

Chapter-1

Introduction & Background

1.1 Background

The main goal of this research work is to design a filtration unit and develop a numerical model which predict the best filter configuration for cleaning the producer gas obtained from the downdraft gasifier system by the use of biomass feedstocks. The use of production gas can be divided into (i) electricity generation and (ii) thermal energy generation. Electricity can be generated by operating an integrated gasification combined cycle plant (IGCC) or by operating an internal combustion engine. With the other means for electricity generation, cleaned producer gas is utilised as gases fuel to run the reciprocating engine (e.g., dual-fuelled diesel engine). This option is useful for small capacity of energy production and is suitable for distributing the electricity in rural areas where electricity is not available.

In section §1.2, we present a brief introduction about energy, its crisis and alternate resources. In §1.3, we discuss about the resources of renewable energy. Classification of renewable energy resources has been presented in § 1.4. In section § 1.5 we talk on biomass feedstocks. In § 1.6, we discuss on gasification. Later on, we explain biomass gasification technologies in § 1.7 followed by details of downdraft gasifier in § 1.7.1. Then we talk on producer gas filtration system in § 1.8 in which we discuss on tar filtration techniques in § 1.8.1, dust and ash particles removal techniques in § 1.8.2. In section § 1.9, we reported need of biodiesel with conventional diesel & producer gas. Findings of the review is mentioned in § 1.10. Research gap is presented in § 1.11, problem statement in § 1.12, objectives of the research work is explained in § 1.13 and methodology of research work in §1.14.

1.2 Introduction

Energy is one of the mainspring for growth and social development. However, such growth and development can be detrimental to the environment and thereby reducing the quality of life on planet. In this way, it is natural to have a basic conflict between growth and development. There are two types of energy resources: Renewable and Non-renewable. 80% of the world's energy requirement is fulfilled by consuming non-renewable energy resources (IEA, 2016) which causes an environmental problem at a local, regional and global scale. Therefore, the output of energy consumption should fulfil the criteria of economic growth and sustainable development to overcome the conflict of

interest. Sustainable development is generally designated as the marriage of economy and ecology to serve the economic development without compromising the ecological balance [1]. When we think about sustainable development, it really means the development under three main pillars: economy, environment and society (UN Department of Economic and Social Affairs, 2014). Consumption of energy resources without having environmental concerns is just like a slow poison for all living beings at present and in future. Therefore, we should be aware of the importance of utilizing renewable energy resources more efficiently.

In the present scenario of huge energy demand, dependency on conventional energy resources certainly creates the crisis in future, especially for developing country. Since the rapid consumption of fossil fuel over billions of people across the world are still unable to assess electricity. Furthermore, if the rapid consumption of fossil fuel continues, our future generation will certainly have to face the shortage of it. Excessive use of conventional energy resources creates environmental issues like global warming potential (GWP) and ozone layer depletion (ODP). Ultimately, we all have to depend upon renewable energy resources to fulfil our current energy requirements, together with economic growth and sustainable development. Hence, further research should be conducted to efficiently produce fuels from other sources with less environmental foot print.

1.3 Resources of renewable energy

Renewable energies are the energy resources that are refreshed by nature continuously. It is derived directly and indirectly from the sun or from other natural movements and mechanisms of the environment. Solar thermal, photochemical, and photo-electric are energies that are directly derived from the sun, whereas wind, hydropower, and photosynthetic energy stored in biomass are the energies obtained from the sun indirectly.

Geothermal and tidal energy are also included under the category of renewable energy resources since these are formed due to natural environmental movements. Fossil fuels and waste products will not come under the category of renewable energy [2].

1.4 Classification of renewable energy resources

There are various forms of renewable energy resources like solar, tidal and ocean, biomass energy, hydro energy, geothermal energy, hydrogen and fuel cells, wind energy etc. Figure 1.1 shows the classification of renewable energy resources [3]. The market of renewable energy resources for electricity generation, heating and transportation have been growing steadily since the last decade. Table 1.1 indicates the global electricity generation from different types of renewable energy resources. It is expected to grow 2.7 times more in the year 2035 in comparison to the year 2010. Consumption of biofuels is projected to be three times more over the same period. The requirement of renewable energy to produce heat will almost double, from 337 Mtoe (mega ton of oil equivalent) in 2010 to 604 Mtoe in 2035 [4].

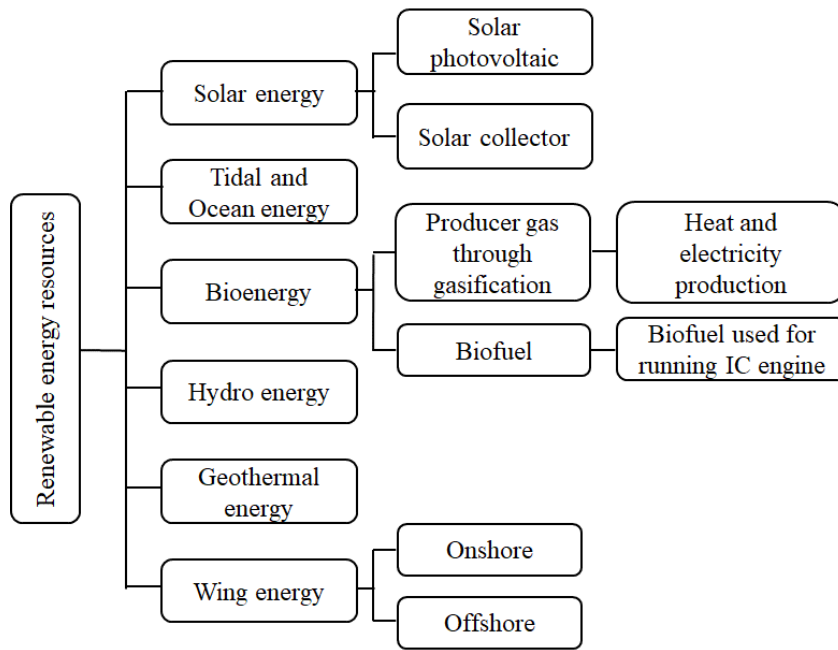


Figure 1.1: Classification of renewable energy resources [3].

