Hydrogen Production System using a Plasma Reactor

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Abstract— *The present article deals with a potential to interconnect the plasma technology of waste processing with the technology of hydrogen separation from syngas using metal hydride alloys. It also describes key components of the system used for syngas cleaning and their succession.*

Keywords— ***hydrogen, plasma reaktor, waste treatment, gasification.***

I. INTRODUCTION

Conventional procedures of hydrogen recovery are not environment-friendly or require a significant amount of energy. One of the environment-friendly methods of hydrogen recovery is hydrogen separation from syngas produced either as a result of biological processes in microorganisms or as a by-product of technological processing of waste, in particular the gasification technology or waste disposal using plasma reactors. At present, a system of hydrogen recovery from such syngas represents a challenge which is only manageable by a few methods which are costly, technologically demanding or time-consuming.

II. THE PLASMA GASIFICATION PRINCIPLE

Plasma arc gasification is a waste-treatment technology based on the principle of producing a plasma arc discharge mostly from a stream of inert gas (argon, nitrogen etc.). With the use of a high-intensity electric field, plasma-forming gas is transformed into plasma. High temperatures along the edges of the plasma arc discharge ensure a stable heat flow required for the thermal decomposition of waste. Due to the effect of high dissociation energy, the organic component of the waste is decomposed into simple gas molecules. Inorganic waste components, in form of liquid slag and an alloy of metals, are accumulated in the lower part of the reactor and periodically discharged through tap holes.

Depending on the percentages of contained combustible components, including mainly hydrogen and carbon monoxide, syngas may be used, after the cooling and cleaning phases, for energy purposes through combustion in incineration plants [1].

An input material for plasma gasification is waste, including biological waste, communal waste, sledge from waste water treatment plants, hazardous waste from hospitals and healthcare facilities, or certain types of waste from production.

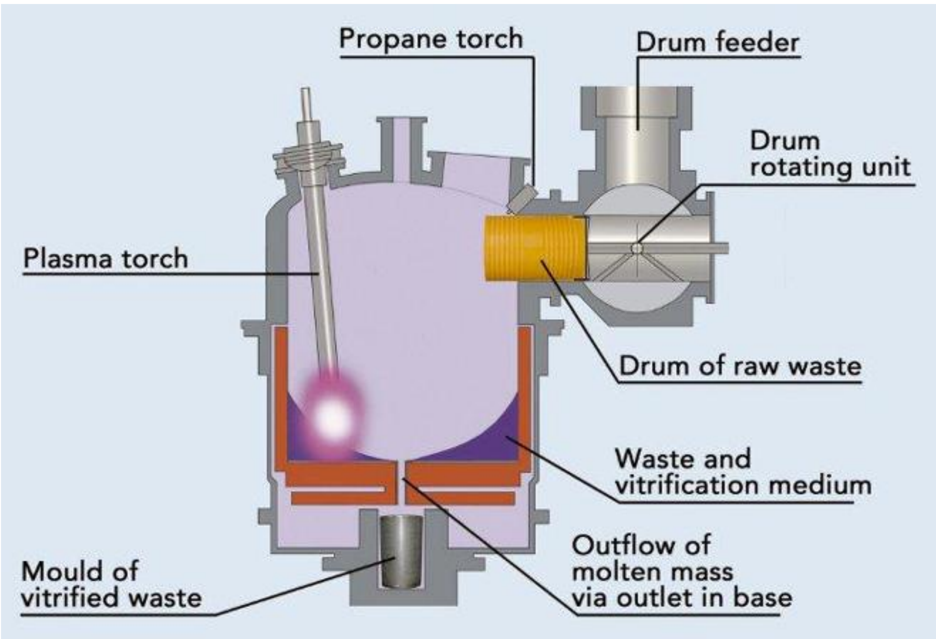

FIGURE 1: Basic system of plasma reactor [3]

First of all, the waste must be subjected to technological treatment. In order to become suitable for processing, the waste must meet certain technological parameters required for individual reactor types. In the case of biological waste and sledge from waste water treatment plants, it must be dried, and only then it may be processed similarly to processing any other waste, i.e. by crushing and granulating. This method is used to create a more compact homogeneous mixture which is easier to handle and improves the regulation of inserting charges into a plasma reactor. After the waste is processed into a size that is easier to handle, it is charged into the reactor. This is carried out using a special feeding device which inserts charges into the plasma reactor where the material decomposes.

