Waste to Hydrogen : Oxy-gasification of Municipal Solid Waste

Sustainable Management of Wastes

Presented by:
Shanta Kumar, Sr. Manager (NTPC-NETRA)
Yashwant Kumar Saini, Executive, NTPC-NETRA

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Introduction

- 35% rise in energy demand by 2030 with an energy import bill reaching $185 billion in 2022
- meeting its net-zero objectives, India is targeting a production of 5 MMTPA of green hydrogen by 2030

Waste

- Suitable waste for generation of energy includes biomass wood waste e.g. timber or paper industry waste, municipal solid waste, sewage sludge, packaging and plastics, solid recovered fuel (SRF) and refuse derived fuel (RDF) from MSW
- MSW normally includes biodegradable waste, recyclable material, inert waste, electronic waste, hazardous and toxic waste which is discarded by the public
- As per central electricity regulatory commission, "Municipal solid waste' implies commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes
- The SWM Rules, 2016 defines "Refuse Derived Fuel" as fuel derived from combustible fraction of solid waste like plastic, wood, pulp or organic waste, other than chlorinated materials, in the form of pellets or fluff produced by drying, shredding, dehydrating and compacting of solid waste
- RDF typically consists of the residual dry combustible fraction of the MSW including paper, textile, rags, leather, rubber, non-recyclable plastic, jute, multilayered packaging and other compound packaging, cellphone, thermocol, melamine, coconut shells, and other high calorific fractions of the MSW
- The station heat rate for power projects which use municipal solid waste (MSW) and refuse derived fuel (RDF) shall be 4200 kcal/kWh

MSW

- 2.0 billion tonnes of MSW are generated each year
- Expected to increase to 3.4 billion tonnes annually by 2050
- GH2 from electrolysis of water.. Rs. 300 per kg of H2
- The potential produce H2 from waste cost-effective (below $1/kg)