Table 1.1: Prediction of world renewable energy use by type [4].

| Renewable energy types | World renewable energy use | | |
|------------------------------|----------------------------|------|--------|
| | 2010 | 2020 | 2035 |
| Electricity generation (TWh) | 4206 | 6999 | 11,342 |
| Bioenergy | 331 | 696 | 1,487 |
| Hydro | 3431 | 4513 | 5,677 |
| Wind | 342 | 1272 | 2,681 |
| Geothermal | 68 | 131 | 315 |
| Solar PV | 32 | 332 | 846 |
| Concentrating solar power | 2 | 50 | 278 |
| Marine | 1 | 5 | 57 |
| Share of total generation | 20% | 25% | 31% |
| Heat demand (Mtoe) | 337 | 447 | 604 |
| Industry | 207 | 263 | 324 |
| Buildings and agriculture | 131 | 184 | 280 |
| Share of total production | 10% | 12% | 14% |
| Biofuels (mboe/d) | 1.3 | 2.4 | 4.5 |
| Road transport | 1.3 | 2.4 | 4.4 |
| Aviation | - | - | 0.1 |
| Share of total transport | 2% | 4% | 6% |

1.5 Biomass feedstocks

Biomass is an organic substance that contains trees, animal materials and agricultural crops. The chemical composition of biomass varies from species to species having high variable moisture contents and fiber structure consist of lignin, carbohydrates or sugar and ash. Biomass is inherently very heterogeneous and has a lower heating value than coal [6], [7].

1.6 Gasification

Gasification is a technology for over a century that flourished before and during World War II. This technology vanished shortly after World War II, when liquid fuel (oil-based) was immediately available. But in the 20th century, gasification technology again became famous and attracted the researcher's interest to become a source of renewable energy. As fossil fuel prices are rising today, and environmental interest is increasing, the technology has attracted their attention and began to develop using more modern and advanced technologies.

Gasification is mainly the thermo - chemical conversion of partial oxidation of organic materials at high temperatures. During the gasification process, energy in biomass or any other organic material is converted into flammable gases (a mixture of CO, CH₄, and H₂), and these gases are condensed into charcoal, water, and secondary products.

The first phase is called pyrolysis, which is an organic substance. Volatile gases and liquids decompose due to the high temperature of the material and coal (mainly non-volatile material with a high carbon content). At the second stage, CO₂ and H₂O react with the hot char and produce CO, H₂, and CH₄ [8]. Finally, producer gas leaving from the reactor with impurities which needs to be cleaned to utilized as a fuel for engines.

Production gas is a mixture of hydrogen, carbon monoxide, methane, carbon dioxide, nitrogen, and other non-combustible gases [9]. The calorific values of the producer gas lie between the range of 4 to 20 MJ/m³, which is dependent on properties of the gasifier and the biomass content carbon and hydrogen. For the gasification air, pure oxygen or a mixture of these may be used as an oxidizing agent. The producer gas obtained using air as an oxidizer agent for gasifier having lower calorific values between 4 and 6 MJ/m³ and higher nitrogen concentration whereas oxygen, and steam-based oxidizer produces higher calorific value 10 and 20 MJ/m³ of producer gas with respect to air [7]. Therefore, the key feature of the gasifier design is to create condition such that the biomass feedstock will convert into charcoal and charcoal produces combustible gases CO, H₂ and CH₄ at a suitable temperature.

1.7 Biomass gasification technologies

The gasifier systems are classified according to the way of interaction of air or oxygen with the biomass inside the gasifier and exit location of the producer gas. Figure 1.3 shows the basic types of gasifier: fixed - bed systems, fluidized bed systems and entrained flow systems. All these reactors are operated at ambient or increased temperature to convert the solid biomass into gases form through thermo - chemical conversion process [6].

