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PERFORMANCE ANALYSIS OF A MODEL PULVERISED COAL COMBUSTION SYSTEM

Ani, Hillary. O[1*]
Utazi, Divine. N[2] .
[1]Department of Mechanical Engineering, Caritas University Amorji-Nike Enugu, Nigeria
[2]Department of Mechanical Engineering, Madonna University, Nigeria
**Correspondence: ani2hillary@gmail.com*

ABSTRACT

Performance analysis of a model pulverized coal combustion system is undertaken.. Performance analyses results show that the system has a maximum thermal efficiency of 46.5%, maximum system efficiency of 43%. This shows an encouraging performance when compared with the thermal efficiencies expected in the brown coal fired plants which are around 42%, and 45% for equivalent new bituminous coal fired units. Furthermore, the performance of the designed system is good when compared with some wood based fuel burners such as the improved vented mud burner (IVM) which has the thermal efficiency values across fuels that varies from 10% to 23%.

Keywords: *Performance analysis and thermal, system, and burner efficiencies.*

INTRODUCTION

Pulverized coal combustion (PCC) is the most commonly used method in coal — fired power plants and is based on many decades of experience. The earliest power plants used hand fed wood or coal to heat a boiler and produce steam. In rural areas several sources indicated that wood is the most widely used domestic fuel. In urban areas, some of the social amenities are possible as a result of coal power and some of its derivatives In 2009, Adinoyi reported that almost half of the world's population depends on wood fuel for cooking

The development of pulverized coal combustion system is a recent development. In the 1880's the earliest power plants used hand fed wood or coal to heat a boiler and produce steam. The coke (a lump coal)-fired tilting furnace for local foundry reported in 2002 by Edwin is one of the earliest technologies in coal combustion. One of the major disadvantages of the system was too much soot formation, which made the system user-unfriendly in health, comfort and convenience. It was reported in www.gradko.co.uk (2010) 15:2:10 that pulverized coal firing was developed in the year 1920. This process brought advantages that included a higher combustion temperature, improved thermal efficiency and a lower requirement for excess air for combustion. The pulverized coal combustion technology is directed towards a system with a fuel conveying tube and a primary air tube which is concentrically arranged within it, wherein the primary air tube on the mouth discharge side terminates at a distance to the mouth opening of the fuel conveying tube, and the burner is connected, or can be connected, to a feed line which conveys pulverous fuel in dense phase. Furthermore, the technology is directed towards a method for combustion of pulverized coal, in a burner with primary air tube and fuel conveying tube, wherein the fuel is fed to the burner by dense phase conveyance and is conveyed by dense phase conveyance inside the burner along the longitudinal axis of the burner. Currently, constructed of brown coal fired plant in Germany now has efficiency of around 42%.

In 2010, 15:2:10 *www.drighthub.com* reported that this technology is well developed and there are thousands of units around the world. The principal developments are, increasing plant thermal efficiencies . In 1981, Kenneth. et al reported that it takes a good deal of skill and technical knowhow to burn fuel efficiently, i.e. without waste. There are two reasons a self respecting engineer should ensure that fuel is burnt efficiently. Firstly, fuel is expensive, and inefficient combustion results in pollution of the atmosphere with noxious gases. Secondly, the correct burning of fuel lies in a good knowledge of the combustion equations which show how fuel is combining with oxygen to release heat and the use of atomic weight and molecular weights are also important.

Thermal Efficiency (πTh)

Following Edwin (2002), the thermal efficiency of the system and the system efficiency are expressed in term of energy of the fuel generated in a unit time and amount of the same
energy utilized eqs(2) and (4).

$$\text{Thermal Efficiency } \pi_{Th} = \frac{\text{Energy Utilized}}{\text{Energy of the fuel generated}} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\pi_{Th} = \left\{ \frac{(M_w C_w + M_p C_p)(T_r - T_i) + M_v L_v}{M_F C_F} \times 100\% \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where:

C_w is specific heat capacity of water
C_p is specific heat capacity of pot
L_v is latent heat of evaporation of water
C_f is specific heat capacity of fuel
C_c is specific heat capacity of charcoal

System Efficiency (πr)

$$\pi r = \frac{\text{Energy Utilized X } 100\%}{\text{Energy of the system generated}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\pi r = \left\{ \frac{(M_w C_w + M_p C_p)(T_r - T_i) + M_v L_v}{M_F C_F + \text{electrical energy}} \text{ X } 100\% \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where the various parameters are as defined previously.