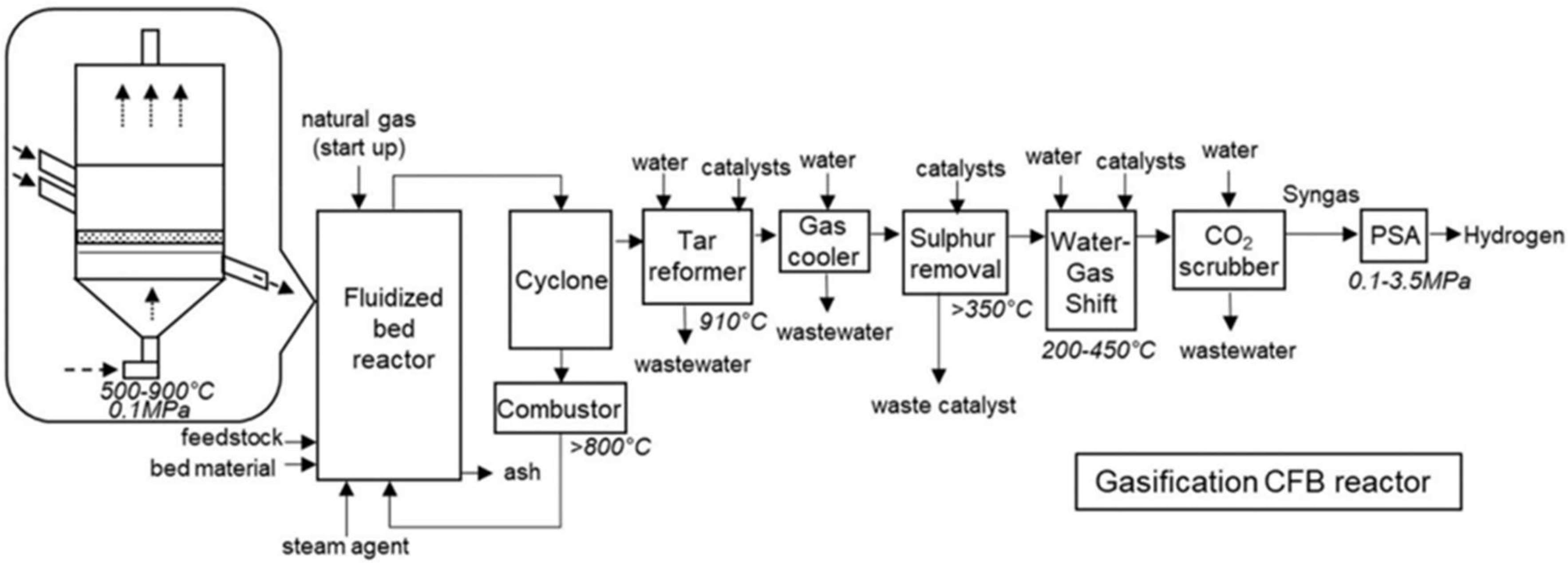
WtH

- **WtH** conversion methods are thermochemical and biochemical techniques differing by energy requirements, operating conditions (temperature and pressures), feedstock inputs, efficiencies, reaction times and final yields
- thermochemical processes (i.e. gasification and pyrolysis) are faster than the biochemical ones (e. g. fermentation), have higher stoichiometric hydrogen yields, higher conversion efficiencies and shorter reaction times
- biochemical processes are less energy intensive.
- The advantage of the thermochemical processes regarding waste management includes a high reduction in waste in mass (70-80%) and volume (80-90%) preserving landfill space.
- The solid residues such as bottom ash and slag may be used as fertilizer in farming.

Gasification

- The gasification process is the conversion of solid material between the temperature of 500 degree C and 1200 degree C in an oxygen-deficient environment at atmospheric pressure (0.1 MPa)
- Autothermal gasification uses partial oxidation of waste within the reactor, in the presence of an oxidant at an amount lower than that required for stoichiometric combustion, to provide the required heat for the reaction. Part of the feedstock is combusted in exothermic reactions to provide heat to gasify the remaining products
- The reducing atmosphere of the process limits the emissions of furans and dioxins that often link the combustion of waste, while the oxygen-deficient condition reduces heat losses and increases energy recovery efficiency
- Gasification of biomass for hydrogen production has a thermal efficiency of 35-50%, up to 52% for steam gasification
- Typical gasifying agents or oxidation media include air, oxygen-enriched air, pure oxygen or steam.
- Steam gasification is endothermic and requires energy input to produce syngas with the quality comparable to the other oxidation agents.
- Beyond the optimum temperature, the hydrogen yield decreases as the temperature accelerates the reaction reducing the ability of cracking and reforming reactions
- The steam to biomass ratio (S/B) is important for steam gasification as the steam reforming reaction is the main reaction producing hydrogen
- Steam or oxygen gasification produces syngas of an HHV of 9.2-16.5 MJ/m3 at standard temperature (25 degree C) and pressure (1 atm)

Gasification Process



The Plasma Gasification Method

- Tolerates flexibility in feeding rate, moisture content and composition of waste material, suitable for mixed biomass feedstocks of variable particle size with minimal preparation
- Produces very small volumes of vitrified slag, and emissions such as particulate matter, mercury and metals requiring pollution control devices
- A life cycle analysis on two-stage plasma gasification for MSW showed that it was environmentally friendly and sustainable
- Massive oxygen and steam are required for plasma gasification where MSW is processed without burning producing synthetic gas and vitrified slag
- Less soot, char, tar, and dangerous gases like oxides of sulfur or nitrogen, or pathogen are the main feature of plasma gasification

Factors Influencing the Syngas Production

- Temp of gasification has an impact
  - CO concentrations grow whereas CO2 and CH4 drop with temperature. Hydrogen concentration is practically constant at most gasification temperatures
- Effect of oxidant/municipal solid waste ratio
- Air atmosphere (equivalent ratio)
- Effect of moisture content in municipal solid waste
- Effect of municipal solid waste composition