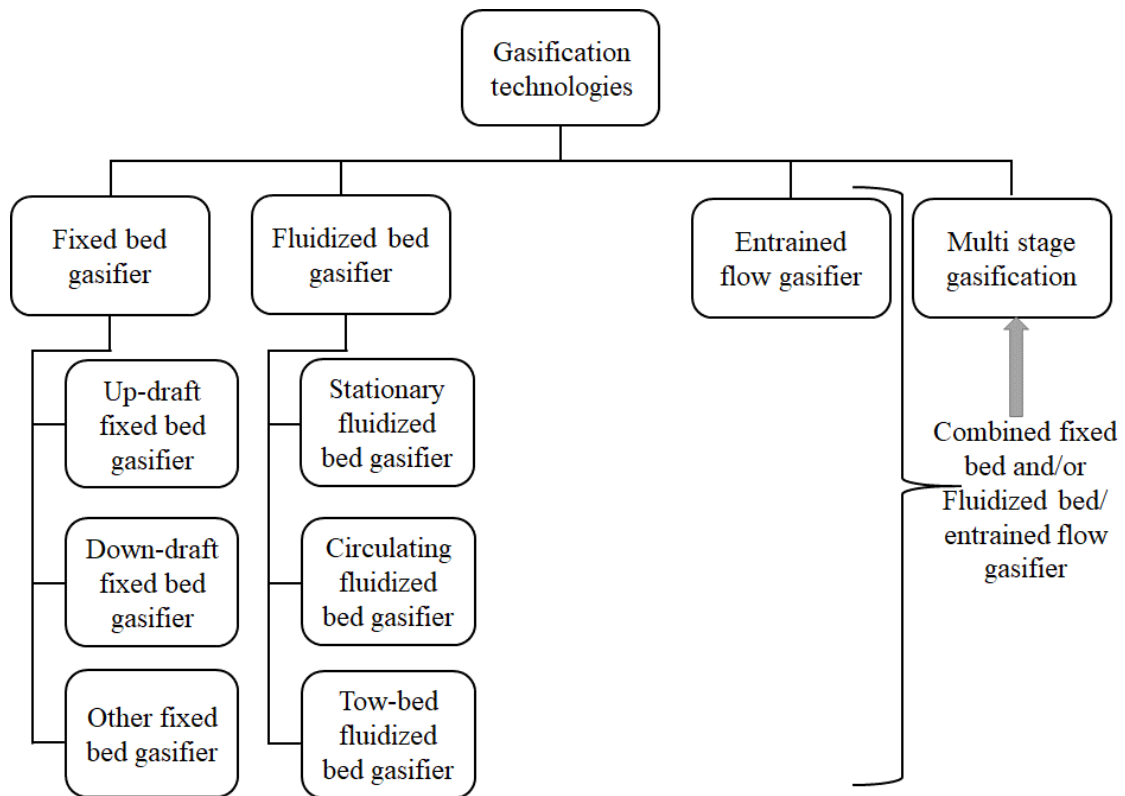


Figure 1.2: Overview of the different gasification technologies, (Source: BIOS, 2010) [6].

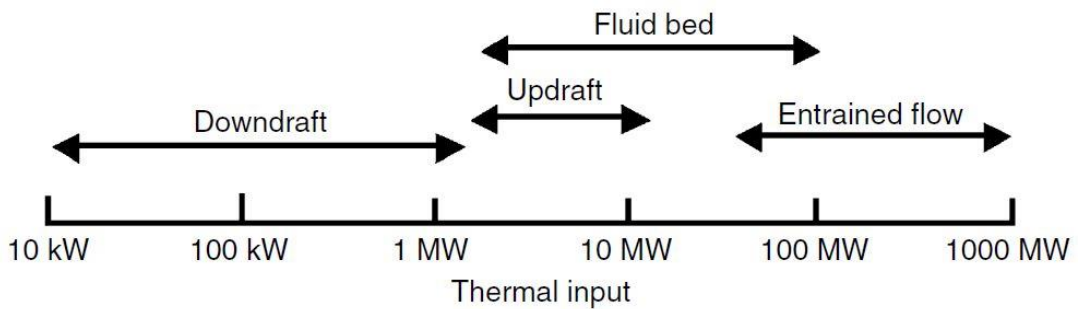


Figure 1.3: Range of biomass gasifiers according to its applicability [5].

In our research, we prefer the downdraft gasifier system which is comes under fixed - bed gasifier system because of its advantages; it is suitable for small scale application, produces low particulate and the most important feature is that it reduces a great amount of tar. Disadvantageous: producer gas having lower heating value, feedstock size limited, moisture sensitive and scale limitation.

1.7.1 Downdraft gasifier

In downstream gasifiers, the reaction zones differ from other gasifiers. Here, steam and oxygen or air are introduced into the gasifier at the lower section (see figure 1.4). Pyrolysis and combustion products are moved in the downward direction. The hot producer gas then passes through the hot char bed where reduction or gasification takes place. This system leads to tar- free but same time having low energy content gases [5].

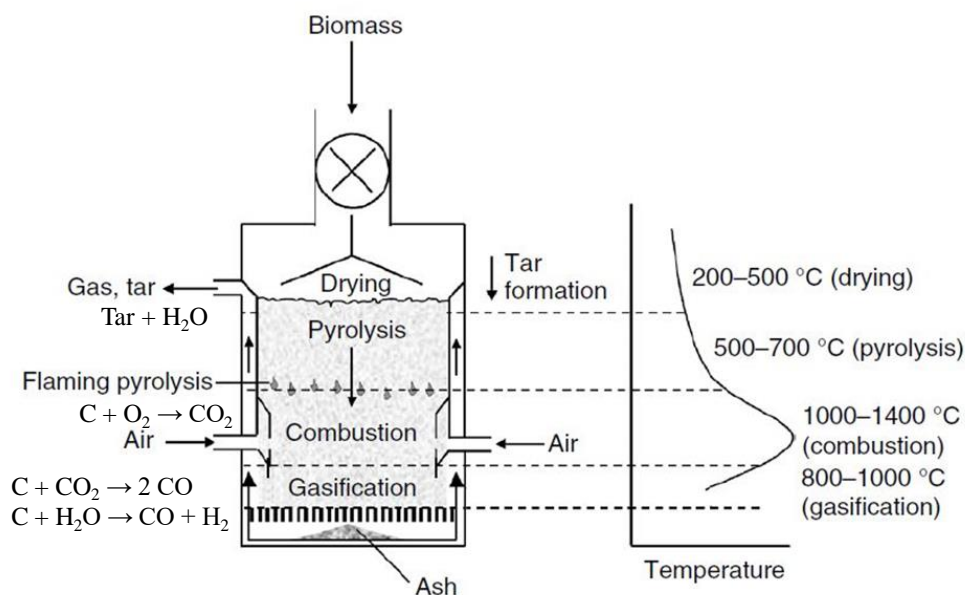


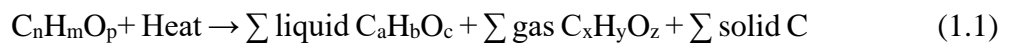
Figure 1.4: Schematic of downdraft gasifier system with temperature profile [5].

a) Process zone of downdraft gasifier:

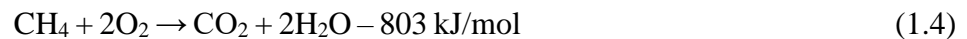
Solid biomass feedstock is converted to the gases form in the gasifier system by adopting the four distinct processes. They are:

- **Drying:** It is the very primary process which occurs before pyrolysis where moisture in the biomass evaporates due to the heat released from the combustion of biomass.

- **Pyrolysis:** In this process, due to the application of heat in the absence of air raw biomass breaks down into the form of tar, gasses, liquids volatile and charcoal. Due to application of heat, biomass starts to decompose rapidly as its temperature reaches above 240°C the feedstock breaks down into solids, liquids and gasses. The sticky liquids released are collectively called 'tar' and solids that remain is called 'charcoal' [5]. It decomposes as:



- **Combustion:** Solid combustible materials usually consist of carbon, hydrogen and oxygen. On complete combustion, carbon dioxide is obtained from combustible coal, and water is generally obtained from hydrogen in steam form. The combustion reaction is exothermic, and the theoretical oxidation temperature is 1450°C [5], [10] – [13].

