SIMULATION OF SOLID FUEL COMBUSTION IN THE CYCLONE COMBUSTION CHAMBER USING FLUENT-14.0

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Special dedication for my beloved mother, Subaidah Binti Abu Bakar,
My siblings, my fiancé and my entire friends,
No have words to except thank you so much for your endless love and support,
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ABSTRACT

Al-Qur'an is Holy Scripture of Islam therefore the printed text itself is treated with a great deal of respect. Unavoidably, there are times when an Al-Qur'an needs to be disposed and burning is one of the method but it require to make sure the scripture is fully burnt and the ashes produce is in the controlled condition. The best way to done this method is by using the Cyclone Combustion chamber. Cyclone combustor is known as the separator of the ash from the gaseous products of the solid fuel. The objectives of this study are to demonstrated the flow characteristic, identify velocity and temperature distributions inside the combustor and to attain the complete combustion process with stoichiometry amount of air is used. The parameters of the simulation were run by using multiphase model, incompressible flow, Realizable k-epsilon turbulent method and heat transfer. The simulation was done by using ANSYS FLUENT version 14.0. The paper-volatiles-air used as mixture phase and air as liquid phase. The inlets velocities for fuel and air are 0.0254 m/s and 14.14 m/s. The simulation was run with prediction the combustion already occur so the chamber walls was set as the hot wall with temperature 773K. Others walls, inlets and outlets were assumed at the ambient temperature, 303K. The simulation results show that the design of inlets merge was influenced the mixture velocity, the higher swirl effect and the temperature increased gradually in the spinning and swirling manner occur can be visualized. The combustion mixture found as rich mixture, so the new air inlet diameter or velocity been suggested for archive the complete combustion. Simulation of new air inlet velocity shows that higher velocity and stagnation temperature occur much faster and the temperature distribution in the emission chimney was lower. As a result that chimney design may use other cheaper capable material.

ABSTRAK

Al -Qur'an adalah kitab suci pengganut agama Islam, oleh itu teks yang dicetak dikendalikan dengan rasa hormat. Adakalanya oleh kerana perkara yang tidak dapat dielakkan, Al–Qur'an perlu dilupuskan. Pembakaran adalah salah satu kaedah pelupusan tetapi kaedah ini perlu dipastikan bahawa kitab tersebut terbakar sepenuhnya dan abu yang terhasil berada dalam keadaan terkawal. Cara terbaik untuk pembakaran terkawal adalah dengan menggunakan Kebuk Pembakaran Taufan. Kebuk Pembakaran Taufan terkenal dengan kebolehan memisahkan abu daripada produk gas bahan api pepejal. Objektif kajian ini adalah untuk menunjukkan ciri-ciri aliran, mengenalpasti halaju dan suhu di dalam kebuk dan untuk mencapai proses pembakaran lengkap dengan jumlah stoikiometri udara digunakan. Simulasi dijalankan dengan menggunakan model berbilang fasa, aliran tidak mampat, kaedah bergelora "*k-epsilon*" dan proses pemindahan haba. Simulasi dijalankan dengan menggunakan perisian ANSYS FLUENT versi 14.0. Kertas-meruap-udara digunakan sebagai fasa campuran dan udara sebagai fasa cecair. Halaju masukan bahan api dan udara adalah pada 0.0254 m/s dan 14.14 m/s. Simulasi dijalankan dengan ramalan pembakaran sudah berlaku maka dinding kebuk pembakaran ditetapkan pada suhu 773K. Suhu pada dinding-dinding lain, termasuklah dinding masukkan dan keluaran ditetapkan pada suhu persekitaran iaitu 303K. Keputusan simulasi menunjukkan rekabentuk gabungan masukan mempengaruhi kelajuan campuran masuk ke dalam kebuk. Kelajuan pusaran yang lebih tinggi dan suhu meningkat dalam keadaan berputar dan berpusar dapat dilihat. Campuran pembakaran didapati terlebih bahan api, maka nilai baru untuk garis pusat atau halaju masukkan udara dicadangkan bagi mencapai pembakaran lengkap. Simulasi baru menggunakan nilai halaju masukkan udara yang baru menunjukkan halaju terhasil lebih tinggi, suhu

sekata berlaku dengan lebih pantas dan taburan suhu di cerobong lebih rendah. Maka rekabentuk cerobong boleh diubahsuai menggunakan bahan lain yang lebih murah.

