

The Impact of Ultrasound-Assisted Freezing on Energy Consumption and Freezing Time of White Shrimp and Striped Catfish

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ABSTRACT

This study investigates the effects of ultrasound-assisted freezing on the freezing time and energy consumption for two economically significant Vietnamese aquatic products: white shrimp and striped catfish fillets. The study begins by highlighting the importance of these products in Vietnam's export market and the need for energy-efficient freezing methods that maintain product quality. Ultrasound waves were used to enhance the freezing process, with experiments conducted at various power levels and intermittent ultrasound application intervals. Results indicate that using ultrasound at a power level of 100W significantly reduced freezing time by 19% for striped catfish and by up to 18% for white shrimp when the ultrasound was applied intermittently at a 0.4 duty cycle (30 seconds on, 20 seconds off). The study also observed that optimal ultrasound application could reduce energy consumption by 17% for striped catfish and 8% for white shrimp. The findings suggest that ultrasound-assisted freezing can be an effective method to enhance freezing efficiency and reduce energy consumption, making it a viable option for industrial applications in aquatic products processing.

Keywords: Ultrasound, White Shrimp, Striped Catfish Fillets, Freezing, Energy Saving.

1.0 INTRODUCTION

White shrimp is a high-value economic product of Vietnam. According to the Shrimp Farmers Journal, it is estimated that in 2023, Vietnam's shrimp exports reached 384.4 thousand tons worth 3.346 billion USD. Alongside, the export situation and demand for striped catfish consumption in Vietnam are also increasing. Striped catfish is not only a rich source of protein but also contains many unsaturated fatty acids, vitamins, and minerals beneficial to health.

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Reducing freezing time, saving energy, and ensuring product quality have become top priorities. Currently, the common method used in our country to preserve export shrimp is quick freezing and storage in cold storage at a temperature not greater than -18°C . However, during the freezing process, when liquid molecules transition to ice crystals, the specific volume of water increases by about 10%. The formation of ice crystals breaks down the tissue and cell structure of shrimp, leading to discoloration and a decrease in the nutritional value of the food. It can be said that the size of ice crystals significantly affects the quality of frozen products. If the size of ice crystals is large and unevenly distributed (inside and outside the cells), there is a high risk of breaking the cell structure. This occurs when the freezing rate is not fast enough. Conversely, small and evenly distributed ice crystals can better maintain the cell structure. This even distribution usually occurs at high freezing rates.

The acceleration of the freezing rate by ultrasound waves is mainly based on the nucleation and promotion of heat and mass exchange processes. However, the effectiveness of ultrasound in assisting freezing depends on the ultrasound intensity, exposure time, and properties of the frozen materials. Each type of materials will require a suitable ultrasound regime during freezing. Therefore, selecting an appropriate ultrasound regime is necessary to optimize the freezing time of the respective materials.

There are many studies worldwide and in Vietnam on ultrasound-assisted freezing. Islam et al. (2014) observed more than a 40% reduction in freezing time for all tested mushroom samples during ultrasound-assisted immersion freezing (20 kHz, 0.39 W/cm^2) in a solution containing 50% ethylene glycol and 50% water. Islam et al. (2015) conducted direct contact freezing of mushrooms. Ultrasound-assisted freezing with a frequency of 20 kHz and an intensity of 0.39 W/cm^2 maintained the initial hardness of mushrooms. In Vietnam, Tin & Bao studied the impact of ultrasound-assisted freezing on the color and quality of striped catfish fillets. Duan and Bao investigated the effect of ultrasound on the freezing time of white shrimp at power levels of 0W, 75W, 100W, 125W, 150W, and 175W. However, no studies have been observed on the energy-saving potential of ultrasound-assisted freezing. Therefore, this paper will focus on the impact of ultrasound-assisted freezing on the freezing time and energy consumption of striped catfish and white shrimp.

2.0 ULTRASOUND-ASSISTED FREEZING PROCESS

Table 1 presents the experimental and measurement equipment used in the freezing process of striped catfish and white shrimp, and Table 2 presents the technical specifications of the freezing equipment used in the experiments.

