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Comparison of Processes for Producing Better Rice Husk Silica Produced from a Field-scale Incinerator

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Authors' contributions

The present study was carried out in collaboration between both the authors. Author RS designed, performed, analyzed, interpreted, and drafted manuscript. Author MT provided technical support and revised the manuscript, and also supervised the research. Both the authors read and approved the final manuscript.

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ABSTRACT

Aim: The "amorphous" state of silica is the critical characteristic necessary for its use in various applications. Extensive experimentation has determined that the highest quality rice husk ash is obtained after treating the ash in two steps: a burning step followed by a curing step. The purpose of this study was to determine how to conduct these two steps such that the highest quality silica possible could be obtained from the ash.
Study Design: Using the solubility of silica as an indicator of the amorphous state, the quality of silica in rice husk ash produced by three treatment processes was evaluated; after all, rice husks were incinerated as a basic treatment.
Location and Duration of Study: The experiments were conducted from 2013 to 2016 at Toyama Prefectural University.
Methodology: Three treatment methods for the curing step were evaluated: a heating drum, insulating drums, and a sink within the incinerator system.

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Results: As a result, the highest solubility silica was obtained from the sink, which produced silica with more than 70% solubility, compared to about 40% in other treatments.
Conclusions: It can be concluded that the ash should be treated within the incinerator system without being exposed to cold temperatures outside.

Keywords: Rice husks; burning and curing steps; solubility.

1. INTRODUCTION

A rice husk is “a bio-ore” for silicon because it contains approximately 20% silica by weight [1]. A material can be a resource if it is accumulated in one place; however, a material cannot be a resource if it exists only in small amounts that cannot be easily gathered. Silicon is the second most abundant element in the Earth’s crust; however, this is not a good resource as the silicon is widely scattered. A rice plant, on the other hand, accumulates silicon in one place: the husk of the rice, which is so rich in silica as to be called a bio-ore for silicon. A critical standard exists for using rice husks as a resource: that of amorphous silica.

Silica, the form of silicon present in rice husks, must be removed from the husks while the silica remains in an amorphous state. To remove the silica, the rice husks must be burned in order to separate organics such as cellulose, hemicellulose, and lignin from the silica. Burning rice husks is not an easy task if the silica must remain amorphous: unless rice husks are properly treated, the silica becomes crystalline, and therefore useless. Empirical evidence demonstrates that high-solubility ash cannot be obtained if rice husks are burned in an uncontrolled way; on the other hand, evidence shows that this desirable type of ash can be obtained when the ash is treated properly [2–4]. The meaning of “properly” was, however, ambiguous for a long time; and some ambiguity still remains. For example, an element of “properly” processing the ash could be its handling after burning, in the curing stage. This raises a number of questions: how should the curing be conducted? How should the ash be handled between burning and curing? Should an external heat source be provided? Should air be forcibly applied to the ash during the curing process?

The purpose of this study was to answer these questions using three rice husk ash treatment methods. Rice husk ash of the highest quality is usually produced from an electric furnace after acid or alkali washing [5,6]; however, an actual field scale incinerator was used in this study. To the authors’ knowledge, no previous studies have utilized a field scale incinerator for high-quality rice husk ash production to date.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Rice husks

Rice husks used in this study were obtained from Koshihikari (*Oryza sativa L.*), one of the main rice cultivars grown in the area where Toyama Prefectural University is located.

2.1.2 Incineration Furnace

An incineration furnace with a boiler system was used for this study. Although several types of rice husk incinerators were described in Soltani et al [7], this study employed a furnace with a simple configuration consisting of moving grates and an air blower system (Fig. 1). The system was simple and cost-effective to make and operate. The combustion capacity of the furnace was 100 kg/h, with kilograms referring to the rice husks as were.

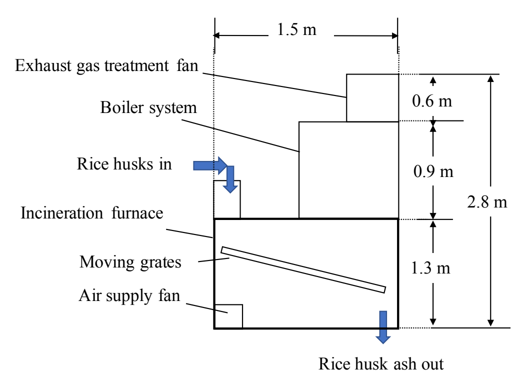

Fig. 1. A simple diagram of the incineration-furnace

2.1.3 Employed methods after burning

A summary of the processes used in this study is shown below in Table 1. Remained carbon in the rice husk ash is burned in curing stage so that air supply is an important function.

