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# DESIGN OF A MOBILE INCINERATOR TO ELIMINATE THE COVID-19 MEDICAL WASTE

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*One of the most important events in recent years is the Covid-19 epidemic, which began in 2019 and continues to this day. The virus is transmitted in several ways, including medical waste (face masks, hand gloves, gowns, covers, etc.) Medical waste has increased, and the only successful way of treatment is incineration. The paper presents a design model of a mobile medical incinerator for Health Care Centres of Covid-19 in Baghdad. The clinical capacity of one centre is 50 beds and the amount of waste produced is 100 kg per day. The mobile incinerator presented has a capacity of 25 kg/h, has high efficiency, and eliminates the transmission of the virus from one area to another, by waste. The incineration process leads to the reduction of waste weight by 75% and waste volume by 95%. The paper presents a model to calculate the volume of the primary and secondary combustion chambers. The mass of gas fuel added to the burners, the volume of flue gases resulted from the medical waste combustion and the residence time of the resulting gases in the secondary combustion chamber are determined.*

**Keywords**: mobile incinerator, medical waste, combustion.

## 1. Introduction

Biomedical waste is increasing annually, approximately from 10% to 20%, due to population growth and technological development. This waste is treated in many ways, but incineration is the most efficient method [1][2][3]. In the previous and current years, the world witnessed a Covid-19 global epidemic. Medical waste has increased due to the rapid spread of the virus and the wearing of protective clothing (disposable) such as face masks and hand gloves by a large number of people [4]. This waste causes many problems if it is not managed and treated correctly and can contribute to the spread of the epidemic [5].

Covid-19 has caused huge amounts of uncontrollable waste. The only treatment was incineration in medical incinerators due to the speed of the process, ease operation and high efficiency. The huge volume of waste is reduced by

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incineration to about 90-95% of the original volume with total disinfection of pathogens, and energy recovery. The advantages of incinerators have become clear and consistent over other treatment methods [6][7][8][9][10]. The disposal of this kind of waste began by moving incinerators to the epidemic area in order to avoid the spread of the epidemic to other areas [11]. Public municipal waste incinerators have been used in some countries [4].

In Iraq, Health Centres and Covid-19 Centres do not have medical incinerators, and if they do, they are old. Biomedical waste is collected from Health Centres and transported to other hospitals that have an incinerator.


Fig.1. Medical waste for hospitals in the medical city incinerator in Baghdad

Therefore, the use of a mobile incinerator leads to proper management and treatment of waste[11][12]. When the biomedical waste is burned inside the primary combustion chamber with the help of air and natural gas, combustion gases ($CO_2$, CO, $H_2$, $H_2O$, $N_2$, $O_2$, and HCl) and ash are produced [13]. The composition of the combustion gases and ash depend on the kind of waste and combustion process. From the combustion process results bottom ash which is removed manually after the temperature drops [14], as presented in Fig. 1

## 2. Medical waste

Biomedical waste is the waste produced from Health Centres and hospitals resulting from treatment, diagnosis or protective measures [14] and has different names like clinical waste or hospital waste. According to the World Health Organization instructions, it is not allowed to burn medical waste with high humidity of more than 30%, non-combustible materials of more than 40%, compressed gas containers, materials containing PVC, cadmium and mercury such as batteries and pressure devices [15]. Health Centres produce medical waste, including waste containing viruses and microbes. This waste is packed in yellow bags and then transferred to the medical incinerators of the hospitals. This waste contains cellulose swabs $C_6H_{10}O_5$, tissue $C_5H_{10}O_3$, plastic polyethene (disposable gowns, face mask, hand gloves, overhead, overshoes) $(C_2H_4)x$, PVC $(C_2H_3Cl)x$, glass $SiO_2$, sharp Fe, and moisture. To eliminate the transmission of viruses to working people and other areas, a mobile incinerator has been designed and proposed in the paper. Parameters, size and capacity of the incinerator, according to the amount of waste generated from a centre, has been determined using the Engineering Equation Solver (EES) program. For example, the Al-Shifa Centre for the treatment of Covid-19 patients in Baghdad, which is affiliated with the Medical City, contains 250 beds and has a very old incinerator, manufactured in 1982. The capacity of the incinerator cannot support the amount of waste generated due to its age. A mobile incinerator can be a suitable solution for this case.

