Available online at www.ap.iauardabil.ac.ir
Islamic Azad University, Ardabil Branch
Anthropogenic Pollution Journal, Vol 4 (1), 2020: 1-14
DOI: 10.22034/ap.2020.1879800.1052
ISSN:1908-1043

Analysis of Environmental Impacts on the Characteristics of Gas Released from Biomass

Reza Alayi*[1], Ehsan Sobhani[2], Atabak Najafi[3]

1. Department of Mechanics, Germi Branch, Islamic Azad University, Germi, Iran
2. Departments of Energy Engineering, Energy Institute of Higher Education, Saveh, Iran
3. Department of Electrical Engineering, Germi Branch, Islamic Azad University, Germi, Iran

*Corresponding author: Email:reza.alayi@yahoo.com

Received: 28 September 2019/ **Accepted**: 12 January 2020/ **Published**: 07 March 2020

Abstract: Due to population growth and increased production of municipal solid waste, it is important to utilize this unused energy source, with the right technology, this resource can be used as energy production. Sources of biomass include various natural and derived materials, such as wood and herbaceous species, solid wastes (e.g. From forest thinning and harvesting, timber production and carpentry residues), agricultural and industrial residues, waste paper, municipal solid waste, sawdust, grass, waste from food processing, animal wastes, aquatic plants and industrial and energy crops grown for biomass In this study, in order to produce gas with high calorific value of solid waste in Tehran, a wide variety of compounds, steam and air intake fixed bed reactor has been investigated to identify the best combination. This essay will focus on the production of bugs with high calorific value. In this research, different compositions of air and steam as a reactor input have been examined and fixed base gasifier behavior in different situations has been specified which demonstrate that, the best amount of air-steam composition with the most heat valuation is 12.26 (lb/s) for air input and 9.989 (lab/s) for steam input.

Keywords: Biomass, Gasifier fixed bed, Gasification, Downdraft, Solid wastes

1. Introduction

The awareness about depletion of fossil fuels, energy dependency, environmental pollution, greenhouse gas emissions and global climate change; together with the potential of biomass to supply large amount of useful energy with reduced environmental impacts have converted biomass in one of the most promising renewable energy sources. Among all biomass conversion technologies, this research focuses on biomass gasification that has the advantage over combustion of more efficient and better controlled steam and air, higher efficiencies in power production and the possibility to be applied for chemicals and fuel production. Alayi et al. 2019; Zainalabedini and Fataei 2016).

The term “biomass” covers a broad range of materials that can be used as fuel or raw materials and which have in common that they are all derived from recently living organisms. This definition clearly excludes traditional fossil fuels since, although they are also derived from plant (coal) or animal life (oil and gas); it has taken millions of years to convert them into their current form. (Shamel et al. 2014; Gopal and Sathiyagnanam 2018; Tan et al. 2018)

Sources of biomass include various natural and derived materials, such as woody and herbaceous species, solid wastes (e.g. from forest thinning and harvesting, timber production and carpentry residues), agricultural and industrial residues, waste paper, municipal solid waste, sawdust, grass, waste from food processing, animal wastes, aquatic plants and industrial and energy crops grown for biomass.(Caputo et al. 2019; Williams et al. 2016) For political purposes, some other materials (such as tires, manufactured from either synthetic or natural rubbers) may be included under the general definition of biomass even though the material is not strictly biogenic. There is also a potential overlap between what is classified as waste and what as biomass. (Toklu 2017; Hosseini et al. 2015)

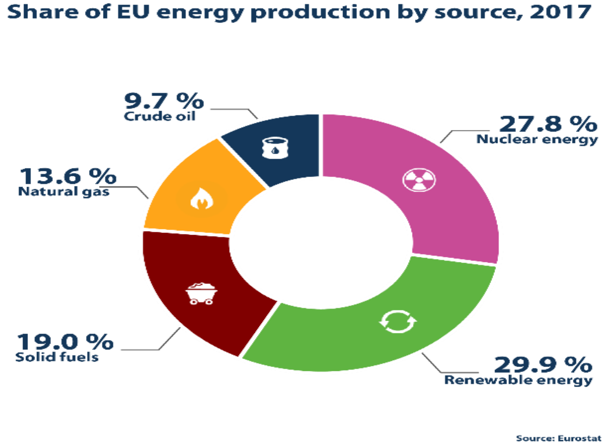
Although biomass is not a major industrial fuel, it supplies 15-20% of the total fuel use in the world. It is used mostly in non-industrialized economies for domestic heating and cooking. In industrialized countries, the use of biomass as a fuel is largely restricted to the use of by-products from forestry and the paper and sugar industries. Nonetheless, its use in industrialized countries is being encouraged as part of strategy for CO2 abatement. (Owusu and Asumadu-Sarkodie 2016; Mousa et al. 2016; Udaiyappan et al. 2017)

The contribution of renewable energies to the energy supply system remains relatively low, although by 2020 renewable energy should account for 20% of the EU's final energy consumption (8.5% in 2005). The European plan on climate change consists of a range of measures adopted by the members of the European Union to fight against climate change (Deng et al. 2016; Weldemichael et al. 2016; Ullah et al. 2015).

The plan was launched in March 2007, and after months of tough negotiations between the member countries, it was adopted by the European Parliament on December 2008. The plan includes the so-called “three 20 targets (20-20-20)”, but in reality it consisted in four proposals. These aims were: (Xu et al. 2015; Ahmed et al. 2016; Achawangkul et all 2016; Saidur et al. 2011)

- To reduce emissions of greenhouse gases by 20% by 2020.
- To increase energy efficiency to save 20% of EU energy consumption by 2020.
- To reach 20% of renewable energy in the total energy consumption in the EU by 2020.
- To reach 10% of biofuels in the total consumption of vehicles by 2020.

