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Temperature during drying of wet cloth using two powerful aerial ultrasonic sources

Mio Ito[1]‡, Takuya Asami[1], and Hikaru Miura[1] ([1]Nihon University)

1. Introduction

In a previous study of drying technology using aerial ultrasonic waves, a standing wave sound field was formed using two small aerial ultrasonic sound sources, and the drying time was shortened at the sound pressure node position in the standing wave sound field[1]. In this paper, two large, powerful aerial ultrasonic sources were used to form a standing wave sound field, and wet cloth was dried at the sound pressure node position in the standing wave sound field to investigate the effect of ultrasonic irradiation on the dry basis moisture content and cloth temperature.

2. Powerful aerial ultrasonic source and formation of standing wave sound field

Figure 1 shows a schematic of the two powerful aerial ultrasound sources used in the study. The ultrasonic source consisted of a 20 kHz bolt-clamped Langevin ultrasonic transducer, an exponential horn for amplitude expansion, and a transmission rod for adjustment of the longitudinal vibration resonance frequency, which were all screwed together, and a rectangular stripe mode transverse vibrating plate (437 × 167 mm, 3 mm thick) fixed to the end of the transducer by screws. Two ultrasonic sources were installed with their vibrating plate surfaces parallel and facing each other 38 mm apart (two aerial sound wave wavelengths) to form a strong standing wave sound field between the plates.

3. Drying experiment

To determine the temperature of the drying sample during drying by aerial ultrasound, the dry basis moisture content during ultrasound irradiation was measured, and the relationships between the drying sample temperature and the ambient dry-bulb temperature, wet-bulb temperature, and relative humidity were also investigated.

3.1. Drying sample and dry basis moisture content

Standard Kanakin No. 3 cloth (size: 44 × 84 mm; thickness: 0.2 mm; material: 100% cotton) was used for the drying samples. To keep the drying samples flat, they were sandwiched between two pieces of stainless-steel mesh (material: SUS304; wire diameter: 0.5 mm; spacing: 2.9 mm; hole opening percentage: 64%) and fixed in place. The drying sample was placed parallel to the vibrating plate surface at the center of the vibrating plate in the x- and y-axis directions, and at the position of the sound pressure node in the standing wave sound field in the z-axis direction.

The moisture content of the drying sample was evaluated with the dry basis moisture content, expressed as

$$\text{Dry basis moisture content} = \frac{W_W - W_D}{W_D} \times 100\ [\%]$$

where W_W is the wet weight of the drying sample and W_D is the dry weight of the drying sample. The initial moisture content was fixed at 150%.

3.2. Experimental method

An electronic balance was used to weigh the drying sample, an analog dry hygrometer was used to measure the temperature and humidity around the apparatus, and an infrared thermography camera (InfRec H8000, Avio) was used to measure the drying sample temperature. The driving frequency of the ultrasonic source was fixed at 20.3 kHz. The aerial ultrasonic source was intermittently driven (repetition of 30 s irradiation and 4 s non-irradiation) because the weight of the drying sample could not be read accurately with an electronic balance during ultrasonic irradiation. The infrared thermography camera was positioned diagonally to the drying sample between the vibrating plate approximately

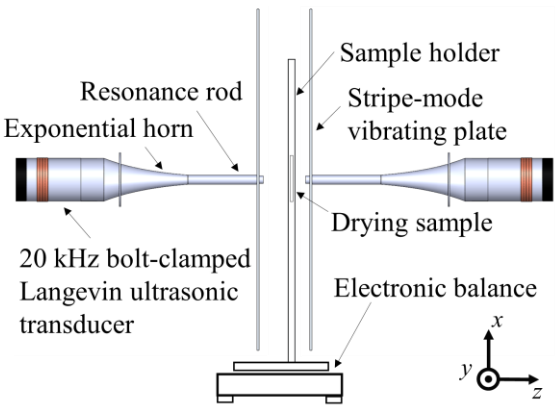

Fig. 1. Schematic of the ultrasonic source

E-mail: csmi21004@g.nihon-u.ac.jp, asami.takuya@nihon-u.ac.jp, miura.hikaru@nihon-u.ac.jp

200 mm from the drying sample. Measurements were taken in the absence of intermittent ultrasonic irradiation. From the measured image data, temperatures at five representative points in the drying sample area were extracted, and the average of the five temperatures was used as the drying sample temperature.

