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THERMAL ENERGY EVALUATION OF THE INCINERATOR MEDICAL WASTE

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ABSTRACT: The global warming problem and the rising cost of energy has raised the interest in the application of alternative energy for the energy system to increase efficiency and to reduce the emission of pollution. However, the key challenge of the energy systems was to find an appropriate way to decrease energy loss and increase the efficiency of energy transfer. This research aimed to evaluate the thermal energy obtained and heat loss from the incinerator waste installed in Suphan Buri Province, Thailand. The incinerator system composed of 6 sections: the first section was a waste hopper and feeder, the second section was the rotary kiln primary, the third section was a secondary chamber, the fourth section was the ash cooling conveyer, the fifth section was cyclone and the sixth section was a stack. This study applied 200 kilograms of waste and 200 liters of diesel oils as raw materials for the incineration process. The results showed that the total flow rate from overall input materials was 875 kilograms per hour and the total heat rate from overall inputs was 3,503,032.25° Kelvin. In terms of heat losses, total heat losses from the surface were 2,789,424.75 ° Kelvin while overall heat losses were 3,503,032.25 ° Kelvin. The results showed high thermal efficiency and suitable for application in the engineering process.

Keywords: Incinerator, Stack, Thermal Energy, Waste

1. INTRODUCTION

The rising cost of energy is seriously concerned worldwide. Also, global warming is one problem from fossil fuels. The interest in the application of alternative energy has, thus, been emerging to increase efficiency and to reduce pollution emission.

Fig.1 Pollution emission and global warming

Ola Eriksson and Göran Finnveden [1] have studied the degree of influence of factors on energy supply and emission of greenhouse gases. The study showed that plastics of a fossil origin could generate significant emissions of greenhouse gases while easily degradable bio-waste generated zero-emission.

Many alternative energy systems are widely applied in many fields such as solar energy, wind energy, etc. However, the key challenge of the energy systems is to find an appropriate way to decrease energy loss and increase the efficiency of energy transfer. This challenge has triggered the interest in finding the methods to perform highly efficient heat transfer. The efficiency of heat transfer of the energy system is normally analyzed by the application of thermodynamic laws and by performing exergy analysis.

Bejan [2,3] has linked the second law of thermodynamics with the principles of heat transfer.

Szargut [4] has identified 3 main causes of exergy losses which were friction (mechanical or hydraulic), irreversible heat transfer (at a finite temperature difference or temperature gradient), and irreversible diffusion (at a finite concentration difference or gradient. Also, he suggested how the loss should be treated in the art of engineering.

Kotas [5] explained that exergy was the standard of energy quality obtained from a given form of energy using the environmental parameters as the reference state. He also described the mechanism of exergy associated with 3 types of energy transfer which were work transfer, heat transfer, energy transfer associated with mass transfer. The energy was a measure of quantity. On the contrary, exergy was a measure of both quantity and quality

Goran [6] compared the main differences between energy and exergy. While energy was applied with the first law of thermodynamics, exergy was applied with the second law of thermodynamics.

Dincer and Rosen [7] applied exergy analysis to Thermal Energy Storage. Based on his study, exergy balance could be expressed as follows: Exergy input – Exergy output – Exergy consumption = Exergy accumulation.

Guo et al [8] presented the energy and exergy analysis of the power generation system which consists of an economizer, an evaporator, a superheater, a steam turbine, a condenser, and a pump.

San [9] performed a second law analysis to determine the efficiency of heat exchanger for waste heat recovery.

Butcher and Reddy [10] presented the temperature profiles across the heat recovery steam generator, network output, second law efficiency, and entropy generation that are simulated for various operating conditions.

Utlu Z [11] studied the energy and exergy analyses of a raw mill in cement production. The first and second laws efficiencies are 84.3% and 25.2% respectively. The heat losses are composed of conduction, convection, and radiation from the surface by about 14,300 MJ/h. The potential of energy saving is estimated at 14,300 MJ/h, which is the energy recovery of 15.7% of energy input in the raw mill. The waste heat recovery from the exhaust gas at the top of the chimney had been studied the thermoelectric converter was installed on the top of the chimney.

The results were showed that electrical energy can be obtained through a thermoelectric converter unit thrown from chimneys in the form of heat energy. The graph showed the electrical power increasing with temperature difference (hot and cold sides).