### 3. Design of the Primary combustion chamber

Primary combustion chamber (Pcch) usually contains two gates. The first gate is for medical waste supply. The temperature inside Pcch reaches up to 1173 K and it is thermally insulated to keep the chamber at high temperature. The entire waste is incinerated and the bottom ash produced is manually or automatically extracted through the second gate [16], as presented in Fig. 2.

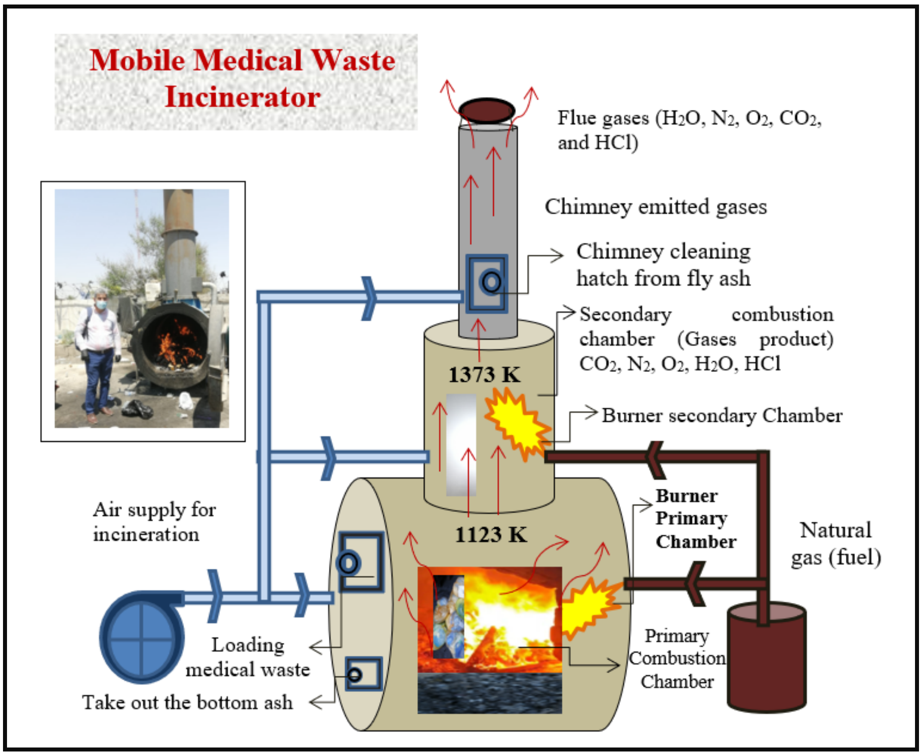


Fig.2. Scheme of a mobile medical waste incinerator

Covid-19 medical waste is characterized by a low density of about 80 [kg/m$^3$]. Needles, sharp things and glass are treated as ashes, while the moisture of the waste, liquid materials, are represented by water. The primary combustion chamber is dimensionally designed on the default shape and mass of the thrust feed to the incinerator [17]. The amount of waste generated from Covid 19 Centres is 100 kg per day and this waste is incinerated in 4 hours resulting a feed rate of 25 [kg/h].

The volume of the primary combustion chamber $V_{Pcch}$ [m$^3$] depends on the mass of waste, $m_w$ [kg] and the density of the medical waste, $\rho_w$:

$$\dot{V}_{Pcch} = \frac{m_w}{\rho_w} \tag{1}$$

Waste components are denoted by A, B, C, D, E, F, Z in [kg/h] and sequentially represents swabs (cellulose $C_6H_{10}O_5$), tissue $C_5H_{10}O_3$, plastic polyethene (disposable gown, face mask, hand gloves, overhead, overshoes) $(C_2H_4)x$, PVC $(C_2H_3Cl)x$, ash, moisture, glass $SiO_2$ and sharp Fe, as presented in Table 1