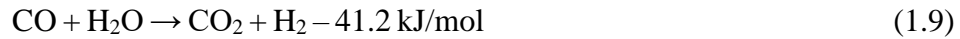


- **Reduction or gasification:** In reduction zone, CO₂ or H₂O is passed across a bed of red hot charcoal, the carbon in the hot charcoal bed is highly reactive with oxygen, and it has such a high affinity towards oxygen that it replaces the oxygen from the H₂O(g) and CO₂ molecules and reduces it to many single bonds as possible. Throughout this process, CO₂ is reduced to two CO molecules, and H₂O is reduced to H₂ and CO [5], [11], [12].

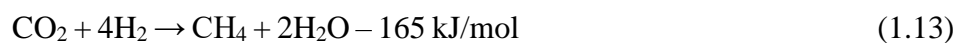
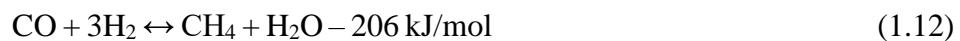
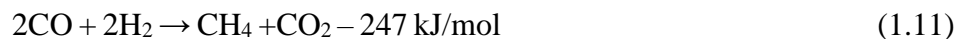


In addition, there are some other important reactions which play a significant role in the gasification process.

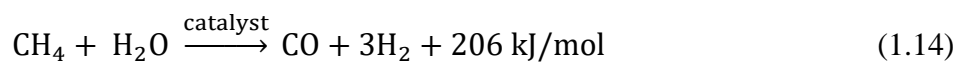
- **Shift reaction:** In the gasification process at the expense of CO, the reaction between steam and carbon monoxide is used to maximize the production of hydrogen [6].



- **Methanation reaction:** Methane (CH₄) is an important component in the producer gas as well as petrochemical and chemical industries. It can be obtained from natural gas as well as from solid hydrocarbons like biomass or coal. For the other sources for getting methane, the hydrocarbons are hydrogenated to obtain synthetic gas or substitute natural gas (SNG). For SNG production, the overall reaction may be expressed as [5], [11], [13]:



- **Steam reforming:** In the steam reforming methane produce CO and H₂ by reacting with steam at temperature range 700 to 1100 °C in the presence of a metal-based catalyst [5].



The above reaction is widely used for hydrogen production from methane, for this, nickel-based catalyst are very effective.

1.8 Producer gas filtration system:

After the production of producer gas from the gasifier system, the producer gas having combustible gases components as well as different types of impurities such as dust, ash

particles, compounds of nitrogen and sulphur (H_2S , CS_2 , SO_2), halides (HCl , HBr , HF) and tar whose some molecules are not dissolved in the water and remain in the gaseous form. These all need to be removed from the producer gas before it is used as a fuel to drive the internal combustion engine (IC engine). The tar compound is known as the molecules having higher molecular weight than the benzene (C_6H_6), including aromatic hydrocarbons, polyaromatic hydrocarbons (PAHs), heterocyclic aromatics, and the like. Some of the tar does not add to the performance of a power plant during the biomass gasification. But some tars are condensed and/or crystallize inside the equipment's which reduces the plant/or engine efficiency. Therefore, the filtration system plays a serious role in order to clean the impurities present in the producer gas. There are different types of filtration systems are available according to the type of impurities.

1.8.1 Tar filtration techniques:

The tar can be removed in two ways: Primary filtration method and secondary filtration method.

- In the primary filtration method, the catalyst is mixed with the biomass feedstock inside the gasifier system. As the catalyst reaches its activation temperature, it starts working and avoids the tar formation in the pyrolysis stage; this method is also called in-situ tar removal approach. In chapter 2, we adopt the primary filtration method for tar elimination. For this, we used calcium oxide as a catalyst which is mixed with biomass feedstock in 10% by weight.

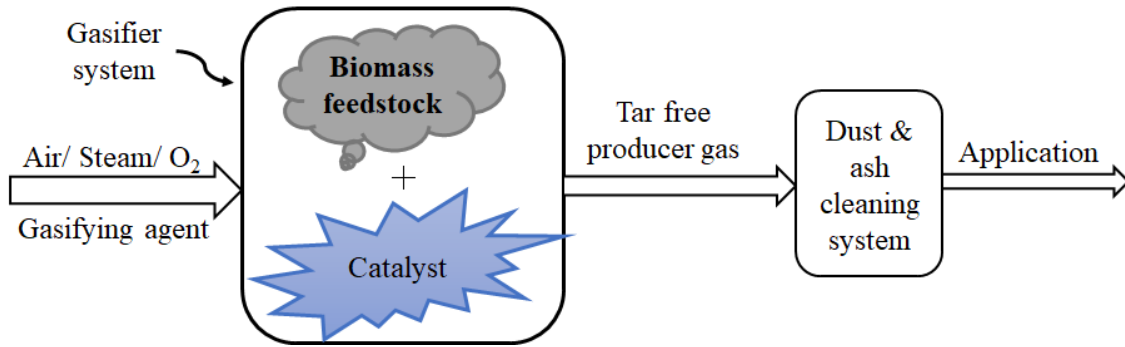


Figure 1.5: Shows the schematic diagram of primary filtration method

- In the secondary filtration method, the tar present in the producer gas is cleaned outside the gasifier system through a separate filtration system in which catalyst coated perforated filters are kept, and producer gas is flown through these filters. In chapter four, we have discussed our designed separate filtration unit and we developed a numerical model for selecting the best configuration of filter parameters which predict the best filtration results when producer gas passes through our designed filtration unit.

