Journal of the Korean Society of Agricultural Engineers
DOI : http://dx.doi.org/10.5389/KSAE.2015.57.5.081

Vol. 57, No. 5, pp. 81~88, September 2015
ISSN 1738-3692 | eISSN 2093-7709

Characteristics of the Gasification from Mixed Fuels of Charcoal and Undried Woodchip

미건조 우드칩과 숯 혼합에 따른 가스화 특성 분석

Wang, Long* · Kang, Ku** · Lee, Tae Ho*** · Choi, Sun Hwa*** · Hong, Seong Gu****,†

왕용 · 강구 · 이태호 · 최선화 · 홍성구

Abstract

바이오매스는 유망한 신재생 에너지이다. 바이오매스는 액체 및 기체 연료로 전환 할 수 있고, 다양한 공정을 통해 열 및 전력을 생산시키는데 사용된다. 바이오매스 가스화 공정은 바이오매스를 일산화탄소, 이산화탄소, 수소 및 메탄으로 이루어진 합성 가스로 전환시키는 기술이다. 바이오매스를 이용한 합성 가스 생산 및 활용은 세계적으로 늘어나는 에너지 필요성을 충족시킬 수 있는 대체에너지이다. 현재, 바이오매스 가스화의 주요 원료는 목질계 우드 칩을 주로 사용하고 있지만, 일반적으로 우드칩의 경우 수분을 다량 함유하고 있기 때문에 가스화 공정을 위해서는 별도의 건조처리를 필요로 한다. 우드칩의 건조에는 많은 에너지가 소요되고, 다량의 우드칩 건조에는 시간과 기상 및 공간적인 환경에 영향을 받는다. 본 연구에서는 미건조 우드칩의 가스화 공정을 위하여 미건조 우드칩에 숯을 각각 10, 30, 50 % 비율로 혼합하여 실험을 수행하였고, 실험결과 생산된 합성가스의 CO 농도 는 숯의 비율에 따라 14.9 ~ 25.6 % 증가되는 경향을 나타내었지만, 반대로 CO_2 및 CH_4 농도는 감소하였다. 이에 따라 합성가스 생산을 위한 미건조 우드칩과 숯의 최적혼합비율은 약 30 %로 판단되며, 발열량은 1285.7 kcal/Nm^3, Gas yield는 2.3 Nm^3/kg 로 나타났다. 이에 적절한 숯의 혼합사용은 미건조 우드칩의 직접적인 가스화에 도움이 될 것으로 사료되며, 바이오매스 건조 공정에 필요한 에너지를 절약할 수 있을 것으로 판단된다.

Keywords: Biomass; Charcoal, Gasification; Synthesis gas; Undried woodchip

Ⅰ. INTRODUCTION

The future is promising for the exploitation of biomass to convert lignocellulosic materials into useful energy, such as heat, electricity or liquid fuel (Teixeira et al. 2012). The utilization of biomass can reduce environmental pollution and carbon dioxide emissions by using traditional energy sources. Biomass energy can be effectively used in developing countries where electrical power is not easily available (Wang, 2014). Gasification is a process that converts organic or any combustible materials, such as coal, petroleum, or biomass, into gas fuel. It is one of the methods for converting different types of fuels into gaseous fuel. This gas is composed of carbon monoxide, carbon dioxide, hydrogen and methane and is called synthesis gas or syngas (Bocci et al., 2014). The process requires a high temperature(usually higher than 700 °C) and a limited supply of oxygen and/or steam. Gasification has advantages over direct combustion since the combustion of syngas produces lower emissions compared to when solid fuels are incinerated. Particularly when gasification is conducted under high temperatures and pressures the sulfur and nitrous oxides (SO_X and NO_X) are easier to remove (Woolcock and Brown, 2013).

Nowadays, woods are a main resource for biomass gasification feedstock in gasification. There are two types of gasifiers: fixed bed gasifier and fluidized bed gasifier. The fixed bed gasifier has solid biomass on the bed. The air or steam is injected and syngas moves up or down through the bed. The fixed bed is the simplest gasifier and appropriate for small scale applications and easy in operations. There are two types in the fixed bed gasifier: updraft and downdraft gasifier (Chopra and Jain, 2008). Advantages of downdraft gasifier system are: flexible adaptation of gas production to load and low sensitivity to charcoal dust and tar content of

* Research Institute of Agricultural & Environmental Science, Hankyong National University
** Graduate School of Future Convergence Technology, Hankyong National University
*** Rural Research Institute, Korea Rural Community Corporation
**** Department of Bioresources and Rural systems Engineering, Hankyong National University
† Corresponding author
Tel.: +81-31-670-5134 Fax: +82-31-670-5139
E-mail: bb9@hknu.ac.kr
Received: June 25, 2015
Revised: August 28, 2015
Accepted: September 10, 2015

fuel; high exit gas temperature; high residence time of solids; high overall carbon conversation. The downdraft gasifier requires limited range of materials' size and moisture (Digman et al., 2009; Hong and Wang, 2011). Because the moisture of fresh woodchip is usually between 45 % and 55 %, a large amount of energy is required to reduce moisture content to about 15 %. High moisture content results in lowering reaction temperature in combustion zone.

