# FACTORS AFFECTING THE OPERATION OF A FIRE TUBE BOILER

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## ABSTRACT

*Boilers are designed to transmit heat from an external combustion source (usually fuel combustion) to a fluid contained within the boiler itself. The steam, or hot water, must be delivered in the desired condition – with respect to pressure, temperature, and quality- and at the desired rate. For economy's sake, the heat should be generated and delivered with minimum losses. In this paper the effect of the variation of certain parameters on the performance of the boiler system have been investigated, such parameter are the fuel flow rate, the air flow rate, the water flow rate, and the steam pressure.*

## INTRODUCTION

Boilers are directly fired tubular apparatus which primarily convert fual energy into latent heat of vaporazation.Fire tube boilers are principally used in small heating and industrial plants, and as locomotive and portable boilers. In these types of installation, the pressure is usually low. The steam demands are relatively small, and occasionally some superheatedis needed (Shields,1961,Austin,1984).

Fire tubes boilers are relatvely inexpensive. Therefore, wherever they are applicable, the cost of installation, including setting, will be considerably less than for a crorresponding water tube boiler. Design and construction of fire tube boilers are such that there is a definite limit to the size in which it is possible to build them. One advantge, however, is the large water- storge capacity; because of this feature, wide and sudden fluctuation in steam demand are met with only a slight change in pressure.This is due to the accumulator effect of the water- storage capacity. Overload capacity is limited, and exit gas temperature rises rapidly with increased output(Higgines,1976, Jonson,1951).

The objectives of this investigation are to study the effects of the variation of certain parameters on the performance of the boiler system ,such parameters are the fuel flow rate, the air flow rate , the water flow rate, and the steam pressure.

## System Description

The TUBOX package fire tube boiler contains a cylindrical shell with cylindrical internal furnace built into the right of the convection part. It consists of three passes for gases: furnace, fire tubes and smoke tubes. The fuel oil is burned in the front section of the furnace or combustion chamber and the combustion products flow back and enter the rear combustion chamber, then flow through the tube passes to the smoke box and discharge into the chimney. Gases enter forcely in fire tubes due to the pressure difference between the furnace and these tubes. Fire and smoke tubes are used in boiler plant to increase the surface area of heat transfer to increase the overall efficiency of the boiler (Shield,1961,SSBC). The technical data of the boiler used for this investigation are listed in table (1).

Table (1) Technical data of the boiler [SSBC]

| | |
|---|---|
| Steam capacity | 16 ton/hr |
| Steam temperature | 158 °C |
| Steam pressure | 6 bar |
| Feed water temperature | 100 °C |
| Air temperature | 25 °C |
| Water flow rate | 2.8 kg/s |
| Air flow rate | 7.3 kg/s |
| Water volume at normal water level | 14.3 $m^3$ |
| Shell diameter | 2800 mm |
| Shell length | 6150 mm |

The study of the factors affecting the operation of the boiler under investigation was directed at establishing boiler operating conditions and the variation of these conditions with the variation of some input variables from a heat transfer view point and its relation to the operation of the boiler depending on the mathematical model investigated by Haweel, et al 2002.

The boiler system was divided into three interactive zone, namely; combustion chamber zone, fire tubes zone, smoke tubes zone. In order to investigate the effects of the input variables and operating conditions of the boiler, four different input variables were selected due to their relevance to the analysis done in the present work. The selected variables were the fuel flow rate, the air flow rate, the water flow rate, and the operating steam pressure.

## RESULTS AND DISCUSSION

### Effect of Fuel Flow Rate

The general effect of fuel flow rate on the boiler operation is to increase all the temperatures in the boiler, but it mostly affects the temperature of the radiation zone due to the formation of soot which increases the luminosity of the flame. The effect of variation of fuel flow rate on the temperature profiles of flame and gas is shown in Fig. (1) for certain values of air flow rate and water flow rate. It is shown that the increase in fuel flow rate leads to an increase in the temperature of the flame and gas for the whole boiler zones in the range of fuel flow rate studied in this work. Also the rate of heat transfer in all zones becomes higher with larger fuel flow rates. The values of the maximum flame temperature and exit temperature for different values of fuel flow rate are shown in Table (2).

