International Journal of Agricultural Management and Development
Available online on: www.ijamad.iaurasht.ac.ir
ISSN: 2159-5852 (Print)
ISSN:2159-5860 (Online)
Research Paper

Theoretical and Experimental Study of Potato Shoot Gasification in Fluidized and Fixed-Bed Gasifier

Mojtaba Javidi Gharacheh[a], Mehdi Khojastehpour[a], Mohammadali Ebrahimi-Nik[a], Wan Azlina Wan Ab Karim Ghani[b]*

Received: 04 August 2017,
Accepted: 28 August 2018

Abstract

A bench-scale updraft gasifier was used as a fluidized- and fixed-bed gasification unit in three modes (fluidized-bed at equivalence ratios (ER) =0.2 and 0.25, and a mode in fixed-bed). The experiments were done in five different temperatures (650, 700, 750, 800 and 850^{o}C). To obtain the required data to develop a thermodynamic equilibrium model, the proximate and ultimate analysis were carried out on potato shoot as feedstock. Since the developed model is a temperature-based model, it gives different outcomes in different temperatures. The model gave a completely exact result to predict CH_4 in fluidized-bed at ER=0.25. The average error for the difference between each produced gas in experiments and the model showed the best result of the model for CO with the error of just 0.7%. Regarding each experiment data difference with the model data, the model was more accurate to be used in fluidized-bed, especially at ER=0.25 than the other two modes. Moreover, the best performance of the model was obtained for CO, N_2 and CO_2, according to the average errors. Since the maximum amount of high heating value (HHV) and carbon conversion efficiency (CCE) was observed at higher temperatures, it can be contended that the model has better performance at higher temperatures.

Keywords:
fixed-bed gasifier;
fluidized-bed gasifier;
modeling; updraft

[a] *Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran*
[b] *Department of Chemical and Environmental Engineering, University Putra Malaysia, Malaysia*
** Corresponding author's email: mkhpour@um.ac.ir*

INTRODUCTION

From global requirements for new sources of energy, biomass is gaining growing attention, and it is the most applied renewable source of energy now in the whole world (Kirkils & Verbong, 2011). In most industries such as agriculture, generating and consumption of energy is of great importance (Ghatrehsamani et al., 2016). Forestry and agricultural residues, human, animal as well as industrial wastes are considered as important sources of biomass. Agricultural wastes are considered as fundamental problems after harvesting the main product. Among these residues, the ones which cannot be restored to the soil are more bothersome. From another point of view, these materials could be considered as a source of energy not a waste (Masmoudi et al., 2014). In order to achieve environmental and economic benefits from this source of energy, efficient and clean ways of using them are of great importance. Although fossil fuels have several applicants in human's current life, environmentally friendly ways to extract energy from biomass could be a great substitute (Vaezi et al., 2011).

Potato is a really compatible plant that is produced in more than 140 countries. The Food and Agriculture Organization of the United Nations (FAO) reported that the world production of potatoes in 2014 was about 385 million tons (Faostat, 2016). China, India, and Russia are the greatest potato producers in the world (FAO, 2011). However, potato planting is common in Iran (Khajehpour, 1999). From about 1.19 million hectares of potato in more than 140 countries of the world, 330 million tons of potatoes would be harvested and after wheat, rice and corn, potato is in the fourth rank in the world (World Potato Atlas, 2015). Despite the fact that it is one of the major agricultural products in all over the world, all potato's stems and leaves (shoots) are considered as wastes because of a toxic content named solanine. Owing to this content, the huge amount of potato shoot cannot be consumed for animal nutrition and it cannot be restored to soil so it could be used as fertilizer. Accordingly, they are thrown away each year, and farmers remove them from their farm (Mweetwaa, 2012). Despite the large amount of fields which are under the potato planting (around 1.19 million hectares), the huge amount of side products of these fields which are the shoots of potatoes are considered to be useless and waste (Dokhani, 2003). Potato shoot can be a promising source of fuel energy. Using these plant tissues to produce energy will help preserve a lot of energy.

Different technologies have been offered to make biomass energy applicable such as composting, burning in waste incineration and energy recovery, pyrolysis, gasification (conversion to gas), biogas production, recycling and reuse of solid wastes (Arnavat, 2011). From among them, thermochemical conversions received great interest due to various kinds of energy that could be offered in this way, such as electricity, liquid, and gaseous fuels. One method to produce fuels which is gaining growing attention these years is gasification (Banapurmath & Tewari, 2009). The produced gas from gasification can be used in several ways like as a fuel for gas engines, gas turbines, and in solid oxide fuel cells (Aloui & Halouani, 2007). As Xiao et al. (2007) mentioned that biomass gasification process can be divided into three main steps: initial pyrolysis, tar- cracking, and char gasification. Air gasification has been done on different kinds of feedstocks like wood sawdust (Cao et al., 2006), pine wood block (Pengmei et al., 2007), hazelnut shell (Midilli et al., 2001) and rice husk (Ghani et al., 2012). The residues of agricultural crops such as wheat, barley, rye, oat, maize, rice, canola and sun flower are considered as high potential bioenergy feedstock (Monforti et al., 2013). The results of study on them showed that the estimated crop residue resources in EU-27 could provide fuel for about 850 plants expected to produce about 1500 PJ/yr (Monforti et al., 2013).

Gasifiers are classified into two main categories according to reactor design: fluidized-bed and fixed-bed (Thunman & Leckner,

2005). Fluidized-bed gasifiers are mostly used for large scale gasification. In this case, as the name implies, the biomass is fluidized in a bed material like sand (Giltrap et al., 2003). On the other hand, fixed-bed gasifiers are simple and usually used for small scale gasification (Babu & Sheth, 2006). Since fluidized-bed gasifiers mainly come with high particle heating rate and uniform product quality, they are considered as potentially efficient gasifiers (Xue et al., 2011).

In order to optimize the biomass gasifier design and performance modeling can be beneficial. Moreover, modeling would be profitable in financial point of view (Ahmed et al., 2012). By far in different studies various models have been proposed as shown in Table 1.

The equilibrium models are based on thermodynamic parameters as well as the chemical equilibrium of the process. Usually the results of the gas composition from the model are not exactly the same with the results of experimental producer gas. The most important components of the syngas are Nitrogen (N_2), Hydrogen (H_2), Carbon monoxide (CO), Carbon dioxide (CO_2) and methane (CH4) (Giltrap et al., 2003). The thermodynamic equilibrium model is a tested method to simulate fuel production and can be helpful to manage the effective factors in gasifier performance. Prediction of the syngas by a validated model can reduce the cost and time that any researcher would spend to know by experiment. The objective of this research is to develop a validated model in order to predict the composition of syngas produced by a fluidized and fixed bed updraft gasifier which is influenced by the feedstock (potato shoot), temperature and the amount of air inlet. Another purpose of this study is to recognize the best performance of the model in different modes of the gasifier.

