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DEVELOPMENT OF ENVIRONMENT FRIENDLY KILNS FOR PRODUCTION OF CHARCOAL

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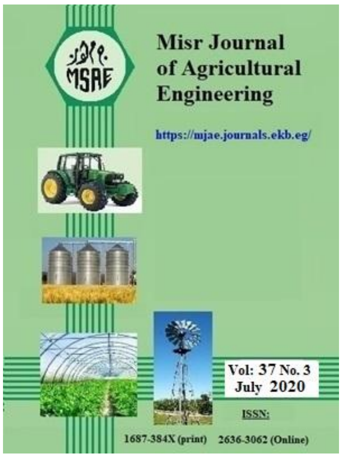


Keywords:
charcoal, kiln, emission treatment, fixed carbon, volatile matter, ash-content.

ABSTRACT

The aim of this study is to develop an environment friendly kiln to reduce emissions and the energy used in the operation of carbonization. The studied factors are two types of wood were used namely "casuarina and citrus" with different moisture-contents of 6.8 and13.1% at pyrolysis temperatures of 300, 350,400 and 450 ^{O}C. The main results in this study can be summarized in the following points: The maximum charcoal yield of 50.38 % was obtained with casuarina wood moisture-content of 6.8 % and kiln temperature of 300 ^{O}C. Meanwhile, the minimum charcoal yield of 32.14 %. was obtained with wood moisture-content of 13.08 % and kiln temperature of 450 ^{O}C. The maximum CO_2 of 17082 mg/m^3 was obtained using emission treatment by burning at kiln temperature of 350 ^{O}C. Moreover, the minimum CO_2 of 2044.8 mg/m^3 was obtained using emission treatment by burning and chemicals at kiln temperature of 50 ^{O}C. The maximum CO of 1859.3 mg/m^3 was obtained without emission treatment at kiln temperature of 350 ^{O}C. Moreover, the minimum CO of 156.9 mg/m^3 was obtained using emission treatment by burning and chemicals at kiln temperature of 50 ^{O}C. The highest charcoal production–cost of 9.84 L.E./kg of was obtained by using "burning + chemical" emissions-treatment at kiln temperature of 450 ^{o}C and moisture content of 13.08 %. Meanwhile, the minimum production cost of 3.21 L.E./kg was obtained by using burning emissions-treatment of kiln temperature of 300 ^{o}C and moisture content of 6.8%.

INTRODUCTION

Charcoal is a solid bio fuel obtained from biomass by means of a chemical process known as "pyrolysis" or simply as "carbonization process". Charcoal consists of the thermal decomposition of biomass in the absence of oxygen. Egypt rank 11th level in the world in the charcoal exportation. Exporting of charcoal adds about 11 million dollars to Egyptian income. There are about 5000 traditional earth-mound kilns in different places of the Egyptian governorates, which have about two million workers. Seventy percent of charcoal which produced from fruit–wood exported to Arab countries and the other 30 % of charcoal exported to Europe and Asia **(Ministry of Environment, 2015).** Egypt produces about 1.445 million tons of charcoal. About 1.425 million tons of charcoal were consumed by a local market. About 21 million tons were exported (**FAO, 2017).**

Foley et al. (2001) reported that the ash content of high-quality charcoal was reported between 0.5 – 5 %, resulting in a range of thermal values between 28 - 33 MJ/kg. **Kaale (2005)** found that charcoal has a higher thermal value per unit weight of firewood of about 31.8 MJ/kg of fully carbonized charcoal with a moisture content of about 5 % compared to about 16 MJ/kg of firewood with moisture content of about 15 % on a dry basis. **Delmas et al. (1991)** reported that emissions from natural charcoal production increase about 10 times higher than standard wood burning. **Gomaa and Fathi (2010)** measured the temperature of the carbonate operation based on a percentage of the products of combustible gases. It was found that the analysis of the advanced gases was: CO: 25 %, CO_2: 15 %, O_2: 5 %, CH_4: 4.5 %, H_2: 2 %, C_2H_6: 1 %, N_2: 47.5 %. **Mugo and Gathui (2010)** evaluated four types of kilns are mainly used in charcoal production, these include; traditional earth kilns efficiently 10 – 15 %, improved earth kilns 24 – 30 %, construction kilns 28 – 30 % and metal kilns efficiently 19 – 30 %. The financial potential of the charcoal product and kilns ability directly affect the choice of the kiln used.

Keita (2010) found that the value of wood heating in general is about 3500 kcal/kg for green wood and 4500 - 4770 kcal/kg for dry wood. Charcoal, however, the heating value near 7500 kcal/kg. **Reumerman and Frederiks (2012)** defined the traditional production process in open pit or furnaces, as implemented in rural areas, is ineffective. Weight efficiency of 10 – 15 %, 7 - 10 kg of wood to produce one kilogram of charcoal. Depending on the sustainability of timber used in the charcoal industry, emissions of greenhouse gases emitted into the atmosphere may be large at the global level. Emission gases in year 2018, which produced from charcoal, were about 250.7 million ton of carbon dioxide **(CAPMAS, 2019)**.

The emissions of traditional charcoal kilns and the pyrolysis of wood cause an excess methane (CH_4) and carbon dioxide (CO_2) and the concentration over average ambient air is about 12 % **(Adam., 2009).** The traditional charcoal-kilns have some disadvantages such as more energy consuming, needing more carbonization-time, and producing more emissions, therefore, the aim of this work is to develop a kiln for charcoal production with high charcoal quality, less cost and low emission.