The original biomass usually has high moisture content, low bulk density and irregular shape, so it need necessary pre-treatments for storing and utilizing in many applications such as drying, cutting, compressing and so on. Biomass moisture content should be decreased to 8 % to 10 % for densification and energy conversion for economic use (Kaliyan and Morey, 2009; Wang and Hong, 2013). The biomass drying can increase the energy density and reduce the difficulties for thermo-chemical conversing to other forms of bioenergy. Higher reaction temperature can be achieved by drying biomass fuels but increase additional cost because of higher energy cost and additional capital inputs (Haque and Somerville, 2013).

Since the drying of biomass needs a large amount of heat energy, undried woodchip can be gasified through supplying oxygen to gasifier or mixing higher calorific fuels. Mixing higher calorific biomass with wet feedstock can reduce the heating energy input in drying process. Charcoal is also a common feedstock for biomass gasification and it has higher calorific values and the reaction temperature can reach over 1200 °C (Wang, 2014). But using charcoal as the only feedstock is not economical. In this study, mixing charcoals with undried biomass fuels was experimentally examined as an alternative fuel preparation to simple drying of woodchips.

Ⅱ. MATERIALS AND METHODS

1. Downdraft gasification system

Gasification of undried woodchip mixed with charcoal was carried out in a downdraft gasification system; the charcoal ratio was ranged from 10 % to 50 %.The gasification possibility and effects of undried woodchip were explored in the present study. The experiments were carried out by a downdraft gasification system (Liaoning intuition of energy resources, China). The downdraft gasification systems comprises of a downdraft gasifier, hot filter, water scrubber, water separator, charcoal filter and a roots blower. The syngas was produced in the gasifier, particles and dusts were removed in the hot filter, then the syngas was washed in the wet scrubber for removing tars, the moisture was removed by water separator and finally reamaining impurities were absorbed by carbon filter. The gasifier diameter was 400 mm, maximum syngas production is 50 Nm^3/hr, and power generation ability is 15 kW. Temperature sensors were installed in gasifier (hearth zone, reduction zone), front part hot filter, hot filter, water scrubber, water separator and charcoal filter. The temperature of each part, flow rate of air and gas, weight change of feedstock and pressure change were recorded by King View program (Welintech Co. Ltd., China). The schematic diagram of downdraft gasification system is presented in Fig. 1.

2. Feedstock

The woodchip and charcoal were prepared in the size of 2~3 cm as shown in Photo 1. The moisture content of undried woodchip was about 40 % and mixed with charcoal in the ratios 10 %, 30 % and 50 % of woodchip weight. The total moisture of feedstock was decreased from 39 % to 18 % since the dry charcoal's mixture. The undried woodchip was mixed in plastic bags for even distribution. The materials were dried in an oven with 105 °C, 24 hours. Then the moisture was calculated.

3. Experimental procedures

The dried woodchip was feed into gasifier from upper cover until cover the hopper. Then the biomass was ignited. The pre-gasification was conducted before test materials were fed into gasifier. Biomass of 10 kg was fed into the gasifier when the temperature of combustion zone and reduction zone become greater than 600 °C. The gas flow rate was controlled by valve with roots blower. And the gas flow rate was kept as 20 Nm^3/hr in the process. The temperature of combustion zone continued to maintain in higher than 600 °C. The produced gas then, passed a cyclone, hot filter, wet scrubber for removing dust and tar. Gas samples were collected at the end of pipe.

