EFFECT OF PARTICLE SIZE AND SECONDARY AIR FOR PARTICULATE BIOMASS COMBUSTION IN A BUBBLING FLUIDIZED BED REACTOR

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ABSTRACT

Biomass combustion is used as basic technology to generate heat by humans for millennia. With the incremental needs of modern man, biomass combustion still plays a major role in heat and power generation. In Sri Lankan context, biomass combustion is extensively used in manufacturing industries for boilers, furnaces, dryers, etc. Even though biomass is abundantly available as an energy source in Sri Lanka, industrial biomass combustion systems are operating under very low efficiencies. Operating these industrial combustion systems in an optimum manner will help in numerous ways to industries, environment and society.

In this study, particulate biomass combustion in a bubbling fluidized bed combustor model is used to evaluate optimum secondary air flow rate rates and particle sizes. First Proximity of particulate biomass (saw dust) was conducted to find out moisture and volatile content, then sieve analysis was conducted to segregate and name the particle sizes. Different particle sizes were fluidized using measured primary air flow and combusted under varied secondary air flow rates and obtained maximum temperature achievement in three distinct locations (top, middle and bottom) in the fluidized bed reactor by using installed temperature transducers. Secondary air flow rates and temperature results were tabulated for each particle sizes to analyze temperature variation. Matlab CFTool feature was used to generate surface fits for all three location (top, middle and bottom) temperature variation against particle size and secondary air flow rates. After evaluation results and surface fits, Optimum operating secondary air flow rates and particles sizes were identified for used lab scale bubbling fluidized bed combustor. Recommendations were suggested for industrial scale particulate biomass combustion systems such as boilers, furnaces, etc. for optimum operation based on lab scale system results.

Key words – particulate biomass combustion, optimum combustion, fluidized bed combustion

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1. INTRODUCTION

1.1.Renewable Energy

Renewable energy is energy that is created from natural processes that are continuously renewed without being exhausted. This includes electromagnetic wave, geothermal energy, wind, tides, hydro, and various forms of biomass. [1]

With the increasing energy requirement & depletion in fossil fuels in the world it is essential that the world move into renewable energy sources like wind, sunlight, tides, geothermal heat and biomass. Many countries have invested highly in the renewable energy field in the past few years and the worldwide investments in renewable energy was around US$286 billion in 2015. [2]

The main investment areas were wind, hydro, solar and biofuels. With enough support and investments, the renewable energy sources can meet a large proportion of the world energy demand at a lower price than the conventional energy sources.

Apart from that, transitioning to renewable energy will give more economical benefits in environmental and other areas which cannot be measured in standard economic accounts. Majorly it will help in the conservation of environment as the renewable energy is considered as clean energy.

1.2.Biomass

Biomass is the biological material that can be used as a fuel source in energy sector. It can be ranging from simple wood logs, wood chips, saw dust, husk, biological sludge, waste to pellets, briquettes made by biological materials, etc. Fossil fuels and coal are not considered as a renewable source of energy, hence in general those fuels are not inside the biomass range. [3]

Most used method of biomass as an energy source is by direct combustion. In this process, the basic conversion of energy is from chemical energy to thermal energy.

Solid biomass, such as wood and garbage, can be burned directly to produce heat by combustion. It can be converted to liquid or gaseous fuels such as biofuels or syngas, biogas, etc. Then these fuels can also be used as a thermal energy source. [4]

Biomass availability in Sri Lanka is more than 4 million MTs per year. The use of biomass for heat generation is widespread in the traditional uses, such as in domestic requirements and the small scale traditional industries.

However, the biggest limitation stopping the widespread adoption of biomass as an energy source, more efficiently and using latest technology, where it can replace the use of nonrenewable fuels, can be identified as, [5]

- Lack of awareness
- Lack of research and technologies
- Lack of capital

1.3.Combustion

Combustion is a reaction a fuel with oxygen to release heat energy. This process is widely used in both domestic and industrial applications. In industries, combustion heat is mainly used to generate steam, hot water, hot air or thermal oils. This process is vital for many day today activities of the man which accounts above 80% of world's energy usage. [6]

Biomass consists of carbon, hydrogen and oxygen, the main products from burning biomass are carbon dioxide and water. If combustion is to sustain fuel, air and heat elements has to be fulfilled. If any of these three are removed, combustion stops. When all three are available in the correct proportion, combustion is self-sustaining, because the fuel releases excess heat to initiate further combustion process.

Generally biomass combustion has three stages, drying, pyrolysis & oxidation

Drying – All biomass carry a moisture content, and this moisture has to be driven out before combustion take place. The heat energy for drying is provided by radiation from flames and from the stored heat in the body of biomass.

Pyrolysis – When the temperature of the moisture free biomass reaches between 200ºC and 350ºC, the volatile gases are released. Pyrolysis products include carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and high molecular weight compounds (tar) that condense to a liquid if cooled. These gases mix with oxygen (O_2) from the atmospheric air and burn resulting a yellowish flame. This is a self-sustaining process as the heat from the burning gases is utilized to dry the fresh fuel and liberate further volatile gases. Char is the remaining substance after all the volatiles have been liberated and burnt out.

Oxidation – At about 800ºC, the char oxidizes. Again oxygen is required, both at the fire bed for the oxidation of the carbon and to mixed with carbon monoxide to form carbon dioxide. Long residence time for biomass in a combustor allows the biomass to be completely consumed. All the above stages can occur within a combustion system simultaneously. [6]

1.4.Main reactions of biomass combustion process.

