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Research

OPTIMIZATION OF SULPHATE LIGNIN RECYCLING IN AIR PLASMA

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ABSTRACT

Article represents low-temperature plasma application to recycle paper and paperboard industry waste. Paper also describes calculation of combustion parameters of water-organic compositions having different formulations. Authors determine the optimal water-organic composition based on sulphate lignin to effective utilize. In this paper it was used a thermodynamic simulation method of burning process in plasma. Authors show experiments that were carried out on laboratory plasma stand. All experimental results are in accordance with calculations.

INTRODUCTION

Lignin is a wood component which is hard to utilize. It produces during wood chemical conversion at paper and paperboard plants (Sarkanaeva *et al.*, 1975; Clopman, 1968).

On the other hand it is a potential raw material resource for many countries. According to the International Lignin Institute annually in the world 70 million tons of technical lignin are produced, but only 2% are used for industrial, agricultural and other purposes. The rest is burned in power plants or disposed as sludge lignin (SlL) (Bogdanov *et al.*, 2000; Pestova, 2013).

Nowadays there are not effective technologies to utilize SlL, although literature review last time shows increasing interest of scientist to this problem.

Sulpate lignin (SL) produces at paper and paperboard plants during chemical digestion of wood. SL equals to 30–35% of the feedstock and has permanent formulation (Holkin, 1989; Ventsyulis et al., 2009):

- Ash 1.0–2.5%;
- Acids (most sulphuric) 0.1–0.3%;
- Water-dilutable compounds 9–11%;
- Resiny compounds 0.3–0.4%;
- Klason's lignin 85% (sulfur content 2.0–2.5% including unconsolidated 0.4– 0.9%).

Often SL is used as boiler fuel. Caloric value of dry lignin is 5500– 6500 kcal/kg, 18–25% humidity – 4400–4800 kcal/kg, 65% humidity – 1500–1650 kcal/kg (Holkin, 1989).

MATERIALS AND METHODS

Effective and environment-friendly utilization of waste based on lignin could be reached in plasma. SL is induced by utilization in form of water-organic composition (WOC) having optimal formulation and adiabatic combustion temperature of 1200°C.

Liquid combustible compositions are compositions with a net calorific value of more than 8.4 MJ/kg. The net calorific value of an inflammable composition should be calculated as the net calorific value of liquid waste Q_l:

$$Q_l = \frac{(100 - W - A) \cdot Q_d}{100} - \frac{2.5 \cdot W}{100}, [MJ/kg], \quad (1)$$

where Q_d is the net calorific value of dry waste [MJ/kg]; W and A are the respective contents of water and solids [%]; 2.5 is the value of latent heat of water vaporization at 0°C [MJ/kg].

The recommendation to regard liquid compositions with $Q_l \geq 8.4$ MJ/kg as inflammable is overstated for many industrial compositions containing combustible components with low values of Q_d.

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A more objective combustibility rate of liquid inflammable compositions is the adiabatic combustion temperature T_{ad}:

$$T_{ad} = \frac{Q_l + C_{was} \cdot t_{was} + \alpha \cdot \vartheta^0_{ox} \cdot C_{ox} \cdot t_{ox}}{\upsilon \cdot C + \frac{W \cdot C_W}{100} + \frac{A \cdot C_A}{100}}, [°C], \quad (2)$$

where C_{was} is the average mass heat capacity of liquid waste [kJ/kg]; t_{was} is the temperature of liquid waste [°C]; α is the oxidant flow coefficient; ϑ^0_α is the theoretical flow of oxidant [m^3/m^3]; C_{ox} is the average heat capacity of the oxidizer [kJ/(m^3·°C)]; t_{ox} is the temperature of the oxidizer [°C]; υ are the combustion products of the inflammable components of liquid waste [m^3/kg]; C is the average volumetric heat capacity of the combustion products of inflammable waste components [kJ/(m^3·°C)]; C_W and C_A are the average mass heat capacity of water vapor and impurities (incombustible mineral materials of composition) [kJ/(kg·°C)].

Fig. 1 shows influence of SL content on adiabatic combustion temperature of optimal WOC.

Based on the calculation findings optimal WOC was determed with maximus SL content (70% water: 30% SL). It has $T_{ad} \approx$ 1200°C net calorific value 6.34 MJ/kg. Plasma recycling of 1 ton/h of such WOC lets to get 1.76 MW-h additional heat energy.

To determine optimal modes of research process equilibrium formulations of gaseous and condensed products were calculated for case SL plasma utilization. Licensed PC program «TERRA» was used for this purposes.

Initial parameters of calculations were pressure (0.1 MPa), temperature range (300–4000 K) and heat transfer agent (air) mass fraction (0.1–0.95).

Fig. 2 shows characteristic equilibrium formulation of gaseous (a) and condensed (b) products of SL plasma utilization in form of WOC where air mass fraction is 72%.