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LIST OF SYMBOLS AND ABBREVIATIONS

AFR	-	Air-fuel Ratio
atm	-	Atmosphere of Pressure
C_{est}	-	Stoichiometry concentration
c_p	-	Specific Heat
CAD	-	Computer Aided Drawing
CFD	-	Computational Fluid Dynamic
CH_4	-	Methane gas
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
D	-	Diameter
FAR	-	Fuel-air Ratio
HV	-	Heating Value
HHV	-	Higher Heating Value
H_2O	-	Water vapor
LES	-	Large Eddy Simulation
LFL	-	Lower Flammability Ratio
LPG	-	Lower Pressure Gas
m	-	Mass
m_a	-	Mass of air
m_f	-	Mass of fuel
N_2	-	Nitrogen
NO_x	-	Nitrogen dioxide
O_2	-	Oxygen
PCC	-	Pressurized Cyclone Combustor

Q	-	Energy input
r	-	Radius
Re	-	Reynolds Number
RPM	-	Rotation per Minute
S	-	Sulfur
UFL	-	Upper Flammability Ratio
V	-	Velocity
3D	-	Three-Dimension
Θ	-	Angle
ρ	-	Density
η	-	Efficiency
ϕ	-	Equivalent Ratio
υ	-	Kinematic Viscosity
-	-	Negative
π	-	Pi
λ	-	Stoichiometry Ratio
ΔT	-	Temperature Different

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Every religion has a holy scripture as guidance through life, same goes with Islam. The holy scripture of Islam is Al-Qur'an. Muslim believes that it is the direct words of Almighty God (*Allah SWT*), and was revealed to the Prophet Muhammad (*SAW*) through the angle of Gabriel (*Jibreel*) as guidance to mankind. So this revelation is regarded as sacred by Muslim, therefore the printed text itself is treated with a great deal of respect. While handling the Al-Qur'an, someone is requires to be in a state of cleanliness and purity and the book itself should be placed in a clean and respectable way.

Unavoidably, there are times when an Al-Qur'an needs to be disposed for example printed materials or children's schoolbooks that contains Al-Qur'an's verses or the entire Al-Qur'an itself that may be old or damaged. These items need to be discarded properly as per Islamic teachings. The words of Almighty God (*Allah SWT*) must be disposed in a way which shows reverence to the holiness of the text (Huda). Islamic teachings with regards to the ways of disposing Al-Qur'an largely fall into three main categories; burying, placing into flowing water or burning. In a nut shell, all three methods are aimed to return the material naturally to the earth.

The first method of disposing Al-Qur'an is burying method. The proper way to do this is by wrapping Al-Qur'an with a cloth and burying it into the deep hole at the area not frequently used such as the graveyard. The second method is placing Al-Qur'an in flowing water such as river or sea so that the words that were made from carbon will be dissolved with the water and the paper will disintegrate naturally. It is recommended to weigh down the Al-Qur'an with heavy object like stone to sink the book. The last method of disposal is burning. Most Islamic scholars agree that burning old copies of the Al-Qur'an in a respectful manner and in a clean place is acceptable as a last resort. In this case, someone must ensure that the Al-Qur'an is fully burnt and destroyed. The ashes that are produced from the burning process should then be buried or scattered in running water (Huda).