*Table 1*

**Characteristic and contents of Covid 19 medical waste**

| Type medical waste | Waste Input [kg/h] | HHV [MJ/kg] | Total Heat flux [kJ/h] | $O_2$ Table 2 [kg/h] | $CO_2$ Table 2 [kg/h] | $H_2O$ Table 2 [kg/h] | HCl [kg/h] |
|---|---|---|---|---|---|---|---|
| Swabs Cellulose $C_6H_{10}O_5$ | A | 23.860 | A· 23,860 | A·1.19 | A·1.63 | A·0.56 | |
| Tissue $C_5H_{10}O_3$ | B | 25.220 | B· 25,220 | B·1.63 | B·1.84 | B·0.76 | |
| Polyethene Plastic, $(C_2H_4)_x$ | C | 37.820 | C·37,820 | C·3.43 | C·3.14 | C·1.29 | - |
| PVC 4% $(C_2H_3Cl)x$ | D | 38.154 | D·38,154 | D·1.28 | D·1.41 | D·0.29 | D·0.58 |
| Ash ≤ 25% | E | 0 | 0 | - | - | - | - |
| Moisture $H_2O$ ≤ 30% | F | 0 | 0 | - | - | - | - |
| Glass & sharps $SiO_2$ & Fe | Z | 0 | 0 | - | - | - | - |

*Table 2*

**Covid 19 medical waste burning process**

| Type of medical waste | COMBUSTION EQUATION OF WASTE | | | |
|---|---|---|---|---|
| Swabs cellulose | $C_6H_{10}O_5$ + $6O_2$ = $6CO_2$ + $5H_2O$ | | | |
| Molecular weight | 162.1 | 6(32) | 6(44) | 5(18) |
| Per 1 kg | 1 | 1.19 | 1.63 | 0.56 |
| A kg | A | A·1.19 | A·1.63 | A·0.56 |

| | | | | | |
|---|---|---|---|---|---|
| Tissue | $C_5H_{10}O_3 + 6O_2 = 5CO_2 + 5H_2O$ | | | | |
| Molecular weight | 118.1 | 6(32) | 5(44) | 5(18) | |
| Per 1 kg | 1.0 | 1.63 | 1.84 | 0.76 | |
| B kg | B | B·1.63 | B·1.84 | B·0.76 | |
| Polyethylene plastic | $(C_2H_4)_x + 3O_2 = 2CO_2 + 2H_2O$ | | | | |
| Molecular weight | 28.1 | 3(32) | 2(44) | 2(18) | |
| Per 1 kg | 1 | 3.43 | 3.14 | 1.29 | |
| C kg | C | C·3.43 | C·3.14 | C·1.29 | |
| PVC | $2(C_2H_3Cl)x + 5O_2 = 4CO_2 + 2H_2O + 2HCl$ | | | | |
| Molecular weight | 2(62.5) | 5(32) | 4(44) | 2(18) | 2(36.5) |
| Per 1 kg | 1 | 1.28 | 1.41 | 0.29 | 0.58 |
| D kg | D | D·1.28 | D·1.41 | D·0.29 | D·0.58 |

### 3.1 Calculation of the air rate of the primary and secondary combustion chambers and excess air

To calculate the amount of air needed for combustion, the total oxygen required for combustion of biomedical waste has been determined from Tables 1 and 2:

$$\dot{m}_{O_2\text{-}req} = \dot{m}_{O_2\text{-}cell} + \dot{m}_{O_2\text{-}tiss} + \dot{m}_{O_2\text{-}pol} + \dot{m}_{O_2\text{-}PVC} \quad (2)$$

Using the values of oxygen from Table 1, Eq 1 become:

$$\dot{m}_{O_2\text{-}req} = 1.19A + 1.63B + 3.43C + 1.28D \quad (3)$$

To find the stoichiometric air, the value of oxygen required for waste combustion from Eq. 3 has been substitute with Eq. 4:

$$\dot{m}_{a\text{-}sto} = \dot{m}_{O_2\text{-}req} \cdot \left(\frac{100}{23}\right) \quad (4)$$

The primary combustion chamber is supplied with excess air of 30% to ensure complete combustion. In case the air is less than the air required for combustion, incomplete combustion occur. If air is more than 30%, temperature of the initial combustion chamber decreases, thus the efficiency of the incinerator decreases. To find necessary amount of air for primary chamber, we substitute Eq. 4 into Eq. 5:

$$\dot{m}_{a\text{-}Pch} = (0.3\dot{m}_{a\text{-}sto}) + \dot{m}_{a\text{-}sto} \quad (5)$$

