

THE DESIGN OF A WASTE HEAT SYSTEM CAPABLE OF HARNESSING ENERGY FROM THE SURFACE OF A CYCLONE DUST COLLECTOR ATTACHED TO A DOWNDRAFT BIOMASS GASIFIER

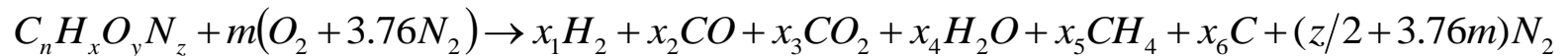
By Nwokolo Nwabunwanne

Supervisor – Prof S. Mamphweli

Co-Supervisor – Prof G. Makaka

Introduction

- Biomass Gasification- is the conversion of biomass material into a gaseous fuel known as syngas.

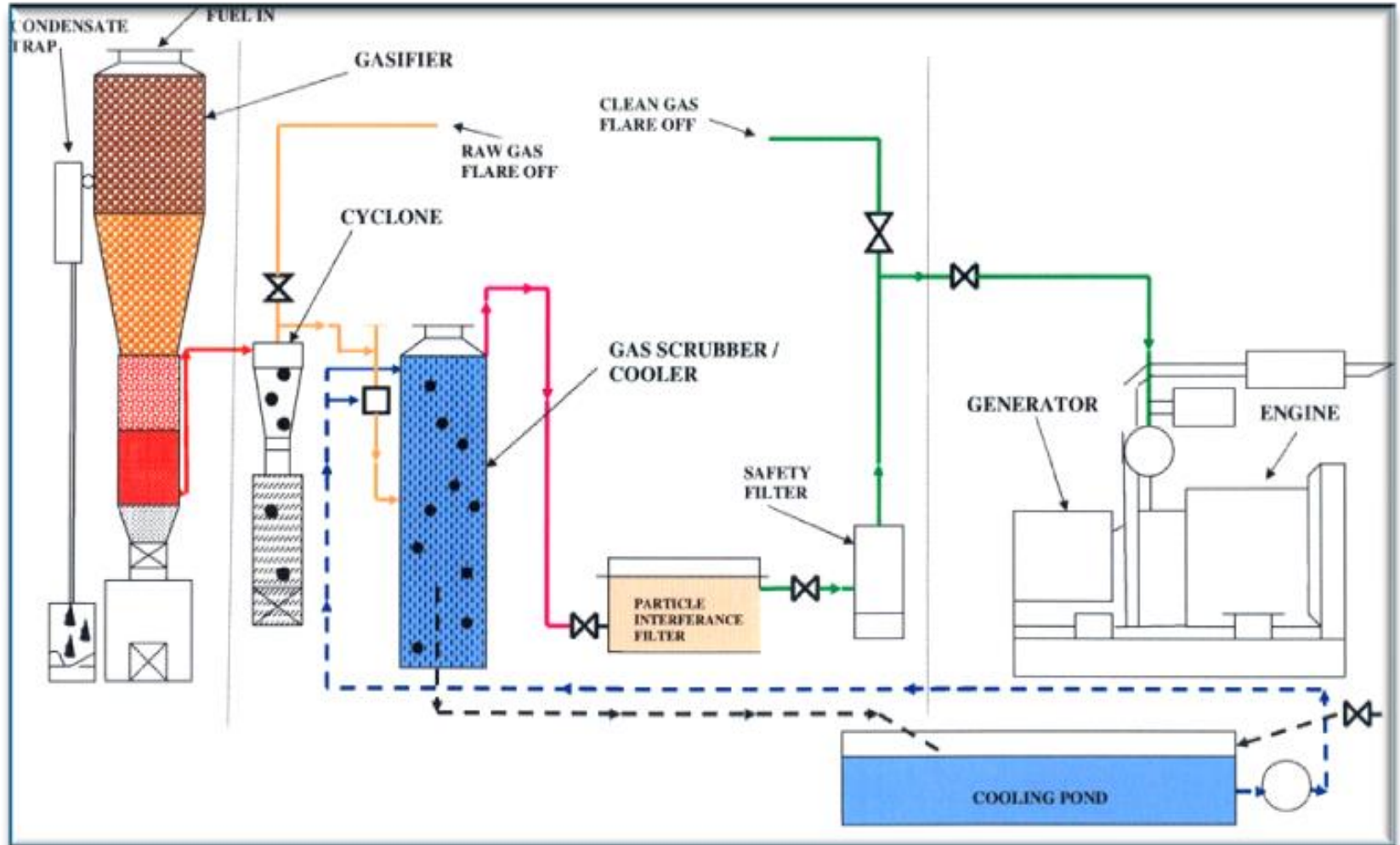


- Where n, x, y and z are the atomic ratio of carbon, hydrogen, oxygen and nitrogen.

$x_1, x_2, x_3, x_4, x_5, x_6$ and m are the stoichiometric amount of the hydrogen, carbon monoxide, carbon dioxide, water, methane, carbon, nitrogen and air.

Johansson Biomass Gasifier

3



Gasification Reactions

Table 1: Shows series of chemical reactions that occur during the conversion of biomass into useful products in a gasification system [Ruiz *et al*, 2013]

Reaction type	Heat of reaction	No
Oxidation reactions		
$C + O_2 \rightarrow CO_2$	-394 kJ/mol	R1
$C + \frac{1}{2}O_2 \rightarrow CO$	-284 kJ/mol	R2
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	-242 kJ/mol	R3
$CH_4 + 2O_2 \leftrightarrow CO_2 + 2H_2O$	+803 kJ/mol	R4
Reduction reaction		
$C + CO_2 \leftrightarrow 2CO$	+172 kJ/mol	R5
$C + H_2O \leftrightarrow CO + H_2$	+131 kJ/mol	R6