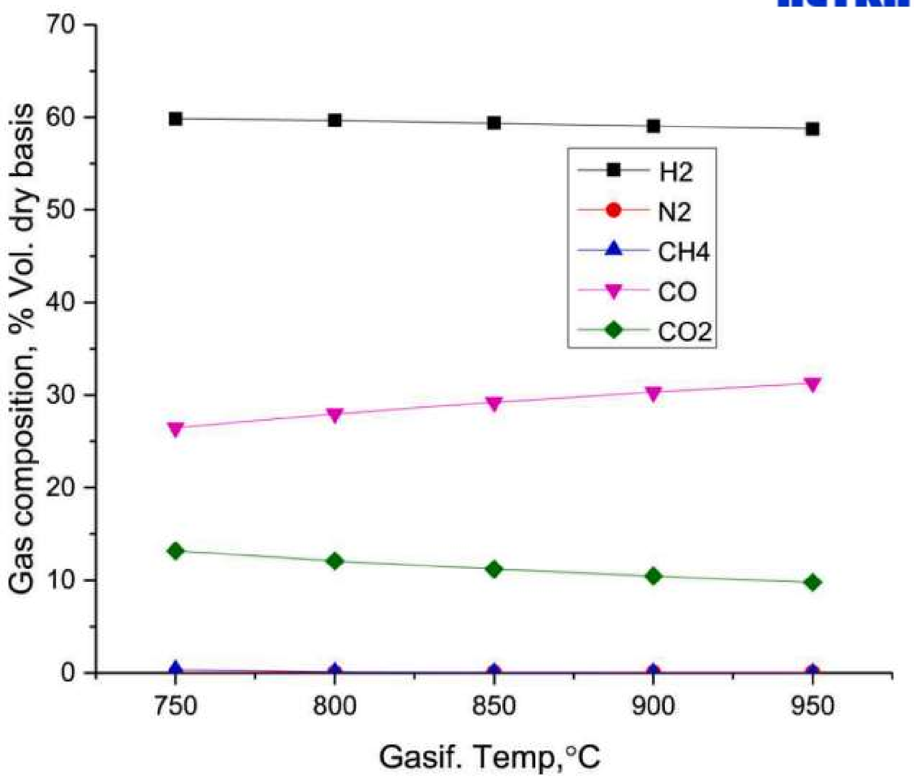


Fig. 19. Effect of the gasification temperature on the product gas [147].

Syngas to Hydrogen

- Syngas produced from gasification requires cleaning, reforming and gas shift reaction processes, and separation processes to generate high purity hydrogen (99.9%).
- Warm or hot gas cleaning techniques can improve thermal efficiency if integrated into combined cycle gasification systems
- **Pressure swing adsorption (PSA)** is a conventional method of hydrogen separation, and it utilizes an adsorbent bed to capture impurities in the syngas at high pressure which are subsequently released as the pressure is reduced. The PSA method requires a minimum of 70 mol% hydrogen in the input gas stream efficiency as high as 99.99%. Adsorption size, velocity, regeneration and adsorbent material decides PSA systems
- **Membrane technologies** is used to adjust the gas composition in syngas. The partial pressure of the hydrogen feed streams forces the permeation and balances with the product stream. Most membrane materials are expensive and susceptible to contamination in the syngas even after cleaning-up processing (9). Using zeolitic frameworks, porous materials with metal nodes linked by imidazole ligands, can isolate selected gases in syngas, leading to increases in the ratio of H2/CO and H2/CO2. The thermal stability of the zeolitic framework at high temperatures (above 230 degree C) is poor though zeolitic imidazolate frameworks-8 nano polymer as a composite material can have high thermal and separation stability and H2/Co2 selectivity.

