Chapter 1 Introduction

1.1 BACKGROUND

The traditional fossil fuels (oil, coal and natural gas) are the major sources of energy in the world. The increasing energy demands have speeded up the exhaustion of theses limited fuel resources leading to the rapid depletion of the fossil fuels. In the existing scenario, years of production left for coal, oil and natural gas are 148 years, 43 years and 61 years respectively. The use of fossil fuels has led to serious energy crisis and environmental problems, i.e. fossil fuel exhaustion and pollutant emission. Carbon dioxide is the main greenhouse gas, and a major part of CO_2 emissions is due to combustion of fossil fuel**s**. Also combustion of fossil fuel produces toxic gases, such as SO_2, NOx and other pollutants, causing global warming and acid rain. Several researches have been made to explore clean and renewable alternatives. As hydrogen is clean and renewable source of energy, it has potential to replace the conventional fossil fuels. Also hydrogen has the highest energy to weight ratio compared to any fuel. Apart from its use as a source of energy, hydrogen can be used for various other purposes in different industries. It is used in hydrogenation process, saturate compounds and crack hydrocarbons. It is a good oxygen scavenger and can therefore be used to remove traces of oxygen. It is also used in manufacturing of different chemicals like ammonia, methanol etc.

Gasification is a thermochemical process in which a carbonaceous fuel is converted to a combustible gas. This combustible gas consists of syngas (synthetic or synthesis gas) which is a mixture of hydrogen (H_2) and carbon monoxide (CO) as well as other gases such as methane (CH_4), carbon dioxide (CO_2), water vapor (H_2O), nitrogen (N_2), higher hydrocarbons and impurities such as tars, ammonia (NH_3), hydrogen sulphide (H_2S) and hydrogen chloride (HCl). The process occurs when a controlled amount of oxidant (pure oxygen, air, steam) is reacted at high temperatures with available carbon in the fuel within a gasifier. Knoef (2005, p. 13) states that the biomass gasification process consists of a number of steps as depicted in Figure 1.1:

a) Pyrolysis: Thermal decomposition of biomass in absence of oxygen to gas, condensable vapours and char.

b) Thermal cracking of vapours to gas and char.

c) Gasification of char by steam or carbon dioxide.

d) Partial oxidation of combustible gas, vapours and char.

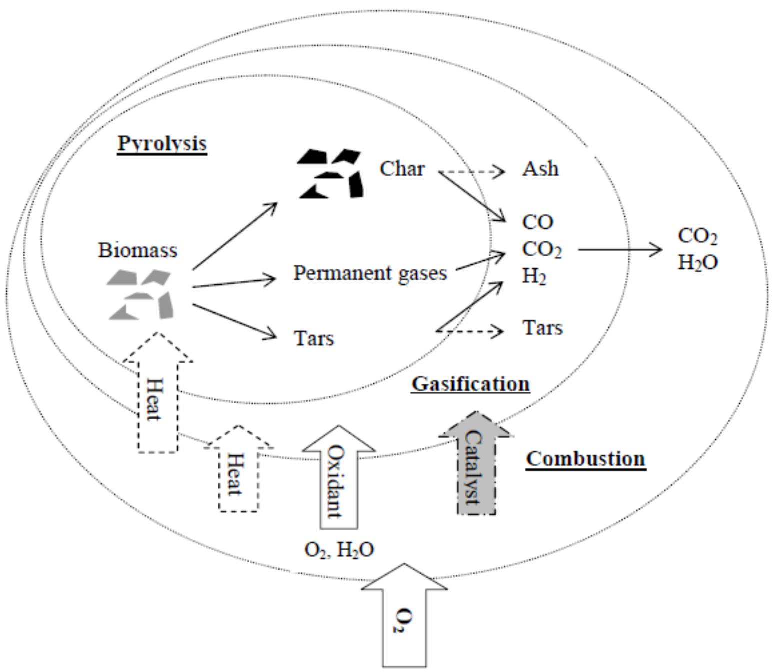

Fig. 1.1 Schematic presentation of gasification as one of the thermal conversion processes, BTG (2002) as presented in Knoef (2005, p. 13).