Graphs show that at temperatures up to 1500 K main gaseous products are N_2, H_2O and CO_2 (fig. 2a). Main condensed products are C(c), Al_2O_3, $CaSiO_3$ (fig. 2b).

Presence of soot C(c) points out that SL utilization

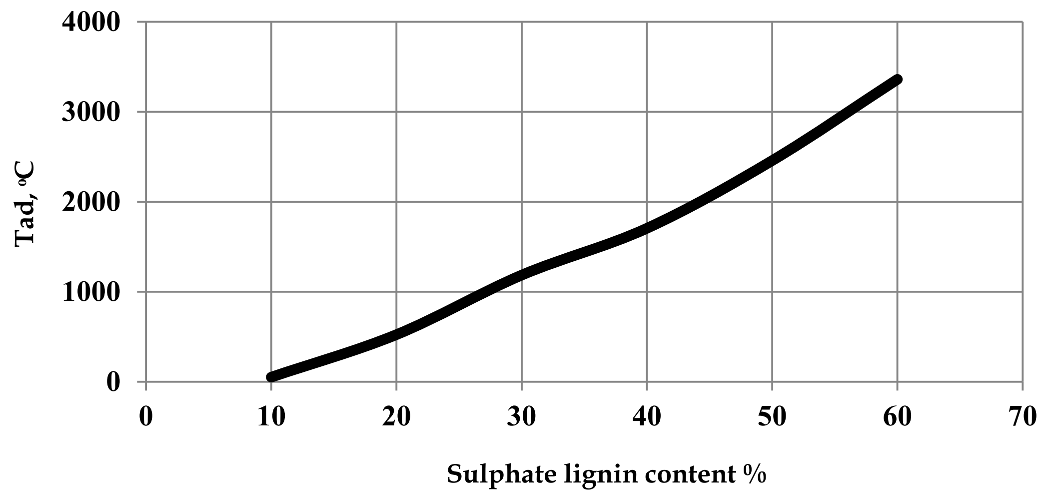
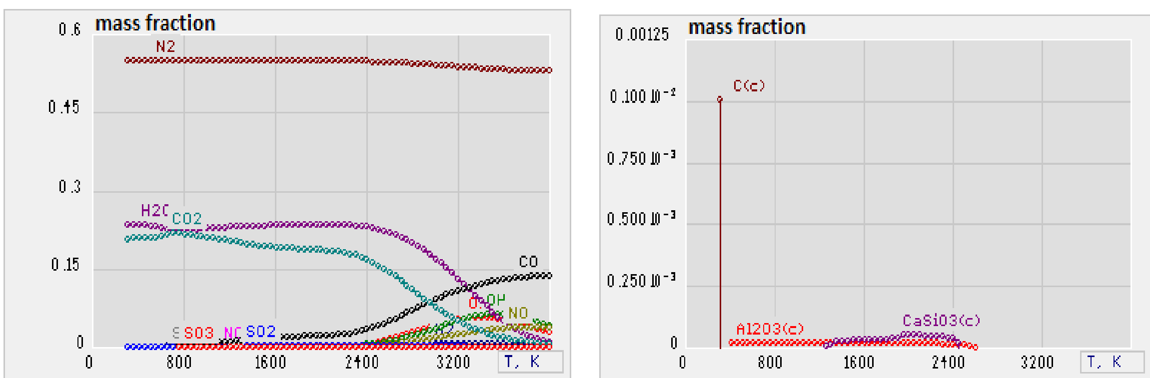
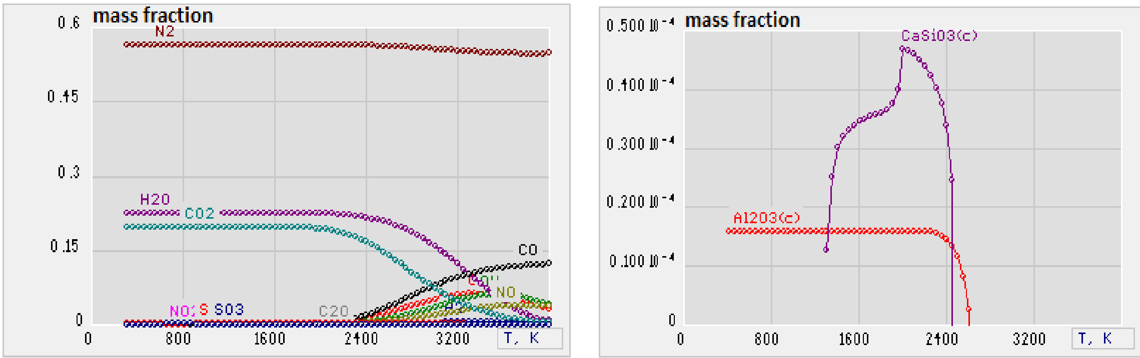


Fig. 1 Influence of SL content on adiabatic combustion temperature of optimal WOC.



a) b)

Fig. 2 Equilibrium formulation of gaseous (a) and condensed (b) products of SL plasma utilization in form of WOC (72 % air: 28 % WOC).



a) b)

Fig. 3 Equilibrium formulation of gaseous (a) and condensed (b) products of SL plasma utilization in form of WOC (74 % air: 26 % WOC).