2.1.3.1 Heating drum

The configuration of the heating drum can be seen in Fig. 2. External heat produced by electricity was introduced indirectly to the drum in order to keep the ash at the desired temperature. Air was taken directly from the outside environment and pumped into the drum.

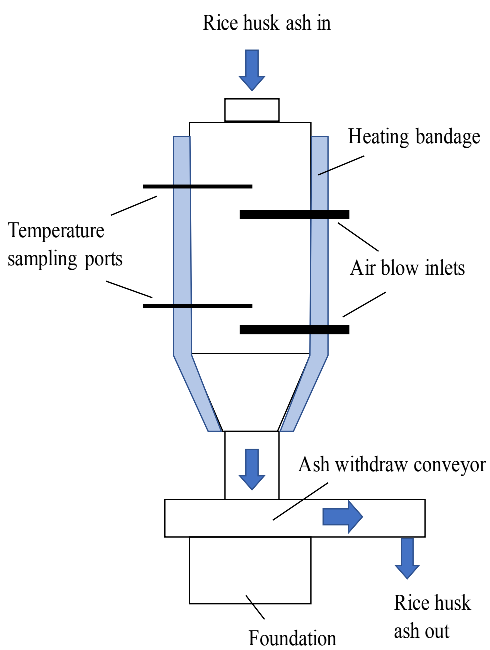

Fig. 2. Diagram of the heating drum

2.1.3.2 Insulating drums

The insulating drums consisted of two drums, i.e., a 100 L drum and a 200 L one (Fig. 3). A 100 L drum was placed into the center of a 200 L drum, with the smaller drum placed such that the space between the two drums would be uniform all the way around, providing added insulation. Air was pumped directly in from the outside environment. No external heat source was applied; the only heat acting on the ash was residual heat from the previous burning stage. This idea came from composting process of organic solid waste [8]. The considering disadvantage of this process is a large influence of ambient temperature. The pile temperature drastically decreases when the ambient temperature is quite low.

2.1.3.3 Sink

The sink was made by removing two lines of fire grates that were originally located at the bottom of the incinerator, and replacing these with a storage sink for the ash (Fig. 4). Air was pumped directly in from the outside environment. The ash in the sink was exposed to an external heat source, which was generated by burning rice husks in the previous step. The furnace was still burning new rice husks while the ash in the sink was curing.

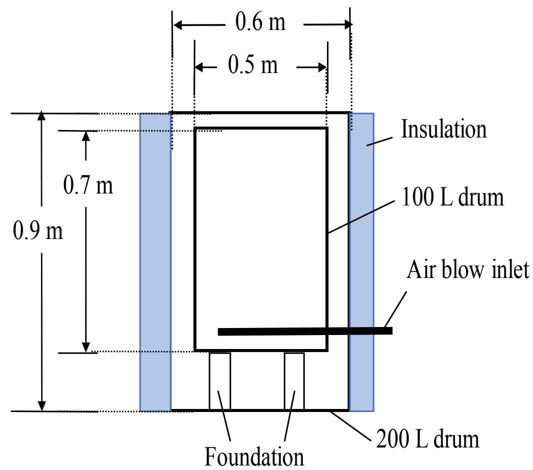

Fig. 3. Diagram of insulating drums

2.2 Methods

2.2.1 Analytical methods

For the purposes of this study, the quality of rice husk ash was determined by solubility only. According to previous studies conducted by Tateda [2] and Tateda et al [3], high solubility values – for example, more than 40% -indicate that ash in is an amorphous state. It can be said that the higher the solubility value of the ash, the better the quality of the ash. The solubility of rice husk silica was measured by two methods: the sodium hydroxide (NaOH) method and the Testing Method 4.4.1.c. Deshmukh et al (2012) used the former method as silica activity index [9]. The latter has been accepted as a standard method while the former is a more simplified method. Solubility values were represented by a mean of triplicated measurements. Details of these methods can be found in Tateda et al (2016) [3]. Values produced by the two methods were closely related [4]. Because of this, the two values were compared for evaluation of ash quality in this study. Mean values were used for representing solubility values. Thermocouples (Type K) were used for temperature monitoring and data were recorded in a data logger (Paperless Recorder GP10, Yokogawa).