Figure (2) shows the effect of increase in fuel flow rate on the water and steam temperature profile in the various zones of the boiler. It is clear that the increase in fuel flow rate will increase the flame and gases temperature, which results in the acceleration on reaching to the saturation temperature.

Figure (3) shows the steam quality profile in the boiler for different values of the fuel flow rates . The steam quality increases normally along the boiler zones for moderate value of fuel flow rate.The steam quality increase with increase fuel flow rates.

Figure (4) shows that the increase in the fuel flow rate increases the flame temperature in the radiation zone, whereas the flue gas exit temperature seems to increase only slightly with the increase in the fuel flow rate. This means that the excess energy generated by the extra fuel will leave to the steam side.

Table (2) Values of the maximum flame and exit temperature for different values of fuel flow rate

| Fuel flow rate (kg/s) | Max. flame temperature (°C) | Exit temperature (°C) |
|---|---|---|
| 0.1 | 2026.183 | 253.531 |
| 0.4 | 2061.942 | 288.441 |
| 1.0 | 2111.153 | 338.921 |
| 1.5 | 2151.294 | 378.114 |
| 2.0 | 2201.881 | 428.021 |

### Effect of Air Flow Rate

The effect of air flow rate on the flame and gas temperature profile is shown in Figure (5) for a certain values of other variables. It is clear that the increase in air flow rate will decrease the radiation zone temperature due to the dilution of the gas in the zone, which leads to decrease the temperature and luminosity of the flame, therefore the heat absorption will decrease. At the same time, it is shown that the temperature of the flue gases at the exit of the boiler increases when the air flow rate is increasing. Although the heat content of the gases leaving the radiation zone is high, a considerable amount of heat leaving with the gases at relatively high temperature out of the boiler can not be avoided due to the limiting conditions of the heat transfer in the convection zone. The values of the maximum and exit temperature for different values of air flow rates are shown in Table (3).

Table (3) The values of the maximum flame and exit temperature for different values of air flow rate

| Air flow rate (kg/s) | Max. flame temperature (°C) | Exit temperature (°C) |
|---|---|---|
| 2.3 | 2231.190 | 15.981 |
| 7.3 | 2061.961 | 98.121 |
| 10.0 | 1961.131 | 188.920 |
| 12.0 | 1871.024 | 288.030 |
| 16.0 | 1970.814 | 458.914 |

Figure (6) shows the effect of increase in air flow rate on the water and steam temperature profile in the various zones of the boiler. The effect of increase in air flow rate is a dilution of gases and reducing the flame and gases temperature which results in decreasing the heat transfer rate.

Figure (7) shows that the increase in the air flow rate decreases the flame temperature in the radiation zone, whereas the flue gas exit temperature seems to increase only slightly with the increase in the air flow rate, this means that the excess energy generated by the extra fuel will leave to the steam side.

## Effect of Water Flow Rate

The effect of water flow rate at a certain values of fuel flow rate and air flow rate was studied. The general effect of the water flow rate on the boiler operation is to decrease all the temperatures in the boiler. Figure (8) represents the effect of water flow rate on flame and gas temperature profile. It is shown that the increase of water flow rate leads to decrease in the temperature of the flame and gas for whole boiler zones in the range of water flow rate studied in this work. The values of the maximum and exit temperature for different values of water flow rates are shown in Table (4).