MATERIALS AND METHODS

Designed kiln for charcoal production: Figs. 3.1 and 3.2 show the photographs, isometric and views of designed kiln. The designed kiln consists of the following parts:

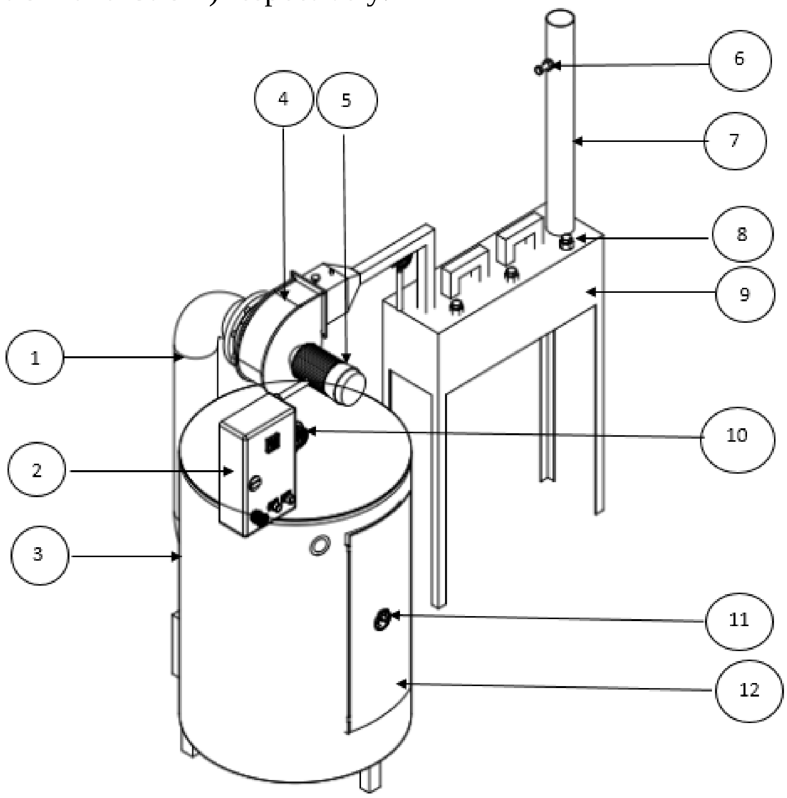
The main frame of the designed kiln was made of steel sheets with 3 mm thickness. The main frame consists of three parts:

(a) Charcoal production-unit body: the charcoal production-unit has height of 105 cm and diameter of 75 cm. The main frame consists of two parts:

1- Carbonization chamber: The carbonization chamber consists of two internal cylinders with a diameter of 65 cm and an external cylinder with 75 cm diameter with height of 80 cm. There is a rock wool (isolation) layer with 10 cm thickness between two cylinders to prevent the heat transfer between them.

2- Fire chamber: The fire chamber consists of internal and external cylinders with diameters of 65 and 75 cm with height of 20 cm. A rock-wool (isolation) layer with 10 cm thickness was installed between the two cylinders to prevent the heat transfer between them

(b) Processing unit control-unit body. The processing unit has length of 75 cm, width of 25 cm and height of 25 cm. Treatment unit used to treat emissions by three stages. The three stages of treatment are passing the emissions in water, life limestone solution and chemical additives (NaOH and CaOH) respectively.



(1) Emission suction-pip, (2) Control unit, (3) Kiln body, (4) Suction fan, (5) Motor, (6) Emission-sensing opening, (7) Chimney, (8) Additives opening, (9) Emission processing-unit, (10) Pressure gauge, (11) Thermometer and (12) kiln door opening.

Fig.1: Photograph of the designed kiln for charcoal production.

(c) control-unit box. The control unit has length of 30 cm, width of 15 cm and height of 40 cm. Control unit used to control of temperature of kiln, connect, and disconnect of the motor.

(d) Electrical motor: Electrical motor single-phase induction motor of with 0.375 kW (0.5 hp) and 2850 r p m was used to operate the suction fan.

Instrumentations:

Emission measurement devices: Emission measurement devices were used to measure the emission. Estimated emissions were monoxide carbon (CO) and carbon dioxide (CO_2). The specifications of the emission measurement devices were shown in Table 1and Fig 3.

Methods:

The field experiments: were carried out at "Ezbet Amr" Village, "Ashmoon", Menoufia Governorate during the years of 2018 and 2019.