Methods for increasing H2 in syngas

- Steam combines with gasifier reactor material to produce hydrogen-rich gas where water gas, water-gas shift, and steam reforming reactions occur which transform steam to hydrogen from material and component

Water-gas	$C + H_2O \leftrightarrow CO + H_2 + 131$ MJ/kmol
Water-gas shift	$CO + H_2O \leftrightarrow CO2 + H_2 - 41$ MJ/kmol
Steam reforming	$CH_4 + H_2O \leftrightarrow CO + 3H_2 + 206$ MJ/kmol

Application of Hydrogen

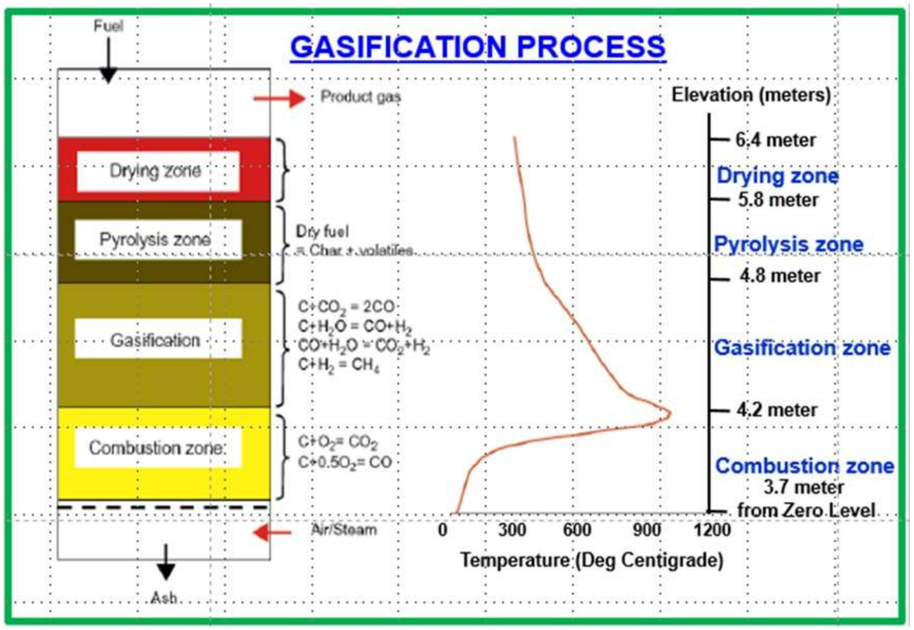
- Hydrogen is becoming popular as a fuel transiting to a hydrogen society to reduce fossil fuel use to tackle climate change.
- The transport sector is the second-largest consumer of hydrogen.
- A fuel cell is an electrochemical device converting the chemical energy of gas like hydrogen or a solid like coal into electrical energy.
- Major types of fuel cells include Proton Exchange Membrane cell, alkaline, solid oxide fuel cell featured by different power densities, hydrogen production rates, and specific energy consumption (kWh).
- Heat for buildings and joining the energy grid by adding a hydrogen fraction to the natural gas network are other alternate applications of hydrogen

Hydrogen Cooking

- Zero emission 'Hydrogen Cooking' demonstrated by supplying hydrogen, which is directly generated in the existing green hydrogen plant at NTPC Energy Technology Research Alliance (NETRA).
- Burning characteristics of hydrogen is much different from LPG or PNG with regards to flame color (almost invisible), flame temperature (1200-1500 degree C0, flame propagation, speed etc. (10).
- Further, hydrogen cannot be premixed with air prior to its ignition to avoid explosive mixture (10).
- In that light hydrogen burner has been developed by M/s Ohmium and integrated with existing LPG cookstove (10).
- The emission from hydrogen burner is only water vapour with zero-carboneous element

Production of Syngas from MSW-RDF at NETRA

- A set up producing syngas through steam-enhanced gasification of MSW-RDF with capacity of 15 TPD feed. The produced syngas is cleaned and conditioned and used as a fuel in IC engine to generate 400 kWe to be fed into grid at NETRA.
- **Preparatory section**
- **In the gasification section**
- **In the gas cleaning section**