1.1.1 REACTIONS

Biomass gasification is defined as incomplete combustion of biomass to produce combustible gases consisting of carbon monoxide (CO), hydrogen (H_2) and traces of methane (CH_4). The reactions involved are represented in Table 1.1[Nikoo et al., 2008].

Table 1.1 Representation of Biomass gasification reactions

$C + O_2 \rightarrow CO_2$	Oxidation reactions	-111 kJ/mol	(1.1)
$C + 1/2\ O_2 \rightarrow CO$		-283 kJ/mol	(1.2)
$C + CO_2 \rightarrow 2CO$	Bouduard Reaction	+172 kJ/mol	(1.3)
$C + H_2O \rightarrow CO + H_2$ (Primary)	Water Gas Reactions	+132 kJ/mol	(1.4)
$C + 2H_2O \rightarrow CO_2 + 2H_2$ (Secondary)			(1.5)
$C + 2H_2 \rightarrow CH_4$	Methanation	-75 kJ/mol	(1.6)
$CO + H_2O \rightarrow CO_2 + H_2$	Water-Gas shift	-41 kJ/mol	(1.7)
$CH_4 + H_2O \rightarrow CO + 3H_2$	Steam Reforming	+21 kJ/mol	(1.8)

1.1.2 GASIFICATION PROCESS

The gasification medium, type of gasification process and the gasifier temperature decide composition of the gas generated (Boerrigter and Rauch, 2005), see Figure 1.2. The gas produced may be classified as product gas (producer gas) or synthesis gas (syngas). At temperatures less than 1000 °C producer gas is formed whereas syngas is obtained at temperatures greater than 1200 °C. Syngas has a higher content of CO and H_2 than producer gas.

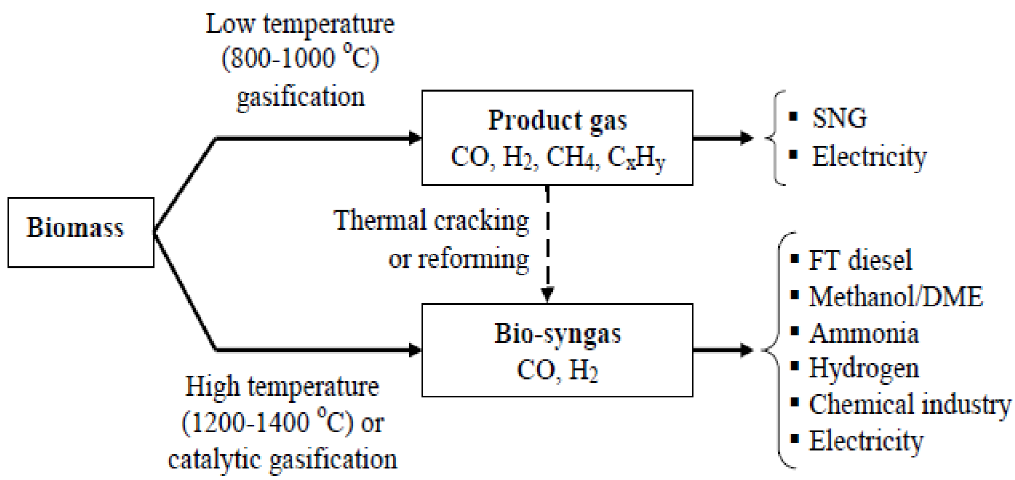

Fig. 1.2 Difference between 'syngas' and 'product gas' with applications, Boerrigter and Rauch (2005, p. 212).

