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NUMERICAL SIMULATION OF COMBUSTION PROCESS IN A FURNACE

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"I hereby to declare that the work is my own except for summaries and quotations which have been duly acknowledged "

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Date : 13 May 2008

Dedicated to my parents, family, friends and companions

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ABSTRACT

Furnace is a contrivance for the production and utilization of heat by the combustion of fuel. This thesis is done focused on the numerical simulation of combustion process in a furnace to analyze the temperature and emission release. Biomass substances that used are wood as a fuel of combustion in the furnace. This project is done by using the simulation work in GAMBIT Software and FLUENT 6.1 software. In the beginning of this project, the modeling of furnace must be done and defining the boundary condition must be correct. The result that obtained in this project is temperature in detail and gas concentration of carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO). The temperature that compared between simulation and experimental work at three points area are nearly same whereas the gas concentration of methane at outlet's of furnace produced from simulation work is 1.84 ppm and carbon dioxide is 43.3 ppm. The concentration of carbon monoxide produced small amount at 7.62 ppm. From this project, temperature and gas concentration can be analyzed clearly compare with experimental work but the result not very accurate compare with experimental.

ABSTRAK

Relau pembakaran adalah rekaan bagi pengeluaran dan pemanasan oleh pembakaran bahan api. Projek ini bertujuan mengkaji dan mejalankan simulasi proses pembakaran kayu di dalam relau pembakaran untuk menganalisa suhu dengan terperinci dan pengeluaran gas-gas semasa proses pembakaran bahan biojisim ini berlaku. Bahan biojisim yang digunbakan untuk pembajaran ini ialah kayu di mana ianya adalah bahan api dalam pembakaran di dalam relau. Projek ini menggunakan kerja simulasi dengan berbantu perisian GAMBIT dan FLUENT 6.1. Permulaaan projek ini, rekaaan model bagi relau pembakaran mesti di lakukan dan sifat pembatasan model perlu di kenalpasti dengan terperinci. Keputusan yang diperolehi dalam projek ini adalah berkenaan dengan suhu terperinci dan gas yang dikeluarkan semasa proses Pembakaran iaitu karbon dioksida(CO_2), metana (CH_4), dan karbon monoksida (CO). Perbandingan suhu di antara kerja simulasi dan amali di atas tiga bahagian tempat di relau pembakaran adalah hamper sama manakala gas yang dikeluarkan seperti metana ialah sebanyak 1.84 ppm dan karbon dioksida ialah 43.3 ppm. Bagi karbon monoksida, jumlah yang dikeluarkan adalah kecil sebanyak 7.62 ppm. Daripada projek ini, didapati bahawa kerja simulasi dapat menganalisa dengan terperinci berbanding amali tetapi keputusan kajian tidak begitu tepat berbanding amali.

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CHAPTER 1

INTRODUCTION

1.1 Project Overview

Global energy consumption is rising due to rapid industrialization and improvement in living standards. Nearly 80 % of the world's energy consumption is fossil fuel based which is causing environmental and health concerns due to increased emissions of CO_2, NO_x and SO_2. After fossil fuels, biomass is the fourth largest source of energy. It supplies about 11-12 % of world's primary energy consumption. In developing countries, it is the predominant form of energy and accounts for about 38 % of their primary energy consumption and in rural areas 90 % of their total energy supplies. As 90 % of the world's population is expected to reside in developing countries by 2050, biomass energy is likely to remain a substantial energy feedstock.

Biomass has high but variable moisture content and is made up of carbon, hydrogen, oxygen, nitrogen, sulphur and inorganic elements. In comparison to fossil fuels, biomass contains much less carbon, more oxygen and a lower heating value in the range of 12-16 MJ/kg. The chemical energy of biomass can be converted to useful forms through biochemical, chemical and thermo-chemical conversion methods. [(*Sokhansanj et al, 2003, Zhou et al, 2003)*]. Only selected biomass can be converted into biogas, ethanol, biodiesel and others through biochemical and chemical methods, whereas most of the biomass material can undergo thermo-chemical conversion, thus making this method much more attractive than the others.

Amongst the thermo-chemical conversion technologies, biomass gasification has attracted the highest interest as it offers higher efficiencies in relation to combustion. Gasification is a partial oxidation process at elevated temperatures (500-1400 °C) that results in producer gas consisting of CO, H_2, CO_2, CH_4, traces of higher hydrocarbons such as ethane and ethane, water vapor, nitrogen (if air is the oxidizing agent) and various contaminants such as small char particles, ash, tar and oil. Gasification of biomass is primarily done infixed and fluidized beds. The fixed bed gasifiers are suitable for small-scale applications (<10MW_{th}) and the fluidized bed configurations are cost effective in large-scale applications that generate over 15 MW_e.