Figure 1 and Figure 2 show the European Union (EU-27) electricity and heat production in 2017, breakdown by different energy sources. It can be observed how biomass represented 2% and 10% of the total production of electricity and heat, respectively.


Share of EU energy production by source, 2017

Source: Eurostat

Figure 1- EU-27 Electricity production in 2017 (www.iea.org)

Because of the low price of fossil energy in Iran, the use of fossil fuel is very high and Renewable energies did not have enough growth and expansion. Figure 2 shows the Energy production in 2015.

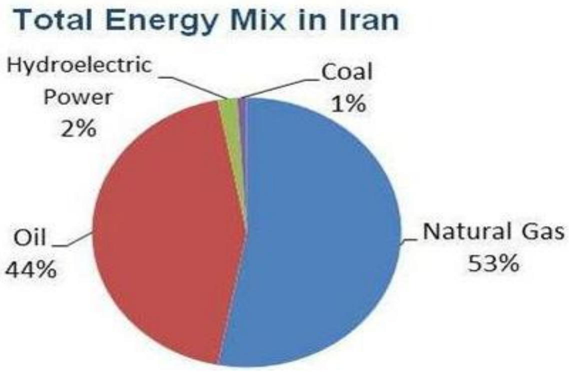


Figure 2- Energy production in 2015 (www.sana.ir)

2. Methodology

Modeling approach

The importance of a mathematical model predicting producer gas composition, from biomass gasification, using elemental analysis of biomass was stated. Among the existing models, equilibrium models were selected because they are simple, rigorous and a useful tool for preliminary calculations.

The gasifier is considered as a continuous flowing and reacting system intended for steady-state operation at constant pressure (atmospheric pressure). The reactor is seen as zero-dimensional, which means that no spatial distribution of parameters is considered, nor is there any change effected with time because all forward and reverse reactions have reached chemical equilibrium. Figure 3 shows all feed and product streams and the different units considered in the pure thermodynamic equilibrium model. Steam generation and air preheating units are optional. Steam generation unites only used if steam is added to the gasifier.

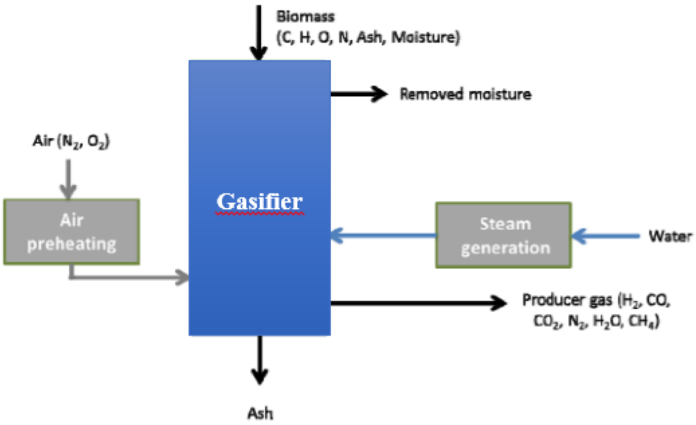


Figure 3- Feed and product streams entering and leaving the gasifier for equilibrium model

For the equilibrium model of this section, the assumptions made by other authors when developing equilibrium models are also applicable:

All carbon content in biomass is converted into gaseous form and reaction temperature and residence time for reactants are sufficiently high to reach chemical equilibrium.

- Ash and nitrogen (from fuel and air) are inert and are not involved in any of the reactions.
- The ideal gas law is applicable.
- The reaction is auto-thermal and no external source of heat is applied.
- The process is completely adiabatic so no heat losses occur from the gasifier.
- The amount of tar in producer gas is assumed to be negligible.
- The pressure in the char bed is atmospheric and constant.
- No radial temperature gradients/concentrations exist.
- No gas is accumulated in the char bed.
- There is no resistance to conduction of heat and diffusion of mass inside the char particles.

- No oxygen is present in the producer gas.
- Producer gas comprises only CO2, CO, H2, CH4, N2 and H2O.

The formula considered to describe the biomass composition in the present model is CHxOyNz. Different correlations from the literature are available for calculating the higher heating value of biomass (HHVb). Because the formulae based on the ultimate analysis are generally more accurate, the HHV in the present model is calculated using the correlation proposed by Channiwala and Parikh (2002):

$$HHV_b\ (MJ/kg) = 0.3491\cdot C + 1.1783\cdot H + 0.1005\cdot S - 0.1034\cdot O - 0.0151\cdot N - 0.0211\cdot Ash \quad (1)$$

The standard enthalpy of formation of biomass is computed using the stoichiometric combustion equation as:

$$h_{f\,b} = LHV_b + 1.h_{f.co2} + \frac{x}{2}.h_{f.\,H2o.g} + \frac{z}{2}.h_{f\,N2} - \{\,1 + r + \frac{x}{4} - \frac{y}{2}\}.\,h_{f.o2} \quad (2)$$

where $hf_{,co2}$, $h_{f,h2o,g}$, $h_{f,n2}$,$h_{f,o2}$ are the enthalpies of formation of combustion products and O_2 under complete combustion of the solid fuel.