In the health and medical field, similar to other fields, energy recovery from medical waste starts to gain interest.

LaGrega G [12] and Office of Technology Assessment]13[defined waste as any substance)solid, liquid, or gas(that has no direct use and is discarded permanently. A waste is considered hazardous if it is flammable, reactive, explosive, corrosive, radioactive, infectious, irritating, sensitizing, or bio-accumulative. Medical waste is limited to infectious, hazardous, and any other wastes that are generated from health care institutions, such as hospitals, clinics, dental offices, and medical laboratories.

Shaaban [14] presented the management of medical waste at hospitals in Egypt. The medical waste was estimated at 75 tons/day from the governmental hospitals in Cairo. The data showed the most appropriate incinerator capacity is 150 kg/h.

Bujak [15] reported the energy efficiency of the incinerator for medical waste. The experimental result showed that the 100 kg of medical waste could be converted to usable energy by about 600-800 kW, and the energy efficiency is in the range of 47-62%.

Veilla E. Matee, Samwel V. Manyele [16] studied the performance of the large-scale incinerator installed in a referral hospital. They found that fuel effectiveness increased linearly with total waste incinerated and incinerator capacity, respectively, depending on the fuel consumption rate. However, the fuel consumption for the large-scale incinerator was too high compared to small-scale incinerator of similar capacity.

Mohsen Saari Pour, Ali Hakkaki-Fard, and Bahar Firoozabadi [17] investigated the performance of a portable incinerator. They reported that increasing the flow rate of the cooling air inside the incinerator could improve the combustion process.

Recently, incinerator waste has been installed at a hospital in Suphan Buri province to manage and utilize medical waste. This research aims to study the efficiency of energy recovery and heat loss of the equipment as the critical inputs for future decision-making for the usage of generated energy.

2. THERMODYNAMICS ANALYSIS

The incinerator waste consists of main equipment as follows: the first section is a waste hopper and feeder, the second section is the rotary kiln primary, the third section is a secondary chamber, the fourth section is the ash cooling conveyer, the fifth section is cyclone and the sixth section is stack.

The first and second laws of Thermodynamics are considered the system. For the case of steady-state steady flow, the balance equations are applied to evaluate the energy of the equipment. The mass balance equation Utlu Z [11] expressed in the form of the rate as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \qquad \text{“Eq.(1)”}$$

Wherever = mass flow rate at the inlet and is the mass flow rate at the outlet.

The general energy balance Utlu Z [11] can be expressed as follows:

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \qquad \text{“Eq.(2)”}$$

Or

$$\dot{Q} + \sum \dot{m}_{in} h_{in} = \dot{W} + \sum \dot{m}_{out} h_{out} \qquad \text{“Eq.(3)”}$$

Where is the rate of net energy transfer in, is the rate of energy transfer out by heat and h is the specific enthalpy.

The first law efficiency Utlu Z [11] expressed as

$$\eta = \frac{\dot{E}_{output}}{\dot{E}_{input}} \qquad \text{“Eq.(4)”}$$

Where η is energy efficiency, $\dot{E}_{useful}$ is energy use, and $\dot{E}_{input}$ is an energy input

Fig.2 Incinerator waste

3. INCINERATOR AND WASTE

The incinerator waste was installed at Suphan Buri Province (Fig.2). The capacity of the incinerator is 300 kg. The incinerator system was composed of 6 sections. The first section is a waste hopper and feeder, the second section is the rotary kiln primary, the third section is a secondary chamber, the fourth section is the ash cooling conveyer, the fifth section is cyclone and the sixth section is stack.

The waste is medical waste. It is composed of 45% of cotton and gauze, 8% of paper, 15% syringe, 25% glove, and 7% other.

Fig.3 Medical waste

The high heating value (HHV) and the average density of the medical waste are 12,327 kJ/kg and 280 kg/m3, respectively.

Table 1 Mass of the system

Item	Input material	T_i (K)	m (Kg/h)	Output material	T_o (K)	m (Kg/h)
1	Waste	303	70	Ash	370	10
2	Air	309	750	Dust	390	60
3	Fuel	310	55	Flue	550	805
	Total		875	Total		875

From Table 1, there were three input materials. One was Waste which had a temperature of 303 ° Kelvin and a flow rate of 303 kilograms per hour. This input yielded Ash with a temperature of 370 ° Kelvin and a flow rate of 10 kilograms per hour.