The Secondary combustion chamber (Scch) is supplied with excess air of 150% of the required air [18]. To find necessary amount of air for secondary chamber, Eq. 4 is substituted into Eq. 6:

$$\dot{m}_{a\text{-}Sch} = (1.5\dot{m}_{a\text{-}sto}) + \dot{m}_{a\text{-}sto} \quad (6)$$

### 3.2 Incinerator mass input balance

The input masses in the incinerator represent the masses of waste components: cellulose swabs $C_6H_{10}O_5$, tissue $C_5H_{10}O_3$, plastic polyethene $(C_2H_4)x$, PVC 4% $(C_2H_3Cl)x$, from Table 1, the dry air, which represents the mass of excess air in the secondary combustion chamber from Eq. 6, and the mass of moisture present in the total input air from the Eq. 8.

$$\dot{m}_{a\text{-}dry} = \dot{m}_{a\text{-}Scch} \quad (7)$$

$$\dot{m}_{a\text{-}H_2O} = 0.0132\,\dot{m}_{a\text{-}Scch} \quad (8)$$

$$\dot{m}_{in} = \dot{m}_w + \dot{m}_{a\text{-}dry} + \dot{m}_{a\text{-}H_2O} \quad (9)$$

### 3.3 Incinerator output mass balance

When medical waste is incinerated, combustion gases, and ash are generated:

$$\dot{m}_{N_2} = 0.77\,\dot{m}_{a\text{-}sto} \quad (10)$$

$$\dot{m}_{a\text{-}exis} = 1.5\,\dot{m}_{a\text{-}sto} \quad (11)$$

$$\dot{m}_{CO_2\text{-}rec} = \dot{m}_{CO_2\text{-}cell} + \dot{m}_{CO_2\text{-}tiss} + \dot{m}_{CO_2\text{-}pol} + \dot{m}_{CO_2\text{-}PVC} \quad (12)$$

The values of $CO_2$ from Table 1 were substitute in the Eq. 10 and the same substitutions for $H_2O$ and HCl:

$$\dot{m}_{CO_2\text{-}req} = 1.63A + 1.84B + 3.14C + 1.41D \quad (13)$$

$$\dot{m}_{H_2O\text{-}rec} = \dot{m}_{H_2O\text{-}cell} + \dot{m}_{H_2O\text{-}tiss} + \dot{m}_{H_2O\text{-}pol} + \dot{m}_{H_2O\text{-}PVC} \quad (14)$$

$$\dot{m}_{HCl\text{-}rec} = 0.58D \quad (15)$$

The entire mass of moisture is the moisture contained in the air, in the waste, and the moisture that is produced when waste is burned. It is calculated as follows:

$$\dot{m}_{H_2O\text{-}t} = \dot{m}_{a\text{-}H_2O} + \dot{m}_{mois\text{-}w} + \dot{m}_{H_2O\text{-}rec} \quad (16)$$

$$\dot{m}_{out} = \dot{m}_{N_2} + \dot{m}_{a\text{-}exis} + \dot{m}_{CO_2\text{-}rec} + \dot{m}_{HCl\text{-}rec} + \dot{m}_{H_2O\text{-}t} + \dot{m}_{ash} \quad (17)$$

### 3.4 Calculation of input energy of the incinerator

The energy that enters in the medical incinerator is the energy generated from calorific value of the waste and the energy generated from primary and secondary combustion chamber burners that operate on natural gas fuel. The use of natural gas increases the temperature in the combustion chambers to obtain complete combustion of waste, eliminates all pathogens and leads to the lowest possible volume with minimum weight of ashes. Energy waste $\dot{Q}_W$ [MJ/h] is:

$$\dot{Q}_W = HHV \cdot \dot{m}_W \quad (18)$$

$$\dot{Q}_{t\text{-}w} = \dot{Q}_{w\text{-}tiss} + \dot{Q}_{w\text{-}cell} + \dot{Q}_{w\text{-}pol} + \dot{Q}_{w\text{-}PVC} \quad (19)$$

$$\dot{Q}_{in\text{-}waste} = \dot{Q}_{t\text{-}w} \quad (20)$$

### 3.5 Calculation of the energy output of the combustion

As a result of the medical waste combustion, flue gases are produced, accompanied by the heat of combustion. Part of heat combustion is lost by radiation and formation of residual ash and the other part with water vapor and gases. This energy can be recovered by heating water or generating electric power, which increases the efficiency of the incinerator.

