CALCULATING THE SOLID WASTE INCINERATOR WITH SAVING ENERGY

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ABSTRACT

In Vietnam, solid waste treatment using incineration is a rather new technology. The calculated method, calculating the field-erected incinerator (capacity of 100 kg/h) supplying natural gas and texture of the wall incinerator was determined. This incinerator has a primary chamber (volume of 2,3 m^3) and a secondary chamber (volume of 1,18m^3). These factors: temperature, turbulence, composition and characteristics of solid waste, moisture, gas ratio were optimized to improve the efficiency of incineration processes, saving fuel, and friendly environment.

Key words: *Incineration, solid waste, saving energy, material balance, heat balance*

INTRODUCTION

In Viet Nam, the amount of solid waste (W) is rapidly increasing in cities due to population growth and economic development. According to the forecast of the Ministry of Natural Resources and Environment, the volume of solid waste generated from urban areas is estimated about 37 thousand tons per day in 2015 and about 59 thousand tons per day in 2020 that is from 2 to 3 times as many solid wastes as that of the current [1]. The applied technology has not responded the required treatment.

The application of other waste treatment methods, such as burning waste, becomes more popular. The waste burning technology can be applied widely for various types of waste, saving space and fast processing. Currently, there are about 50 solid waste incinerators, mostly small - capacity systems (under 500 kg/h), and 400 medical waste incinerators in Viet Nam [10]. The investment of small capacity incinerators is the temporary solution which is contributing to decrease rapidly the amount of solid waste. However, the small capacity incinerators have not any polluted air treatment systems. Besides, the operating of these incinerators is not guaranteed and technical elements are not optimized in the incinerator design leading to polluted air and increased operating costs [10].

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There are some types of incinerators such as: field erected incinerator, rotary kiln incinerator, fluidized bed combustor incinerator, and so on but the field-erected incinerator is the most popular, easily operating, low operating cost, and conformity with Viet Nam's condition [19].

Consequently, this paper referred to the method of calculation of domestic waste incinerator with supplying natural gas to improve the efficiency of incineration processes and saving energy when operating incinerators.

THE METHOD OF CALCULATION

The method of calculation is based on material balance and heat balance [6]

Material balance equation:

$\sum G_i = \sum G_o \leftrightarrow G_w + G_{DO} + G_{sa} = G_{ao} + G_{so} + G_a$

Material input G_i (kg/h)	*Material output G_o (kg/h)*
-Domestic waste G_w (kg/h)	-Air out : G_{ao} (kg/kg)
-Fuel: G_{DO}(kg/h)	-Steam follow smoke: G_{so} (kg/kg)
-Supplied air: G_{sa} (kg/h)	-Ash : G_a (kg/kg)

Heat balance equation:

$\sum Q_i = \sum Q_o \leftrightarrow Q_w + Q_{DO} + Q_m + Q_{sa} + Q_w^b + Q_{DO}^b = Q_{sm} + Q_a + Q_{op} + Q_{sl} + Q_{wa}$

Based on these equations, heat generated in one hour and gas output is determined, so the volume of incinerator is calculated.

Heat input Q_i:	*Heat output Q_o:*
-Heat of dry domestic waste : Q_w	-Heat of smoke: Q_{sm}
-Heat of fuel : Q_{DO}	-Heat of steam out: Q_{so}
-Heat of moisture of supplied air: Q_m	-Heat of ash : Q_a
-Heat of supplied air: Q_{sa}	-Heat lost by opening the door: Q_{op}
-Heat of burning waste: Q_w^b	-Heat lost by the wall: Q_{wa}
-Heat of burning fuel: Q_{DO}^b	

CALCULATION IN DESIGN

The incinerator is designed with the capacity of 100kg/h. Domestic waste is loaded by the mode of interruption. The waste load cycle is two times / hour (50kg/time).

Material balance

Calculating the supplied fuel (G_{DO})

The amount of the supplied DO to burn domestic wastes is x (kg)

The domestic waste components consist of food wastes, paper, carton, yard wastes, plastics, rubber, textiles, wood… The mechanical components of domestic wastes were determined [18,4].