Table 1: *Experimental and Measurement Equipment*

Description	Unit	Value
Compressor stage 1	HP	5/8
Compressor stage 2	HP	1
Air-cooled condenser	kW	1.2
Air-cooling evaporator	kW	0.45
Super SS weight scale	-	-
Fox 1004 thermometer	-	-
CHN SPEC CS-10 colorimeter	-	-
Ultrasound power meter	-	-

Description	Unit	Value
Alternating relay timer	-	-
Emic single-phase 220V electricity meter	-	-

Table 2: Technical Specifications of Freezing Equipment

Description	Unit	Value
Freezing capacity	kg/batch	1
Dimensions of the freezing device	mm	1630 x 800 x 700
Dimensions of material trays	mm	580 x 240 x 2
Dimensions of the emitter plate	mm	260 x 130 x 30
Freezing chamber temperature	°C	-35 to -40
Operating voltage	V	220 ± 5%
Operating frequency	Hz	50

The experimental procedure is as follows: the freezing machine is first started and run until the air temperature in the freezing chamber reaches -35°C. During this time, shrimp are peeled and striped catfish fillets are cut, then cooled to 10°C. When the air temperature in the chamber reaches -35°C, a temperature probe is attached to the middle of the shrimp and fish fillets, then the shrimp and striped catfish are placed on the freezing tray in the cabinet. Shrimp and striped catfish are placed on the tray in a single layer and not stacked. The shrimp and fish fillets with temperature probes in all experiments are placed in the same position (right at the front of the freezing tray and above the ultrasound emitter). The product temperature is recorded every 5 minutes until the product core temperature reaches -18°C, at which point the experiment ends. Ultrasound is turned on from the moment the shrimp and striped catfish are placed into the cabinet until the experiment ends.

Adjusting ultrasound power: The power is stopped on the power supply unit, then adjusted to the desired power level. The desired power level is measured and displayed digitally on the PZEM-022 power meter.

Creating intermittent ultrasound ratios (start-stop time): The alternating relay is connected to the input port on the ultrasound power supply, the start-stop time value is set on the alternating relay, and then power is supplied to the relay.

Measuring energy consumption for one batch: The total system's energy consumption is measured through a CV140 single-phase electricity meter.

3.0 RESULTS AND DISCUSSION

3.1 Impact of Ultrasound on Freezing Time

Figure 1 shows the freezing time of striped catfish fillets at various ultrasound power levels and continuous ultrasound exposure at power levels of 75, 100, 125, 150, and 175 W at a frequency of 20 kHz. The results show that when continuous ultrasound exposure is applied at 100 W, the freezing time is shortened by about 8% compared to without ultrasound assistance, specifically 68 minutes versus 74 minutes. This indicates that continuous ultrasound exposure causes a thermal effect; therefore, at power levels of 75, 125, 150, and 175 W, the freezing time increases compared to without ultrasound assistance.

Similarly, **Figure 2** presents the freezing time of white shrimp at ultrasound power levels of 75, 100, 125, 150, and 175 W at a frequency of 20 kHz. The results show that at power levels of 100W and 125W, the freezing time is shortened compared to without ultrasound

assistance, specifically 53 minutes and 50 minutes compared to 55 minutes without ultrasound. This confirms that for shrimp, ultrasound power levels of 100W and 125W are effective in reducing freezing time. Meanwhile, the freezing time using ultrasound power levels of 75W (57 minutes), 150W (60 minutes), and 175W (66 minutes) is higher compared to without ultrasound. This value tends to increase as ultrasound power increases.

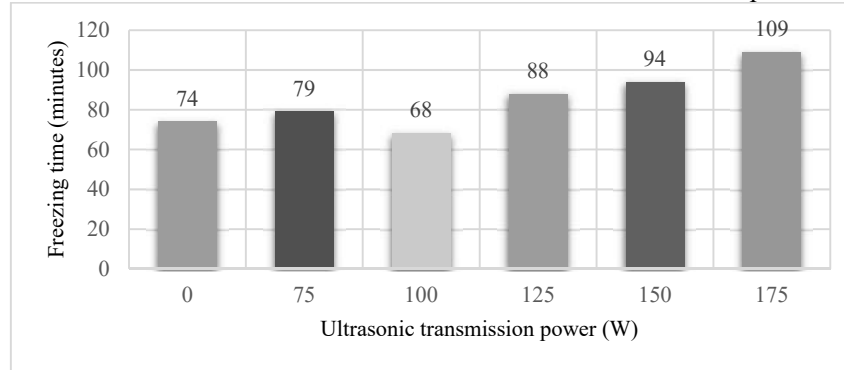


Figure 1. Freezing time of striped catfish fillets at various ultrasound power levels

