The Direct combustion of olive cake inside a designed boiler provided by traveling chain bed

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Abstract

In this work an experimental rig was designed and built to burn olive cake directly by using the travelling chain bed method in a conventional water heating boiler. Olive cake was burned inside the boiler under various air fuel ratios, and the boiler efficiency was obtained. Olive cake sample was analyzed, combustion gas products under various air to fuel ratios were also analyzed, combustion gas products under various air to fuel ratios were also analyzed and ash analysis was carried out. The behavior of combustion in the olive cake burning system follows in general the behavior of conventional combustion systems.

The boiler, whose capacity was 30kW. Operated to burn olive cake continuously with a maximum measured flame temperature of 726°C. The work showed that the olive cake may be used as new source of energy in a modern and efficient way. The boiler efficiency achieved was about 90%.

Keyword: olive cake , air fuel ratios, traveling chain bed, maximum measured flame, gas products, conventional water heating boiler.

1. INTRODUCTION

Jordan still depends completely on petroleum as a main source of energy. But the increasing growth of its economy and the fluctuating and the high cost of petroleum, make it necessary to utilize new and renewable source of energy [1-3]. These renewable sources are wind energy, solar energy, oil shale, bio-energy… etc.

One of the renewable sources of bio-energy which has been overlooked is olive cake, called locally, "Jiffet", which is the residue that remains after mechanical extraction of oil from the olives. Kiritsakis (1988) [4], estimated that olive cake constitutes about 13-30% of the total weight of the olive material, and Abu-Qudais and Okasha (1995), [5] reported its calorific value is about 20-26 MJ per Kilogram.

Olive growing is spread over two regions of Jordan, in the west and north-east. According to sources in the Department of Statistics of Jordan [6], the olive growing area (12 million trees) covers 24% of Jordan's total arable surface area, accounting for 74% of the surface planted with fruit trees. The olive tree has always been given special attention and care in this country, as seen in its growing olive acreage, which reached 640 dunums in 2016, (64

000 ha). Average annual olive production over the last five years is of 151 000 tonnes (t), while olive oil production is of approximately 23000t and the average production of table olives is of 27 000 t as shown in figure 1.Another report which is reported by the ministry of agriculture, department of statistical studies (2016) indicates that the local olive cake may be obtained for 25 J.D. per ton. Such a price is considerably cheaper than any other type of locally available fuel [7].

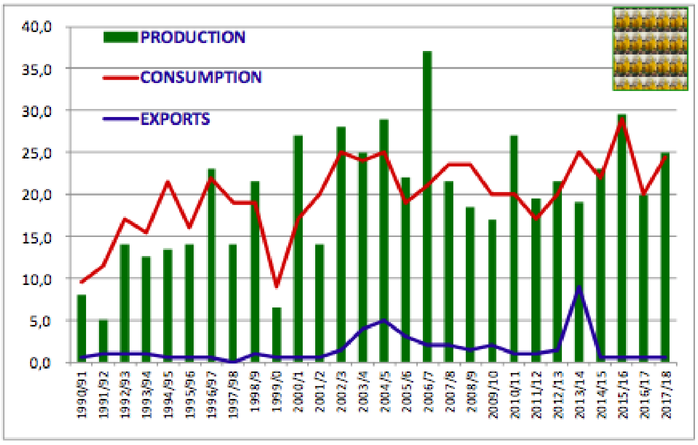

Figure1. Olive oil in thousands Tonnes in Jordan,trends1990/1-2017/18(ref.)

A previous study on olive cake by Hamdan (1994) [8]indicated that olive cake is almost sulfur free which reduces the impact on the environment when it is burned. Further, the same study indicated that the olive cake had rather high calorific value about (25MJ /Kg). The previous work, however, used the method of open fire on a batch- type basis.

This work investigates the utilization of olive cake as a source of energy in boilers using the travelling bed method. In contest with the previous one, this method is of continues burning. Its performance during combustion process, and its pollution impact an environment were studied.