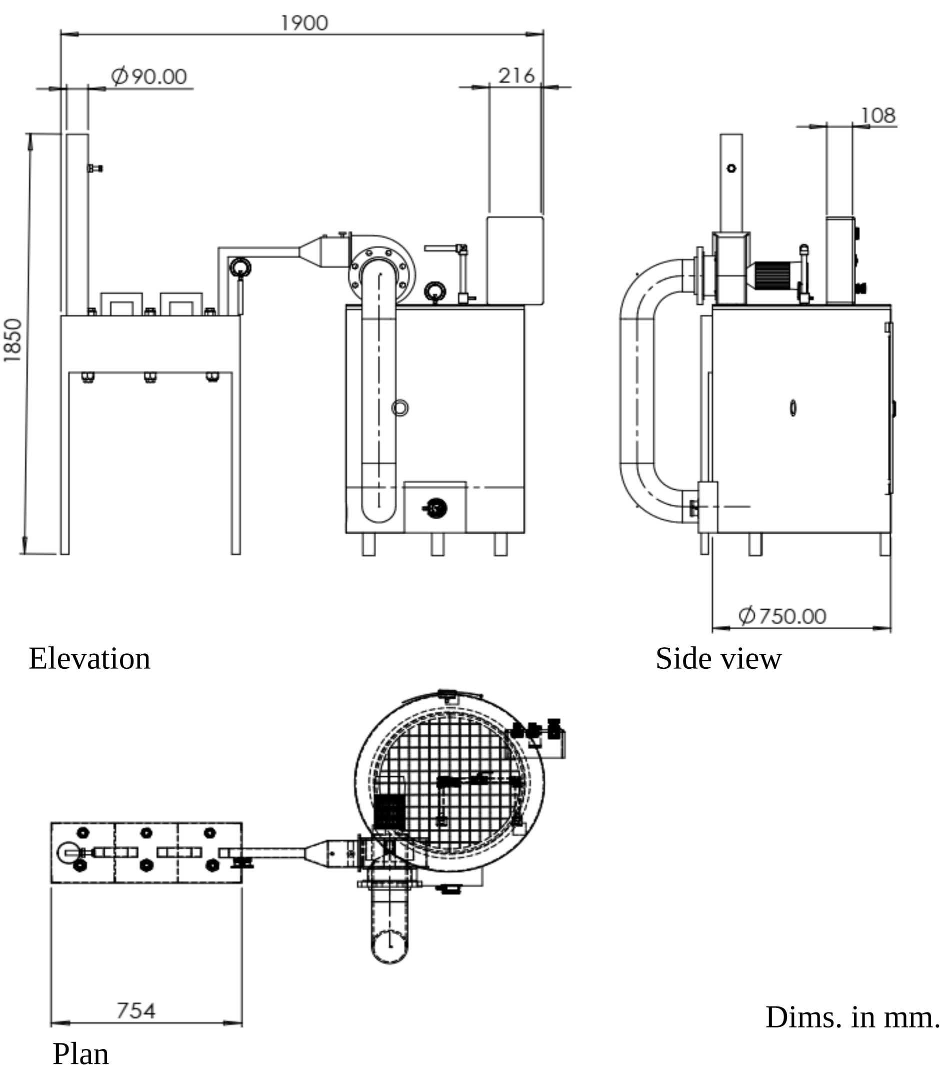


Fig. 2: Views of the designed kiln for charcoal production.

Table 1: Specifications of the automobile emission analyzer.

Items	Values	
Made in	Chine	Chine
Model	AZ 7752	UT337A
Measure	CO_2	CO
Range	0 : 9999 ppm	0 : 1000 ppm
Resolution	1 ppm	1 ppm
Dimensions, mm.	205 (L) x 70 (W) x 56 (D)	197 (L) x 55 (W) x 34 (D)
Weight	220 g	140 g
Power	(1.5V)Battery	(1.5V)Battery

Tested parameters.

The tested parameters of kiln performance were:

1- Type of wood: casuarina-tree blocks with mean dimensions of 5 x 5 x 20 cm and citrus branches with diameter range of 3 – 6 cm.

2- Pyrolysis temperature: Pyrolysis temperatures were 300, 350, 400 and 450˚C were tested. The tested temperature range was chosen according to **Rautiainen, 2014.**

3- Method of emissions treatment: Burning, “burning and chemicals” and without emission treatment methods were tested.

Fig. 3: Photograph of the emission measurement devices.

Measurements:

In The performance of designed kiln was tested by measure the following items:

1- Charcoal yield, kiln productivity, carbonization time and costs were measured using casuarina wood at all tested moisture contents and temperatures.

2- Emissions of kiln: Emissions of kiln were measured at sensing openings of chimney, suction fan and cooling pipe using casuarina wood with moisture content of 6.8 % at all tested temperatures and treatment methods. The emissions were measured by devices CO_2 meter model of "AZ 7752" and CO meter model of "UT337A". To convert concentration in ppm to mg/m^3, the following equation was used at constant atmosphere pressure of 1 bar and air temperature of 25 ^{O}C **(Terrie., 2006):**

$$\text{Concentration (mg/m}^3\text{)} = \frac{\text{concentration (ppm)} \times \text{molecular weight}}{24.45} \quad \ldots\ldots(1)$$

Where:

Molecular weight for CO_2 = 44.01 g/mol and Molecular weight for CO = 28.01 g/mol.

Charcoal yield.

The charcoal yield was determined by using the following equation **(Ronsse et al., 2013)**:

$$\text{Charcoal yield, \%} = \frac{M_{CH}}{M_{WO}} \times 100 \quad \ldots\ldots (2)$$

Where:

$M_{CH:}$ Mass of charcoal, kg and $M_{WO:}$ Mass of wood, kg.

Kiln productivity.

The kiln productivity was calculated by using the following equation **(Mady, 1999):**

$$\text{Productivity, kg/h} = \frac{w}{t} \quad \ldots\ldots(3)$$

Where:

W: Charcoal mass of kiln output, kg and T: Operating time, h.