This study would focus on one of the method of disposal only which is burning method. In Malaysia contexts, the old method of burning process have to go through three steps which are separating process, shredding process and burning process before the ashes can be scattered in the running water. To simplify this process, a simulation study on solid fuel combustion will be conducted. The Al-Qur'an manuscripts will be considered as the solid fuel. Combustion is a process of energy conversion, from chemical energy (fuel reacting with oxygen) to radiant and thermal energies. Energy, mass and momentum are converted during the combustion process. Complete combustion will release the maximum potential energy which would result as the same amount of the thermal energy that has been used.

1.2 Problem Statement

In the process of burning Al-Qur'an manuscripts in bulk, the common problems that occur are imperfect burning process and the ashes that are produced from the process is difficult to control. These common problems has raised concerned amongst Muslim as there is a regulation (*fatwa*) state by (Jabatan Agama Islam Malaysia , 1992) that to dispose an Al-Qur'an through burning process; the book need to be completely destroyed and the ashes need to be contained in order to collect and release the ashes it into running water.

Therefore, a study should be done to analyze the solid fuel combustion process by considers the Al-Qur'an manuscripts as the solid fuel and the burning process in cyclone system so that it can be done in the controlled condition.

1.3 Objective

The objectives of this study are:

1. To demonstrate the flow characteristic inside the cyclone combustor.
2. To identify the velocity and temperature distributions inside the combustor.
3. To attain complete combustion process with stoichiometry amount of air is used.

1.4 Scope of Study

The research will do in collaboration with *Pejabat Mufti Johor* and *Pejabat Agama Batu Pahat* to dispose the old Al-Qur'an using solid fuel combustion analysis properly as required by Islamic *fatwa*. In the solid fuel combustion analysis, the focuses are on the flow characteristics, velocity and thermal distributions in the cyclone combustor. This process will be achieved by using simulation software. The process of complete combustion would be ascertained through calculation.

1.5 Significant of Study

The study of Al-Qur'an disposal process using solid fuel combustion process can be a useful data to create a furnace that can solve the problems that occur during the disposal process. The furnace will provides numerous benefits including time and cost saving as less manpower would be required to run the furnace and bulk of manuscripts can be burned in shorter time compared to the old method. This would be a more efficient option as the disposal process is combined into one system and the ash that is produced is eco-friendly.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Solid waste is an unwanted product by the modern civilization. According to the Solid Waste Management Department surveys, annual solid waste generated in the Malaysia is around 6 million tons and 17.1 percent of it is used paper (National Solid Waste Management Department, 2012).

Landfills are the place of solid waste disposal. The increasing amount of solid waste requires new waste sites and this is difficult to be established. Alternatives to this problem include reduction, recycling, composting and incineration. Incineration is an economical option as it includes energy recovery from the waste product. Recoverable energy is stored in chemical form in waste material that contain hydrocarbon.

Al-Qur'an manuscript is in the form of paper. However, it cannot be recycled because the holiness of the scripture should be maintained. Basically paper is made from wood and this is one of the biomass fuels. Wood stored energy from sunlight by photosynthesis in bond of carbon, hydrogen and oxygen molecules. Combustion is the process which flammable materials are allowed to be burnt in the presence of oxygen thus releasing heat (energy). For the purpose of this study, the Al- Qur'an papers would be considered as the solid fuel and the combustion will be conducted through simulation process.

2.2 Solid Fuel

Based on (Spliethoff, 2010) book, solid fuel or coal is a mixture of organic material which is responsible for the energy content of the fuel and mineral matter that present significant challenges in the design and operation of a power plan. Coal can be rank based on it degree of deterioration or in other word the carbon percentage as shown in Figure 2.1. The lowest degree of deterioration found in lignite while anthracite is the coal that has maximum degree of deterioration. Intermediary stages are bituminous coals (Souza-Santos, 2004).

Wood → Peat → Lignite → Bituminous coal → Anthracite
(brown coal) (common coal) (purest form of coal)

Figure 2.1: The rank of coals
(TutorVista)

The properties of coal can be separating into two categories which are the physical properties and the chemical properties. Physical properties are including the heating value of coal, moisture content volatile matter and ash. The chemical properties refer to the chemical element constituents such as carbon, hydrogen, oxygen and sulphur and this composition has a strong influence on its combustibility.