The specific enthalpies for different substances have the same reference point (59F) and are calculated. Air is assumed to be dry air and consists of 21% O2 and 79% N2 on volume basis. If enriched air is used as a gasification agent, then the oxygen percentage of the mixture is increased. The enthalpy of water and steam used in this model is the one provided by for “H2O”. If the water temperature is below 100ºC, and considering that the whole process takes place at atmospheric pressure, the water enthalpy is calculated using the one provided for “H2O” and adding the specific evaporation enthalpy (-2442 kJ/kg).

The specific enthalpy of biomass (hb) at a given temperature is computed by means of the following expression obtained from the correlation for the heat capacity of municipal solid waste:

$$H_b\ (kj/kg) = h_{f\,.b} + \frac{0.003867.(T^2 - 298^2)}{2} + 0.1031.\,(T-298) \quad (3)$$

Ash specific enthalpy is assumed to be zero.

The specific enthalpy of producer gas leaving the gasifier is calculated using the specific enthalpy of the individual gaseous components. The gasification efficiency is defined as the ratio of the usable heat content of the producer gas to the heat content of the feed biomass:

$$\eta_{CG}(\%) = \frac{LHV_g\,.m_g}{LHV_b\,.m_g} \;.\; 100 \quad (4)$$

The equivalence ratio (ER) is defined as the moles of oxygen actually supplied to the gasifier to that required for stoichiometric combustion:

$$ER = \frac{AF\ ratio_{measured}}{AF\ ratio_{measured}} \quad (5)$$

where AF ratio stands for the air to fuel ratio (Nm3 air/kg fuel).

The specific enthalpy of particles leaving the gasifier is calculated using the same expression for char because, in their experiments, Bentzen et al stated that the particles leaving the gasifier were mostly soot.

From now, not all carbon contained in biomass is converted into gas species, it is necessary to define the concept of carbon conversion efficiency (ɳC) as:

$$\eta_c(\%) = \frac{Total\ amount\ of\ carbon\ in\ the\ gas\ outlet\ stream}{Total\ amount\ of\ carbon\ in\ the\ biomass\ inlet\ stream}\ .10 \quad (6)$$

Tar specific enthalpy is calculated using a correlation obtained by applying Jobaks method. The procedure followed to obtain.

$$h_{tar} = -4.659.\,10^{-7}\ .\ (T-273.15\,)^3 + 0.00193.\ (T-273.15)^2 + 0.131.\ (T-273.15) - 176.4 \quad (7)$$

where T is temperature expressed in K.

Table 1- Analysis of (chemical) wastes in Tehran (source: Statistical Journal (Summer 82), Quarterly Statistical solid waste management in Tehran)

Ultimate analysis	(wt% dry basis)
C	48.72
H	6.86
O	41.07
N	2.87
S	0.48

3. Results

The analysis of the produced fuel can be seen in Table 1. As can be seen, the fuel is solid. According to this table, the low heating value of biogas fuel at 77 ^{0}F equals 11806btu/lb. This indicates the high energy content of this fuel.

Table 2- Analysis of the reactor feed (Fuel summary)

Fuel phase	Solid
LHV (77 ℉)BTU/lb	11806
HHV (77 ℉) BTU/lb	12450
Fuel Supply Temperature(℉)	77
Total LHV+ Sensible Haet (BTU/lb)	11806
Total fuel enthalpy (BTU/lb)	12480

Tables 3 show feed material and reactor characteristics used in the simulation Considering the bed pressure and temperature respectively 390Psia and 2120F.

Table 3- Experimental setup parameters used in the simulation

Gasifier Temperature (˚F)	1652-1832
Gasifier pressure (psia)	390
air separation unit pressure (psia)	390
air separation unit temperature (˚F)	438.1
Air mass flow rate (lb/s)	12.26-20.47
steam mass flow rate (lb/s)	9.809-15.35
slag temperature (˚F)	212