Power requirements:

The power requirement was estimated by using the clamp meter to measure the line current strength and the potential difference value. The total electric power requirement u was calculated according to **"Kurt, 1979"** by the following equation:

$$P = (I \times V \times \cos\theta) / 1000 \quad \ldots\ldots(4)$$

Where:

P: Power requirement, kW, I: Line current strength, Amperes, V: Potential difference, Voltage and Cos θ: Power factor, equal 0.8.

Estimating the costs of using the kiln: Cost of operation was calculated according to the equation given by **Awady (1978),** in the following form:

$$C = p/h\,(1/a + i + t/2 + r) + (Ec * Ep) + m/144 \quad (5)$$

Where:

C = hourly cost, p = price of kiln, h = yearly working hours, a = life expectancy of the machine, i = interest rate/year, t = taxes, r = overheads and indirect cost ratio, Ec = Electricity consumption kW.h/h, Ep = Electricity price L.E/kW.h, "144" are estimated monthly working hours. *Notice that all units have to be consistent to result in L.E/h.

RESULTS AND DISCUSSION

Effect of moisture-content and kiln temperature on charcoal yield

Fig. 5 shows the effect of moisture-content of casuarina wood and kiln temperature on charcoal yield. The maximum charcoal yield of 50.38 % was obtained with wood moisture content of 6.8 % and kiln temperature of 300 ^{O}C. Meanwhile, the minimum charcoal yield of 32.14 %. was obtained with wood moisture-content of 13.08 % and kiln temperature of 450 ^{O}C. The decreasing of charcoal yield by increasing wood moisture-content and kiln temperature is due decreasing the mass of produced charcoal. Multiple regression analysis was carried out to obtain a relationship between charcoal yield data as a function of both wood moisture-content and kiln temperature. The following multiple prediction equation was obtained:

$$E_k = \frac{1650.77}{M.C^{0.362} * T^{0.483}} \qquad (R^2 = 0.993) \quad (6)$$

Where: E_k: charcoal yield, %., M.C: Wood moisture-content, % and T_c: Temperature, ^{O}C .

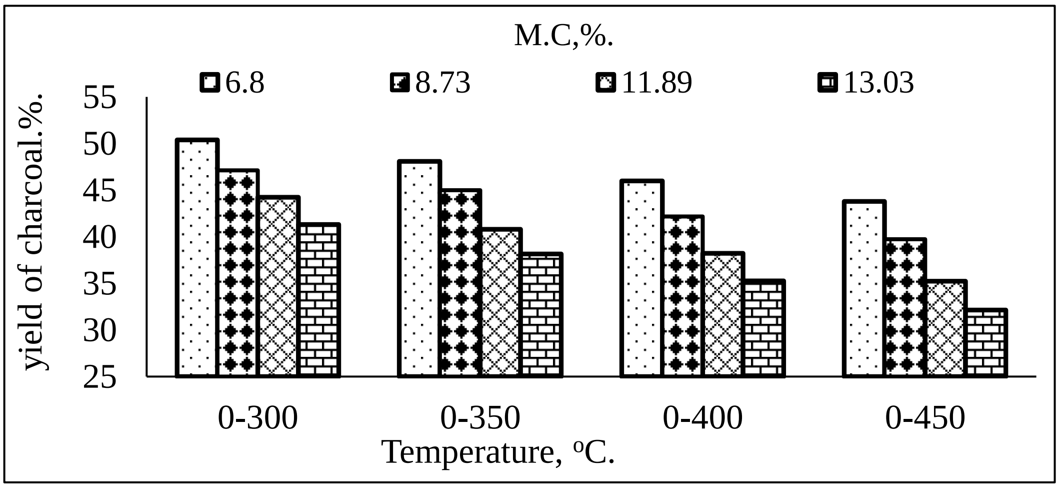


Fig. 5: Effect of wood moisture-content and kiln temperature on charcoal yield.

Effect of wood moisture-content, kiln temperature and emissions-treatment on carbonization time.

Figs. 6 and 7 show that the increasing kiln temperature from 300 to 400 ^{O}C the carbonization-time range increased from 7 - 12 to 10.45 -15.4 h at all tested wood moisture-contents with emissions burning.

By increasing wood moisture-content from 6.8 to 13.08 % the carbonization time range increased from 7 - 10.45 to 12 - 15.4 h at all tested kiln-temperatures with emissions burning.
At wood moisture-content of 6.8 %, by increasing kiln temperature from 300 to 450 ^{O}C the carbonization times were increased from 7 to 10.45 h and from 9.15 to 13.3 h by increasing kiln temperature from 300 to 450 ^{O}C with and without burning of emissions respectively.
At wood moisture-content of 6.8 %, the results show that the carbonization time without emissions burning increased by 22.35 % as compared with emissions burning at all tested kiln-temperatures. The increasing of carbonization time by increasing wood moisture-content and kiln temperature is due to increase the time needed to get rid of moisture.