The second input was Air which had a temperature of 309 ° Kelvin and a flow rate of 750 kilograms per hour. This input yielded Dust with a temperature of 390 ° Kelvin and a flow rate of 60 kilograms per hour.

The last input was Fuel which had a temperature of 310 ° Kelvin and a flow rate of 55 kilograms per hour. This input yielded Flue with a temperature of 550 ° Kelvin and a flow rate of 805 kilograms per hour.

The total flow rate from overall input material was 875 kilograms per hour and that from overall outputs was 875 kilograms per hour.

4. EXPERIMENTAL MEASUREMENT

This experiment was carried out in the summer season in Suphan Buri Province, Thailand. To experiment, thermocouples type K (range: 0-1250 ºC, accuracy ± 0.5 ºC) were installed for measuring the temperature at different positions as shown in Fig. 2. The thermocouples were connected to a data logger (Hioki, Model: 8422-52, accuracy ± 0.8%).

The infrared thermometer (UT 301A) was measured the surface temperature of the stack, combustion chambers, and the kiln. The inlet air temperatures intake the combustion chambers were measured using the velocity probe (TSI Model 8380, range 0-50 m/s, error ± 0.5%).

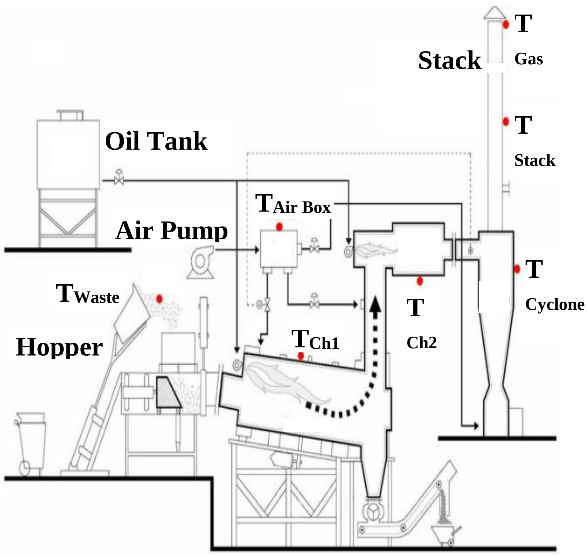

Fig. 2 Schematic of incinerator and measuring positions

5. RESULT AND DISCUSSION

The mass balance of the system is presented on the law of mass conservation as follows:

$$\sum \dot{m}_{in} = \dot{m}_{waste} + \dot{m}_{f,1} + \dot{m}_{a,1} + \dot{m}_{f,2} + \dot{m}_{a,2} \quad \text{“Eq.(5)”}$$

$$\sum \dot{m}_{out} = \dot{m}_{ash} + \dot{m}_{fl} + \dot{m}_{dust} \quad \text{“Eq.(6)”}$$

The energy balance in the system is presented on the law of energy conservation as follows:

$$[\dot{m}_{waste}(HHV) + \dot{m}_f(HHV) + \dot{m}_a c_{p,a} T_a] = \dot{Q}_{loss} + [\dot{m}_{ash} c_{p,ash} T_{ash} + \dot{m}_g c_{p,g} T_g + \dot{m}_{dust} c_{p,dust} T_{dust}] \quad \text{“Eq.(7)”}$$

The energy balance of the system, which was arranged according to the energy components given in Table 2

Heat losses in the system are composed of three modes of heat transfer. Heat losses with the convection are between outside air temperatures and surface temperatures. The heat losses with the conduction are due to the temperature differences of the outer and inner surfaces. Heat losses with the radiation occurred from the outer surface and ambient air. The total heat losses could be calculated by Utlu Z [10] by applying the following equation:

$$\dot{Q}_{total} = \dot{Q}_{conv} + \dot{Q}_{cond} + \dot{Q}_{rad} \quad \text{“Eq.(8)”}$$

Based on the experiment and calculation, the heat loss for the incinerator waste was 2,789,424.75 K.