1.2 COMBUSTION OF OLIVE CAKE

Traditionally, olive cake was used as a fuel in open fires. Specifically, it was used as a bed upon which large chunks of combustible are burned. Combustion of a solid fuel of large particle size in general needs a grate at the furnace bottom to hold a bed of fuel. Some from of feeder mechanism places the fuel on the grate automatically. Air enters under the bottom of the grate and passes through holes in it and penetrates the fuel bed. The air mixes with the hot fuel bed as it passes through and releases its stored chemical energy by combustion.

Olive cake consist of mixture of combustion elements, which are carbon, hydrogen, volatile material, traces of olive oil, and a small amount of sulfur which may be neglected. To burn these combustion elements an adequate amount of air should be supplied, and thoroughly mixed with the adequate amount of air should be supplied, and thoroughly mixed with the olive cake. A high furnace temperature should be maintained to ignite the incoming fuel- air mixture, provide enough furnace volume and allow enough time for completing the combustion reaction.

In olive cake combustion process the main problems are associated with fuel feeding, and handling. Air supply has certain requirement which should be considered.

M. Abu Qudais,[9] produced energy from olive cake by using Fluidized bed combustor for energy production from olive cake. Y. H. Khraisha, and et al. [10], used direct combustion of olive cake by means of fluidized bed combustor to conduct the performance of olive cake combustion. Hammad and et al. [11], carried out a simulation study for olive cake combustion. The study was carried out using ANSYS/Fluent software to solve numerically the governing equations of continuity, momentum, energy and mass diffusion using finite volume method. The simulation results show that the adiabatic flame temperature reaches 1270K.

2. COMPUSTION RIG DESIGN

2.1 GENERAL

Although the objective of this work was essentially to develop a method for burning olive cake without specifications the design of boiler but it was found that the burning of this fuel in a boiler is the best way to evaluate its combustion properties. Most small boilers are of fire tube type in which the combustion gases pass through the interior of tubs, the shape of the combustion chamber is a cylindrical or parallelepiped as shown in figure 2.

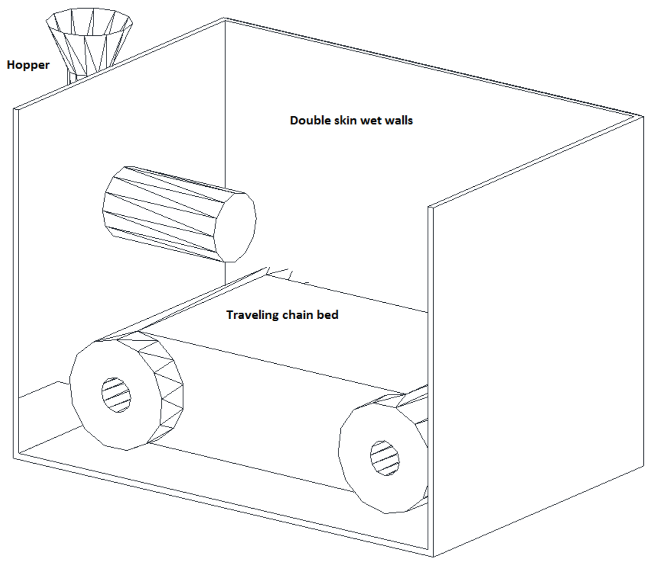

Figure 2. Schematic drawing of the designed boiler

A parallelepiped was chosen here in this experiment for its suitability for traveling chain bed, also the designed boiler is of 30 (kW) capacity which is considered small capacity. However, a chain is used to carry the fuel along the boiler. The width of the chain is 22 cm, and 80 cm. long as shown in figure 3.

