Design of gas cleaning unit for biomass gasifier

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Abstract. Biomass is considered as renewable energy and its energy potential is promising due to the reason that biomass is a more evenly dispersed source over the earth and thus available nearly worldwide. The challenge is to remove the biomass-derived contaminants such as tar, particulates, H2S and HCl, alkali compounds from the product gas, and then use it for other applications. The objective is to design a proposed gas cleaning unit using ANSYS for the downdraft biomass gasifier and thereby remove the contaminants. From the simulation it was concluded that, the outlet temperature of the downdraft gasifier found from the simulation is 1285.7 K. From the simulation of the proposed cleaning unit, the outlet temperature of 1264.6 K is formed.

1. Introduction
With the continuously increasing demand for energy, our current primary energy source, fossil fuels are getting depleted, which are used to support economic growth. The gasification process can be used as a backup plan for the production of electricity; but is necessary to remove impurities produced such as particulates, sulphur oxides, CO2 and others. Alessandro Vulpio et. al [2] discussed mainly the 2D ANSYS simulation of the downdraft gasifier using the wooden pellets. This journal has been used for the validation of the simulation that has been modelled in this report. Here the gasification of the wooden pellets has been done and these results have been used for the validation purpose. Here a test case taken from literature has been simulated with an alternative set of reactions. George Yaw Obeng et. al [3] discusses mainly about the gasification process with the help of the coconut husks. The results indicate that 62–65% of the whole coconut fruit can be generated as wastes in the form of husks and shells. It also found out that as the water evaporated gradually from the raw un-charred coconut wastes during the combustion process, charred coconut wastes would likely produce less CO pollutant emissions than the raw un-charred coconut wastes.

2. Geometric modelling of biomass gasifier and cleaning unit.
The geometric modelling of the downdraft gasifier is made in the ANSYS. The schematic diagram of the downdraft gasifier system is shown in Figure 1. The dimensions of the system are 481mm in height and 178mm in diameter to do the simulation. The proposed geometric model is also designed and modelled in ANSYS. The length of the model is 101mm. it has a width of 8mm. It has a negligible thickness. The simulation work is done in 3D.

The cleaning unit consists of 3 main parts. First is the outer sheet of the metal cover. The metal sheet cover is made of stainless steel. The next part is ceramic wool. It is inside the metal cover. The final part is the perforated tube which is also made of steel. The hot air from the gasifier is made to pass through the gas cleaning unit. Shown below is the schematic diagram of the proposed cleaning unit (Figure 2). Grid independence study is performed to eliminate/reduce the influence of the number of grids/grid size on the computational results. If any changes in geometry, meshing grids definitely
will be changed. When grids changed, we need to ensure the grid independence is applied. Grid Independence study of the gasifier was done by meshes 74768, 131453, 192658, 259831, and 412627 in the 3D model. The optimum value is taken as 259831; the temperature shown is 1285.7K. Grid Independence study of the cleaning unit was done by meshes 9465, 15453, 22651, and 38065 in the 3D model. The optimum value is taken as 22651; the temperature shown is 1264.5K.

![3D geometric model of downdraft gasifier](image1)

**Figure 1.** 3D geometric model of downdraft gasifier

![3D geometric model of cleaning unit](image2)

**Figure 2.** 3D geometric model of cleaning unit

3. **Details of CFD analysis.**

The CFD analysis was carried out using the ANSYS-FLUENT. The following assumptions are considered for the simulation of the downdraft gasifier.

- 3D steady state.
- In-compressible flow.
- Adiabatic wall condition at combustion zone.

The equations are:

**Continuity Equation:**
\[
\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (rp v_r) + \frac{1}{r} \frac{\partial}{\partial \theta} (\rho v_\theta) + \frac{\partial}{\partial z} (\rho v_z) = 0
\]  
(1)

**Energy Equation:**
\[
\frac{1}{r} \frac{\partial}{\partial r} \left( k r \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \frac{\partial}{\partial \theta} \left( k \frac{\partial T}{\partial \theta} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + q_v = Q
\]  
(2)
Momentum Equation: \[ \nabla \cdot (\vec{V} \otimes \vec{V}) = -\nabla \rho + \rho \nabla^2 \vec{V} + g \quad (3) \]

In mesh generation, the problem domain is divided into a large number of tiny cells. The number of cells in the domain has a great effect on the simulation results. Grid Independence study of the downdraft gasifier was done by meshes 74768, 131453, 192658, 259831, and 412627 in the 3D model. The optimum value is taken as 259831; the temperature shown is 1285.7K. Grid Independence study of the proposed cleaning unit was done by meshes 9465, 15453, 22651, and 38065 in the 3D model. The optimum value is taken as 22651; the temperature shown is 1264.5K.

