Renewable and Sustainable Energy Reviews 91 (2018) 1045–1064

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A critical assessment of tar generated during biomass gasification - Formation, evaluation, issues and mitigation strategies

Rakesh N, S. Dasappa*

Centre for Sustainable Technologies, Indian Institute of Science, Bangalore 560012, India

ARTICLE INFO

Keywords:
Tar
Biomass gasification
Producer gas
Renewable energy
Gas cleaning

ABSTRACT

Biomass gasification receives attention as a promising method to utilize biomass, a fuel which is carbon neutral. The producer gas/syngas which is an energy carrier obtained through this method finds use in engines, fuel cells, Fischer-Tropsch reactors, methanol synthesis and as an input for chemical industries, after the required quality levels for the above applications are achieved. To use the producer gas/syngas for power generation on a commercial scale, the required gas quality has to be established. Producer gas obtained from biomass gasification has several contaminants like particulate matter, tar and gaseous species like H_2S, NH_3. The contaminants present in the producer gas, depending upon their nature and the amount, pose issues to power generation systems. Tar, which is a mixture of varying molecular weight hydrocarbon molecules, generated from the thermo-chemical conversion processes of organic materials, could condense at low temperatures, and lead to clogging or blockage in end-use application devices, filters, and fuel lines. So, it is essential to reduce or transform the tar present in the producer gas to utilize the biomass gasification systems for power generation. This paper attempts to provide a critical assessment of tar generated during biomass gasification, covering the sundry aspects of formation, evaluation, issues and mitigation strategies. The paper gives an introduction to biomass gasification systems, followed by a detailed description of tar, including the definition and the chemistry of formation and destruction. An explanation of the various aspects of tar sampling, characterization and analysis, is presented next. The suitability of different tar analysis approaches is compared from an end-use device perspective. Then the multifarious issues posed by the presence of tar in the syngas on the end-use devices is discussed. The last part of the paper describes several tar mitigation strategies used by researchers.

1. Introduction

The gasification of biomass as a thermochemical conversion process has been studied by several researchers from the Second World War times [1]. Some research groups have revisited the technology from the early 1980s after the 1970s' oil crisis and also recently as an option for the mitigation of climate change and the provision of energy to remote areas [1–6]. Biofuels and waste accounted for about 10% of the global primary energy supply in 2014 as shown in Fig. 1. It has been pointed out by several researchers that biomass can be a route for emission reduction and generation of electricity in a renewable manner for the future and also to achieve energy security, energy independence, economic growth and sustainable development [7–14]. The utilization of biomass for power generation and thermal applications can be carried out through two major routes, viz; thermochemical and biological conversion processes, with each having its own advantages and disadvantages.

Gasification is a promising approach to convert solid biomass into useful combustible gaseous species through the thermochemical conversion route. Extensive experimental and modeling studies have been carried out on the use of biomass gasification generating producer gas [2,15–17], oxy-steam gasification for generating hydrogen-rich syngas [18,19] and also on the co-gasification of biomass with coal [20]. Several recent documents have also discussed about biomass gasification and the advancements happening in this realm of research [12,21–27]. A substantial amount of research has been carried out on the utilization of the gaseous species for various applications and literature is available on their use in IC engines [28], GT [29], SOFC [30–32] and for FT synthesis of diesel [33]. The obtained raw product gas having impurities must be conditioned to meet the different needs [34]. Of the many types of reactors used for generating power, the downdraft configuration produces raw gas which is acceptably clean, and this gas needs further conditioning for utilization in reciprocating engines [22] or gas turbines [29]. Biomass gasification produces three outputs: solids (char and ash), gases and condensable tars [35] apart from heat. Tars and particulate matter are major contaminants present

* Corresponding author.
E-mail address: dasappa@iisc.ac.in (S. Dasappa).

https://doi.org/10.1016/j.rser.2018.04.017
Received 29 August 2016; Received in revised form 10 February 2018; Accepted 8 April 2018
1364-0321/

Nomenclature

PG	Producer Gas
IC engine	Internal Combustion engine
SOFC	Solid Oxide Fuel Cell
FT	Fischer-Tropsch
GT	Gas Turbine
PAH	Poly Aromatic Hydrocarbons/Polycyclic Aromatic Hydrocarbons /Polynuclear Hydrocarbons
FC	Fuel Cell
PID	Photo Ionization Detector
LIF	Laser-Induced Fluorescence
FID	Flame Ionization Detector
UV	Ultraviolet
UV/VIS	Ultraviolet–Visible
IR	Infrared
FTIR	Fourier Transform Infrared
MBMS	Molecular Beam Mass Spectrometer
LED	Light-emitting Diode
MS	Mass Spectrometer
GC	Gas Chromatograph
TOF/MS	Time-of-flight Mass Spectrometry
LI	Laser Ionization
EI	Electron Impact
HPLC	High Performance Liquid Chromatography
mGT	micro Gas Turbine
GT	Gas Turbine
MCFC	Molten Carbonate Fuel Cell
CCD	Combustion Chamber Deposits
PEMFC	Polymer Electrolyte Membrane Fuel Cell
HCCI	Homogeneous Charge Compression Ignition
ESP	Electrostatic Precipitator
RBC	Rotating Biological Contactor
SPA	Solid Phase Adsorption
PNA	Polynuclear Aromatics
LHV	Lower Heating Value
LAMS	Laser Mass Spectrometry
YSZ	Yttria Stabilized Zirconia
GDC or CGO	Gadolinium Doped Ceria
SPME	Solid-phase Micro Extraction
IPA	Isopropyl alcohol
1°	Primary
2°	Secondary
3°	Tertiary
R & D	Research and Development

