Modeling of fresh paddy aeration on transporting barges in Mekong Delta, Vietnam

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ABSTRACT

The Mekong Delta is regarded as the granary of Vietnam, with an annual production of 24.1 million tons (2023). Currently, fresh paddy is transported directly from farmers' fields to drying facilities or rice mills. Given the extensive river and canal system in the Mekong Delta, the majority of paddy (up to 92%) is transported by barges. While barge transportation is more cost-effective (91,000 VND/ton for a 100 km distance) compared to truck transportation (269,000 VND/ton), it has significant drawbacks, such as a longer transportation time of 3 to 5 days. Moreover, because the paddy is wet during transport, it is prone to discoloration (yellowing), which reduces its quality. To address this issue, this research developed an experimental paddy aeration model as a foundation for implementing aeration on barges during transportation. The model was tested with 1.4 tons of fresh paddy, specifically the DT80 variety, in Cai Lay, Tien Giang province. Key parameters monitored and analyzed included paddy temperature, moisture content, ambient conditions, and grain quality. The model was tested with a specific airflow rate of 129 ± 23 m^3/h per ton. The paddy temperature in the aeration model was maintained at 28.8°C, similar to the ambient temperature of 28.3°C. As a result, the whiteness of the aerated paddy was preserved at 3.6% after three days, whereas it decreased from 3.6% to 3.2% in paddy transported without aeration. The application of aeration helped reduce quality losses, particularly discoloration, caused by the high temperatures of fresh paddy during transportation.

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1. Introduction

Rice (*Oryza sativa* L.) is a major staple food crop for half of the world's population. With an annual production of about 24.1 million tons in 2023, the Mekong Delta is considered the granary of Vietnam. Unlike traditional practices, farmers now sell their fresh paddy to traders immediately after harvesting. The traders then transport the paddy to rice mills for drying and processing. Due to the Mekong Delta's extensive river system, paddy and other agricultural products are primarily transported by barges (Nguyen et al., 2015). In Long An province, for instance, 90% of fresh paddy is transported by barge (Nguyen et al., 2019). However, this method has disadvantages, including long transportation times, which can lead to losses, particularly in grain quality, due to discoloration caused by the high temperature within the grain pile on barges. Discoloration is triggered by fungi, bacteria, and environmental conditions such as high humidity and temperature (Gummert et al., 2020). The higher the temperature of grains during storage or transportation, the more intense the browning reaction (Fatharani et al., 2022).

Aeration involves the forced movement of ambient air through a grain bulk using fan power to improve grain storability. This technique is widely used in stored grain management programs in the United States to modify the microclimate within the grain bulk, reducing or eliminating the development of harmful organisms by lowering and stabilizing grain temperatures (Navarro et al., 2012).

While aeration technology has been applied to dry paddy in storage in Vietnam and other parts of the world, there has been limited research on its application to fresh paddy, particularly during barge transportation after harvesting. To address these research gaps, this study was conducted to identify the parameters affecting grain quality during barge transportation, complemented by experiments using a model.

2. Materials and Methods

2.1. Survey on the status of paddy transport in Mekong Delta

A survey was conducted in Tien Giang province, where the experimental model was installed, to assess the status of paddy transportation. Data were collected using a questionnaire, which included the ratio of paddy transported by different types of transportation (barges and trucks), transport costs, transport duration, and the advantages and disadvantages of each method. The sample size was determined using the following formula (Yamane, 1967; Israel, 1992):

$$n = \frac{N}{1+Ne^2} \quad (1)$$

Where: n is the number of samples (paddy transport barges); N is the estimated total number of paddy transport barges; and e is the estimated error level. With the annual rice production of 24.1 million tons/year, the annual transport capacity of barges of 1,000 tons/year, and the expected accuracy level of 0.1, the number of samples was computed at 99.6 (≈ 100) samples for survey in Mekong Delta. For the first stage of this study, a survey was conducted with 24 samples in the case of Tien Giang province with a rice production of 765,000 ton/year.

2.2. Experimental model design

Based on the practical size of a barge used for paddy transport, a model was designed for initial experiments with the dimensions of the aeration chamber of 2.5 m height (similar to the height of the paddy pile on barges), 1 m width and 1 m length (Figure 1).

