Novel Phosphorus Recovery from Sewage Sludge Using Supercritical Water Gasification

by Apip Amrullah

NOVEL PHOSPHORUS RECOVERY FROM SEWAGE SLUDGE USING SUPERCRITICAL WATER GASIFICATION

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ABSTRACT: The aim of this work is to develop a new phosphorus recovery from sewage sludge using the supercritical water gasification treatment. The experiment was carried out using a laboratory scale continuous reactor under several temperatures in the range of 350-600 ºC. The pressure was kept at 25 MPa and varying residence time in the range of 5-30 s. It was found in this study that the phosphate ions could be collected as precipitate in the supercritical water gasification and phosphorus could be successfully recovered and separated from the organics. Surprisingly, phosphorus was released to the liquid phase in inorganic form much before the completion of gasification. This behavior of phosphorus was expressed in the reaction model incorporated with the precipitation model. The model fit well with the experimental result.
Keywords: phosphorus, precipitation, supercritical, sewage sludge.

1 INTRODUCTION

The global warming issue, depletion of fossil fuel, and increased energy consumption are global concern in the current era. To cope these issues renewable energy is a promising solution. Biomass is easy to use due to its chemical energy form. Among various kinds of biomass, sewage sludge is one promising source. Sewage sludge is wet biomass with high moisture content (85%). To avoid the high drying cost, supercritical water gasification is effective because drying is not necessary [1,2].

Supercritical water gasification technology has recently been paid more attention. Supercritical water serves not only as good solvent for organic materials but also reactant for hydrogen gas production [3].

On the other hand, sewage sludge is a secondary phosphorus (P) resources and important for P recovery in wastewater treatment plant. Commonly, phosphorus in sewage sludge can be classified into organic and inorganic phosphorus. Nowadays, various methods of phosphorus recovery have been proposed, most of which are biochemical method.

A few years ago, Arakane et al. [4] applied a new technique for P recovery from excess sludge by using MPA process under subcritical condition. Zou and Wang [5] reported that the P in domestic wastewater could be recovered via crystallization as HAP. As is well known, biochemical conversion takes time, and only organics that microorganisms can digest can be treated.

Supercritical water can decompose organics [6–8], leaving phosphorus in inorganic form behind in the liquid phase. One of the characteristics of supercritical water is low solubility. Therefore, an objective of this study is to develop new technology for phosphorus recovery as well as the behavior of phosphorus conversion and to determine the kinetics of the reaction model incorporated with the precipitation model.

2 EXPERIMENTAL SECTION

2.1 Materials

Sewage sludge as a feedstock was collected from a wastewater treatment plant in Higashi-Hiroshima, Japan. The sewage sludge was filtered and pulverized in ball mill, and then sieved to particle size of 40 µm.

2.2 Experimental procedures

All experimental runs were carried out using a laboratory scale continuous flow reactor. The details have been described previously [9]. Briefly, it is a laboratory scale tubular reactor of stainless steel SS316 with inner diameter of 2.17 mm, outer diameter of 3.18 mm, and length of 12 m. Initially, water was fed into the reactor. Subsequently, the pressure was kept 25 MPa using a back-pressure regulator and the reactor temperature was brought up to the desired value. The feedstock was then fed using feeding system with the agitation speed of 400 rpm. After the reactor reached the desired experimental condition, the feedstock was fed into the reactor using feeding system. To ensure steady-state condition, the feedstock was fed into the system for 1 h prior to sampling. The effluent was analyzed for remaining organics and product gas composition. At the same time, phosphorus in the effluent water was analyzed for its inorganic form and organic form amount. The precipitated phosphorus in the supercritical water reactor was recovered by sending water after the supercritical water gasification experiment. The detailed experimental conditions are shown in Table I.

Table I: Experimental conditions

Feedstock	Sewage sludge
Concentration	0.1 wt%
Temperature	350–600 ºC
Pressure	25 MPa
Residence time	5, 10, 20, and 30 s
Reactor length	12 m

3 RESULTS AND DISCUSSION

3.1 Carbon Gasification Efficiency (CGE)

The effect of temperature and reaction time on the carbon gasification efficiency (CGE) is shown in Table II. The CGE for all runs is calculated on the basis of the carbon content in the feedstock. The effect of temperature on CGE was more significant than that of the residence time.

Table II: CGE for each temperature

Residence time [s]	Temperature [°C]						
	350	375	400	450	500	550	600
	CGE						
5	0.17	0.10	0.35	0.38	0.41	0.63	0.59
10	0.18	0.10	0.35	0.34	0.41	0.60	0.60
20	0.20	0.17	0.40	0.38	0.46	0.62	0.64
30	0.21	0.19	0.47	0.48	0.50	0.64	0.72

3.2 Phosphorus yield

The phosphorus in the effluent water was analyzed for its inorganic form and organic form amount. The results for phosphorus yield are shown in Table III.

Table III: Yield of inorganic phosphorus and organic phosphorus form

Temp	P yield	Residence time [s]			
[°C]	[mol-P/mol-P]	5	10	20	30
350	Organic P	0.4	0.2	0.1	0.0
	Inorganic P	0.4	0.6	0.7	0.7
	Precipitation IP	0.1	0.1	0.2	0.2
375	Organic P	0.5	0.3	0.2	0.2
	Inorganic P	0.2	0.2	0.1	0.0
	Precipitation IP	0.3	0.5	0.8	0.8
400	Organic P	0.5	0.3	0.2	0.2
	Inorganic P	0.2	0.2	0.1	0.1
	Precipitation IP	0.3	0.5	0.8	0.8
450	Organic P	0.5	0.3	0.2	0.2
	Inorganic P	0.3	0.2	0.2	0.1
	Precipitation IP	0.3	0.5	0.8	0.9
500	Organic P	0.2	0.0	0.0	0.0
	Inorganic P	0.6	0.8	0.7	0.7
	Precipitation IP	0.3	0.2	0.3	0.3
550	Organic P	0.2	0.0	0.0	0.0
	Inorganic P	0.6	0.8	0.7	0.6
	Precipitation IP	0.3	0.2	0.3	0.3
600	Organic P	0.0	0.0	0.0	0.0
	Inorganic P	0.7	0.8	0.7	0.6
	Precipitation IP	0.2	0.2	0.3	0.4

As shown in Table III, the organic form of phosphorus disappeared at the beginning of the reaction rapidly, and inorganic form of phosphorus dominated. It was found that precipitation successfully took place because sending cold water after the supercritical water gasification to the reactor resulted in dissolution of the phosphorus, recovered separately from the organic part.

This behavior of phosphorus was expressed in the reaction model incorporated with the precipitation model. The model successfully regenerated the experimental result.

4 CONCLUSION

We conducted gasification of sewage sludge in supercritical water gasification using a laboratory scale continuous reactor and successfully recovered phosphorus separated from the organics. Phosphorus was released to the liquid phase in inorganic form much before the completion of gasification. Supercritical water gasification is effective in treating sewage sludge to recover phosphorus separated from organics. Conversion to inorganic form of phosphorus is rather rapid, and it can be precipitated in the supercritical water reactor, separated from organic compounds.

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