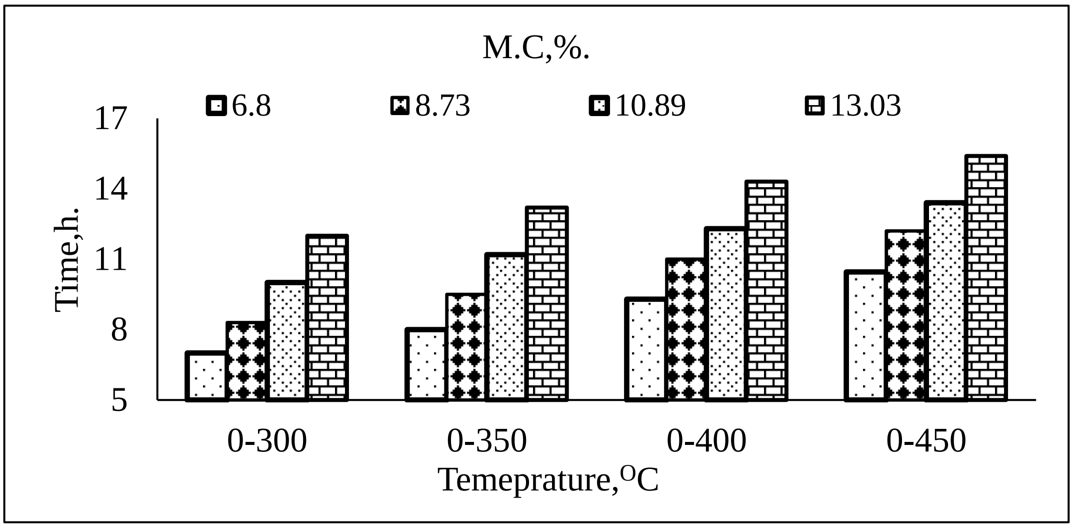


Fig. 6: Effect of wood moisture-content and kiln temperature on carbonization time with emissions burning.

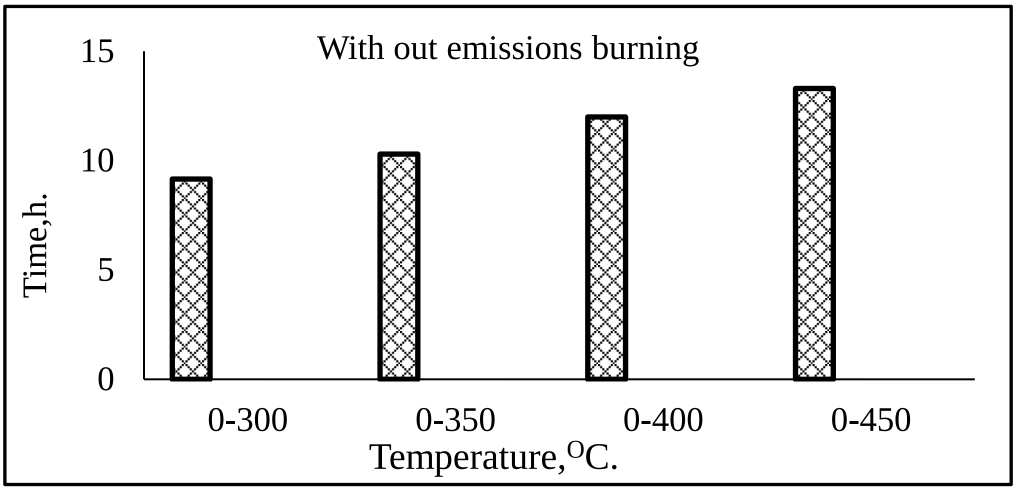


Fig. 7: Effect of kiln temperature on carbonization time at constant wood moisture-content of 6.8 % and without emissions burning.

Effect of wood moisture-content and kiln temperature on kiln productivity.

Fig. 8 shows the effect of wood moisture-content and kiln temperature on kiln productivity. The maximum kiln-productivity of 7.20 kg/h was obtained with wood moisture content of 6.8 % and kiln temperature of 300 ^{O}C. Meanwhile, the minimum kiln-productivity of 2.10 kg/h. was obtained with wood moisture-content of 13.08 % and kiln temperature of 450 ^{O}C. Date show that by increasing kiln temperature from 300 to 450 the kiln productivity decreased by 41.35 % at all tested wood moisture-contents. The decreasing of kiln productivity by increasing wood moisture-content and kiln temperature is due to decreasing the produced mass of charcoal. Multiple regression analysis was carried out to obtain a relationship between kiln-productivity data as a function both of wood moisture-content and kiln temperature. The following multiple prediction equation was obtained:

$$Pr = \frac{87733}{M.C^{1.02} \times T^{1.31}} \quad (R^2 = 0.976) \ldots\ldots (7)$$

Where: Pr: kiln productivity, kg/h, M.C: Wood moisture-content, % and T_c: Temperature, ^{O}C.