Table (4) The values of the maximum flame and exit temperature for different values of water flow rate

| Water flow rate (kg/s) | Max. flame temperature (°C) | Exit temperature (°C) |
|---|---|---|
| 0.5 | 2141.188 | 368.662 |
| 2.8 | 2061.980 | 288.513 |
| 5.0 | 1976.042 | 203.914 |
| 7.5 | 1881.281 | 108.021 |
| 10.0 | 1781.211 | 80.941 |

Figure (9) shows the effect of increase of water flow rate on the water and steam temperature profile in the various zones of the boiler. The increase in water flow rate retards reaching to the saturation temperature due to the decrease in the flame and gases temperature which leads to the decrease in heat transfer rate.

Figure (10) shows the steam quality profile in the boiler for different values of the water flow rates . The steam quality increases normally along the boiler zones for moderate value of water flow rate.The steam quality decrease with increase water flow rates.

Figure (11) shows that the increase in the water flow rate decreases the flame temperature in the radiation zone, whereas the flue gas exit temperature seems to decrease only slightly with the increase in the water flow rate.

## Effect of Secondary Air Temperature and Percent Primary Air

The effect of increasing the secondary air temperature on the flame and gas temperature profile is shown in Figure (12). It is seem that raising the secondary air temperature significantly increases the flame length but has a minor effect on the maximum values of flame temperature. The increase in flame length results from a decrease in the entrainment rate of the secondary air owing to its lower density. The small effect of secondary air temperature on maximum flame temperature is due to the offsetting influences of: (1) heat transfer from the flame which over a greater length should drop the flame temperature, and (2) the sensible heat added to the flame by the preheated air which raises the flame temperature(Gorog,1983).

The predicted effect of raising the percent primary air on the flame and gas temperature profile is shown in Figure (13). Thus, the flame length is seem to decrease with increasing primary air while the peak flame temperature increase. It follows that the reduction in flame length overrides the increase in heat flux in the flame zone resulting from increased primary air.

## Effect of Steam Pressure

The flame and gas temperature profile in the boiler at steam pressure 9 bar is shown in Figure (14). In this figure, it is shown that the increasing in steam pressure of the boiler leads to decrease the temperature of the flue gas exit slightly. The reason is that when the pressure increases, the enthalpy of steam will increase which means that a large quantity of heat will transfer to the water side before leaving the boiler.

Figure (15) shows the water and steam temperature profile in the boiler at steam pressure 9 bar. This figure indicates that increasing the steam pressure of the boiler increases the saturation temperature.

Figure (16) shows the steam quality profile in the boiler at steam pressure 9 bar. In this figure, increasing the steam pressure of the boiler leads to decrease the steam quality. The increase in steam pressure leads to the increase in the velocity of steam as well as to the decrease in the density difference between water and steam, which make the separation of steam and water more difficult and then decreases the steam quality.

Figures (17 to 19) represents the temperature distribution of flame and gases, temperature distribution of water and steam, and steam quality distribution respectively at 3 bar pressure. Reverse effect of decreasing of pressure can be noticed.