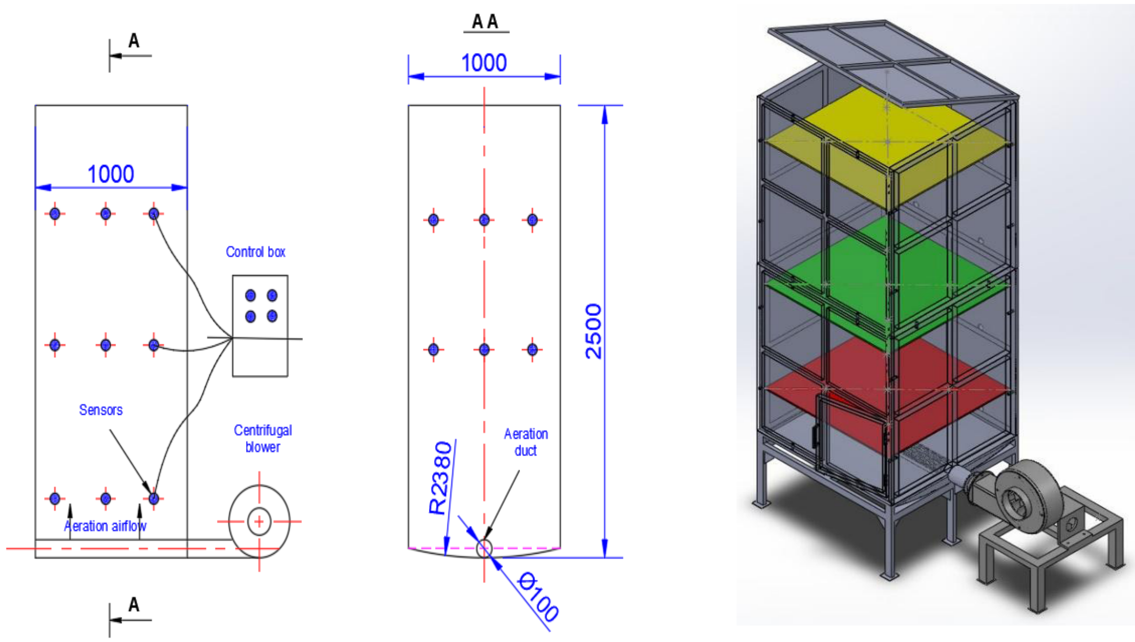

Figure 1. Experimental model (+ 3D) for fresh paddy aeration.

The model was loaded with 1.4 tons of fresh paddy, a DT80 variety, in Cai Lay, Tien Giang province. Inside the model, a set of sensors was installed in layers to monitor the temperature and humidity of the airflow, as well as the temperature of the grains. During the test, the parameters monitored included moisture content (MC), temperature, and relative humidity (RH) of the ambient air at the study site. The moisture content of the grain was measured using a moisture meter (Kett PM-600), and a digital scale with an accuracy of 0.01 g was used for weighing the paddy samples. Additionally, the static pressure of the airflow through the grain layer was measured and computed based on the following equation.

$$P = P_{1m} * h \qquad (1)$$

Where: ΔP is the static pressure (Pa); h is the height of the grain layer (m); and ΔP1 m is the static pressure for each 1 m height of the grain layer (Pa/m), which is computed as follows:

$$P_{1\,m} = \frac{a*V^2}{ln\,(1+b*V)} \qquad (2)$$

Where: V is the exit velocity of airflow (m/s); a and b are coefficients (a = 25700 and b = 13.2 for paddy).

2.3. Grain quality tests

Grain quality assessment was conducted based on criteria, such as head rice recovery (HRR), discoloration, whiteness percentage and amylose content. HRR was measured on milled rice and calculated using the following equation:

$$HRR,\% = \frac{Weight\ of\ whole\ grains}{Weight\ of\ paddy\ samples} x100 \qquad (2)$$

Discoloration: This parameter was assessed based on the transparency which was measured using a milling meter (MM1D), with a range of 0.01 - 8.00%. The meter was also used to measure the whiteness and milling degree.

3. Results and Discussion

Figure 2. Barges for paddy transportation in Mekong Delta.

Transportation of paddy by barges was normally from 3 to 5 days for a distance of 100 - 200 km. It may take more time when the river is stuck by a dense layer of water hyacinth. The long time of transporting, together with the wet paddy being transported, the paddy is often yellowed, reducing its quality, and causing a loss in grain quality. Although transportation by truck takes less time, its cost is much higher, and it is unable to be applied in areas with a diverse river system in Mekong Delta.

As a result, the costs were 91,000 and 269,000 VND/ton for 100 km transportation by barges and trucks, respectively (Figure 3). Similarly, in Mekong Delta, rice straw bales are also mainly transported by barges and trucks. At the same distance, the costs are 470,000 VND/ton/km and 564,000 VND/ton for 100 km transporting straw bales by barges and trucks, respectively (Nguyen et al., 2015).