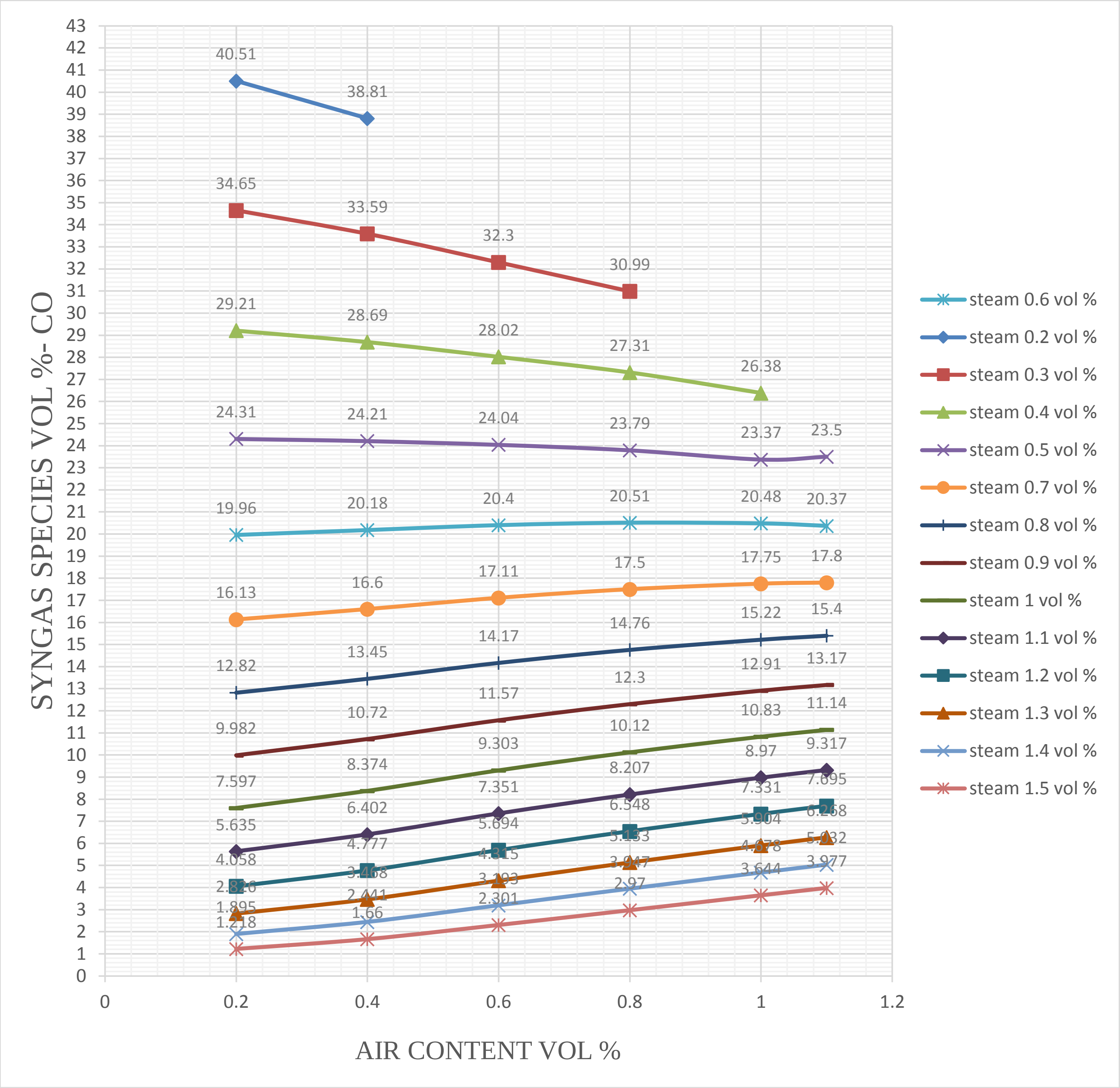


Figure 4- Effect of steam and air on carbon monoxide

As can be seen from Fig. 4, carbon monoxide is inversely related to the inlet air to the bed, with the increase in inlet air decreasing the production of monoxide except steam mass equal 0.2. With the increase of steam, the production of monoxide increased and decreased after steam of 1.5. The lowest carbon monoxide is in the vapor of 1.5 and in the air of 1.1 with a value of 1/218% and the highest carbon monoxide is in the vapor of 0.2 and in the air of 0.25 with a value of 40/51%.

