CHARACTERISTICS OF SYNGAS PRODUCTION BY MICROWAVE PLASMA GASIFICATION

Melda Ozdinc Carpinlioglu, Aytac Sanlisoy
Gaziantep University, Mechanical Engineering Department, Gaziantep 27310 TURKEY
Corresponding author: Melda Ozdinc Carpinlioglu, e-mail: melda@gantep.edu.tr

REFERENCE NO
WSTE-04

ABSTRACT

The basic aim of the conducted research through the code number of 115 M389 of TUBITAK is to determine syngas production ability of a variety of solid wastes by a new- emerging technological waste to energy method of microwave plasma gasification. An operational study of MCw GASIFIER is presented briefly in this paper.

Keywords:
Syngas , Microwave plasma gasification , MCw GASIFIER

1. INTRODUCTION

A microwave plasma gasification process for a variety of solid waste samples through a laboratory-sized research plant called as MCw GASIFIER is the concern of the paper. The conversion of solid waste into syngas is discussed as a function of input power and amount of plasma environmental gas under the light of the relevant literature ([*1-4*]. A variety of coal (Turkish –Şırnak CTR, Russian CR, South African CSA), sawdust (pine PSD, hornbeam HSD) and polyethylene, PP are the used waste- fuel of the process. The utilized methodology for an efficient plasma gasification is presented. The basic characteristics of syngas which are chemical content, energy content and temperature are given to determine energy conversion characteristics of the fuel. The utilized plasma power range is between 3000 W to 6000 W and air is the utilized plasma environment gas at the rates of 50 L/min, 75 L/min and 100 L/min.

2. EXPERIMENTAL TEST SYSTEM: MCW GASIFIER AND METHODOLOGY

MCw GASIFIER is an open cycle blower type atmospheric set-up which is given in Figure 1. The microwave plasma generation and control system is of MUEGGE. The system description is given in Table 1. The system is able to generate microwave plasma at a varying input power up to 6000 W at a frequency of 2450 MHz. Air is used as the plasma environment gas in the operational study presented. The system characteristics are given in Table 1.

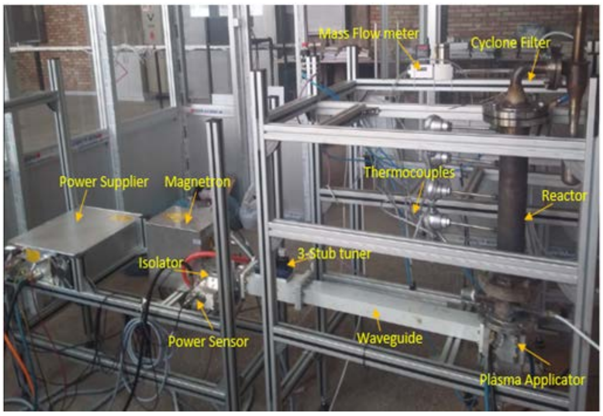


Figure 1.a: Photograph of System.

Solid waste samples of 3 different coal, 2 kinds of sawdust and polyethylene pellets (specified by codes of CR, CSA, CTR, HSD, PSD, PP) were used as fuel in powder form. The experimental results of proximate and ultimate analysis of the samples; are given in Table 2.

Plasma gasification of the fuel is produced in the fixed bed atmospheric pressure reactor with the application of microwave plasma. The outputs of the process is the so-called syngas and the residues left in the cyclone filter. Thermodynamic analysis based upon syngas characteristics is the key point for the determination of waste to energy conversion.

As is given in the recent article of the authors [3] thermodynamic analysis is provided in terms of first law and second law efficiency terms, η_{ES},, η_{EXS}, content conversion efficiency parameters, CCE and hydrogen quality H_q. The defined syngas based parameters are given in Table 3.

1.1. Operational study of MCw GASIFIER

The generation of microwave plasma flame is such that flame sustainability is almost independent of power for P≥ 3000 W. Therefore system operational study is conducted in the range of 3000 W- 6000 W.