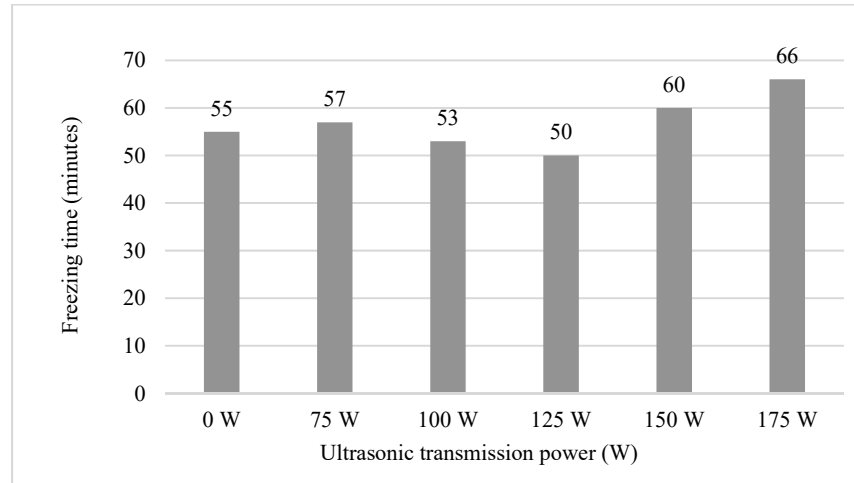


Figure 2. Freezing time of white shrimp at various ultrasound power levels

3.2 Impact of Intermittent Ultrasound Exposure on Freezing Time

Previous studies have shown that continuous ultrasound exposure affects freezing time. Prolonged ultrasound exposure causes a thermal effect, increasing freezing time. From experimental results on the impact of ultrasound on freezing time, it is observed that ultrasound only positively affects the phase transition during the freezing process. Therefore, an experiment on freezing striped catfish fillets was conducted at 100 W power (ultrasound exposure temperature 0 to -5°C) with intermittent ratios of 0, 0.2, 0.4, 0.6, and 0.8. The intermittent ultrasound ratio is calculated using the formula:

$$A = \frac{T_{off}}{T_{off} + T_{on}} \quad (1)$$

In which:

T_{on} – freezing time with ultrasound assistance

T_{off} – freezing time without ultrasound

Therefore:

- $A = 0$: continuous ultrasound exposure
- $A = 0.2$: 30s on, 7.5s off
- $A = 0.4$: 30s on, 20s off

- A = 0.6: 30s on, 45s off
- A = 0.8: 30s on, 120s off
- A = 1: no ultrasound exposure

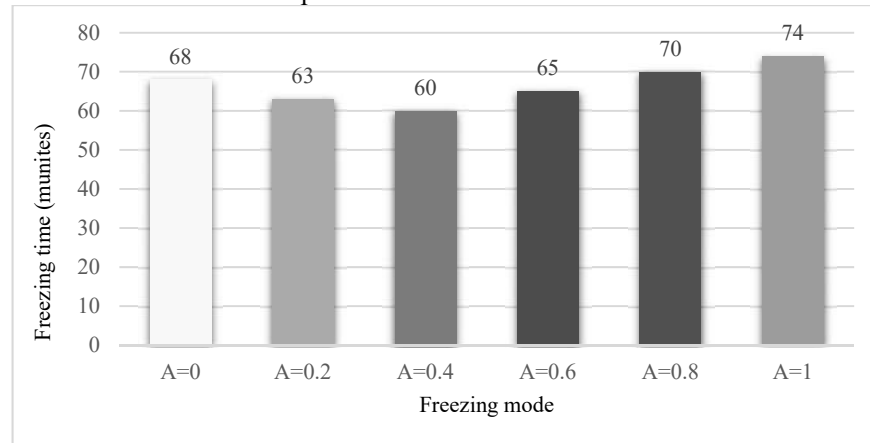


Figure 3. Impact of intermittent ultrasound exposure on freezing time of striped catfish fillets