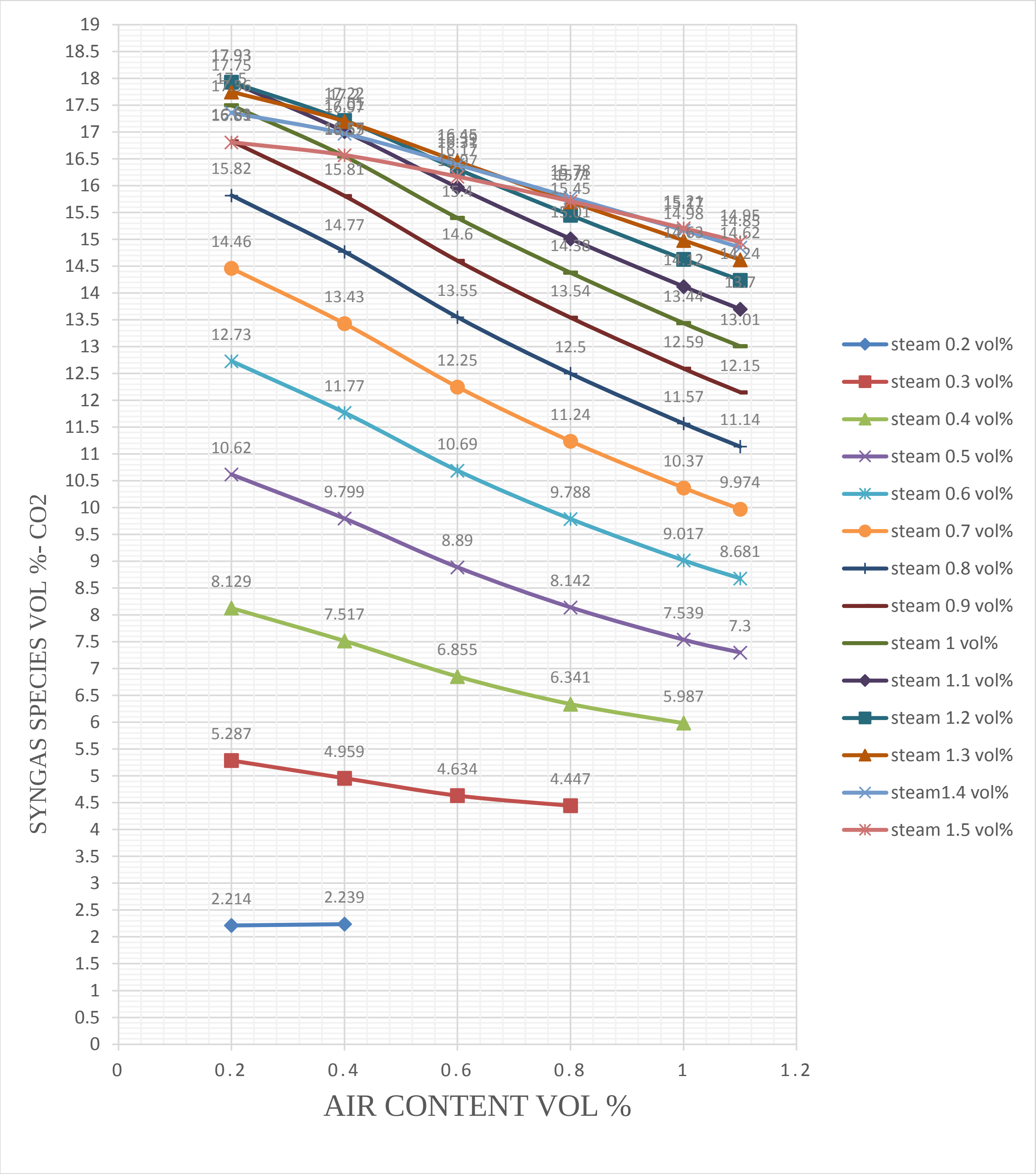


Figure 5- Effect of steam and air on carbon dioxide

As can be seen from Fig. 5, carbon dioxide is direct relationship to the inlet air to the bed, with the increase in inlet air increasing the production of dioxide. The lowest carbon dioxide is in the vapor of 0.2 and in the air of 0.25 with a value of 2/214% and the highest carbon dioxide is in the vapor of 1.2 and in the air of 0.25 with a value of 17/93%.

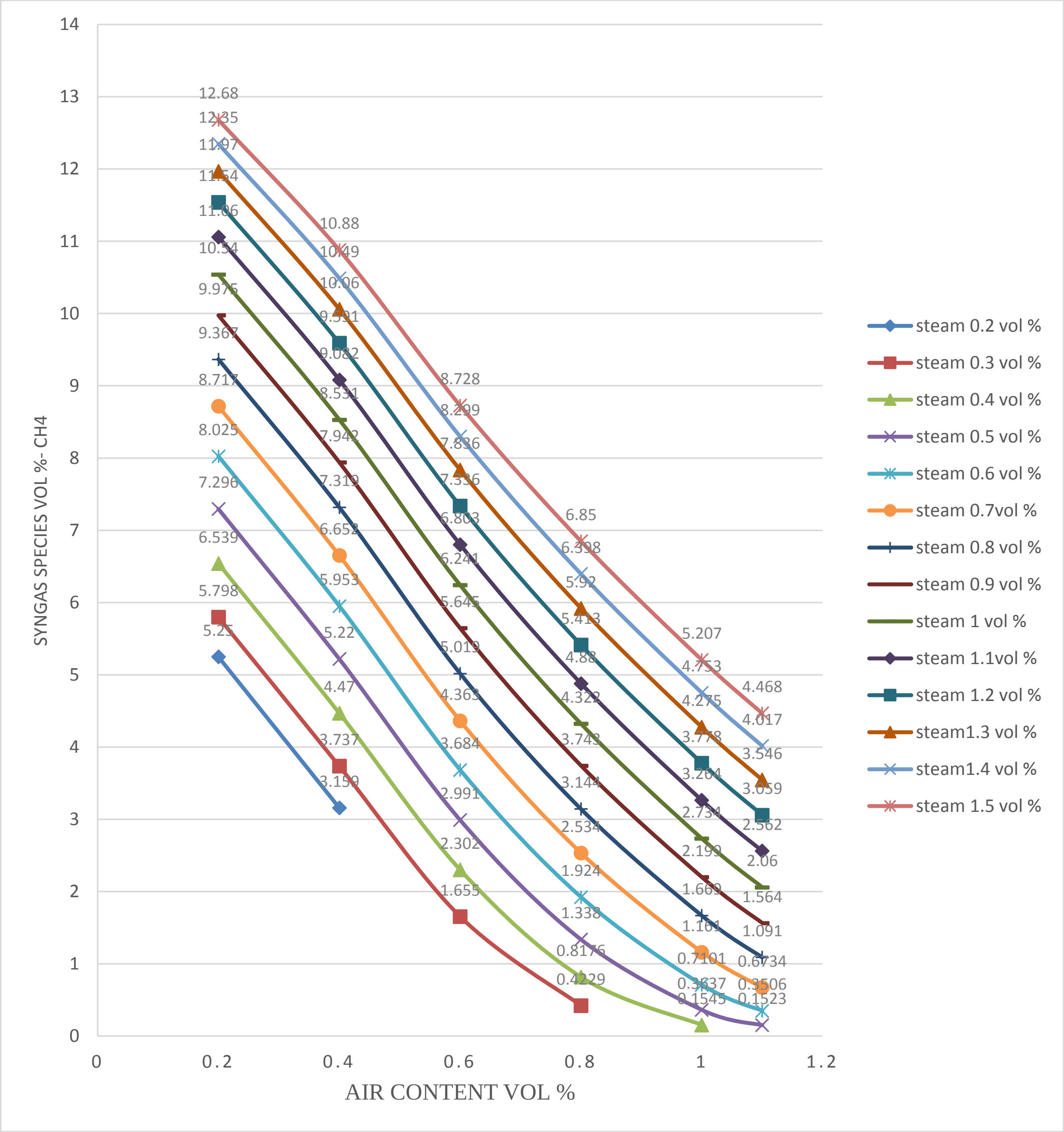


Figure 6- Effect of temperature on methane

The volumetric percentage of methane gas is the most important factor in the thermal value of gas. As can be seen from Fig. 6, methane is inversely related to the inlet air to the bed, with the increase in inlet air increasing the production of methane. The lowest methane is in the vapor of 0.2 and in the air of 0.4 with a value of 3/159% and the highest methane is in the vapor of 1.5 and in the air of 0.25 with a value of 12/68%.