in the gas. Some of these contaminants are soluble in water while the others are soluble in organic solvents. The organic condensable compounds that are condensable at room temperature, formed during thermo-chemical reactions are defined as tars. The main species of tar that are generated during biomass gasification could range from single to five-ring type of aromatic hydrocarbons [35]. This necessitates a careful design and utilization of sophisticated cleaning equipment downstream, to ensure the required gas quality. The increase in the requirement of cleaning equipment affects the overall economy of the process. In biomass gasification systems, the presence of tar in the output gas is one of the main issues to be dealt with. The tar could condense at a reduced temperature, thus resulting in blockage in the process equipment such as engines, turbines, and burners [36].

Since the presence of tar poses challenges to the development of biomass gasification technology for end use applications, an in-depth understanding of tar becomes necessary. An understanding of the various aspects of tar – formation, analysis, effect on end-use devices and mitigation strategies, is essential to deal with the tar-laden producer gas obtained from biomass gasification. Several past documents have described about the tar obtained from biomass gasification [4,36–44]. A considerable amount of research has taken place recently in this area of research. The authors have felt the need for a document which consolidates the literature available regarding all the diverse aspects about this topic, including the recent advancements, to provide a comprehensive overview of the present scenario. This paper aims to bridge this gap and elucidate these multifarious aspects of tar. This would make the document helpful for students and researchers working in this area of research.

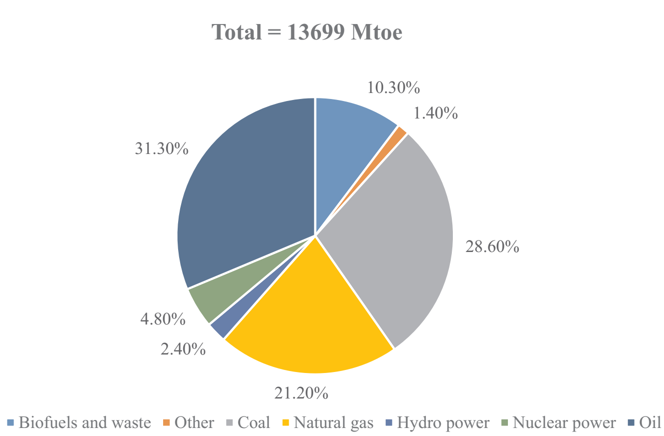

Fig. 1. World total primary energy supply (TPES) 2014 by fuel [45].

This document is divided into six sections. After the Introduction, Section 2 deals with the types of gasification systems. There is a considerable amount of literature available on this topic. The features of the various gasification systems are elucidated in this section. The knowledge of the different types of gasifiers is essential when dealing with the topic of tar. Section 3 deals with the definition, formation, classification, and decomposition of tar. There has been a significant amount of discussions about the definition of tar itself. The chemistry of formation is discussed after this. The classification of tar and the decomposition are discussed after that. Section 4 is about tar analysis. There are various techniques of analysis and the variety of these methods makes it difficult to compare the performances of different gasifiers. These techniques are discussed in this section. Several publications contain detailed discussions on the tar analysis approaches, of which the conventional cold solvent trapping method gained immense popularity. There have been many recent advancements, especially related to the techniques of online tar analyses. The effect of tar on various end-use devices is explained in Section 5. This is a research topic crucial to the success of the gasifier based systems because of the issues of reliability and maintenance requirement on the systems, associated with the presence of tar in the PG. Section 6 deals with the tar mitigation strategies like the primary and secondary treatment methods. The tar mitigation strategies include careful design and operation of the gasifier and the associated systems as well as methods of treatment of the PG for cleaning.

2. Biomass gasification - Processes and types

All organic materials that have originated from plants are referred to as biomass. It is a complex mixture of organic compounds and polymers, and the main types of compounds are lignin and carbohydrates like cellulose and hemicellulose, whose ratios and resulting properties are species dependent. Lignin, which is the cementing agent for cellulose, is a complex polymer consisting of phenylpropane units,