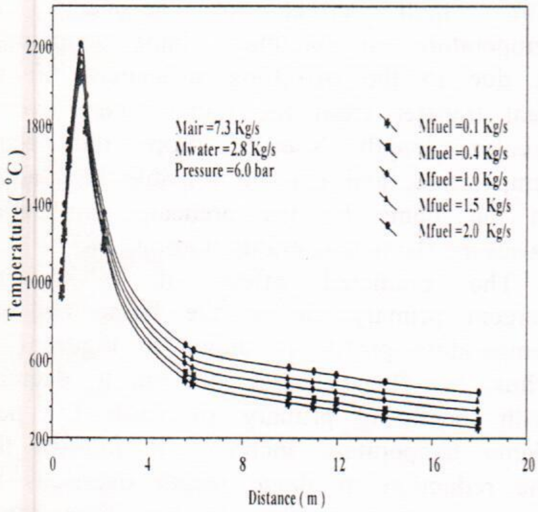


Fig. 1- Effect of Fuel Flow Rate on flame and Gas Temperature Profile

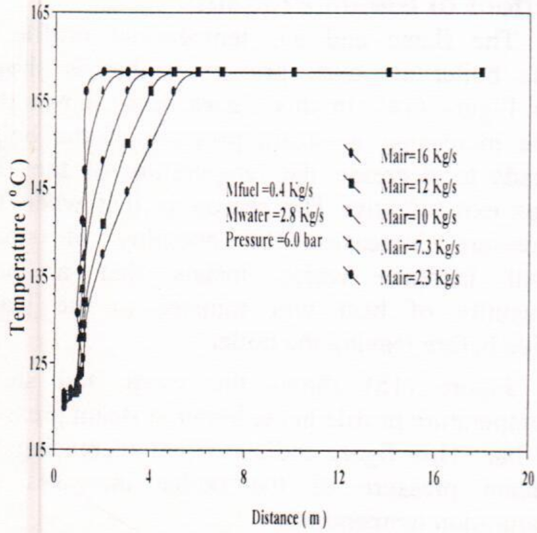


Fig. 2- Effect of Fuel Flow Rate on Water and Steam Temperature Profile

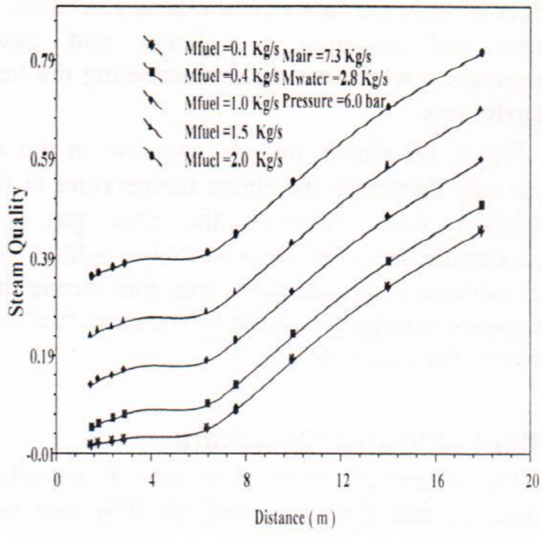


Fig. 3- Effect of Fuel Flow Rate on Steam Quality

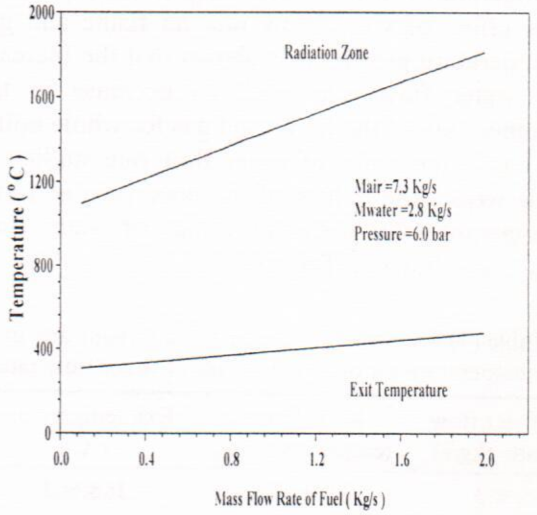


Fig. 4- Effect of Fuel Flow Rate on Radiation Zone and Gas Exit Temperatures