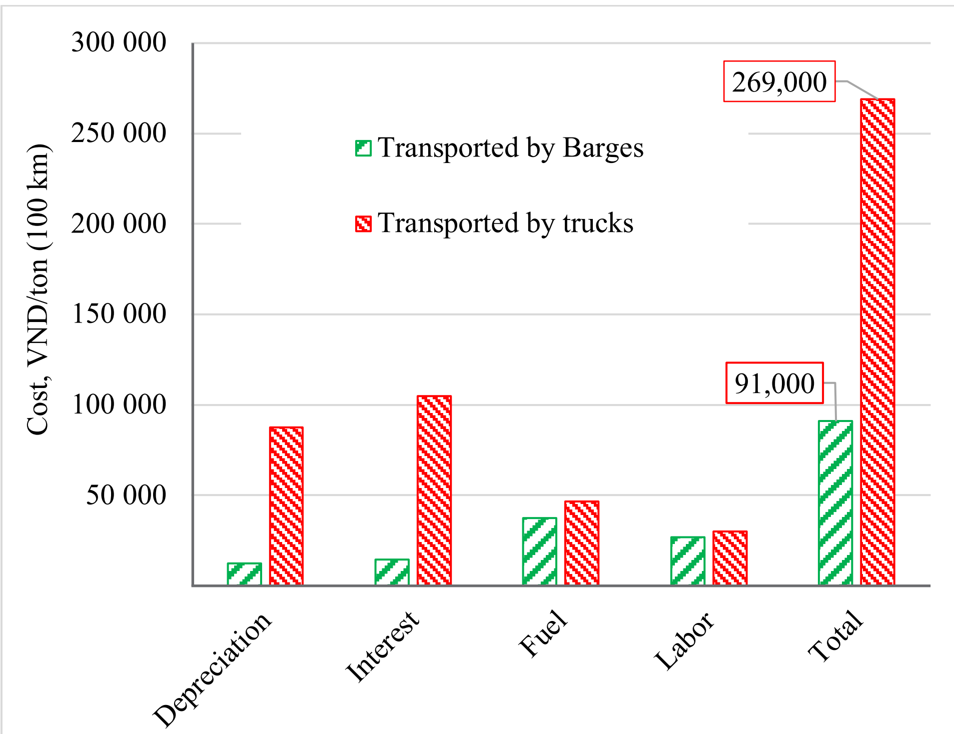

Figure 3. Components of transportation cost.

3.2. Testing results on the aeration model

Airflow rate for aeration: The airflow for aeration was supplied using a centrifugal blower with a specific airflow rate of 129 m^3/h per ton, corresponding to 2.2 m^3/min per ton, for the paddy layer of 2.5 m height in the model and the exit velocity of 3.2 m/s. According to Ranalli et al. (2002), a specific airflow rate for aerating with a 7 m height was tested at 1.3 m^3/min per ton, corresponding to an exit velocity of 4.3 m/s. However, it was 0.1 m^3/min per ton for the aeration of maize in a bin with a capacity of 597 tons (Maier, 1994). It meets the requirement for uniform airflow distribution with the exit velocity of less than 9 m/min (Navarro et al., 2012).

Temperature: The temperature of paddy in the model with aeration is 27.8°C, which is lower than the ambient temperature of 30.4°C on average. As shown in Figure 4, the bigger difference in temperature between the grains and ambient air was at noon. The reason for the lower temperature of the grains was due to the high temperature at noon while it is rather stable for the grains which were cooled at night and in the early morning.