There are two methods to analyze coal that are ultimate analysis and proximate analysis. Ultimate analysis determines all coal component elements and the proximate analysis determines only fixed carbon, volatile matter, moisture content and ash percentages. Fuels are evaluated based on the amount of energy or heat that it releases per unit mass or per mole during combustion of the fuel. Such a quantity is known as the fuel's heat of reaction or heating value. Heats of reaction may be measured in a calorimeter, a device in which chemical energy release is determined by transferring the released heat to a surrounding fluid. The amount of heat transferred to the fluid in returning the products of combustion to their initial temperature yields the heat of reaction (Weston, 1992).

2.3 Combustion

(Weston, 1992) mentioned that combustion is the conversion of a substance called a fuel into chemical compounds known as products of combustion by combination with an oxidizer. Combustion is a change in the form of energy; through reaction, chemical energy is converted primarily to radiant and thermal energy for use in processes that change properties to make economically useful product (Fives North American, 2012). The combustion process is an exothermic chemical reaction that releases energy as it occurs. Thus combustion may be represented symbolically by:

$$Fuel + Oxidizer = Products\ of\ combustion + Energy \tag{2.1}$$

In combustion processes the oxidizer is usually atmospheric air. Atmospheric air contains approximately 21 percent oxygen (O_2) by volume and the other 79 percent of other gases is mostly nitrogen (N_2). Thus for every mole of oxygen required for combustion, 3.76 moles of nitrogen must be introduced as well (Bayless). It is assumed that the nitrogen will not normally undergo any chemical reaction. This statement can be simplified as in the Equation (2.2).

$$Air = \frac{79\%.Nitrogen}{21\%.Oxygen} = \frac{3.76.Nitrogen}{1.Oxygen} \tag{2.2}$$

2.4 Stoichiometry Combustion

Stoichiometry combustion is also known as the theoretical combustion. The majority of fuels contain only the elements carbon, hydrogen, oxygen, nitrogen and sulfur. The aim of the stoichiometry is to determine the exact amount of air to be used to completely oxidize the fuel to products carbon dioxide, water vapor, nitrogen and sulfur dioxide. Figure 2.2 represent a stoichiometry combustion system of methane (CH_4) with air (oxygen and nitrogen, as reactants) to form carbon dioxide (CO_2), nitrogen (N) and water (H_2O) (as product) (El-Mahallawy & Habik, 2002).

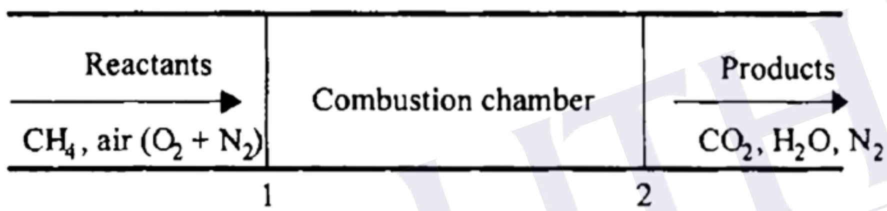

Figure 2.2: Stoichiometry combustion for CH4 and air
(El-Mahallawy & Habik, 2002)

Equation (2.3) describes the breakdown of the bond between atoms forming the molecules of methane and oxygen, and their arrangement to construct molecules of carbon dioxide and water. The chemistry would be unchanged by the inert diluents nitrogen. The coefficients in the Equation (2.3) are determined from the considerations of atom conservation and for the chemical correct, or stoichiometry, proportions of reaction – with no excess fuel or oxidant. (El-Mahallawy & Habik, 2002)

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2 \tag{2.3}$$

2.4.1 Air-Fuel Ratio

Air-fuel ratio (AFR) is the ratio between air and fuel to get the complete combustion. It is important to know how much oxygen or air must be supplied for complete combustion of a given quantity of fuel. This information is required in sizing fans and ducts that supply oxidizer to combustion chambers or burners and for numerous other design purposes. The mass air-fuel ratio (AFR) for complete combustion may be determined by calculating the masses of oxidizer and fuel from the appropriate reaction equation (Weston, 1992).

