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การศึกษาการแผ่กระจายของรังสีอินฟราเรดภายในห้องอบแห้ง
A Study on Distribution of Infrared Ray in the Drying Chamber

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Abstract

A study on distribution of infrared (IR) ray in the drying chamber, at different radiation intensities generated by an IR emitter, was conducted by measuring air temperature inside the chamber, on absorbing surfaces installed as horizontal planes. The testing aimed to describe the radiant distribution on the test planes, being placed with different spacings. The air temperature distribution was analyzed, based on response surface methodology (RSM) obtained from a second order polynomial model (R^2=0.908). The surface and contour plots of air temperature levels (response) on the absorbing surfaces in the drying chamber were made. The results would be useful for the selection of an appropriate size of area for drying with uniform distribution of IR according to the user's requirement.

Keywords: Drying chamber, infrared ray, distribution

บทคัดย่อ

การศึกษาลักษณะการแผ่กระจายของรังสีอินฟราเรดภายในห้องอบแห้ง จากอุปกรณ์กำเนิดรังสีอินฟราเรดที่ระดับความแรงของรังสีระดับต่างๆ ดำเนินการโดยการวัดอุณหภูมิของอากาศภายในห้องอบตามระนาบราบ เพื่ออธิบายการแผ่กระจายของรังสีมายังระนาบราบทดสอบที่อยู่ห่างจากอุปกรณ์กำเนิดรังสีระยะต่างๆ กัน โดยทำการวิเคราะห์ลักษณะการแผ่กระจายของรังสีด้วยการวิเคราะห์พื้นที่ตอบสนอง และสามารถอธิบายความสัมพันธ์ของปัจจัยต่างๆ ในรูปสมการโพลิโนเมียลอันดับสอง (R^2=0.908) รวมถึงแสดงลักษณะการแผ่กระจายของรังสีด้วยเส้นชั้นระดับอุณหภูมิของอากาศในห้องอบตามระนาบราบ ซึ่งผลการศึกษาดังกล่าว สามารถนำไปใช้ในการเลือกขนาดของพื้นที่อบแห้งที่มีการกระจายตัวของรังสีสม่ำเสมอตามเกณฑ์ที่ผู้ใช้กำหนด

คำสำคัญ: ห้องอบแห้ง รังสีอินฟราเรด การแผ่กระจาย

INTRODUCTION

Infrared (IR) drying has been gaining interest in agro-industry because of its high thermal efficiency and fast heating rate/response time, simplicity of the required equipment, easy to accommodation of IR heating with convective, conductive and microwave heating and significant energy saving.

Because infrared radiation drying is fundamentally different from convection drying, it is necessary to have a better understanding of the distribution of infrared ray from an emitter which radiates to moist materials, with each material in the drying chamber receiving the radiation uniformly. In the moist material, water absorbs energy extremely efficient with wavelengths ranging from approximately 2.5 to 7 microns. Radiation intensity and the distance between emitter to the radiation absorbing surface (drying area) are important factors to consider (Ratti, Mujumdar, 1995).

Many researchers have developed the IR drying chamber for testing. Afzal, T.M., Abe, T., (2000) simulated the moisture changes in barley during the drying by using IR heater (40x30 cm^2, operated at 200 V, 750 W), installed over sample holding tray (20x20 cm^2) at distance of 15 cm. Das, I., Das, S.K., Bal, S., (2004) evaluated the effect of radiation intensity and grain bed depth on quality of parboiled rice, using IR incandescent lamp (250 W) and adjusting the distance between the lamp and the radiation absorbing surface (the tray was 102

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mm in diameter). Amaratunga K.S.P. et. al.,(2005) studied on a laboratory catalytic infrared (CIR) dryer, the emitter was 0.265 m above the vibrating tray (0.8 x 0.4 m^2) (G).

Consideration on the designing conditions of IR dryer was more important, to confirm that the IR radiation was uniformly radiated to absorbing surface. However, there was a dearth of report that explained about an approach to the design and development of an IR dryer. This study was conducted to elucidate the effect of radiant intensity and distance between emitter and absorbing surface on radiant distribution, corresponding to the designing conditions of IR dyer.

METHODOLOGY

The experimental was set up to determine the radiant distribution using IR energy, shown in Figure (a). The IR dryer with overall dimensions of 1.20 m (L) x 0.90 m (B) x 1.20 m (H), gas-fired radiator (0.15 x 0.55m, medium to far infrared radiation wavelength) was mounted on a construction that could be moved up and down for adjusting the distance between the emitter and the radiation absorbing surface.