Stoichiometry	Heat of reaction (kJ/mol)	Name
Biomass $\rightarrow$ char+ tar + H_2O+ light gas	> 0	Biomass devolatilization
Char Combustion		
$C_2 + \frac{1}{2} O_2 \rightarrow CO$	-111	Partial Combustion
$C + O_2 \quad CO_2$	-394	Complete combustion
Char Gasification		
$C + CO_2 \rightarrow 2\,CO$	+173	Boudouard reaction
$C + H_2O \rightarrow CO + H_2$	+131	Steam gasification
$C + 2\,H_2 \rightarrow CH_4$	-75	Hydrogen gasification
Homogeneous Volatile Oxidation		
$CO + \frac{1}{2} O_2 \rightarrow CO_2$	-283	Carbon monoxide oxidation
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	-243	Hydrogen oxidation
$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$	-283	Methane oxidation
$CO + H_2O \rightarrow CO_2 + H_2$	-41	Water gas shift reaction
Tar Reactions		
$C_nH_m + (n/2)\,O_2 \rightarrow nCO + (m/2)H_2$	Highly endothermic + 200 to 300	Partial oxidation
$C_nH_m + nCO_2 \rightarrow (m/2)H_2 + (2n)\,CO_2$		Dry reforming
$C_nH_m + nH_2O \rightarrow (m/2 + n)\,H_2 + nCO_2$		Steam reforming
$C_nH_m + (2n - m/2)\,H_2 \rightarrow nCH_4$		Hydrogenation
$C_nH_m\,(m/4) \rightarrow CH_4 + (n-m/4)\,C$		Thermal cracking

Table 1.1- Main reactions of biomass combustion

1.5.Biomass Combustion Systems

Most commonly used method of converting biomass energy into thermal energy is direct combustion. There are many different technologies available for biomass combustion, all of these major technologies can be divided into two categories,

Fixed bed combustion systems

Fixed bed combustion technologies are mainly categorized into Underfeed Stokers and grate firing.

i. Underfeed Stokers -
ii. Grate Firings – Both fixed & moving grate types are available.

Fluidized bed combustion systems

Fluidized bed combustion technology can also be categorized into two main categories such as bubbling fluidized bed and circulating fluidized bed. In this experiment, a bubbling fluidized apparatus is used for evaluating the combustion against particle sizes of biomass and secondary air flow variations. [7]

2. RESEARCH GAP IDENTIFICATION AND COMPARISON

It was identified that most of the industrial boilers/furnaces in Sri Lanka which using particulate biomass (saw dust, rice husk, wood chips, etc.) as the fuel are operated inefficiently. Most local industries suffer due to low efficiencies of industrial biomass particulate boilers/furnaces which makes local industries uncompetitive. Unnecessary biomass consumption due to low efficiencies has an adverse impact on environment as well.

In most of the cases, followings are the reasons for low efficiencies,

1. Moisture in biomass particulate matter.
2. Amount of excess air is not optimized with biomass particle size

There are very few studies on this real industrial issue. In this research, secondary air flow rate and variation of particle size were evaluated to study the optimum combustion range of particulate biomass.

3. OBJECTIVES

To study the particulate biomass combustion in the industrial application and evaluate draw backs.

To evaluate the effect of particle size and secondary air requirement for particulate biomass combustion in fluidized bed reactor

4. APPARATUS

Following equipment & materials were used for this experiment.

- Fluidized bed combustor
- Resistance temperature Detectors
- Flow Meters
- Blower
- Saw dust
- Sieving instruments.
- PPE

Figure 4.1- Fluidized bed combustor apparatus

Figure 4.2- Blower used in Fluidized bed apparatus

Modifications done to the apparatus

- In order to carry on the experiment efficiently & generate a proper fluidized bed, combustor was modified by installing baffles at the bottom of the combustion apparatus.
- It was decided to carry out experiment for 6 particle sizes, but due to practical reasons experiment was done for four different particle sizes.
- A new blower and a secondary air flow duct system was installed.