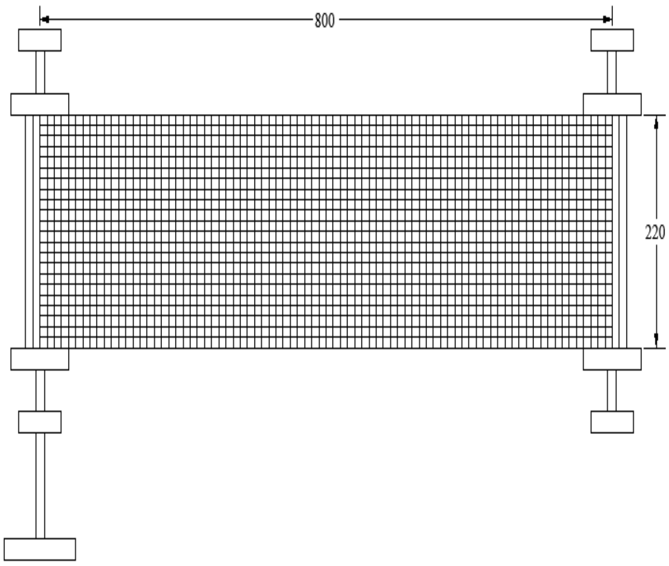

Figure 3. Traveling chain bed with rollers and cups

2.2 BOIER DESGN

The boiler was designed to suit mainly the combustion of olive cake. The traveling bed method was selected for burning this type of fuel because it provides enough time for it to burn. Since it ensure that the surface of the incoming olive cake is ignited from the heat of the boiler flame and from the heat reflected by the boiler walls. The flame and incandescent zone move down through the incoming fuel bed and the ignition plane is indicated such that it intersected with the traveling bed surface. As shown in figure 2.

The incandescent zone extends from the ignition plane beyond which no ash remains on the travelling bed. Also, this method helps in gradual burning and produces moderates ignition temperature. The traveling bed method was mainly selected because it is suitable to hold the particles of the olive cake to prevent them from sliding down towards the bottom of the boiler without being burned.

The walls of the boiler were made to withstand the high temperature of the traveled burnt matrix of the olive cake, therefore the walls were surrounded by water jacket of 5 cm thickness and these walls were made of sheets metal of 1.5 mm thickness.

The water jackets have two functions are removing the excess heat generated by passing cooling water through it, and providing a suitable means for the measurement of the boiler output. Fire tubes also incorporated into the design to provide a proper channel for the fire to be delivered as much as possible away from the screw feeder, thereby protecting the feeder and the fuel inside it from fire. The upper part of the combustion chamber is designed to give enough space to olive cake flame to spread uniformly, this chamber is designed to take a parallelepiped shape because this fits better the travelling chain. Fire tubes also incorporated into the design to provide a proper channel for the fire to be delivered as much as possible away from the screw feeder, thereby protecting the feeder and the fuel inside it from fire.

Ash handing has a great consideration in designing the boiler. The traveling bed method is used to allow the remaining ash to fall in the ash pit which is located in the rear of the bottom of the boiler. After that this ash is collected manually in a suitable box to take it away the boiler site as shown in figure 4. Thermocouples to measure temperatures inside the boiler are located as shown in figure 5.

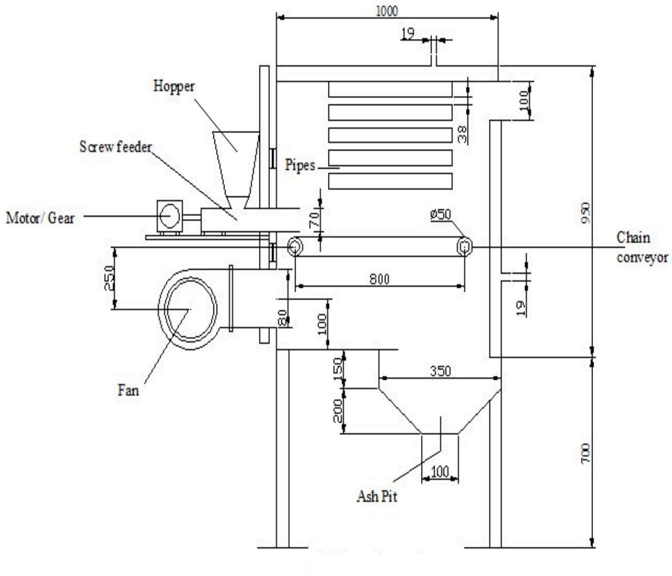

Figure 4. Schematic diagram of the setup, dimensions in mm.