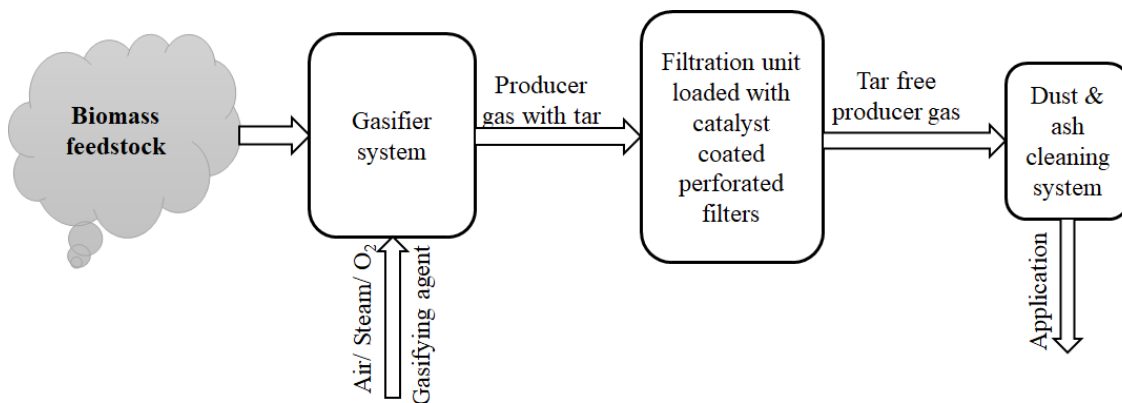


Figure 1.6: Shows the schematic diagram of secondary filtration method.

Jordan et al. [14], found that of the three quantities of in-bed *CaO* used (2 wt.%, 4 wt.%, 6 wt.%) and 6 wt.% of the additive was found to be the most effective at increasing syngas yield, reducing the tar concentration and decreasing the tar dew point. Li et al. [15] developed a novel and low-cost nano-Ni catalyst on the support of gamma-Al₂O₃, prepared by deposition-precipitation (DP) method for tar removal in biomass catalytic

gasification or pyrolysis. The nanoparticles size was between 12 nm and 18 nm. In this study, the tar removal efficiency exceeded 99% at 800⁰C. This indicates that the prepared NiO/gamma-Al₂O₃ catalyst in comparison with the commercial and other nickel-based catalysts has higher efficiency. The contents of H₂ and CO in gas increased significantly with 49.2% H₂, and 42.2% CO generated at 800⁰C. The nano-NiO/gamma-Al₂O₃ catalyst improved the gas product quality better than the commercial one, with higher H₂ and CO but lesser CO₂ contents observed, even at the lower reaction temperature.

Selection of catalyst is the main part of the filtration system. After going through the several research papers based on tar filtration, we come to the conclusion that the nickel-coating over alumina is the best pair of catalyst for cleaning the producer gas impurities. The different types of catalyst to be used for producer gas cleaning has been shown in Table 1.2. The highlighted catalyst are the common pair for removing all impurities.

Table 1.2: Shows the different types of catalyst for removing the impurities present in the producer gas.

| Serial no. | Catalyst compound | Catalyst efficiency (%) | Temperature (°C) | References |
|--------------------------|--|-------------------------|------------------|------------|
| Tar removal catalyst | | | | |
| 1 | Ni-Co/Si-P | 99 | 100 | [16] |
| 2 | Ni/Al₂O₃ | 38-100 | 850-900 | [17] |
| 3 | Ni/Dolomite | 84-98 | 850-900 | [17] |
| 4 | CaO/Ni | 99 | 900 | [17] |
| 4 | Porous ceramics | 87 | 850 | [16] |
| 5 | Ni/BCC | 88.9 | 900 | [18] |
| Ammonia removal catalyst | | | | |
| 1 | Ni-Zn/Al₂O₃ | 95 | 650 | [17] |
| 2 | Ni/Dolomite | 95 | 850-900 | [17] |
| 3 | Ni-Co/Si-P | 99 | 800 | [16] |
| Sulfur absorbent | | | | |
| 1 | Ni/Dolomite | 85 | 800 | [17] |
| 2 | ZnFe ₂ O ₄ | 98-99 | 600 | [19] |
| 3 | MnO/CuO | 80 | 600 | [19] |
| 4 | CaO | 85 | 850 | [17] |
| Halide removal catalyst | | | | |
| 1 | Ni/Dolomite | ----- | 800-900 | [17] |
| 2 | Mg(OH) ₂ | ----- | ~800 | [20] |
| 3 | BaO | ----- | ----- | [17] |
| 4 | CaO | ~85 | ----- | [17] |

For tar removal, nickel is coated over alumina-based perforated filter which is kept inside the filtration unit. As the filtration unit reaches the desired temperature in which catalyst start working, the producer gas is allowed to pass through it for cleaning. The quality of the producer gas can be improved by selecting the filter position at which it is kept inside

the filtration unit and the quantity, both need to optimize. As the more number of catalyst coated perforated filters are kept inside the filtration unit, the gas flow will be restricted. As a result, a considerable pressure drop can occur. On the other side, less number of perforated filters will not adequately clean the producer gas. Therefore, to resolve this problem, a numerical model has been developed, which help to select the best optimum filters parameters. The full discussion in this regard has been done in chapter 4.

- **Catalyst preparation for secondary filtration method:**

Nickel nano powder is synthesized by reducing nickel in an aqueous solution with reductant agent hydrazine hydrate. Solution A is prepared in a separate beaker in which 0.5 gm of nickel chloride ($\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$) and 1.0 gm Al_2O_3 is mixed then add 60 ml of distilled water and leave it till nickel chloride completely dissolved. Another solution B is prepared in another beaker in which 1.0 gm of NaOH is dissolved in 20 ml of distilled water later on adding 20 ml of hydrazine hydrate (N_2H_4). Now solution B is added in solution A; the combined solution colour turned into royal blue [21]. The combined solution is stirred for 6 hrs at room temperature then filter the precipitate (wash with water repeatedly to remove unwanted materials) and dry at 70°C overnight.

Following chemical reactions are belongs to the reduction of Ni^{2+} to Ni.