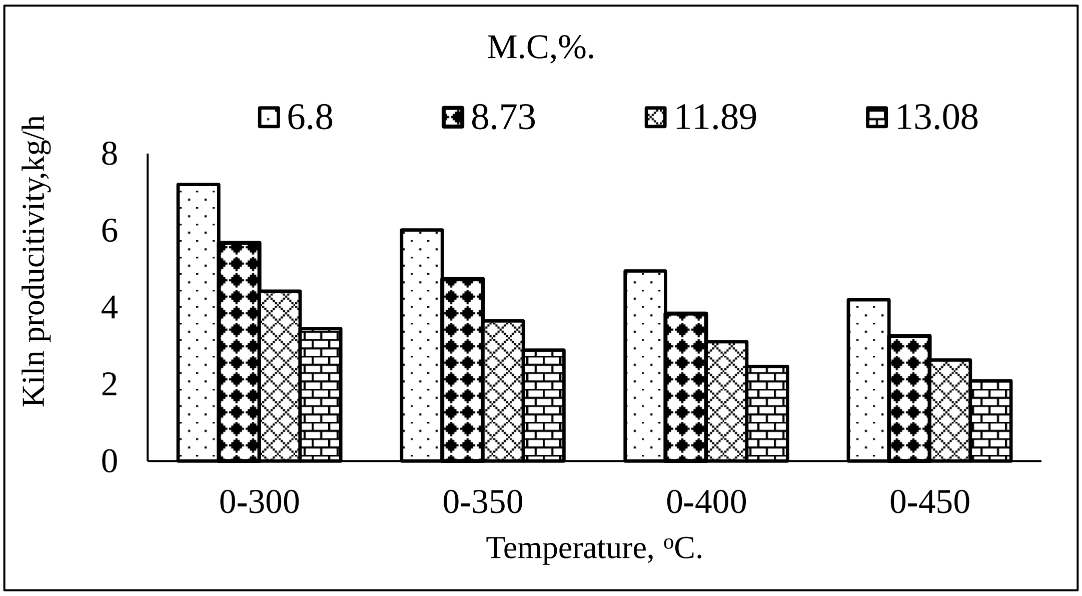


Fig. 8: Effect of moisture-content and temperature on kiln productivity.

Effect of kiln temperature and emissions-treatment on carbon dioxide and monoxide (CO_2 and CO) percent.

Fig. 9 shows the effect of kiln temperature and emissions-treatment on CO_2 and CO percent for casuarina wood.

(a) CO_2.

The maximum CO_2 of 17082 mg/m^3 was obtained using emission treatment by burning at kiln temperature of 350 ^{O}C. Moreover, the minimum CO_2 of 2044.8 mg/m^3 was obtained using emission treatment by burning and chemicals at kiln temperature range of 50 ^{O}C. The values of CO_2 without, by burning and by “burning + chemical” emission-treatments were 2269.8 – 6807.6, 3281.4 – 17082 and 2044.8 – 2860.2 mg/m^3 respectively at all tested kiln-temperatures.

(b) CO.

The maximum CO of 1859.3 mg/m^3 was obtained using emission treatment by without emission treatment at kiln temperature of 350 ^{O}C. Moreover, the minimum CO of 156.9 mg/m^3 was obtained using emission treatment by burning and chemicals at kiln temperature of 50 ^{O}C. Results were obtained using the method of treating emissions by burning and chemical from 156.9 to 591.1 at different temperature under study. According to (**ES: 6122/2008**).

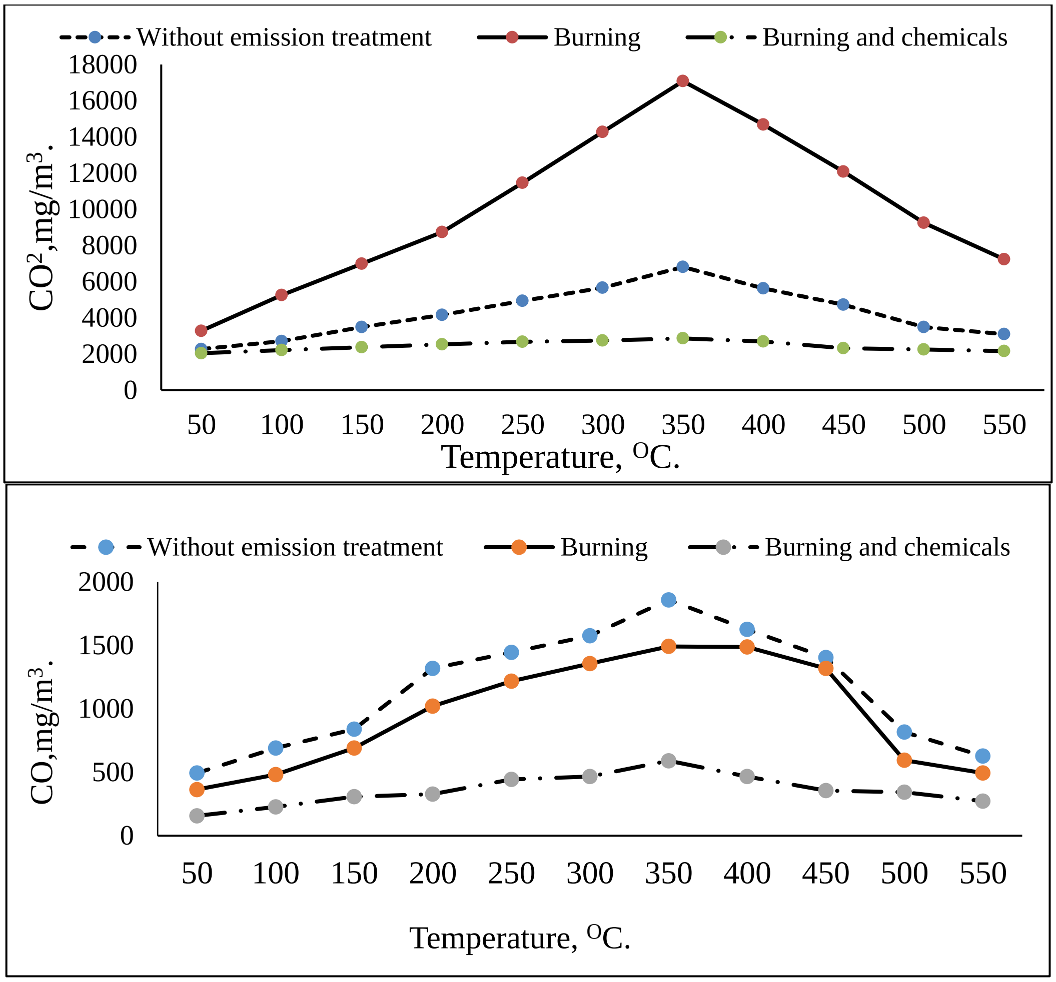


Fig. 9: Effect of kiln temperature and emissions-treatment on CO_2 and CO for casuarina wood.