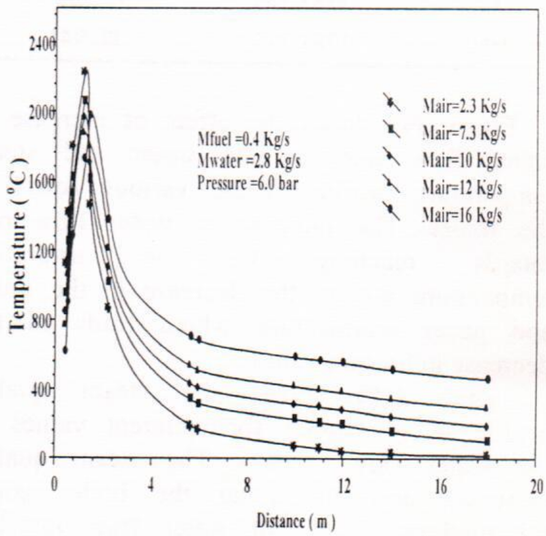


Fig. 5- Effect of Air Flow Rate on Flame and Gas Temperature Profile

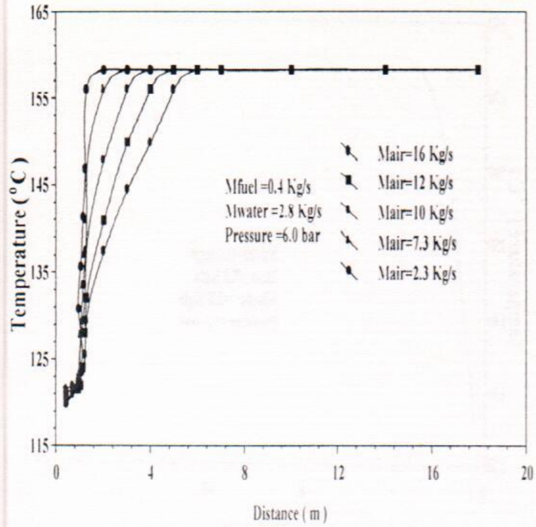


Fig. 6- Effect of Air Flow Rate on Water and Steam Temperature Profile

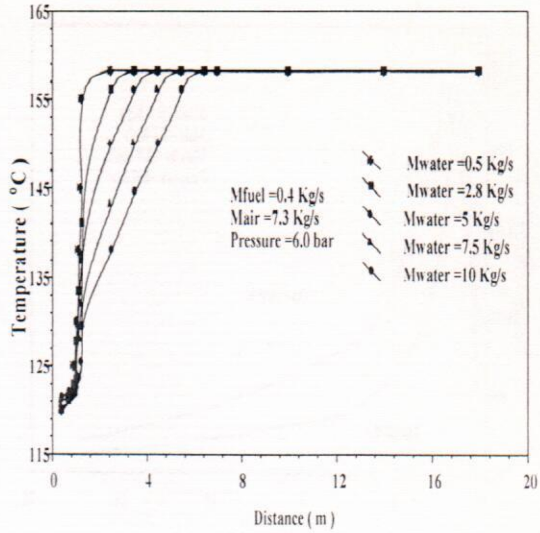


Fig. 9- Effect of Water Flow Rate on Water and Steam Temperature Profile

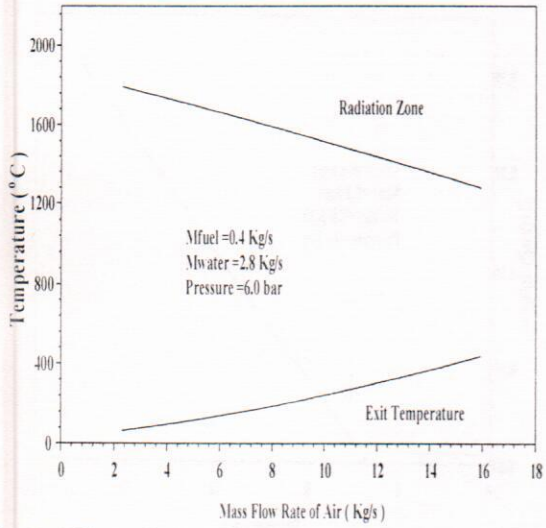


Fig. 7- Effect of Air Flow Rate on Radiation Zone and Gas Exit Temperatures