4. Results and Discussion

4.1 Material properties used in simulation.

The material properties that are used for the simulation process has been displayed in Table 1.

| Material            | Density, kg/m³ | Specific Heat, J/kg K | Thermal Conductivity, W/m K |
|---------------------|----------------|-----------------------|-----------------------------|
| Air                 | 1.225          | 1006.43               | 0.0242                      |
| Biomass             | 8000           | 502.416               | 45                          |
| Stainless Steel     | 1200           | 2600                  | 0.048                       |
| Ceramic Wool        | 40             | 840                   | 0.04                        |

4.2 Optimum value of ER for a gasifier.

The equivalence ratio is defined as the ratio of the mass flow rate of air-fuel mixture to air that is supplied. In the gasification of biomass, the equivalence ratio is one of the most important parameters that are used to predict the process performance and also the design of the gasifier. The mass flow rate value of feedstock is set at 0.011 kg/s for all the simulations while the airflow rate changes according to the ER. The stoichiometric ratio of air to wood is 6:1. The ER values selected are 0.19, 0.24, 0.31 and 0.43. The simulation is done on these 4 values.

ER=0.19

ER=0.24
A relatively low value of the equivalence ratio may result in many problems, such as; leading to a low heating value of gases produced with an excessive amount of char formation thus further resulting in incomplete gasification process. On the other hand, a large value of equivalence ratio can result in an excessive formation of products through a complete combustion process. From the Figure 3 it is has been understood that the first contour that is 0.19, 0.31 and 0.43 cannot be taken because in the first case the supply of oxygen is too much and there is a large increase in the temperature at the centre of the gasifier i.e. the combustion zone, whereas the in the next cases there is no much reaction takes place. The difference between the four conditions lies in the gas exit temperature: the higher the Equivalence Ratio, the lower is the outlet gas temperature. Here the optimum value is taken as 0.24.
4.3 Validation of the Downdraft Gasifier Simulation.
Here for the validation of the ANSYS simulation of the downdraft gasifier, another journal value has been used [2]. This journal has done a simulation of the downdraft gasifier with wooden chips. Here the simulation of the gasification was done and the biomass properties of coconut husk were provided as the input. So, to validate the simulation that was modelled, another simulation was modelled and calculated, providing the biomass properties of the wooden chips. The mass flow rate is taken as 0.011 kg/sec in both cases. From the graph plotted below, it is been verified that the temperature distribution is uniform and hereby validating the same.

![Validation graph]

**Figure 5.** Validation of the present work with the reference journal.

4.4 Results of Simulation of Proposed Cleaning Unit.

The temperature contour of the proposed cleaning unit has been shown in figure. From the temperature contour, it is being confirmed that the outlet gas temperature is 1264.6 K. The maximum temperature inside the proposed cleaning unit is about 1285.7 K. The temperature distribution is shown in the Figure 6.

![Temperature distribution graph]

**Figure 6.** Temperature distribution of the proposed cleaning unit along the horizontal distance.
5. Conclusions
From the simulation results, it has been concluded that:

- The maximum temperature that is obtained from the ANSYS simulation of the downdraft gasifier is 1365 K. The outlet temperature of the downdraft gasifier found from the simulation is 1285.7 K.
- The validation of the simulation of the downdraft gasifier was done with the help of the reference journal [2].
- The syngas produced is directly supplied from the downdraft gasifier to the proposed cleaning unit in the simulation and the temperature distribution of the same is found out. From the simulation of the proposed cleaning unit, it was concluded that an outlet temperature of 1264.6 K is formed. The inlet temperature of 1285.7 K was supplied to it.

References
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