Calculation of the Burner Efficiency (π_{Cc})

Now from combustion chamber parameters,the equation relating the heat input, the combustion chamber area and the input temperature,
according to Edwin [2002] is given as.

$$T_{ii} = K \left\{ \frac{H}{A} \right\}^{0.25} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where

T_{ii}	=	Input temperature of the fuel combustion
H	=	Actual heat input
A	=	Combustion Chamber area covered by radiant heat transfer
K	=	Thermal conductivity of fuel for coal, k= 38 W/MK

According to Johnson, A.J and Auth, G.H(19 51) was given and heat energy generated from the combustion of coal per second is obtained as 33.4KJ/Sec. i.e 33.KW.

Following Adinoyi(2009), the power consumption (PC) of a burner can be express as: PC={MF(1-X)-1.5Mc}/60t………………………………………………………..(6)
Where X is the moisture content of the fuel and other parameter are as defined previously.
According to Mayhew et al(1980), thermal efficiency of the combustion chamber is given as: $\eta_{Cc}=\{(T_i-T_{ii})/T_i\}\times 100$………………………………………………………..(7)

where $T_i=1350^oC$

$T_{ii}=808^oC$

From eqs (1),(3),(5)&(7), the efficiencies are as in the table 4.

Determining the combustion parameter

From the ultimate analysis of the fuel, the fuel sample has the following composition by mass
C75.2%; 010.4%; N1.7%; S0.92%; 115.3%; Ash 6.5%
For 100kg of fuel, the combustion equation becomes

$$\frac{75.2C}{12} + \frac{5.3H}{1} + \frac{1.7N}{14} + \frac{0.92S}{32} + \frac{10.40}{16} + 6.5\ Ash + a\ (0.2\ 102 + 0.79N2)$$

$$= bH2O + d\ CO_2 + e\ SO_2 + 6.5\ Ash + (\frac{17}{28}+0.79a)\ N_2 \quad \ldots(6)$$

From the balance of those constituent elements

H-balance: $2b=5.3$; $b=\frac{5.3}{2}=2.65$

C-balance: $d=\frac{75.2}{12}$; $d=6.27$

S-balance: $e=\frac{0.029}{32}$ $e=0.029$

0-balance: $\frac{10.4}{16}+(2a \times 0.21) = b + 2d + 2e$

0.65 + 0.42a b+2e

0.42a= (2.65) + (2 x 6.27) + (2 x 0.029)- 0.65

0.42a=14.598

$a=\frac{14.598}{0.42}$

a=34.76

For 1kg of fuel

C +	**H +**	**N +**	**S +**	**0 +**	**Ash +**	**0.21a02 +**	**$0.79aN_2$**
0.752	0.053	0.017	0.0092	0.104	0.0065	2.336	7.689

$$=bH_20 + dCO_2 + eSO_2 + 6.5Ash + (\frac{1.7}{28}+ 0.79a)\ N_2 \quad \ldots\ (7)$$

0.477 2.759 1.856 0.065 7.706

Performance Testing of the Pulverized Coal Combustion System to Estimate the Goodness of the Analysis.

The tests conducted on the system included water boiling test and simmering test using 0.4mm particle size fuel. The tests were conducted in an open environment.

Test procedure.

Water Boiling Test

The coal was crushed, dried and sieved to obtain a uniform grain size. The screw conveyor trough, combustion chamber and the pot were thoroughly cleaned and dried. The test was conducted in an open air at the National Centre for Energy Research and Development, University of Nigeria, Nsukka (UNN). A measured amount of charcoal was weighed for each test. The same type of coal was used for the series of tests; it was therefore ensured that there was sufficient fuel (coal) available for the tests, stored in the same place so as to have uniform dryness. The pot, and lid were weighted, and then a measured amount of water by volume (about two-thirds the pot capacity) was added to the pot and weighted again, to determine the mass of the water. This was repeated for each test.

A known mass of charcoal was introduced into the combustion chamber and about 20m1 of kerosene was sprinkled on it to initiate burning and allowed to burn till red hot. The system already connected to a power source was put on immediately. The pot and fuel (coal) were put on the pot seat and silo respectively. The time of the day, the environmental condition (ambient temperature) and the initial temperature of the water were recorded. Thereafter the commencement of the test the temperature of the water was recorded at intervals of ten (10) seconds until the moment the water came to a vigorous boil and the content of the silo is exhausted. The pot was then removed from the chamber and power source turned off immediately. The final mass of the remaining water and the final temperature of water were then measured and recorded and data are given on table 1. The tests were carried out on the 20th of September, 2011 starting at about 12pm in the afternoon.