Measurements were made with total powers of 0 and 20 W supplied to the two sets of ultrasonic sources. These were repeated three times, and the average of the results was obtained.

3.3. Experimental results

Figure 2 shows the results of the drying for a total input power of 0 W. The vertical axis shows the dry basis moisture content, the dry- and wet-bulb temperatures, the drying sample temperature, and relative humidity, and the horizontal axis shows the elapsed time. The constant drying rate period was from the start of the measurement to about 3100 s, and the decreasing drying rate period is from this point to the end of the measurement. The drying sample temperature was 21.4 °C at 150% dry basis moisture content, which was close to the wet-bulb temperature. The drying sample temperature was around 21 °C until about 3100 s, which was the constant drying rate period, and then the drying sample temperature increased as the decreased drying rate period. The drying sample temperature when the dry basis moisture content reached almost 0% was 27.1 °C, which was only 0.7 °C above the dry-bulb temperature.

Figure 3 shows the results of the drying for a total input power of 20 W. The vertical and horizontal axes are the same as in Fig. 2, although the elapsed time on the horizontal axis represents only the 1/5 that in Fig. 2. The constant drying rate period was from the start of the measurement to about 410 s, and then decreasing drying rate period is from this point to the end of the measurement. The time during which the constant drying rate period was constant during sonic irradiation was about 1/7 of that without sonic irradiation in Fig. 2, indicating that ultrasonic irradiation had a large drying effect. The drying sample temperature was 21.2 °C at 150% dry basis moisture content, which was close to the wet-bulb temperature. After ultrasonic irradiation, the drying sample temperature increased to around 22.0 °C until about 410 s, which was the end of the constant drying rate period, and then the drying sample temperature increased further as the decreased drying rate period. The drying sample temperature when the dry basis moisture content reached almost 0% was 31.3 °C, which was only 4.5 °C above the dry-bulb temperature. This was attributed to the sound wave energy being absorbed by the cloth drying sample.

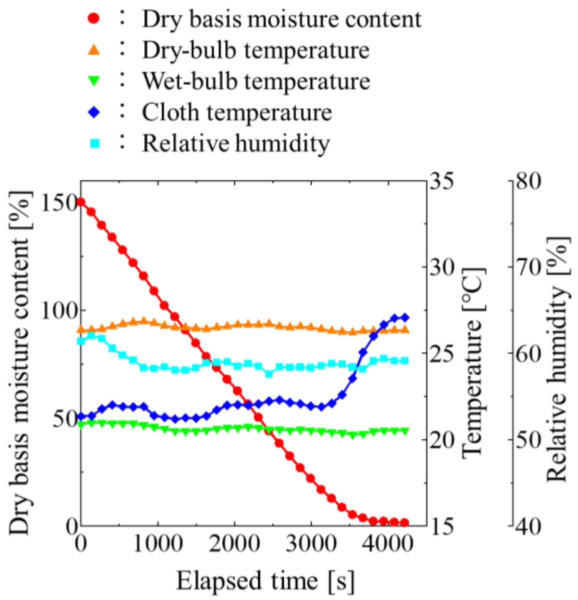

Fig. 2. Moisture content and temperature change for a total input power of 0 W.

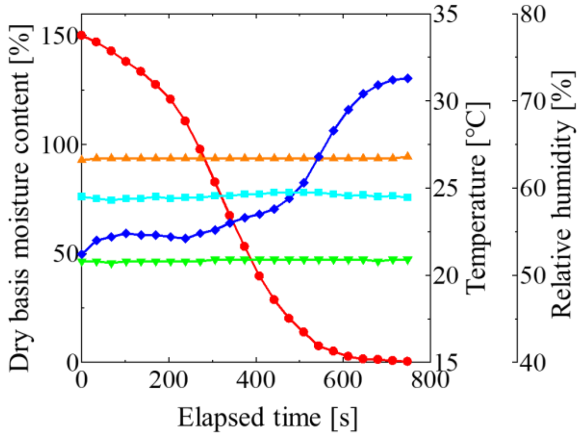

Fig. 3. Moisture content and temperature change for a total input power of 20 W.

4. Conclusion

Two large, powerful aerial ultrasonic sources were used to form a standing wave sound field, and wet clothes were dried at the sound pressure node position in the standing wave sound field. The increase in cloth temperature at a total input power of 20 W was larger than that at 0 W, indicating that ultrasonic irradiation caused the temperature of the cloth to slightly increase.

Acknowledgment

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References

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