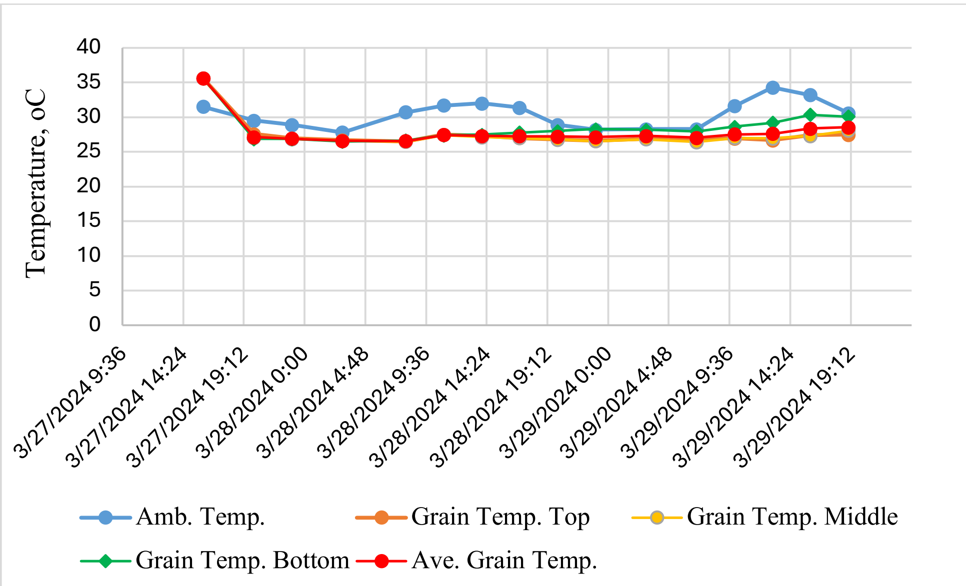

Figure 4. Fluctuation of aeration air and grain temperature.

Grain moisture content: A small but significant drying effect (moisture loss per aeration cooling cycle) was typically experienced. Although the main purpose of aeration was to cool the bulk grain, the moisture content of the grain descreased by 3%, from 25.5 to 22.7%, after the 49 h of aeration. It is explained that the moisture content was reduced due to the fundamentals of the moisture (H_2O) was produced from the respiratory process of the grain, which was removed from the grain pile during areation process. The data analysis resulted in a regression equation as shown in Figure 5. In practice, the reduction rate depends on the conditions of the ambient air around the model. As mentioned, the primary purpose of aeration is to remove heat from the paddy pile and control the grain temperature to prevent discoloration during transportation. Thus, the grain pile is aerated in both sunny and rainy conditions of the wearther.

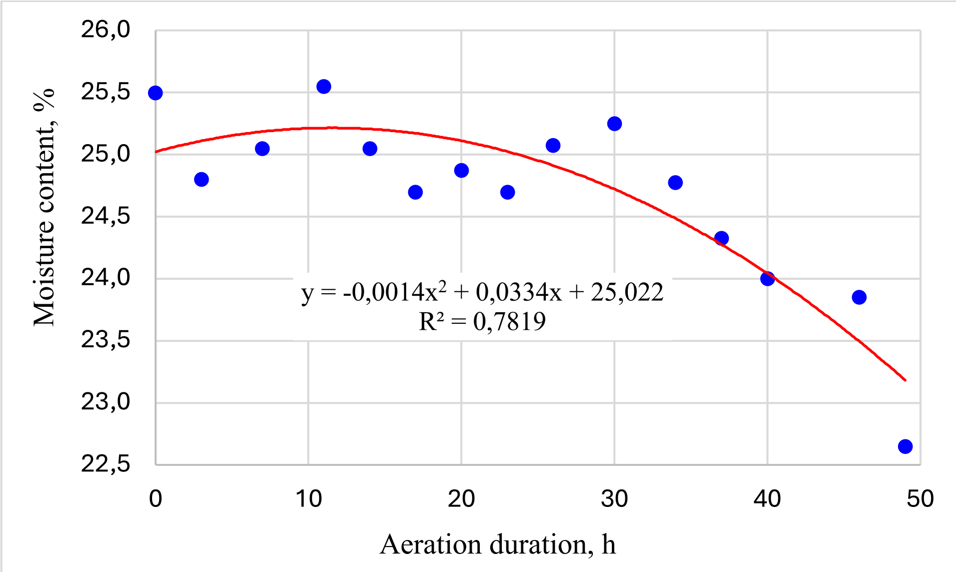

Figure 5. Grain moisture content reduction in aeration duration.

Grain quality: As a result, the whiteness of the paddy with aeration is maintained at 3.6% after three-day aeration, while it reduced from 3.6 to 3.2% for the paddy on a barge without aeration (Figure 6). This result indicates that the application of aeration helps reduce quality losses by preventing the paddy on the barges from turning yellow due to the high temperatures fresh paddy can reach during transportation.

There was no significant difference in whiteness percentage and amylose content between the paddy with aeration in the model and the paddy without aeration on barges. However, the head rice recovery was 1.1% lower for the treatment without aeration, compared to that of the treatment with areation.