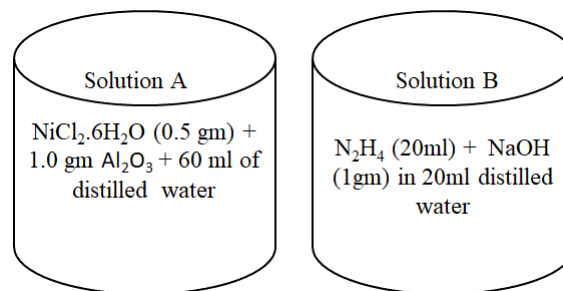
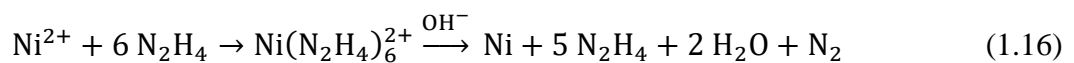


Figure 1.7: Shows the block diagram of catalyst preparation process.

X-ray diffraction (XRD) report confirmed the nickel catalyst coating in an Al_2O_3 .

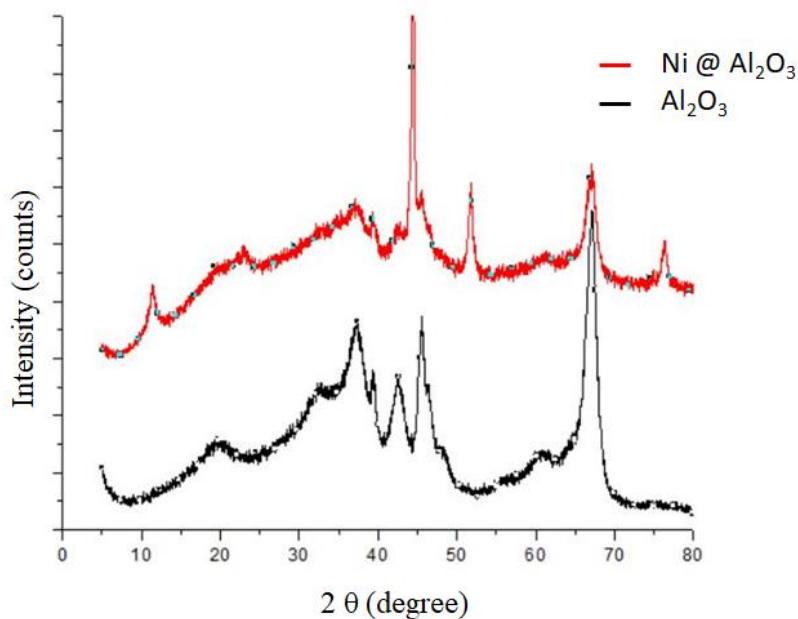


Figure 1.8: Shows the XRD report of nickel catalyst coating on Al₂O₃

The nickel catalyst sample powder after sonication, filtration and drying following characteristics peaks are observed for nickel $2\theta = 37.00, 42.00, 45.00$ and 67.00° for Ni @ Al₂O₃ over Al₂O₃. The intensity of peaks for nickel loaded on Al₂O₃ with Al₂O₃ are overlapping in various degrees, this confirms the coating is done very well on the base material.

After getting the good results of catalyst coating on base material we again coated the nickel catalyst on alumina based perforated filter which is to be used for eliminating the tar and other impurities present in the producer gas.

The previous catalyst preparation process is the same, only Al₂O₃ is not mixed with the nickel chloride in solution A. Later on, alumina-based perforated filters are dipped in a combined solution and stirred for 3 hrs at room temperature then take out the filters and put them all in a dryer at 75°C for 12 hrs. After 12 hrs, take out filters from the dryer and leave it to reach room temperature. Repeat the same process from dipping the perforated filters in a combined solution for second layer coating and continue for more coating.



Figure 1.9: Shows the single layer catalyst coating in an alumina based circular hole perforated filters.

The quality of the producer gas can be enhanced by gasifier design parameters, operating parameters and filtration techniques.

Tinaut et al. [22], developed a kinetic model for the study of air superficial velocity and biomass particle size on temperature field, maximum temp, biomass consumption rate and gasification relative fuel-air ratio and validated the result with the experimental data.

Sheth et al. [23], suggested that by changing the air flow rate the equivalence ratio changes that effect on producer gas composition, temperature, calorific value and gas production rate per unit weight of biomass. They also studied the effect of air flow rate and moisture content on biomass consumption rate. They explained that with an increase in the moisture content in fuel, biomass consumption rate decreases and vice -versa for an increase in the airflow rate.

Zainal et al. [24], studied that the biomass gasifier system performance may be evaluated in terms of the flow rate of the producer gas, cold gas and mass conversion efficiencies, the calorific value of the producer gas. Also, the producer gas quality

depends on various factors such as the size of the feedstock, moisture contents in the feedstock, location of the air supply nozzle, air flow rate of the gasifier and the volume of the reduction zone.

Roy et al. [25], used the different feedstocks like Eucalyptus wood (EW), Bamboo wood (BW), Wheat straw (WS), Rice straw (RS), Coconut shell (CS) to know the effect on gasifier operation and critical char bed length. They studied the variation of char flow rate along the length of the reduction zone for different feedstock at different flow rates. They showed that the char flow rate decreases along the length of the reduction zone and increases with the increase in flow rate. Variation of temperature along the length of the reduction zone at different feed rates were studied and showed that as feed rate increases, temperature along the reduction zone increases.

Sharma [26], carried experimental study on 75 kW, downdraft (biomass) gasifier system and studied with the variation of gas flow rate, variation in pressure drop across gasifier, spray tower pressure drop, the pressure drop across the filter, gas composition, calorific value. Thermocouple fixed at the process zone to measure the temperature. The pressure drop across gasifier with time was also studied at a constant gas flow rate in non-firing and firing mode. In non-firing mode, the freshly charged gasifier bed arrangement gives the less flow resistance compared to the extinguished gasifier bed arrangement. They also investigate the effect of pressure drop on ash deposition in fired gasifier bed as well as tar deposition in the sand filter. They found as the pressure drop increases across the gasifier bed the ash deposition on the bed increases, this is due to obstruction created in the flow of gas.