1.1.3 NEED FOR BIOMASS GASIFICATION

Biomass is considered as a potential renewable and sustainable source from which hydrogen can be produced due to its CO_2 neutrality and lower emission of nitrogen oxides (NOx) and sulphur dioxide (SO_2) during combustion. The efficient utilization of biomass resources is of utmost importance if renewable energy is to replace a significant proportion of fossil fuels.

The traditional biomass combustion based technologies achieve low electrical efficiencies (20-25%) and therefore cannot compete with fossil fuels. Biomass gasification coupled with advanced power generation systems such as gas turbines or fuel cells offer much higher efficiencies. This technology can help satisfying many objectives, including increasing the contribution of renewable energy, improving energy efficiency, increasing security of supply (indigenous resource), raising the level of combined heat and power (CHP) and reduction of greenhouse gas emission.

1.1.4 ORGANIC RANKINE CYCLE UTILIZATION

CHP based polygeneration strategy can further be improved by Organic Rankine Cycle (ORC) technology as shown in Figure 1.3. It is similar to the conventional steam Rankine cycle used in power generation plants, however, steam is replaced by an appropriate organic fluid. The Steam Rankine Cycle (SRC) utilizes mainly combustion of fossil fuels such as coal or the nuclear fission as heat source; however not effective for low temperature heat source. At low temperature heat source, ORC is a viable alternative as organic fluids give higher cycle efficiency than water (J. Sarkar, 2015).

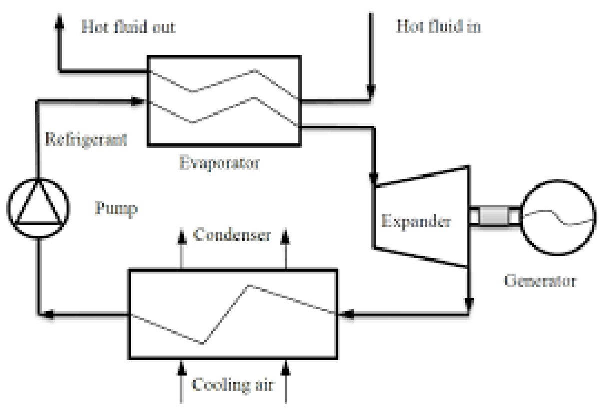

Fig.1.3 Schematic Layout of Organic Rankine Cycle (ORC)

1.1.5 COMBINED COOLING, HEATING AND POWER SYSTEM

CHP can be coupled with heat driven refrigeration cycle for yielding combined cooling, heat and power (CCHP), as represented in Figure 1.4. The heat driven refrigeration cycle does not require any electricity excluding the small pump consumption and can be operated by using the heat of hot gases coming out from biomass gasification. Hence, the biomass based tetra-generation (cooling, heat, power and syngas) system can be used, which provides refrigeration effect, heat, power generation along with syngas production.