Table 1.
Summary of the Literature on the Gasification of Agricultural Wastes

Authors	Feedstock (Gasifier type)	Modeling	Main result
Di Blasi, 2000	(downdraft gasifier)	Unsteady numerical model	Most effective factors on the dynamic behavior of the reactor: -Quality of the producer gas -the structure of the reaction front
Xie et al., 2012	forestry residues (two-stage biomass gasifier and solid oxide fuel cell system)	A multi-physics model	Electrical efficiency of the system=25% fuel utilization efficiency=44%
Giltrap et al., 2003	(downdraft gasifier)	One dimensional model	The amount of CH_4 was overestimated
Zainal et al., 2001	Wood, paper, paddy husk and municipal waste (downdraft gasifier)	Equilibrium model	increase in moisture→ -nitrogen and methane were almost constant -hydrogen and carbon dioxide increased -carbon monoxide decreased
Roy et al., 2013	Blend of cow dung and wood (IC engine)	One dimensional model	- cow dung cannot be a suitable feedstock -its mixture with woody can be considered as an applicable feedstock
Plis and Wilk, 2011	Wood and oat husk pellets (fixed-bed gasifier)	Thermodynamic Equilibrium model	-the produced gas was completely different - oat husk is not capable to produce enough high calorific value syngases
Yan et al., 2018	Biomass/coal char blends	Kinetic modeling	biomass blending ratio affects: - the particle structure - composition
Jiang et al., 2017	Coal	A modeling tool to explore the theory of reverse combustion	hot linkage and abundance of char in place after reverse combustion linking are of benefit to underground coal gasification
Mozafari et al., 2017	Waste tire	Thermodynamic framework	maximum hydrogen efficiency: pyrolysis→35.45% gasification→98.03%
Current Study	Potato shoot	Thermodynamic Equilibrium model	-

METHODOLOGY

The implementation phase

In order to investigate the performance of a bench-scale gasifier, experiments were done on the gasifier in two different modes (fixed and fluidized bed), and a thermodynamic equilibrium model was developed. It has to be known in which mode the model would be able to predict closer results to experimental data. To use the gasifier as fluidized-bed dried sand with two different ERs (0.2 and 0.25), and to obtain fixed-bed dried sand with the ER equal to 0.2 was employed. Potato shoot is a toxic agricultural waste which cannot be restored to the soil. This is the reason it is used as the feedstock of this study. The potato shoot samples were pelletized and fed into the updraft gasifier three times with the feeding rate of 0.116 kg/hour. Feeding was done three times in order to obtain homogeneous gas. Gasification was done in five different temperatures from 650^{oC} to 850^{oC} with 50^{oC} interval. Figure 1 shows a complete view of the updraft gasifier which is mounted in University Putra Malaysia. The reactor in the Figure 1 was made of stainless steel with 850mm height. Its internal diameter was 50mm. potato shoot cubes were feed from the right side of the reactor and the hot produced gas came out through the left side. The produced gas losses heat in two steps, firstly gas goes through a condenser covered by cold water and secondly goes through a three-neck bottle which was sank in ice-water. After reducing the heat, the gas goes through a piece of cotton, on which the tar was collected. The gas was led into silica gel cubes to reduce its moisture content. The syngas also collected three times and analyzed to search the gas components. The reactor was equipped with thermocouples and temperature indicator controller. The reactor was directly heated by an electrical furnace.

Figure 1. A complete preview of the gasifier reactor and other parts (a) feedstock inlet, (b) syngas outlet, (c) condenser, (d) reactor, (e) air inlet, (f) silica gel, (g) tar collection cotton, (h) ice-water

Developing the model

To develop the model, some inputs are required such as chemical formula and moisture content of sample, air inlet to the gasifier and gasification temperature. Proximate and ultimate analysis on the sample is needed in order to reach the inputs. The results of proximate and ultimate analysis can be seen in Table 2.

According to the results of ultimate analysis shown in Table 2, percentage of carbon in chemical formula of potato shoot is 42.2%. Mass number of carbon is 12, so:

$$C: 42.2/12=3.52 \quad (1)$$

Table 2
Proximate and Ultimate Analysis of Potato Shoot

Proximate analysis	**(%)**
Volatile matter	62.7
Fixed carbon	16.3
Ash	15.8
Moisture	5.25
Ultimate analysis	
Hydrogen	5.97
Carbon	41.65
Oxygen	48.88
Nitrogen	3.4
Sulfur	0.1

Mass numbers of hydrogen, oxygen, nitrogen and sulfur are 1, 16, 14 and 128, respectively. Due to the percentage portion of each element obtained from the ultimate analysis:

$$H \quad 6.148/1=6.148 \quad (2)$$
$$O \quad 46.74/16=2.92 \quad (3)$$
$$N \quad 3.611/14=0.26 \quad (4)$$
$$S \quad 1.29/128=0.01 \quad (5)$$

Based on a single atom of carbon, the portion of each element in chemical formula is calculated from the equations 6-9:

$$H \quad 6.148/3.52=1.747 \quad (6)$$
$$O \quad 2.92/3.52=0.83 \quad (7)$$
$$N \quad 0.26/3.52=0.074 \quad (8)$$
$$S \quad 0.01/3.52=0.003 \ (negligible) \quad (9)$$

Hence, the chemical formula of potato shoot would be $CH_{1.747}\ O_{0.83}\ N_{0.074}$. Air inlet supplied by air compressor and its amount calculated by a rotameter. Gasification temperature is calculated by a thermometer hanging from the top of the gasifier into the reduction zone. After preparing all inputs, global gasification reaction is utilized to develop the model.

$$CH_xO_y N_z + m_w H_2 O + X_g(O_2+3.76N_2) \rightarrow X_1CO + X_2 H_2 + X_3 CO_2 + X_4 H_2 O + X_5 CH_4 + (z/2+X_g\ 3.76) N_2 \quad (10)$$

Five Xis in the right side of the reaction are unknowns which have to be calculated to compare with the amount of gas components from experimental data in both fluidized and fixed bed. In the global gasification, $CH_xO_yN_z$, mw and X_g are chemical formula of typical woody material, amount of moisture content and oxygen in each kilo mole of feedstock, respectively. $CH_xO_yN_z$ for potato shoot was obtained $CH_{1.747}\ O_{0.83}\ N_{0.074}$. By thermal gravimetric analysis (TGA), the amount of moisture content (MC) in the sample can be obtained, therefore referring to the below formula mw was calculated 1.65 (Zainal et al., 2001).

