Analysis of Chimney Type Fire Tube Heat Exchanger

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Abstract

Fire tube heat exchangers are widely used in industry for different applications. The high efficiency fire tube heat exchanger is always favorable. Many studies have been done on fire tube boilers, testing its performance under different conditions. In this study analysis of a chimney type fire tube heat exchanger will be analyzed under different air fuel ratios, different tube locations and different tube diameters. It has been found that the heat transfer to water increases by increasing tube diameter, moreover the heat transfer increases by locating tube a part from the fire source as the hot gases become more homogeneous. The multi-tube configuration proves to be more effective than single tube configuration. More investigations are required to optimize the chimney type FTHE specially for multi-pass configuration.

Keywords: Fire tube, Heat Exchangers, Chimney Type, Heat Transfer, Energy Efficiency, Water Heating.

Introduction

Heat exchanger (HE) is a device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly in contact. Heat exchangers are widely used in refrigeration, air conditioning, space heating, power production, and chemical processing. One common example of a heat exchanger is that used in boilers where heat is transferred from the hot gasses out of combustion to the water in boiler tubes. This type of heat exchangers is called fire tube heat exchanger (FTHE). Many studies have been done to investigate the performance of fire tube boilers, most of which to increase the boiler efficiency of decrease the heat losses from the boiler Ref.[3, 4]. Improving the performance of FTHE has great impact on its practical applications Ref [6, 8], the high performance of the FTHE will widen its usage in industry and affect the competition of the market. Many researches have been done to understand the behavior of the FTHE Ref. [1, 2, 5 and 7]. In this paper the performance of a chimney type FTHE is investigated in terms of different parameters, fuel air ratio, tube diameter and distance from fire for both single tube and multiple tubes configurations. The effects of these parameters on the heat transfer to the working fluids were analyzed.

Experimental Setup

A chimney type FTHE was constructed to perform the tests of this study; Figure 1 shows the schematic diagram of the chimney type FTHE with dimensions. The Heat Exchanger (HE) is constructed in chimney configuration; it consists of four holes that accept different copper tube diameters (1 cm, 1.5 cm, 2.2 cm, 2.8 cm) each 24 cm long. Three thermocouples are used to measure the temperatures of water inlet and outlet and the temperature of gas outlet. See (Figure 2)

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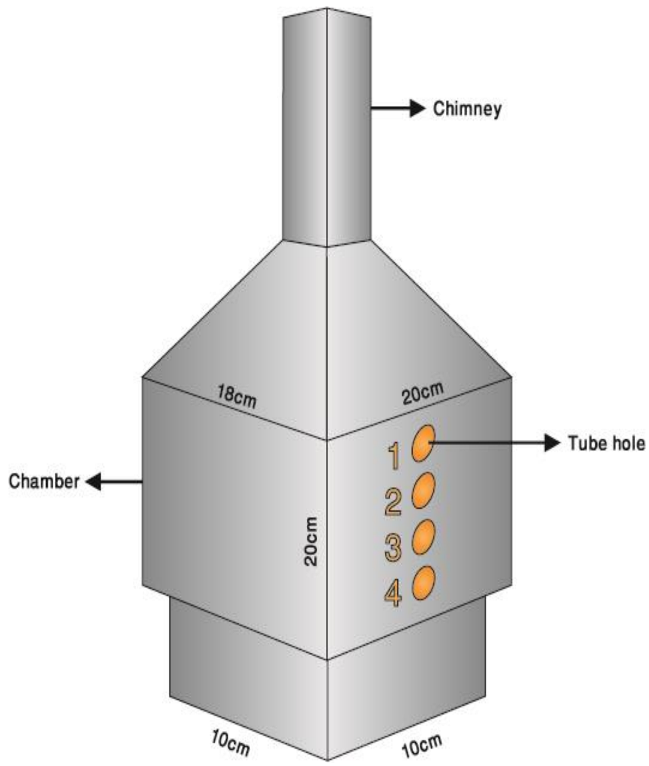


Figure. 1. Schematic diagram of the Chimney Type Fire Tube Heat exchanger with dimensions.