$C + 2H_2 \leftrightarrow CH_4$	+74.8 kJ/mol	R7
$C + \frac{1}{2}O_2 \rightarrow CO$	-111 kJ/mol	R8
Shift reaction		
$CO + H_2O \leftrightarrow CO_2 + H_2$	+41.2 kJ/mol	R9
Methanization reaction		
$2CO + 2H_2 \rightarrow CH_4 + CO_2$	-247 kJ/mol	R10
$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	+206 kJ/mol	R11
$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	-165 kJ/mol	R12
Steam reactions		
$CH_4 + H_2O \leftrightarrow CO + 2H_2$	+206 kJ/mol	R13
$CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$	+36 kJ/mol	R14

Previous study on SJBG

5

Table 2: Optimum operating condition of the gasifier [Mamphweli and Meyer, 2009]

Parameter	Value/Quantity
Fuel/air ratio	0.26
Pressure	1 bar
Temperature (Maximum)	1300°C
Air Temperature	25°C
Fuel Moisture content	10-12%

Table 3: Average gas composition of the Gasifier [Johansson, 2002]

Gases	CO	H ₂	CO ₂	CH ₄	N ₂
Composition (%)	22.3-24.3	22.3-22.5	10.7-9.8	1.90-2.10	42.9-41.5

Table 4: Determined Efficiencies of the System [Nwokolo *et al*, 2014]

Efficiency Type	Value (%)
Cold gas efficiency	88.11
Electrical power efficiency	23.2
Overall Efficiency	20.5

Problem Statement

6

- There is a significant heat energy lost in gas scrubber.
- Gas temperature drops from between 450°C – 500°C to room temperature.
- Heat exchanger will improve thermal efficiency.