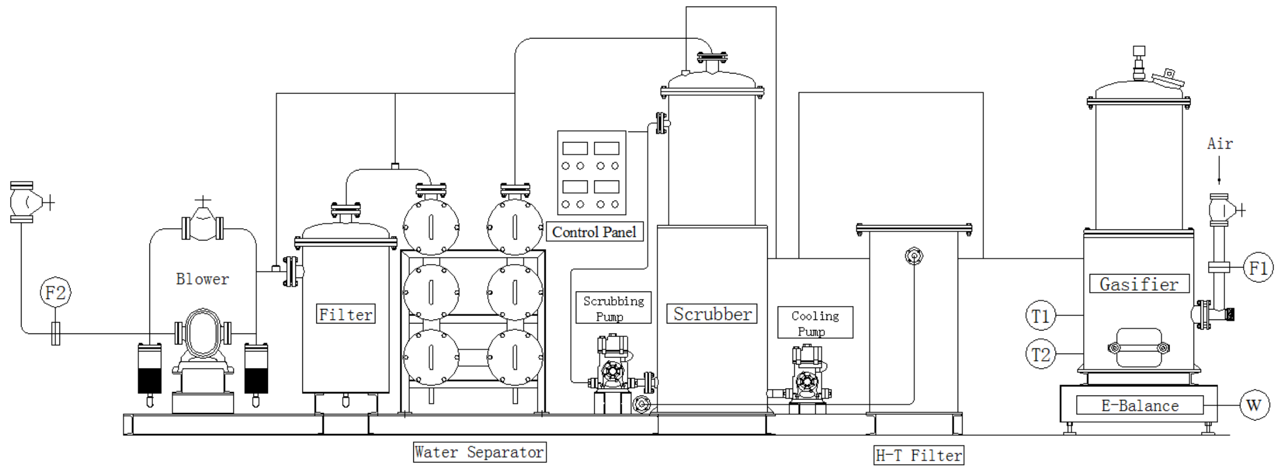

Fig. 1 Schematic diagram of downdraft gasification system [T1: temperature of combustion zone, T2: temperature of reduction zone; W: electronic load cell scale, F1: air flow rate meter, F2: gas flow rate meter]

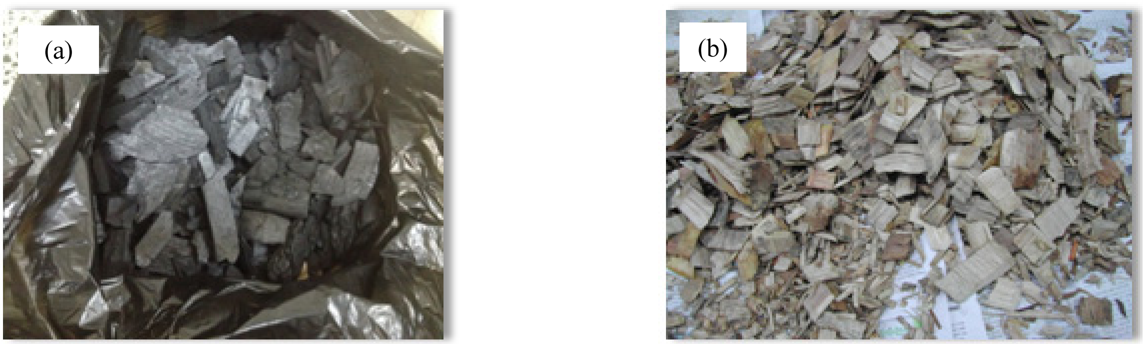

Photo 1 Charcoal (a) and woodchip (b) used in experiments

4. Data collection and analysis system

The temperature, flow rate of air and syngas and biomass weight changes were recorded by the data acquisition system, King View. Syngas composition was analyzed in the real time. An online gas analyzer (Mode Biogas 310, Korea) was used in the study, which can analyze CO, CO_2, H_2, CH_4 and O_2 in the syngas. the heating value is calculated in low heating value (LHV).

Ⅲ. RESULTS AND DISCUSSIONS

1. The proximate and ultimate analysis of feedstock

The proximate and ultimate analysis of woodchip and charcoal are presented as Table 1.

2. Temperatures

The temperature changes are shown in Fig. 2 at different zones of gasifier. $T_{reduction}$ is the temperature at reduction zone and T_{hearth} at combustion zone. When undried woodchips (UW) were provided, reaction temperatures increased with the higher mixing ratio of charcoal(MC).

In a typical dried woodchip gasification after the ignition, the temperature of the hearth began rising rapidly from room temperature to 800 or more. The temperature of hearth continued to rise and then goes up to 1200 °C. The temperature of the reduction zone, is up to 600 °C and even up to 800 °C. The temperature of the pyrolysis zone is lower than that of the temperature of the reduction zone, which was about 400 °C to 500 °C.

