Journal of Environmental Chemical Engineering 3 (2015) 689–702

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

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

A review on the fuel gas cleaning technologies in gasification process

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ARTICLE INFO

Article history:
Received 3 December 2014
Accepted 7 February 2015
Available online 17 February 2015

Keywords:
Fuel gas cleaning
Removal of particulates
Heavy and alkali metals
Dioxins and furans
Tar cleaning

ABSTRACT

The product gas produced from gasification of solid fuel contains various impurities such as particulates, toxin gases, tar, vapours of heavy metals, etc. Presence of tar is a major issue which requires to be addressed before the use of gas product in the downstream process. Tar causes problems in the process equipment like flow channels, power generating units, etc. Generally gasification technology is adapted for the utilization of low grade coal, municipal solid waste, agro-waste, bio-waste, etc., which generates toxic and emits various hazardous compounds of chlorine, sulphur, nitrogen and heavy metals like Mn, Cd and Hg. Various alkali metals like Na, K, etc., generated through the gasification of wastes also create problem in the downstream processes when condensed at low temperature. The key challenge to commercializing gasification technology is to generate a clean fuel gas which meets the global emission standards. This paper provides a comprehensive overview of the fuel gas cleaning methods those are used to remove the contaminants and gas impurities generated from various types of reactor for gasification of coal or biomass.

Introduction

India is the sixth largest energy consumer in the world, accounting for 3.4% of the global energy and the major part of the energy consumption is contributed by coal. The country has 298.94 billion tonnes of coal and 43.22 billion tonnes of lignite reserves as on 2013 [1]. Therefore, the use of coal is bound to increase or at least remain steady for years to come and the demand for electricity in India is expected to exceed 950,000 MW by 2030. Another severe issue is that pollution level at several major cities in India is on rise. The increasing demand of electricity and rise of pollution level should simultaneously be considered as both are the wheels of same vehicle, i.e., development. Therefore, the clean fuel technology is the need of hour [1–3].

In the current scenario, one solution could be to introduce gasification technology instead of the conventional direct burning of coal in power plants which creates a lot of health hazards [4]. The gasification process converts organic materials or fossil fuel based carbonaceous compound into carbon monoxide, hydrogen and carbon dioxide, which is achieved by reacting the solid fuels at high temperatures with a controlled amount of oxygen and/or steam. Gasification of fossil fuels is currently being used on industrial scales to generate electricity in some countries, but gradually biomass and low grade coal gasification is bound to gain momentum in the coming years. Fuel gas could also be produced at the site of coal mines through gasification and may be sent back to the power plants or household as a clean fuel. Fuel gas production at site is also beneficial to the mankind as there is no toxic emission unlike conventional power plants. Other advantage of gasification process is that it does not contain the toxic compounds like dioxins and furans unlike the direct combustion process [5,6].

Despite the numerous advantages of gasification process, the technology is still in the developing stage due to some challenges. Impurities such as tars, particulate matters, NH_3, H_2S, HCl and SO_2, which are unavoidably produced during gasification and generally sustained in the producer gas, cause severe problems in downstream applications [7–11]. These contaminants must be removed before the gas is being used for internal combustion engine, fuel-cell and for secondary conversion into liquid fuels or chemicals by Fischer–Tropsch synthesis [12–15].

The present work focuses on the study of removal processes of the particulate matters, tar, sulphur compounds, alkali and heavy metals, nitrogen and chlorine compounds from raw fuel gas in gasification process. A comprehensive literature survey of the above subject has been conducted.

Impurities in fuel gas and environmental pollution

The fuel gas from gasification processes contains various amounts of impurities and particulate matters originating from

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http://dx.doi.org/10.1016/j.jece.2015.02.011
2213-3437/

the solid fuel and particle attritions from the bed. There are certain elements inherently present in solid fuel which creates pollution to the environment when it is burnt or gasified. Prominent among them are sulphur, chlorine, alkali metals (sodium and potassium) and several other heavy metals like Ba, Zn, Ni, Cu, Fe, Pb, Mn, Mg, and Cd. These toxic elements are of concern today as they are creating a lot of health hazards, both on human body as well as on livestock. Although the toxic effects of alkali metals have negligible effects on living being, still it creates a lot of problem during downstream applications. Alkali metals principally potassium and sodium and alkaline earth metals like calcium, etc., are present in biomass and coal. These elements have the tendency to vapourize at temperature in thermal conversion facility where they react with silica, sulphur and chlorine. Downstream heat recovery reduces product temperature. This results in condensation of inorganic compounds that cause deposits, fouling and corrosion [16].

Table 1 shows the major pollutants coming out from the emission of coal burning/gasification and the problems created on human body. Advanced technologies today partially offer solutions to some of these problems. For raw fuel gas cleaning there are basically three techniques, i.e., hot gas cleaning which operates above 300 °C, cold gas cleaning which operates below 100 °C, while warm gas cleaning operates in between the two extremes [17,18]. Especially, the integration of these systems in larger scales has to be surveyed more carefully. For a successful implementation of gasification in commercial fuel gas production, the effluent gas must conform to allowable limits regarding particulate and other impurities.