The values of CO without, by burning and by "burning + chemical" emission-treatments were 493.7 – 1859.3, 364.3 – 14912.6 and 156.9 – 705.7 mg/m^3 respectively at all tested kiln temperatures. Without emissions treatment, the increased of CO_2 and CO by increasing kiln temperature from 100 to 350 ^{O}C is due to increasing of fixed carbon. Moreover, decreasing of CO_2 and CO by increasing kiln temperature from 350 to 450 ^{O}C is due to thermal decomposition of whole cellulose, which release the CO_2 and CO by burning. In addition to, if wood is heated under lack of oxygen conditions, the chemical process is then the incomplete combustion with carbon monoxide formation:

$C + ½\ O_2 = CO.$

On other hand, emission treatment by burning, CO_2 increased by increasing kiln temperature from 50 to 350 ^{O}C because of the following reasons:

- Each kg of methane burnt results in 2.75 Kg of carbon dioxide.
- For every fixed amount of carbon burned, a fixed amount of carbon dioxide and monoxide are produced.
- Organics and CO are naturally combusted to CO_2

Cost of using the developed charcoal kiln for charcoal production.

Table 2 shows the total costs of using the developed kiln for charcoal production. The maximum production cost of 9.84 L.E./kg was obtained by using "burning + chemical" emissions-treatment at kiln temperature of 450 ^{o}C and moisture content of 13.08 %. Meanwhile, the minimum production cost of 3.21L.E./kg was obtained by using burning emissions-treatment of kiln temperature 300 ^{O}C and moisture content of 6.8 %.

The operation and production costs according to prices of year 2019 were 12.93 L.E./h and 5.35 L.E./kg at optimum conditions of kiln operation at moisture-content 6.8 % and temperature 450 ^{O}C

Table 2: Effect of moisture content and kiln temperature on operation and production costs.

Emissions-treatment	Moisture content, %.	Productivity, kg/h.				Production cost, L.E./kg.			
		Kiln temperature, ^{o}C.				Kiln temperature, ^{o}C.			
		300	350	400	450	300	350	400	450
Without	6.8	7.19	6.01	4.94	4.19	3.36	3.64	4.40	4.98
	8.73	5.67	4.73	3.83	3.25	4.03	4.67	5.40	6.13
	11.89	4.42	3.64	3.10	2.62	4.95	5.72	6.45	7.33
	13.08	3.44	2.89	2.46	2.08	6.12	6.98	7.89	8.98
Burning	6.8	7.19	6.01	4.94	4.19	3.21	3.64	4.20	4.75
	8.73	5.67	4.73	3.83	3.25	3.84	4.39	5.15	5.84
	11.89	4.42	3.64	3.10	2.62	4.70	7.99	6.14	6.99
	13.08	3.44	2.89	2.46	2.08	5.79	6.62	7.50	8.98
Burning + Chemicals	6.8	7.19	6.01	4.94	4.19	3.56	4.05	4.70	5.35
	8.73	5.67	4.73	3.83	3.25	4.28	4.91	5.80	6.61
	11.89	4.42	3.64	3.10	2.62	5.27	8.68	6.94	7.94
	13.08	3.44	2.89	2.46	2.08	6.52	7.49	8.51	9.84

CONCLUSION

The optimum conditions of using the developed kiln were moisture content of 6.81 %, kiln temperature of 450 ^{o}C and using "burning + chemical" emissions-treatment. The results at optimum previous-parameters were: charcoal yield of 43.8 %, carbonization time of 10.45 h, kiln productivity 4.191 kg/h, "CO_2 and CO" emissions of 2313 and 356.3 mg/m^3 and charcoal production-cost of 5.35 L.E./kg.

REFFERENCES

Adam, J. C. (2009) Improved and more environmentally friendly charcoal production system using a low-cost retort–kiln (Eco-charcoal), Renewable Energy (34): 1923–1925.

Awady, M. N. (1978) Engineering of tractors and agricultural machinery, Text Bk., col. Ag, Ain-shams Univ., 5 th. Ed.: 164 - 167.

CAPMAS "Central Agency for Public Mobilization and Statistics", 2019.

Delmas, R. A., A. Marenco, J. P. Tathy, B. Cros, and J. G. Baudet. (1991). Sources and sinks of methane in the African Savanna. .96(D4):7287–99.

ES: 6122/2008. Egypt standards. Charcoal. Part1: general requirement for charcoal used as fuels.

FAO. **(2017)** Food and Agriculture Organization of the United Nations Principles, criteria and indicators for sustainable charcoal production, criteria and indicators for sustainable wood fuels, P: 150-155.

Foley, G. (2001) Sustainable wood fuel supplies from the dry tropical woodlands. Washington (DC, USA): ESMAP.

