# Emissions of $SO_2$, NO and $NO_2$ in biogas incinerator during Solid Waste gasification

Ningbo Gao, Aimin Li *
School of Environmental & Biological Science & Technology
Dalian University of Technology
Dalian 116024, China

*Abstract*— **A laboratory scale updraft fixed bed gasifier was designed to study the characteristics of gasification and incineration of organic solid wastes. Research had been carried out on the emission characteristics of $SO_2$, NO and $NO_2$ of solid wastes in the gasifier in different operation condition, the effects of reactor temperatures (650°C-790°C), gasification mediums (air and oxygen) and the flow rate of gas mediums (1m³/h, 3m³/h and 6m³/h) on the emission of $SO_2$, NO and $NO_2$ were studied. The results showed that lower reactor temperature and flow rates of gas medium were in favor of the yield of $NO_x$ and $SO_2$ reducing. The maximum concentrations of $NO_x$ and $SO_2$ were 77ppm and 98ppm in exhaust gas from afterburning chamber, respectively.**

***Keywords-organic solid waste; gasification and incineration; $NO_x$ and $SO_2$***

## I. INTRODUCTION

With significant prominent volume reduce and energy recycle, technology of incineration is regarded as one of the traditional methods to disposal solid waste. However, it is not a friend way with incineration technology for environment due to serious secondary pollution. Even the damage on environment is much more than that of solid wastes themselves [1, 2].

The main advantages of gasification-combustion system versus other alternatives are the decreasing volume of the ashes formed in comparison with the initial raw material. The stabilization of the material and the energy recovery due to the organic destruction and the conversion of unhealthy or noxious materials into harmless materials, it is one of the development directions of solid waste thermochemical treatments [3]. In fact, on one hand, gasification technology can be applied to convert the solid waste into a useable energy forms like electricity, combustible gases, synfuels, and to reduce the waste volume. Additionally, it prevents from the toxic organic compounds and fixes the heavy metals in the resultant solid ash as well as produces gas mixture, which can be efficiently utilised in the boilers for heat recovery and/or power generators for electricity generation[4], and the lower pollution technologies, on the other hand, is the base research of utilizing synthesis gases that produced from gasifier to generate electricity. The research on the pollutant levels of synthesis gases burning can give the reference to the industrial application of technologies.

Gasification is a form of "non-burn transformation" or "conversion" technology. Like distillation and pyrolysis (heating in the absence of oxygen) it turns solid waste into products for the fuel industry. Through participating in any of air, oxygen, steam or their mixture gases, organic solid wastes are oxidated partially and produce synthesis gases that can be utilized as fuels. The principle stages in the gasification are dryness, pyrolysis, oxidation and reduction. Gasification process is energetically self-sustaining as no thermal input is required at steady state conditions. During the gasification process, solid waste undergoes a complex physical and chemical change starting with the drying or removal of water contained as moisture. The dried solid waste is then pyrolysed. Finally, the pyrolysis products, for example, pyrolysis gases, tars and chars and vapours enter into the gasification layer, where they are concurrently oxidized and then reduced to sythesis gases at the reduction zone. The principal stages in the gasification are drying, pyrolysis, oxidation and reduction.

During the solid waste gasification, oxidation zone temperatures have been measured between 900°C and 1200°C. The gasification products mainly include carbon monoxide, carbon dioxide, hydrogen, methane, high chain hydrocarbon gases, vapours, nitrogen (if the gasification media using air), and other pollutants like residual char particles, ashes, and tars[5].

In this paper, the characteristics of organic solid waste gasification and producer gas incineration were studied. Experimental investigation was carried out at different operation condition for the emission characteristics of $SO_2$, NO and $NO_2$ during biogas incineration.

## I. EXPERIMENTAL SETUP

The experimental procedure used in performing gasification experimental is shown in Fig.1 and consisted of four parts: (1) a batch type, counter-current (updraft) fixed bed gasifier, (2) afterburning combustion chamber (3) feed gas supply system and (4) measuring equipments.