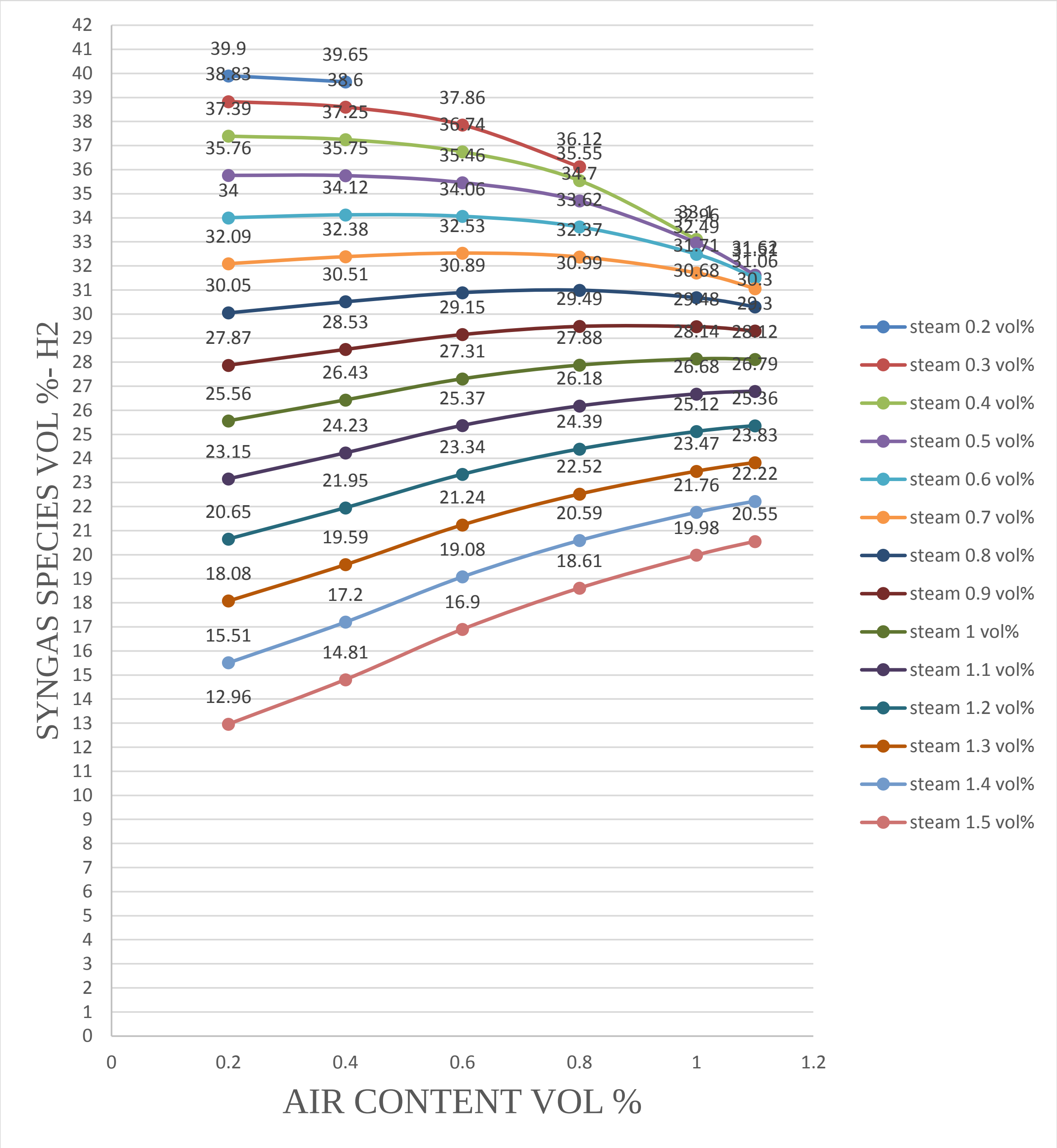


Figure 7- Effect of steam and air on hydrogen

The volumetric percentage of hydrogen gas is the most important factor in the thermal value of gas. As can be seen from Fig. 7, hydrogen is direct related to the inlet air to the bed, with the increase in inlet air increasing the production of hydrogen. The lowest hydrogen is in the vapor of 1.5 and in the air of 0.25 with a value of 12/96% and the highest hydrogen is in the vapor of 0.2 and in the air of 0.25 with a value of 39/9%.

