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Simulation of Heat Integration for Gasification of Waste Plastic Materials in Insulated Rotary Kiln Reactor

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Abstract

Production of plastic materials has been increased dramatically over the past few decades due the majority usage daily live. Substantial quantities of plastic materials have accumulated in the natural environment and in landfills. Discarded plastics are growing disaster because disposal of waste plastics poses a great hazard to the environment and most plastics are slowly biodegradable. Therefore, an urgent needed to disposal of waste plastics because the effective method has not yet been implemented. The fast majority of researches have been conducted to recycle of thermoplastic-based materials, while recycling of thermoset polymers are impossible due to their natures. Gasification as thermo-chemical treatment for reprocessing of thermosetting polymers-based waste plastics into useful materials has been proposed. The objective of the present research work is to investigate gasification of thermosetting and thermoplastics wastes in a rotary kiln reactor. A mixture of waste plastics and paper–pulp with ratio of 9:1 was used as a dry feedstock to the reactor with a rate of 1000 kg/h. At high temperature, the raw materials of plastics tend to decompose to carbon monoxide (CO) and hydrogen (H2) as main products, which well-known syngas. Utilization of these gases for use a feedstock for the production of new petrochemicals and plastics has been extensively investigated. The amount of total heats in the high-temperature gasification of polymers is one of the important parameters. Algorithm in the MATLAB software was established to investigate the heat losses from the reactor. The simulation of the heat transfer showed that the heat loss decreases with an increase in the refractory thickness. The analysis of the heat transfer process indicated that the heat losses using refractory thicknesses of 2, 4, and 6 cm were 354.0, 202.6, 143.3 kcal/K.d.F, respectively. Because gasification of polymers is endothermic process, the optimum thickness was 6 cm.

Keywords: Waste plastics; gasification; rotary kiln reactor; heat transfer.

1. Introduction

Plastics have become common materials of our everyday lives, and many of their properties. Such as durability, energy efficiency, light weight, coupled with a faster rate of production and design flexibility, the plastics are employed in entire gamut of industrial and domestic areas.Plastics are produced from petroleum derivate and are composed primarily of hydrocarbons but also contain additives such as antioxidants, colorants and other stabilizers. Disposal of plastics poses a great hazard to the environment and the effective method has not yet been implemented. Plastics are slowly biodegradable polymers mostly containing carbon-hydrogen, and few other elements like nitrogen. Due to its non-biodegradable nature. Plastics are chemicals that bond together to produce a solid material at room temperature.[1] The use of plastic materials in daily life has continuously increased over the last 30 years. The amount of plastic consumed has increased by a factor of 60

over this period [1].
Plastics can be divided into two main basic categories: Thermoplastics and Thermosets. The general concerns about environmental protection and resource conservation have led to the development of a variety of solid waste management techniques Figure 1.1 to reduce both the environmental impact of the different types of waste and the depletion of natural resources.

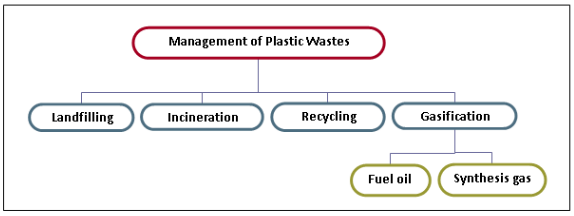

Figure 1.1: Management of waste plastic

Gasification is essentially thermal decomposition of organic matter under inert atmospheric conditions or in a limited supply of air.In the general sense, gasification is the conversion of a carbonaceous material into a gaseous product for the production of energy products and by products in an oxygen starved environment. One of its major advantages lies in the fact that it is not necessary to separate the different polymers present in the plastic wastes. Moreover, in many cases plastic wastes are gasified while mixed with other components of the solid waste stream [2].
However, the economics of a gasification process largely depend on the value and possible applications of the synthesis gas, either as an energy source by combustion or for the synthesis of various chemicals (methanol, ammonia, hydrocarbons, acetic acid, etc.) [2].
The carbonaceous or “organic” material in waste is processed in an oxygen deficient environment with heat to produce a syngas comprising mostly of carbon monoxide (CO) and hydrogen (H_2).
Chemical bonds of the carbonaceous materials (complex chemical compounds) break down with heat to produce the more simple and thermodynamically stable gaseous molecules of CO and H_2.[2]
Polymer thermal decomposition is an endothermic process. The rotary kiln reactor is a cylindrical vessel, inclined slightly to the horizontal, which is rotated slowly about its axis. The material to be processed is fed into the upper end of the cylinder. As the kiln rotates, material gradually moves down towards the lower end, and may undergo a certain amount of stirring and mixing. Hot gases pass along the kiln, sometimes in the same direction as the process material (co-current), but usually in the opposite direction (counter-current). The hot gases may be generated in an external furnace, or may be generated by a flame inside the kiln. In order to protect the outer steel shell of the kiln from high temperatures within the kiln the whole of the kiln is lined with refractory materials which insulate the shell from both the high temperatures and the potentially corrosive reactions that take place within the kiln. It may consist of refractory bricks or cast refractory concrete. The shell temperature needs to be maintained below around 350°C in order to protect the steel from damage where "hot spots" indicative of refractory failure.