Solid waste samples are fed in the reactor and a static-fixed bed is formed. The plasma applicator connected to the reactor head is at the bottom of the fixed bed. Therefore plasma flame is in upflow pattern. System is operated under atmospheric conditions. The utilization of plasma environment gas is air at the rates 50 L/min, 75 L/min and 100 L/min. The basic measurements are:

1. The local temperature measurements through the B type (Pt18Rh-Pt) thermocouples embedded at 5 locations (from the plasma applicator) of the reactor located at y/h =0.28 to y/h= 0.92 where h is 625 mm from the plasma applicator along the length of the reactor. The thermocouple locations are having equal intervals of 100 mm after the first thermocouple location close to the plasma applicator at the head of the reactor.
2. The measurement of MRU VARIO plus Semi –Continuous Syngas Monitoring System
3. The process time of gasification
4. The amount of the solid residue left at the cyclone filter at the end of the gasification
5. SEM analysis of solid residue

The operational study for each waste sample is such that start and end of the plasma gasification is determined by the output of Syngas Monitoring System. The process end is sensed by the content of syngas which is turned into pure air. Temperature measurements are taken at each 1 second interval and temperature data are stored in Elimko E-PR-110 model data acquisition card. The time- average of the collected data give the local magnitudes of temperature in the reactor. The outputs of the syngas monitoring are taken at each 2 second intervals. The time-average of syngas monitoring give the chemical content – distribution of fraction of components of the syngas during the gasification.

Temperature of syngas, Tsyn is defined as the average of the 5 different local time- averaged temperature measurements inside the reactor.

The operational study is done at a fixed amount of fuel used as 250 g. The process time for each case have differences depending on the type of the fuel applied power and used air amount. The measurements are taken timely through the gasification therefore a dynamic assessment of gasification is possible. The operational study range is given in Table 4.