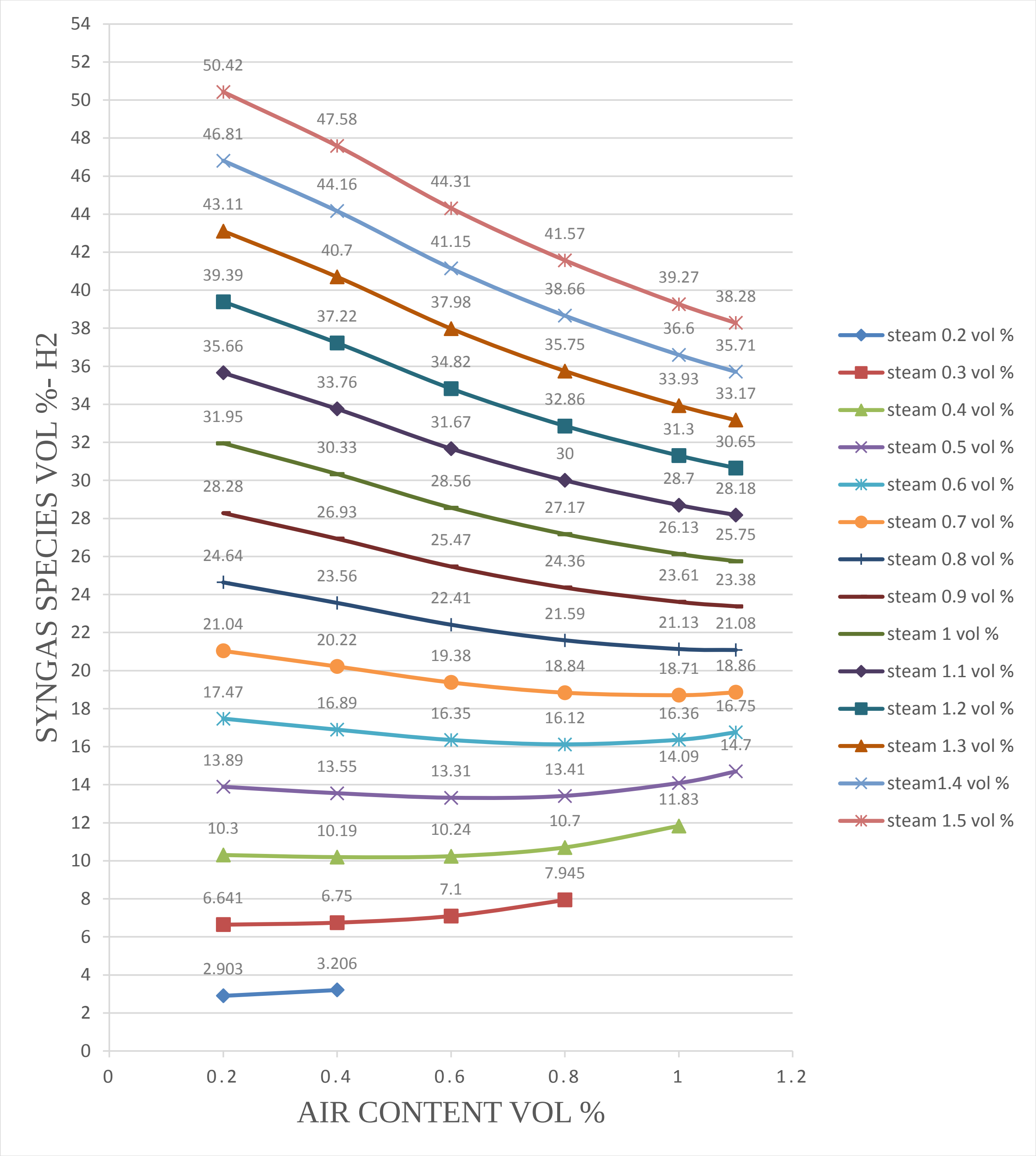


Figure 8- Effect of steam and air on water

Water is one of the harmful factors in the system that causes corrosion. As can be seen from Fig. 8, water is direct related to the inlet air to the bed, with the increase in inlet air increasing the production of water. The lowest water is in the vapor of 0.2 and in the air of 0.25 with a value of 2/903% and the highest water is in the vapor of 1.5 and in the air of 0.25 with a value of 51/42%.