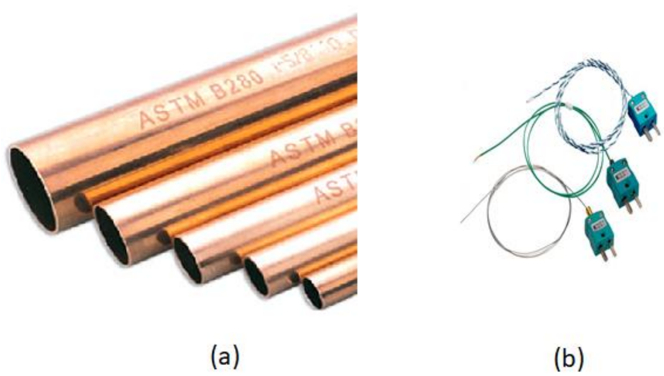


Figure. 2 (a) used copper tubes (b) thermocouples.

The flow meter is connected to the heat exchanger to measure the flow rate of water. The fiberglass insulation covers the chamber to reduce heat loss from the chamber. A Flame Propagation and Stability Unit (FPSU) (Figure 3) is used to produce a flame at different air-fuel ratios to ensure a source of heat. The fuel used is Liquefied Petroleum Gas (LPG) with 50% of each butane and propane composition. See (Figure 3)

Figure. 3. Flame Propagation and Stability Unit.

The plugs are used to close the unused hole. The holes are either closed by plugs to present the single tube heat transfer, or by empty tubes to present the multi-tube nature heat transfer. Different tubes diameters are used to analyze the best heat transfer diameter. The air fuel ratio is varied to obtain the effect of heat supply on the heat transfer to water. Figure 4 represents the test set, with the chimney type FTHE and the FPST unit.

Figure. 4. Actual chimney type Fire Tube Heat Exchanger equipped with Flame Propagation and Stability Unit to control the combustion process.

Experimental Procedure.

To analyze the performance of FTHE the HE is installed and connected with the required diameter tube in the first location of the FTHE chamber. The rest of chamber holes are closed by the plugs to prevent heat losses through the holes. Nest the FPSU is turned on at the required air fuel flow rates to supply the required heat input. After which the water tap is opened at the specified water flow rate and let the water to flow through the pipe. Measures of the water flow rate, the thermocouples temperatures of inlet and outlet water and the temperature of exhaust gases are recorded. The previous steps are repeated for different air-fuel ratios, tube locations, heat input for single tube and multiple tube configurations.

The experimental device (FTHE) design dimensions and experimental parameters are listed in table 1.

Table 1: FTHE design dimensions and experiments parameters.

Chimney Type Fire Tube Heat Exchanger	
The chamber	20 cm width, 18 cm length, 20 cm height
The chimney	4.5 cm width, 4.5 cm length
inlet gas hole	10 cm width, 10 cm length
Air Flow: Glass variable area flow meter	0-0.6 Liters/sec
Gas Flow: Glass variable area flow meter	0-0.2 Liters/sec
Burner Tubes: Four interchangeable steel burner tubes	12.5 mm diameter burner tube
Tube Diameters	1 cm, 1.5 cm, 2.2 cm, 2.8 cm
Holes locations	2.5 cm, 7.5 cm, 12.5 cm and 17.5 cm

The experiments have been performed for different tube diameters tube distance from fire and air fuel ratios as listed in previous table.