A laboratory scale updraft fixed bed gasifier is designed as a vertical rectangle reactor, as shown in Fig.1. The feedstock is supplied from the top and feed gas is added from the bottom of gasifier. The heating zone of the furnace is made of SiC ceramic and the reactor's dimensions: 115 mm long, 60 mm wide and 390 mm high. Outside of gasifier, firebrick linings were used for heat preservation. The feedstock is fed at the top of the reactor and moves downwards with reaction process. The air or steam intake is located at bottom and gasification

* Corresponding author: Tel& Fax: +86 0411 8470 7448
E-mail address: leeam@dlut.edu.cn. (Aimin Li)

978-1-4244-2902-8/09/$25.00 ©2009 IEEE

TABLE I. THE COMPOSITION AND RATIO OF SAMPLES

| Sample | Weight (kg) | Ratio of molar (%) |
|---|---|---|
| Wood scrap | 7.6 | 50 |
| Rice husk | 2.9 | 19 |
| Tire | 2.3 | 15 |
| Rubber | 2.5 | 16 |
| Total | 15.3 | 100 |

producer leaves system from top of reactor. A 6 kW electric furnace as energy input heats the reactor. The temperature of the gasifier freeboard may reach 950°C, when the temperature of the internal surface of the furnace is at 1000°C. Temperature was measured by three K-type thermocouples to record the temperature–time profile and was controlled by a personal computer. The three thermocouples were distributed at top, middle and bottom of reactor, respectively.

A steel pipe connects gasifier and afterburning combustion chamber (called afterburner). The produced fuel gas from gasifier is burned completely in afterburner. At the top of afterburner a 6.97 kW burner was set to combust the raw fuel gas and to assure the produced fuel gas burned completely. At the bottle of afterburner, an outlet which connected with an induced draft fan was designed to make sure the exhaust gas expelled from afterburner. The whole system pressure is lower than atmospheric pressure. Two K-type thermocouples also were used to record the temperature profiles of the afterburner. One was fixed at top and the other was suspended at the bottom of afterburner.

A feed gas supply system mainly supplies different gasification media gases with steady and adjustable flow rate. Air blower supplies air into gasifier and the air supply to the gasifier is provided by fans and is controlled to maintain certain flow rate by flowmeter. Air tank supplies pure oxygen into gasfier and the flow rate was also controlled with a flowmeter. Steam generator was designed to produce 100-120°C steam. Different voltages control the flow rate of steam and it can produce different flow capacities steadily.

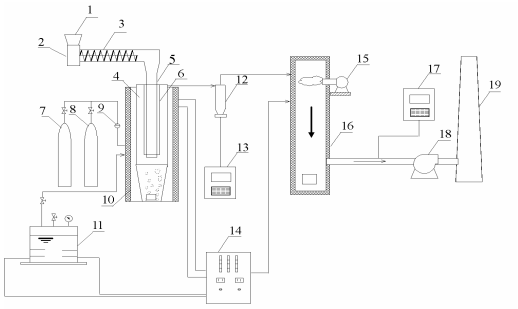


Fig 1. Schematic of the Experiment System
1.feed 2.gear case 3.screw feeder 4.reactor 5.biomass drop tube 6.reactor 7.oxygen bottle 8.air bottle 9.flowmeter 10.heating elements 11.steam generator 12.collect gasbag 13.flue gas analyzer 14.power and control board 15.combustor 16.afterburning combustion chamber 17.flue gas analyzer 18.fan 19.smoke pipeline

TABLE II. PROXIMATE ANALYSIS AND ULTIMATE ANALYSIS OF SAMPLES

| Sample | Wood scrap | Rice husk | Tire | Rubber |
|---|---|---|---|---|
| $M_{ad}$ | 12 | 17.18 | 1.02 | 1.15 |
| $V_{ad}$ | 75.05 | 38.98 | 64.92 | 67.03 |
| $A_{ad}$ | 0.54 | 17.38 | 6.55 | 29.74 |
| $FC_{ad}$ | 12.41 | 26.46 | 27.51 | 2.08 |
| C | 50.4 | 46.18 | 49.1 | 53.22 |
| H | 5.97 | 5.96 | 6.8 | 7.09 |
| O | 42.37 | 36.43 | 5.9 | 7.76 |
| N | 0.15 | 4.46 | 0.1 | 0.5 |
| S | 0.05 | 0.42 | 1.5 | 1.34 |

The system was fitted with chromel/alumel (K-type) thermocouple to measure temperature of gas at the gas outlet, the bottom and the middle temperature of gasifier, gas inlet and outlet temperature of afterburner. The temperature values were recorded continuously at 3 minutes intervals. A small portion of the gas was taken out of the main gas line, between the gasifier and afterburning chamber. Producer gas during each run was filled in rubber gas sampling bags at 10 min intervals. The gas in the rubber bags was used latterly for analysis on Gas Chromatograph for carbon monoxide, carbon dioxide, hydrogen, oxygen, nitrogen, methane, acetylene, ethane and ethylene compositions. A Teto350XL smoke gas analyzer is used on-line to analyse of the gas expelled from afterburner, that is $N_2$, $O_2$, $H_2$, CO, $CO_2$, $C_xH_y$, NO, $NO_2$, $NO_x$.

