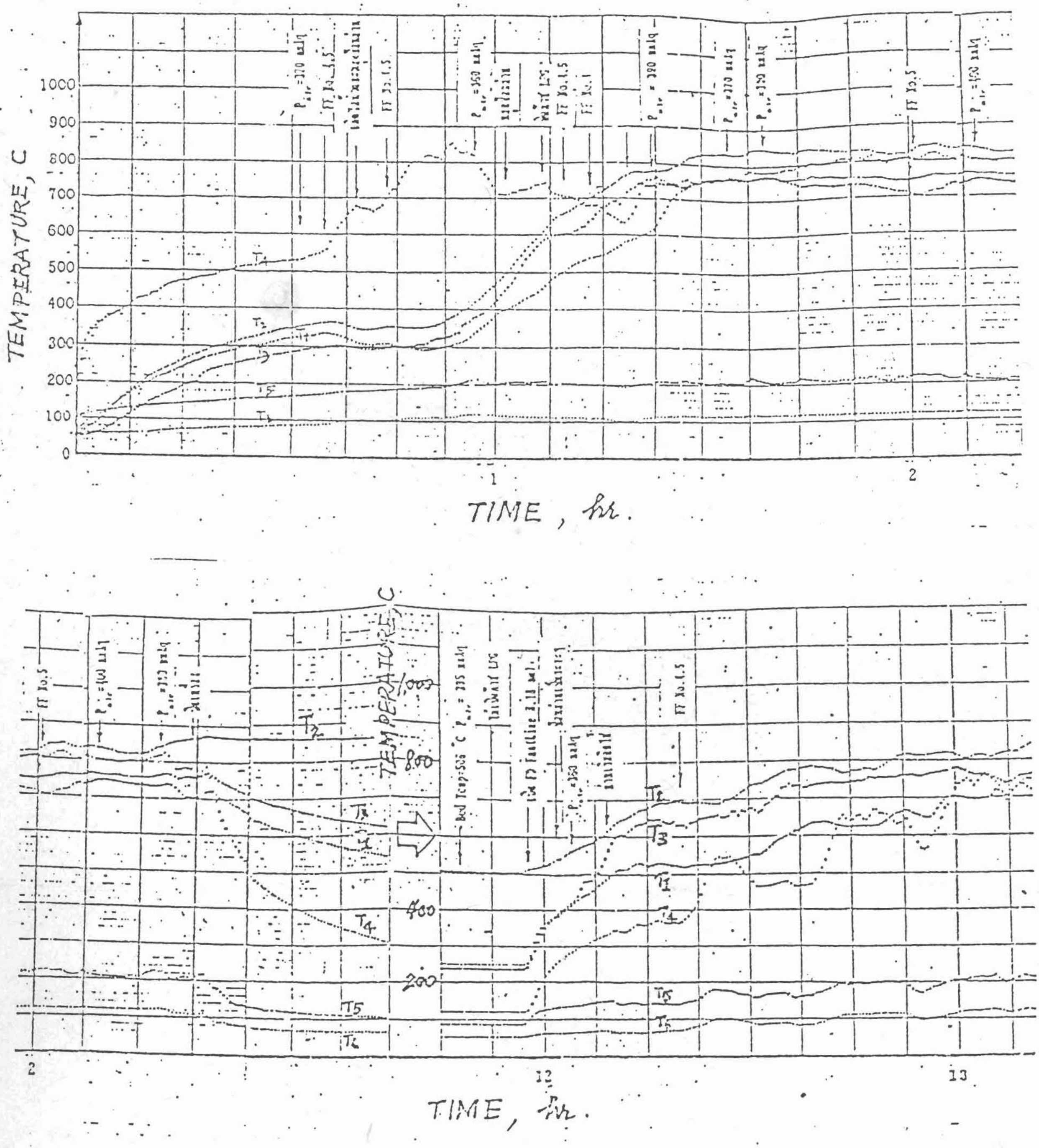
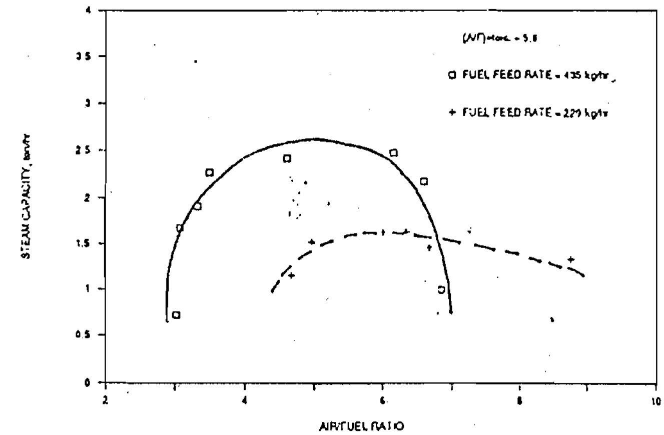
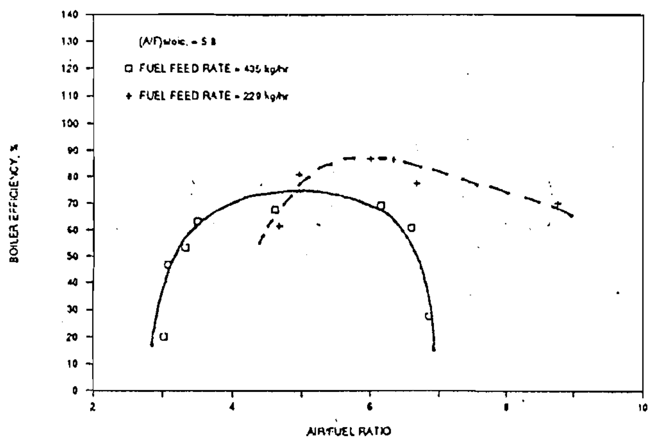