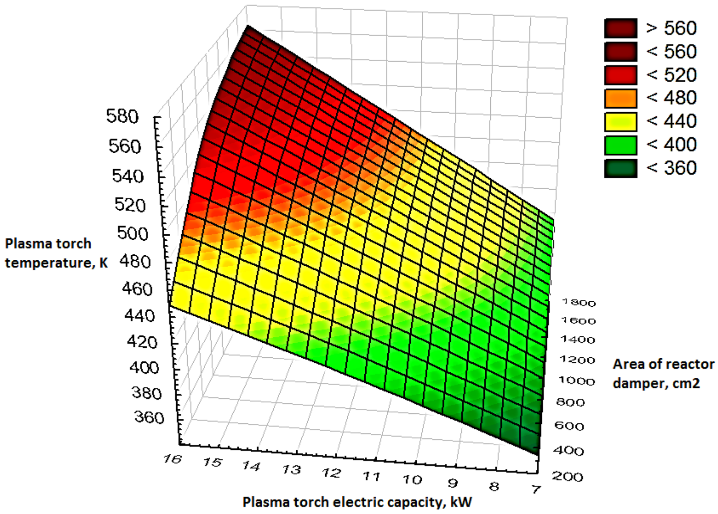


Fig. 4 Influence of plasma torch electric capacity generated by plasmatron and area of reactor damper on plasma torch temperature.

process in air plasma in this case (72% of air) occurs abnormally.

Increase in air mass fraction from 72% to 74% leads to disappearance of soot C(c) (fig. 3b). This fact suggests that SL utilization process in air plasma in this case (74% of air) occurs normally.

It should be noticed that absence of NO among gaseous products (fig. 3a) confirms that at temperatures up to 1500 K research process occurs normally when air mass fraction was increased up to 74%.

According obtained results next optimal modes of SL utilization process could be recommended for practical application:

– Heat transfer agent of plasma: air;

– WOC formulation: 70% water: 30% SL;

– Mass fraction of phases: 74% air: 26% WOC;

– Temperature interval: 1200 ± 100°C.

RESULTS

Some experiments were carried out on plasmatron. Fig. 4 represents influence of plasma torch electric capacity generated by plasmatron and area of reactor damper on plasma torch temperature.

Based on the functional connection it is obviously that plasma torch electric capacity generated by plasmatron and area of reactor damper have a strong effect on plasma torch temperature.

Fig. 5 represents influence of plasma torch electric capacity generated by plasmatron and area of reactor damper on unit efficiency.

According to obtained results of mode research, it is possible to conclude that optimal mode parameters are next: anode current (4 A), input area of reactor impeller (1155–1485 cm^2). In this case, unit efficiency reaches 51.6% and maximum plasma torch temperature equals 255°C.

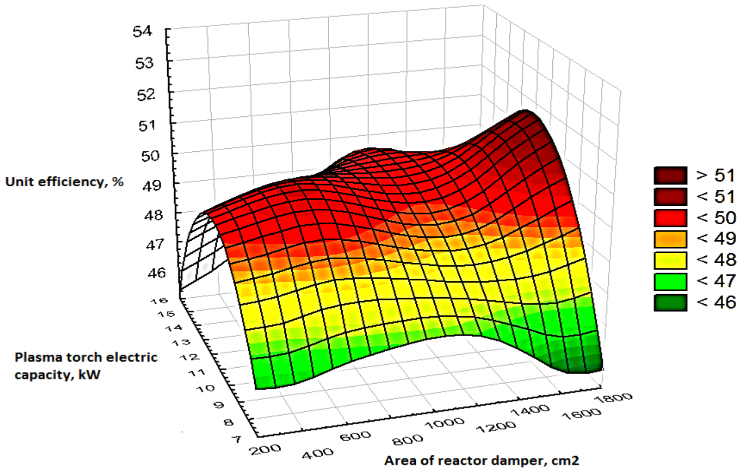


Fig. 5 Influence of plasma torch electric capacity generated by plasmatron and area of reactor damper on unit efficiency.

Taking into account this temperature data and temperature of plasma torch, it should be that plasma torch is able to provide an inflammation and an ignition of WOC in rector.

CONCLUSION

On the grounds of carried out experiments it is possible to make a conclusion that optimal HFT plasmatrom operational mode could be reached with anode current of 4 A, input area of reactor dumper from 1155 to 1485 cm^2. Wherein coefficient of efficiency of plasma module reaches 51.6% and maximum plasma flow temperature is 255°C.

All the obtained results could be used in creating commercial plants based on HFT plasmatrom for effective plasma recycling and utilization of different industrial wastes.

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