Fig. 2 shows the temperature changes of hearth and reduction zones in the gasification reactions. When 10 % of

Table 1 Proximate and ultimate analysis of feedstock

Biomass	Proximate analysis (wt%)			Ultimate analysis (wt%)					Calorific value (MJ/Kg)
	VM*	FC*	Ash	C	H	N	O	S	
Wood chip	56.7	11.6	2.2	49.8	5.6	0.2	44.4	–	12.84
Charcoal	25.2	74.8	2.7	82.0	3.0	0.2	13.5	0.2	30.23

* VM : Volatile matter, FC : Fixed carbon

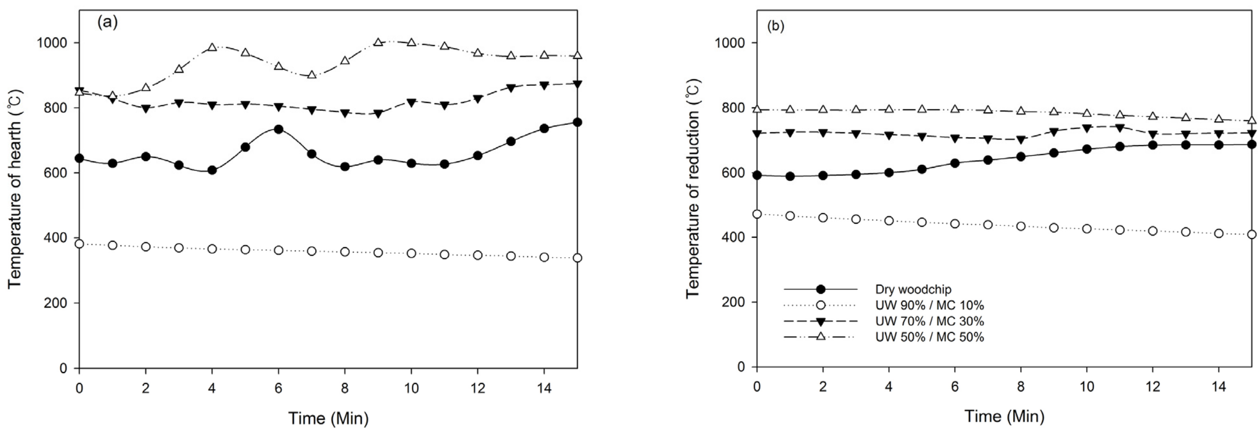

Fig. 2 Temperature changes at hearth (a) and reduction zone (b) by different feedstock conditions

charcoal was mixed, temperature at the reduction kept about 540 °C and the hearth temperature was about 630 °C. The average temperatures in reduction zone were increased from 540 °C to 772 °C by mixing ratio from 10 % to 50 %, and the average hearth temperature also increased from 630 °Cto 948 °C. It indicates that additional amount of charcoal provides more heat in combustion zone and reduction zone. When dried woodchip was provided, the temperature range lied in between mixing ratios 10 % and 30 %. The temperatures of reduction zone was reached to a typical temperature from 600 °C to 700 °C. The average temperature of reduction zone was 540 °C when charcoal ratio was 10 %. They were higher than 700 °Cwhen charcoal ratio were 30 % and 50 %. The temperature changes in gasification have relationships with the chemical reactions participated in biomass gasification as follows (Hosseini et al., 2012; Ghassemi and Markadeh, 2014):

Combustion reaction:

$$\mathbf{CO + 1/2O_2 = CO_2 - 283\ MJ/Kmol} \quad (1)$$

$$\mathbf{C + O_2 = CO_2 - 394\ MJ/Kmol} \quad (2)$$

$$\mathbf{C + 1/2O_2 = CO - 111\ MJ/Kmol} \quad (3)$$

Gasification reaction:

$$\mathbf{C + CO_2 = 2CO - 110\ MJ/Kmol} \quad (4)$$

Water-gas shift reaction:

$$\mathbf{CO + H_2O = CO_2 + H_2 - 41\ MJ/Kmol} \quad (5)$$

As shown in the equation (5), H_2 was produced from the moisture in biomass. In the undried woodchip gasification the temperature of the combustion zone is not high enough due to high moisture content. Enough heat should be provided from combustion zone to reduction zone. The reaction temperature decreased as the increased of moisture content and it shifted the equilibrium of equation (5), steam-carbon reaction and methane reforming reaction towards the formation of CO_2 and H_2O (Kaewluan and Pipatmanomai, 2011).