$$m_w = 24MC/18(1-MC) \quad (11)$$

Regarding CHN analysis of the sample, X_g also can be calculated as below:

$$X_g = mass\ of\ the\ material \times \frac{1mol}{molecular\ weight\ of\ the\ material} \times \frac{\%O\ in\ the\ material}{1\ mol\ material} \times \frac{molecular\ weight\ of\ O}{1\ mol\ O} \quad (12)$$

where, mass of the material as weighed in the analytical lab of UPM was 0.23g. Molecular weight of the sample would be:

$$12+1\times1.747+16\times0.83+14\times0.074= 28.063$$

And, %O from ultimate was %46.74. By substituting these amounts in equation 12, X_g becomes 0.06. To calculate the five un-

knowns, five equations are required. Three mass balance equations for C, H and O in the global gasification equation, and two equilibrium constant equations (K_1 and K_2) were considered to solve gasification equation. Five mentioned equations are as below:

Cbalance: $X_1+X_3+X_5=1$ (13)

H balance: $2X_2+2X_4+4X_5=1.747+2\times1.65$ (14)

O balance: $X_1+2X_3+X_4=0.83+1.65+2\times0.06$ (15)

$$K_1 = \frac{n_{CH_4}}{(n_{H_2})^2} = \frac{X_5}{{X_2}^2} \quad (16)$$

$$K_2 = \frac{n_{CO_2} n_{H_2}}{n_{CO} n_{H_2O}} = \frac{X_3 X_2}{X_1 X_4} \quad (17)$$

where, K_1 and K_2 are obtained from equilibrium constants of methane formation and shift reaction:

methane formation: $C+2H_2 \leftrightarrow CH_4$ (18)

shift reaction: $CO+H_2O \leftrightarrow CO_2+H_2$ (19)

K1 and K2 can be obtained by the following equations (Zainal et al., 2001):

$$lnK_1 = \frac{7082.848}{T} + (-6.567)\, lnT + \frac{7.466\times10^{-3}}{2}T + \frac{-2.164\times10^{-6}}{6}T^2 + \frac{0.701\times10^{-5}}{2T^2} + 32.541 \quad (20)$$

$$lnK_2 = \frac{5870.53}{T} + 1.86\, lnT + 2.7\times10^{-4}T + \frac{58200}{T^2} + 18.007 \quad (21)$$

where, T is gasification temperature. By entering all equations in MATLAB and try to solve them together, just temperature would be unknown which can be inserted as an input for each temperature in MATLAB software. Now a MATLAB code is ready to solve equations and find five unknowns due to each temperature, while in previous models just one constant temperature as a sample inserted to the equations and the set of equations solved by Newton-Raphson method (Zainal et al., 2001). When user inserts the temperature as the input, the software would solve the equations and give different answers in which non-imaginary and positive answers are acceptable. The temperature measured via a thermocouple hanging through the reactor from the head of the reactor to the reduction zone. After receiving the results for unknowns from MATLAB and substituting them into the gasification global reaction the model was developed.

Validating the model

The results of experiments on the percentage of syngas components were obtained from the analytical lab at UPM. The amount of high calorific value gases and effective in the model are collected and other components such as O_2, C_2H_2 and etc. neglected, since they are not considered in the global gasification reaction. After finishing the experiments and developing the model, the experiments results were compared with the results of model in order to investigate the validity of the model. The results of experiments in each mode was compared with the model in related temperatures separately to know in which mode and temperature the model performs better than other conditions. The results of the model and experiments were compared in different ways to assure about the validity of the model which are discussed completely in next section.

RESULTS AND DISCUSSION

Evaluation of model performance

Figure 2 compares each gas portion in produced gas in the experimental results in different modes with predicted results of model at 650^{oC}. For H_2 model over predicted in comparison with other modes. Although, in this case the model's error for the three modes was not negligible, in fixed bed gasifier it was more than the others. The amount of N_2 in the produced gas in all modes and in the model was more than all other components. Comparing the results of all experimental data with the model showed that the amount of this component was more than what model predicted. The results of the model to predict the amount of CO and CH_4 were more than experiments in all cases. The best model per-

formance in this case was for fluidized-bed at ER=0.2 with the error of 7%. ER can affect the gasification process. Increasing ER increases the air into the reactor which leads to rise in gasification temperature, so it can accelerate the gasification process (Lv et al., 2004).

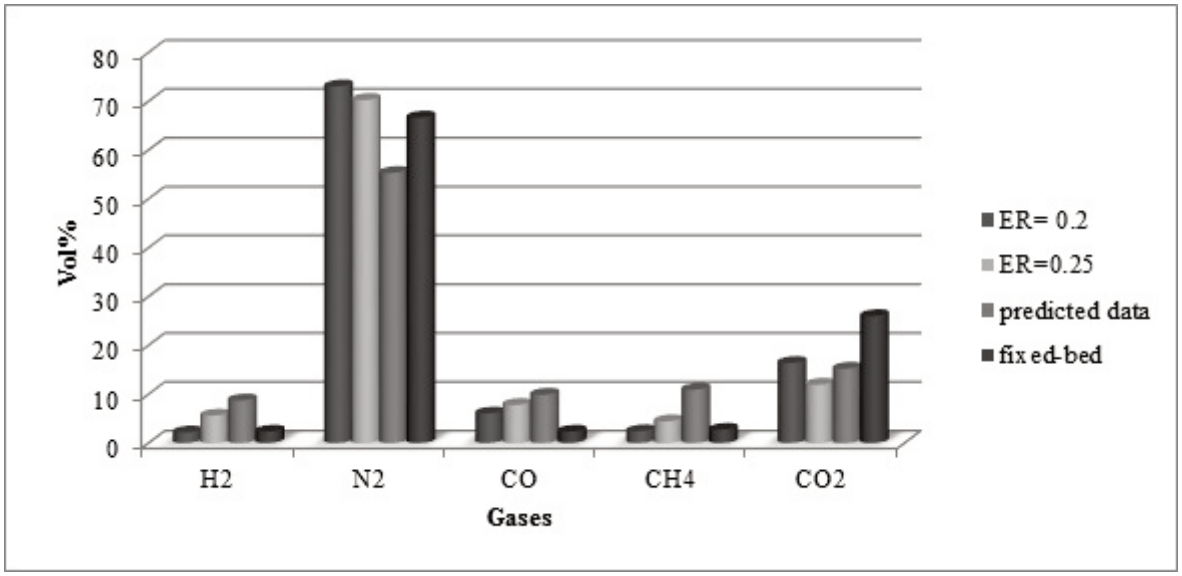

Figure 2. Comparison of experimental data in different modes with predicted data at 650^{oC}

Figure 3 demonstrates the differences between experimental and model results for different modes of at 700^{oC}. The model overestimated the amount of all gas components except for N_2 for all modes. The most exact results for H_2 and CO from model were for fluidized-bed at ER=0.2. The least error for fluidized-bed under this circumstance was for N_2 and CO_2 but in fixed-bed the model was more trustful to predict CH4 than other syngases in contrary with the results of Simone et al. (2013).