Research results show that intermittent ultrasound exposure positively affects freezing time. **Figure 3** shows that at intermittent ratios of 0.2, 0.4, and 0.6, the freezing time is lower than without ultrasound assistance and with continuous ultrasound exposure. At a 0.4 ratio, the freezing time is the shortest among the freezing modes, reducing by about 18.9% compared to without ultrasound assistance. This can be explained by the fact that for the 0.4 intermittent ratio at 100 W power, corresponding to 30s on and 20s off, this is a reasonable intermittent ratio for ultrasound to create compression and expansion effects on the material, creating bubbles to enhance heat transfer. Then, voids will form inside the material combined with a reasonable intermittent time to favorably form and develop ice crystals. For the 0.2 intermittent ratio at 100 W power, corresponding to 30s on and 7.5s off, the off time is too short, causing ultrasound to create a thermal effect that melts the formed ice crystals. Conversely, at a 0.8 ratio, the off time is significantly longer than the on time, reducing the beneficial effects of ultrasound on the material. Therefore, selecting a suitable intermittent ratio is very important in shortening freezing time.

Similarly, the impact of intermittent ultrasound exposure on the freezing time of shrimp was also investigated. The test cases for shrimp include:

- Without ultrasound exposure. (A = 1 – no ultrasound exposure)
- Ultrasound power 75 W. (A = 0 – always on)
- Ultrasound power 100 W. (A = 0, A = 0.4, A = 0.8)
- Ultrasound power 125 W. (A = 0, A = 0.4, A = 0.8)

These values are shown in **Table 3** below.

Table 3. Freezing time at various ultrasound power levels and intermittent exposure ratios

Ultrasound power (W)	0 W	75 W	100 W			125 W		
Intermittent ratio (A)	1	0	0	0,4	0,8	0	0,4	0,8
Freezing time (minutes)	55	57	53	48	53	50	45	51

Figure 4 shows the freezing time of shrimp at various ultrasound power levels and intermittent exposure ratios. **Figure 4** indicates that at a 0.4 intermittent ratio with 125 W

ultrasound power, the freezing time is the shortest at only 45 minutes compared to 55 minutes without ultrasound, a reduction of 18.2% in freezing time. This is a significant reduction in freezing time. The 0.4 intermittent ratio is also suitable for freezing striped catfish, reducing freezing time by 18.9% compared to without ultrasound assistance.

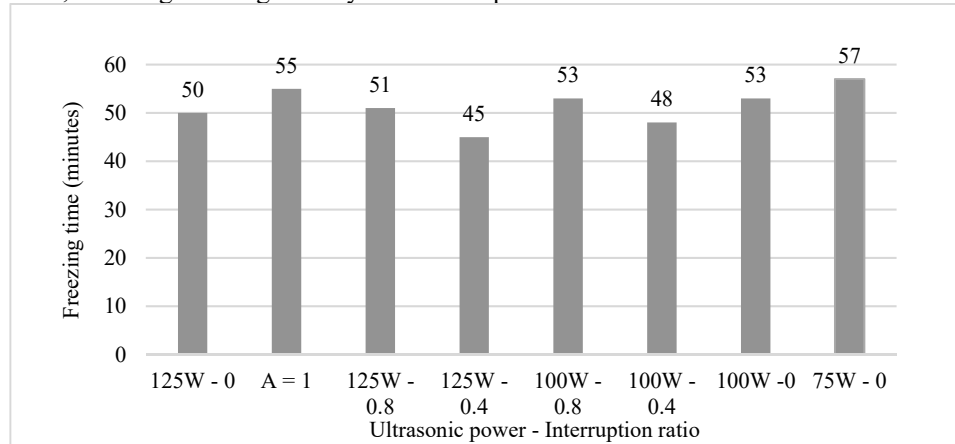


Figure 4. Impact of intermittent ultrasound exposure on freezing time of shrimp

3.3 Impact of Ultrasound on Freezing Energy Consumption

Experimental results comparing to the energy consumption of freezing striped catfish fillets with ultrasound assistance at 100 W power and various intermittent ratios and without ultrasound assistance are presented. **Figure 5** shows that with ultrasound assistance at 100 W power and a 0.4 intermittent ratio, the energy consumption is the lowest at 1.9 kWh compared to 2.3 kWh without ultrasound, a 17.4% reduction in energy consumption. This indicates that selecting a suitable ultrasound power and intermittent ratio can shorten freezing time and reduce energy consumption during the freezing process.