According to Son et al. [27], as gasification temperature increases, H_2 concentration increases and CH_4 decreases, while CO_2 increases till equivalence ratio increases then decrease. As the air-fuel ratio increases, LHV and cold gas efficiency increases and then

decreases. Syngas exhaust temperature was higher than that of LPG and has a lower level of NO_x emission. In the case of syngas, NO_x emission decreases with increase in engine load while in case of LPG it increases. As engine load increases, CO and HC emission increases and CO emission was higher than HC.

According to Gai et al. [28], since non-woody biomass is a fuel which contains a relatively high amount of chlorine, sulphur and ash, so the gas obtained from gasification of non-woody biomass has a comparatively high concentration of chlorine and sulphur compounds compared with that of woody biomass. The sulphur and chlorine are partly bounded to the ash, causing partial ash sintering or bed bridging, which can be harmful to the gasifier and downstream equipment. They check the different ways to reduce chlorine and sulphur concentration and variation of different forms of sulphur compound with equivalence ratio. The collection temperature also influences the concentrations of chlorine and sulphur in the ash.

Banapurmath et al. [29], studied the combination of Diesel and Producer Gas, Honge oil and Producer Gas, Honge oil methyl ester (HOME) and producer gas used as a fuel in those engines having a carburettor and without carburettor. The purpose of using vegetable oils is its properties which is very similar to the diesel oil, and also vegetable oil is promising alternatives oil which can replaced diesel oil. Among all fuel combination, they selected Honge oil (*Pongamia Pinnata* Linn) and reduced its viscosity by transesterification process to convert in Honge oil methyl ester (HOME). The vegetable oil releases more smoke than the diesel, therefore, to minimize the smoke, dual fuel operation is adopted. As a result, engine performance increased. Modification in the carburettor is required to maximize the performance of a dual fuel mode engine to be used as Honge oil–producer gas and HOME–producer gas as a fuel.

1.8.2 Dust and ash particles removal techniques:

The producer gas second serious problem is having dust and ash particles. These dust particles create severe problems while producer gas is used for driving the internal combustion engines. Different techniques are available like cyclone separator, baghouse filters, water scrubber etc., for removing the dust and ash particles from the producer gas. Among all techniques, cyclone separator is the best choice it is also called dry collectors which remove dust, droplet, and ash particles at low cost and low maintenance. The operating principle of the cyclone separator is that it paves a rotary path to the gases, increasing the settling rate by many times than the gravitational separators.

Many researchers are working on the cyclone separator for removing dust and ash particles from the air, producer gas etc., cyclone efficiency is influenced by cyclone design, operational parameters like- vortex finder length, vortex finder diameter, tangential velocity, etc., input gas temperature, pressure, viscosity.

Shin et al. [30], studied effects of high temperature and pressure environment on high-efficiency cyclone separator. Higher pressure increases the collection efficiency of a cyclone, but higher temperature decreases the collection efficiency of the cyclone, it can be explained by a change in density and viscosity at higher temperature and pressure. They have also studied the effects of length of vortex finder, a diameter of vortex finder, tangential velocity over extreme conditions. As vortex finder diameter increases, efficiency decreases, Vortex finder length doesn't affect efficiency more, but if it is less beyond a certain limit, it decreases efficiency, Higher tangential velocity decreases cut point diameter. The experimental and numerical investigation shows comparative results for this investigation.

Fassani et al. [31], found the effect of higher solid loading on cyclone parameters. Pressure drop increases with an increase in inlet velocity, but with a change in solid

loading, pressure drop doesn't change much. Pressure drop ratio is found to be average 0.47 with respect to clean air flow pressure drop. Collection efficiency increases up to 12 kg of solid/kg of gas, but after that, it decreases.

Senapati et al. [32], studied four different geometry of cyclones to extract unburnt carbon particles. Chan and Shi model measured pressure drop, which was fitted with experimental result very well. Cyclone having only cylindrical barrel part has the lowest efficiency and highest pressure drop. Highest collection efficiency is found in a cyclone having longer cone than the cylinder and having vortex finder.

Altmeyer et al. [33], developed software to calculate cyclone performance parameters using different empirical models. They compared the different empirical model with experimental results. Cut size diameter is predicted well by Mothes and Loffler model above 5 m/s velocity. For lower flow rate Barth model gives a good result but for higher flow rate Mothes and Loffler model gives better results. Flow rate higher than 10 m/s Mothes and Loffler and Lorenz give a better prediction of efficiency and pressure drop.

Different empirical models are compared with experimental results by Gimbun et al. [34]. They studied Iozia and Leith, Li and Wang model, Koch and Licht model, and Lapple model. Li and Wang model predict efficiency well at room temperature. For larger particles, Lapple and Koch - Licht models underestimate efficiency. Lapple model is suitable for high temperature and pressure. For higher pressure Koch - Licht model is suitable. The detailed discussion has been done in chapter 3

1.9 Need of biodiesel

The quality of the producer gas much affects the diesel fuel consumption when producer gas is used together with diesel to drive dual-fuelled diesel engine. Producer gas quality deteriorates due to impurities present in the producer gas; therefore, the filtration system needs to be attached with the gasification system. On the other hand, the blending of

biodiesel with conventional diesel also reduces diesel consumption at a fixed rate even bad quality of producer gas is supplied with the diesel. Looking to present status of convention diesel availability and prices, it is obvious that human might struggle to run their vehicles by only diesel. And therefore, the production of biodiesel and blending with conventional diesel is an essential demand for the present condition. Many researchers are working on the field associated with biodiesel production technology, modification of diesel engine to be run by blended fuel for efficiency enhancement, biodiesel storage time and its emissions.

Meher et al. [35], investigated on the emission quality of such oils and have found that the emissions have less carbon dioxide and carbon monoxide released upon combustion but the level of oxides of nitrogen formation increases slightly.