The experimented results for different fuel conditions were summarized as shown in Table 2. The temperature at reduction zone was increased by charcoal ratio from 630 °C to 948 °C. It was higher than dry woodchip gasification (676 °C) when charcoal ratio from 30 % (833 °C). The temperature of reduction zone rose by charcoal addition. It seems that the

Table 2 Summary of experimental results of undried woodchip gasification mixed with charcoal

Biomass	Dry woodchip	UW 90 % / MC 10 %	UW 70 % / MC 30 %	UW 50 % / MC 50 %
Moisture (%)	10	39	32	18
Aver. T_{hearth} (℃)	676	630	833	948
Aver. $T_{reduction}$ (℃)	654	540	732	772
Feed (kg/h)	7.1	5.1	8.6	7.7
Dry Feed (kg/h)	6.4	3.87	5.16	6.3
AVER. Air (Nm^3/h)	10.5	6.0	10.9	9.0
AVER. Gas (Nm^3/h)	18.8	10.1	19.5	13.2
ER	0.34	0.29	0.44	0.29
CO (%)	21.1	16.8	22.1	24.6
CO_2 (%)	13.6	12.6	10.6	10.3
CH_4 (%)	4.7	2.7	2.6	1.5
H_2 (%)	14.8	14.1	15.5	15.6
O_2 (%)	0.0	0.0	0.0	0.0
LHV (MJ/Nm^3)	6.0	4.6	5.4	5.3
LHV ($kcal/Nm^3$)	1422.5	1097.3	1285.7	1268.6
Gas yield (Nm^3/kg)	2.65	1.98	2.30	1.72
Cold gas efficiency (%)	68.4	51.7	69.7	54.6

gasification carried out not well when charcoal ratio was 10 % due to very high moisture content. The temperature of reduction zone was not changed as much as combustion zone, from 600 °C to 772 °C. The temperature of reduction was 770 °C when charcoal ratio was 20 %. If seems that combustion process was extended to lower layer reduction zone. The syngas flow was not constant because the pressure changes occurred in gasifier. The syngas flow rate was 10.1 Nm^3/h due to the pressure drop through the fuel layers.

The ER(Equivalence ratio) value is the ratio of actual air-fuel ratio to the stoichiometric air-fuel ratio. It was calculated and average gas composition was also shown in Table. 2. The ER value ranged from 0.29 to 0.44 when charcoal ration from 10 % to 50 % in undried woodchip gasification. The ER value was 0.34 in dry woodchip gasification. The ER value was 0.44 when charcoal ratio was 30 %.

3. Gas composition and heating value

The main compositions of syngas are N_2, CO, CO_2, H_2, and CH_4. O_2 was also measured. The syngas composition was analyzed every 5 minutes. The syngas compositions are shown in the Fig. 3. CH_4 concentration was usually about 1~5 % with the experiment. The gas composition from the experiment for undried woodchip was not presented because the gasification process was not consistent. The CO concentration was below 20 % when charcoal ratio was 10 %, and higher than 20 % when 30 % and 50 %. The CO concentration ranged from 17.5 % to 15.8 % when charcoal ratio of 10 %. The CO_2 concentration ranged from 10.3 % to 10.9 % and below 15 % when charcoal ratio from 30 % to 50 %. The variation for CO_2 is opposite to that of CO. The decrease in the percentage of CO_2 shows better conversion into CO in the reduction zone (Bhattacharya et al. 1999; Zainal et al., 2002). The gasification process was not stable during the reaction when charcoal ratios were 10 %. The CO concentration was raised and the CO_2 concentration was decreased by mixing ratio of 30 % or more. It was found the H_2 concentration nearly remained about 15 % except when charcoal was 20 %. It seemed that the H_2 production was not affected by moisture in feedstock. The CH_4 concentrations was stable in all cases and the ranged from 1.5 % to 4.6 %. CH_4 concentration was 4.6 % when charcoal ratio was 20 % and was lowest as 1.5 % when mixing ratio was 50 %.

The average gas composition and LHV of syngas are presented in the Fig. 4. It was shown that the CO

