Case Study

Project Bluegen - Hydrogen from Biomass

Task Objectives

Jesmond Engineering partnered up with the University of Hull and Aston University on a BEIS funded project to produce hydrogen from biomass. Gasification will be used to convert the biomass into a gas, this gas will then be cleaned and separated to give hydrogen.

Jesmond Engineering was tasked with designing the full system that takes biomass sludge from a bio-refinery, converts it into pellets. These pellets are then sent to a gasifier and converted to syngas. The syngas is cleaned before the hydrogen (H_2) yield is maximised and separated from the rest of the syngas mixture.

Section 1 – Biomass Preparation

The biomass sludge that is received from the bio-refinery requires a lot of processing to get it ready for gasification. First of all, the alkali metals from the sludge have to be removed and to do this a deionised water wash was implemented. From the wash, the biomass has absorbed water which needs to be removed. This problem was solved by using a belt filter press and a rotary dryer. The belt filter press removes the free water whilst the rotary dryer releases the bound water, making for an energy efficiency technique. After the water has been removed the biomass needs milling to reduce it's particle size, this aids with pelletisation as the smaller particles stick together better. After pelletisation the pellets are feed into the gasifier via a screw feeder.

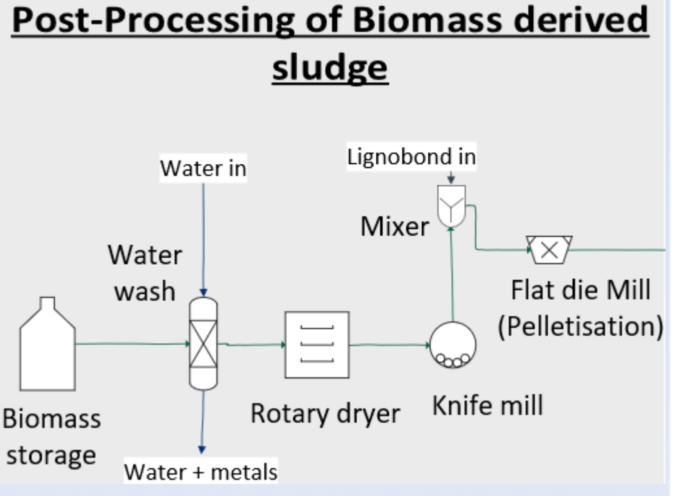

Figure 1 Block Flow Diagram of Section 1

Section 2 - Gasification

Gasification is a thermochemical process that converts organic materials into fuel gases without combustion. Gasification typically occurs at temperatures greater than 700°C and the gas given off is called syngas (synthesis gas).There are several types of gasifiers that can be used from a downdraft to an entrained flow. The decision was made to use a bubbling fluidised bed gasifier as it has several key advantages including providing an even heating distribution, a uniform syngas and a very high conversion rate of the biomass. This due to the fluidised bed which means gas is blown through a powder at a velocity greater than the terminal velocity of the powder which gives the material fluid like properties. Silica sand was chosen for the fluidised bed material as it has a high melting temperature. This is very important as gasifiers run at very high temperatures. The fluidising medium was a 1% O_2 and 99% N_2 gas mixture.

To design the gasifier, correlations found in literature were used calculate aspects of the reactor, such as the reactor diameter and minimum fluidization velocity. The design, based on these correlations, was modelled in ANSYS Fluent to allow for evaluation these correlations and to optimise the design.

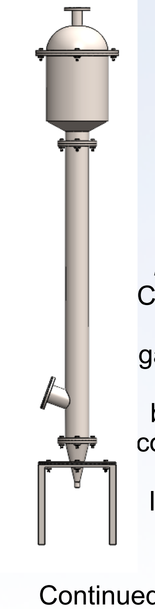

Figure 2 CAD model of the gasification reactor based on correlations found in literature.

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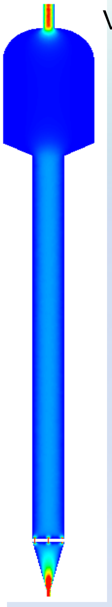
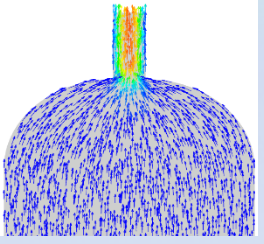
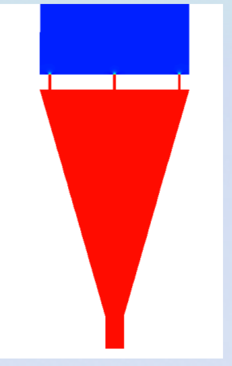


Velocity Magnitude



Velocity Vectors

Pressure Distribution



Computational Fluid Dynamics (CFD) Analysis was used to aid/influence the design of our gasifier. Jesmond Engineering developed CFD models, a simulation framework and methodology to use as a base for optimisation.

A single-phase model was selected to model the gas-phase and an inlet velocity was applied at the air inlet. Constant material properties were applied at operating temperatures of 800 °C

The main areas of the gasifier that required design improvement were highlighted with each iteration having CFD analysis conducted, specifically looking at pressure losses and velocity profiles.