Energy loss by radiation is 5% of the energy added to the incinerator [19].

$$\dot{Q}_{loss} = 0.05\dot{Q}_{in\text{-}waste} \quad (21)$$

The energy of ash formation from the beginning of combustion to its end is:

$$\dot{Q}_{ash} = \dot{m}_{ash} \cdot c_{p\text{-}ash} \cdot \Delta T \quad (22)$$

where: $\dot{m}_{ash}$ is the remaining ash, $c_p$ is the specific heat of the ash and has a value of 0.000831 MJ/(kg K) [17]; $\Delta T = T_2 - T_1$ where $T_1$ is the temperature of the combustion chamber when entering the waste, and $T_2$ is the secondary combustion chamber temperature, K.

The resulting energy from dry gases is represented by the mass rate of dry air and its components of nitrogen and oxygen with the mass of carbon dioxide and hydrochloric gas [20].

$$\dot{Q}_{dry\text{-}g} = \dot{m}_{dry\text{-}g} \cdot c_p \cdot \Delta T \quad (23)$$

$$\dot{m}_{dry\text{-}g} = \dot{m}_{N_2} + \dot{m}_{a\text{-}exis} + \dot{m}_{CO_2\text{-}rec} \quad (24)$$

where: $c_p$ = 0.001086 MJ/ (kg K) is the specific heat of the dry gas.

Substituting all these values into the equation 23 will determine the energy of the resulting dry gases.

Energy of water vapor is produced from moisture in the air, waste and water vapor resulting from combustion:

$$\dot{Q}_{H_2O} = \dot{m}_{H_2O\text{-}t} \cdot c_p \cdot \Delta T + \dot{m}_{H_2O\text{-}t} \cdot H_v \quad (25)$$

where: $c_p$ = 0.002347 MJ/ (kg K) is the specific heat of the water and $H_v$= 2.4603 MJ/kg (latent heat constant of water vapor).

Substituting all these values into Eq. 25 will determine the energy of the resulting water vapor.

$$\dot{Q}_{out} = \dot{Q}_{loss} + \dot{Q}_{ash} + \dot{Q}_{dry\text{-}g} + \dot{Q}_{H_2O} \quad (26)$$

Substituting all these values into Eq. 26 will lead to the energy produced by combustion. This amount of energy can be used and recovered in water heating or electric power generation. The energy recovery process increases the efficiency of the incinerator.

### 3.6 Energy required for gas fuel burners to reach 1373 K

The Energy required from the additional fuel to achieve the highest design temperature of the secondary combustion chamber at 1373 K, with 5% of radiation loss:

$$\dot{Q}_{net} = \dot{Q}_{in\text{-}waste} - \dot{Q}_{out} \tag{27}$$

$$\dot{Q}_{fuel} = \dot{Q}_{net} + 0.05\dot{Q}_{net} \tag{28}$$

where: $\dot{Q}_{fuel}$ - energy required from auxiliary fuel (MJ/h), natural gas at 1373 K, and 20% excess air requires 0.0158052 MJ/$m^3$ [19]. Therefore, when natural gas burns with air, consideration should be given to dry products and moisture for combustion from additional fuels and through the combustion reactions of gas with air, where the mass of dry products per $m^3$ of gas fuel is 14.41 kg/$m^3$ and moisture is 1.59 kg/$m^3$ [21].

$$\dot{V}_{fuel} = \frac{\dot{Q}_{fuel}}{0.01508052} \tag{29}$$

$$\dot{m}_{fuel} = \rho_{fuel} \cdot \dot{V}_{fuel} \tag{30}$$

where: $\dot{V}_{fuel}$ - volume flow rate required for natural gas, [$m^3$/h]; $\dot{m}_{fuel}$ -mass flow rate of gas, [kg/h].

$$\dot{m}_{dry\text{-}fuel} = 14.41 \cdot \dot{V}_{fuel} \tag{31}$$

$$\dot{m}_{mois\text{-}fuel} = 1.59 \cdot \dot{V}_{fuel} \tag{32}$$

where: $\dot{m}_{dry\text{-}fuel}$ - mass flow rate of dry products from fuel at 20 % excess air [kg/h] and $\dot{m}_{mois\text{-}fuel}$ - mass flow rate of moisture from fuel [kg/h].