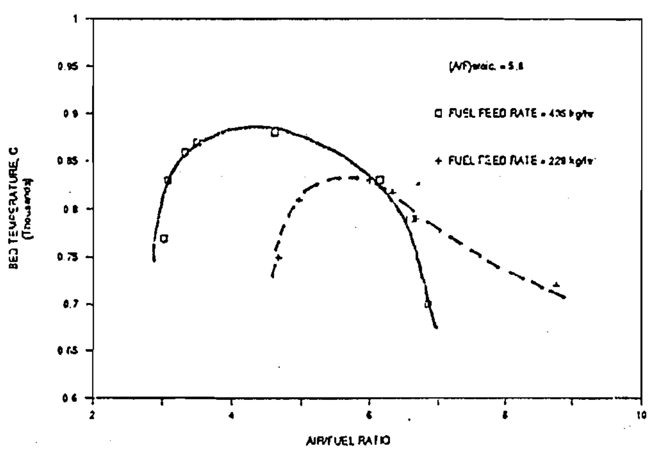
Figure 6 Temperature responses for various periods of fluidized bed boiler operation.



(a)



(b)



(c)

Figure 7 Effect of A/F ratio on (a) steam production rate, (b) boiler thermal efficiency, and (c) mean bed temperature.

5. CONCLUSIONS

The performance of a 2 MWth fluidized bed water-tube boiler was studied using Thai lignite as a fuel. In warming up the bed to 350 C using premixed LPG and over-bed pilot gas burner, it was discovered that there was an optimum fluidized air velocity which gave minimum consumption of LPG. This information is necessary for economical start-up of boiler operation. Boiler performance was investigated to examine the effect of A/F ratio on steam production and boiler efficiency. The drop in boiler performance was observed at A/F ratio smaller than the stoichiometric ratio of 5.8 for the case of high fuel feed rate. This was hypothesized to result from competition between heat loss with flue gas and heat generation from the combustion. It was suggested that further work should be performed on a coal of smaller size range to ensure high burning rate of fuel particles.

6. ACKNOWLEDGEMENTS

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