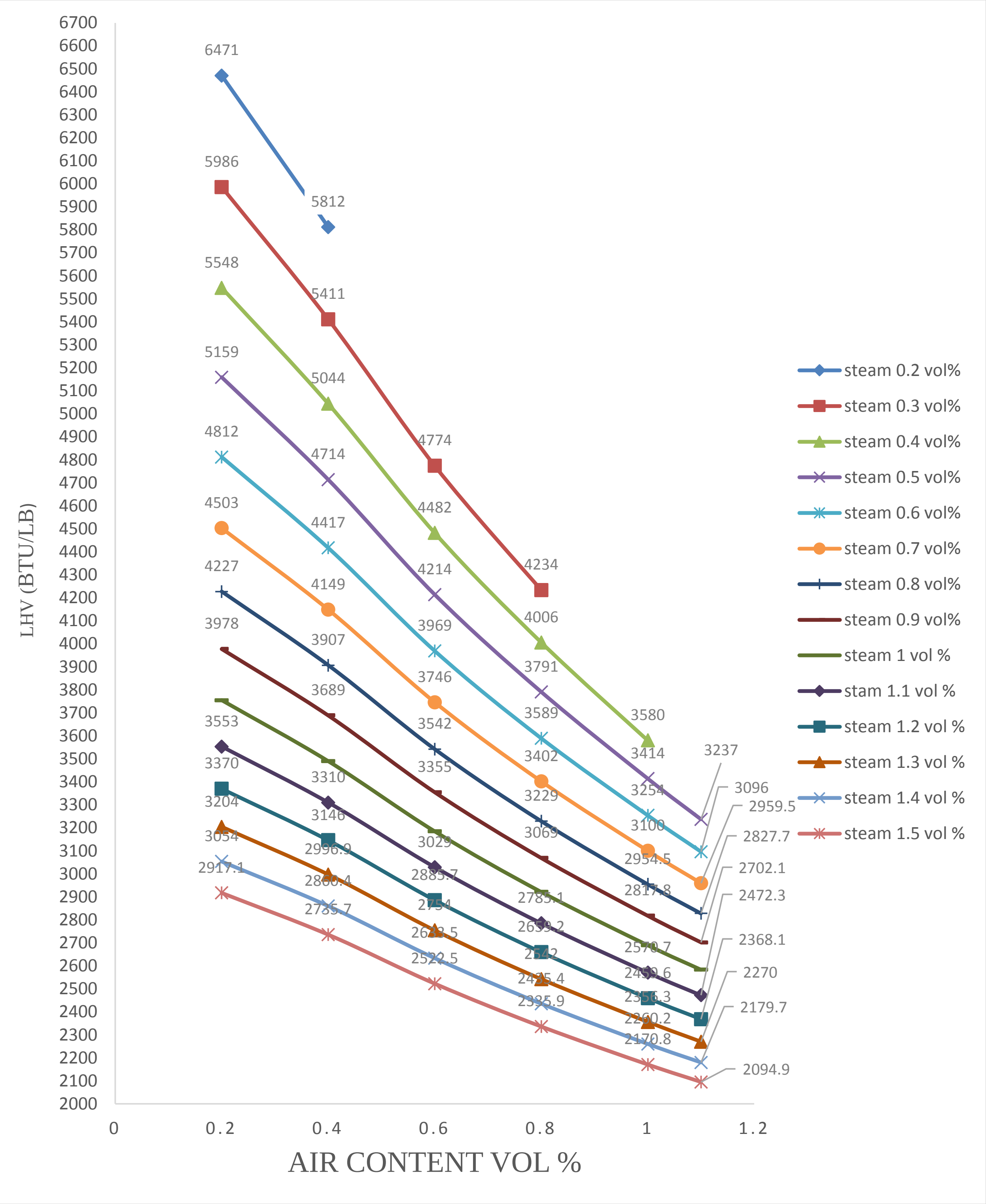


Figure 9- Effect of steam and air on LHV.

As can be seen from Fig. 9, LHV (Lower Heating Value) is indirect related to the inlet air to the bed, the lowest LHV is in the vapor of 1.5 and in the air of 1.1 with a value of 2094/9btu/lb and the highest LHV is in the vapor of 0.2 and in the air of 0.25 with a value of 6471btu/lb.

4. Discussion

A solution to the waste problems confronted by municipalities no doubt requires a strategy that integrates several technologies including, waste reduction, recycling, landfilling and waste-to-energy. According to the chemical composition of MSW, a maximum of 40% are paper, plastics, metal and glass suitable for recycling (Life After Fresh Kills, 2001). The remaining quantity that is not recyclable has a heating value roughly half that of coal. Yet most of this essentially renewable, negatively priced energy feedstock is transported to landfills, despite several studies that have shown conclusively that landfilling is the most environmentally degrading means to treat waste. Waste-to-energy, which converts the non-recyclable and combustible portion of the waste to electricity, reduces the amount of materials sent to landfills, prevents air/water contamination, improves recycling rates and lessens the dependence on fossil fuels for power generation. The two most viable forms of waste-to-energy are combustion and gasification.

Converting Municipal Solid Waste (MSW) to energy has the environmental advantages of reducing the number of landfills, preventing water/air contamination, and lessening the dependence on oil and other fossil fuels for power generation. Gasification is a technology that can be cost competitive with combustion and offers the potential for superior environmental performance However, before it can be considered to be a clear-cut solution for waste disposal in large municipalities, its long-term reliability must be demonstrated.

The gasification process is a common process for energy extraction. These kinds of processes have vast range of applications in the industry.

Simplicity, implementation capability in different capacity, pollution reduction by Methane gas release prevention, possibility to implement in different areas that can be used as local energy production system, are some of its advantages.

According to the suitable resources that can be used as the Input of these systems in Iran, localization, improvement and implementing this equipment can supply some of the energy needs locally in the remote areas, creating job opportunities and reducing the usage of fossil fuels.

5. Conclusion

In this research, different compositions of air and steam as a reactor input have been examined and fixed base gasifier behavior in different situations have been specified which demonstrate that, best amount of air-steam composition with the most heat valuation is 12.26 (lb/s) for air input and 9.989 (lb/s) for steam input. The highest amount of LHV is about 6471 BTU/LB for steam=0.2%.

6. Acknowledgment

The authors would like to have many thanks to Dr. Alibakhsh Kasaeian, associate professor of Tehran University, for his precious advice, encouragements and helps.

for ethical approval of performing the project and monitoring its implementation process. This project approved in Islamic Azad University of Germi Branch, so it is the authors duty thanks all of the staff of these institution.

7. Additional information and declarations

Funding

There was no funder for this study.

Grant Disclosures

There was no grant funder for this study.

Competing Interests

The authors declare there is no competing interests, regarding the publication of this manuscript.

Author Contributions

Reza Alayi: purposed the plan, analyzed the data, and tables, authored or revised drafts of the paper, and approved the final draft.

Ehsan Sobhani: conceived and designed the experiments, analyzed the data, contributed reagents /materials/analysis tools, prepared figures, and tables.

Atabak Najafi: conceived and designed the experiments contributed reagents /materials/analysis tools, prepared figures, prepared figures, and tables.

Data Availability

All the data are shown in the tables of this article.

Ethics Statement

The present study is the result of collecting and analyzing the results of collaborative work among the authors of this article and has not been published elsewhere.

Supplemental Information

There is no supplementary information on this paper. Any questions and request for more information should be addressed on correspondence author.

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