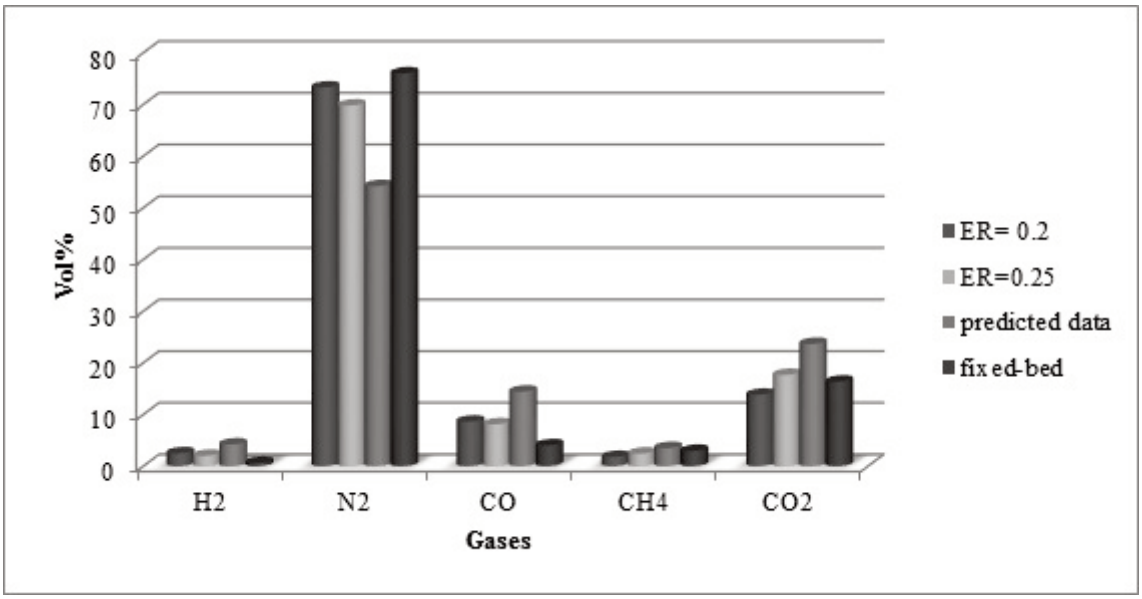

Figure 3. Comparison of experimental data in different modes with predicted data at 700^{oC}

For fluidized-bed at ER=0.25 and 750^{oC}, the model gives more accurate results for CO, CO_2 and N_2, with the errors of just 6%, 12% and 17%, respectively. The most reliable results for CO were obtained from the model at ER=0.2 and fixed-bed for 750^{oC}.To predict CO under this condition for ER=0.2 small amount of underestimation and for fixed-bed a little overestimation was observed with the error of 7%. As shown in Figure 4, the model over predicts the amount of CH_4 in comparison with other modes. In this case the model's result was closer to fixed-bed result.

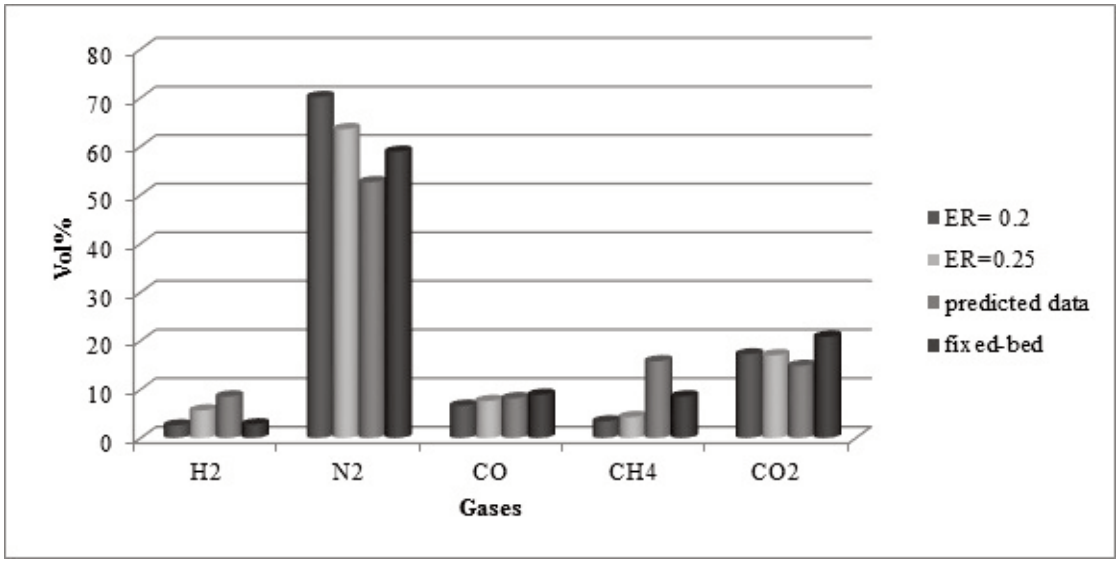

Figure 4. Comparison of experimental data in different modes with predicted data at 750^{oC}

The comparison between experimental and model results at 800oC can be seen in Figure 5. The model estimates the amount of H_2 more than actual ones in all modes, anyway, the results of fluidized-bed at ER=0.25 in comparison with the other two modes were closer to the model. In contrary with H_2 and CO, the predicted amounts of N_2 and CO_2 were low in comparison with experimental results. For N_2 and CO_2 the model predicts closer results to experiment in fixed-bed with errors of 6 and 11%, respectively. To predict CH4, the model gave the most accurate results for fluidized-bed at ER=0.2 in which the error was 15%.