To determine the radiant distribution on absorbing surface, the 0.5 x 0.4 m area, set as grid which consisted of meshes (0.1 x 0.1 m), was installed and shown in Figure 1 (b). The absorbing area occupied a quarter of the absorbing surface, set on horizontal plan.

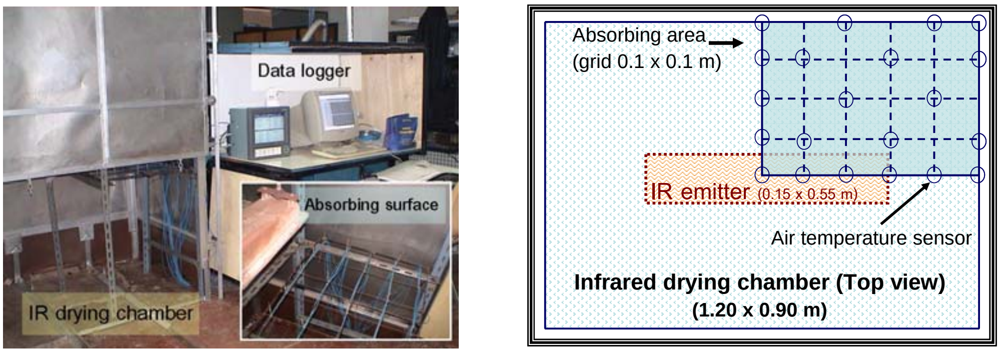

Figure 1 (a) Gas-fired infrared dryer; (b) Installation of air temperature sensor on tray which was designed as grid.

The factorial design with three replications was used in this study. Radiation intensity varied from 700 °C (2.97 μm), 800 °C (2.70 μm) and 900 °C (2.47 μm). The distances between emitter and absorbing surface were set at 0.20, 0.30, 0.40 and 0.50 m. Temperature values of emitter and air in chamber were recorded by using data logger (YOKOGAWA model DX200) at each 20 second with type K thermocouples.

The temperature values were recorded during the experiment. Starting with the initial stage, the emitter was burned and controlled by gas regulator, air temperature was increased until reaching a steady stage, where the values trended to constant which were analyzed by ANOVA and mean values comparison.

RESULTS AND DISCUSSION

Radiant distributions in IR drying chamber were recorded and selected in term of air temperature at the steady state point, which were analyzed by ANOVA. The details and statistical analysis of distributions are given in Table 1.

Table 1 Descriptive statistics of air temperatures distribution (°C), due to the effect of radiant intensity and distance between emitter and absorbing surface (m).

Distribution of Air Temperature	Infrared drying conditions setting (Emitter temperature,°C / Distance between emitter and absorbing surface, m)											
	700 / 0.5	700 / 0.4	700 / 0.3	700 / 0.2	800 / 0.5	800 / 0.4	800 / 0.3	800 / 0.2	900 / 0.5	900 / 0.4	900 / 0.3	900 / 0.2
Max Temp	61.40	62.70	71.00	93.80	77.40	76.20	81.50	122.90	100.50	103.30	115.80	167.60
Mean Temp	56.36	59.42	63.06	75.14	71.63	71.78	70.47	93.31	92.53	94.41	99.25	121.30
Min Temp	52.00	55.90	55.40	60.60	65.30	67.90	62.50	69.90	85.40	88.20	86.80	89.30
Temp Range	9.40	6.80	15.60	33.20	12.10	8.30	19.00	53.00	15.10	15.10	29.00	78.30
St Deviation	2.12	1.49	3.96	9.32	2.67	1.92	4.42	14.75	3.58	3.08	6.53	24.49

The descriptive statistic results show that air temperature values on the horizontal plan which absorbed IR radiation trended to increase when the plan was close to the emitter, but temperature distributions were at wide range. On the other hand, the uniformity of air temperature distribution as appeared with the installed emitter away from the radiation absorbing plan, especially at the distance of 0.4 m between emitter and absorbing surface at each emitter temperature level, air temperature distribution seem uniform as shown as low variance values.

A response surface method (*RSM*) was applied for analysis of the effect of working variables, the IR drying conditions setting (factors) of the radiant distribution with readings on air temperatures on the absorbing surface (responses). In such method of the response studied, the regression analysis was used, the variables were assumed to correlate with a second order polynomial equation. An ANOVA was conducted to assess the significant effects of the factors (at 95% confidence level) on the response. The following expression was found adequate with R^2 value of 0.908.

$$T = 346.47 - (0.671E) - (3.288H) - (0.481L) - (0.556W) - (0.00162EH) - (0.000808EL) - (0.000677EW) + (0.0218HL) + (0.0178HW) + (0.00790LW) + (0.000594E^2) + (0.0436H^2) + (0.00309W^2)$$

Where: T = air temperature (°C), E = emitter temperature (°C), H = distance between emitter and absorbing surface (m), L= length of absorbing area (m), W= width of absorbing area (m).