Calculating the supplied air: The chemical reactions occurred during combustion:

$2C + O_2 \rightarrow 2CO$ (1)

$CO + ½ O_2 \rightarrow CO_2$ (2)

$2H_2 + O_2 \rightarrow H_2O$ (3)

$N_{2w} + O_2 \rightarrow 2NO$ (4)

$N_{2sa} + O_2 \rightarrow 2NO$ (5)

$NO + ½ O_2 \rightarrow NO_2$ (6)

$S + O_2 \rightarrow SO_2$ (7)

$2Cl_2 + 2H_2O \rightarrow 4HCl + O_2$ (8)

At the high temperature and burned in the residual oxygen condition, CO born in reaction (1) will react with O_2 to convert to CO_2

The equilibrium constants of reactions (5) and (6) are calculated by the formula:

$$K_1 = \frac{[NO]^2}{[N_2].[O_2]} \; ; \; K_2 = \frac{[NO_2]^2}{[NO].[O_2]^{1/2}} \quad [9]$$

When the temperature is between 1000^0K and 1500^0K, K_1 is in $7,5.10^{-9} - 1,7.10^{-5}$ [9] so NO was born very small. While the temperature raises so K_1 increases and K_2 decreases, and the temperature of the secondary combustion chamber is about 1100^0C, nitrogen exists mostly in the form NO, so NO_2 is generated by 0.

y is the amount of nitrogen in the air at the chemical reaction (5); z is the amount of chlorine in the reaction; and the residual chlorine is 1,2 - z (kg / kg).

Gas ratio is $\alpha = 1,2$ [6]. The air is supplied by the method of convection, for this reason, the incinerator need to maintain the negative pressure inside it during the burning process.

The average temperature of the atmosphere is 25°C and moisture is 80% [5].

Based on reaction equations from (1) to (8); and K_1 (at 1100^0C) → y is found out, from those points, the mass input and output of substances are calculated in the table 2.

Table 1: *Mechanical components and mass of substances in x kg of DO and 100 kg of domestic waste*

Component	Percent by weight of 1kg DO (%)	Mass of substances in DO of x (kg)	Percent by weight of 100kg wastes (%)	Total mass (kg)
C	86,5	0,865x	27,4	27,4 + 0,865x
H	12,5	0,125x	3,6	3,6 + 0,125x
O	0,2	0,002x	21,8	21,8 + 0,002x
N	0,3	0,003x	0,5	0,5 + 0,003x
S	0,5	0,005x	0,1	0,1 + 0,005x
Cl			1,2	1,2
Moisture (M)			30	30
Ash			15,4	15,4

Table 2: *The mass input and output of substances*

Substances input		*Substances output*	
Component	Mass (kg/kg)	Component	Mass (kg/kg)
Domestic waste	100	Ash	15,4
DO	x	Steam	68,66+ 1,3298x-0,2716z
The mass of wet air	424,2611+ 17,5108x - 1,19z	CO_2	100,466 – 3,171x
		SO_2	0,2 + 0,01x
		HCl	1,028z
		Cl_2	1,2 – z
		NO	$1{,}212 + 0{,}049x - 3{,}4.10^{-3}z$
		O_2 residual	16,162 + 0,666x – 0,045z
		N_2 residual	320,951+ 13,229x – 0,899z
G_i	524,261 + 18,510x - 1,19z	G_o	524,867 + 18,509x – 1,191z

Heat balance

Heat input

Calculating the heat of dry domestic waste: $Q_w = G_w.C_w.t_w$ [16]

Where G_w is mass of domestic waste (kg); C_w - the specific heat of waste (Kcal/kg.^{0}C) (C for each component of domestic wastes showed in table 3 [3]; t_w: The temperature of domestic wastes (^{0}C).

Table 3: *The specific heat of each component of waste*

Component	Mass (kg)	Specific heat (Kcal/kg. ^{0}C)
Noncombustible materials	15,4	$C_{ash} = 0{,}18$
Moisture of materials	30	$C_{moisture} = 1$
Combustible materials	54,6	$C_{combustion} = 0{,}26$

Calculating the heat of DO: $Q_{DO} = G_{DO}.C_{DO}.t_{DO}$ [16]

Where G_{DO} is the mass of DO to burn 100 kg of waste, C_{DO}- the specific heat of DO (C_{DO} = 0,45 (Kcal/kg. ^{0}C)) [2].

Calculating the heat of the supplied air: $Q_{sa} = G_{sa}.C_{sa}.t_{sa}$

Where C_{sa} – the specific heat of air (C_{sa} – 0,24 (Kcal.kg.^{0}C)) [17]; G_{sa} – the volume of the supplied air

Calculating the heat of moisture of the supplied air: $Q_m = G_m.C_{so}.t + G_m.r_{so}$ [16]

Where C_{so} - the specific heat of steam, C_{so} = 0,487 (Kcal/kg.^{0}C) [17]; r_{so}– The heat-evaporation of water, r_{so} = 540 (Kcal/kg) [17]; $G_m = 0{,}015.\ G_{sa}$

Calculating the heat of dry domestic waste: $Q_w^b = q_w^b.G_w$ (Kcal)

Where q_w^b – The heating value of waste; q_w^b = 81C + 246H – 26(O – S) – 6M [kJ/kg] [6]

Calculating the heat of DO: $Q_{DO}^b = q_{DO}^b.G_{DO}$ (Kcal)

Where q_{DO}^b - The heating value of DO: q_{DO}^b = 339C + 1256H – 108,8(O – S) – 25,1(M + 9H) [kJ/kg] [14].