Experimental Results

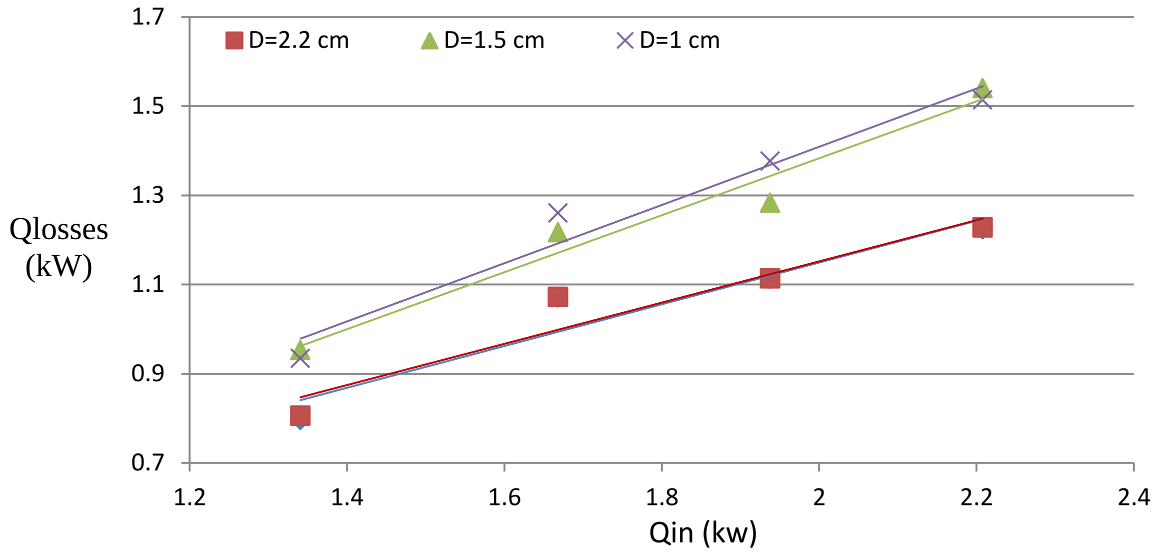
To examine the heat gain by water, heat losses, log mean temperature difference, heat transfer coefficient and Nusselt number the data were taken for each tube diameter and location, a sample data is listed in table 2.

Table 2. Sample Data, Calculations and Results taken from test 1.

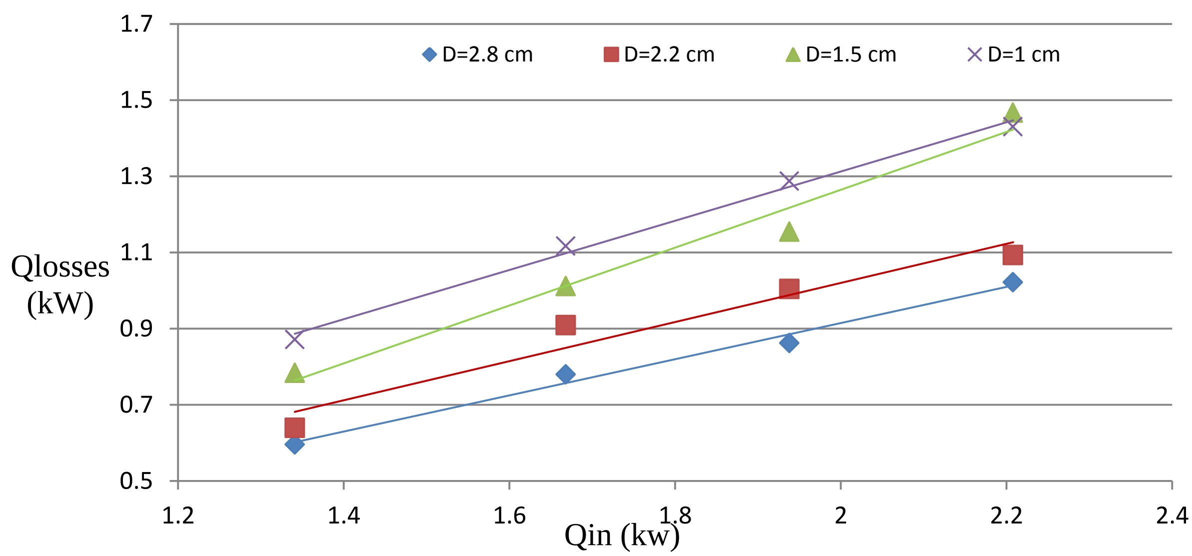
$\dot{m}_a$= 4.2× 10^{-4} (kg/s), $\dot{m}_f$= 2.7× 10^{-5} (kg/s) Tgo(avg)=441 c°										
Tube location	**Twi c°**	**Two c°**	**ΔTw c°**	**Texhaust c°**	**Qexhaust kW**	**Qwater kW**	**Qlosses kW**	**h W/m²K**	**ΔTlm c°**	**Nu W/m·K**
1	18	19.9	2.1	580	0.3254	0.2199	0.7957	24.7	422	1.15
2	18	21.4	3.4	426	0.2359	0.356	0.7491	40.1	421	1.86
3	18	23	5	402	0.222	0.5235	0.5955	59	420.5	2.74
4	18	25.2	7.2	355	0.206	0.7538	0.3812	85.3	419	3.96