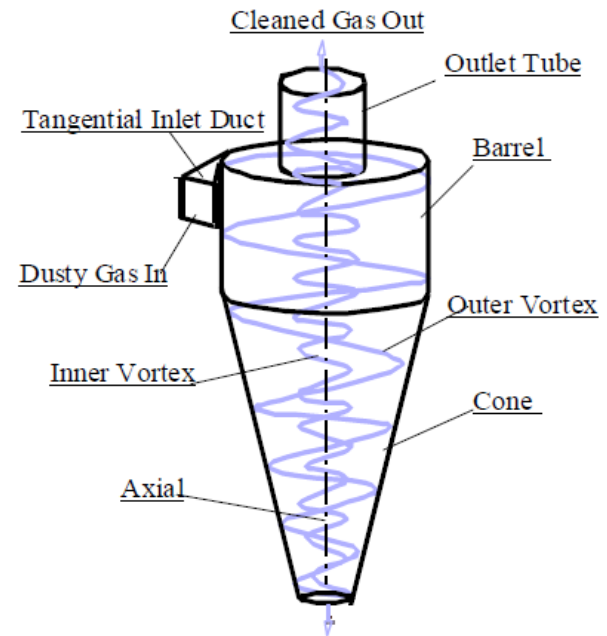


Figure 2: Schematic flow diagram of a cyclone [Wang, 2004]

Research Objectives

7

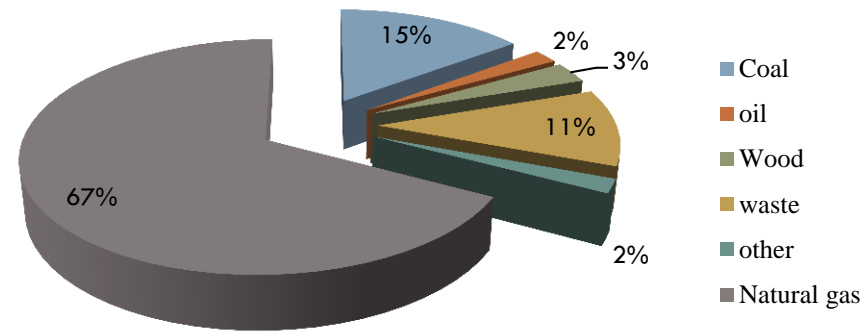
- To quantify the amount of heat that could be recovered so as to ascertain the feasibility of heat recovery from the surface of the cyclone.
- To employ mathematical modeling for predicting the quantity of heat that could be effectively harnessed from the surface of the cyclone.
- To manufacture and monitor the performance of a cyclone heat exchanger capable of harnessing the heat from the hot syngas as well as removing fine carbon particles.
- To compare the results obtained through mathematical modeling to the measured results in order to validate the mathematical model developed.
- To employ the developed model in the optimization of heat recovery from the surface of the cyclone.
- To evaluate the impact of heat recovery at the cyclone on the overall thermal efficiency of the gasifier system.

Significance of the Study

8

- Combined heat and power (CHP)
- Enhanced efficiency
- Efficient fuel Utilization
- Environmental benefits
- Diversification

CHP Fuel Distribution



[Bluestein, 2004]

