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Simulation of Arc Plasma Gasification Based on Experimental Conditions

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Abstract. An EPJ process simulation model was set up and verified to simulate the plasma gasification process of the medical wastes. The influence of ER value and SAMR value was simulated based on experimental conditions including material feeding rate, furnace temperature and medical waste properties. Results shows that ER=0.3 is a turning point for medical waste plasma gasification. The required input plasma power and volume flow of combustible constituents in syngas reach the maximum at ER=0.3. The balance of syngas composition and required input plasma power should be overall considered. Results shows that the SAMR value mainly influences the amount of H element and N element in the system at a fixed ER value, thus influencing the proportions of H_2 and N_2 in monotonous ways. Input plasma power needed and combustible syngas flow increase with the increasing SAMR.

1 Introduction

Medical wastes are hazardous wastes produced along with daily medical treatment, which contain large amounts of medical plastics of high polymer like infusion bags, needle tubing and products of plant fibers like masks and cotton swabs. With high organic constituent in medical wastes, the harmless and reclamation disposal of medical wastes can be realized by high temperature gasification.

Arc thermal plasma gasification and melting technology is rising in China recently. Various types of gases flow through the gas passage of the plasma torch and can be ionized by the arc generated at high voltage, forming plasma jet with high temperature and producing a high temperature(usually higher than 1200°C) in gasification furnace which is far higher than conventional heating methods. Organics of the wastes are completely decomposed into small molecules like CO, H_2 and light hydrocarbons under high temperature and reducing atmosphere while inorganic matters are melt and later cooled down to form compact vitreous outside the furnace. As the Arc thermal plasma gasification and melting technology can realize thoroughly harmless, resourceful and reductive disposal, it is suitable to be applied in medical wastes disposal.

Process simulation is set up based on the thermomechanical analysis. Mountouris et al[1] set up an GasifEq model (equilibrium plasma gasification model) to describe the plasma gasification process, made thermomechanical analysis and verified the model; M.Minutillo et al[2] studied gasification process influenced by different gasification agents using a EPJ(EquiPlasmaJet) model; Mazzoni et al[3] simulated the plasma gasification process of municipal wastes and its blends based on Aspen Plus. In China, some small similar experimental systems are starting running recently and only a few process simulations are reported on sludge, biomass and coal[4]. This research did some works on the medical wastes plasma gasification based on EPJ model, aiming to provide some references to application of our self-designed plasma torch with high power and our related updraft plasma gasifier.

2 Model setup and verification

2.1 EPJ model set up

Process simulation of gasification model set up is usually a zero-dimension model and is set up based on several assumptions: 1) Solid wastes mix uniformly with gasification agents; 2) All reactions reach chemical equilibrium; 3) Reaction temperature is high enough to omit the tar and oil; 4) Ash content does not participate with reactions.

According to the EPJ model[2], the whole plasma gasification process is divided into several parts in an updraft gasifier as material drying, material pyrolysis, high-temperature and low-temperature gasification, split and mixing. The main flow sheet is presented below in Fig.1.

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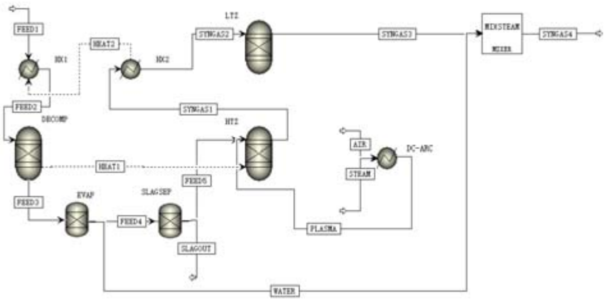

Fig. 1. Main flow of the EPJ model

2.2 Model verification

To test the rationality of the model and parameters, the material constituents and conditions used by Minutillo[2] were selected as Table 1 showed.

Table 1. Simulation parameters of verification case[2]

	Ultimate analysis%		Industrial analysis%	
Wastes	Cad	48.23	Mad	20
	Had	6.37	Aad	13.81
	Oad	28.48	Vad	75.95
	Nad	1.22	FCad	10.23
	Sad	0.76		
	Clad	1.13		
Input conditions	Material input rate		1kg/s	
	Plasma input power		4.2MW	
	Gas flow rate		0.782kg/s	
	Gas type		air	
	Gas temperature		2500°C	
	Steam sep ratio		85%	
	Syngas temperature		1240°C	
	Operating pressure		1atm	

The comparison of our result and Minutillo result[2] is presented in Table 2. According to the result, there is little error and the model is reliable.