1.2 Problem Statement

Furnace almost use for scarcely of land such as garbage dump site. It also disposes solid waste in combustion process to reduce emission release. In current furnace had been designed nowadays, from experimental work, the temperature net is recorded when combustion process is running and this process will show the temperature come out from the outlet whereas the gas concentration in this process difficult to recorded.

The main factor in this project is to analyze wood combustion process in furnace in terms of temperature in details and emission release. So, the simulation on wood combustion need to be done using the CFD software in determines the temperature in detail and emission released as gas concentration profile that will reduce when the combustion process is running in furnace.

1.3 Objective

The objective of this study:

- To analysis wood combustion process in terms of temperature in detail and gas concentration profile which are carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4).

1.4 Project Scope

The scope of this project work generally involved the following:

- Literature review specifically furnace and wood combustion process
- Draw a furnace through Gambit software
- Simulate the wood combustion process in the furnace using FLUENT 6.1

CHAPTER 2

LITERATUTRE REVIEW

2.1 Introduction of Furnace

Furnace is a contrivance for the production and utilization of heat by the combustion of fuel. The word is common to all the Romance tongues, appearing in more or less modified forms of the Latin *fornax.* But in all those languages the word has a more extended meaning than in English, as it covers every variety of heating apparatus; while here, in addition to furnaces proper, we distinguish other varieties as *ovens, stoves* and *kilns.* The first of these, in the form *Ofen,* is used in German as a general term like the French *four;* but in English it has been restricted to those apparatus in which only a moderate temperature, usually below a red heat, is produced in a close chamber. Our bakers' ovens, hot-air ovens or stoves, annealing ovens for glass or metal, &c., would all be called *fours* in, French and *Olen* in German, in common with furnaces of all kinds. Stove, an equivalent of oven, is from the German *Stube,* a heated room, and is commonly so understood; but is also applied to open fire-places, which appears to be somewhat of a departure from the original signification.

Furnaces are constructed according to many different patterns with varying degrees of complexity in arrangement; but all may be considered as combining three essential parts, namely, the fire-place in which the fuel is consumed, the heated chamber, laboratory, hearth or working bed, as it is variously called, where the heat is applied to the special work for which the furnace is designed, and the apparatus for producing rapid combustion by the supply of air under pressure to the fire. In the simplest cases the functions of two or more of these parts may be combined into one, as in the smith's forge, where the fire-place and heating chamber are united, the iron being placed among the coals, only the air for burning being supplied under pressure from a blowing engine by a second special contrivance, the tuyere, guiro, twyer or blast-pipe; but in the more refined modern furnaces, where great economy of fuel is an object, the different functions are distributed over separate and distinct apparatus, the fuel being converted into gas in one, dried in another, and heated in a third, before arriving at the point of combustion in the working chamber of the furnace proper.[(Davies and Clive ,1970).]

2.2 Function

The furnace transfers heat to the living space of the building through an intermediary distribution system. If the distribution is through hot water (or other fluid) or through steam, then the furnace is more commonly termed a boiler. One advantage of a boiler is that the furnace can provide hot water for bathing and washing dishes, rather than requiring a separate water heater.

Air convection heating systems have been in use for over a century, but the older systems relied on a passive air circulation system where the greater density of cooler air caused it to sink into the furnace, and the lesser density of the warmed air caused it to rise in the ductwork, the two forces acting together to drive air circulation in a system termed "gravity-feed; the layout of the ducts and furnace was optimized for short, large ducts and caused the furnace to be referred to as an "octopus" furnace.

By comparison, most modern "warm air" furnaces typically use a fan to circulate air to the rooms of house and pull cooler air back to the furnace for reheating; this is called forced-air heat. Because the fan easily overcomes the resistance of the ductwork, the arrangement of ducts can be far more flexible than the octopus of old. In American practice, separate ducts collect cool air to be returned to the furnace. At the furnace, cool air passes into the furnace, usually through an air filter, through the blower, then through the heat exchanger of the furnace, whence it is blown throughout the building. One major advantage of this type of system is that it also enables easy installation of central air conditioning by simply adding a cooling coil at the exhaust of the furnace.

Air is circulated through ductwork, which may be made of sheet metal or plastic "flex" duct and insulated or uninsulated. Unless the ducts and plenums have been sealed using mastic or foil duct tape, the ductwork is likely to have a high leakage of conditioned air, possibly into unconditioned spaces. Another cause of wasted energy is the installation of ductwork in unheated areas, such as attics and crawl spaces; or ductwork of air conditioning systems in attics in warm climates.