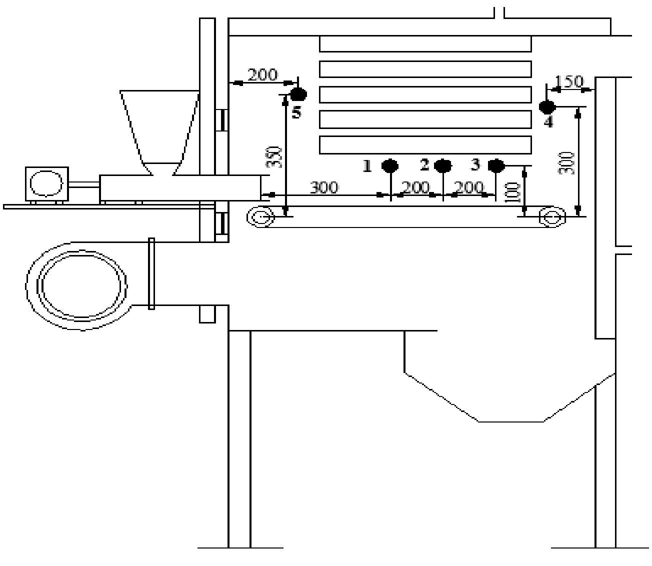

Figure 5. Schematic diagram of thermocouples location, dimensions in mm.

3. DESIGN CALCULATIONS

The heat released from this boiler is arbitrary selected to be 30 KW. The higher heating value of the olive cake used as fuel in this boiler was measured to be about 25,420 KJ/Kg fuel. The fuel rate may be calculated by the simple equation.

$$fuel\ rate = \frac{Boiler\ Capacity}{HHV} \qquad (3.1)$$

Introduction the previous values, the fuel rate becomes:

$$fuel\ rate = \frac{30}{25{,}420} = 0.001181\ Kg/s$$

The chain available in the market has a width of 22 cm. and a length of 80 cm. , then the chain area is A = $22 \times 80 = 0.176m^2$

The rate of heat released per unit is defined by

$$\dot{H} = \frac{Boiler\ Capacity}{Chain\ Area} \qquad (3.2)$$

$$\dot{H} = \frac{30}{0.176} = 170.4545\ KW/m^2$$

Based on this figure of heat released the chain speed is calculated as follows:

Assume that the ignition plane moves in a vertical direction at a speed U_v. Then the heat released may be obtained also by the equation

$$\dot{H} = \frac{\rho_f \times U_v \times A \times HHV}{A} = \rho_v \times U_v \times HHV$$

$$U_v = \frac{\dot{H}}{\rho_v * (HHV)} \qquad (3.4)$$

$$U_v = \frac{170.4545}{0.62 \times 10^3 \times 25.420} = 1.0813 \times 10^{-5} m/s$$

Now assume the ignition plane moves in a horizontal direction speed U_v then

$$fuel\ rate = \rho_f U_h A_c \qquad (3.5)$$

Where A_c is the bed cross-sectional area.

If the bed thickness is t and its width is w then

$$U_h = \frac{Fuel\ Rate}{\rho \times w \times t}$$

$$= \frac{0.0011802}{0.62 * 1000 * 0.22 * 0.02} = 4.33 \times 10^{-4} m\ /s \qquad (3.6)$$

Therefore, the ignition plane moves in an inclined direction with a velocity of

$$U = \sqrt{{U_v}^2 + {U_h}^2}$$

$$U = \sqrt{(1.0813 \times 10^{-5})^2 + (4.33 \times 10^{-4})^2} = 4.33 \times 10^{-4} m\ /s \qquad (3.7)$$

Which is basically the same as U_h. Therefore neglect the movement of the ignition plane in the vertical direction and consider only its movement in the horizontal direction.In this work, for the given $\dot{H}$value, the speed of the travelling chain was in the range of 0.0003-0.0005 m/s , which covers the speed of the ignition plane $U = 4.33 \times 10^{-4} m/s$ found previously.

3.1. CHAIN DRIVER CALCULATION

The chain driver which is composed of the chain rollers, pulley, chain, belt and motor wheel are shown below in figure.6.

