Faculty of Engineering
University of Nigeria, Nsukka
22nd- 25th June, 2021

Proceedings of the
2021 Sustainable Engineering and
Industrial Technology Conference

CFD Simulation Of A Sub-Bituminous Coal Gasifier Using ANSYS Fluent

Agabi, A.J.[a,b], A.Nasir[a], O. J. Okegbile[a], A.S. Kovo[a]

[a]*Department of Mechanical Engineering, Federal University of Technology, Minna, Niger State, Nigeria.*
[b]***Email:*** nimilen@yahoo.com

Abstract

The simulation of the gasification of Onyeama coal in an updraft gasifier was carried out in order to develop necessary baseline combustion reaction data for the assessment of Onyeama coal combustion performance at high temperatures. ANSYS fluent was successfully used in the simulation of the coal. The heat transferred from the inner surface which was around the maximum 7.59 x102 K to the outer surface which was around the minimum 2.98 x102 K. There is high production of CO than CO2 in this process and higher H2 than H2O, CH4. Mean values of: 808K and 0.002Pa and exit 808K and 0.0003Pa were obtained for temperature and pressure. The average mass flux that occurred between the inlet and outlet resulted not more than 0.5% which conclusion from our simulation shows that the mass balance is good.

Keywords: ANSYS, Onyeama coal, temperature, pressure, producer gas

1. INTRODUCTION

This topic aims to find an alternative route needed to make coal more feasible for energy production. Coal production process as a solid fuel releases some amount of energy and thermal reaction which can/cannot be environmentally friendly to human lives. A procedure to understand fully the behaviour of onyeama coal at high temperatures, thus making it easier for these discoveries to be adopted for use in power plants and to make onyeama coal more marketable. In the current energy outlook, coal gasification process is considered as a viable fuel upgrading path, allowing the transformation of a solid fuel into synthetic natural gas as gaseous energy vector (syngas) [1]. Coal is a solid fuel and its gasification leads to release of abundant amount of energy and thermal decomposition to produce gases such as H_2, CO, CO_2, H_2O, CH_4, C_2H_6, tar, and char [2, 3]. Tar and char can further react with O_2 and H_2O supplied to form more H_2, CO, CO_2 and CH_4. Some of these reaction products are useful and friendly while some are unfriendly to us and our environments [4].

This work draws insight from onyeama coal produced in Nigeria using updraft gasifier for the research. A complete CFD model using ANSYS FLUENT following a process simulation taking insights from experiments which was conducted for the work. Some equations were solved for this procedure such as diffusive mass transfer, Fick's law in order to generate the turbulence parameters needed for turbulence modelling. Pressure plays also an important role in the gasification process thus favoring the production of methane.

2. MATERIALS AND METHOD

The coal used in this work is Onyeama Coal from Nigeria with composition shown in Table 1. The updraft gasifier was in used in this research. The updraft system consists of a screw conveyor embedded in a feedstock hopper, the gasification chamber or reactor, a cyclone, a wet scrubber and a gas filter. A centrifugal blower with a regulator delivers a measured amount of air (33m2/hr), cyclone diameter of 200mm from design calculation to the gasification chamber. A model used for the simulation is shown in Figure 1. In the gasifier 61kg/min (as per design calculation) of coal is broken down by the use of heat in an oxygen-deficient environment to yield a combustible product gas. The heat for gasification is generated through combustion of part of the coal feed material on the grate of the reactor.

Table 1: Composition of Onyeama coal.

Proximate analysis		Ultimate analysis	
Moisture %	5.87	H%	3.8
Volatile matter	29.61	C%	86.55
Fixed carbon	63.61	N%	1.2
Ash	1.25	S%	0.6
Calorific value	33.33	ASH	1.25

3. RESULTS AND DISCUSSION

CFD-model has been taken from process simulation results that balanced the data gained from the condition of experiments. The convective part was solved together with the solution of the flow field. The diffusive mass transfer contains laminar diffusion (using Diffusion coefficients and Fick´s laws) and turbulent diffusion that was calculated using turbulence parameters generated by turbulence modeling. Figure 1 below shows the temperature gradient in the coal packed bed of the symmetrical view. The heat transferred from the inner surface which was around the maximum 7.59