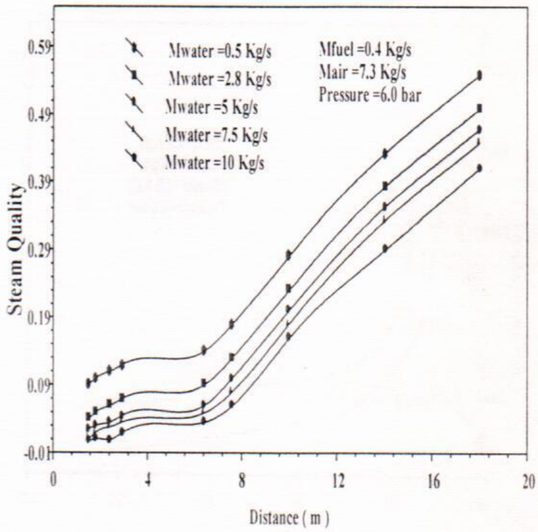


Fig. 10- Effect of Water Flow Rate on the Steam Quality

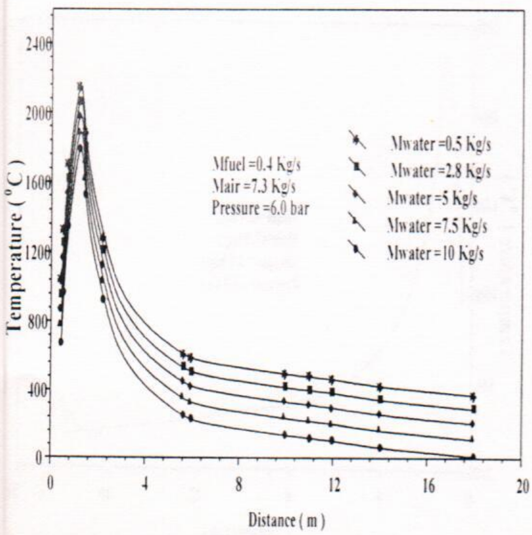


Fig. 8- Effect of Water Flow Rate on Flame and Gas Temperature Profile

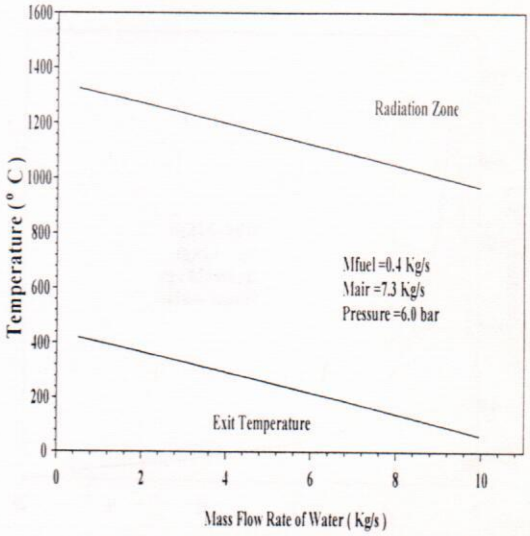


Fig. 11- Effect of Water Flow Rate on Radiation Zone and Gas Exit Tem

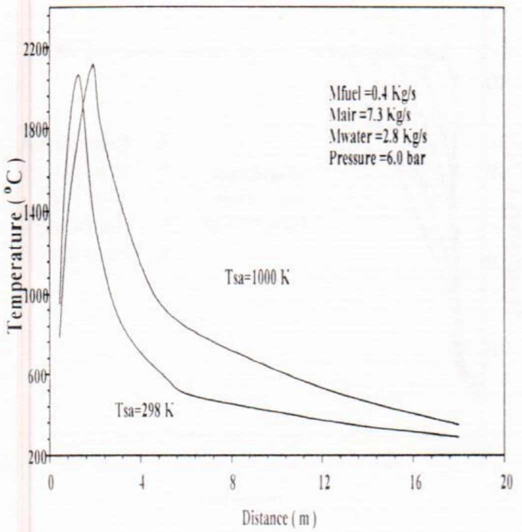


Fig. 12- Effect of Secondary Air Temperature on Flame and Gas Temperature Profile