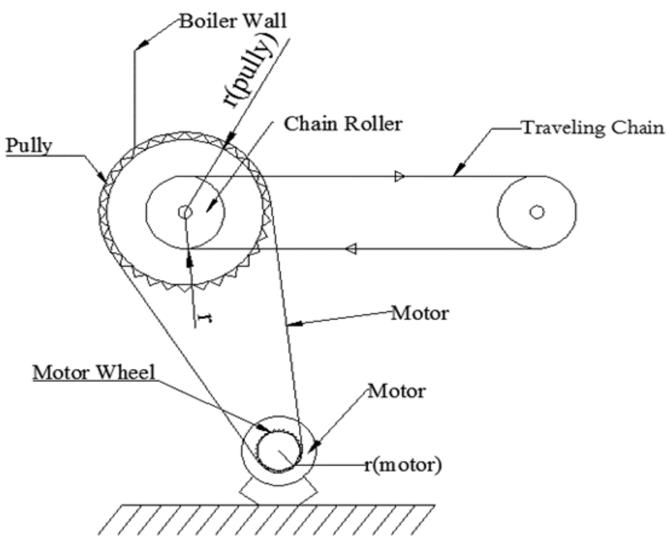

Figure 6. Schematic diagram of chain drive

The chain rollers are selected of 2.5cm radius. Based on the previously calculated chain speed U, the roller regular speed ω is given by

$$\omega = \frac{U}{r} \qquad (3.8)$$

Where r is the roller radius. Hence

$$\omega = \frac{4.33 \times 10^{-4}}{0.025} = 0.01732\,\frac{rad}{s}$$

And the rotating speed of the roller is given by

$$N = \frac{\omega \times 60}{2 * \pi}$$

$$N = \frac{0.01732 \times 60}{2 * \pi} = 0.1654\,rpm \qquad (3.9)$$

The roller is attached to a pulley of diameter D, which is driven by an electric motor via a chain belt. Let the speed of the motor be N_m and the motor wheel diameter isD_m. Hence

$$(\omega r)_m = (wr)_{pulley}$$

$$\omega_m = \omega_{pulley}\frac{r_{pulley}}{r_{motor}} \qquad (3.10)$$

Or putting speed in terms of the rotating speed.

$$N_m = N_{pulley}\frac{r_{pulley}}{r_{motor}} \qquad (3.11)$$

But $N_{pulley} = N_{roller} = 0.1654$ and $r_{pulley} = 10.5\ cm.$ and $r_{motor} = 4\ cm,$

$N_m = 0.01654 * 10.5/4$ =0.4342 rpm.

4 RESULTS AND DISCUSSION

The temperature of the flame inside of the boiler and the concentration of the main pollutants were measured in this work. The reason that the temperature was of interest is that it is in direct relation to the dilution coefficient or the higher the combustion efficiency is the pollutant consternations especially that of carbon monoxide gave an induction on the degree of the complements of the reaction.

4.1. Temperature distribution inside the boiler

The variation of the temperature distribution inside the boiler with air fuel is shown in figures (7) and 8). The general behavior of the curves is that initially as the air fuel ratio increases, the flame temperature increases. However, a certain point will be reached beyond which the temperature drops with the air fuel ratio. This is due to the fact that as the air fuel ratio increases the mixture becomes more lean and hence the temperature decreases

In this work the initial rich conditions were achieved easily, as shown in the figures (7) and (8). However stoichiometric conditions, which are indicated by maximum temperature were not reached due to apparatus limitations.