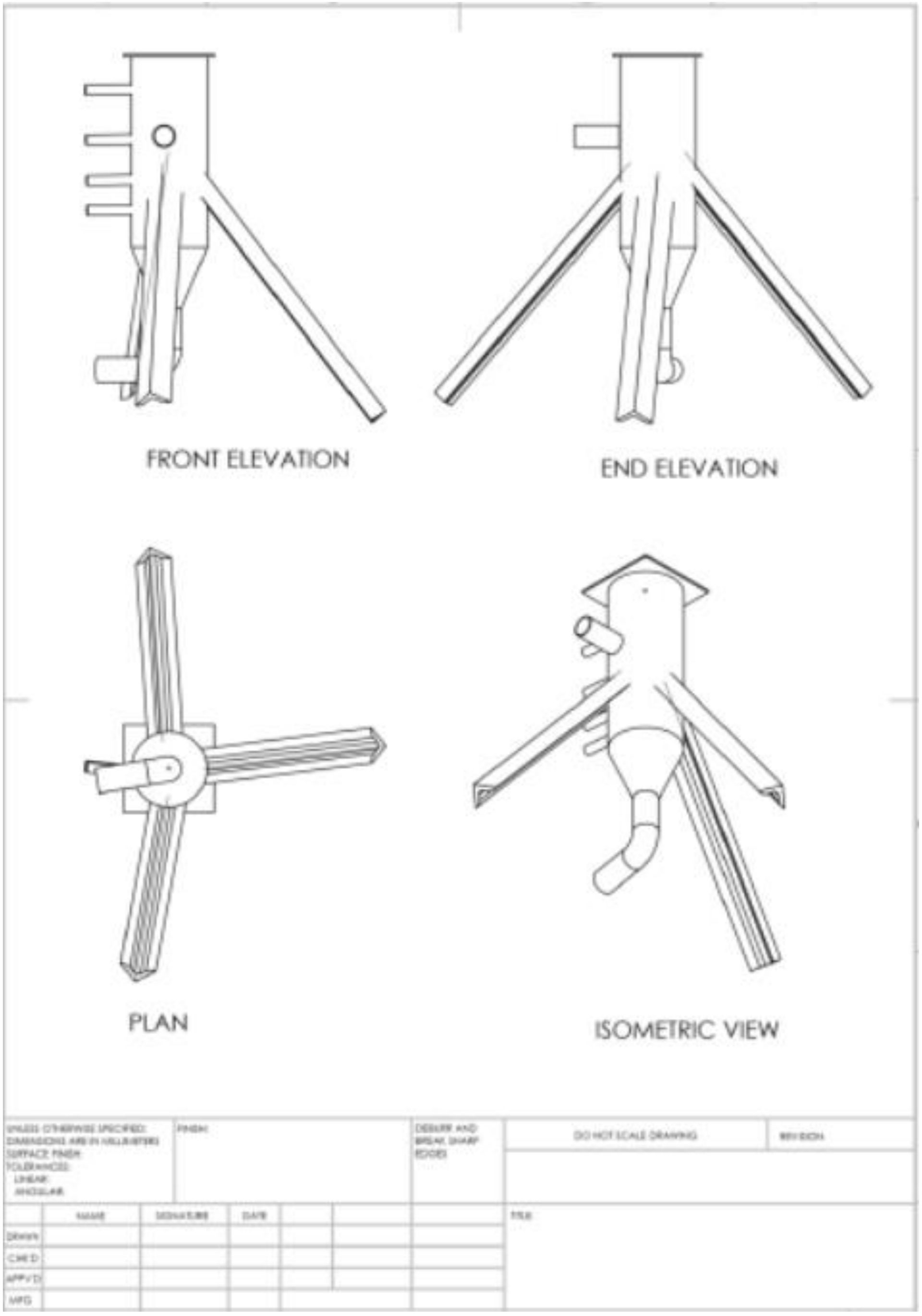

Figure 4.3 - Fluidized bed combustor (Front/End/Plan elevations and isometric view)

5. METHODOLOGY

5.1.Combustor assembly diagram and details

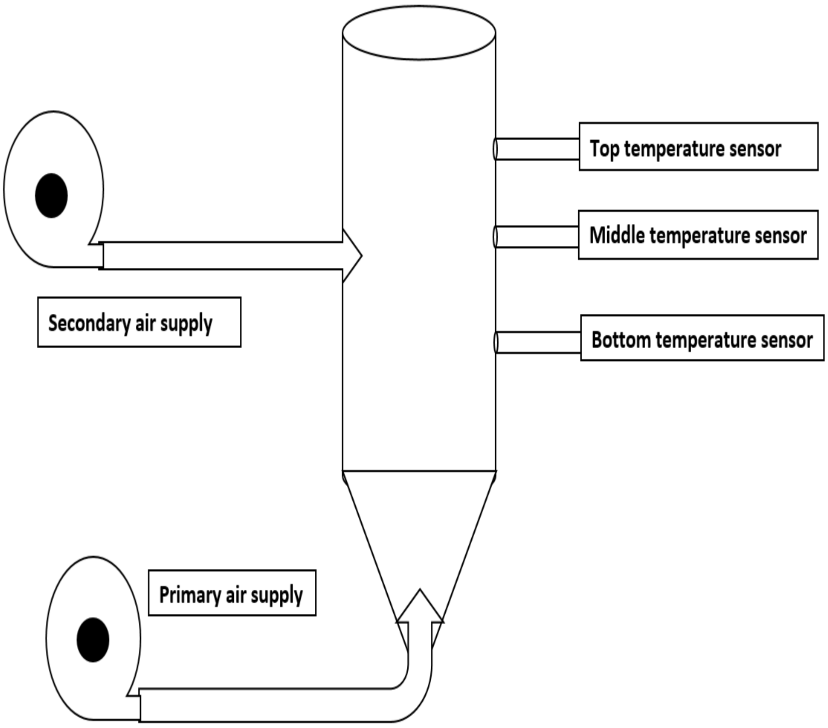

Figure 5.1- Schematic Diagram of Combustor Assembly

Height of cylindrical combustion chamber is 0.48m and inner diameter is 0.128m. Conical primary air distributor has a 60^o angle. Secondary air flow intake point is 0.23m from the top of apparatus. Top, middle and bottom temperature sensors are located 0.11m, 0.21m and 0.31m from the top of apparatus.

5.2.Proximate Analysis

First proximate analysis is conducted to determine the properties of the sample which used for the experiment.

Under proximate analysis moisture content and volatile matter were measured in saw dust sample which used for the research experiment. Moisture content was determined by keeping the sample under 105°C and volatile matter was determined under the temperature of 650°C.

Determination of moisture content

Weight of Crucible = 20.52 g

Weight of (Crucible + wood) = 22.28 g

Weight of (Crucible + wood) after Drying = 22.15 g

Moisture content = 7.4 %

Determination of Volatile Matter

Weight of Crucible = 19.49 g

Weight of (Crucible + wood) = 21.18 g

Weight of (Crucible + wood) after Drying = 19.65 g

Volatile Matter = 83.2 %

5.3.Sieve analysis

Sieve analysis was done to get six different particle sizes out of the initial saw dust sample. This was done using the sieving machine in unit operation laboratory. From this analysis a particle size distribution was achieved, results are mentioned below.

After doing sieve analysis, proper primary air flow rate which suits all of these particle sizes were identified.

Particle size (µm)	Weight (g)
<45	4.385
45-125	16.445
125-500	134.47
500-1400	67.769
1400-2800	43.275
2800-5600	15.444

Table 5.1- Sieve analysis results

5.4.Fluidizing the bed

Then, a specific particle size was selected to be used in fluidizing the bed. Then, 5.5cm saw dust bed was prepared & started giving the primary flow to fluidize the saw dust bed.