Four types of organic solid waste such as wood scrap, rice husk, rubber, and tire were mixed with different proportions as samples used in this work (see TABLE. 1). RETSCH SM-200 disintegrator crushed the samples. The mixture was crushed and sieved to approximate 0.5 cm. Table 2 shows the proximate analyses and the ultimate analyses for this mixture.

## II. RESULTS AND DISCUSSION

### A. Production Curve of $NO_x$ and $SO_2$ When Combustor Working in Afterburning Chamber

As the afterburning combustion chamber running along and without sample in gasifier, curves of $NO_x$ emission from combustion (with temperature of 1000°C) is shown in Fig.2. Peak concentration of $NO_x$ was 61ppm with no $SO_2$ being detected, which was due to reaction of $N_2$ and $O_2$ in high temperature atmosphere created by diesel oil (0#) burning in afterburning combustion chamber. Since concentration of $NO_2$ (~1ppm) was far less than the concentration of $NO_x$ and NO, it had not been illustrated in Fig.2. In addition, Fig.2 showed that NO was a little much higher than $NO_x$ in exceptional spot. Because the experiment errors were produced by little time's lag of monitoring on-line timely recorder situated at the back of system.

### B. Effect of Temperature on Emissions of $NO_x$ and $SO_2$

Temperature is a key factor to emissions of $NO_x$ and $SO_2$, in order to investigate its effect on gasification, experiments with oxygen flow of $3m^3/h$ were conducted in different temperatures. It can be illustrated from the experimental results shown in Fig.3. The concentrations of $NO_x$ and $NO_2$ were obviously different in various temperatures. Results showed that high temperature accompanying with high $NO_x$ concentration and low temperature corresponding with low concentration. At the beginning of reaction, the bottom of gasifier exits a dense phase area with sufficient oxygen where fuel was burned sufficiently and nitrogen in the fuel can be oxidized easily, whereas in the upper thin phase area $NO_x$ did not have proper reductive reaction condition. Especially, without plenty of reductive radical of OH and CH, which results in more production of $NO_2$ in a short time, the maximum amount of $NO_2$ reached approximate 14ppm in each temperature, a small peak existed in the production curve of $NO_2$. Subsequently, the concentration of $NO_2$ decreased and run to stable. It can be predicted that higher temperature prefers $NO_x$ forming and lower temperature may restrain its production. The base emission of $SO_2$ in the synthesis gas varied in the range of 33-13ppm in the temperature of 650°C, and 98-24ppm in 790°C. In either temperature the production curves of $SO_2$ had narrower variation. As reaction time increase, the concentration of $SO_2$ showed a decreasing trend. This may be due to the amount of sulfur in organic solid waste becoming more less. However, this cannot indicate that temperature has no influence on the production of $SO_2$. Higher temperature is, more sufficient gasification reaction goes on. Some inorganic sulfur and sulfur chain may produce more $SO_2$ reacted with oxygen.

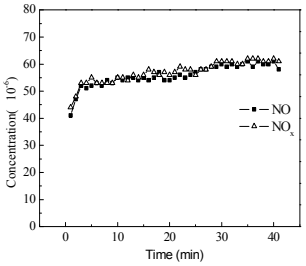


Fig2. Curves of $NO_x$ emission from combustion without sample in gasifier

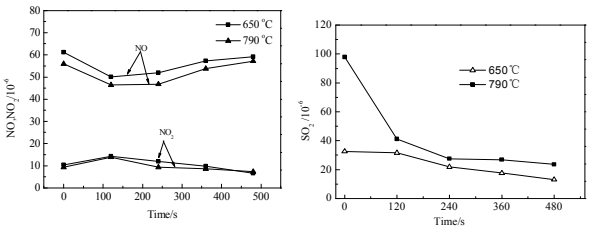


Fig3. Comparison of $NO_x$ & $SO_2$ emission values with different temperature

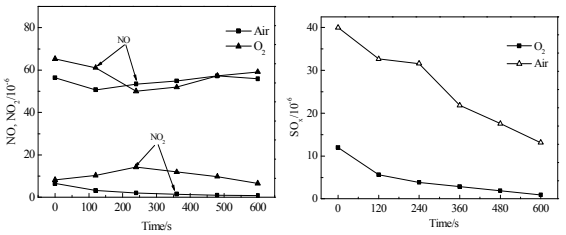


Fig4. Comparison of $NO_x$ & $SO_2$ emission value with different gasification medium