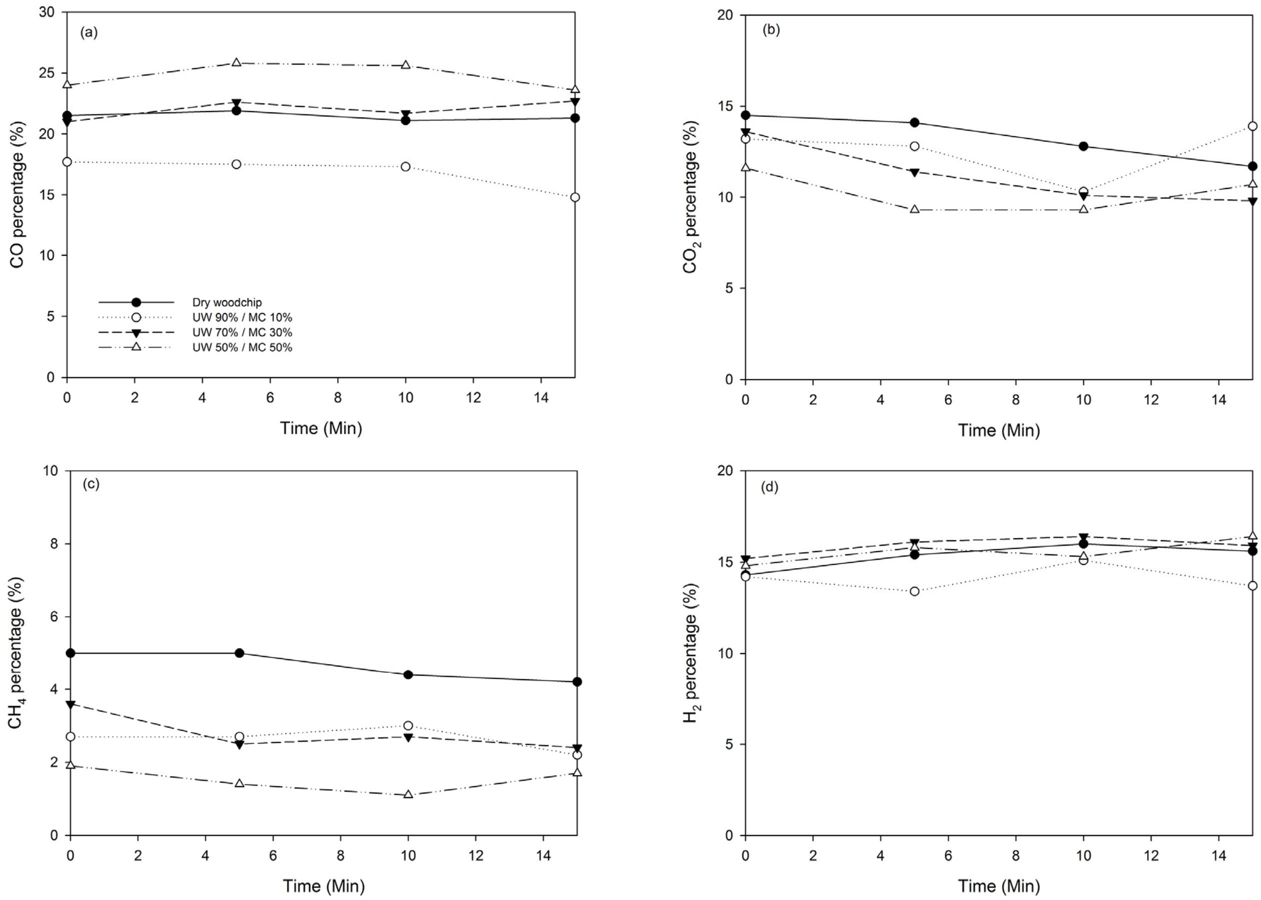

Fig. 3 Gas composition changes by undried woodchip gasification with charcoal additions (a) CO concentration (b) CO_2 concentration (c) CH_4 concentration (d) H_2 concentration

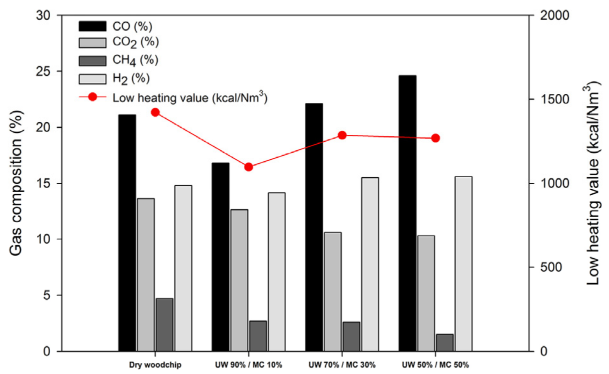

Fig. 4 Average gas composition and lower heating value changes for different fuel conditions

concentration was 14 %when charcoal ratio from 10 %. But it increased higher when mixing ratio from 30 % to 50 %. H_2 concentrations increased slightly higher from 11.0 % to 15.6 % as the charcoal ratios change. Higher H_2 concentration seemed the result of water gas shift reaction and low temperature due to high moisture content (Bhattacharya et al., 1999). The CO_2 concentration was 12.6 % when charcoal ratio was 10 %. But CO_2 concentration decreased to 10.6 % when charcoal ratio was 30 %. The CO_2 concentrations did not change significantly when mixing ratio increased from 30 % to 50 %. The CH_4 concentration decreased slightly from 2.7 % to 1.5 % when the mixing ratio increased from 10 % to 50 %. The CH_4 concentration was 4.7 % in dry woodchip gasification. This was higher than those when mixed fuels were provided.