Removal of fuel gas impurities

Particulate matters removal

Particulate matter in gasifiers ranges from less than 1 μm to more than 100 μm and it varies on the basis of composition and type of feedstock [25]. Classification of particulate matters is done on the basis of aerodynamic diameter. Residual carbon and inorganic compounds constitute the bulk of particulate matters. Alkali metals (Na and K), alkaline earth metals (Ca), silica (SiO_2) and other metals like Fe and Mg compounds constitute the inorganic materials [26,27]. Minor constituents in particle matters include arsenic, selenium, antimony, zinc and lead [28]. The critical issues with particulate matters involve fouling, corrosion and erosion of downstream components like gas turbine blades, etc., [29–31]. There are three different techniques used for its removal.

Hot gas particulate matters removal

The removal techniques of particulate matters from fuel gas are mainly based on three categories, i.e., inertial separation, barrier filtration and electrostatic separation [32].

Inertial separation. It operates using mass and acceleration principles for the separation of heavier solids from lighter gases. Three significant devices of this category are impact separators, dust agglomerators and cyclone, but the most trusted one is cyclone among them [28]. Cyclones utilize centripetal force to create vortex for particulate removal which can comfortably operate at 1000 °C and is one of the most widely used techniques for particulate separation.

The design of cyclone is based on the characteristics of the particle and the gas stream. Different approaches have been developed in the past [33]. A 'cut point' is made so that the particle may obtain a balance between centrifugal and drag force. The cut point is the particle size at this point and denoted by X50 or d50 which means that it has the removal efficiency of 50% [25]. Although cyclones are mature technology, the separation efficiency of reverse flow cyclone using partial recirculation is more than the conventional Stairmand high efficiency designs. Particulate removal surpasses 99.6% in cyclones when compared with low temperature high efficient devices such as venturi and pulse jet bag filters [34]. As per Lee et al. [35], a high-temperature and high-pressure dust collector has been tested at 800 °C and 3 atm and the overall collection efficiency is found to be over 99.999%.

Filters. When a gas stream passes around granules or through a porous monolithic solid, the filters are known as barrier filters. During filtration, particulate matters are separated in four steps which are diffusion, inertial impaction, gravitational settling and particle collection. It occurs as a result of random collisions with the filter media as they deviate from the gas streamlines [31].

Ceramic or metallic materials are the common raw materials for the construction of rigid filters. They have the capability to remove 99.99% of particulate matter of size smaller than 100 μm with operating temperature above 400 °C [36]. There are candle filters which are made up of clay-bonded silicon carbide (SiC) as well as monolithic and composite ceramics and can sustain high temperature [37]. Metals may also be introduced to prevent ceramics from damage in hostile conditions and also to provide catalytic activity [38]. Ceramic filters are fragile, which led to the development of sintered metal barrier filters where the operational temperature may be raised to 1000 °C. The concentrations of particulate matters could be as low as 10 mg/m^3 with filtration

Table 1
Effect of toxic elements on human beings.

Toxic elements	Effect on human beings
Dioxin/furans	Cloracne, reproductive, developmental problems, damages the immune system, interfere with hormones and also causes cancer [19].
Sulphur oxides	Asthma, chronic bronchitis, air ways inflammation, eye irritation, psychic alteration, heart failure [20].
Nitrogen oxides	Damages cell membranes in the lung tissue, causes constriction of the lung way passage, nasal irritation and pulmonary discomfort is common [20].
Arsenic	Induces reactive oxygen species (ROS) and oxidative stress. Binds to thiols, alters signal cascade, imbalance in antioxidant levels. Triggers apoptosis & cell death, nausea, decrease in production of red and white blood cells, sensation of pin and needles in hand & feet [21].
Chromium	Nose ulcers, skin ulcer, asthma, shortness of breath or wheezing, allergic reactions leading to severe redness and swelling of skin, long term exposure leads to damage of kidney, circulating and nerve tissues as well as skin irritation [22,23].
Copper	Gastrointestinal: metallic taste, nausea, vomiting, gastrointestinal bleeding, Renal: haematuria, oliguria, elevated urea, creatinine & acute tubular necrosis [22,23].
Cadmium	Gastrointestinal symptoms: nausea, vomiting, abdominal pain, diarrhoea, salivation, tenesmus, haemorrhagic gastroenteritis, may result in pulmonary fibrosis, headache, cadmium fume pneumonitis, hepatic necrosis, Renal necrosis, cardiomyopathy, chills, weakness & dizziness [22,23].
Lead	Damages the brain and kidney, in pregnant women, high level of exposure may cause miscarriage, high level exposure in men can damage the organs responsible for sperm production [24].
Mercury	Exposure to high level can permanently damage the brain, kidney and developing foetuses, effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing and memory problems [21].