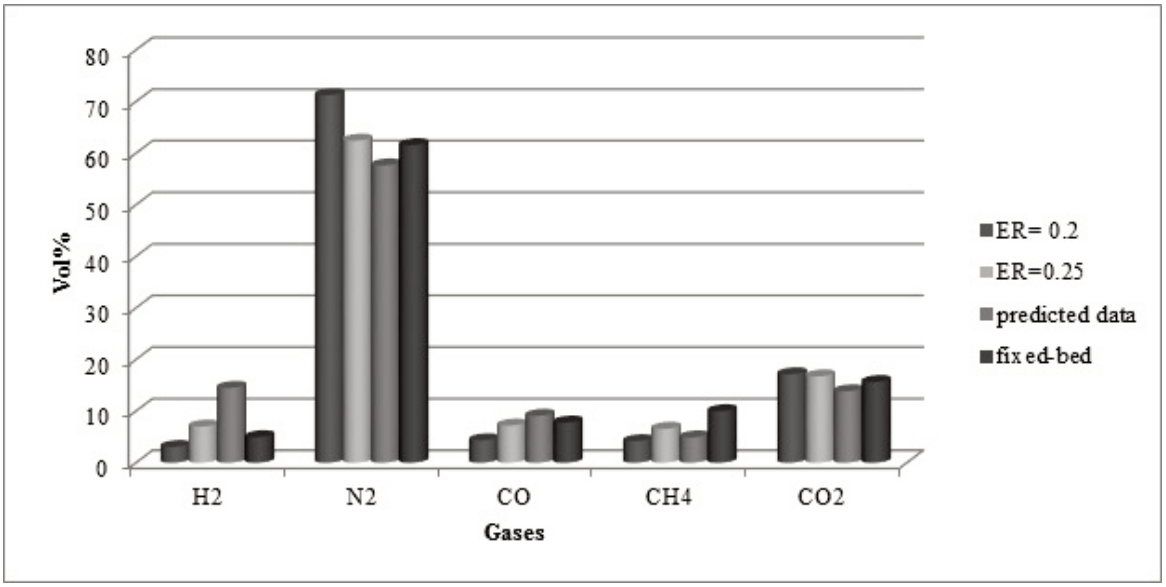

Figure 5. Comparison of experimental data in different modes with predicted data at 800^{oC}

Unlike for CO_2, the model predicts the amount of H_2 more than all experimental modes at 850°C. Comparing all related results of experiments, the closest result to predicted data at 850°C was for fluidized-bed at ER= 0.25 with the error of 15%. As shown in figure 6 the model doesn't seem valid enough to predict H_2 in fixed-bed because of high amount of error. Totally at 850°C, the model's results were close enough to experimental results to be considered as a valid model for this situation except for CO_2. As Xie et al. (2012) implied the amount of CO_2 increases by increasing ER. This result is in compliance with the result of the current study (Xie et al., 2012). The least error for fluidized-bed was at ER=0.25 with the error equal to 0 and for fixed-bed the error was 9%. When ER increased from 0.15 to 0.25 in the study done by Doranehgard et al. (2017), syngas and hydrogen yield had an increasing trend, rising from 2.1 to 2.45 Nm^3/kg biomass and 37–41 g/kg biomass respectively. In this case, the results of the mentioned research are in agreement with the results of the current study. In the second stage, ER ascended from 0.25 to 0.3, where the hydrogen yield decreased, it is not in compliance with the results obtained from gasification of potato shoot (Doranehgard et al., 2017). In contrast to the mentioned results in the current study, an increase in the ER decreased fuel gases and Lower Heating Value (LHV) in the research done by Monteiro et al. (Monteiro et al., 2017). In the study done by Sales et al. the ER was calculated using mass balance. They reported an optimum ER of less than 0.412, which confirmed the ERs used in the current study (Sales et al., 2017).

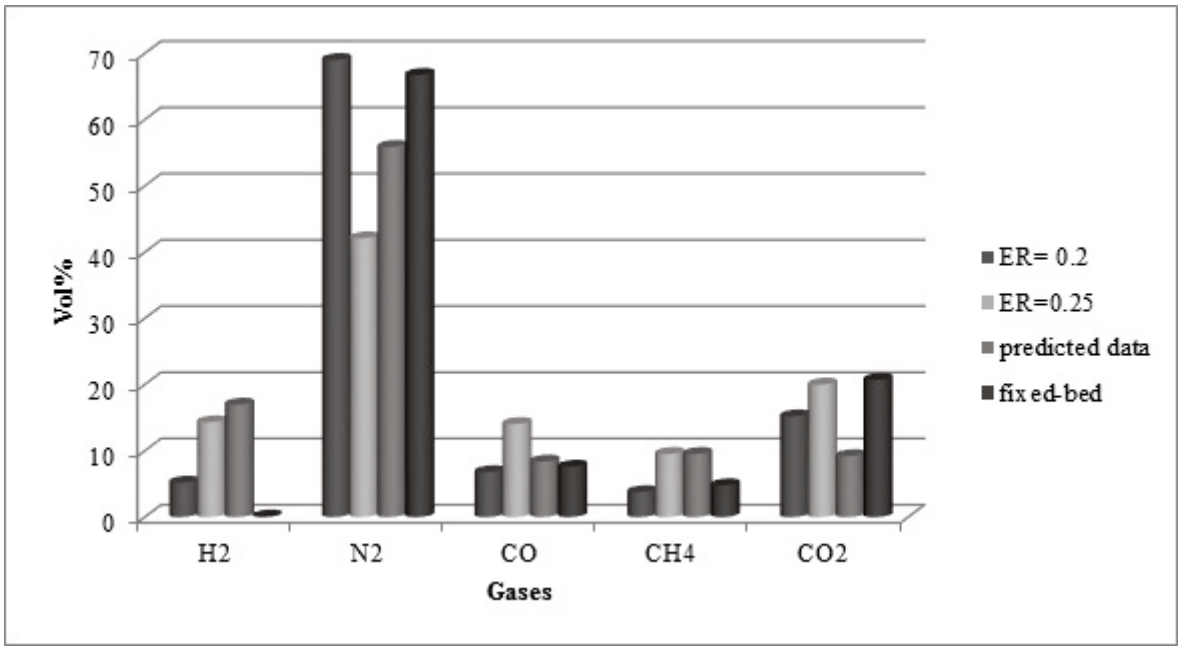

Figure 6. Comparison of experimental data in different modes with predicted data at 850°C

Figure 7 shows the differences between average experimental and model results in different modes and statistical point of view that LSD method was employed. For H_2, the results obtained from the model and experimental data at ER=0.25 were the same and there were no significant difference between them, unlike for ER=0.2 and fixed-bed. Similar to H_2, the difference between predicted and experimental results for N_2 at ER=0.25 was not significant and could be considered reliable. The difference between the predicted and experimental results at both ERs was negligible for CO and CO_2. Therefore, in statistic point of view, the model is valid to predict these product gases for all modes. According

to this analysis exactly like N_2, for CH_4 also the model results has no significant difference with experiment results at ER=0.25 and fixed-bed but different from experiment results at ER=0.2.