4. Cold gas efficiency, gas yield and ER (equivalence ratio)

The frequently quoted for gasification process are cold gas efficiency (CGE) and carbon conversion. Cold gas

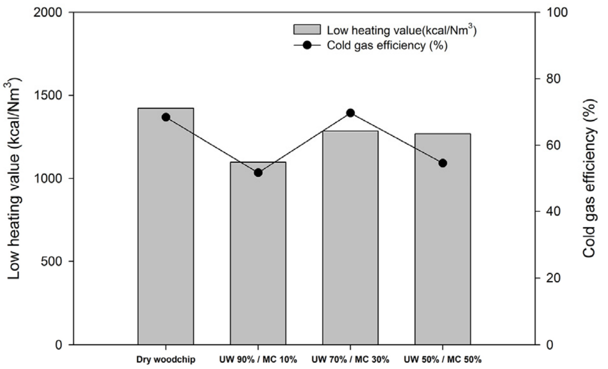

Fig. 5 Cold gas efficiency and lower heating value changes in different feedstock

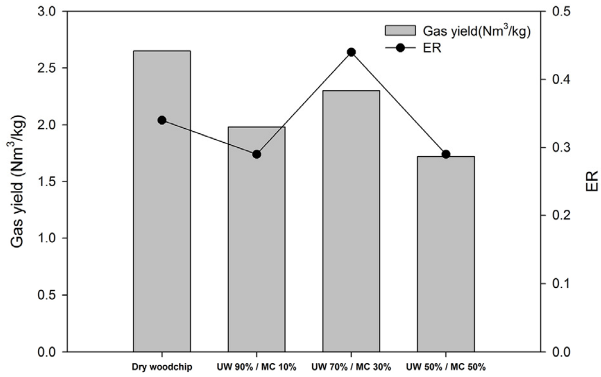

Fig. 6 Gas yield and equivalence ratio changes in different feedstock

efficiency is one of the factors for assessment of gasification process. It is defined as the ratio of energy of the producer gas obtained per kg of biomass to the LHV of the biomass material as shown in the following equation (Higman and Burgt, 2008):

Cold gas efficiency (%) =

$$\frac{Heating\,value\,of\,syngas\,(MW)}{Heating\,value\,of\,feedstock\,(MW)} \times 100 \qquad (6)$$

The cold gas efficiencies with different feedstock are compared in Table 2. As given in the above equation, cold gas efficiency depends upon the calorific value and the amount of producer gas released at the constant LHV of biomass. Cold gas efficiency and lower heating value changes in different feedstock is presented in Fig. 5. It was found that cold gasification efficiency was ranged from 50 % to 60 %.The cold gas efficiency was 51.72 % when charcoal ratio was 10 %. values were similar when charcoal ratio was 30 % and dry woodchip was used (69.7 % and 68.4 %). The 30 % of charcoal mixed with undried woodchip had better gasification efficiency than others because it had higher LHV value and low charcoal ratio.

The experimental results show that the ER value ranges from 0.29 to 0.44 in Fig. 6. The ER value was 0.44 when charcoal ratio was 30 % which has highest LHV. And it showed a higher efficiency than others. The gas yield from dry woodchip gasification ranged 2.65 Nm^3/kg. And the gas yield of undried woodchip mixture was 1.98 Nm^3/kg when charcoal ratio as 10 %, 1.72 Nm^3/kg when charcoal ratio as 50 %. The highest gas yield was 2.3 Nm^3/kg when charcoal ratio as 30 %. And it can be found that the gas yield increased with the ER value.

The undried woodchip gasification was carried out by charcoal addition and the best gasification efficiency occurred at charcoal ratio as 30 %, it had higher cold gas efficiency, gas yield and heating value than other mixing ratios. It indicates that drying all feedstock may not be required when appropriate woodchip or other biomass mixing with charcoals. The capital cost of biomass dryer is AU$ 15M for 20 ton/h evaporation load and the operating cost is about AU$ 31/tone of water evaporated (Haque and Somerville, 2013). So drying costs could be saved by mixing high calorific biomass even torrefacted biomass in the future (Xu et al., 2014).