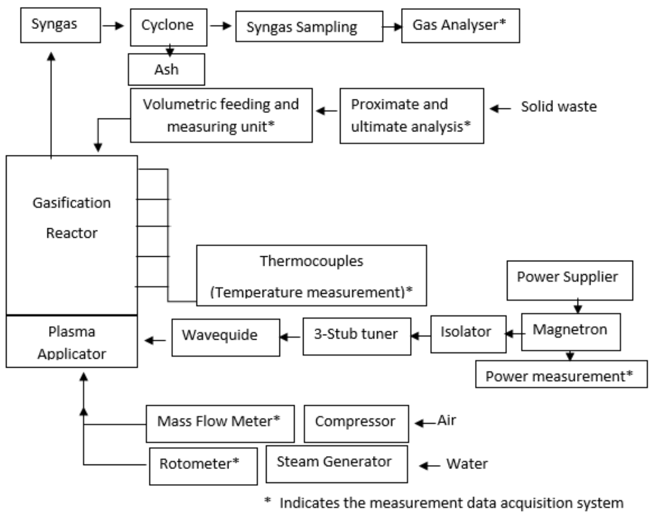


Figure 1b: Sketch of the realized set up with the conceptual process description

Table 1: Details of MCw GASIFIER System with Air Utilization as Plasma Gas

SYSTEMS OF MCw GASIFIER	TYPE	SUB-SYSTEMS(COMPONENTS)	CHARACTERISTICS-FUNCTION	UTILIZED RANGE
MICROWAVE PLASMA GENERATION AND CONTROL SYSTEM	MUEGGE (SOFTWARE PROGRAM: Muegge MX model control software	MX6000D-110K model power supplier MH6000S-213BF model magnetron head (In combination with Isolator, 3 Stub-Tuner, Wave Guide Plasma Applicator)	Generation of Power up to P= 6000 W Generation , control and transmission of microwave signal to introduce plasma	W < P < 6000 W SENSITIVITY : 1% VARIATION IN P Frequency of 2450 MHz
GASIFICATION REACTOR	HOME MADE FIXED FUEL BED ,CYLINDRICAL , SWIRLING INLET OF PLASMA GAS AT REACTOR HEAD	REACTOR HEAD (In combination with plasma applicator) MAIN BODY	MATERIAL: Stainless Steel Diameter: 8,1 cm Length : 50 cm UPWARD FLOW OF PLASMA FLAME	
PLASMA ENVIRONMENT FEEDING SYSTEM	Air Supplier: Lupamat LKV 30/8 model screw compressor.	Flow rate measurement: ALICAT MCR-250SLPM-D model mass flow controller is used	Compressed air which has maximum 8 bar pressure and 4850l/min flow	RANGE OF AIR FLOW: 50 ,75,100 l/min
FUEL-SOLID WASTE	Russian Coal CR South African Coal CSA Turkish Low Grade-Sirnak Coal CTR Hornbeam Sawdust HSD Pine Sawdust PSD Polyethtlene Particle PP		Coal Particle Size: 0.1 mm Sawdust Particle Size:1 mm Material Density –Measured kg/m3 CR: 701 CSA: 750 CTR: 930 HSD:230 PSD: 219 PP: 212	14.7 g/min - 35.71 g/min
MEASUREMENT AND DATA ACQUISITION SYSTEM	Local Temperature Measurement :B type (Pt18Rh-Pt) thermocouple Elimko E-PR-110 model data acquisition card. MRU VARIO plus Semi – Continuous Syngas Monitoring System	Up to 1820℃. Accuracy is ±4 C Oxygen 0-25% Carbon Monoxide 0-10 % /30%/100% Carbon Dioxide 0-10 % /30%/100% Methane 0-10 % /30%/100% Hydrogen 0-10 % /100%	Resolution: 0.01% Repeatability 1% Fs Response Time : 30 Seconds (From Analyzer Inlet Port) Linearity Error: 1%Fs Detection Limit : 0.05% Respectively 1 Ppm	SAMPLING RATE : 1 l/min- 1.33 l/min

Table 2: Measured Material Characteristics of Solid Waste Samples -Proximate Analysis * Adiabatic Bomb Calorimeter [5]

Fuel - Solıd Waste	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Calorific Value kJ/kg*	C (%)	H (%)	O (%)	N(%)	S (%)
CR	3.15	23.51	67.46	5.87	31336.05	66.81	4.49	21.72	1.00	0.11
CSA	3.40	25.94	55.94	14.71	30758.85	62.56	4.08	17.61	0.64	0.40
CTR	0.85	36.67	21.05	41.43	19954.03	42.18	3.75	5.96	0.35	6.33
HSD	17.39	72.58	10.02	0.69	21352.90	36.15	6.24	56.92	0.00	0.00
PSD	21.35	69.54	8.53	0.58	17941.66	39.66	6.45	53.30	0.00	0.00
PP	0.19	94.90	0.91	5.44	-----------	69.6	10.26	16.14	0.00	0.00

Table 3: Syngas –based definitions of thermodynamic analysis [3]