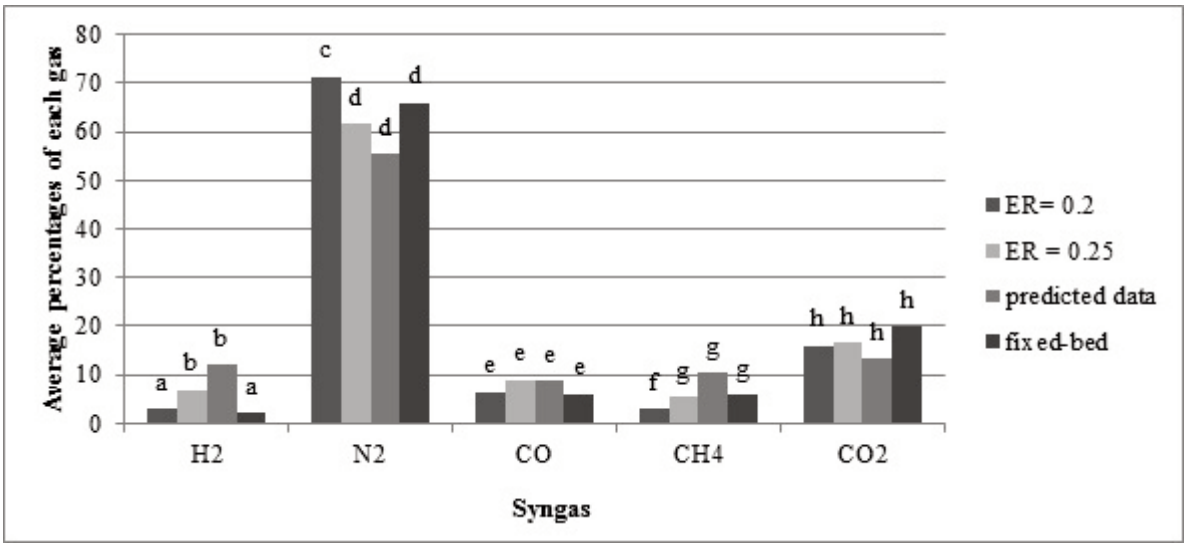

Figure 7. Comparing the average percentages of produced gases at different experimental modes with predicted data

As can be seen in all temperatures, similar to the results of Zainal et al. (2001) the amount of N_2 was more than all other gas components. Generally, the least error for fluidized-bed at ER= 0.2 and ER= 0.25, and fixed-bed was observed for CO_2 at 650^{oC}, CH4 at 850^{oC} and N_2 at 800^{oC}, respectively. The related errors were 7, 0 and 6%, respectively. Considering the average error for each mode, for fluidized bed at ER=0.2 the best results obtained for CO_2 with the average error of 16%, following by N_2 and CO with errors of somehow more than 20%. On average, ER=0.25 showed better results than ER=0.2 with the average errors of 0.7% for CO and 9% for N_2. In this case CO_2 was at the third rank with the error of 20%. For fixed-bed, the model's closest result was for N_2 with 14% error, CO and CO_2 were at the next steps. Since the better results in all modes observed for CO, CO_2 and N_2, similar to what Simone et al. reported in their study, according to average errors the model is more trustful to predict these three mentioned components (CO, CO_2 and N_2) than the other two (H_2 and CH_4) (Simone et al., 2013). In total, to predict N_2 the best performance of the model observed for fluidized-bed at ER=0.25, then for fixed-bed and fluidized-bed at ER=0.2 was at the last rank. To predict CO the best results of the model obtained for fluidized-bed at ER=0.25. In this case, fluidized-bed at ER=0.2 and fixed-bed were at the next steps, respectively. The closest results of the model to predict CO_2 was shown for experimental data of fluidized-bed at ER=0.2. Similar to the results of predicting CO, to predict CO_2 also fixed-bed was the least accurate data for the model.

By comparing the results of all experimental data with the results of the model separately, the most accurate result was obtained to predict CH4 in fluidized-bed at ER=0.25 in which the result of model was exactly the same as the results of the experiment. By considering the average errors, the best result of the model was for CO with the error of just 0.7%. In sum, the model is most trustful to be used in fluidized-bed especially at ER=0.25. Furthermore, according to the average errors the best performance of the model was obtained for N_2, CO and CO_2, therefore, it is not recommended to be used to estimate the amount of H_2 and CH4 specially for fluidized-bed at ER=0.2 and fixed-bed.

Effect of temperature on HHV and CCE

At ER=0.2 the produced gas reached to its maximum high heating value (HHV) at 850°C equal to 3.02 MJ/Nm3. HHV can be calculated by the following equation (Xiao et al. 2007):

$$HHV= (CO\% \times 3018+ H_2\% \times 3052+CH_4\% \times 9500)(0.01\times 4.1868)(KJ/Nm^3) \quad (22)$$

where, CO%, H_2% and CH_4% are the volumetric composition of the syngas produced, respectively. As table 3 illustrates, increasing temperature of the gasifier increased the amount of HHV. In typical biomass gasification process, when temperature increases, the H_2 and CO will increase due to gasification reactions that occur simultaneously during the process, thus, this causes increase in HHV as the H_2 and CO are the major role in the equation (Xiao et al., 2007). Regarding equation 22, the portion of CO, H_2 and CH_4, are the most effective components of produced gas on HHV. According to the experiments' results at 650°C, the portion of CO, H_2 and CH_4 were more at ER=0.25 in comparison with other modes, therefore, HHV in this mode was the most. As Table 3 demonstrates, increase in ER leads to increase in HHV in all temperatures. By increase in temperature more than 750°C, the amount of CH_4 and CO and consequently HHV was more in fixed-bed than the other modes. It would be interesting to be noted that even in higher temperatures H_2 had higher amounts at ER=0.25 than the others. The tar and light hydrocarbons were not considered in the presented model, which leads to overestimation of HHV. The portion of char, oil and tar were 18.7%, 3.4% and 0.4%, respectively. Carbon Conversion Efficiency (CCE) showed a maximum value, 81.32% at the temperature 850°C which was calculated as below (Hernández et al., 2010):

$$CCE= 1- M_a/M_b \times 100\% \quad (23)$$

where, Ma is total mass of biomass after experiment and Mb is total mass of biomass before experiment. Increase in temperature also leads to increase in CCE in this study. Higher temperature increases the carbon conversion because of improving the gasification process (Xie et al. 2012). Additionally, when temperature increases, the CCE will also increase as high temperature provides high degree of combustion which converts most of the organic matter of biomass to syngas (Lv et al., 2004).