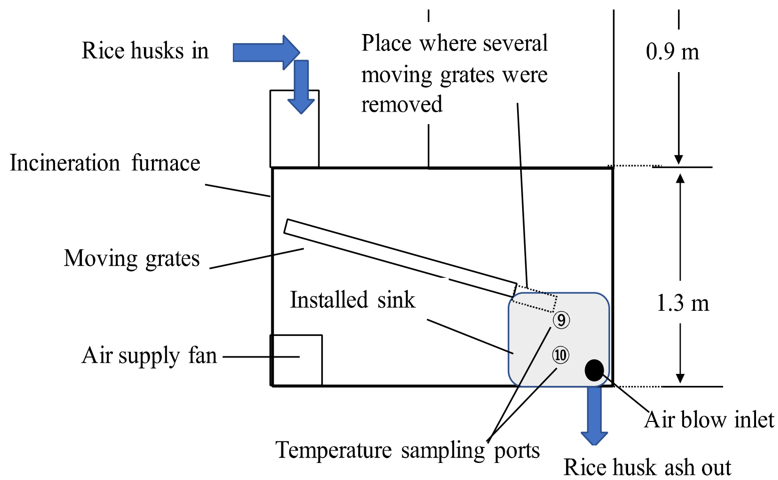

Fig. 4. Diagram of the sink

Table 1. Summary of the methods used in this study

	Heating drum	Insulating drums	Sink
Volume (L)	300	100	200
External heat Source	Yes Electricity	No	Yes External heat from rice husk burning
Air supply	Yes (10 l/min)	Yes (10 l/min)	Yes (open air on top and 3 l/min in bottom)
Configurations	Fig. 2	Fig. 3	Fig. 4

2.2.2 Experimental methods

The rice husks as were, which had a moisture content of 10–13% before burning, were burned in the incineration furnace at 500–800˚C. Next, the resultant rice husk ash was put through the treatment processes in Table 1. One day after the introduction of the ash into each process, ash samples were taken at the 20 cm-depth from the surface of the ash pile, at its center. Temperatures were taken during operations at designated points in the ash pile.

3. RESULTS AND DISCUSSION

The solubility of the silica produced by each process is shown in Table 2. According to the table data, the solubility of the ash produced from the sink process was high in comparison to other curing methods. The solubility of ash from the heating drum was the lowest. Solubility values were strongly influenced by temperatures within the ash piles.

However, these results cannot be explained by pile temperatures alone, as the solubility values of ash from the sink were extremely high compared to those from the insulating drums, which reached close temperatures. The pile temperatures in the insulating drums with air reached 300˚C, which is similar to the temperature of the ash pile in the sink. Although those temperatures were close, solubility values in the two processes were quite different.

Usually, the processes such as a gasifier [10], a fluidized bed combustor [11–13], a moving grate [13], and a suspension chamber [13] have only a burning step. Burning and curing comprise two different steps [4]. From our long empirical experience with burning rice husks, we have found that not only burning rice husks but also curing them is extremely important in order to produce high solubility, i.e., high-quality ash. In the burning step, rice husks burn with no other heat source except for the start-up ignition, in this case, provided by kerosene. Cellulose, semi-cellulose and other compounds are burned during this step, creating excess heat that can be used to heat water or generate electricity. Moreover, carbon dioxide generated in this step could be provided to nearby greenhouses for agricultural uses. Rice husk ash is blackish because the ash is usually removed from the incineration system at this point. The second step, curing, is very important for producing high-quality ash. The main purpose of this step is to remove or burn out nonflammable carbon, i.e., fixed carbon, from the surface of the ash. Based on the concept, the three processes above were proposed and performed in this study. The simplified total flows are shown in Figs. 5–7.

The incinerator in Figs. 5–7 played the role of the burning step in each process, and the heating drum, the insulating drums, and the sink were considered the curing step in each process. In the first two curing methods, represented in Figs. 5 and 6, the curing step - namely, the heating drum and the insulating drums - was outside of the incinerator system. The ash created in the incinerator was manually carried via bucket into the heating drum; on the other hand, the ash was sent into the insulating drums by a conveyor tube, as shown in Fig. 8.

The ash temperatures rapidly decreased upon removal from the incineration system. The period during transferring by bucket or sending by conveyer tube decreased the temperature due to low atmospheric temperatures in Japan, especially in winter. The conveyor tube, made of iron, became extremely cold in winter temperatures, and the ash that was sent from the incinerator cooled down to atmospheric temperatures as the metal of the conveyor removed heat from the ash (Figs. 5 and 6). However, the conveyor tube was gradually heated by this process, and much of the ash sent into the insulating drums remained at a high temperature. In the cases of the heating drum and the insulating drums, the removal of the ash from the incinerator system for transfer became a critical problem: the resultant rapid decrease of ash temperature made solubility low.