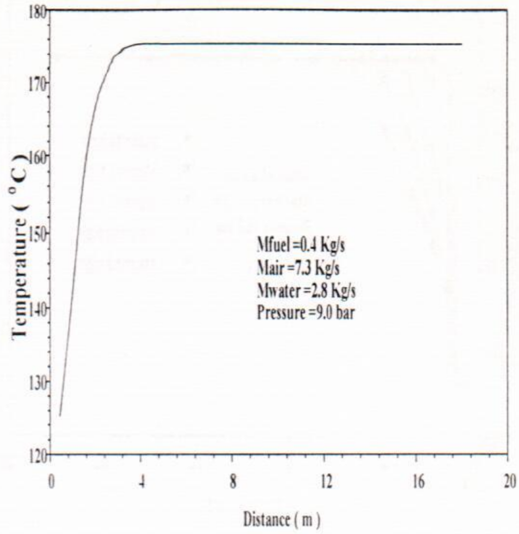


Fig. 15- Temperature Profile for Water and Steam Stream

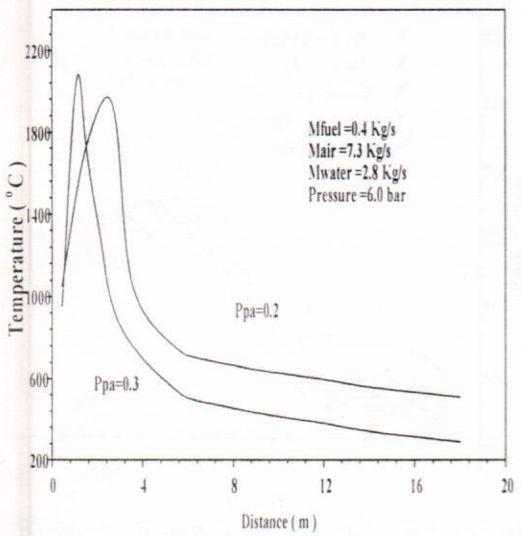


Fig. 13- Effect of Percent Primary Air on Flame Flame and Gas Temperature Profile