In compliance with ER=0.2 at ER=0.25 and fixed-bed the highest HHV was observed at 850°C. At ER= 0.25 also an increasing rate was seen for HHV by increasing temperature with 17%, 5.7% and 0.6% char, oil and tar, respectively. At ER=0.25 and 850°C, HHV was 7.39 MJ/Nm3 which is the highest HHV in all modes. In contrary with ER=0.2, table 3 shows the highest amount of CCE for ER=0.25 at 650°C but similar to the results of ER=0.2 for other temperatures increase in temperature leads to increasing CCE. Comparing the results shown in Table 3 indicates that HHV and CCE increase with increase in ER in all temperatures. As can be seen in Table 3 an increasing trend is observed in HHV and CCE by increase in temperature in fixed-bed similar to other modes. What's more, in fixed mode the amount of HHV and CCE was less than the related results for all temperatures in fluidized-bed in both ERs.

CONCLUSION

A thermodynamic equilibrium model was developed and solved to predict the gas composition of potato shoot gasification. Proximate and ultimate analysis should be done in order to have the required data to develop the model. According to these results, chemical formula of potato shoot as the feedstock of current study, and oxygen in each kilo mole of feedstock were $CH_{1.747}$ $O_{0.83}$ $N_{0.074}$ and 0.06, respectively. Moisture content also obtained from TGA analysis which is needed to calculate the amount of mw. A bench-scale updraft gasifier also applied to achieve the real data from the experiments in order to validate the model's data under different considered conditions. The conditions considered in these

Table 3
Effect of Temperature on HHV and CCE

Temperature		650℃	700℃	750℃	800℃	850℃
HHV(MJ/Nm^3)	ER=0.2	1.99	2.12	2.53	2.6	3.02
	ER=0.25	3.47	2.24	3.4	4.42	7.39
	Fixed-bed	1.83	1.94	2.13	2.38	2.78
	Predicted	6.53	3.75	8.4	4.96	7.02
CCE (%)	ER=0.2	79.72	58	78.92	79.44	81.32
	ER=0.25	83.04	77.68	79.96	81.88	82.96
	Fixed-bed	78.6	78.81	78.89	79.23	80.11

experiments were five different temperatures in three different ERs. Generally, the model results reach to a good agreement with experiment especially for fluidized-bed gasifier at ER= 0.25. The model results were close enough to experimental results to be considered as a valid model in all modes specifically to estimate the amount of N_2, CO and CO_2. Mainly the model was observed to have higher amount of error in lower temperatures; however, the amount of error was not huge enough in lower temperature to make model be considered as invalid under these conditions.

The average error for the difference between each produced gas in experiments and the model showed the best result of the model for CO with the error of just 0.7%. Briefly, the developed model can predict the performance of an updraft gasifier with satisfactory agreement with experimental data in all modes. According to the results of HHV and CCE, performance of the gasifier is mainly better in fluidized-bed than fixed-bed especially at ER=0.25. It can lead to this conclusion that at higher temperatures the gasifier performs with higher efficiency, as HHV and CCE have an increasing trend by temperature. By considering the potential of potato shoot to produce high calorific value gases such as H_2, CO and CH_4, which was observed in the experiments of this study, this agricultural residue can be mentioned as a source of energy not waste.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by Ferdowsi University of Mashhad (Grant No. 37231).

REFERENCES

Ahmed, T.Y., Ahmad, M.M., Yusup, S., Inayat, dA., & Khan, Z. (2012). Mathematical and computational approaches for design of biomass gasification for hydrogen production: A review. *Renewable and Sustainable Energy Reviews*, *16*, 2304-2315.

Aloui, T., & Halouani, K. (2007). Analytical modeling of polarizations in a solid oxide fuel cell using biomass syngas product as fuel. *Applied Thermal Engineering*, 27, 731-737.

Arnavat, P. M. (2011). *Performance modeling and validation of biomass gasifiers for trigeneration plant*. Unpublished dissertation, Department of Mechanical Engineering, University of Rovirai Virgili, Spain.

Babu, B.V., & Sheth, N.P. (2006). Modeling and simulation of reduction zone of downdraft biomass gasifier: effect of char reactivity factor. *Energy Conversion and Management, 47*, 2602-2611.

Banapurmath, N.R., &Tewari, P.G. (2009). Comparative performance studies of a 4-stroke CI engine operated on dual fuel mode with producer gas and Honge Oil and its Methyl Ester (HOME) with and without carburetor. *Renewable Energy, 34*,

1009-1015.

Cao, Y., Wang, Y., Riley, J.T., & Pan, W.P. (2006). A novel biomass air gasification process for producing tar-free higher heating value fuel gas. *Fuel Processing Technology, 87*, 343-353.

CIP. (2015). World Potato Atlas. Retrieved from https://research.cip.cgiar.org/confluence/display/wpa/Iran.

Di Blasi, C. (2000). Dynamic behavior of stratified downdraft gasifiers. *Chemical Engineering Science, 55*, 2931-44.

Dokhani, Sh., Keramat, J. & Rofigari Haghighat, Sh. (2003). Changes in glycoalkaloids and alfasolanine in potatoes during storage and thermal process. *Journal of Soil and Water Sciences, Science and Technology of Agriculture and Natural Resources, 7*, 171-183(In Persian).

Doranehgard, M.H., Samadyar, H., Mesbah, M., Haratipour, M., & Samiezade, S. (2017). High-Purity Hydrogen Production with in Situ CO_2 Capture Based on Biomass Gasification. *Fuel, 202*, 29–35.

FAO. (2011). Potato World. Retrieved from http://www.fao.org/potato-2008/en/world/.2008.

FAOSTAT. (2016). Food and Agriculture Organization of the United Nations (FAO). FAOSTAT Database. Retrieved from http://faostat.fao.org/beta/en/#data/QC.

Ghani, W.A.W.K., Moghadam, R.A., Salleh, M.A.M., & Tavasoli, A. (2012). Gasification performance of rice husk in fluidized bed reactor: a hydrogen-rich production. *Journal of Energy and Environment, 4*(1), 7-11.