The equation showed that air temperature distribution was effected by both factors. The interaction coefficients were significant, but the quadratic effect of width of absorbing surface was non-significant, and was eliminated. The negative sign of the radiant intensity variables was indicated by increasing emitter temperature and close distance between emitter and absorbing surface, the air temperature had wide range of distribution. The response could be explained by three dimension surface plots as show in Figure 2.

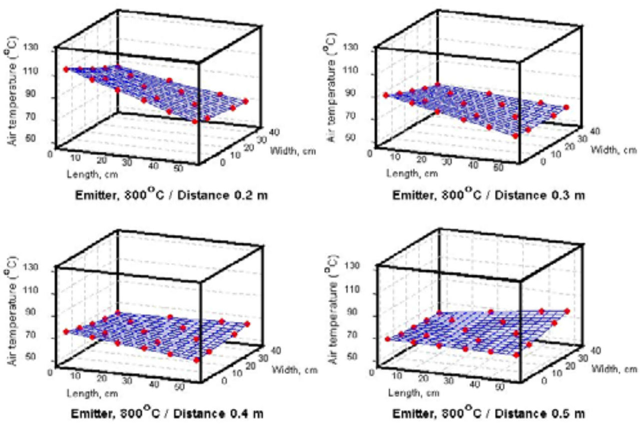

Figure 2 Surface plot of air temperature distributions (°C) and emitter temperature (constant at 800 °C) at different distances between emitter and absorbing surface (0.20, 0.30, 0.40 and 0.50 m) versus absorbing area of radiant distribution (width (m), length (m)).

The response surfaces of radiant distribution were predicted by means of equation as a function of a quarter of absorbing surface (length x width). The responses were calculated from fixed emitter temperature at 800 °C at different distances between emitter and absorbing surface (0.20, 0.30, 0.40 and 0.50 m). The air temperature at 0.2 m and 0.3 m cases were in the falling rate period. However, a uniform distribution was found at 0.4 m and 0.5 m as shown with low variance values as shown in Table 1.

The obtained results could be used for the selection of an appropriate size of area for drying with uniform distribution of IR according to the user's requirement. For example, IR drying conditions which was set up for emitter temperature of 800 °C and distance between emitter and absorbing surface of 0.4 m, could be selected for the desirable area of drying with square about 0.7 m x 0.65 m, with range of distribution about ± 3°C, as shown by contour plot in Figure 3 The 0.3 m x 0.2 m., inside of the desirable area was designed to be holed and used to ventilate the mixed air (natural air and combustible air) which flowed inside from the base and was exhausted at the top of the drying chamber. Finally, the drying tray with the desirable area had a vibrating unit for moist materials to receive the radiant heat uniformly.

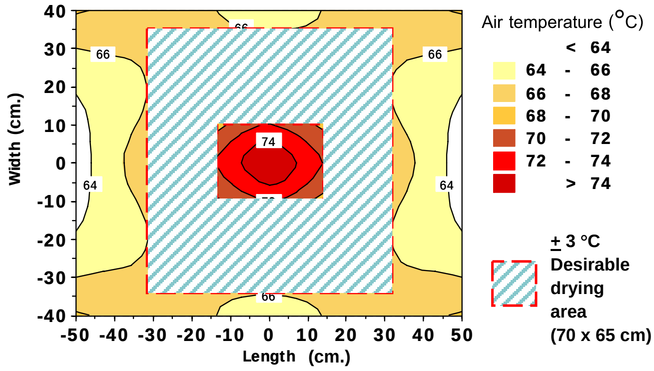

Figure 3 Determination of desirable area for drying with uniformly radiant distribution (± 3 °C), using contour plot of air temperatures at emitter temperature (800 °C) and distance 0.40 m between emitter and absorbing surface.

CONCLUSIONS

The radiant distribution in IR drying chamber was obtained from a second order polynomial model of air temperature (R^2=0.908). Wide range of distribution appeared at the high emitter temperature levels with close distance between emitter and absorbing surface. On the opposite, a uniform radiant distribution was obtained with far off distances. Therefore, according to the user's criteria for an efficient IR drying chamber, RSM analysis was used in order to select a desirable area for drying, examined by surface and contour plots.

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