2. Material and Methods

The feed rate = 1000 kg dry feed/hr which contain the proportion of plastic in the municipal waste stream thermoplastics 80% , thermosettings 10% and paper − pulp plant mixtures 10% , in rotary kiln reactor. The reactor is operating at 1100 °C, The combustion system is a key elementin efficient thermal processing of bulk solids in a rotary kiln.

2.1. Heat Transfer in a Rotary Reactor at High Temperature

2.1.1. Radiant Heat Transfer from Flame and Combustion gas

The radiant heat transfer coefficient, hrg, to two solid surfaces is calculated by Equation 2.1 :

$$h_{rg} = \frac{d_f}{d_{ti}}(\epsilon_f \epsilon_m)(4.88) * \frac{\left[\left(\frac{(T_f+273)}{100}\right)^4 - \left(\frac{(T^*+273)}{100}\right)^4\right]}{T_f - T^*} \quad [kcal/m^2.hr.^oC] \tag{2.1}$$

Where: d_f is the outer diameter of the flame,$\in_f$ is the emissivity of the flame, ϵ_m is the average emissivity of the solids layer surface and the inner wall surface and T^* is the average temperature of the above two surfaces. From the end of the flame, combustion gas flows in the reactor. In this region, Equation 2.2 should be applied.

$$h_{rg} = (\epsilon_g \epsilon_m)(4.88) * \frac{\left[\left(\frac{(T_g+273)}{100}\right)^4 - \left(\frac{(T^*+273)}{100}\right)^4\right]}{T_g - T^*} \quad \left[kcal/m^2.hr.^oC\right] \tag{2.2}$$

Where: T_g is temperature of gas.

2.1.2. Radiant Heat Transfer from Inner Wall Surface to Surface of Rotating Solids Layer

We define the radiant heat transfer coefficient from the hot inner wall to the layer of solids by $(h_{rs})_{HC}$ on the basis of the surface area of the inner wall, to which the rotating solids contact [3].

$$(h_{rs})_{HC} = \epsilon_H (1-\epsilon_g)\epsilon_C (4.88) * \frac{\left[\left(\frac{(T_H+273)}{100}\right)^4 - \left(\frac{(T_C+273)}{100}\right)^4\right]}{T_H - T_C} \quad \left[kcal/m^2.hr.^oC\right] \tag{2.3}$$

Where: T_H is temperature of rotate.

2.1.3. Heat Transfer Coefficient by Direct Contacting of Solids from The Hot Wall Surface

$$(h_p)_{HC} = 1.13 \left[\frac{(K_e.\rho.C_s.N)}{\chi}\right]^{1/2} \quad \left[kcal/m^2.hr.^oC\right] \tag{2.4}$$

Where: ρ is Density of feed stockkg/m^3, C_s is Specific heat of feed stock $kcal/kg.^oC$, K_e is Effective thermal conductivity of feed stock$\frac{kcal}{m.hr.^oC}$, χ is surface which contacts rotating solids and N is rate of rotate 1/min.

Heat loss to outside is obtained by Equation 2.5:

$$\pi \left(\bar{d}_t\right)\left(\frac{K_s}{l_w}\right)(T_H - T_w) = \pi(d_{t_o})(h_c + h_r)_w (T_w - T_o) \tag{2.5}$$

Heat balance at the inner surface of the reactor is given by Equation 2.6:

$$(1-\chi)h_{rg}(T_f - T_H) = \chi[(h_{rs})_{HC} + (h_p)._{HC}](T_H - T_c) + \frac{d_t K_s}{d_{ti} l_w}(T_H - T_w) \tag{2.6}$$

$$(h_c + h_r)_w = .05T_w + 7 \tag{2.7}$$

Where: $(h_c+h_r)_w$ is heat transfer coefficient from outer surface of reactor.

3. Results and Discussion

3.1. Heat Transfer Coefficient and Temperature

Calculated the values of heat flux q_w from the outer surface of a kiln in each region combustion and cracking region [4].