Research Method

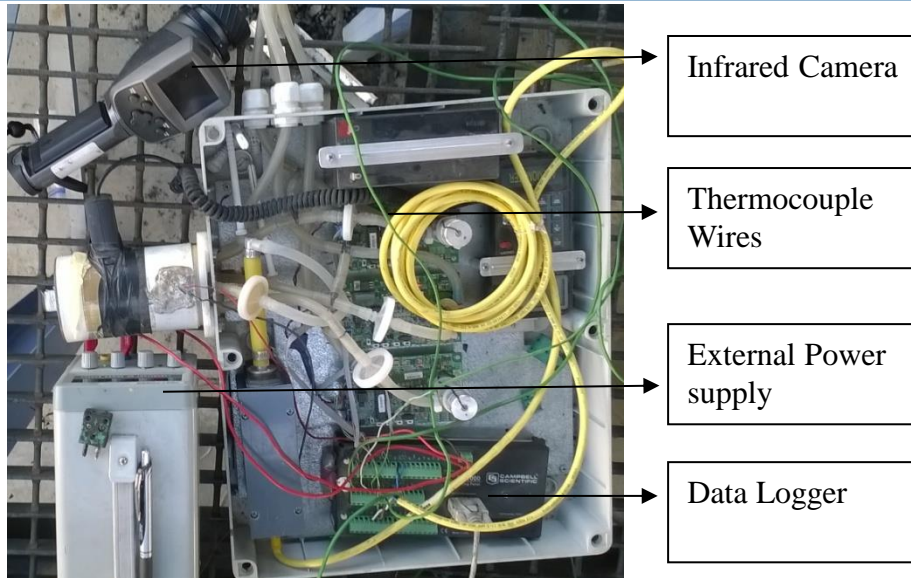


Figure 3: Temperature measurement setup

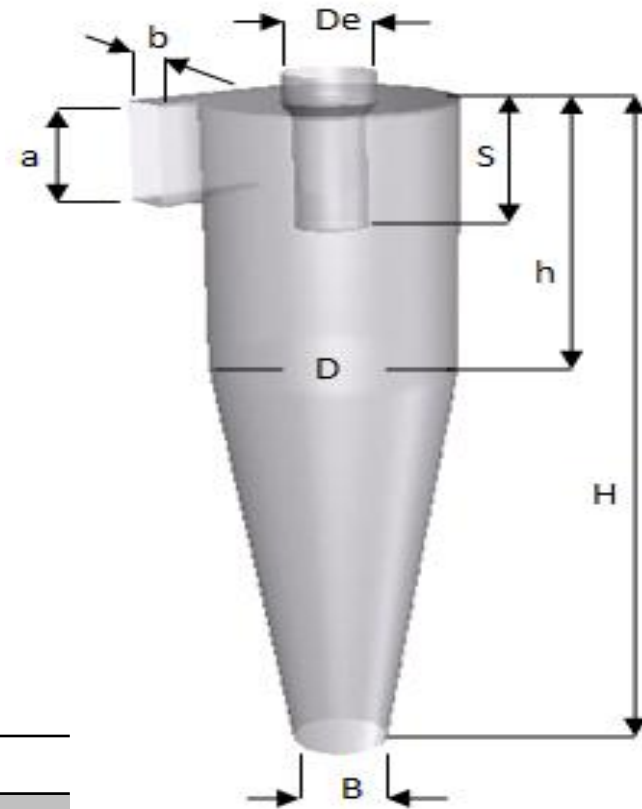


Figure 4: Cyclone Dimensions

Table 5: Main dimensions of the cyclone

Item	Dimensions (cm)
Cyclone cylinder height	22
Cyclone cone height	101
Cyclone outside diameter	111
Cyclone inlet duct length	50
Vortex finder length	45