Test #1:

In test number one the single tube heat transfer configuration was tested for different tube locations (2.5, 7.5, 12.5 and 17.5 cm from fire), different tube diameters (2.8, 2.2, 1.5 and 1 cm) and different heat inputs ($\dot{Q}_{in} = 1.341\ kW$, $\dot{Q}_{in} = 1.6685$ kW, $\dot{Q}_{in} = 1.938$ kW and $\dot{Q}_{in} = 2.208$ kW).



(a)



(b)

Figure 5. Curves represent the relation between heat losses with heat input to the fire tube heat exchanger for different tube positions (a) position 1, (b) Position 4.

Figure 5 represents the relation between heat losses with heat input to the fire tube heat exchanger for different tube diameters (2.8, 2.2, 1.5 and 1 cm) and for two positions ((a) position 1, (b) Position 4). From these two figures it is noted that the heat losses are greater for small tube diameters and it increases as the heat input increase. The effect of tube position is also noticed from the differences in figure 5 (a) and (b), the heat losses are reduced as the tube is taken a part from the fire source. This behavior is due to the non-uniform temperature near the fire source, it emphasize on the importance of making the hot gases homogeneous before heat is established between the hot gases and the FTHE surface.

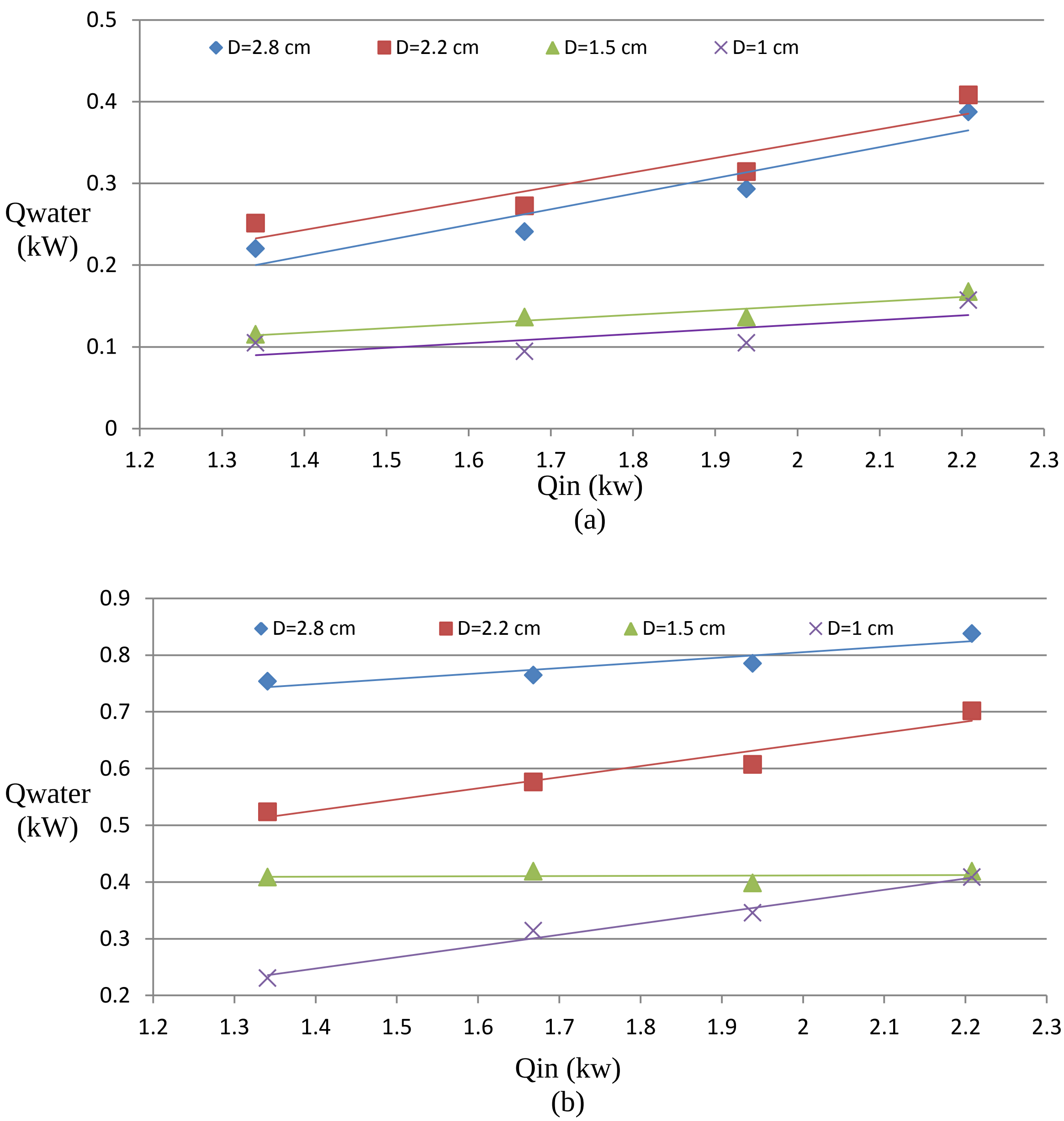
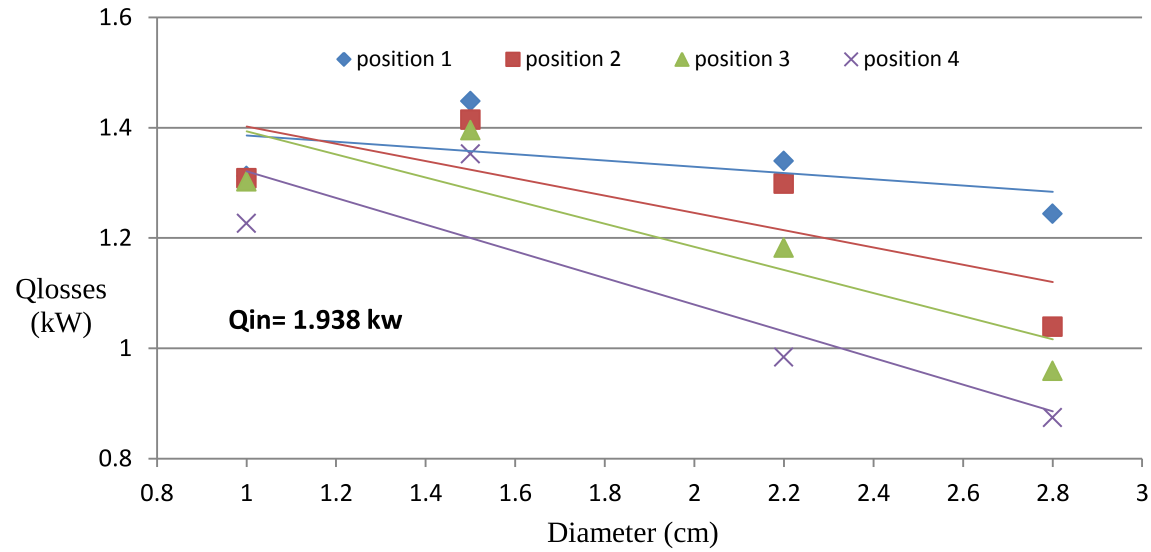