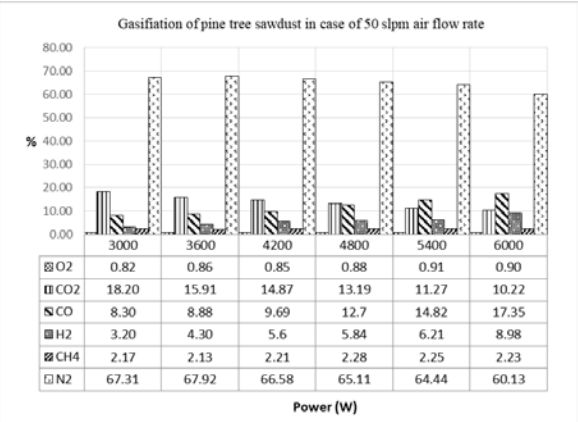
PARAMETER	DEFINITION
η_{EP}: First law efficiency of process η_{EXP}: Second law efficiency of the process	$\eta_{EP[\%]} = \frac{\dot{m}_{syn}(kg/s) \times HHV_{syn}(kJ/kg)}{\dot{m}_{fuel}(kg/s) \times HHV_{fuel}(kJ/kg)}$ $\eta_{EXP}[\%] = \frac{\dot{m}_{syn}(kg/s) \times Ex_{syngas}(kJ/kg)}{\dot{m}_{fuel}(kg/s) \times Ex_{fuel}(kJ/kg)}$
H_q: Hydrogen quality of syngas	$H_q[\%] = \frac{\dot{m}_{H_2}}{\dot{m}_{syn}}$
η_{ES}: First law efficiency of system η_{EXS}: Second law efficiency of the system	$\eta_{ES[\%]} = \frac{\dot{m}_{syn}(kg/s) \times HHV_{syn}(kJ/kg)}{\dot{m}_{fuel}(kg/s) \times HHV_{fuel}(kJ/kg) + W_{plasma}}$ $\eta_{EXS}[\%] = \frac{\dot{m}_{syn}(kg/s) \times Ex_{syngas}(kJ/kg)}{\dot{m}_{fuel}(kg/s) \times Ex_{fuel}(kJ/kg) + Ex_{plasma}(kW)}$
η_{HG}: Hot gas efficiency of system	$\eta_{HG[\%]} = \frac{\dot{m}_{syn}(kg/s) \times \left(HHV_{syn}(kJ/kg) + c_{p(syn)}(kJ/kg.K)(T_{syn} - T_o)(K)\right)}{\dot{m}_{fuel}(kg/s) \times HHV_{fuel}(kJ/kg) + W_{plasma}(kW)}$

Table 4: Operational Range of Mcw Gasifier

SOLID WASTE - FUEL	AIR l/min	FUEL GASIFICATION RATE RANGE g/min	USED PLASMA INPUT POWER W
CR, CTR, CSA,HSD, PSD,PP	50 75 100	14,7-35,71	3000, 3600, 4200, 4800, 5400, 6000
NUMBER OF TEST CASES	108	Amount of Fuel	250 g

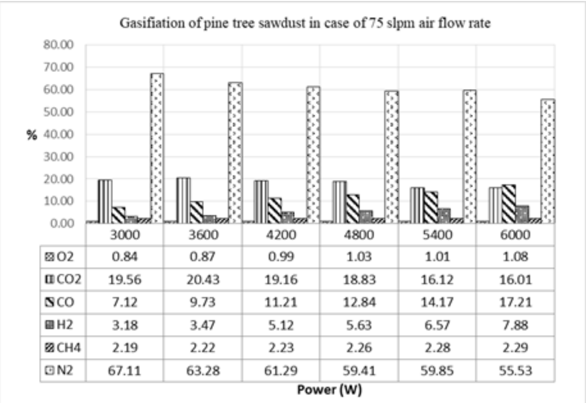
3. RESULTS AND DISCUSSION

Syngas production is a function of used fuel , applied power, and amount of plasma environment gas. The gasification rate is the parameter governing the procedure. In order to describe a sample case for the syngas characteristics the maximum gasification rate obtained in the operational study belonging to PSD at a variety of air flow rates are given . Figure 2 gives the syngas composition as function of power and air flow rate. Influence of power on distribution of the content is similar such that increase in power resulted in an increase of carbon monoxide , hydrogen, oxygen and nitrogen meanwhile a reduction is observed for carbondioxide and an almost constant methane. Oxygen and nitrogen amounts are almost the same for all of the cases. Figure 3 gives the local temperature variation during gasification process. The local temperature variation and the maximum magnitudes are similar for the covred cases. Syngas temperature . At maximum power of 6000 W the maximum syngas temperature is determined as 1168 C for 50l/min air flow rate increase in air flow rate results in a reduction in syngas temperature as 1152 C for 75l/min and 1128 C at 100l/min. Thermodynamic analysis results based upon the calculations described in [3] are given in Table 5. As can be seen increase in power is reflected in all calculated thermodynamic parameters. System efficiency is less than the process efficiency.