## 4. Design of the secondary combustion chamber

Secondary combustion chamber (Scch), also called the post-combustion chamber comply with European, Canadian, Australian and American law requirements. According to the type of incinerator used, the temperature of this designed room reaches more than 1273 K to eliminate all pathogens and viruses and complete the combustion. The combustion gases and volatiles remain for 0-3 seconds depending on the room size and room temperature to complete the combustion of gases and volatiles in the secondary chamber. Its size is smaller than Pcch. The secondary chamber volume requirement is to achieve a residence time of the resulting gases of 1 second at 1373 K.

### 4.1 Total dry product

The total dry product represents all dry gases generated from the burning of biomedical waste and support fuel (natural gas) in [kg/h].

$$\dot{m}_{dry\text{-}total} = \dot{m}_{dry\text{-}g} + \dot{m}_{dry\text{-}fuel} \tag{33}$$

Assuming that the dry gases generated from burning waste and fuel have the characteristics of air where the ideal gas law applies (pV= nRT) it is possible to calculate the volumetric flow rate of the produced dry gases at 1373 K ($\dot{V}_{pro}$)

$$\dot{V}_{pro} = \dot{m}_{dry\text{-}total} \cdot \left(\frac{1}{3600}\right) \cdot \frac{22.4}{29} \cdot \left(\frac{T_2}{273}\right) \tag{34}$$

where: $\dot{V}_{pro}$ - volumetric flow rate of the produced dry gases $m^3/s$, R= (22.4 $m^3$)/(29 kg dry product), and $T_2$=1373 K.

### 4.2 Total moisture

The sum of the total moisture is the moisture from waste, from combustion air, from combustion reactions and moisture of fuel, and is calculated as follows:

$$\dot{m}_{H_2O_{t+f}} = \dot{m}_{H_2O\ t} + \dot{m}_{mois\text{-}fuel} \tag{35}$$

where: $\dot{m}_{H2Ot+f}$ - the sum of the total moisture [kg/h].

Using the ideal gas law, it is possible to calculate the volumetric flow rate of the moisture generated gases at 1373 K:

$$\dot{V}_{mois} = \dot{m}_{H_2O_{t+f}} \cdot \frac{1}{3600} \cdot \frac{22.4}{18} \cdot \frac{T_2}{273} \tag{36}$$

where: $\dot{V}_{mois}$ - volumetric flow rate of the moisture $m^3/s$, R= (22.4 $m^3$)/(18 kg moisture) and $T_2$=1373K. So, the total volumetric flow rate of the gases generated from the combustion of waste and fuel with air is $\dot{V}_{g\,Scch}$ ($m^3/s$)

$$\dot{V}_{g\ \ Scch} = \dot{V}_{pro} + \dot{V}_{mois} \tag{37}$$

When determining the volume of the secondary combustion chamber appropriate to the volumetric flow rate of the generated gases, the residence time of the generated gases in the secondary combustion chamber can be determined:

$$\tau = \frac{\dot{V}_{Scch}}{\dot{V}_{g_{Scch}}} \tag{38}$$

where: $\tau$ - the residence time of the gases generated by combustion, [s]; $V_{Scch}$ - secondary combustion chamber volume, [$m^3$]. The height of the room from the front of the burner flame to the location of the thermal sensor is calculated to maintain the time of the residence time of the gases for one second.

To find the total energy input after adding fuel:

$$\dot{Q}_{in\ \ total} = \dot{Q}_{in\ \ waste} + \dot{Q}_{fuel} \tag{39}$$

$$\eta_{inc} = \frac{\dot{Q}_{out}}{\dot{Q}_{in}} \tag{40}$$

where: $\dot{Q}_{in\ total}$ - the total energy entering the incinerator [MJ/h]; $\eta_{inc}$ - incinerator efficiency.