The convection around the surface of the rotary kiln primary, secondary chamber, and stack was calculated from

$$\dot{Q}_{conv} = \pi D_o hl(T_{sf,out} - T_a) \quad \text{“Eq.(9)”}$$

The conduction through the cylinder calculated from

$$\dot{Q}_{cond} = \frac{(T_{sf,in} - T_{sf,out})}{\frac{\ln(r_o / r_i)}{2\pi kl}} \quad \text{“Eq.(10)”}$$

The radiation from the surface to the ambient air calculated from

$$\dot{Q}_{rad} = \pi D_o \varepsilon\sigma(T^4_{sf,out} - T^4_a) \quad \text{“Eq.(11)”}$$

The energy efficiency of the system is calculated from Eq. 4, using energy analysis values from table 2. The calculated efficiency was 79.6%.

Due to this experiment, the energy output is heat losses from the surface system and energy input is total materials (waste, oil, and air).

Table 2 Energy balance of the system (Input)

Item	Input material	Cp(kJ/kh)/ HHV(kJ/kg)	T (K)	m (kg/h)	Q (K)
1	Waste	12,327	303	70	862,890
2	Air	1.005	309	750	232,908.75
3	Fuel	43,767.7	310	55	2,407,223.5
	Total			875	3,503,032.25

From Table 2, there were three input materials. One was Waste which provided energy transfer at

12,327 kJ/kg with a temperature of 303 ° Kelvin and a flow rate of 70 kilograms per hour. The heat rate from this input was 862,890 ° Kelvin.

The second input was Air which provided energy transfer at 1.005 kJ/kg with a temperature of 309 ° Kelvin and a flow rate of 750 kilograms per hour. The heat rate from this input was 232,908.75 ° Kelvin.

The last input was Fuel which provided energy transfer at 43,767.7 kJ/kg with a temperature of 310 ° Kelvin and a flow rate of 55 kilograms per hour. The heat rate from this input was 2,407,223.5 ° Kelvin

The total flow rate from overall input materials was 875 kilograms per hour and the total heat rate from overall inputs was 3,503,032.25° Kelvin.

Table 3 Energy balance of the system (Output)

Item	Output material	Cp(kJ/kh)/ HHV(MJ/kg)	T (K)	m (kg/h)	Q (K)
1	Ash	0.75	370	10	2,775
2	Dust gas	1.05	390	60	24,570
3	Flue gas	1.55	550	805	686,262.5
	Heat losses from surface				2,789,424.75
	Total			875	3,503,032.25

From Table 3, there were three outputs. One was Ash which provided energy transfer at 0.75 MJ/kg with a temperature of 370 ° Kelvin and a flow rate of 10 kilograms per hour. Heat loss from this output was 2,775 ° Kelvin.

The second output was Dust Gas which provided energy transfer at 1.05 MJ/kg with a temperature of 390 ° Kelvin and a flow rate of 60 kilograms per hour. Heat loss from this output was 24,570 ° Kelvin.

The last output was Flue Gas which provided energy transfer at 1.55 MJ/kg with a temperature of 550 ° Kelvin and a flow rate of 805 kilograms per hour. Heat loss from this output was 686,262.5 ° Kelvin.

Total heat losses from the surface were 2,789,424.75 ° Kelvin while overall heat losses were 3,503,032.25 ° Kelvin.

6. CONCLUSION

This study aims to study the efficiency of energy recovery and heat loss of the incinerator waste installed at a hospital in Suphan Buri Province, Thailand. The incinerator waste consists of main equipment as follows: the first section is a waste hopper and feeder, the second section is the rotary kiln primary, the third section is a secondary chamber, the fourth section is the ash cooling conveyer, the fifth section is cyclone and the sixth section is stack.

To experiment, thermocouples type K (range: 0-1250 ºC, accuracy ± 0.5 ºC) were installed for measuring the temperature at different positions. Besides, The infrared thermometer and the inlet air temperatures intake the combustion chambers were also installed. The waste is medical waste composed of 45% of cotton and gauze, 8% of paper, 15% syringe, 25% glove, and 7% other.

Mass and energy balances were analyzed using the incinerator process. The thermal efficiency was defined by energy losses from the surface divided energy input. The medical waste was used for combustion and analyzed the thermal energy.

The result showed that the total flow rate from overall input materials was 875 kilograms per hour and the total heat rate from overall inputs was 3,503,032.25° Kelvin. In terms of heat losses, total heat losses from the surface were 2,789,424.75 ° Kelvin while overall heat losses were 3,503,032.25 ° Kelvin. Besides, the results showed high thermal efficiency and suitable for use in the waste heat process and application engineering process.

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