3.1.1. In The Combustion Region:

Let T_f = 1100 °C, T_C=990 °C, T^*=1000 °C, From Equation 2.1, we obtain:

$$h_{rg} = 112.66 kcal/m^2.hr.^\circ C$$

Equation 2.3 gives:

$$(h_{rs})_{HC} = 137.35 kcal/m^2.hr.^\circ C$$

With Equation 2.4:

$$(h_p)._{HC} = 471.67 kcal/m^2.hr.^\circ C$$

Substituting the above numerical values to Equations 2.5, 2.6, and 2.7, we get:
$T_w = 171^\circ C, T_H = 950^\circ C$,
$(h_c + h_r)_w = 16.47 kcal/m^2.hr.^\circ C$
$q_w = 16.47 * (171 - 20) = 2492.8 kcal/m^2.hr.^\circ C$

3.1.2. In The Thermal Cracking Region:

Same procedure for the thermal cracking region get $q_w = 1254 kcal/m^2.hr$
Heat loss per 1 kg of dry feed = 143 $Kcal/Kg.d.f$
By using computer program (MATLAB) the data in Table 3.1 have been obtained.
Refractory can be considered a long term investment with associated financial benefit. Hence, there is a definite economic limit to the amount of refractory, which is justified. An increased thickness is uneconomical and cannot be recovered through small heat savings. This limiting value is

Table 3.1: Prediction of effect change of refractory thickness on rotary kiln surface temperature and total thermal loss

Thickness of refractory (m)	Surface Temp. combustion region °C	Surface Temp. cracking region °C	Thermal Loss $\frac{Kcal}{Kg.d.f}$
0.01	378	243	583.002
0.02	286	189	353.972
0.03	239	159	256.97
0.04	209	140	202.638
0.05	187	126	167.695
0.06	171	115	143.246
0.07	158	107	125.129
0.08	148	100	111.159
0.09	139	100	101.866
0.1	132	100	94.361

termed as economic thickness of insulation. Specified 60 mm is thickness provides the highest.
It's clarified where: as increasing in thickness of refractory will be decreasing in external wall surface temperatures for combustion region and cracking region. A typical refractory will be capable of maintaining a temperature drop of 1000°C or more between its hot and cold faces.
The shell temperature needs to be maintained below around 350°C in order to protect the steel from damage, and continuous infrared scanners are used to give early warning of "hot spots" indicative of refractory failure.

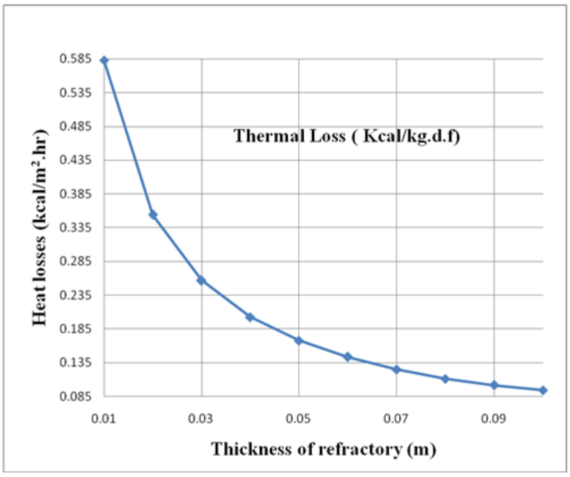

Figure 3.2: Effect of change of refractory Thickness on the heat losses

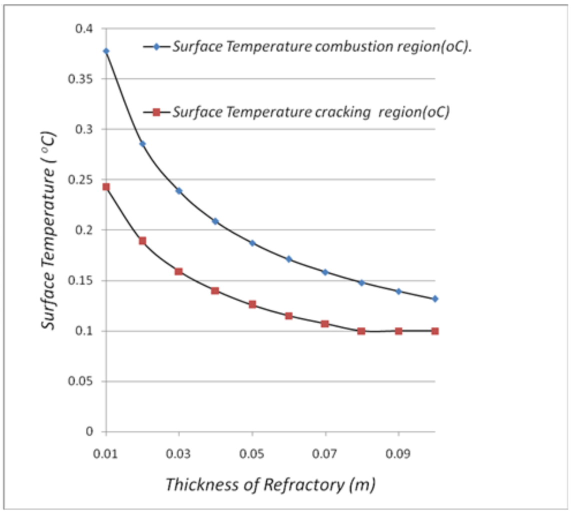

Figure 3.1: The effect of change of refractory thickness on the temperature of out surface of rotary kiln

From the Figure 3.2 note that heat losses is decrease from 567 to 85 kcal/m^{2}hr approximately 85% with increase in thickness of refractory from 0.01 to 0.1 m.

4. Conclusion

Thickness of refractory plays a key role to reduce heat loss from rotary kiln surface as well as the protection of shell rotary reactor temperature where maintained below around 350°C in order to protect the steel from damage where "hot spots" indicative of refractory failure.

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