## 5. Results and discussions

This study involved designing a mobile medical incinerator for easy access to the desired site and as needed to reduce the rapid transmission of the virus from one region to another. Iraq does not have mobile medical incinerators. When the epidemic appeared in Iraq, modern centres were built for this purpose. Waste collected from health centres was transferred to the hospitals that had an incinerator and this facilitated the spread of the virus.

The EES software was used to find the design parameters of the incinerator according to the quantity and type of waste for the hospital. For example, we considered an amount of $m_w$ = 100 kg waste with the following composition: cellulose = 20%, tissues = 8%, polyethylene = 35%, PVC = 4%, total ash = 13%, $H_2O$ = 20%. For an input flow of 25 kg/h results A: swabs cellulose = 5 kg/h, B: tissues = 2 kg/h, C: plastic polyethylene = 8.75 kg/h, D: PVC = 1 kg/h, Z: (glass and sharp) + E = 3.25 kg/h, F: waste moisture = 5 kg/h. $T_1$ = 293 K, $T_2$ = 1373 K.

The main results for an incinerator with a capacity of 25 kg/h were: the volume of the primary and secondary combustion chamber: $V_{Pcch}$ =1.25 m$^3$, $V_{Scch}$ =0.693 m$^3$, the residence time of the gases in the secondary chamber: $\tau$ = 1 second, and gas fuel volume: $\dot{V}_{fuel}$ = 9.371 m$^3$/h. Table 3 shows all parameters of design incinerator mobile.

*Table. 3*

**Design parameters of a mobile medical waste incinerator using the EES software program**

| | | | | | |
|---|---|---|---|---|---|
| $m_{w}$ | 100 kg | $\dot{m}_{H2O-t}$ | 26.71 kg/h | $\dot{Q}_{H2O}$ | 133.4 MJ/h |
| $\dot{m}_{w}$ | 25 kg/h | $\dot{m}_{out}$ | 471 kg/h | $\dot{Q}_{out}$ | 679.9 MJ/h |
| $\dot{m}_{O2-req}$ | 40.5 kg/h | $\dot{m}_{dry-g}$ | 440.5 kg/h | $\dot{Q}_{fuel}$ | 148.1 MJ/h |
| $\dot{m}_{a-sto}$ | 176.1 kg/h | $\dot{m}_{fuel}$ | 11.71 kg/h | $\dot{Q}_{in-total}$ | 686.9 MJ/h |
| $\dot{m}_{a-Pch}$ | 228.9kg/h | $\dot{m}_{dry-fuel}$ | 135 kg/h | $V_{Pcch}$ | 1.25 m$^3$ |
| $\dot{m}_{a-Sch}$ | 440.2kg/h | $\dot{m}_{mois-fuel}$ | 14.9 kg/h | $\dot{V}_{fuel}$ | 9.371 m$^3$/h |
| $\dot{m}_{a-H2O}$ | 5.811kg/h | $\dot{m}_{dry-total}$ | 575.5 kg/h | $\dot{V}_{pro}$ | 0.621 m$^3$/s |
| $\dot{m}_{in}$ | 471.1 kg/h | $\dot{m}_{H2O, t-f}$ | 41.61 kg/h | $\dot{V}_{mos}$ | 0.0723 m$^3$/s |
| $\dot{m}_{N2}$ | 135.6 kg/h | $\dot{Q}_{t-w}$ | 538.8MJ/h | $\dot{V}_{g-Sch}$ | 0.6933 m$^3$/s |
| $\dot{m}_{a-exis}$ | 264.1kg/h | $\dot{Q}_{in-waste}$ | 538.8 MJ/h | $V_{Scch}$ | 0.6933 m$^3$ |
| $\dot{m}_{CO2-rec}$ | 40.71 kg/h | $\dot{Q}_{loss}$ | 26.94 MJ/h | $\tau$ | 1 s |
| $\dot{m}_{H2O-rec}$ | 15.9 kg/h | $\dot{Q}_{ash}$ | 2.917 MJ/h | $\eta$ | 0.9897 |
| $\dot{m}_{ash}$ | 3.25 kg/h | $\dot{Q}_{dry-g}$ | 516.6 MJ/h | $V_{Pcch}$ | 1.25 m$^3$ |
| $\dot{m}_{HCl-rec}$ | 0.58 kg/h | $\dot{m}_{H2O-t}$ | 26.71 kg/h | | |

In previous studies, it has been found a balance for the input and output masses and energy for a medical incinerator using diesel [16]. This work was part of our research paper in the same circumstances but using different type of fuel.