(C, H, O, W, S are the mass percent of carbon, hydrogen, oxygen, moisture and sulfur).

Consequently, the heat was born when burning x kg DO: Q_{DO}^b = 42187,21.x (Kcal).

Heat output

When calculating heat output, the average temperature in the primary combustion chamber is used at 650^{0}C and the secondary combustion chamber is used at 1100^{0}C.

Calculating heat of the ash: $Q_a = G_a.C_a.t_a$ (Kcal) [16]

Where G_a is the mass of noncombustible materials (kg); C_a the specific heat of ash.

(C_a = 753,5 + 0,25.($\frac{9}{5}$. t + 32) [17]; t_a – the temperature made the ash (1100°C))

Calculating heat of the smoke: Q_{sm} $G_{sm}.C_{sm}.t_{sm}$ [16]

Where G_{sm} is the mass of combustible air C_{sm}- the specific heat of air (Kcal/kg.°C).

Air contains about 99% the volume of nitrogen and oxygen, and 1% the others [5]. The specific heat of the substances in the air is showed by the table 4 [3].

Table 4: *The specific heat of the substances in the air at 1100°C*

The substances in the air	CO_2	NO	SO_2	HCl	Cl_2	O_2	Steam	Inert air
C (kcal/kg.°C)	0,313	0,29	0,21	0,22	0,31	0,27	0,6	0,125

$\rightarrow Q_{KL} = Q_{CO2} + Q_{NO} + Q_{N2} + Q_{HCl} + Q_{Cl2} + Q_{SO2} + Q_{O2}$

Calculating heat of the steam out: $Q_{so} = G_{so}.C_{so}.t_{so}$ [16]

Calculating heat lost by the wall: $Q_{wa} = (3\div5)\% \ (Q_w^b + Q_{DO}^b)$ (Chosen 5%)

Calculating heat lost by opening the door: $Q_{op} = 10\% \ Q_{wa}$

Table 5: *Heat values in the heat balance equation*

Heat input		*Heat output*	
Component	Heat (Kcal)	Component	Heat (Kcal)
Q_W	1174,2	Q_a	5082
Q_{DO}	11,25x	Q_{sm}	141346,30 + 5475,286 − 389,979z
Q_{sa}	2507,946 + 103,512x − 7,038z	Q_{so}	45315,6 + 877,668x – 179,256z
Q_m	3462,062 + 142,891x – 9,715z	Q_{wa}	118,04 + 2109,361x
Q_w^b	2360,8	Q_{op}	11,804 + 210,936x
Q_{DO}^b	42187,21.x		
Q_i	9505,008+42444,863x-16,753z	Q_o	191873,746 + 8673,251x – 569,235z

Following the heat balance equation: $Q_i = Q_o \Leftrightarrow 182368,738 - 33771,612x - 552,482z = 0$ (**)

The equation (**) is solved with z ($0 \le z \le 1,2$) (z is the amount of chlorine in the reaction (8)). If z = 1,2 chlorine will join absoltutely reaction → x = 5,38 (kg). To change x = 5,38 (kg) and z = 1,2 (kg) into the equation (*) → y = 0,171 (kg). To change x, y, z in the values of the table 6.

Table 6: *The mass input and output of substances*

Substances input		*Substances output*		
Component	Mass (kg)	Component	Mass (kg)	Mass of mole (kmol)
Domestic waste	100	Ash	15,4	
DO	5,38	Steam	75,488	4,194
The mass of wet air	517,04	CO_2	117,525	2,671
The mass of real air	509,397	SO_2	0,254	$3.96.10^{-3}$
		HCl	1,2336	0,034
		Cl_2	0	0
		NO	1,471	0,049
		O_2 residual	19,691	0,615
		N_2	391,044	13,966
		Total	622,107	21,533

Dust is made up about 25% of the ash [3] → G_d = 25%.15,4 =3,85 (kg/h)

The volume of the smoke goes out:

$$Q=\frac{G_{go}}{\rho_{go(25^0C)}.3600}=\frac{509,397}{1,1817.3600}=0,119\ (m^3/s)$$