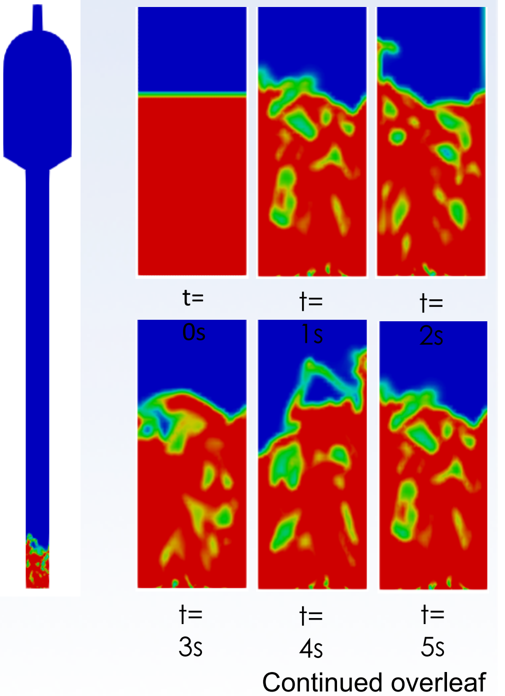
Once the design was optimised, a two-phase Eulerian model was selected to model mass/momentum exchange inside the reactor between sand and air. A Granular model was used to simulate the transport of sand in a fluidised bed, which allowed features such as bed expansion/sand movement.

CFD analysis indicated:

- The wind box needed to be angled to reduce a pressure drop between the nozzle and distributor plate and also to evenly spread gas across the plate.
- A low-velocity zone at the head of the gasifier to prevent sand from being transported out of the gasifier. The height of the gasifier also exceeds the transport disengagement height (TDH)
- Dome shape given to the low velocity zone to increase the pressure/ velocity of Syngas as if leaves the gasifier.

CFD methods developed during this project can be extended to additional models such as:

- Addition of a third solid particle phase to model biomass pellets
- Activation of thermal effects such as the inclusion of headed gas/sand
- Inclusion of species transport to model both homogenous and heterogeneous chemical reactions in the gasifier



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Section 3 – Syngas Cleaning

Now that syngas has been produced, it requires cleaning. Cleaning involves: Removing particulate matter like dust, ash or sand from the fluidised bed; removing light and heavy tars with the use of a wet packed bed absorber; a stripper/absorber unit to remove acid gases such as CO_2 and H_2S; guard beds that contain catalysts to adsorb compounds from the syngas such as HCL, COS, HCN, Mercury, etc.

The first stage of syngas clean up us particulate removal and this is done via the use of cyclones and ceramic filters which trap and then store any ash/sand in a container and is then separated so the sand can be recycled and the ash can be sold off as a by-product.

The second stage is to remove tars from syngas as they can cause clogging/fouling downstream. To remove the tars, a novel idea has been applied – use of vegetable oil as the scrubbing medium instead of water. This solvent has been chosen as it can be reused without losing too much efficiency. The packing in the scrubber will be made up of wood chipping because it is a cheap/ sustainable resource and once deemed un-useable for the process, can be burnt to provide a heat source. Syngas and oil flow counter-currently with the syngas leaving the top of the column.

The final stage of syngas clean-up is to remove/reduce any gases in the syngas that are legally required to be removed/reduced. What needs to be removed depends on what is present in the biomass after it has undergone its alkali wash. Gases such as the ones listed above all require specific guard beds that contain specific catalysts in order for them to be adsorbed. Once syngas has undergone this process, it can be considered clean and sent to the final section of the process.

