Phosphorus Behavior in Supercritical Water Gasification of Sewage Sludge

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Abstract

Phosphorus is an important nutrient for living organism and a non-substitutable constituent of agricultural fertilizers. In this study, the phosphorus behavior in supercritical water gasification (SCWG) of sewage sludge was investigated. A continuous reactor was employed in this study. The experimental condition has been decided at 500, 550 and 600 °C and varies residence time 5, 10, 20, 30, 40, 50 and 60 s and a fix pressure 25 MPa. The effect of temperature and residence time for behavior of phosphorus in supercritical water gasification (SCWG) of sewage sludge was investigated. The result showed that the organic phosphorus (OP) was rapidly converted into inorganic phosphorus (IP) at 5-10 s.

1. Introduction

Nowadays, phosphorus resources is getting limited. Since phosphorus is considered as one of fundamental elements for living organisms [1], recovery and reuse of this element is urgently needed. Sewage sludge are represents an important secondary phosphorus source. Sewage sludge is a waste water treatment by-product rich in phosphorus (the P2O5 content of sewage sludge ashes ranges from 14% to 25%)[3,4].

Various technologies have been employed to convert sewage sludge into beneficial secondary energy via combustion, pyrolysis[5] and supercritical water gasification[3,6]. However, sewage sludge content has a lot of water with 85% water content, causing high drying cost when combustion and pyrolysis is applied. Hence, SCWG is considered as a promising technology to convert biomass containing high-moisture compounds such as sewage sludge since the gasification reaction takes place under supercritical water condition. Aceles at al.[3] have conducted the gasification of dewatered sewage sludge in SCW for energy recovery combined with phosphorus recovery. However, batch reactor was employed in their study. However, detailed study about phosphorus behavior in supercritical water gasification of SS has not been examined well. Thus, the objective of this study is to investigate the phosphorus behavior in supercritical water gasification of SS. A continuous reactor was employed, the pressure can be constantly controlled and elucidation of the reaction kinetics is much more precise than that in a batch reactor

2. Experimental (or Procedures)

The SCWG of sewage sludge was carried out in continuous reactor. The schematic of the experimental apparatus is shown in **Fig.1**. The reactor was made of SS316 steel tubing (i.d. 2.17 mm, o.d., 3.18 mm, and length 12 m). The reactor was placed inside the electric furnace. Initially, water was fed into the reactor. Subsequently, the pressure is increased to 25 MPa using a back pressure regulator. The feedstock was then fed using feeding system with the agitation speed of 400 rpm. After reactor reach the desired experimental condition, the feedstock was fed into the system. To ensure a steady-state condition, the feedstock was fed into the system for 1 h prior to sample collection. All reaction products were cooled in a heat exchanger, and when a constant gas generation rate had been achieved, gas samples were collected in vials and their compositions were determined. Liquid samples were also collected to determine the total organic carbon (TOC) content. Phosphorus yield in liquid phase was determined using ion chromatography (IC) to quantify inorganic phosphorus (IP), and molybdenum blue method to quantify total phosphorus (TP). IP and TP yields were determined using Eq. (1) and (2).

$$IP\ yield = \frac{\text{IP in liquid sample [mol−P]}}{\text{TP in feedstock [mol−P]}} \qquad (1)$$

$$TP\ yield = \frac{\text{TP in liquid sample [mol−P]}}{\text{TP in feedstock [mol−P]}} \qquad (2)$$

From Eq. (1) and (2) we can derive the equation to determined organic phosphorus (OP) and left IP. The equation as follows:

$$OP\ yield = TP\ yield - IP\ yield \qquad (3)$$

$$left\ IP\ yield = 1 - TP\ yield \qquad (4)$$

Were, left IP yield is part of phosphorus it was remaining in the reactor during the cooling down of reactor after the experiment, and also it was found in aqueous phase. All experimental runs were conducted in triplicate, and the average was taken.