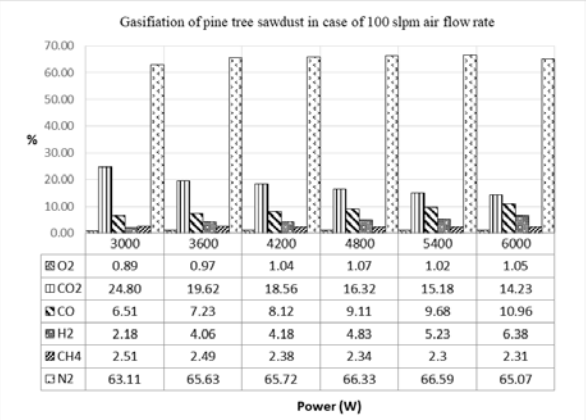
	3000	3600	4200	4800	5400	6000
O2	0.82	0.86	0.85	0.88	0.91	0.90
CO2	18.20	15.91	14.87	13.19	11.27	10.22
CO	8.30	8.88	9.69	12.7	14.82	17.35
H2	3.20	4.30	5.6	5.84	6.21	8.98
CH4	2.17	2.13	2.21	2.28	2.25	2.23
N2	67.31	67.92	66.58	65.11	64.44	60.13

Figure 2.a: The produced syngas fractions for the gasification of (PSD) in case of 50 sL/min air flow rate



	3000	3600	4200	4800	5400	6000
O2	0.84	0.87	0.99	1.03	1.01	1.08
CO2	19.56	20.43	19.16	18.83	16.12	16.01
CO	7.12	9.73	11.21	12.84	14.17	17.21
H2	3.18	3.47	5.12	5.63	6.57	7.88
CH4	2.19	2.22	2.23	2.26	2.28	2.29
N2	67.11	63.28	61.29	59.41	59.85	55.53

Figure 2.b: The produced syngas fractions for the gasification of (PSD) in case of 75 sL/min air flow rate



	3000	3600	4200	4800	5400	6000
O2	0.89	0.97	1.04	1.07	1.02	1.05
CO2	24.80	19.62	18.56	16.32	15.18	14.23
CO	6.51	7.23	8.12	9.11	9.68	10.96
H2	2.18	4.06	4.18	4.83	5.23	6.38
CH4	2.51	2.49	2.38	2.34	2.3	2.31
N2	63.11	65.63	65.72	66.33	66.59	65.07

Figure 2.c: The produced syngas fractions for the gasification of (PSD) in case of 100 sL/min air flow rate

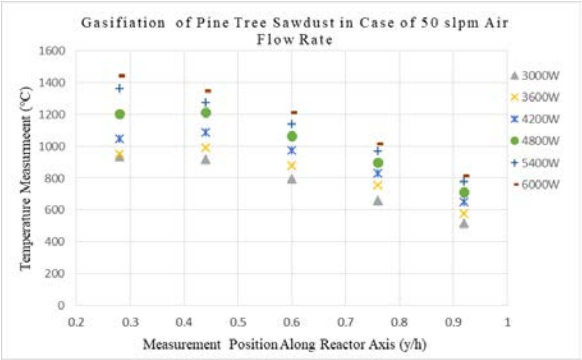


Figure 3.a: The temperature distribution for the gasification of (PSD) in case of 50 sL/min air flow rate

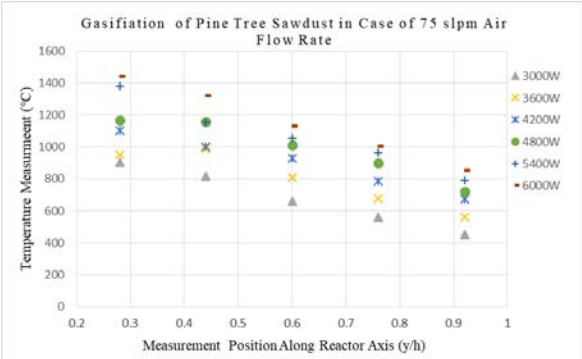


Figure 3.b: The temperature distribution for the gasification of (PSD) in case of 75sL/min air flow rate