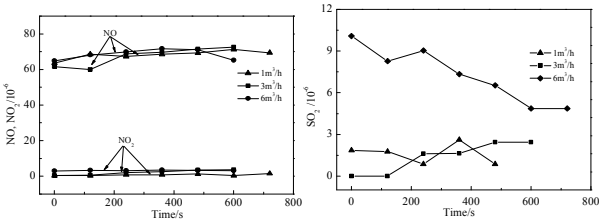


Fig5.Comparison of $NO_x$ & $SO_2$ emission value with different gas flow rate

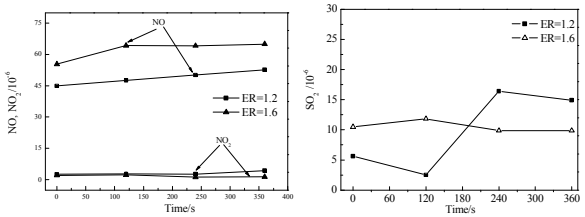


Fig6.Comparison of $NO_x$ & $SO_2$ emission under different work conditions

### C. Effect of gasification medium on emissions of $NO_x$ and $SO_2$

#### (1) Different gasification medium has different effects on emissions of $NO_x$ and $SO_2$

Gasification medium has significant effect on the composition of gasification production. The results of experiment with air and oxygen as gasification medium and in the flow rate gas of $3m^3/h$ were shown in Fig.4. It can be seen in the figure that the produced $NO_x$ concentration with oxygen as gasification medium is higher than that with air. With high concentration of $O_2$, the temperature of system rised sharply and reached 1150°C, then resulted in the forming of fuel nitrogen oxide more easily. This is disadvantageous to the process of combustion. The concentration of NO and $SO_2$ produced is lower because of inadequate reaction with air as gasification medium.

As more nitrogen exists in air, the oxygen concentration is lower than pure oxygen at the same flow rate. Deoxidized reaction was strengthened as insufficient oxygen reacts with nitrogen of strong ability of deoxidization in the process of gasification and combustion, which transforms organic nitrogen in fuel into $N_2$. In the environment of poor oxidization, inorganic sulfur turns to be more difficult to be oxidized, which leads to increasing of $N_2$ and loss of sulfur in

process of gasification. Accordingly, the concentration of $NO_x$ and $SO_2$ decreases in combustor chamber.

**(2) Effect of different flow rate on $NO_x$ and $SO_2$ with homogeneous gasification medium**

Oxygen flow rate varied from $1m^3/h$, $3m^3/h$ and $6m^3/h$ and keep other operation condition as same as mentioned above. Because medium products of HCN and NHi transfer to $N_2$ easily in low oxygen concentration and contrarily transfer to $NO_x$, whose concentration increases with increase of oxygen flow rate, as shown in Fig.5. As oxygen flow rate was increased from 1-$6m^3/h$, the concentration of NO increased obviously, attaining up to 73ppm at the oxygen flow rate of $3m^3/h$, and $NO_2$ decreased from about 3ppm to 1ppm with increasing of oxygen flow rate. According to Zeldovich reaction mechanism, since $NO_2$ comes from oxidation of NO and is so active in high temperature that is easily deoxidized to NO, it always keeps low concentration. $SO_2$ concentration had narrower variation in the oxygen flow rate of $1m^3/h$ and $3m^3/h$. The concentrations of $SO_2$ reached 2ppm and 3ppm respectively in the oxygen flow rate of $1m^3/h$ and $3m^3/h$. However, with the flow rate of $6m^3/h$, significant variation was showed from 10-5ppm. This might be explained by some inorganic sulfur which steady with less oxygen but produce $SO_2$ easily in high oxygen concentration[14].