$$Q = V \times \rho \times C_p \times \Delta T \quad \text{Equ 2}$$

Temperature Result and Discussion

10

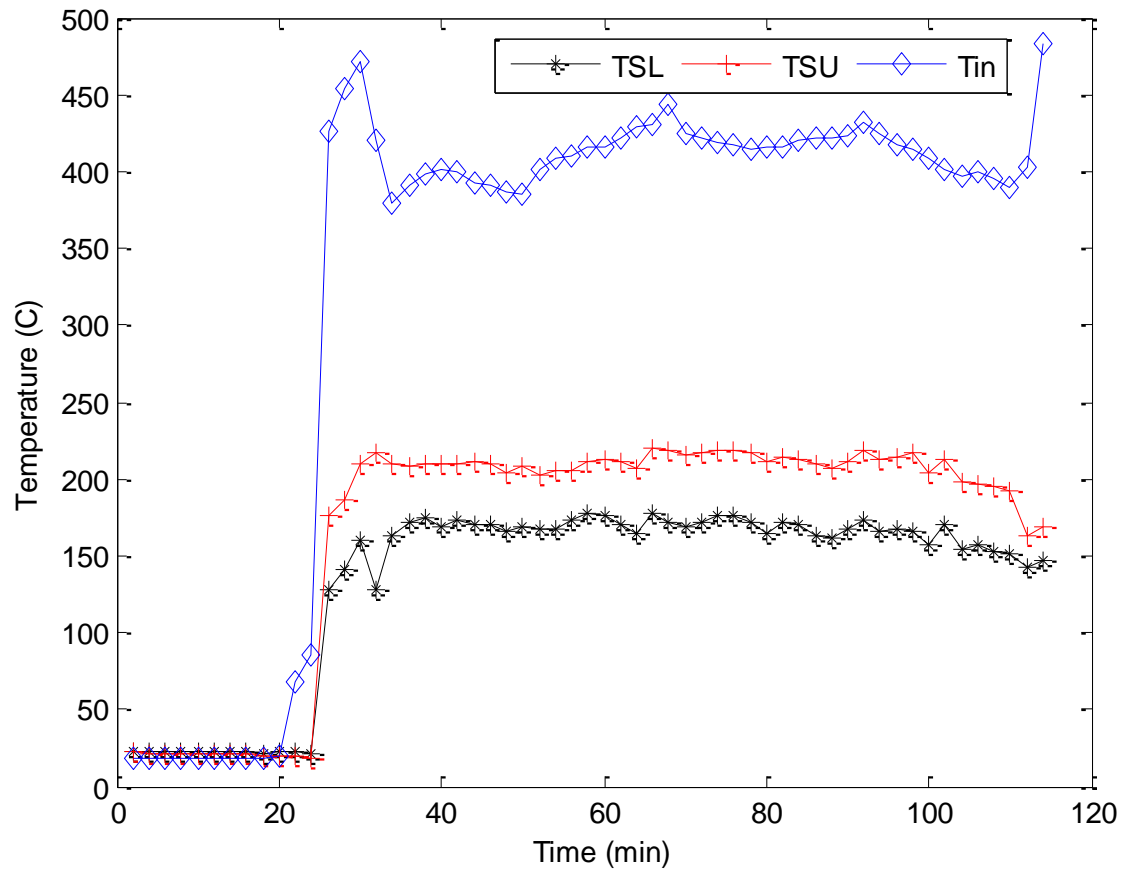


Figure 5: Gas inlet and cyclone surface temperature profile within the first 120mins