The electrical current passes through electrodes, creating an arc between them or between the electrode and the reactor bottom. The most frequently used plasma-forming gas is nitrogen, due to its good accessibility, and in a high-intensity electric field it transforms into plasma.

III. SYNGAS CLEANING SYSTEM

Thermal Syngas generated during a thermal process must be cleaned of undesired components. The cleaning process consists of several phases aimed at preparing syngas for hydrogen separation using metal hydride alloys. The cleaning phases are as follows:

- Removal of particulate matter;
- Removal of acids;
- Removal of oxygen; and
- Removal of present water in form of vapour or aerosol.

3.1 Removal of particulate matter

In terms of waste processing in a plasma reactor, particulate matter may be divided into 3 basic categories:

- Coarse particles PM10 – particles with a diameter of 10 micrometres or less – these particles may easily pass to the lung tissues where they settle and cause health problems;
- Fine particles PM2.5 – particles with a diameter of 2.5 micrometres or less – they have multiple negative effects on human health, primarily affect the airways;
- Particles larger than 10 micrometers.

In practice, particulate matter is separated using devices for particulate matter separation which are based on the principle of separating particles of pollutants from a stream of gas passing through the separator surfaces (either directly onto the separator wall, for example in gravity or cyclonic separators, or inside a separator, for example in electric or rotary separators). In most separators, particulate matter must be removed from the separator surfaces, either continuously or in certain time intervals, while the filter regenerates [2].

Particulate matter removal devices operate on one of the key separation principles:

- Gravity principle – e.g. a louvered separator – using gravity forces;
- Inertia principle – e.g. a cyclonic separator or a fan separator;
- Electrostatic principle – using Coulomb force, with the efficiency as much as 99.99 %;
- Diffusion principle – forces of molecular origin induce diffusion of particles, applicable to particles smaller than 1 μm;
- Interception principle – particles moving near the separation surface may separate through it thanks to their final size; and
- Centrifuge principle – the movement of particles towards the separator surfaces is induced by the centrifugal force.

Considering the above listed physical principles, particulate matter separators are categorised as follows:

- Dry mechanical separators – dry separation;
- Wet mechanical separators – wet separation;

- Filters;
- Electrostatic separators.

3.2 Removal of acid

Waste treatment is a process in which it is impossible to avoid the presence of certain substances, for example sulphur, chlorine etc., which may interact with other present elements, such as hydrogen or oxygen, with the result of forming acids. These acids represent a significant risk either for the environment into which they may be released, or primarily for metal hydride alloys from which hydrogen will be separated from the remaining syngas components. The effect of such acids is extreme degradation of metal hydride alloys, and in some alloys there is a potential of formation of hazardous or toxic substances which may be released into the environment and contaminate it.

One of the most probable products of reactions in the event of a higher percentage of sulphur, with regard to an excessive content of H_2 and O_2-deficient atmosphere, is H_2S. Although it is not an acid, it is extremely toxic [4].

During the dry processes of desulphurisation, hydrogen sulphide is absorbed and decomposed into sulphuric acid or elementary sulphur. These processes exhibit a lower potential of removing hydrogen sulphide, but they do not require supplying air to the system or use toxic catalysers.

This process is very slow when the sulphur content in the gas is high. In the case of production of syngas with a low content of sulphur, the application of a desulphurisation system based on dry processes is possible; however, if the sulphur content is high, this process is unsuitable. The desulphurisation process is described by the following equation:

$$2Fe(OH)_3 + 3H_2S \rightarrow Fe_2S_3 + 6H_2O \quad (1)$$

Following the saturation, the material may be regenerated as described by the following equation:

$$2Fe_2S_3 + 6H_2O + 3O_2 \rightarrow Fe(OH)_3 + 6S \quad (2)$$

IV. SYSTEM OF INTERCONNECTING A PLASMA REACTOR WITH A MH SEPARATOR

With regard to the efforts aimed at hydrogen recovery by separation from syngas produced in a plasma reactor, syngas must be cleaned, as described above, or otherwise treated; sometimes even the equipment to be used for such treatment must be adjusted. The whole system should consist of a set of successive devices which will remove all undesired substances from syngas. A basic scheme is shown in Fig. 2.