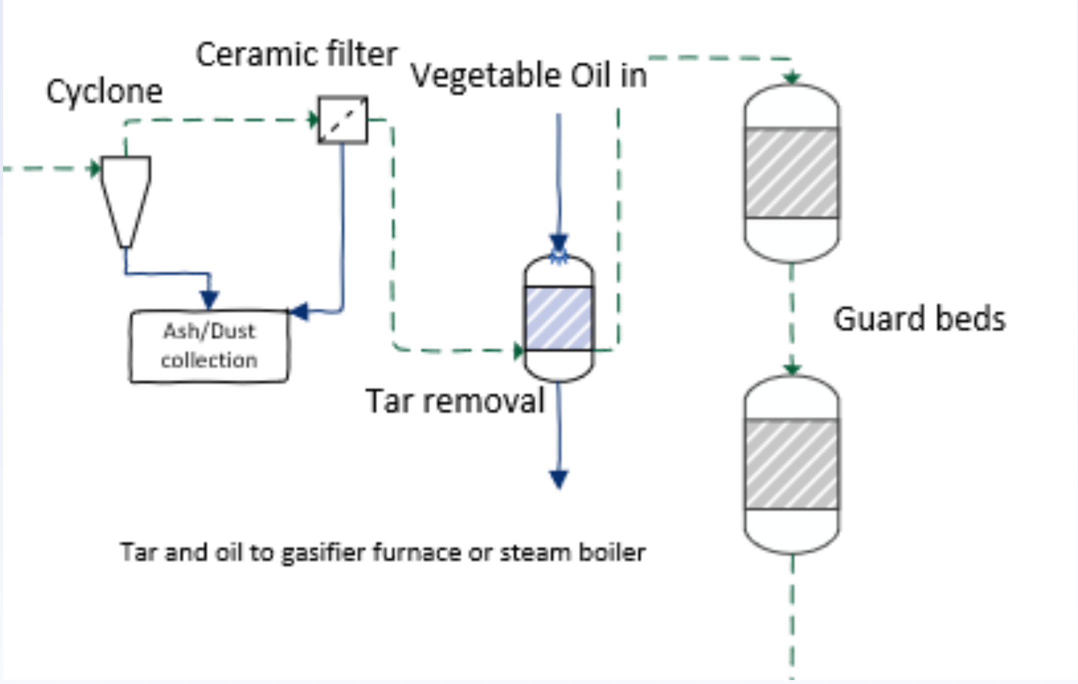

Figure 3: Block diagram of section 3 – Syngas cleaning

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Section 4 – Hydrogen Enrichment

The equation for WGSR is below. The reaction is reversible and mildly exothermic(gives out heat) in the forward direction.

$$H_2O\ (g) + CO\ (g) = CO_2\ (g) + H_2\ (g)$$

The Water Gas Shift reaction (WGSR), takes place in two stages at different temperatures and different catalysts. The main reason for the guard beds in *Section 3* is for WGSRs because if not removed, those poisonous gases will damage the catalysts, driving up costs.

The first shift reactor operates at 673k with an iron based catalyst and then a range of promoters and stabilisers to avoid catalyst deactivation. CO is taken down from 12% to 2.8% in the first stage. The second WGSR operates at 513k with a Copper based catalyst and this further brings down CO in syngas from 2.8% to 0.5%. The reason for the second WGSR operates at a lower temperature is because its thermodynamically favourable if you are producing the maximum possible yield of H_2.

The next part of the process is where H_2 is actually produced with the use of PSA units where H_2 is then produced at over 99% purity. Because of the way PSAs work, it will be necessary to have 2+ units. PSA units work in 4 stages

- **Adsorption:** Non-hydrogen gases adsorbed under pressure until an adsorption limit has been reached
- **Depressurisation**: H_2 is released and the bed is depressurised to reduce the affinity of the non-hydrogen portion of the gas mixture.
- **Regeneration:** Bed is purged with hydrogen so the final stage can happen. The non-hydrogen gases are dumped from the vessel and the H_2 is purged from another vessel into the bed.
- **Repressurisation:** Bed is returned to original pressure using H_2 from the product line and the process can start again.

The off-gas from the PSA units contains H_2, Nitrogen, CO_2, CO, Methane and water.. The off-gas will be sent through another H_2 PSA to recover any missed hydrogen and then a nitrogen PSA will be employed to separate nitrogen, which can be used in various parts of the process. The remaining off-gases leaves the PSA units and enter a cryogenic distillation column. Here CO_2 is cooled, solidifies and separated from the gas stream. The other gases are separated when the column reaches their respective liquefying temperatures. These gases can all be sold off or reused in the process in some capacity.

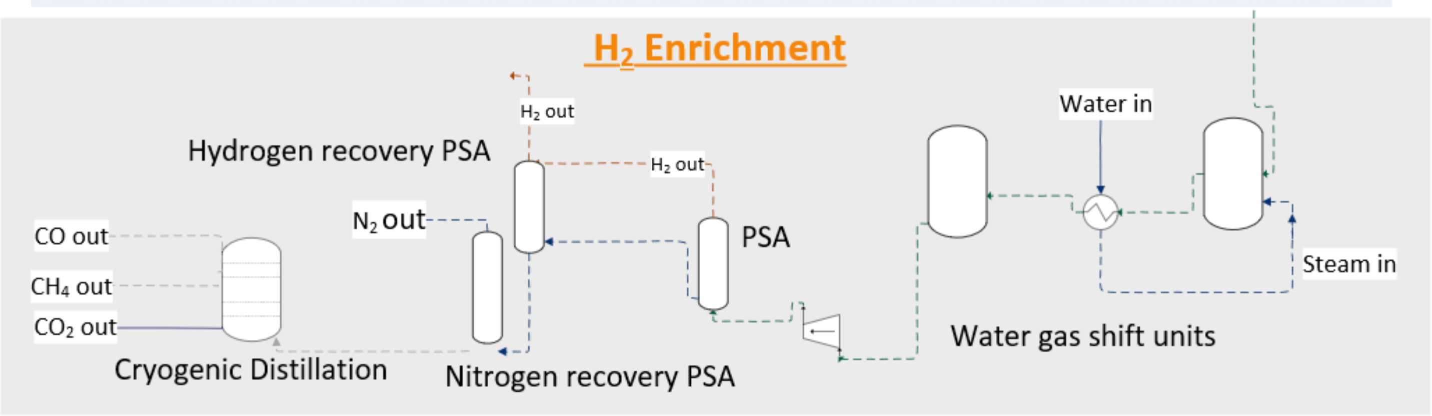

Figure 4: Block diagram of section 4 – Hydrogen Enrichment

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