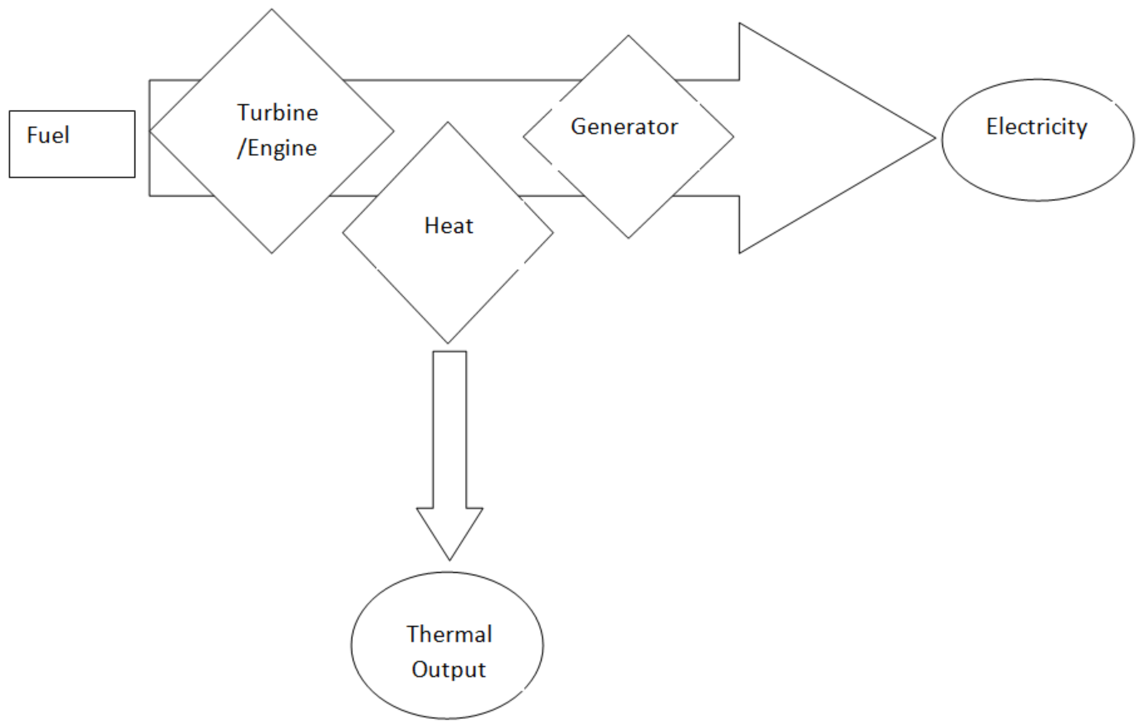

Fig. 1.4 Schematic Layout of Combined Cooling, Heat and Power system

1.2 MOTIVATION FOR PRESENT WORK

The combination of feedstock and gasifying agent determines the composition of syngas produced and hence its end use. The oxidants typically used are oxygen or air and/or steam. Syngas to be used for power generation requires high concentrations of carbon monoxide and hydrogen and hence oxygen is used as a suitable gasifying agent. On the other hand, when syngas is to be used for synthesis of chemicals, larger concentrations of carbon dioxide and methane are desired and hence, steam is used as a gasifying agent.

The CHP by biomass gasification has advantages such as higher biomass to power efficiency, higher flexibility concerning the used feedstock and reduction of green house gas emissions. Furthermore, CHP based polygeneration strategy can further be improved by Organic Rankine Cycle (ORC) technology, in which organic fluid is used as a working substance. Many investigations on various biomass combustion powered ORC multigeneration system have been carried out within past decades, however, studies on CHP by biomass gasification are very limited. Many Researchers have analyzed the combination of an air gasification system with CHP (D. Mertzis, 2014; J. Kalina, 2010; J. Wang, 2016; J. Wang, 2016; Damartzis Th, 2012; N. Kabalina, 2016). However, their main motivation was the considerations of the economic and eco-friendly aspects of the combined system. There has not yet been a combined system which would yield hydrogen/ syngas along with simultaneous maximization of the Performance Index (PI).

Furthermore, the review of literature shows that many studies were carried out on waste heat based CCHP systems (Xu F, 2000; Hasaan A, 2002; Goswami D.Y, 2004; TammG, Goswami D.Y,2004; Maraver D, 2013; Huang Y, 2013). However, the studies integrating syngas production along with CCHP systems have not yet been reported. Furthermore, the previous CCHP systems mainly used vapor absorption refrigeration cycle whereas ejector refrigeration systems have been used in limited capacity. From the state of the art of the research gap the following points can be inferred which motivates author to carry out further research works.

a) There is a need to develop a combined heat and power system where cogeneration of heat and power occurs simultaneously mainly operated with organic fluids as working agents (via Organic Rankine Cycle).

b) There is a need to develop a polygeneration system to produce heat, cooling (via ejector refrigeration system), power and syngas in which the performance of the system depends on the selection of the biomass material.