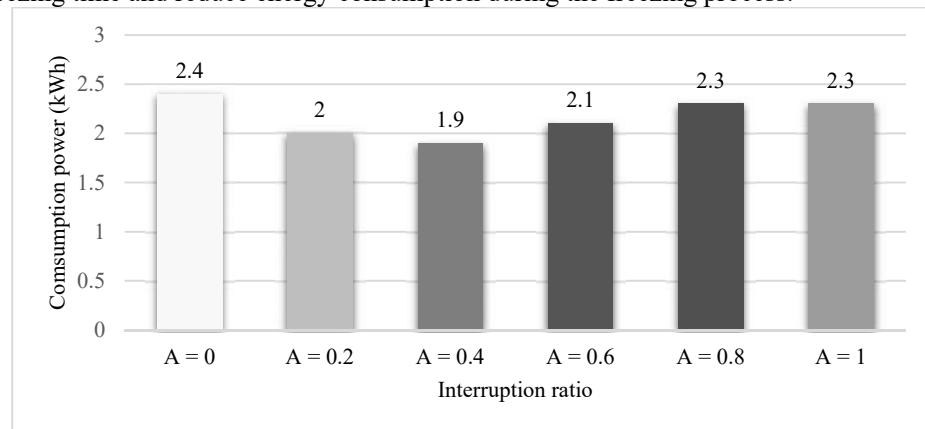


Figure 5. Impact of ultrasound on energy consumption for striped catfish fillets freezing

Similarly, the impact of intermittent ultrasound exposure on the energy consumption of shrimp freezing was also investigated. **Figure 6** presents the energy consumption of shrimp freezing at ultrasound power levels of 75W, 100W, and 125W with various intermittent ratios. The results show that at 125W ultrasound power and a 0.4 intermittent ratio, the energy consumption is the lowest, saving about 7.5% compared to without ultrasound assistance.

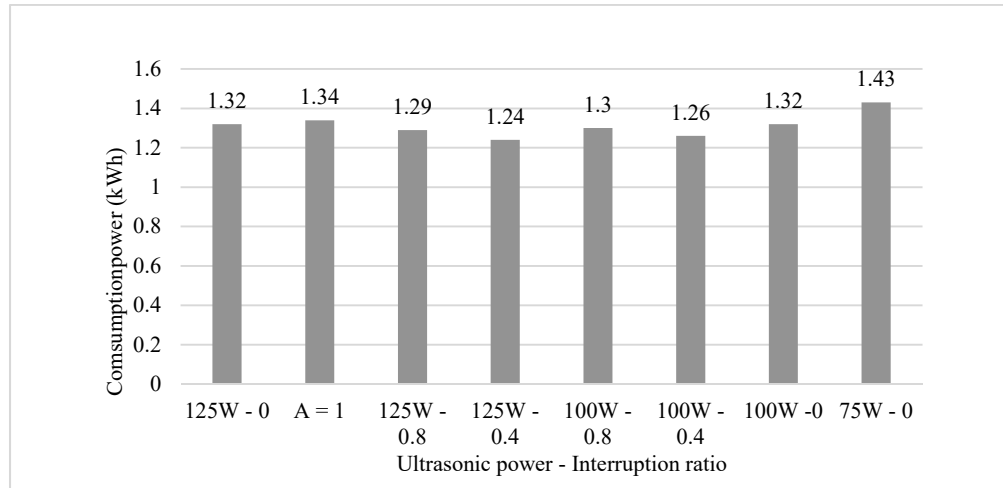


Figure 6. Impact of ultrasound on energy consumption for shrimp freezing

4.0 CONCLUSION

This paper presents an experiment on the impact of using ultrasound at 20 kHz frequency to assist the freezing process of striped catfish fillets and shrimp on freezing time and energy consumption. The results show that ultrasound power significantly affects freezing time. For striped catfish freezing, ultrasound power at 100 W will help reduce freezing time compared to without ultrasound. For shrimp freezing, the ultrasound power is 125 W. The difference in ultrasound power can be explained by the thickness of the frozen product. Both cases of freezing striped catfish and shrimp show that the 0.4 intermittent ultrasound ratio will yield the shortest freezing time. Regarding energy consumption, the experimental results show that the lowest energy consumption corresponds to the case of freezing striped catfish and shrimp at ultrasound powers of 100 W and 125 W, respectively, both with a 0.4 intermittent ratio. The energy savings in these two cases are about 17% for striped catfish and 8% for shrimp. The encouraging results from this study could be applied on an industrial scale to reduce freezing time and save energy consumption.

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