There was a control in the blower itself which can change 4 separate flow rates and the air duct was controlled with a control valve. So, the control was done through two methods; blower air control and the control valve. After few flowrate attempts saw dust bed were fluidized.

5.5.Combustion inside the reactor

Saw dust was dried in an oven to remove the moisture. Saw dust particles were mixed with standard amount (10ml) of kerosene to initiate the combustion. The bed was fluidized using only the primary air flow before ignition. Once the ignition was given the secondary air flow was supplied.

5.6.Obtaining Readings

After setting bed into fluidized stage, flow rate of primary blower was measured by getting 3 values in 3 distinct places at the opening of blower inlet to calculate primary air flowrate.

After the combustion started, secondary air flow blower was opened and flow rate of secondary air flow rate was measured by getting 3 values in 3 distinct places at the opening of combustor inlet.

As our changing parameter is secondary air flow rate, under the same fixed primary air flow rate, secondary air flow rate was varied for each particle size. Four experiments were carried out for one particle size minimum.

Highest reaching temperatures were measured at the top, bottom and middle of the combustion apparatus. By keep watching the continuous growth of temperature readings in RTD, peak temperature was identified by the time it starts decreasing the temperature values. At the same time readings of rest of the two places were noted.

5.7. Analyzing Readings

Temperature vs secondary air flowrate and particle sizes 3D graphs were plotted by using MATLAB. To identify the correlation of secondary sir flowrate and particle sizes with temperature (Top, middle and bottom locations) surface fittings ere done by CFTOOL (3D curve fitting tool), MATLAB.

6. PRACTICE LIMITATIONS AND POSSIBLE ERRORS

- Insulation was not done for the reactor which leads to a heat loss. Since analysis is on temperature pattern against secondary air flows & saw dust particle sizes, this error will not affect to final results and findings significantly.
- Measuring of the air flow rates of primary and secondary inlets has done by measuring point velocities using an anemometer. By taking few reading of selected points and averaging the reading will eliminate errors of measuring flowrate to greater extent.
- Inconsistent particle shapes may cause errors. This error is minimized by using sieve analysis and selecting particle size ranges.

7. RESULTS

As mentioned in the above sections, experiments were done by taking one particle size at a time. And within each particle size a minimum of 4 experiments were performed. Particle sizes 1 and 6 were left out because of the difficulties occurred.

Anyway, the parameters used for the calculations and the particle sizes considered are as follows.

Bed height (cm)			5.5cm
Primary blower air intake point	Diameter (cm)	Reading 1	8.7
		Reading 2	9.5
		Reading 3	8.7
		Mean	8.9
	Area (cm^2)		63.202
Secondary blower air intake point	Diameter (cm)	Reading 1	9.8
		Reading 2	7.1
		Reading 3	8.5
		Mean	8.47
	Area (cm^2)		56.352

Table 7.1- Dimensions of blower air intake points and biomass bed

Particle Sizing		
Size code	Size	Mean (mm)
6	3.35 mm - 2.80 mm	3.075
1	2.80 mm - 2.00 mm	2.4
2	2.00 mm - 1.40 mm	1.7
3	1.40 mm - 0.85 mm	1.125
4	0.85 mm - 0.60 mm	0.725
5	less than 0.60 mm	0.3

Table 7.2- Particle sizing details

7.1.Images of used particle sizes

Figure 7.1 - Particle size -1

Figure 7.2 - Particle size -2

Figure 7.3-Particle size -3

Figure 7.4-Particle size - 4

As mentioned in the above sections, experiments were done by taking one particle size at a time. And within each particle size a minimum of 4 experiments were performed. Particle sizes 1 and 6 were left out because of the difficulties occurred.

Parameters used for the calculations and the particle sizes considered are as follows.

7.2.Results

Results obtained for each particle size are as follows.

Particle Size 1

#	Temperature (C)			Secondary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s* 10^-4)	Primary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s* 10^-4)
	Top	Middle	Bottom	measurement 1	measurement 2	measurement 3			measurement 1	measurement 2	measurement 3		
1	522	565	520	1	0.8	0.9	0.90	50.72	1.9	2.1	1.8	1.93	122.19
2	617	567	520	2.4	1.6	1.7	1.90	107.07	1.6	1.9	1.8	1.77	111.65
3	588	478	480	1.4	1.3	1.6	1.43	80.77	1.6	2.5	1.8	1.97	124.29
4	555	517	588	2	1.8	2.7	2.17	122.09	1.7	2.5	2.2	2.13	134.83
5	587	590	500	1.5	1.5	2.1	1.70	95.80	1.8	1.9	3.5	2.40	151.68
6	510	512	384	1.2	1.1	1.5	1.27	71.38	1.8	1.9	3.6	2.43	153.79
7	607	615	630	1.6	1.9	2.3	1.93	108.94	1.6	1.8	3.3	2.23	141.15
8	553	559	571	1.6	1.8	2.1	1.83	103.31	1.6	1.8	3.3	2.23	141.15

Table 7.3- Results of particle size 1

Particle Size 2

#	Temperature (C)			Secondary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s * 10^-4)	Primary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s * 10^-4)
	Top	Middle	Bottom	measurement 1	measurement 2	measurement 3			measurement 1	measurement 2	measurement 3		
1	520	523	602	0.7	0.8	0.7	0.73	41.32	1.5	1	1.5	1.33	84.27
2	592	550	506	1.6	1.5	1.5	1.53	86.40	1.4	2.1	1.8	1.77	111.65
3	514	538	600	1.6	2.1	2.1	1.93	108.94	1.4	2	1.6	1.67	105.33
4	440	488	480	2.6	2.6	2.6	2.60	146.51	1.4	2.1	1.7	1.73	109.55
5	615	547	492	0.4	0.6	0.9	0.63	35.69	1.3	1.5	2.1	1.63	103.23
6	445	525	550	1.7	1.7	1.7	1.70	95.80	1.3	1.5	2.1	1.63	103.23