Figure 7. Variation of flame temperature and air fuel ration inside the boiler

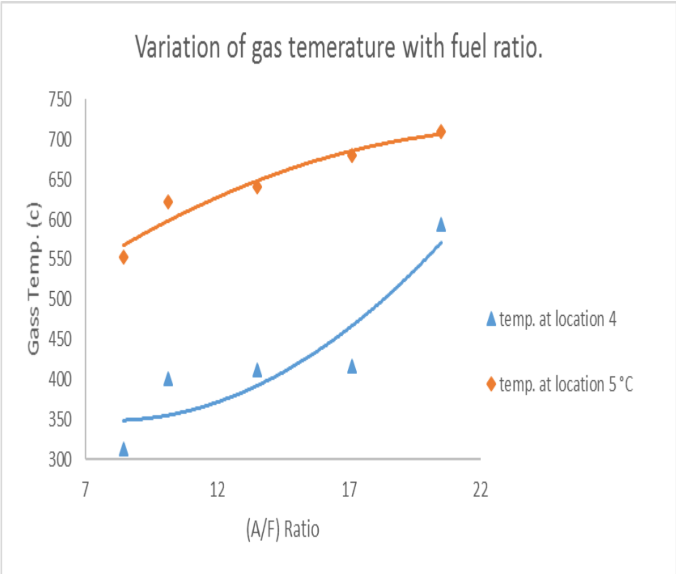

Figure 8. Variation of exhausted gases temperature with A/F ratio

4.2. Effect of air fuel ratio on the temperature distribution inside the boiler

It is clear from figure (9) and (10) below, and for all air fuel ratios, that the thermocouple at location three reads the highest temperature. This is due to the fact that the combustion. Further the minimum was recorded at location two. This contradicts the expected results, which implies that temperature should increase along the traveling chain. This Contradiction is due to the fact that the temperature at this location drops as the relatively cold of air passes this location.

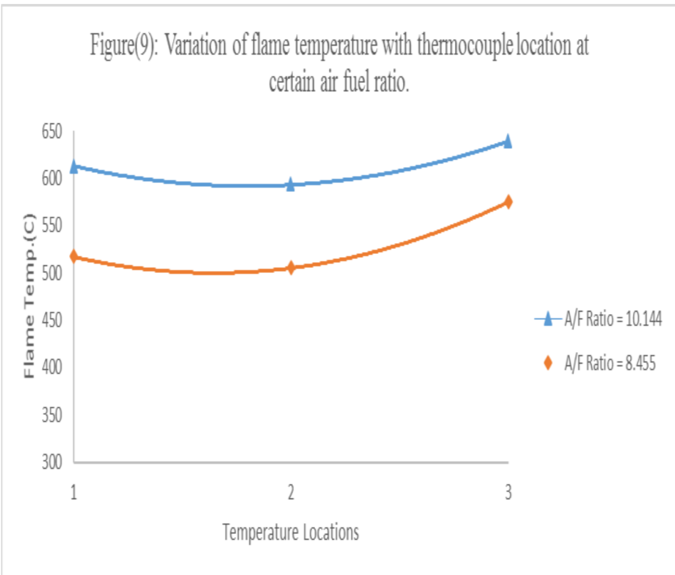

Figure 9. Variation of flame temperature with thermocouple location at certain A/F ratio

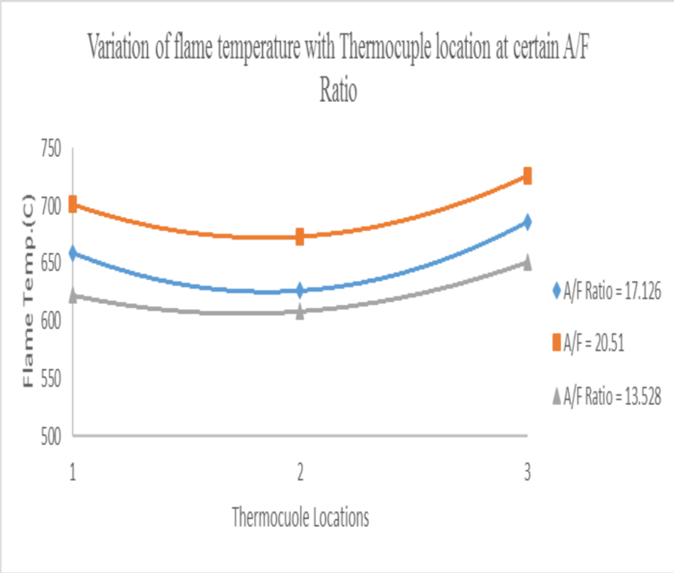

Figure 10. Variation of flame temperature with thermocouple location at certain A/F ratio

4.3 Effect of air fuel ratio and heat transfer and boiler efficiency

As shown in figure (11) both the heat transfer and the boiler efficiency increase with air fuel ratio. This due to fact that as air fuel ratio approaches the stoichiometric temperature within flame is maximized and hence both the heat transfer and efficiency.