The strongest advantage of the sink process was that the sink existed within the incinerator system (Fig. 7). Rice husks were burned in the incinerator and the resulting ash was sent into the sink without exiting the incinerator system.

The idea of the sink process resulted from a long continuous operation of incineration. Initially, the incinerator was operated by continuously withdrawing the ash, with the removed ash then stocked in empty drums to await disposal, usually for use in soil conditioning materials. Typically in this process, no stock of ash would remain inside the incinerator. However, at several points during these continuous operations, empty drums were not available for removing the ash, and thus the ash remained in the incinerator. This is not part of the normal operation of the incinerator, but a small space exists to permit ash to remain in the incinerator in case the ash discharge screw is out of order. In these cases of ash accidentally remaining in the incinerator, it was found that the solubility of the ash kept in the stock space showed high solubility characteristics. The stock space was then widened for this study in order to evaluate its effectiveness in promoting higher ash quality.

In this third curing method, the ash enters the curing step with its high incineration temperatures retained. Because the curing step involves an endothermic reaction, external heat should be provided, and in this case, the heat from the burning step provides the necessary heat for the ash in the curing step. Temperature monitoring in the sink is shown in Fig. 9. According to this figure, temperatures remained around 400˚C during the curing step in the sink treatment method. Observing the results in Table 2, temperatures in the sink need to remain around 400˚C in order to obtain ash with a high solubility. According to Moriizumi et al. (2004), the temperature around 390-400°C was the key for a drastic impact on organics [14]. The temperature of 400°C was kept in the process because the heat flowed continuously from the burning step to the curing step without interruption (Fig.7). From this observation, exiting the incineration system received a tremendous disadvantage.

Table 2. Data summary of three processes

	Heating drum	**Insulating drums**	**Sink**
	air (10 l/m)	air (10 l/m)	air (3 l/m)
Solubility (%) on average	25.5	41.0	70.4
Temperature (˚C) in ash pile	89-117	300	380-400
Time of sampling	1 day later	1 day later	1 day later