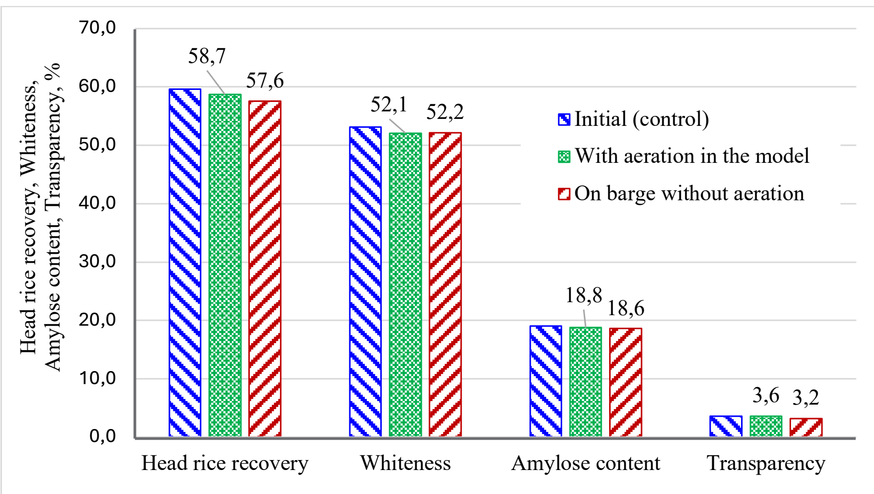

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Figure 6. Grain quality.

3.3. Designed aeration system for transporting barges

Based on the test results with the model, an aeration system was designed to be installed on a barge with a transport capacity of 60 tons, as shown in Figure 7. The system consists of the following main components: a diesel engine, a centrifugal blower, aeration ducts, sensors and instruments. The centrifugal blower with an airflow rate of 2 m^3/s, corresponding to a specific airflow rate of 120 m^3/h per ton, was driven by a separate 12-hp diesel engine installed on the barge. With a grain layer height of 2.5 m, the required static pressure corresponds to 116 mm H_2O.

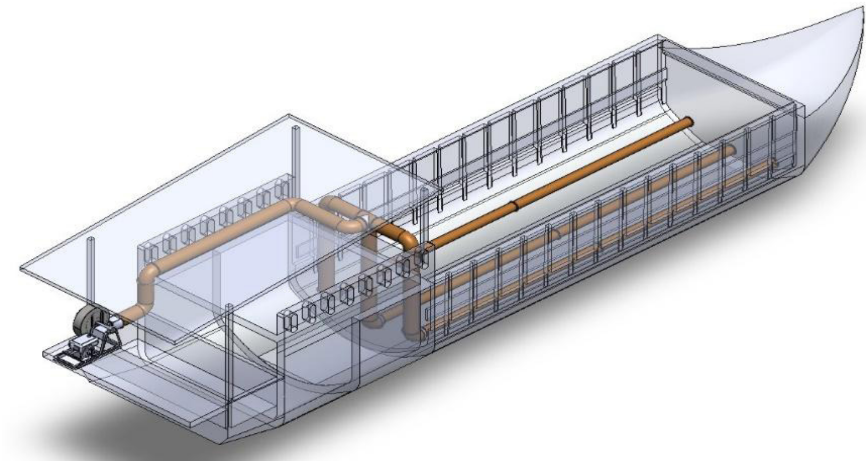

Figure 7. Aeration system designed for barges.

3.4. Environmental impact assessment

By reducing losses, the application of this technology indirectly contributes to a reduction in greenhouse gas emissions (GHGE). The higher the grain losses lead to the higher GHGE. For the stage of transporting paddy, GHGE coefficient was 0.41 kg CO_2-eq/ton per km, mainly due to fuel consumption (Gummert et al., 2020). In addition, the loss of grain quality means the loss of input materials in rice production, which contributes to GHGE during the production process. Based on the GHGE coefficient of 0.22 - 0.37 kg CO_2-eq/kg of paddy (Gummert et al., 2020; Win et al., 2020; Nguyen & Nguyen, 2023), the rice production of 24.1 million tons/year, and the estimated reduction in grain quality losses of 1%, due to on-barge aeration application, the total GHGE reduction was computed as 53,300 - 88,800 tons/year in Mekong Delta, Vietnam.

4. Conclusions

Based on the survey results, most of fresh paddy in Mekong Delta was transported to rice mills using barges after harvesting. The total cost of transportation was computed for each type of transportation (barges and trucks). It was found that the cost of transporting paddy by barges was one-third lower than that by trucks. To establish the basic parameters for designing an aeration system to be installed on barges, a model was designed and tested in Cai Lay district, Tien Giang province. The results showed that the grain temperature with aeration was controlled to be equal to or lower (especially at noon) than the ambient air temperature around the model. In terms of grain quality, transparency was maintained in samples with aeration, whereas it was lower in samples from barges without aeration. This indicates that aeration could prevent discoloration, primarily caused by the high temperature of fresh paddy during transportation. Additionally, the reduction in losses contributed to a decrease in GHGE from inputs used in rice production.

Conflict of interest

The authors declare that they have no conflict of interest.

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