For the ratio calculation, the amount of mole needs to be verified. The amount of substance may be indicated by its mass or by the number of moles of the substance. A mole is defined as the mass of a substance equal to its molecular mass or molecular weight (Weston, 1992). Based on the periodic table of element (*APPENDIX B*), the molecular weights commonly used in combustion analysis are stated in Table 2.1.

Table 2.1: Amount of molecular weight in the combustion molecule

ELEMENT	MOLECULAR WEIGHT (g/mol)
C	12
H_2	2
O_2	32
N_2	28

Based on Equation (2.3), the air-fuel ratio of it can be determined. The AFR for methane can be writing as:

$$AFR = \text{Mass of Air } (m_a) \,/\, \text{Mass of Fuel } (m_f) \qquad (2.4)$$

$$= 2(O_2 + \frac{79}{21} N_2) \Big/ CH_4 \qquad (2.5)$$

$$= [(2)(32) + (2)(3.76)(28)] \,/\, [(12 + 4)] = \underline{17.16}$$

Thus, 17.16 kilogram of air must be supplied for each kilogram of methane completely consumed. An alternate approach to find the fuel-air ratio, (FAR) is the inverse of the air-fuel ratio (AFR).

In actual condition, it is possible to supply an exact amount of air to a burner to burn the fuel for archived stoichiometry combustion. There are two types of non-stoichiometry mixture which are lean and rich mixture. The term of lean or rich used where respectively oxidant and fuel are available in excess of their stoichiometry properties (El-Mahallawy & Habik, 2002). Equation (2.6) is the equivalence ratio, ϕ, which is the ratio of the actual fuel-air ratio to the theoretical fuel-air ratio. The stoichiometry ratio, λ, is the inverse of ϕ.

$$\Phi = \frac{FAR_{actual}}{FAR_{stoich}} = \frac{AFR_{stoich}}{AFR_{actual}} = \frac{1}{\lambda} \quad (2.6)$$

From Equation (2.6), types of mixture can be defined. When the equivalent ratio is less than one, the mixture is called lean; when greater than one, it is called rich. For stoichiometry condition, the equivalent ratio is equal to one. Lean mixture mean that excess of air while rich mixture mean is the fuel supplied are more than necessary. This statement has been simplified in Table 2.2.

Table 2.2: Type of Combustible Mixture, Equivalent and Stoichiometry Ratio

RICH MIXTURE	STOICHIMETRY MIXTURE	LEAN MIXTURE
Excess of fuel	Balance	Excess of air
$\phi > 1$	$\phi = 1$	$\phi < 1$
$\lambda < 1$	$\lambda = 1$	$\lambda > 1$

Excess air is defined as the difference between the actual and the theoretical air supplied. Accordingly, the percentage of excess air (%ES) is:

$$\%EA = (\lambda - 1) \times 100\% \quad (2.7)$$

REFERENCES

ANSYS. (n.d.). *ANSYS CFX*. (ANSYS, Inc.) Retrieved November 03, 2013, from http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+CFX

ANSYS. (n.d.). *ANSYS CFX Combustion and Radiation*. (ANSYS, Inc) Retrieved November 05, 2013, from http://www.ansys.com/Support/Training%20Center/Courses/ANSYS%20CFX%20Combustion%20and%20Radiation

ANSYS. (n.d.). *ANSYS Meshing*. (Ansys, Inc.) Retrieved November 06, 2013, from http://www.ansys.com/Products/Workflow+Technology/ANSYS+Workbench+Platform/ANSYS+Meshing

Bayless, D. (n.d.). *Chapter 11: Combustion*. Retrieved May 6, 2013, from The Ohio University: http://www.ohio.edu/mechanical/thermo/Applied/Chapt.7_11/Chapter11.html

Biofuels Academy. (2012). *Cyclone Separator*. Retrieved May 14, 2012, from Biofuels Academy: http://biofuelsacademy.org/index.php?p=2_8

Brito, D. d., Mori, M., & Martignoni, W. P. (2008). Study of Different Approached for Modelling Cyclones using CFD.