Table 7.4- Results of particle size 2

Particle Size 3

#	Temperature (C)			Secondary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s* 10^-4)	Primary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s* 10^-4)
	Top	Middle	Bottom	measurement 1	measurement 2	measurement 3			measurement 1	measurement 2	measurement 3		
1	520	551	619	0.8	0.8	1.2	0.93	52.59	1.2	1.7	1.5	1.47	92.69
2	403	460	503	1.5	1.6	2.2	1.77	99.55	1.1	1.8	1.5	1.47	92.69
3	451	501	531	2	2.3	2.6	2.30	129.61	1.2	2.2	1.6	1.67	105.33
4	190	258	278	2.2	2.9	3.1	2.73	154.02	1.1	1.9	1.5	1.50	94.80
5	612	598	626	0.9	1.4	1	1.10	61.99	1.1	2	1.6	1.57	99.01
6	540	530	668	1.2	1.1	1.4	1.23	69.50	1.5	1	1.8	1.43	90.59
7	576	545	587	1.6	1.6	2.1	1.77	99.55	1.1	1.5	1	1.20	75.84
8	410	477	460	2	2.1	2.5	2.20	123.97	1.1	1.6	1.6	1.43	90.59
9	360	410	415	1.7	2	2.5	2.07	116.46	1.2	1.4	2	1.53	96.91
10	650	626	586	0.4	0.6	0.5	0.50	28.18	1.4	2.3	1.5	1.73	109.55

Table 7.5- Results of particle size 3

Particle Size 4

#	Temperature (C)			Secondary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s * 10^-4)	Primary air flow velocity point measurement (m/s)			Average (m/s)	Flowrate (m3/s * 10^-4)
	Top	Middle	Bottom	measurement 1	measurement 2	measurement 3			measurement 1	measurement 2	measurement 3		
1	496	511	549	0.8	0.8	1.1	0.90	50.72	1	1.9	1.4	1.43	90.59
2	465	519	620	1.2	1.3	1.7	1.40	78.89	1.2	1.9	1.6	1.57	99.01
3	305	376	565	1.3	1.5	1.8	1.53	86.40	1	1.9	1.5	1.47	92.69
4	309	420	442	1.8	2.3	2.3	2.13	120.21	1.1	1.9	1.6	1.53	96.91

Table 7.6- Results of particle size 4

7.3.Results Analysis

The results were analyzed in two main ways to understand the variation of temperature with each considered parameters.

- Temperature variation with secondary air flow rate for each particle size. (four particles sizes)
- Temperature variation with secondary air flow rate & particle sizes. (3D Graphs for bottom, middle & top positions)

7.4.Temperature variation with secondary air flow rate

Particle size 1

Secondary air Flowrate m3/s (At 30C/ 0barg)	Temperature (°C)		
	Top	Middle	Bottom
50.72	522	565	520
71.38	510	512	384
80.77	588	478	480
95.80	587	590	500
103.31	553	559	571
107.07	617	567	520
108.95	607	615	630
122.10	555	517	588

Table 7.7-Temperature variation with secondary air flow rate for particle size 1

Particle Size 2

Secondary air Flowrate m3/s (At 30C/ 0barg)	Temperature (°C)		
	Top	Middle	Bottom
35.69	615	547	492
41.33	520	523	602
86.41	592	550	506
95.8	445	525	550
108.94	514	538	600
146.52	440	488	480

Table 7.8-Temperature variation with secondary air flow rate for particle size 2

Particle Size 3

Secondary air Flowrate m3/s (At 30C/ 0barg)	Temperature (°C)		
	Top	Middle	Bottom
28.17	650	626	586
52.6	520	551	619
61.99	612	598	626
69.5	540	530	668
99.56	403	460	503
99.56	576	545	587
116.46	360	410	415
123.98	410	477	460
129.61	451	501	531

Table 7.9-Temperature variation with secondary air flow rate for particle size 3

Particle Size 4

Secondary air Flowrate m3/s (At 30C/ 0barg)	Temperature (°C)		
	Top	Middle	Bottom
50.72	496	511	549
78.89	465	519	620
86.41	305	376	565
120.22	309	420	442

Table 7.10-Temperature variation with secondary air flow rate for particle size 4

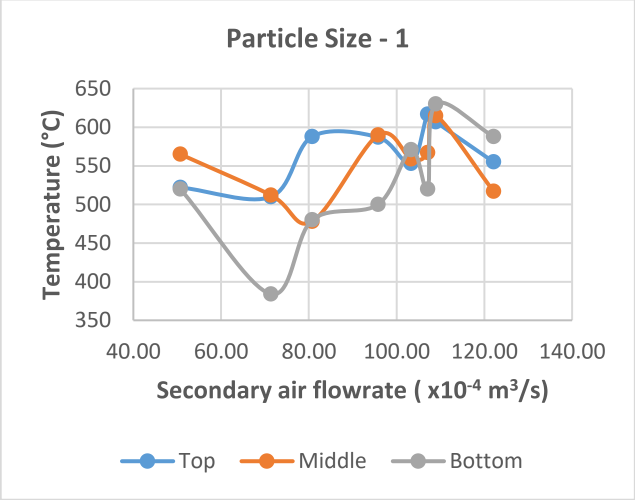

Figure 7.5- Graph for Temperature variation with secondary air flow rate of particle size-1