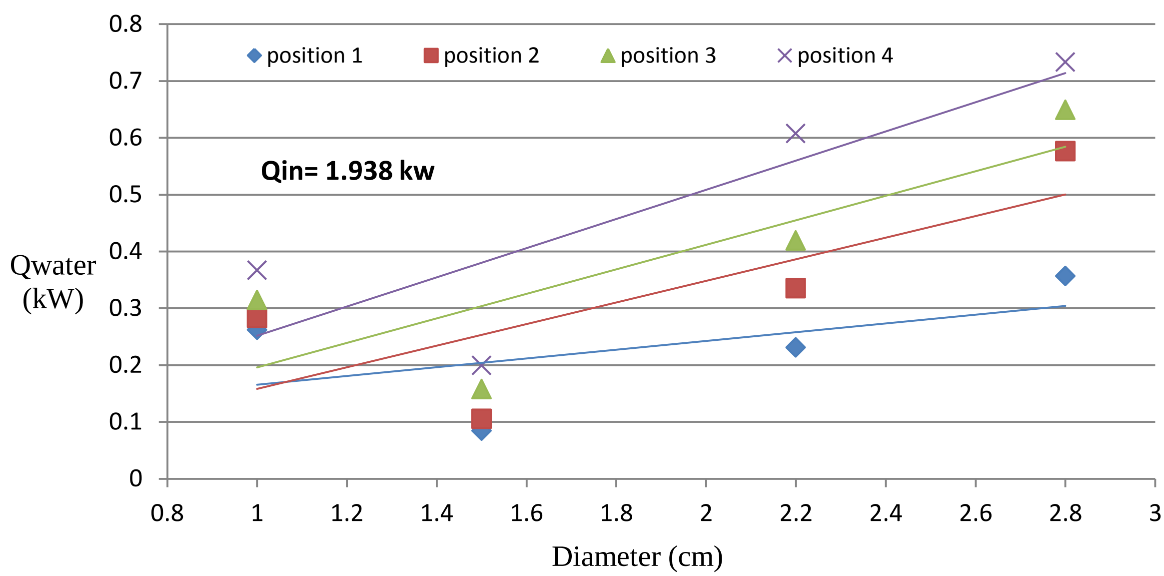
Figure 6. Curves represent the relation between heat inputs with heat transferred to water in the fire tube heat exchanger for different tube positions (a) position 1, (b) Position 4.

Figure 6 represents the relation between heat transfer to water with heat input to the fire tube heat exchanger for different tube diameters (2.8, 2.2, 1.5 and 1 cm) and for two positions ((a) position 1, (b) Position 4). From these two figures it is noted that the heat transfer to water increases by increasing the heat input due to the higher temperature from the hot gasses and its effects on convection and radiation heat transfer. The effect of tube position is also noticed from the differences in figure 6 (a) and (b), the heat transferred to water is increased as the tube is taken a part from the fire source. Higher tube diameter results in higher surface area and thus more heat is transfer to water.

Test # 2:



(a)



(b)

Figure 7. Curves represent the effect of tube diameter on (a) heat losses, (b) water heat gain.

In test number two the multiple tube heat transfer configuration was tested for different tube locations (2.5, 7.5, 12.5 and 17.5 cm from fire), different tube diameters (2.8, 2.2, 1.5 and 1 cm) and different heat inputs ($\dot{Q}_{in} = 1.938$ kW). In this test the plugs are replaced by closed empty tubes to simulate the multi-tube configuration. This multi-tube configuration is expected to make the flow over the tubes more turbulent which may increase the heat transfer to the water inside the tube.

Figure 7 represents the effect of tube diameter on (a) heat losses and (b) water heat gain, for different tube diameters (2.8, 2.2, 1.5 and 1 cm) and different tube locations (2.5, 7.5, 12.5 and 17.5 cm from fire). It is clear from the figure that heat transfer to water increases by increasing the tube diameter and the location of the tube for the same heat input. Whereas the heat losses decreases with increasing tube diameter and decreasing location. Comparing results for the same heat input for single and multiple tube configurations indicates that the heat transferred to water is higher with multi-tube configuration (7.3 kW for multi-tube and 6.7 kW for single tube), this increment is due to the turbulent flow of the hot gases which increase the heat transfer coefficient and make the flow of the hot gases well mixed.

Conclusion

The chimney type fire tube heat exchanger has many industrial applications, especially in industry. The energy of exhaust hot gases from the different manufacturing processes could be recovered using such a chimney type FTHE. The best energy recovery conditions are tracked in this study. The chimney type FTHE with variable tube diameters, variable tube locations and for both single pass and multi-pass type configurations are tested in this study. It has been found that the heat transfer to water increases by increasing tube diameter, moreover the heat transfer increases by locating tube a part from the fire source as the hot gases become more homogeneous. The multi-tube configuration proves to be more effective than single tube configuration. More investigations are required to optimize the chimney type FTHE specially for multi-pass configuration.

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