The author of [20] designed a fixed medical incinerator for a number of hospitals with a capacity of 50 kg/h, the waste for government hospitals at a rate of 65-75 kg/day, and the waste for private hospitals at a rate of 11 to 13 kg/day. The waste is transferred to the incinerator site, which causes the transmission of viruses to that area. The incinerator characteristics are $V_{Pcch}$= 2.5 $m^3$, $V_{Scch}$= 1.0127 $m^3$ and the amount of fuel 14.4 $m^3$/h to reach to 1373 K. The amount of waste depends on the number of patients, so if the amount of waste is less than 25 kg/day, as in private hospitals, the amount of fuel consumed will be higher in addition to the process of managing and transporting waste [20].

Another researcher [17] designed a fixed medical incinerator for 4 hospitals with a capacity of 100 kg per hour, the distance between the hospitals was 100 km, which causes the transmission of viruses to those areas, and the characteristics of incinerators were: $V_{Pcch}$ = 8 $m^3$, $V_{Scch}$=3.07 $m^3$, and the fuel rate 29.52 $m^3$/h. The size of the combustion chambers was large in relation to the burning of the amount of waste per hour, so it needed a high amount of fuel to reach a temperature of 1373 K, which affected the efficiency of the incinerator especially for small quantities of waste, additionally at the cost of waste transport and management[17].

Compared to other work conducted in literature, the incinerator presented in this paper has the advantage of being mobile. The mobility of the incinerator comes with important advantages such as: high efficiency, small dimensions, easy to move, eliminates viruses at the place of the epidemic limiting the spread, reduces costs for waste transportation, reduces service workers, facilitates the process of waste management reducing risks to human health and the environment.

It was shown that the huge increase in medical waste during the period of Covid-2019 pandemic, led to an increase in the number of infected people due to the rapid transmission of the virus [22]. It was highlighted the need to fill the existing gaps in the management of medical waste during the epidemic and to shed light on such studies [23], and medical incinerators proved to be the best solution for the treatment of medical waste during this period [24] .

## 6. Conclusions

COVID-19 is a very dangerous disease that infected millions of people in the world. The main purpose of designing a mobile incinerator was to reduce the transmission of the virus from a zone to another zone through medical waste. When the pandemic appeared, centres dedicated to treating this disease have been built in Iraq with an average capacity of 50-100 beds. Some hospitals have been converted into centres for treating pandemic patients in Baghdad. It was a positive step, but the medical waste produced by these centres was transferred to other areas that contain medical incinerators.

In this research, a mobile medical incinerator for a capacity of 25 kg/h has been designed, to reduce epidemic transmission. The mobile incinerator is characterized by high efficiency, reducing the weight of waste by 75% and waste volume by 95%, facilitating medical waste management, dispensing with special vehicles for transporting medical waste, ease to move and small size.

Input masses (471.1 kg/h) represented by medical waste, excess air, and humidity in the air is approximately equal to the output masses (471 kg/h) represented by nitrogen gas in excess air, and the rest of the excess air, carbon dioxide gas, water vapor resulting from moisture in waste, air and combustion products, hydrochloric gas, and residual ash. The input energy, is represented by calorific value contained in the waste (538.8 MJ/kg), but the total energy output for combustion is $\dot{Q}_{out}$ = 679.9 MJ/h, where the difference must be compensated by natural gas fuel with an amount of $\dot{V}_{gas}$ = 9.371 $m^3$/h.

The primary combustion chamber burner needs 4.6855 $m^3$/h gas, and the secondary combustion chamber burner needs 4.6855 $m^3$/h to reach the secondary combustion temperature of 1373 K. It was found that the volumetric flow rate of the gases produced by combustion is 0.6933 $m^3$/s. The volume of the secondary combustion chamber is 0.6933 $m^3$ and the volume of the primary combustion chamber is 1.25 $m^3$. The residence time of the gases in the secondary combustion chamber is 1 second. The mobile incinerator has a high efficiency of 99%.

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