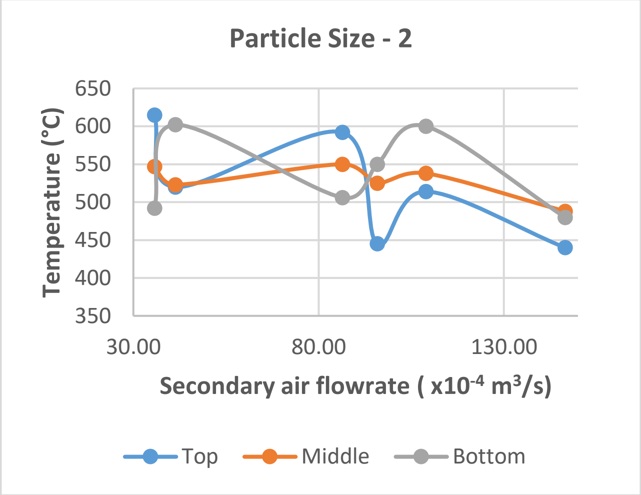

Figure 7.6 -Graph for Temperature variation with secondary air flow rate of particle size-2

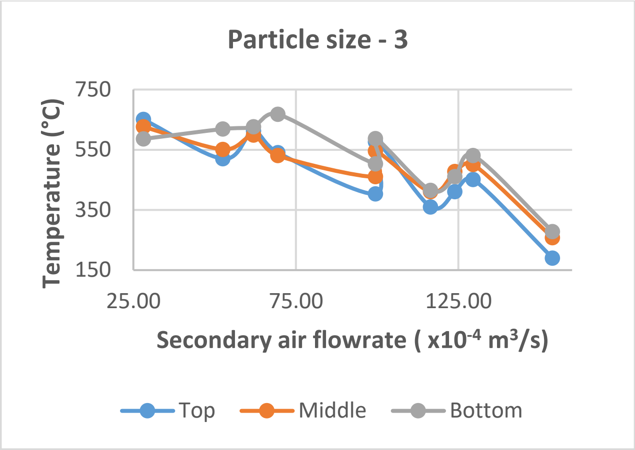

Figure 7.7- Graph for Temperature variation with secondary air flow rate of particle size-3

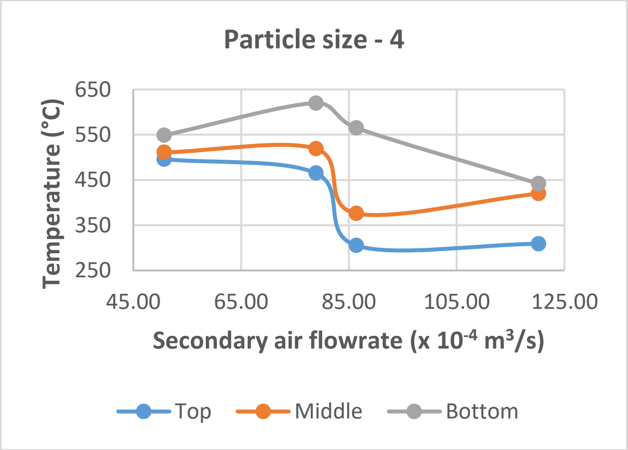

Figure 7.8- Graph for Temperature variation with secondary air flow rate of particle size-4

I) Temperature variation (top position) with secondary air flow rate & particle size

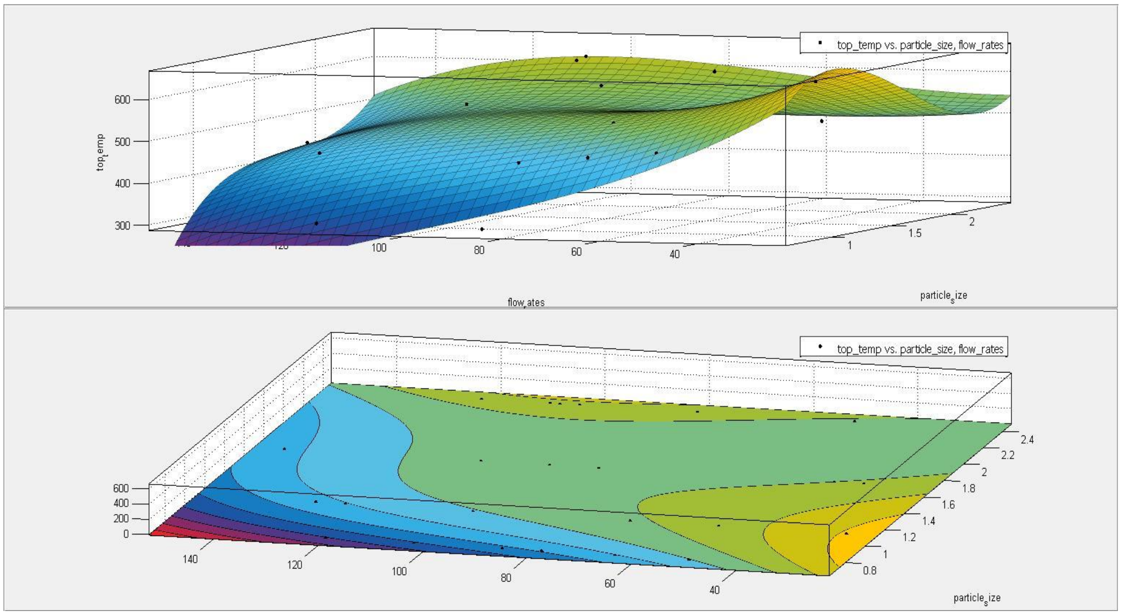

Figure 7.9- 3D Graph for top position temperature variation with secondary air flow rate and particle size