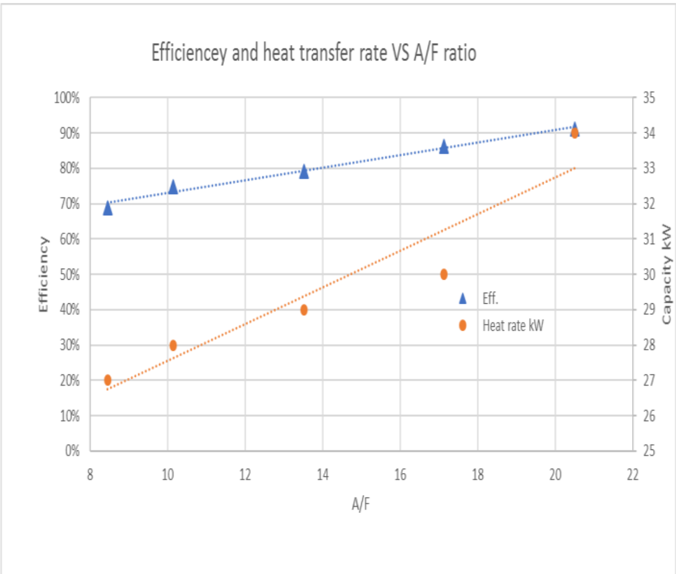

Figure 11. Efficiency and heat transfer rate VS A/F ratio

4.4 Volumetric product concentration of carbon monoxide and carbon dioxide

It is noticed from figure 12 that as the air fuel ratio increase the carbon monoxide volumetric concentration decreases, while that of carbon dioxide increases. This may be explained by the fact, as the quantity of air increases oxygen will react with carbon monoxide to from carbon dioxide.

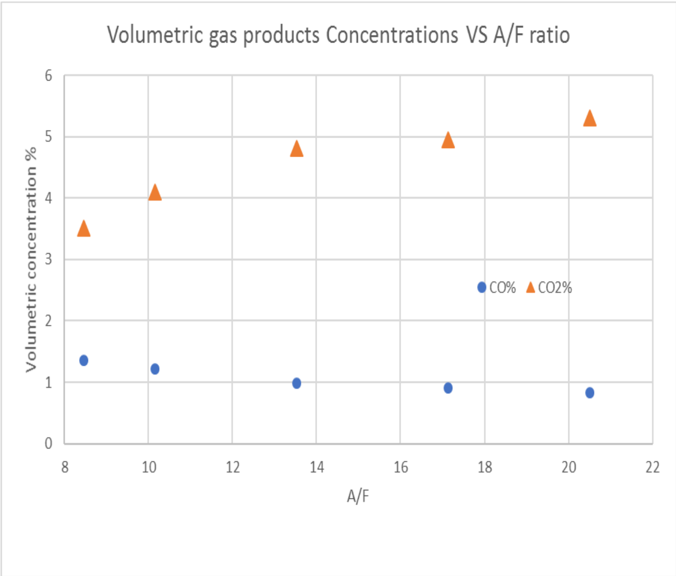

Figure 12. Volumetric gas product s concentrations Vs A/F

5. CONCLUSIONS

The behavior of combustion in the olive cake burning system follows in general the behavior of conventional combustion systems. As the air fuel ratio increases, the flame temperature increases. At a certain point, the temperature drops with the further increase in the air fuel ratio. Similar conclusion may be drawn regarding the boiler efficiency as the air fuel ratio increases, the boiler efficiency increases. From this work, it may be concluded that the designed solid fuel burner was successfully designed, built, and operated continuously to burn olive cake. Boiler Efficiency, a maximum flame temperature of 726℃, and boiler capacity conducted and obtained. Hence olive cake may be used as a new clean and Sulphur free source of energy in Jordan.

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