Temperature Results

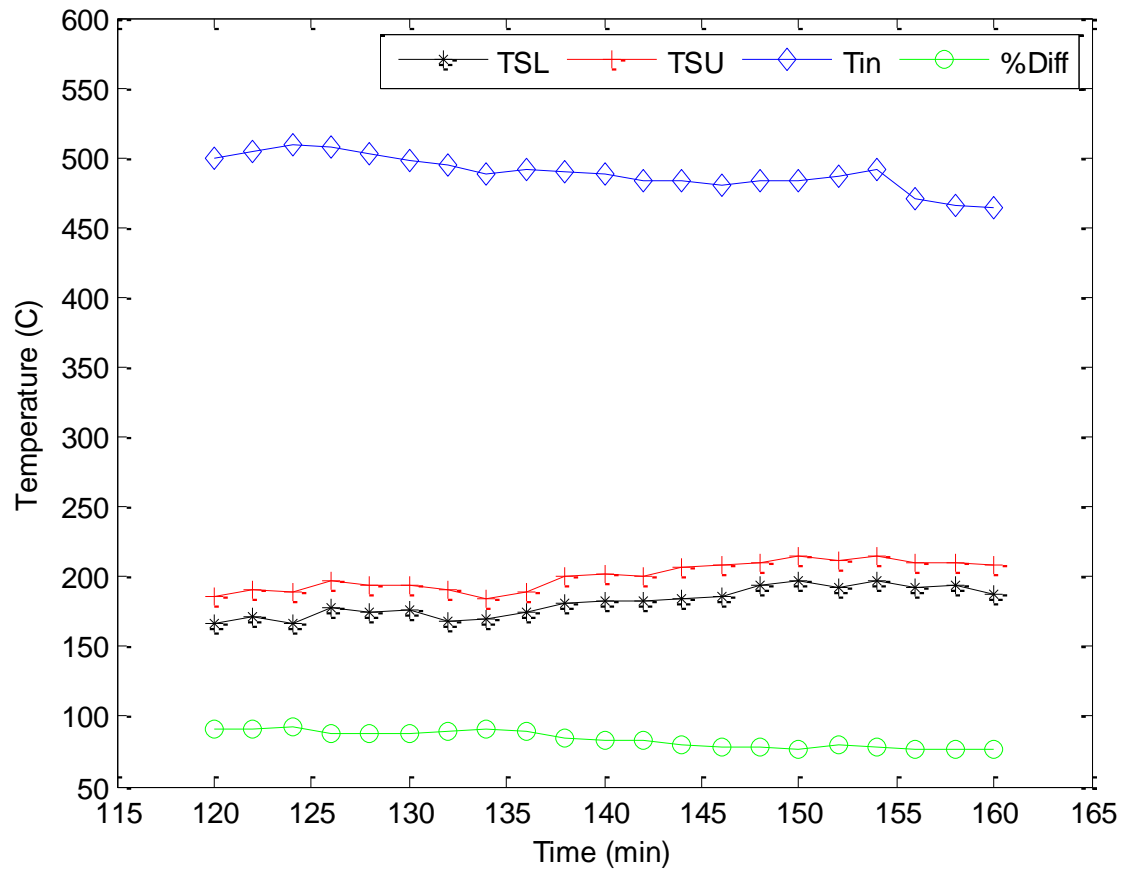


Figure 6: Gas inlet and cyclone surface temperature profile after the first 120mins