Ⅳ. CONCLUSIONS

Biomass gasification produces syngas as fuel gas for power generation, heating and gaseous substrate in other chemical or biological application. Woodchip is a common biomass in gasification. Drying is a necessary pre-treatment for gasification, particularly in downdraft gasifier. Utilization of undried woodchip with a certain ratio of mixing with charcoal may be an economic and industrial approach. In this study charcoal was mixed with undried woodchip in different ratios in downdraft gasification. It was found that the CO composition and the calorific value of syngas were increased with charcoal ratio under acceptable reaction conditions. The CO_2 and CH_4 concentrations were decreased with the increase of mixing ratio with charcoal. The LHV reached up to 1285.7 kcal/Nm^3 when charcoal ratio was 30 %. The LHV was not increased significantly when charcoal ratio increased. The mixing 30 % of charcoals resulted in acceptable reactions in terms of LHV and gas compostions. indicating that undried woodchips cab be directly used in downdraft gasifications. Mixing charcoal with wet biomass feedstock is an economic and simple way to gasify the wet biomass directly and it can save the energy required in biomass drying process.

Acknowledgements

This work was supported by the “Development of 20ton/day biomass gasification for low tar syngas production and energy co-production technology” of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) granted financial resource from the Ministry of Trade, Industry and Energy, Republic of Korea (No. 2012T1002 01657)

REFERENCES

1. Bhattachary, S. C., A. H. M. Mizanur, and H. L. Pham, 1999. A study on wood gasification for low-tar gas production. *Energy* 24(4): 285-296.
2. Bocci, E., G. L. Morini, M. Sisinni, M. Moneti, L. Vecchione, A. Di Carlo, and M. Villarini, 2014. State of Art of Small Scale Biomass Gasification Power Systems: A Review of the Different Typologies. *Energy Procedia* 45: 247-256.
3. Digman, B., J. S. Hyun, and D. S. Kim, 2009. Recent progress in gasification/pyrolysis technologies for biomass conversion to energy. *Environmental Progress & Sustainable Energy* 28(1): 47-51.
4. Ghassemi, Markadeh, 2014. Effects of various operational parameters on biomass gasification process; a modified equilibrium model. *Energy Conversion and Management* 79: 18-24.
5. Haque, N. and M. Somerville, 2013. Techno-Economic and Environmental Evaluation of Biomass Dryer. *Procedia Engineering* 56: 650-655.
6. Higman, C. and M. van der Burgt, 2008. *Gasification Processes. Gasification (Second Edition)*. C. Higman and M. v. d. Burgt. Burlington, Gulf Professional Publishing: 91-191.
7. Hong, S. G. and L. Wang, 2011. Experimental Evaluation of Synthesis Gas Production from Air Dried Woodchip. *Journal of the Korean Society of Agricultural Engineers* 53(6):17-22. (in Korean)
8. Hosseini, H., L. Dincer, and M. A. Rosen, 2012. Steam and air fed biomass gasification: Comparisons based on energy and exergy. *International Journal of Hydrogen Energy* 37(21): 16446-16452.
9. Kaewluan, S. and S. Pipatmanomai, 2011. Gasification of high moisture rubber woodchip with rubber waste in a bubbling fluidized bed. *Fuel Processing Technology* 92(3): 671-677.
10. Kaliyan, N. and R. Vance Morey, 2009. Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy* 33(3): 337-359.
11. Psomopoulos, C. S., A. Bourka, and N. J. Themelis, 2009. Waste-to-energy: A review of the status and benefits in USA. *Waste Management* 29(5): 1718-1724.
12. Teixeira, G., L. V. Steeneb, S. Salvadorc, F. Gelixa, J. L. Dirionc, and F. Pavietd. 2012. Gasification of char from wood pellets and from wood chips: Textural properties and thermochemical conversion along a continuous fixed bed. *Fuel* 102: 514-524.
13. Wang, L., 2014. *Syngas production and fermentation for producing bioethanol from biomass and waste*. Ph. D. thesis. Hankyong National University.
14. Wang, L. and S. G. Hong, 2013. The Impacts of Operational Conditions on Charcoal Syngas Generation using a Modeling Approach. *Journal of the Korean Society of Agricultural Engineers* 55(4):17-22. (in Korean)
15. Woolcock, P. J. and R. C. Brown, 2013. A review of cleaning technologies for biomass-derived syngas. *Biomass and Bioenergy* 52: 54-84.
16. Xu, F., K. Linnebur, and D. Wang, 2014. Torrefaction of Conservation Reserve Program biomass: A techno-economic evaluation. *Industrial Crops and Products* 61: 382-387.
17. Zainal, Z. A., A. Rifau, G. A. Quadir, and K. N. Seetharamu, 2002. Experimental investigation of a downdraft biomass gasifier. *Biomass and Bioenergy* 23(4): 283-289.