Table 2. Simulation result comparison of EPJ model

Constituents	Simulation value(%,mol)	Result from Minutillo(%,mol)
CO	33.79	33.79
H_2	21.025	21.02
N_2	26.957	26.96
CO_2	0	0
H_2O	11.689	11.69
CH_4	5.988	5.99
HCl	0.316	0.32
H_2S	0.219	0.22
COS	0.0156	0.02

3 Plasma gasification simulation of Medical wastes

3.1 Material property and parameters

For the account of operation costs, our self-designed plasma torch is mainly applied in the disposal of medical wastes. Basic properties of typical medical wastes are quoted from research paper of Hongmei Zhu[5], including the industrial and ultimate analysis of various medical wastes constituents like plastic products as infusion apparatus, injectors and medical gloves, fiber products as cottons, bamboo sticks, gauze and paper masks, besides, possible biological tissues are similarly replaced by the properties of pork liver. According to research paper[5], a typical medical waste composition is 10.34% infusion apparatus, 8.47% injectors, 16.88% medical gloves, 6.21% cottons, 12.93% bamboo sticks, 11.49% gauze, 6.75% paper masks and 26.93% biological tissues. According to linear principle of blend constituents, mixture properties of medical waste is calculated as Table 3 shows.

Table 3. Properties of medical wastes

	Ultimate analysis%		Industrial analysis%	
Medical wastes	Cad	61.08	Mad	4.95
	Had	8.59	Aad	2.17
	Oad	19.59	Vad	86.78
	Nad	3.32	FCad	6.11
	Sad	0.23	Qad(J/g)	28199

According to our plasma gasification experiment with our self-designed air arc plasma torch and gasifier as Fig.2 shows, the power is variable between 30-250kW, the high and low gasification temperatures are 1700°C and 1200°C respectively.

Fig. 2. Air arc plasma torch(30-250kW) and gasifier(bottom 1200°C, top 1700°C)

Based on the experimental parameters, gasification process was simulated with variable ER(air equivalence ratio) value and SAMR value(steam and air mass ratio) to provide some references to engineering application[6,7].

Definition of indexes like ER and SAMR are as follows:

$$ER = \frac{Air_{realin}}{Air_{thoeryneed}} \quad (1)$$

$$SAMR = \frac{m_{steam}}{m_{air}} \quad (2)$$

Where Air_{realin} means the real air flow into the furnace, $Air_{thoeryneed}$ means the air flow needed for completely oxidation, m_{steam} means the mass flow of steam and m_{air} means the mass flow of air.

3.2 Simulation result and analysis

3.2.1 Simulation result with variable ER value

In simulation of ER influence, the ER values were set from 0.15 to 0.7,the plasma input power was adjusted to maintain a furnace high-temperature zone of 1700ºC, and the feeding rate of the material was set at 50kg/h.

The plasma input power curve varying with the ER value is showed in Fig.3. As the curve in Fig.3 shows, the plasma input power gradually increases to 152kW while the ER increases but keeps below 0.3, it is mainly because when ER value is rather low, the whole process is dominated by the endothermic gasification reactions, the heat released by oxidation is too less to compensate the heat needed by the added cold air, so the plasma input power has to increase to maintain the gasification temperature. However, as the ER continuing to increase, the plasma input power lowers down to 22kW, because partial oxidation reactions release more and more heat to hold the temperature and support the endothermic gasification reactions. It can be foreseen that the process might be self-maintaining when the ER is approaching 1 and the process becomes a combustion reaction due to the high heat value of the material. As the average heat efficiency of the plasma torch is about 0.7 according to our data from cooling system, when the ER value is among 0.15-0.7, the input plasma power is 22-152kW, the real torch power is calculated to be 31-217kW and can be covered by our plasma torch.