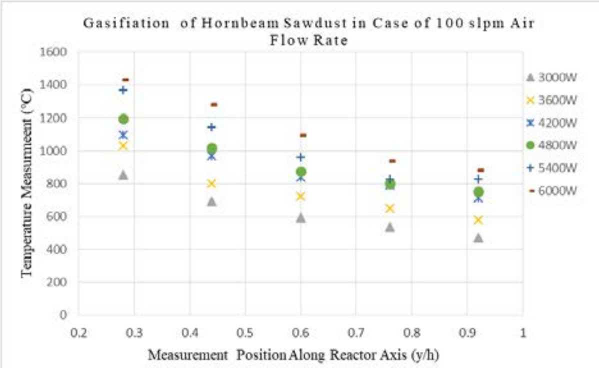


Figure 3.c: The temperature distribution for the gasification of (PSD) in case of 100 sL/min air flow rate

Table 5: Sample thermodynamic analysis results

AIR FLOW RATE L/min	Hydrogen quality-Hq %	First law Efficiency-EP %	First law Efficiency-ES%	Hot gas efficiency %	Process Exergy efficiency %	System Exergy efficiency %
50	0.21	43.28	27.24	35.84	16.33	8.84
	0.29	46.30	27.66	36.86	18.51	9.40
	0.39	50.91	29.11	39.30	21.82	10.50
	0.41	54.92	31.02	42.15	25.67	12.17
	0.44	58.45	32.14	43.98	29.34	13.47
	0.66	65.56	36.37	48.59	32.59	15.12
75	0.21	47.85	32.30	40.91	15.22	8.99
	0.23	53.45	34.58	45.33	20.64	11.56
	0.35	56.99	36.49	48.55	23.95	13.24
	0.38	59.18	37.01	50.19	27.50	14.77
	0.45	62.11	38.20	52.15	30.32	15.95
	0.55	66.38	41.09	55.71	33.98	18.02
100	0.14	50.93	35.67	44.40	15.36	9.50
	0.27	57.97	39.13	50.82	20.43	12.07
	0.28	58.70	38.04	52.42	25.97	14.58
	0.33	60.61	38.41	52.98	27.39	14.95
	0.36	60.65	37.58	53.62	30.98	16.45
	0.45	60.88	38.33	55.37	33.26	18.01

4. CONCLUSIONS

The operational study is presented and the preliminary calculations on syngas characteristics are described without considering the amount of residue left as a sample case. The inclusion of residue measurements is the current study which is still going on.

Acknowledgements

The presented paper - operational study of MCw GASIFIER is in the content of a research project with grant number 115M389 supported by Turkish Scientific and Technological Research Council TUBITAK-TURKEY.

References

[1] B. Leckner, Process aspects in combustion and gasification Waste-to-Energy (WtE) units. *Waste Management*, 2015, Vol. 37, 13-25.

[2] A. Sanlisoy, M. O. Carpinlioglu, paper presented at the *4th International Conferance on Renewable Energy Generation and Application*, France, 2016.

[3] M. Ozdinc Carpinlioglu, A. Sanlisoy, Performance assessment of plasma gasification for waste to energy conversion: A methodology for thermodynamic analysis. *International Journal of Hydrogen Energy*, 2017.

[4] L. Tang, H. Huang, H. Hao, K. Zhao, Development of Plasma Pyrolysis/Gasification Systems for Energy Efficient and Environmentally Sound Waste Disposal. *Journal of Electrostatics*, 2013, Vol. 71, 839-847.

[5] A. Sanlisoy, H. Melez, M. O. Carpinlioglu, Characteristics of the Solid Fuels for the Plasma Gasification. *Energy Procedia*, 2017, Vol. 141, 282-286.