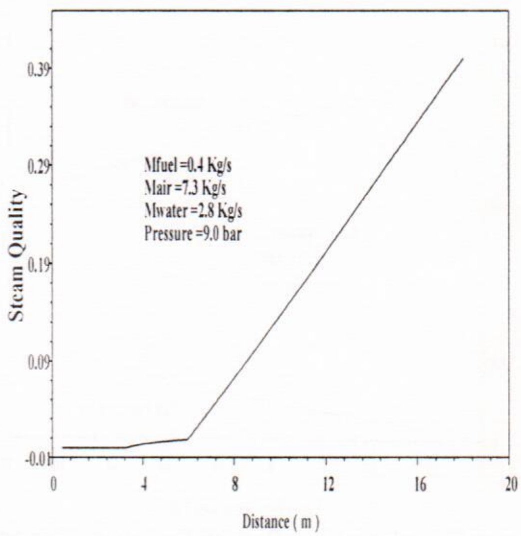


Fig. 16- Steam Quality Profile

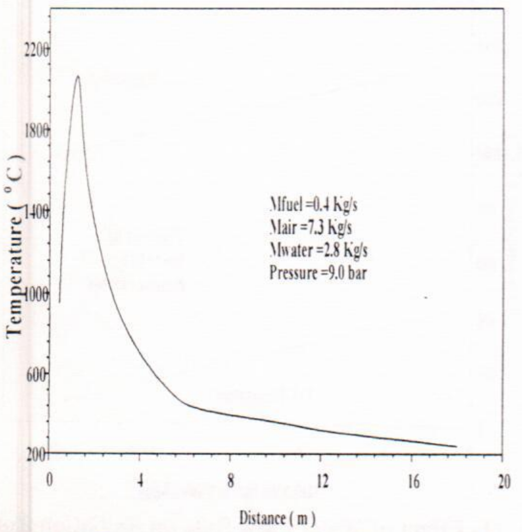


Fig. 14- Temperature Profile for Flame and Gas Stream

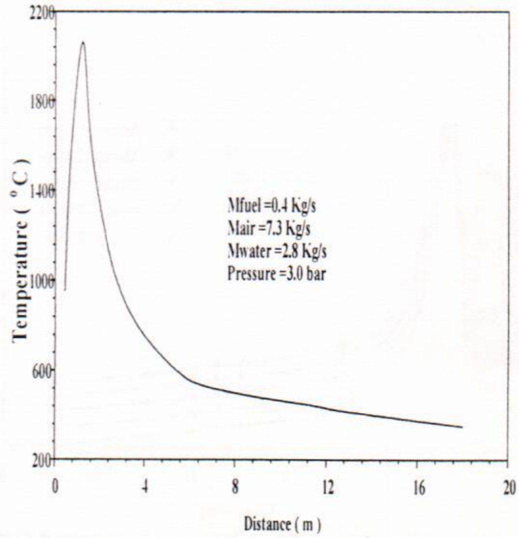


Fig. 17- Temperature Profile for Flame and Gas Stream

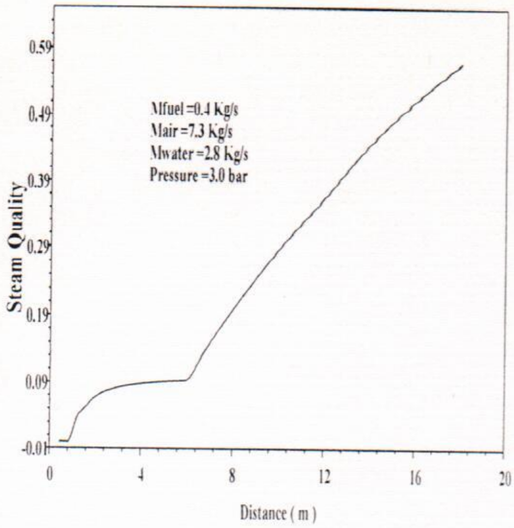


Fig. 18- Temperature Profile for Water and Steam

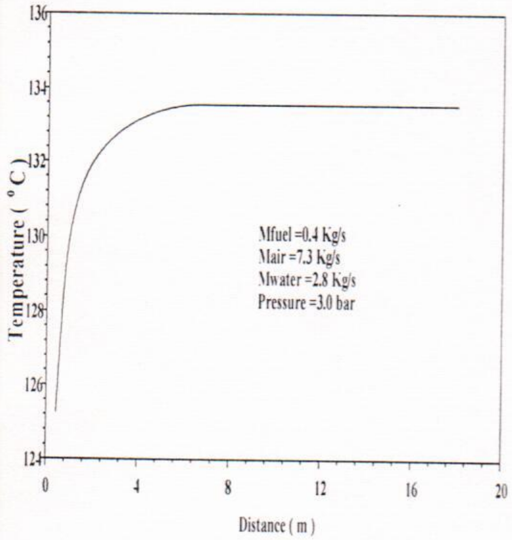


Fig. 19- Steam Quality Profile

## CONCLUSIONS

1. The radiation zone temperature increase with increasing fuel flow rate while it decrease with increasing air flow rate.
2. The increase in air flow rate has a cooling effect on the radiation zone temperature but it causes an increase in the temperature of the gases in the convection zone.
3. The increase in water flow rate leads to decrease in the temperature of the flame and gas for whole boiler zones
4. The excessive increase in fuel flow rate for a constant load of the boiler may lead to the so called the boiling crisis which leads to the tubes failure as result of thermal stresses.
5. The major effect of the steam pressure is to change the saturated temperature of the water with slightly changing the temperature of the gases exit.
6. The increase steam preasure cuase to decrease the density difference between water and steam and then decrease the steam quality.

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