<u>MATLAB curve fit model details for top position temperature variation</u>

Linear model Poly33:

f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y

+ p12*x*y^2 + p03*y^3

Coefficients (with 95% confidence bounds):

p00 = 344.5 (-1093, 1782)

p10 = -13.75 (-40.14, 12.65)

p01 = 1258 (-782.6, 3299)

p20 = 0.08431 (-0.1657, 0.3343)

```
       p11 =       6.218  (-8.417, 20.85)

       p02 =      -970.6  (-2145, 203.7)

       p30 =  -0.0002635  (-0.001347, 0.0008196)

       p21 =    -0.01364  (-0.08837, 0.06109)

       p12 =     -0.5894  (-4.353, 3.174)

       p03 =       201.2  (-39.59, 441.9)

Goodness of fit:

  SSE: 4.239e+04

  R-square: 0.8091

  Adjusted R-square: 0.6863

  RMSE: 55.02
```

II) Temperature variation (middle position) with secondary air flow rate & particle size

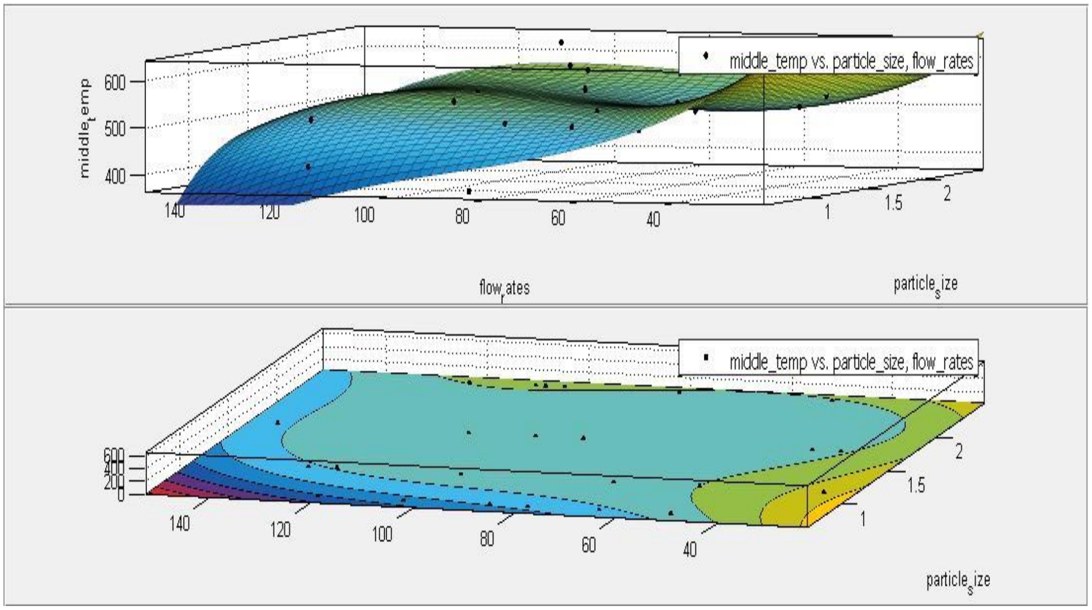

Figure 7.10-3D Graph for middle position temperature variation with secondary air flow rate and particle size

MATLAB curve fit model details for middle position temperature variation

Linear model Poly33:

f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y

+ p12*x*y^2 + p03*y^3

Coefficients (with 95% confidence bounds):

p00 = 713.8 (-339.5, 1767)

p10 = -15.49 (-34.83, 3.854)

```
p01 =        537  (-958.7, 2033)

p20 =     0.1189  (-0.06435, 0.3021)

p11 =      6.168  (-4.556, 16.89)

p02 =     -522.6  (-1383, 338)

p30 =       -0.0004508  (-0.001245, 0.0003428)

p21 =       -9.87e-06  (-0.05477, 0.05475)

p12 =     -1.574  (-4.331, 1.184)

p03 =      130.1  (-46.38, 306.5)
```

Goodness of fit:

```
  SSE: 2.276e+04

  R-square: 0.7168

  Adjusted R-square: 0.5347

  RMSE: 40.32
```

III) Temperature variation (bottom position) with secondary air flow rate & particle size