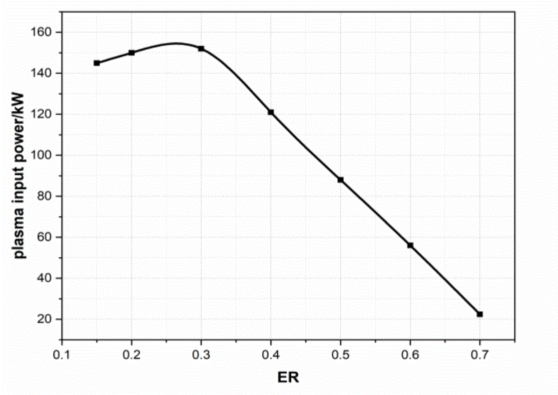

Fig. 3. Plasma input power varying with ER value

Fig.4 shows the gasification products constituents. According to the simulation result, the constituents of gasification products are greatly influenced by the ER value, which shows a gradually deepening degree of the oxidation. As we can see from the Fig. 4, the formation of H_2 and CH_4 presents obvious competition in cases when ER is lower than 0.3. CH_4 decomposes rapidly in the initial stage to form H_2 through reaction $CH_4 + O_2 \rightarrow CO + H_2$. CO keeps converting to CO_2 with ER increasing. A turning point for the process is at ER=0.3. The gasification enters a second stage when H_2 starts to form H_2O and CO accelerates to form CO_2 with ER value higher than 0.3. The share of N_2 keeps growing as the air volume increasing and O_2 being consumed to raise the oxidation valences.

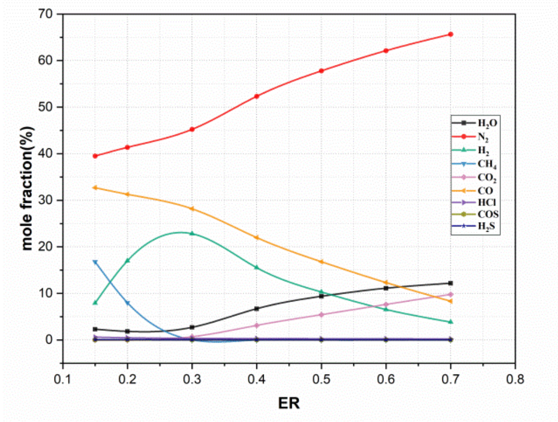

Fig. 4. Gasification products influenced by ER

CH_4, H_2 and CO are combustible and wanted constituents in gasification products, Fig.5 showed the volume flows of the syngas and amount of CH_4, H_2 and CO. It can be seen that the volume flow of combustible constituents reaches the maximum of 8.853m^3/min at ER=0.3. Synthesize all the simulation results and it can be concluded that the gasification products have best combustibility at ER=0.3, but the required input plasma power also reaches the highest. When choosing a proper ER value, the balance of syngas composition and required input plasma power should be overall considered.

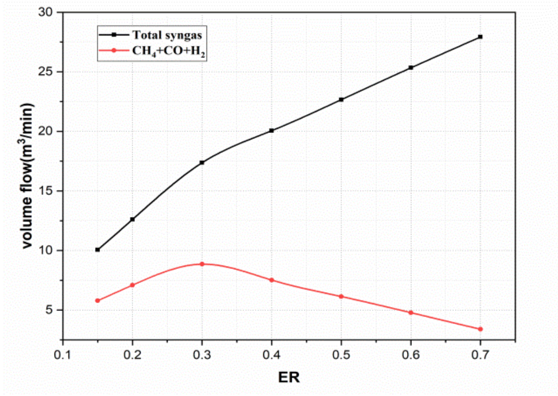

Fig. 5. Syngas volume flow influenced by ER

3.2.2 Simulation result with variable SAMR value

To improve the yield of combustible constituents in syngas, steam can be added to the process, partly taking the place of air from an independent inlet or severing as working medium of the plasma torch. To investigate the influence of H_2O, the simulations took the conditions of a fixed ER value of about 0.4, the plasma input power was adjusted to maintain a furnace high-temperature zone of 1700ºC, the feeding rate of the material was set at 50kg/h. SAMR values are solely adjusted to show the influence.

According to simulation result in Fig.6, the required input plasma power increases with the increasing SAMR. This is because that the increasing SAMR strengthens the gasification reactions which are endothermic.