The following rare but difficult-to-diagnose failure can occur. If the temperature inside the furnace exceeds a maximum threshold, a safety mechanism with a thermostat will shut the furnace down. A symptom of this failure is that the furnace repeatedly shuts down before the house reaches the desired temperature; this is commonly referred to as the furnace "riding the high limit switch". This condition commonly occurs if the temperature setting of the high limit thermostat is set too close to the normal operating temperature of the furnace. Another situation may occur if a humidifier is incorrectly installed on the furnace and the duct which directs a portion of the humidified air back into the furnace is too large. The solution is to reduce the diameter of the cross-feed tube, or install a baffle that reduces the volume of re-fed air. [(Fiveland, W.A., Crosbie, A.L., Smith A.M. and Smith, T.F., 1991)]

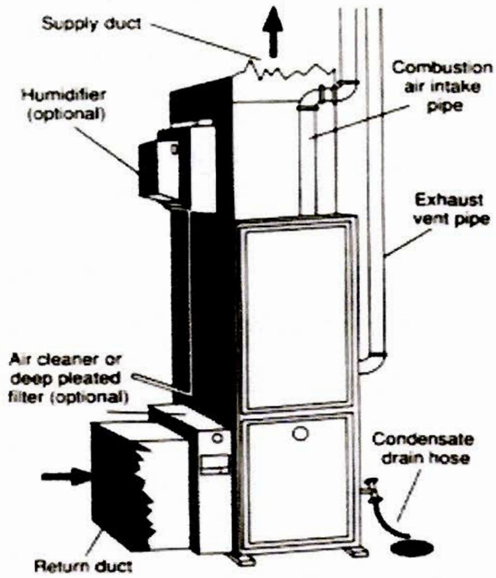

Figure 2.1: Schematic of a condensing furnace.

(Source: American Society of Mechanical Engineers)

2.3 Combustion

Combustion or burning is a complex sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat or both heat and light in the form of either a glow or flames. In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen or fluorine, and the products are compounds of each element in the fuel with the oxidizing element. For example:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat$$

$$CH_2S + 6F_2 \rightarrow CF_4 + 2HF + SF_6 + heat$$

A simpler example can be seen in the combustion of hydrogen and oxygen, which is a commonly used reaction in rocket engines:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{heat}$$

The result is simply water vapor.

In the large majority of the real world uses of combustion, the oxygen (O_2) oxidant is obtained from the ambient air and the resultant flue gas from the combustion will contain nitrogen:

$$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2 + \text{heat}$$

As can be seen, when air is the source of the oxygen, nitrogen is by far the largest part of the resultant flue gas.

In reality, combustion processes are never perfect or complete. In flue gases from combustion of carbon (as in coal combustion) or carbon compounds (as in combustion of hydrocarbons, wood etc.) both unburned carbon (as soot) and carbon compounds (CO and others) will be present. Also, when air is the oxidant, some nitrogen will be oxidized to various, mostly harmful, nitrogen oxides (NOx).

2.4 Types of Combustion

2.4.1 Rapid Combustion

Rapid combustion is a form of combustion in which large amounts of heat and light energy are released, which often results in a fire. This is used in a form of machinery such as internal combustion engines and in thermo baric weapons. Combustion is double replacement reaction. On the other hand a chemical reaction is single replacement reaction.

2.4.2 Slow Combustion

Slow combustion is a form of combustion which takes place at low temperatures. Respiration is an example of slow combustion.

2.4.3 Complete Combustion

In complete combustion, the reactant will burn in oxygen, producing a limited number of products. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. When elements such as carbon, nitrogen, sulfur, and iron are burned, they will yield the most common oxides. Carbon will yield carbon dioxide. Nitrogen will yield nitrogen dioxide. Sulfur will yield sulfur dioxide. Iron will yield iron (III) oxide. It should be noted that complete combustion is almost impossible to achieve. In reality, as actual combustion reactions come to equilibrium, a wide variety of major and minor species will be present. For example, the combustion of methane in air will yield, in addition to the major products of carbon dioxide and water, the minor products which include carbon monoxide, hydroxyl, nitrogen oxides, monatomic hydrogen, and monatomic oxygen.

2.4.4 Turbulent Combustion

Turbulent combustion is a combustion characterized by turbulent flows. It is the most used for industrial application (e.g. gas turbines, diesel engines, etc.) because the turbulence helps the mixing process between the fuel and oxidizer.