After the particulate matter and acid gases are removed from syngas, oxygen must be removed from the gas stream, as it is an important contaminant which may damage or even completely deteriorate metal hydride alloys; as a result, this would put the metal hydride separator out of service. For the purpose of oxygen removal, in this case it is more appropriate to let it react with the present oxygen, with the result of producing water in the presence of catalyser – palladium. This method facilitates reduction of the oxygen content in syngas down to dozens of ppm. However, this may result in a partial increase in humidity in the gas.

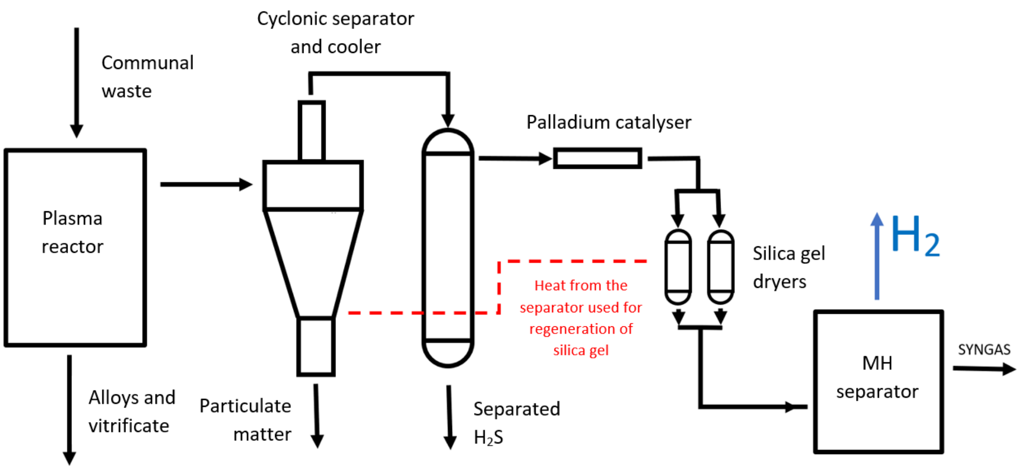

FIGURE 2: Basic system of connection plasma reactor with MH separator

V. METAL HYDRIDE SEPARATOR OF HYDROGEN

Hydrogen separation from syngas may be carried out while applying several methods, mostly based on the principle of membrane separation of individual components. However, such separation puts high requirements on the membrane production technology and service life. An interesting alternative may be the use of metal hydride alloys which are able to absorb hydrogen into their intermetallic structures; this facilitates efficient hydrogen separation from the remaining syngas components.

5.1 MH separator principle

A separator is a simple device consisting of a set of electromagnetic valves, pressure meters, pressure vessels and heating/cooling devices. A basic separator scheme is shown in Fig. 3.

Gas from a plasma reactor enters the system in the mixing feeder zone. In the scheme, the inlet from a plasma reactor is replaced with a mixing feeder for initial experiments in which a constant syngas mixture will be used, unlike the gas produced in a plasma reactor, because in that case the syngas composition continuously changes, depending on the waste composition and quantity.

Gas pressure is measured using a digital manometer before it enters the separator. Behind the electromagnetic valve which facilitates the supply of syngas into the system, there is a reduction valve which prevents a sudden pressure increase in the system.

Following a regulated entry into the system, syngas passes into a metal hydride separator where hydrogen is stored into the intermetallic structure of a metal. As hydrogen storage is an exothermic reaction, the container must be cooled to prevent overheating. The container is cooled by the system of Peltier thermocouples which are able, thanks to electrical energy, to heat up one side while cooling down the other side of the container. The heated side must be then cooled down by the system of water processor coolers which are able to prevent overheating of that side above the maximum operating temperature of the Peltier thermocouple. After certain period of time defined by the software, the inlet piping closes and stops the gas supply to the separator. Using a digital manometer located near the pressure vessel, changes in pressure are measured. Such changes are caused by storing hydrogen in the alloy. As soon as the pressure decrease in the separator system stops, it is possible to conclude that there is no hydrogen left in the system or that the alloy has been fully saturated.