Cengel, Y. A., & Cimbala, J. M. (2010). Fluid Dynamics: Fundamentals and Application. New York: Mc Graw Hill Higher Education.

CFD Online. (2012, January 03). *Meshing*. (CFD-Online) Retrieved November 06, 2013, from http://www.cfd-online.com/Wiki/Meshing

Chung, L. (2003). *Ignition Temperature of Paper*. Retrieved April 20, 2013, from The Physics Factbook™: http://hypertextbook.com/facts/2003/LewisChung.shtml

Cuypers, F. (2010). Explosion safety during low temperature pyrolysis of CCA treated wood.

Damaschke, N. (n.d.). *Natural Gas*. Retrieved May 10, 2013, from Alternative Energy: http://www.tc.umn.edu/~dama0023/naturalgas.html

Dayah, M. (1997, October 1). *PTable*. Retrieved April 30, 2013, from Dynamic Periodic Table: http://www.ptable.com/#

Direct Industry. (2013). *CFD Software*. Retrieved November 8, 2013, from http://www.directindustry.com/industrial-manufacturer/cfd-software-74890.html

El-Mahallawy, F., & Habik, S. E.-D. (2002). Combustion Stoichiometry and Thermochemical Calculation; Combustion Stoichiometry. In *Combustion Fundamental* (p. 20). UK: Elsevier Science Ltd.

Energy Efficiency Guide for Industry in Asia. (2006). *Fuels and Combustion*. Retrieved March 20, 2013, from Thermal Equipment: Fuels and Combustion: www.energyefficiencyasia.org

Engineer ToolBox. (n.d.). *Water Vapor - Specific Heat*. Retrieved November 30, 2013, from http://www.engineeringtoolbox.com/water-vapor-d_979.html

Engineers Edge. (2000). *Thermal Properties of Metals*. (Engineer Edge, LLC) Retrieved November 30, 2013, from http://www.engineersedge.com/properties_of_metals.htm

Fives North American. (2012). Combustion Fundamentals. North America.

Fungtammasan, B., Jittrepit, P., Torero, J., & Joulain, P. (1995). *An Experimental Study On The Combustion Characteristics Of Sawdust In A Cyclone Combustor.*

GBC. (2013). *Swingline Stack-and-Shred 60X*. (GBC-Machine) Retrieved November 30, 2013, from http://www.gbc-machines.com/Swingline-Stack-and-Shred-60X_10897.htm

Habmiegern. (2003). *Combustion Analysis*. Retrieved April 15, 2013, from *For Our Environment and Our Customers' Money:* http://www.habmigern2003.info/index.html

Hristova, M., & Tchaoushev, S. (2006). *Calculation of Flash Points and Flammability Limits of Substances and Mixtures*.

Huda. (n.d.). *Disposal of Quran; What is the correct and respectful way to dispose of the Quran?* Retrieved Feb 27, 2013, from Islam About.com: http://islam.about.com/od/quran/a/Disposal-Of-Quran.htm

Hutagalung, M. (2008, June 02). *Understanding Coal Analysis*. Retrieved May 14, 2013, from Majari Magazine: http://majarimagazine.com/2008/06/understanding-coal-sample-analysis/

International Energy Coal Generation Facilities. (n.d.). *Coal Fired Power Generation*. (Itnernational Energy Coal Generation Facilities) Retrieved April 28, 2013, from http://www.rst2.edu/ties/acidrain/iecoal/how.htm

Jabatan Agama Islam Malaysia . (1992, August 22). *Disposal Of Al-Qur'an*. Retrieved February 20, 2013, from http://www.e-fatwa.gov.my/fatwa-kebangsaan/pelupusan-al-quran

Johari, A., Hashim, H., Mat, R., Alias, H., Hassim, M. H., & Rozainee, M. (2012). *Generalization, Formulation and Heat Contents of Simulated MSW with High Moisture Content*. Journal of Engineering Science and Technology , 701 - 710 .