ISBN 0000-0000

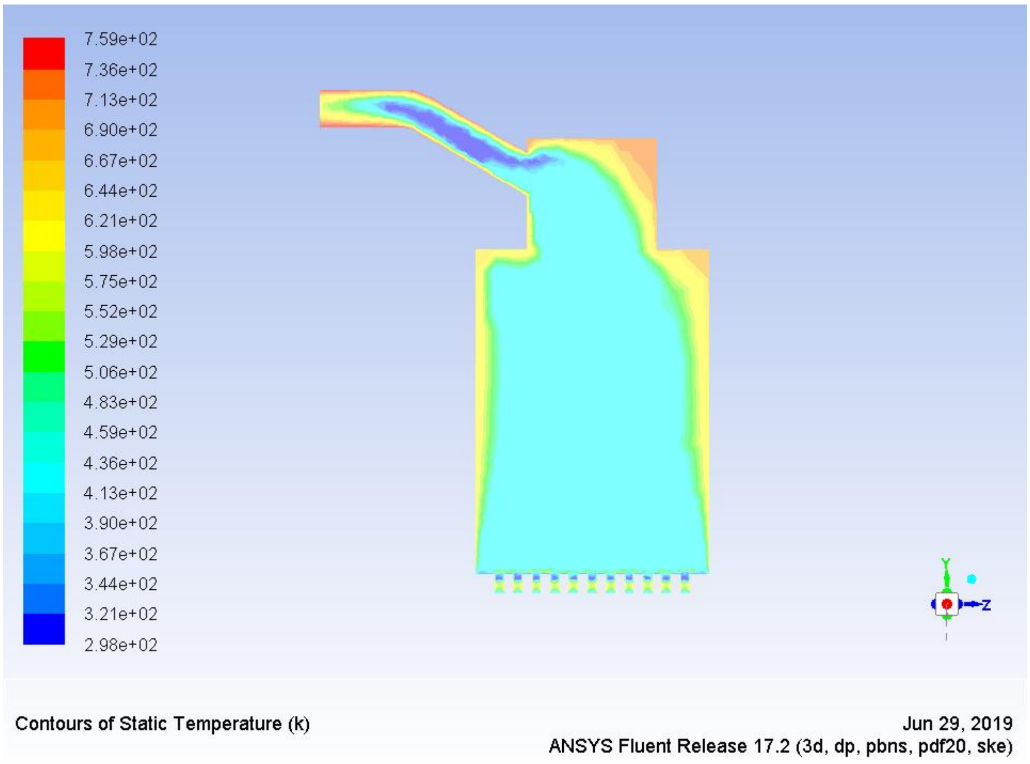

Figure 1: Simulation results showing Temperature profile of the gasifier bed from gasification of Onyeama coal.

Table 2: Mechanical properties of heat-treated samples before corrosion test [5].

Parameter	Minimum	Maximum	Mean	Exit
CO (%)	0.02	0.19	0.019	0.019
CO_2 (%)	0.023	0.22	0.08	0.07
H_2 (%)	0.002	0.032	0.003	0.003
H_2O (%)	0.005	0.089	0.089	0.089
CH_4 (%)	0.007	0.07	0.049	0.053
Temp (K)	415	1460	808	808
Pressure (Pa)	0.003	0.002	0.002	0.0003

$\times 10^2$ K to the outer surface which was around the minimum 2.98 $\times 10^2$ K.

Figure 2 displayed the pressure profile. From Figure 2 it can observed that the pressure increases from -3.25$\times 10^{-5}$Pa to 0.255Pa. Pressure is an important factor in a gasification process. High pressure may favor the production of methane and low pressure favor the production of CO, CO_2 and

4. FINDINGS AND ARGUMENTS

4.1. Temperature profile

CFD-model obtained from process simulation results that balanced the data gained from the condition of experiments. The convective part was solved together with the solution of the flow field. The diffusive mass transfer contains laminar diffusion (using Diffusion coefficients and Fick´s laws) and turbulent diffusion obtained using turbulence parameters generated by turbulence modelling. Figures 1 displayed the temperature profile of the gasification. The gas and solids temperature in the jet zone is critical for the successful operation of the coal gasification process. In the jet region, char particles combust with O_2, resulting in a high-temperature zone that is key to ash agglomeration. However, there is a need to control the maximum bed temperature to avoid undesirable clinkers, especially in the grid zone. The coal feedstock and oxidant injected into the first stage leads to combustion. Carbon and oxygen react at the initial stage to give CO, the CO then react with oxygen to give CO_2.

Gasification with oxygen (partial combustion):

$2C + O_2 \longrightarrow 2CO$ H = −123.1 kJ/mol Combustion with oxygen

$2CO + O_2 \longrightarrow 2CO_2$ H = −405.9 kJ/mol

The oxidation and combustion reactions generate significant heat and the temperature in the middle of first stage is raised to over 552K for Onyeama coal. Due to the feed of oxygen being insufficient for full combustion, some of the coal is consumed and converts into CO and H_2 via gasification process by reacting with CO_2 and H_2O. Because these two equations are endothermic reactions, the temperature in the exit of bottom vessel is lowered to around 350K for Onyeama coal. Temperature distribution within the updraft gasifier inner shell at desired operating condition is given temperature profile contour. The maximum average temperature of gasifier achieves approximately 759K for Onyeama coal (see Figures 1).