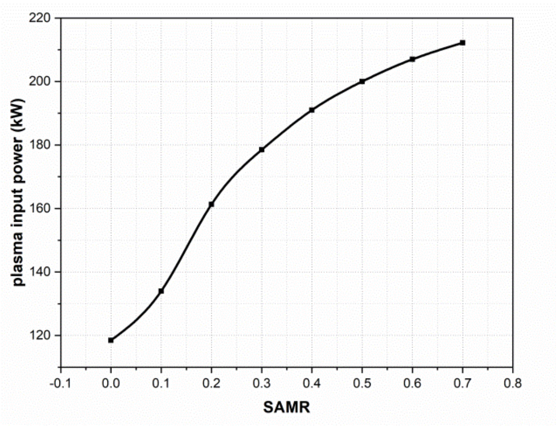

Fig. 6. Plasma input power varying with SAMR value

The constituents of gasification products is showed in Fig.7. As the Fig.7 shows, the proportion of N_2 obviously reduces with the increasing SAMR due to the reduction of air and N_2, while the proportion of H_2O increases rapidly at lower SAMR and grows slowly at higher SAMR with more H_2O takes part in gasification reaction. As a result, the proportion of H_2 increases rapidly with more H_2O fed in. Since the ER value is fixed, the proportions of CO and CO_2 change little with the increasing SAMR. It can be concluded from the simulation results that the variation of SAMR mainly changes the whole ratio of H element in the system, which leads to the increasing of H_2. And the formation of H_2 from H_2O consumes much energy.

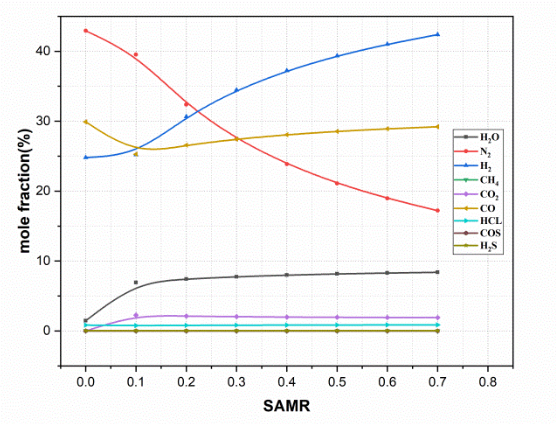

Fig. 7. Gasification products influenced by SAMR

The volume flows of the syngas and amount of CH_4, H_2 and CO are showed in Fig. 8.It can be seen from Fig.8 that the volume flow of combustible constituents keeps increasing with the SAMR, while the total gas flow firstly increases and then decreases. This trend can be simply explained by the share gap of H_2 increasing and N_2 decreasing. SAMR=0.1 is apparently a turning point. For more combustible and high heat value syngas, it is obvious that higher SAMR value is a better choice.

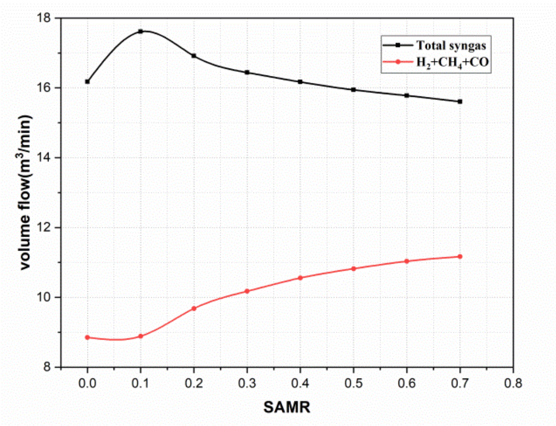

Fig. 8. Syngas volume flow influenced by SAMR

4 Conclusion

1) An EPJ process simulation model is set up and the reliability is verified by comparison with a reported case.

2) The influence of ER value is simulated based on experimental conditions. Results showed that ER=0.3 is a turning point for medical waste plasma gasification. The required input plasma power and volume flow of combustible constituents in syngas reach the maximum at ER=0.3. CH4 decomposes rapidly in the initial stage to form H2 in cases when ER lower than 0.3, H2 starts to form H2O and CO accelerates to form CO2 with ER value higher than 0.3.

3) The influence of SAMR value is simulated based on experimental conditions at a fixed ER value. Results showed that the SAMR value mainly influences the amount of H element and N element. Input plasma power needed and combustible syngas flow increases with the increasing SAMR.

Acknowledgements

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