When the alloy is saturated, the remaining syngas components are withdrawn. The first phase consists of releasing the overpressure using the electromagnetic valve and the reduction piping. Subsequently, after the pressure decreases down to approximately 0.1 to 0.3 bars, the electromagnetic valve closes and the remaining syngas is exhausted using a vacuum pump.

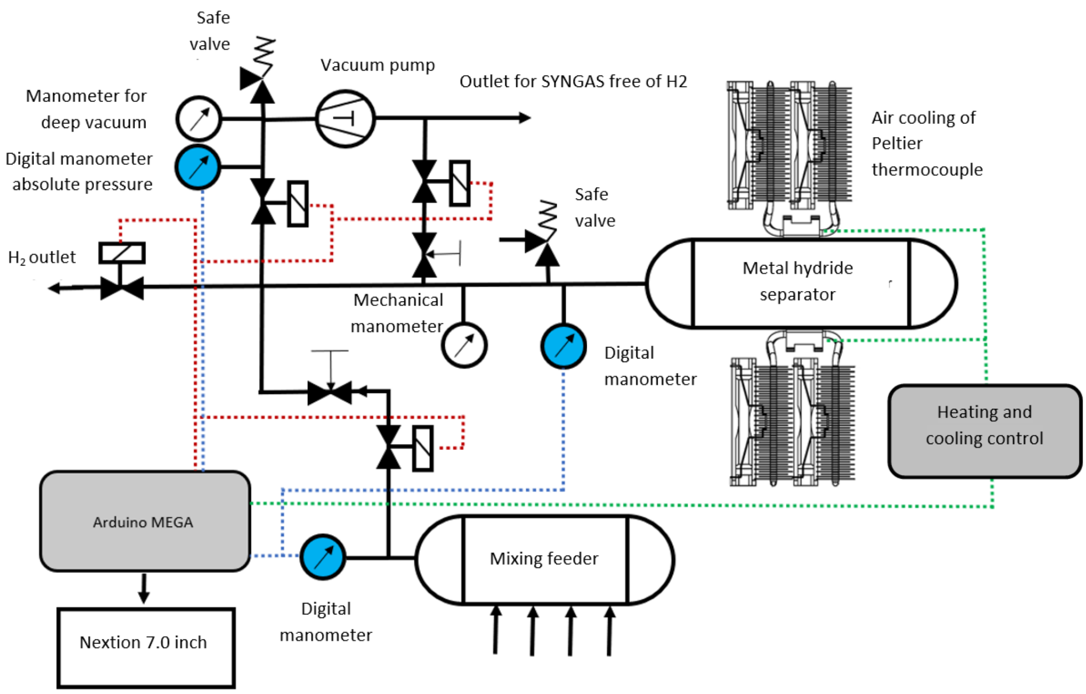

FIGURE 3: System of MH separator

In the vacuum pump area, there are digital and mechanic manometers for absolute pressure which is also able to measure deep vacuum.

The exhaust time must not exceed the period determined on the basis of the measured properties of individual alloys, due to subsequent exhaust of hydrogen from the alloy. In order to prevent this, exhaust of the remaining components must not exceed the shortest necessary period. Following the exhaust, hydrogen is forced out of the alloy. For this purpose, the alloy must be heated up to the operating temperature. That is when the polarity of Peltier thermocouples is reversed, i.e. the surface which was cooled down during hydrogen storage is now heated up, and vice versa. Heating causes hydrogen desorption and a pressure increase. After the pressure is increased to a certain value determined according to predefined conditions related to the operating conditions of the alloys and the required conditions at the hydrogen outlet from the system, electromagnetic valves open and hydrogen is let into the system for further processing.

VI. CONCLUSION

The measurement system described in the article will soon be subjected to the construction and testing phase while the emphasis will be put mostly on testing the resistance of metal hydride alloys to acids produced during the thermal decomposition of communal waste. Furthermore, alloys will be tested for their resistance to CO and CH4 and the effects of alloys on a potential decomposition of these substances.

ACKNOWLEDGEMENTS

Acknowledgments: This paper was written with the financial support of the granting agency VEGA within the project solution No. 1/0108/19 and No. 1/0626/20 and of the granting agency KEGA within the project solution No. 005TUKE-4/2019.

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