Graboski et al. [36], reported that the production of biodiesel is one aspect and its storage is another. With increase in the storage time, the quality of the biodiesel decreases, and it mainly occurs due to oxidation of the methyl esters which forms many oxidative products like peroxides and hydro-peroxides, fatty acids and various aldehydes, ketones and organic acids which undesirably increases the kinematic viscosity, acid value and peroxide values and decreases the oxidative stability which is measured in terms of induction period.

Karavalakis et al. [37], used different anti-oxidants namely AO1, AO2, AO3, AO4; first three are synthesised, and the fourth one is natural-based to be used in different biodiesel samples namely: Soyabean methyl ester (SBME), rapeseed methyl ester (RME), high oleic sunflower oil (HOSME) and palm oil methyl ester (PME) and compared their oxidative stability in terms of induction period before 6 months of storage time. They found the induction period for both distilled water and citric acid purified

methyl esters obtained from different oils and concluded that citric acid has anti-oxidant qualities which enhances the induction period of the fresh sample, but its effectiveness decreases with time and therefore cannot be used for the biodiesel protection against oxidation for long-term storage time.

Lin et al. [38], investigated the burning characteristics of the biodiesel in terms of flash point, cetane index and carbon residue with the storage time and storage temperature. They put the freshly prepared palm-oil biodiesel in a water bath at a temperature of 60⁰C and 20⁰C separately in the form of four samples, two in each water bath. One of the two contains the anti-oxidant and other was devoid of that. They concluded from this experiment that the oxidative stability of the biodiesel decreases with increase in the storage temperature which leads to lowered flash point, lower cetane index and higher carbon contained along with the degrade effects with the storage time alone. They carried out the experiment for 3000 hrs and concluded that the formation of the oxidative product is accelerated with the increase in the temperature as a result of which the amount of heat released is decreased, and amount of carbon residue is increased which have further adverse effects on the working of the corresponding compression-ignition engine.

Karavalakis et al. [39] investigated on the storage stability of various biodiesel blends:-7, 10, 20 % v/v with the commercial diesel oil for a period of 10 weeks and their results revealed that antioxidants tert-butylhydroquinone (TBHQ), propyl gallate (PG) and pyrogallol (PA) were most effective additives in the neat methyl esters and butylated hydroxytoluene (BHT) and butylated hydroxyanisol (BHA) were least effective. But, for biodiesel blends, the oxidative stability of the fuel wholly decreased with increase in the proportion of the biodiesel in the fuel, and it was found that the most effective additives were PG, PA, BHT and BHA, but astonishingly TBHQ was least effective.

Yang et al. [40], studied the chemical and mass composition change of neat biodiesel samples sourced from s

Soyabean and canola oil in B5 and B20 v/v, blends with commercial diesel oil at ambient temperature and air exposure for 190 days. They observed mass-loss in pure diesel and biodiesel blended samples but no appreciable losses in a neat biodiesel sample. They also found that the evaporation rate of biodiesel samples was lower than that of diesel samples because of the higher boiling point of biodiesel as compared to the fossil diesel oil.

Khalid et al. [41], examined the effect of the storage time of a variant of biodiesel ratio at various storage temperatures on exhaust emissions and fuel properties. The storage time was 60 days, and the biodiesel blend ranged from B5 to B45. The storage temperature ranged between 50°C and 3°C. The density of the biodiesel increased when the storage time increased resulting in viscosity increase especially in higher storage temperature of 30°C and biodiesel blending ratio (B45). Also, high blending ratio exhibits a small variation in CO emissions. Therefore, storage duration, blending ratio and the oxygenated fuel contents responsible for the physical fuel properties is also the mechanism responsible for the decreased CO emissions.

After through literature, we conclude that the very few articles published regarding the determination of deterioration of burning characteristics of the biodiesel over the storage time which is the prime concern for commercialisation of the fuel which includes:-flash point, amount of heat release and cetane number. Therefore, in this thesis, kinematic viscosity and calorific value of the Soyabean methyl ester (SBME) in different storage period for a storage span of 15 days has been studied, and its emissions under various loads and compression ratio in different blends are investigated.

1.10 Findings from the review

Followings are the finding from the literature review:

- Gasifier system has become a more viable option for medium-scale power generation with the recent improvements in materials and structures.
- Earlier, the gasifier system produced producer gas with significant tar content and other impurities.
- Many researchers have worked over the geometry of filtration unit to enhance the efficiency of filter and reduce impurities present in the producer gas.
- Impurities like tar, incombustible gases, dust and ash particles removal from producer gas is the major challenge in gasifier system.

1.11 Research gap

Followings are the research gaps that needs attention and investigation:

- Most of the filtration unit of gasifier system uses catalyst like dolomite and Ni, calcined dolomite, Ni/Al₂O₃ etc. to make it effective towards tar removal.
- But the research work regarding the design of a filtration unit and development of a numerical model for predicting the best filter configuration of multistage filtration system for best filtration results has not been done till now.
- Limited literatures are available on numerical modelling of multistage filtration system, therefore, designing of the filtration unit would contribute to a great insight towards the producer gas cleaning system.

1.12 Problem statement

Followings are the problem statements:

- Gasifier system without effective filtration unit produces significant tar content.
- Cyclone separator removes particulate matter of medium range only.

- Recognition of catalyst and design of catalytic converter used in filtration unit is a major challenge.
- More attention toward the quality of producer gas is required to reduce the cost of fuel used in IC engine for power generation.

1.13 Objectives of the research work

- To design a filtration unit: an integral part of gasifier system.
- Investigating the multistage filtration system for regulating the pressure with minimum losses in the system.
- Develop three-dimensional turbulent numerical model.
- Validation of the model with the experimental results.
- Design studies for best configuration of filter parameters.
- Study of Biodiesel blending with conventional diesel to know the effect of storage time on its calorific value and emission at different blending ratios.

1.14 Methodology of the research work

The methodology of the research work has been depicted in the flow chart as shown in figure A.1, page no. 196, mentioned in appendix A.

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