Ghatrehsamani, S., Ebrahimi, R., NewazKazi, S., Badarudin Badry, A., & Sadeghinezhad, E. (2016). Optimization model of peach production relevant to input energies – Yield function in Chaharmahal va Bakhtiari Province, Iran. *Energy, 99*, 315-321.

Giltrap, D.L., McKibbin, R., & Barnes, G.R.G. (2003). A steady state model of gas-char reactions in a downdraft biomass gasifier. *Solar Energy, 74*, 85-91.

Hernández, J.J., Aranda-Almansa, G., & Bula, A. (2010). Gasification of biomass wastes in an entrained flow gasifier: effect of the particle size and the residence time. *Fuel Processing Technology, 91*, 681-692.

Jiang, L., Chen, Z., & Farouq Ali, S.M. (2017). Modelling of reverse combustion linking in underground coal gasification. *Fuel, 207*, 302-311.

Khajehpour, M. (1999). *The Production of Industrial Crops* (4thEd.). Isfahan: Jahad Daneshgahi.

Kirkils, A.F., & Verbong, G.P.J. (2011). Biomass gasification: Still promising? A 30-year global overview. *Renewable and Sustainable Energy Reviews, 15*, 471-481.

Lv, P.M., Xiong, Z.H., Chan, G.J., Wu, C.Z., Chen, Y., & Zhu, J.X. (2004). An experimental study on biomass air-steam gasification in a fluidized bed. *Bioresource Technology, 95*, 95-101.

Masmoudi, M.A., Sahraoui, M., Grioui, N., & Halouani, K. (2014). 2-D Modeling of thermo-kinetics coupled with heat and mass transfer in the reduction zone of a fixed bed downdraft biomass gasifier. *Renewable Energy, 66*, 288-298.

Midilli, A., Dogru, M., Howarth, C.R., & Ayhan, T. (2001). Hydrogen production from hazelnut shell by applying air-blown downdraft gasification technique. *International Journal of Hydrogen Energy, 26*, 29-37.

Monforti, F., Bodis, K., Scarlat, N., & Dallemond, J.F. (2013). The possible contribution of agricultural crop residues to renewable energy targets in Europe: A spatially explicit study. *Renewable and Sustainable Energy Reviews, 19*, 666–677.

Monteiro, E., Ismail, T.M., Ramos, A., El Salam, M.A., Brito, P.S.D., & Rouboa, A. (2017). Assessment of the Miscanthus Gasification in a Semi-Industrial Gasifier Using a CFD Model. *Applied Thermal Engineering, 123*, 448–457.

Mozafari, A., Farshchi Tabrizi, F., Farsi, M., & Seyed Mousavi, S.A. H. (2017). Thermodynamic modeling and optimization of thermolysis and air gasification of waste tire. *Journal of Analytical and Applied Pyrolysis, 126*, 415-422.

Mweetwaa, A.M., Huntera, D., Poea, R., Kim, C., Harich Ginzberg, I., Tokuhisa, J.G., & Veilleux, R. E. (2012). *Steroidal glycoalkaloids in Solanumchacoense. Phytochemistry, 75*, 32–40.

Pengmei, L., Zhenhong, Y., & Longlong, M. (2007). Hydrogen-rich gas production from biomass air and oxygen/steam gasification in a downdraft gasifier. *Renewable Energy, 32*, 2173-2185.

Plis, P., & Wilk, R.K. (2011). Theoretical and experimental investigation of biomass gasification process in a fixed bed gasifier. *Energy, 36*(6), 3838–3845.

Roy, P.C., Datta, A., & Chakraborty, N. (2013). An assessment of different biomass feedstocks in a downdraft gasifier for engine application. *Fuel, 106*, 864-868.

Sales, C.V.B., Maya, D.M.Y., Lora, E.E.S., Jaén, R.L., Reyes, A.M.M., Andrade, A.M.G.R.V., & Martínez, J.D. (2017). Experimental Study on Biomass (eucalyptus spp.) Gasification in a Two Stage Downdraft Reactor by Using Mixtures of Air, Saturated Steam and Oxygen as Gasifying Agents. *Energy Conversion and Management, 145*, 314–323.

Simone, M., Nicolella, C., & Tognotti, L. (2013). Numerical and experimental investigation of downdraft gasification of woody residue. *Bioresource Technology, 133*, 92-101.

Thunman, H., & Leckner, B. (2005). Influence of size and density of fuel on combustion in a packed bed. *Processing Combustible Institute, 30*, 2939-2946.

Vaezi, M., Passandideh-fard, M., Moghiman, M., & Charmchi, M. (2011). Gasification of heavy fuel oils: A thermochemical equilibrium approach. *Fuel, 90*, 878-885.

Xiao, R., Jin, B., Zhou, H., Zhong, Z., & Zhang, M. (2007). Air gasification of polypropylene plastic waste in fluidized bed gasifier. *Energy Conversion and Management, 48*, 778-786.

Xiao, R., Zhang, M., Xiaong, Y., Zhou, H., Duan, Y., Zhong, Z., Chen, X., Shen, L., & Huang, Y. (2007). Air blown partial gasification of coal in a pilot plant pressurized spout-fluid bed reactor. *Fuel, 86*, 1631-1640.

Xie, J., Zhong, W., Jin, B., Shao, Y., & Liu, H. (2012). Simulation on gasification of forestry residues in fluidized beds by Eulerian–Lagrangian approach. *Bioresource Technology, 121*, 36-46.

Xue, Q., Heindel, T.J., & Fox, R.O. (2011). A CFD model for biomass fast pyrolysis in fluidized-bed reactors. *Chemical Engineering Science, 66*, 2440-52.

Yan, L., Cao, Y., & He, B. (2018). On the kinetic modeling of biomass/coal char co-gasification with steam. *Chemical Engineering Journal, 331*, 435-442.

Zainal, Z.A., Ali, R., Lean, C.H., & Seetharamu, K.N. (2001). Prediction of the performance of a downdraft gasifier using equilibrium modeling for different biomass materials. *Energy Conversion and Management, 42*(12), 1499–1515.

How to cite this article:
Javidi Gharacheh, M., Khojastehpour, M., Ebrahimi-Nik, M. and Wan Ab Karim Ghani, W. (2018). Theoretical and Experimental Study of Potato Shoot Gasifier in Fluidized and Fixed-Bed Gasifier. *International Journal of Agricultural Management and Development, 8*(4), 487-500.
URL: http://ijamad.iaurasht.ac.ir/article_542574_d6c8c4d5be2adba862bf9e3e5f8efaa0.pdf