Thermal Image and Temperature Gradient

12

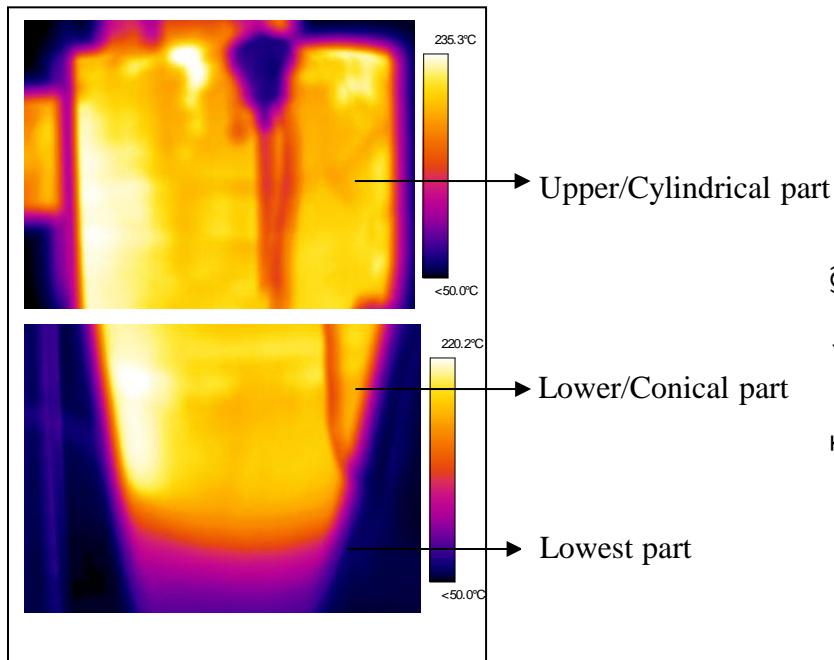


Figure 7: Thermal image of the cyclone

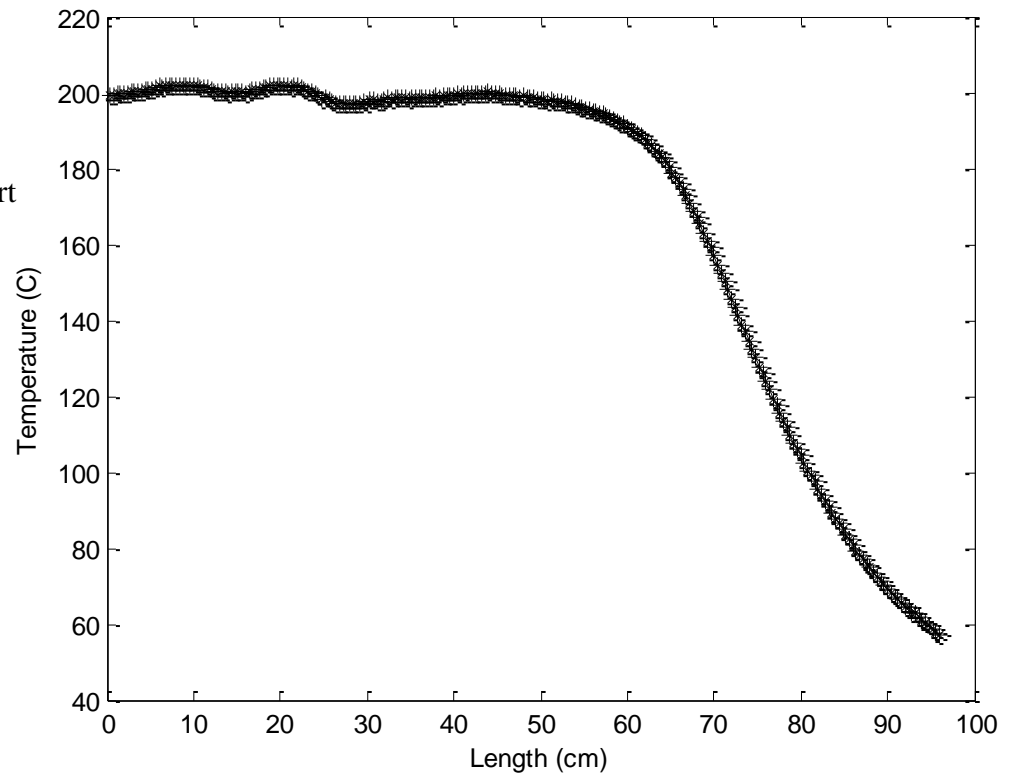


Figure 8: Temperature gradient along the length of the cyclone

Quantity of Heat Determination

Table 6: Parameters for estimation of heat quantity

Item	H ₂	N ₂	CH ₄	CO	CO ₂	Total
Molar mass (g/mol)	2.02	28.01	16.04	28.01	44.01	118.09
% Composition of gas	22.30	42.90	1.90	22.30	10.70	100.1
Mass (g)	2.01	53.65	1.36	27.89	21.02	105.93
Specific heat capacity(kJ/kg K)	14.32	1.04	2.22	1.02	0.84	19.44

➤ Hence the total quantity of heat was determined using equation 2 and parameters presented in table 7 and were found to be 665893.07kcal.

Table 7: Waste heat temperature classifications and some source examples [US DOE, 2008]

Type	Temperature range	Example source
High	1650°C – 649°C	Hydrogen plant, Fume incinerator
Medium	650°C – 230°C	Gas turbine exhaust, Catalytic crackers
Low	232°C and lower	Welding machines, Annealing Furnaces

Future Work

14

- Cyclone surface temperature will be measured at 25%, 50%, 75% and 100% electrical load using type-k thermocouples and thermal camera.
- Model development.
- Model Validation and Optimization.
- Design and manufacturing of the heat exchanger.
- Performance monitoring of the heat exchanger.
- Thermal efficiency evaluation.

15

Thank You