Gomaa, A. H and M. Fathi (2010) A simple Charcoal Kiln for hard woods or another dense Biomass. ICEHM2000, Cairo University, Egypt: 167- 174.

Kaale, B. K. (2005). Baseline study on biomass energy conservation in Tanzania. SADC Programme for Biomass Energy Conservation (ProBEC) Report.355.

Keita, J. D. (2010) "Wood or Charcoal – which is better" Unasylva - No. 157-158 - Small-scale forest enterprises. Vol. 39, 1987/3 and 4, An international journal of forestry and forest industries, FAO - Food and Agriculture Organization of theUnited Nations, Rome.

Kurt, G. (1979) Engineering formulas, 3rd Ed., MacGraw Hill Book N. Y.

Mady, M. A. (1999) developing a manual cutting machine suitable for mechanical cutting stalks. Misr J. Agric. Eng., 16(3):449 - 459.

Mugo, F and T. Gathui (2010) Biomass energy use in Kenya. In A background paper prepared for the International Institute for Environment and Development (IIED) for an International ESPA workshop on biomass energy: 19–21.

Rautiainen, M. (2014) Torrefied and carbonized wood, fuel properties and turn of exothermic reaction. M. Sc. thesis. Forest Sciences. Dept, Agriculture and Forestry. Fact. of Engineering, Helsinki Uviv.30-36.

Reumerman, P. J and B. Frederiks (2012) Charcoal Production with Reduced Emissions, 12th European Conference on Biomass for Energy, Industry and Climate Protection, Amsterdam.

Ronsse, F., D. Dickinson., R. Nachenius, and W. Prins. (2013). Biomass pyrolysis and bio char characterization Department of Bio systems Engineering, Faculty of Bioscience Engineering, Ghent University (Belgium) pp:1-24.

Terrie, K. B. (2006) Understanding units of measurement. Environmental Science and Technology Briefs for Citizens.

تطوير أفران صديقة للبيئة لإنتاج الفحم النباتي

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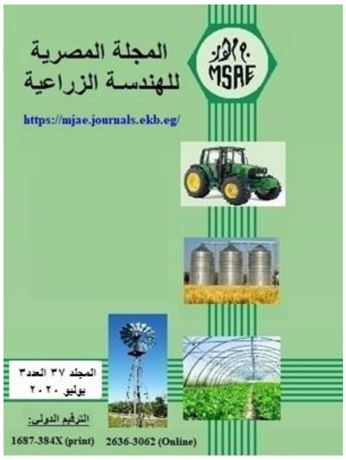

الكلمات المفتاحية:
الفحم النباتي، فرن فحم، معالجة الانبعاثات، نسبة الكربون، المواد المتطايرة، نسبة الرماد.

الملخص العربي

تهدف الدراسة الى تطوير أفران لإنتاج الفحم النباتي صديقة للبيئة، ودراسة العوامل المؤثرة على أدائه. وتم دراسة العوامل التالية: أربعة محتويات رطوبة لخشب الجازورين وهي ٦,٨، ٨,٧٣، ١١,٨٩ و ١٣,٠٣%. ودراسة أربع درجات حرارة للتفحيم وهي ٣٠٠، ٣٥٠، ٤٠٠ و٤٥٠ درجة مئوية لتقييم أداء الفرن المطور. وتم دراسة نوعين من معالجة الانبعاثات مرة بإعادة حرق الانبعاثات في بيت النار ومرة بدون وخشب جازورين محتوي رطوبي ٦,٨ % لتقدير زمن التشغيل. وتم اختبار قطع من أخشاب الجازورين ونواتج تقليم الموالح عند محتوي رطوبة ٦,٨ و٧ %. تم الحصول على أعلي كفاءة ٥٠,٣٨ % باستخدام خشب جازورين محتوي رطوبة ٦,٨٨ % عند درجة حرارة ٣٠٠ درجة مئوية. بينما تم الحصول على أقل كفاءة ٣٢,١٤ % باستخدام خشب جازورين بمحتوي رطوبة ٦,٨٨ % عند درجة حرارة ٤٥٠ درجة مئوية. تم الحصول على أعلي نسبة ثاني أكسيد كربون وأول أكسيد كربون ١٧٠٨٢ و ١٨٥٩,٣ ملليجرام/ م٣ على التوالي باستخدام الحرق في معالجة الانبعاثات عند درجة حرارة ٣٥٠ درجة مئوية. بينما تم الحصول على أقل نسبة ثاني أكسيد كربون و أول أكسيد كربون ٢٠٤٤,٨ و ١٥٦,٩ ملليجرام/م٣ على التوالي باستخدام الحرق والمعالجة الكيمائية معاً في معالجة الانبعاثات عند درجات حرارة "٥٠ درجة مئوية". وأوصت المواصفات القياسية المصرية بأن نسبة غاز أول أكسيد الكربون يجب لا تزيد عن ٨٠٠ ملليجرام/م٣. تم الحصول علي أعلي تكاليف تشغيل 9.84 جنيه/ كجم عند محتوي رطوبي ١٣,٠٨ % ودرجة حرارة ٤٥٠ درجة مئوية باستخدام خشب الجازورين. وتم الحصول على أقل تكاليف تشغيل ٣,٢١ جنية/كجم عند محتوي رطوبي ٦,٨ % ودرجة حرارة ٣٠٠ درجة مئوية بأستخدام خشب الجازورينا.