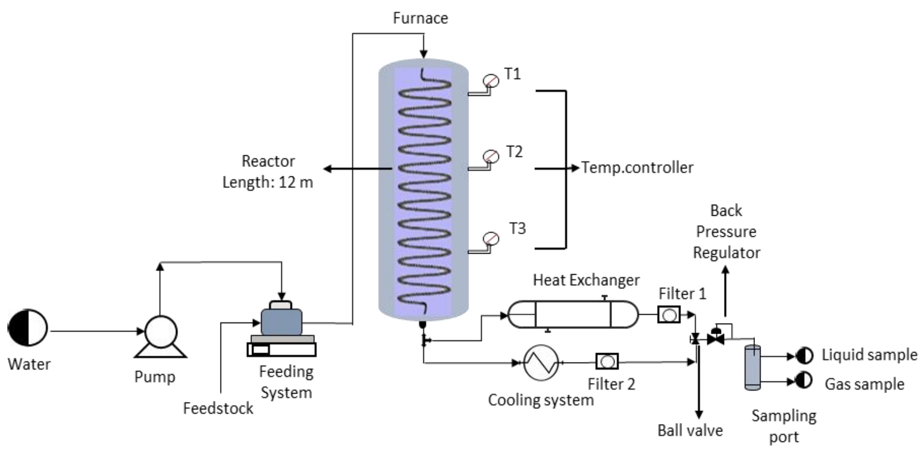

Fig.1. Experimental apparatus

3. Results and Discussion

Fig.2. shows the phosphorus yield at 500 °C with different residence time. The yield of organic phosphorus (OP) decreased with time. Inorganic phosphorus increased at 10 s and decreased to 0.6 mol-P/mol-P at 60 s.

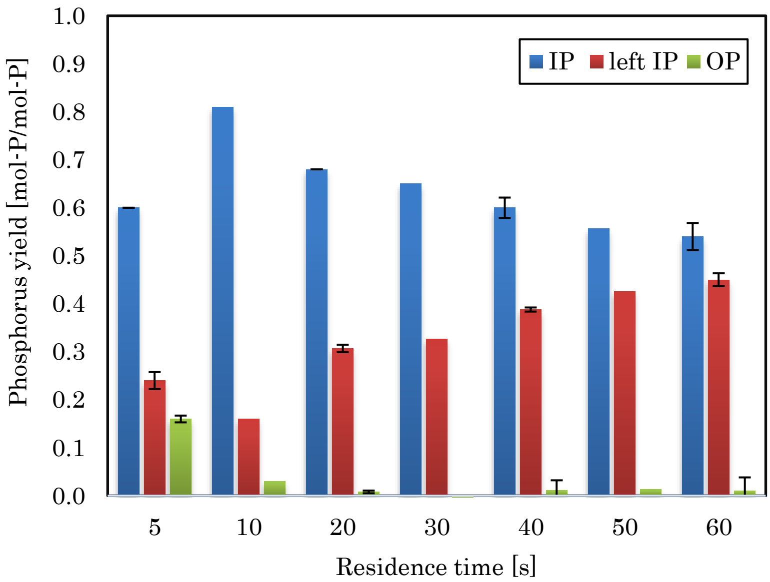

Fig.2. Effect of residence time on phosphorus behavior in SCWG of sewage sludge at 500 °C

Fig.3. reveals the effect of residence time on phosphorus behavior at 550 °C. The yield of organic phosphorus (OP) decreased with time, whereas the inorganic phosphorus (IP) increased at 10 s and decreased slowly with time.