Innovative Features

- Gasifier shell has two jackets one above another: 1. for air preheating (topside) 2. Steam generation (Bottom side) : Prevent Overheating & Recycle heat
- The required quantity of air by gasifier to generate desired quantity of gas is supplied by air blower, which changes speed by sensing gasifier outlet pressure with the help of VFD: 1. Maintain air quality. 2. Air is passed through top side jacket of gasifier to preheat air
- The steam generated in the bottom side jacket of gasifier is mixed with preheated air in steam injector and then introduced in gasifier
- The ash coming out from the bottom of the gasifier is wet as it comes out through the water seal.
- Water vapour, TAR and phenolic compounds etc., which are generated in the gasification process, are separated in the gas cleaning section. The separated liquids called TAR and PHENOLIC WATER (mixture of water and phenolic compounds) are the liquid pollutants of this process and both the compounds have some calorific value. Therefore, TAR and PHENOLIC WATER are recycled back to the gasifier for re-firing. This recycling helps to utilize available heat value and to reduce effluent making zero liquid discharge (ZLD) process.
- Gas cooler has two sections. The gas is cooled to 20°C in gas cooler which is used as pre-cooler for scrubber outlet gas. The scrubber outlet gas is cooled by 20°C. This precooling is helps to reduce load on Chiller

Chemical Processes involved in Gasification and way to Green Hydrogen

- In current design of Gasification Plant, the Producer Gas output has Carbon Monoxide (CO) between 16% to 18% by volume and Hydrogen between 12% to 14% by volume. Major constituent of the Producer Gas is Nitrogen, between 55% to 60% by volume. Calorific value of Producer Gas is determined by percentage of Carbon Monoxide, Hydrogen and these inert gases in the Gas. Following reactions happen in the Gasification process:
- $C + O_2 = CO_2 + Heat$
- $C + CO_2 = 2CO - Heat$
- $CO + H_2O = CO_2 + H_2 - Heat$
- It is clear from the above reactions that CO2 formation is required for heat generation and Hydrogen generation. Higher the Hydrogen, higher is calorific value of Producer Gas but it also generates CO2 (inert for PG as fuel), which reduces calorific value.

Enrichment of Oxygen Present in air

- Enrichment of oxygen present in air by 5% shall reduce presence of Nitrogen inert in the Producer Gas, but Hydrogen production does not necessarily increase. Hydrogen production (in absolute terms) is a function of heat available for endothermic reaction and quantity of additional steam injection possible in the Gasifier.
- . It is expected that the hydrogen generation can be increased by upto 40% with 10% enrichment of oxygen in air. In other words, for the same 1500 kg/h Producer Gas generation, Hydrogen Generation capacity would be 21 kg/h and potential for hydrogen recovery at 75% yield is 378 kg/day.

PRODUCER GAS COMPOSITION	Composition with ambient air		Composition with O2 Enrichment (by 5%)	Composition with O2 Enrichment (by 10%)
	Vol%	Weight %	Vol%	Vol%
CO	16.3%	18.0%	18.8%	21.1%
H_2	13.2%	1.0%	15.2%	17.1%
CH_4	1.1%	0.7%	1.3%	1.4%
CO_2	7.2%	12.5%	8.3%	9.3%
N_2	58.4%	64.3%	52.0%	46.1%
O_2	0.1%	0.1%	0.1%	0.1%
Ar	0.6%	0.9%	0.7%	0.8%
SO_2	0.0%	0.0%	0.0%	0.0%
H_2O	3.0%	2.1%	3.5%	3.9%
VM	0.1%	0.3%	0.1%	0.1%

Comparison of Hydrogen Generation options with electrolysis and gasification

- Net Export of power from MSW-RDF project to Hydrogen plant : 400 kW
- Hydrogen generation potential by electrolysis : 192 kg/day
- Producer Gas generation : 1500 kg/h
- Hydrogen generation potential (Without Oxygen Enrichment) : 270 kg/day (@75% recovery)
- Hydrogen generation potential (With Oxygen Enrichment) : 378 kg/day (@75% recovery)

THANKS