The volume of the combustion chambers

The primary combustion chamber

The theoretic volume of the primary combustion chambers is calculated:

$$V_{SC}{}^{LT}=\frac{Q_{SC}}{q_v}\ [8]$$

Where Q_{SC} is the heat born in 1 hour (Kcal/h); q_v Density of the volume ($q_v = 120.10^3$ (Kcal/m^3.h) [14] and the heat of the primary combustion chamber make up about 80% Q_o [17]

$$V_{SC}{}^{LT}=\frac{Q_{SC}}{q_v}=\frac{0,8.(191873,746+8673,251x-569,235z)}{120.10^3}$$
$=1,58\ (m^3)$

The capacity is 100kg/h $\rightarrow V_w = G_w/\rho$ = 100/289 = 0,35 (m^3) (with the specific gravity of waste ρ = 289 kg/m^3) [1], The real volume of the primary combustion chamber is affected of the capacity (selected 0,9) and the time (selected 0,95)

The real volume of the primary combustion chamber is: $V_{PC}{}^{R}=\frac{1,93}{0.9.0.95}=2,26 \approx 2,3(m^3)$

Thus, the real size of the primary combustion chamber is:

a x b x H = 1,25 x 1,15 x 1,6 (m^3)

The secondary combustion chamber

The theoretic volume of the secondary combustion chamber is calculated: $V_{SC}{}^{TH} = \theta.q$ (m^3) [2].

Where θ is the retention time of the smoke in the combustion chamber (selected θ = 1,5s); q – the volume of the smoke born in 1s (m^3/s)

On the other hand: Pq = nRT where: n: the mole of the air: $n=\frac{21,533}{3600}=5,981.10^{-3}$ (kmol/s)

R- Constant: R = 0,082; q- The volume of the air born in 1s; T- Temperature (K); P- Pressure (atm)

$$q=\frac{nRT}{P}=\frac{5,981.10^{-3}.0,082.(1100+273)}{1}=0,673(m^3/s)$$

$$V_{SC}{}^{TH} = 1,5.0,673 = 1,0095\ (m^3)$$

The real volume of the secondary combustion chamber is affected of the capacity (selected 0,9) and the time (selected 0,95)

$$V_{SC}{}^{R}=\frac{1,0095}{0,9.0,95}=1,18\ (m^3)$$

The size of the secondary combustion chamber a×b×h = 0,65×1,15×1,6 m

The size of the grate: $F_g=\frac{V}{h_h}$ [9]

Where V is the volume of wastes (m^3); h_h the height of wastes on the grate (m) (selected h_w = 0,2 m [6])

When the capacity is 100kg/h, the waste load cycle is 2 times/hour (50kg/time) and ρ_w = 289 (kg/m^3) [1].

$$\rightarrow F_g=\frac{50}{289.0,2}=0,865\ (m^2)$$

The refractory

The combustion wall consists of 4 layers [6]: firebrick, diatomit brick, fibrous glass, flat-steel.

Table 7: *Characteristics of the refractorys*

Refractory	Specific gravity ρ (kg/m^3)	Coefficient of conduction λ (W/m.^{0}C)	Specific heat C_P (kcal/kg.^{0}C)	Thickness (mm)
Samot firebrick	1900	0,475	0,275	230
Diatomit brick	740	0,18	0,22	113
Fibrous glass	16	0,0372	0,2	50
Flat-steel	7850	46,5	0,119	3

CONCLUSION

The domestic waste incinerator (the capacity of 100kg/h) is designed with 2 chambers (the primary combustion chamber is 2,3 m^3, and the secondary combustion chamber is 1,18 m^3), the size of the grate is 0,865 m^2 and it insured the good heatproof and heat-insulated refractory. *When operating the* incinerator it is supplied to natural air, so it saves energy and low operating costs.

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TÓM TẮT
TÍNH TOÁN LÒ ĐỐT CHẤT THẢI RẮN TIẾT KIỆM NĂNG LƯỢNG

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Tại Việt Nam, xử lý chất thải rắn bằng phương pháp đốt là một công nghệ khá mới mẻ và gặp nhiều khó khăn. Bài báo đã đưa ra phương pháp tính, tính toán thiết kế lò đứng hai cấp đốt chất thải công suất 100 kg/h có cấp khí tự nhiên với buồng sơ cấp là 2,3 m^3 và buồng thứ cấp là 1,18 m^3, đưa ra kết cấu của tường lò. Thiết kế này đã tối ưu hóa các yếu tố như: nhiệt độ, mức độ xáo trộn của không khí cấp với chất thải, thời gian lưu cháy, thành phần và tính chất của chất thải, độ ẩm, hệ số cấp khí để giúp nâng cao hiệu quả quá trình đốt chất thải, tiết kiệm nhiên liệu, thân thiện với môi trường

Từ khóa: *thiêu đốt, chất thải rắn, tiết kiệm năng lượng, cân bằng vật chất, cân bằng nhiệt lượng*

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