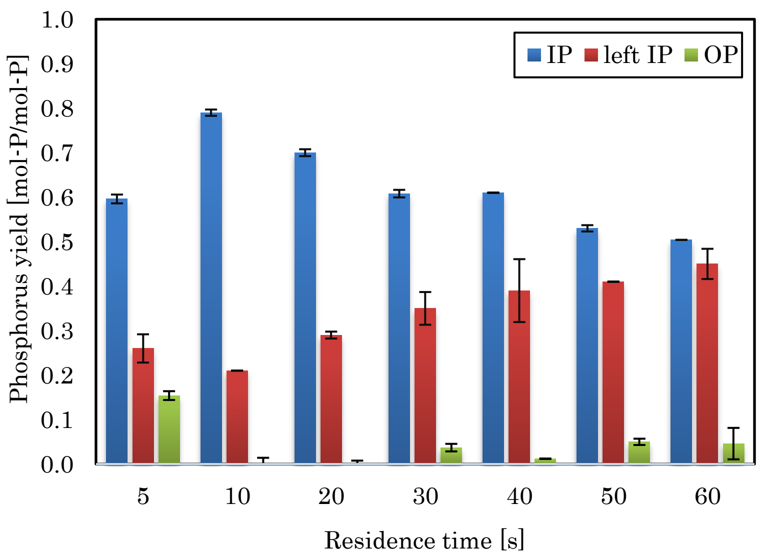

Fig.3. Effect of residence time on phosphorus behavior in SCWG of sewage sludge at 550 °C.

Effect of residence time on phosphorus behavior at 600 °C is shown in **Fig.4.** As observed, IP yield as high as 0.84 mol-P/mol-P was achieved at 10 s. The organic phosphorus (OP) yield decreased with time.

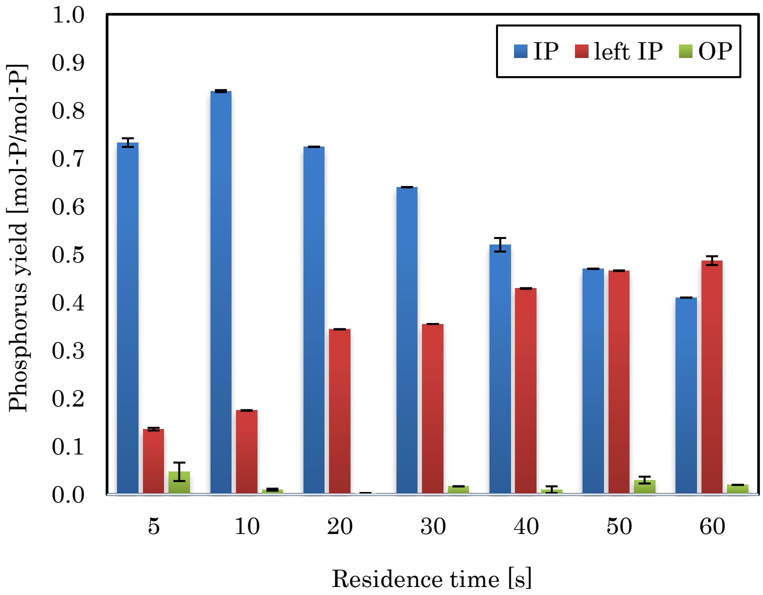

Fig.4. Effect of residence time on phosphorus behavior in SCWG of sewage sludge at 600 °C.

It could be confirmed that the residence time effected on phosphorus yield in liquid product. Overall, the organic phosphorus (OP) was rapidly converted into inorganic phosphorus (IP) within short residence time of 10 s. Interestingly, the yield of left IP for all experimental condition also increased with temperature and time. It is due to the fact that part of phosphorus re-dissolves during the cooling down of reactor after the experiment.

4. Conclusion

The forms of P in supercritical water gasification (SCWG) of sewage sludge were investigated in this study. Reaction parameters including reaction temperature and residence time were studied to explore the behavior of phosphorus from liquid products after SCWG of sewage sludge. The organic phosphorus (OP) was almost converted into inorganic phosphorus (IP) during SCWG at short residence time (10 s). The yield of left IP also increased with temperature and time. It is due to the fact that part of phosphorus re-dissolves during the cooling down of reactor after the experiment.

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