Karthika, A. S., Shiblemon, K. V., & Lal, S. A. (2010). *Numerical Analysis of Flow In A Vortex Combustion Chamber.*

Korenberg, J. (1991). USA.

National Solid Waste Management Department. (2012). WASTE MANAGEMENT. Kuala Lumpur: Ministry of Housing and Local Government.

PaperOnWeb. (n.d.). *Density of Paper and Paperboard*. Retrieved November 8, 2013, from http://www.paperonweb.com/density.htm

PaperOnWeb. (n.d.). *Properties of Paper*. Retrieved November 8, 2013, from http://www.paperonweb.com/paperpro.htm

Pi-wen, H., Si-yi , L., Gong , C., Bo , X., Lei , C., & Jin-bo , W. (2012). Gasification of biomass char with air-steam in a cyclone furnace. *Renewable Energy* , 398-402.

Rensselaer Hartfold. (2007). *Chapter 4*. Retrieved March 20, 2013, from http://www.ewp.rpi.edu/hartford/~stephc/EP/Research/Waste%20Cycle/mamara_edu.pdf.

Shalaby, M. H. (2007). *On The Potential Of Large Eddy Simulation To Simulate Cyclone Separators*.

Smedberg, M. (2009). Evaluation of Fluidized Bed Furnace and Moving Grate Furnace for Incineration of Municipal Waste.

Souza-Santos, M. L. (2004). Solid Fuel; Introduction. In *Solid Fuel Combustion and Gasification* (p. 18). New York: Marcel Dekker, INC.

Spirax Sarco. (n.d.). *Boiler Efficiency and Combustion*. Retrieved May 10, 2013, from Spirax Sarco: http://www.spiraxsarco.com/resources/steam-engineering-tutorials/the-boiler-house/boiler-efficiency-and-combustion.asp

Spliethoff, H. (2010). Power Generation from Solid Fuels. In *Power Systems* (p. 16). Springer-Verlag Berlin Heidelberg.

Surjosatyo, A., & Priambodho, Y. (2011). *Investigation of Gas Swirl Burner Characteristic on Biomass Gasification System Using Combustion Unit Equipment (CUE). 33*.

The Engineering ToolBox. (n.d.). *Water - Dynamic and Kinematic Viscosity*. Retrieved November 28, 2013, from http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Themelis, N. J., Kim, Y. H., & Brady, M. H. (2002). Energy recovery from New York City solid wastes.

TutorVista. (n.d.). *Amorphous Forms of Carbon*. Retrieved May 6, 2013, from TutorVista.com: http://www.tutorvista.com/content/science/science-ii/carbon-compounds/amorphous-carbon.php#wood-charcoal

Unite SteelWorkers. (n.d.). *Wood Dust Safety*. Retrieved from http://usw2009.ca/wooddustsafety.htm

West Fraser. (2013). *Properties of Wood Dust.* Canada.

Weston, K. (1992). Fuels and Combustion. In *ENERGY CONVERSION* (p. 85). PWS.

Wikipedia Foundation, Inc. (2013, November 19). *Computational fluid dynamics*. Retrieved November 20, 2013, from http://en.wikipedia.org/wiki/Computational_fluid_dynamics

Yunus, A. C., & Michael, A. B. (2011). *Thermodynamics; An Engineering Approach* (Vol. Seventh Edition). New York: Mc Graw Hill Higher Education.

Yunus, C. A., & John, C. M. (2010). *Fluid Mechanics; Fundamentals and Application* (Vol. Second Edition). New York: Mc Graw Hill.

Zabetacis, M. G. (1965). *Flammability Characteristics of Combustible Gases and Vapors*. Washington, D.C.,.