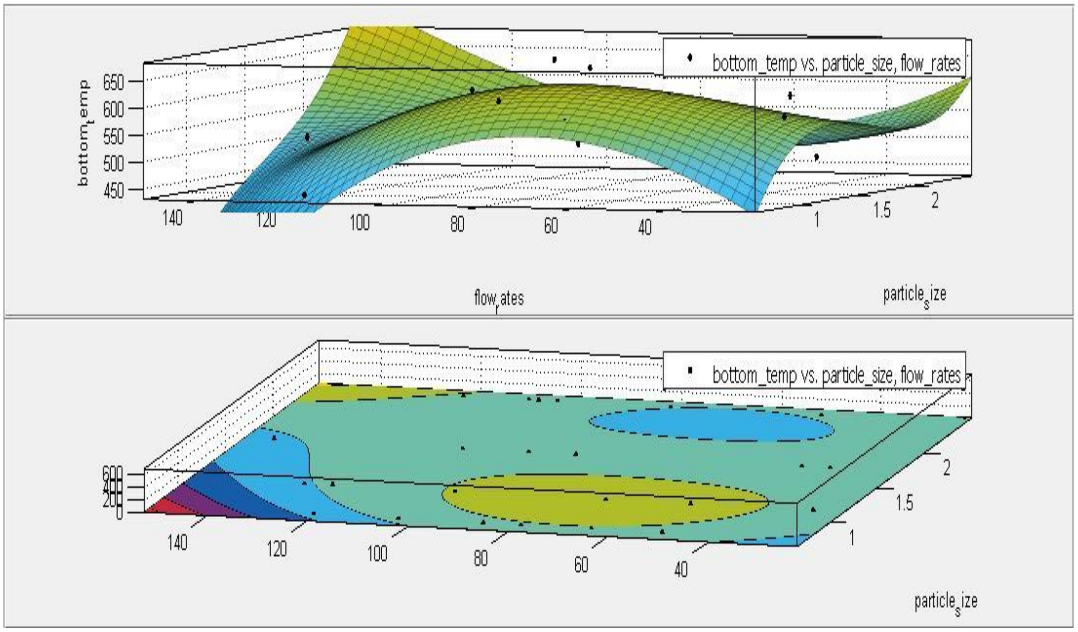

Figure 7.11- 3D Graph for bottom position temperature variation with secondary air flow rate and particle size

<u>MATLAB curve fit model details for bottom position temperature variation</u>

Linear model Poly33:

f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y

+ p12*x*y^2 + p03*y^3

Coefficients (with 95% confidence bounds):

p00 = -435.2 (-1626, 755.3)

p10 = 12.21 (-9.655, 34.07)

p01 = 1658 (-32.74, 3348)

p20 = -0.07484 (-0.2819, 0.1323)

```
       p11 =      -7.695  (-19.82, 4.426)
       p02 =      -961.8  (-1934, 10.85)
       p30 =  -0.0001256  (-0.001023, 0.0007715)
       p21 =     0.05734  (-0.004553, 0.1192)
       p12 =     -0.0965  (-3.214, 3.021)
       p03 =       195.6  (-3.781, 395)
Goodness of fit:
  SSE: 2.908e+04
  R-square: 0.6364
  Adjusted R-square: 0.4027
  RMSE: 45.58
```

8. DISCUSSION

8.1.Top position temperature variation

As per the results, it’s clear that highest temperature is observed for smaller particle sizes of saw dust which is obvious as smaller particles have higher surface area and percentage of full combustion is highest. In this research, top position temperature is highest for 0.8mm to 1.2mm particle size range for the secondary velocity of 20 x 10^{-4} m^3s.

There is another peak temperature is observed for largest particle sizes (2.4mm) at a secondary flow of 90 x 10^{-4} m^3s. This shows larger particle sizes require more excess air for full combustion compared to smaller particles.

For all particle sizes, if secondary air flow is higher than 140 x 10^{-4} m^3s top position temperature is reducing drastically. This is due to excessive air supply and energy is used up for heating excess air.

Fairly good combustion is observed in two regions,

1. Particle size 0.4mm to 2.0mm (If secondary air flow is less than 40 x 10^{-4} m^3s)
2. Particle size 2.0mm to 2.5mm (If secondary air flow is 60 x 10^{-4} m^3s to 110 x 10^{-4} m^3s)

8.2.Middle position temperature variation

According the 3 dimensional graphs, both top & middle position temperatures vs particle size & secondary air flowrates follow similar pattern.

Smaller particle sizes (0.5mm to 1.5mm) with secondary air flow rate less than 40 x 10-4 m3s is achieving highest temperature for middle position and similar to top position temperature variation, another optimum range can be observed in larger particles (greater than 2.2mm) at higher secondary airflow rates.

Similar to previous case, due to excessive air supply temperatures are drastically dropped for flow rates above 140 x 10-4 m3s.

8.3.Bottom position temperature variation

Bottom position temperature variation pattern against particle size and secondary air flow rate is not similar to top and middle positions.

Bottom position is below the secondary air flow intake point and middle and top position temperature sensors were located above the secondary air intake point, therefore effect of secondary air flow is different for bottom position which is clearly seen when comparing it with other two graphs. Hence in our analysis bottom temperature variation is not further discussed.

9. CONCLUSION

Most of the industrial boilers’ efficiency which use particulate biomass as fuel source in the country are in the range of 35% to 55%. It leads excessive consumption of biomass which is undesirable for industries, environment and community.

Following reasons are the common root causes for low efficiencies,

- Insufficient supply of secondary air for combustion
- Excessive air supply which carry unburnt particulate biomass (severe if particle sizes were too small)
- Particle size variation is not considered when operating
- Excessive air supply which carry generated heat without proper usage
- High moisture content in particulate biomass

In this research, particle sizes and secondary air flow rates variations with furnace temperature were analyzed to evaluate the optimum range of secondary air flow rate for optimum range of particle sizes.

According to temperature variation with secondary air flow rates & particle sizes 3D plots,

- When particle size less than 0.5mm has gained very low temperatures (Temperature get further decreased with increment of secondary air flow)

When comparing with industrial scale systems, this is similar to escape of unburnt/partial burnt biomass without participating to full combustion process.

- When secondary air flow rates are greater than 130 x 10^{-4} m^3/s, gained temperatures were very low

This comparable with industrial scale systems which operates with excessive secondary air and it leads to heat dissipation by heat up the excess air.

It’s better to avoid these two regions when operating a particulate biomass combustion in a bubbling fluidized bed reactor. In an industrial scale system, particle size segregation is not done but secondary air flow rates can be changed.

As per our findings, it’s recommended to conduct a sieve analysis for a sample of particulate biomass fuel time to time for industrial scale systems to make adjustments if particle size distribution has significant changes. Secondary air flow rates should be limited to avoid unburnt carryover and heat loss due to excessive air heat up.

Laboratory scale bubbling fluidized bed reactor which used for experiment has optimum operating range 40 x 10^{-4} m^3/s to 130 x 10^{-4} m^3/s for particle sizes greater than 0.5mm.

10.REFERENCES

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