4.2. Pressure Profile

Figures 2 displayed the pressure profile. The Gasifier although working at atmospheric pressure, has the static pressure of the gasifier varied with the height of the gasifier due to the generation of combustion

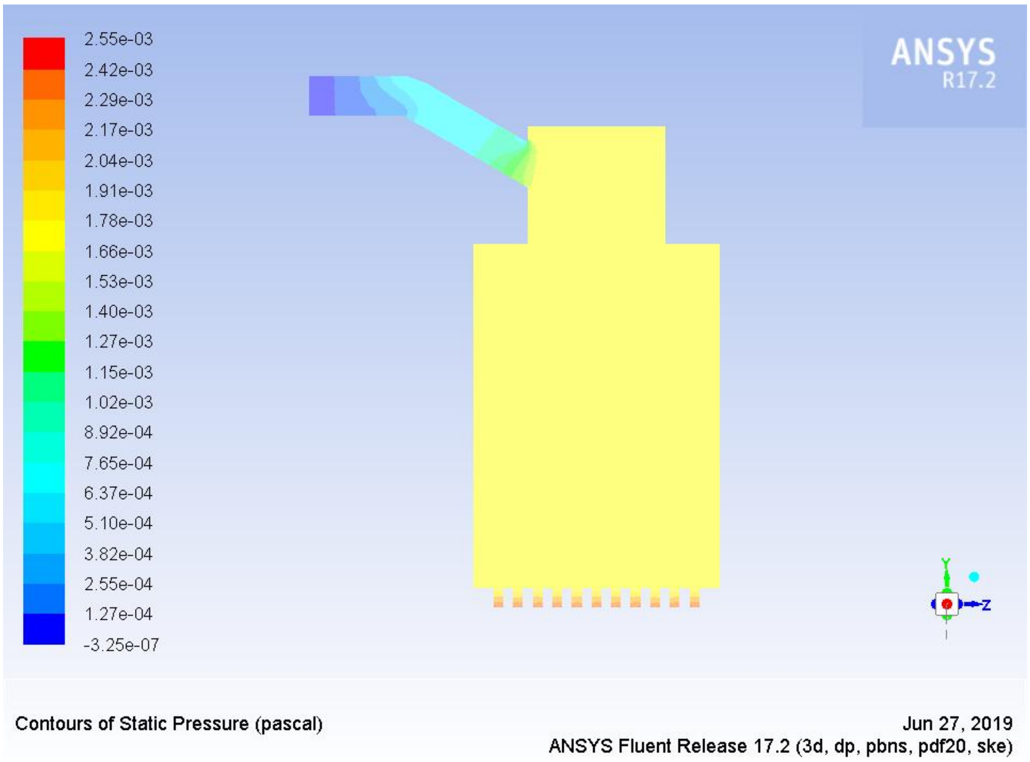

Figure 2: Simulation results showing Pressure profile of the gasifier bed from gasification of Onyeama coal.

gaseous products. It can be observed that the pressure increases from -3 $\times 10^{-7}$Pa to 0.00255Pa for Onyeama coal (see Figures 2). Pressure is an important factor in gasification process. High pressure may favor the production of methane and low pressure favor the production of CO, CO_2 and H_2.

5. CONCLUSION

Using ANSYS FLUENT was a good choice for the simulation of onyeama coal, this is because of the nature and flexibility of the software. There was a decrease in the transfer of heat from the inner surface to the outer surface due to heat transfer concerns and losses, also there was increase in pressure from the inlet to the outlet, while low pressure favors the production of CO and CO_2. Finally, the net average heat flux value was conserved too. Going further on this project, other parameters can be varied such as density, boundary conditions in FLUENT, so as to know if these variations can have any effect on the gasification of coal.

References

[1] S.S Hla, D. Harris, and D. Roberts. Gasification conversion model. Technical report, Cooperative Research Centre for Coal in Sustainable Development, Australia, 2007.

[2] S. Benyahia and M. Syamlal. The effect of model parameters on the predictions of core-annular flow behavior in a fast fluidized gas/solids bed. In *Annual Meeting Conference Proceedings*, pages 3283–3297, 2004.

[3] M. N. Chukwu, C. O. Folayan, G. Y. Pam, and D.O. Obada. Characterization of some nigerian coals for power generation. *Journal of Combustion*, Australia:1–11, 2016.

[4] A.D. Engelbrecht, B.C. North, B.O. Oboirien, R.C. Everson, and H.W.P.J. Neomagus. Fluidized-bed gasification of high-ash south african coals: An experimental and modelling study. *Ind. Fluid. South Africa*, page 145–160, 2011.

[5] X. Wang, J. Baosheng, and Z. Wenqi. Three-dimensional simulation of fluidized bed coal gasification. *Chemical Engineering and Processing*, 48(2):695–705, 2009.