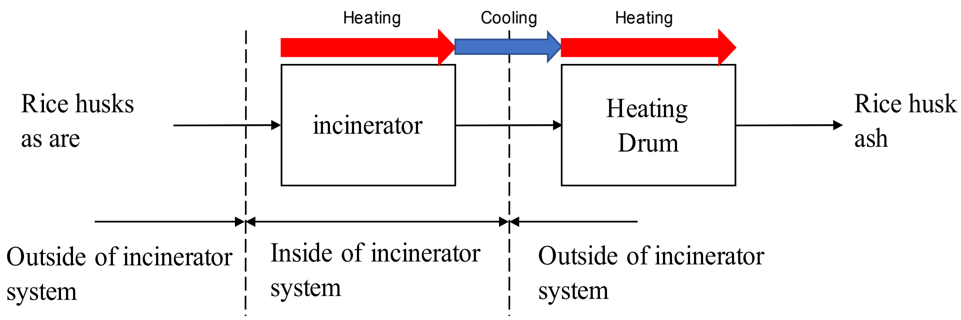

Fig. 5. The process flow of the heating drum

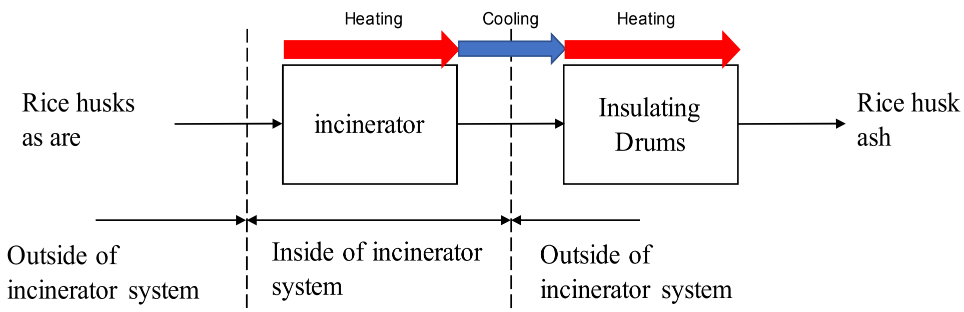

Fig. 6. The process flow of the insulating drums

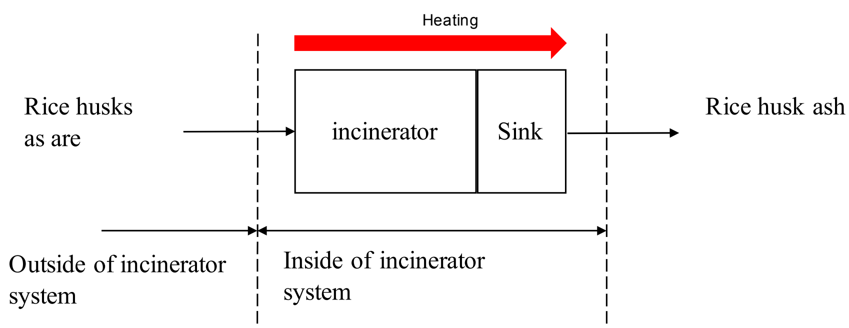

Fig. 7. The process flow of the sink

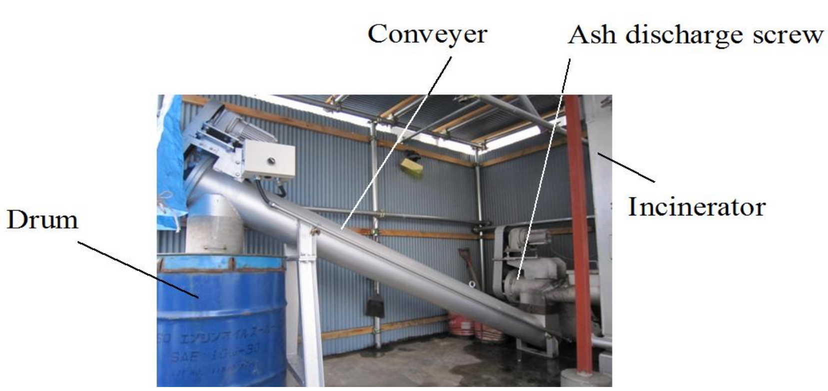

Fig. 8. The conveyor tube used for transferring the ash from the incinerator into the insulating drums

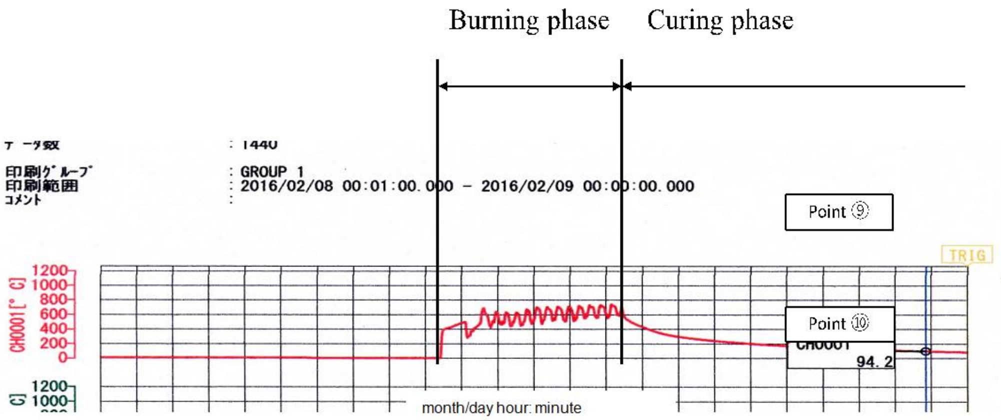

Fig. 9. Temperature profiles in the sink process

4. CONCLUSIONS

In light of the results obtained in this study, the following conclusions were reached.

1. To obtain high solubility ash, the rice husks must be submitted to a two-step process, that of burning followed by curing;
2. After undergoing these two steps, the ash can show high solubility, i.e., more than 70%;
3. The solubility of the ash increases when the ash is put through these two treatments within the same system, i.e., the incinerator, without being removed; and
4. The sink process is easily made by modifying an incinerator which stakeholders currently own.

If rice husks are burned for heat alone, they are burned at high temperatures, creating less valuable ash because a high percentage of the silica in the ash is crystallized. The crystalline silica is also carcinogenic, creating an additional problem. If the ash burning is controlled and conducted at low temperatures, much less heat is produced; however, the value of the ash will be much higher and could be sold at a high price. Whether a community chooses heat or high-quality ash depends on conditions within the community. The heat is needed if a community does not have electricity, but more valuable ash can be produced when rice husks are burned in a mass reduction treatment. The optimal choice, however, is to pursue both valuable ash and heat. With consideration for their specific situation, a community should handle rice husks as a resource, with the opportunity of bringing happiness and prosperity to its next generation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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