Test Results for Boiling of Water

The test results for boiling of water are shown in table 1

The temperature variation during boiling is shown in table 2

Table 1: Test result for boiling of water

Ambient temperature	23°C
Initial water temperature T_i	23°C
Final water temperature, T_f	98°C
Time spent to boil	50 sees
Mass of empty pot, M_P	0.270kg
Mass of fuel coal consumed in boiling, M_{FB}	0.050kg
Initial mass of water	2.000kg
Average mass of water evaporated during boiling, M_{VB}	0.020kg
Total mass of water evaporated M_V	0.420kg
Final mass of water, M_W	1.580kg
Average mass of charcoal used in boiling, M_{CB}	0.020kg
Caloric value of coal, C_F	33.4 MJ/Kg
Specific heat capacity of pot C_p	0.9KJ/Kg °C
Latent heat of vaporization of water L_V	2.24MJIKg

Table 2:Temperature variation during boiling

Time (sec_s)	Temperature
0	23.0
10	33.3
20	66.9
30	76.2
40	81.8
50	98.0

Water Simmering Test

Simmering involves the heating of boiling water at a constant temperature for about 3minutes. The procedure for the test is the same as that for the boiling test. At the end of the test, measurements were taken and recorded accordingly on table 3

The Test Result for Simmering Of Water

The test results for simmering of water are shown in table 3

Table 3:Test result for simmering of water.

Ambient temperature	23°C
Initial water temperature	23°C
Final water temperature, T_f	98°C
Time spent to simmer, t	180sec
Mass of empty pot, M	0.270 kg
Mass of fuel(coal) consumed in simmering, M_{fs}	0.100kg
Initial mass of water, M_{wi}	2.000kg
Average mass of water evaporated during simmering, M_{vs}	0.400kg
Total mass of water evaporated, M_v	0.420kg
Final mass of water, M_{wf}	1.580kg
Average mass of charcoal used simmering, M_{cs}	0.005kg
Calorific value of coal, C_f	33 .4MJ/Kg
Specific heat capacity of pot, C_{pp}	0.9kg/kj^{0}C
Latent heat of vaporization of water, L_v	2.26MJ/Kg

Table: 4. Results of the analysis

Coal consumed for boiling	0.05kg
Coal consumed for simmering	0.10kg
Total coal consumed	0.15kg
Thermal efficiency for boiling	41.5%
System efficiency for boiling	39.7%
Thermal efficiency for simmering	46.5%
System efficiency for simmering	43%
Thermal efficiency of the combustion chamber	40.1%

CONCLUSION

In coal analysis, the fineness of coal is the most important measurement in determining the performance of a pulverizer and therefore the method of sampling becomes highly important. The British Standard method of using sieve meshes and the fischer-wheeler sieve shaker to obtain the sample and to determine the classification of fineness becomes very useful in coal fuel burners. In order to make the fullest use of primary air, it is essential to have a uniform fuel bed as possible. A small size graded fuel gives the best air distribution. Small sized, uniformly graded, coal(eg) >1/2in<2in provides best air distribution of primary air and optimum performance. High proportions of fines (<1/8 in) or of large lumps (>2 in) cause uneven distribution of air and patchy fires. The higher the rank of the coal, the finer the grinding required. Grading usually required is 70% < 170 B.S sieve and all through 72 B.S sieve. With anthracites, >80% must be 170 B.S sieve and preheated air must be used to obtain good combustion.

The good performance of the system can be attributed to a number of factors. The first is the insulation material used, is ideal for the system. This minimizes the rate of heat loss across the walls of the combustion chamber by conduction, convection and radiation, and enhances a good proportion of heat to be conserved within the chamber. The size of the chamber is small and the heat generated is high, this tends to promote a high concentration of heat in the chamber. The efficiency of the system can be improved further by proper covering of the chamber top and incorporation of chimney for flue gas exit. Thorough insulation by a series of layers; say three to four, with different materials would play greater part in improving the efficiency further.

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Rafael Enparatza TEKNIKER, Production Engineering Department Otaola 20,
E-20600 Eibar, spain renparantza@tekniker.es722,2006.

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