**(3) Effect of excessive air coefficient on emission of $NO_x$ and $SO_2$**

Experiments were carried out for excessive air coefficient increase from 1.2 to 1.6. Concentrations of several kinds of producing gases with either excessive air coefficient value were depicted in Fig.6. Excessive air coefficient value determined the reaction degree of gas across afterburning chamber comparing with its reaction equation. Air excessive coefficient relates closely with reaction temperature in afterburning chamber, in some degree, high air excessive coefficient depende on high temperature, two effects were showed as follows: on the one hand with high air excessive coefficient, reaction temperature in afterburning chamber rises and gas-producing quantity raises for reaction rate's acceleration, on the other hand high air excessive coefficient make oxidation reaction accelerate, which is helpful of producing more $NO_x$ and $SO_2$. it is very important for gasification and combustion to choose proper air excessive coefficient. It is easily seen from experiment that mean producing-quantity of $NO_x$ with air excessive coefficient of 1.6 was 1.25 times than that of 1.2 but total quantity of $NO_x$ was only 66ppm, which was the result that little excessive air provided more oxygen which avail oxidation of nitrogen along with high temperature in afterburning chamber. Air has a well warm-up process as its entering firebox from combustor chamber. Oxygen firstly reacts with combustible gas from gasification furnace, the remainder oxygen produces $NO_x$ by reacting with nitrogen, so it can make combustion, gasification and incineration more efficient to adjust the air flow rate of incineration chamber.

## III. CONCLUSIONS

The effect of factors on emissions of $NO_x$ and $SO_2$ in gasification and combustion smoke is analyzed in this paper. The following conclusions can be drawn.

(1) Temperature has important effect on $NO_x$ and $SO_2$ emission. NO production rate increases obviously and however, the production of $SO_2$ varies inconspicuously with temperature.

(2) At different operation conditions, such as types and flow rate of gasification medium, gasification condition, have effect on emissions of $NO_x$ and $SO_2$.

(3) The maximum concentrations of $NO_x$ and $SO_2$ are 77ppm and 98ppm respectively in the excluded gas from combustion, which proves the decrease degree of combustion in afterburning chamber since the concentrations meet the national emission control regulations with all data, has been transferred to standard condition.

## REFERENCES


[1] L. BÃÃbar, StehlÃÃk P., Havlen L. et al. "Analysis of using gasification and incineration for thermal processing of wastes". Applied Thermal Engineering. 2005, 25(7):1045-1055.

[2] R. Warnecke. "Gasification of biomass: comparison of fixed bed and fluidized bed gasifier". Biomass and Bioenergy. 2000, 18:489-497.

[3] A. Demirbas. "Biomass resource facilities and biomass conversion processing for fuels and chemicals". Energy Conversion and Management. 2001, 42(11):1357-1378.

[4] M. Dogru, Midilli A., Howarth C. R. "Gasification of sewage sludge using a throated downdraft gasifier and uncertainty analysis". Fuel Processing Technology. 2002, 75(1):55-82.

[5] V. Belgiorno, De Feo G., Della Rocca C. et al. "Energy from gasification of solid wastes". Waste Management. 2003, 23(1):1-15.

[6] S. C. Hill, Douglas Smoot L. "Modeling of nitrogen oxides formation and destruction in combustion systems". Progress in Energy and Combustion Science. 2000, 26(4-6):417-458.

[7] U. Kesgin. "Genetic algorithm and artificial neural network for engine optimisation of efficiency and NOx emission". 2004, 83(7-8):885-895.

[8] J. JE. "Formation and reduction of nitrogen oxides in fluidized bed combustion". Fuel. 1994, 73(9):1398-1415.

[9] J. Werther, Ogada T. "Sewage sludge combustion". Progress in Energy and Combustion Science. 1999, 25(1):55-116.

[10] J. P. Dunn, Koppula P. R., G. Stenger H. et al. "Oxidation of sulfur dioxide to sulfur trioxide over supported vanadia catalysts". Applied Catalysis B: Environmental. 1998, 19(2):103-117.

[11] T. Kojima, Assavadakorn P., Furusawa T. "Measurement and evaluation of gasification kinetics of sawdust char with steam in an experimental fluidized bed". Fuel Processing Technology. 1993, 36:201-207.

[12] G. Schuster, Löffler G., Weigl K. et al. "Biomass steam gasification - an extensive parametric modeling study ". Bioresource Technology. 2001, 77(1):71-79.

[13] W. J. Wendt JOL, Corley TL. "Post Flame Behavior of Nitrogenous Species in the Presence of Fuel Sulfur. I. Rich, Moist, CO/Ar/O2 Flames". Combust and Flame. 1983, 49:261-274.

[14] J.L.Ontiveros, T.L.Clapp, D.S.Kosson. "Physical properties and chemical species distributions within municipal waste combuster ashes". Environmental Progress. 1989, 8(3):222-206.