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Temperature Distribution of Hot Air Flow in Heating Zone for Drying Application

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Keywords: Drying, Heating zone, Hot air flow, Rectangular duct, Temperature distribution.

Abstract. The temperature distribution of hot air flow in heating zone of a rectangular duct has been investigated for drying application. The experimental set-up consists of a heater and a fan to generate the hot air flow in the range of temperature from 40 to 100°C and the range of air velocity between 1.20 and 1.57 m/s. An increase of the heater power supply increases the hot air temperature in the heating zone while an increase of air velocity forced by fan decreases the initial temperature at the same power supply provided to generate the hot air flow. The temperature distribution shows that the hot air temperature after transferring through air duct decreases with an increase of the length of the rectangular duct. These results are very important for the air flow temperature and velocity control strategy to apply for heating zone design in the drying process.

Introduction

Drying is the oldest unit operation found in most industrial sectors. Drying technology is not only related to the food processing industry, but also extends to a wide range of applications in the chemical, biochemical, pharmaceutical, and agricultural sectors. However, drying is widely used for enhancing the food preservation. Drying preserves foods by removing enough moisture from food to prevent decay and spoilage that successful drying depends on: enough heat to draw out moisture, without cooking the food; dry air to absorb the released moisture; and adequate air circulation to carry off the moisture [1]. When drying foods, a drying temperature is the key parameter to remove moisture as fast as possible but, however, it must not seriously affect the flavor, texture and color of the food. If the temperature is too low in the beginning, microorganisms may survive and even grow before the food is adequately dried and if the temperature is too high and the humidity too low, the food may harden on the surface [1]. This makes it more important to control the proper temperature in the drying zone.

Many researchers have studied the drying process based on mathematical model and simulation in order to predict the temperature and velocity profile of hot air flow in the drying chamber [2-5]. Pimsamarn et al. [3] numerically investigated the distribution of air flow and temperature by using Computational Fluid Dynamics (CFD) of the average exhaust air temperature of 56 °C with air velocity of 1.75 m/s. Boyce [6-7] and Sanderson et al. [2] performed drying tests in small beds of grain under uniform airflow that the location of the drying front by measuring air temperatures was successfully identified. In addition, temperatures within drying chamber under uniform air velocity have been investigated experimentally to estimate the mathematical model of drying process [8-10]. Gu et al. [11] performed the experimental study to investigate the temperature distribution at various positions in the in-bin drying of grain. As mentioned above, although there are many theoretical and experimental drying studies to determine the temperature and velocity distribution in the drying zone to estimate the humidity contents for various drying processes, there have been limited works on the estimation of temperature distribution in heating zone which generate the hot airflow entering the drying chamber that is also very important to control the desired temperature and keep the quality of hot air for drying process.

In this study, the temperature distribution of hot air flow inside the heating zone in rectangular duct has been experimentally investigated when the heater power supply is varied between 30 – 100% under various air velocities from 1.20 – 1.57 m/s. This investigation is very significant for a further design of control approach to keep the properly required drying temperature in the future.

Experimental set-up and procedure

In the experimental methodology, the atmospheric air forced by electrical fan flows across a heater to generate hot air passing through the non-insulated rectangular duct as shown in Fig. 1. The electrical heater power supply was varied from 30% to 100% to obtain the different value of the input air temperature when a 500 W heating coil was used. The air velocity flowing through the rectangular duct was varied from 1.20 to 1.57 m/s by changing the power supply to fan. The air velocity was measured by using a Panasonic SUNX Photo Sensor PM-K44. The temperatures inside the rectangular duct at various positions were measured by RTD (resistance temperature detector) as shown in Fig. 2. The range of temperature and air velocity varying in this study was generally used in the drying process [4, 9-10].

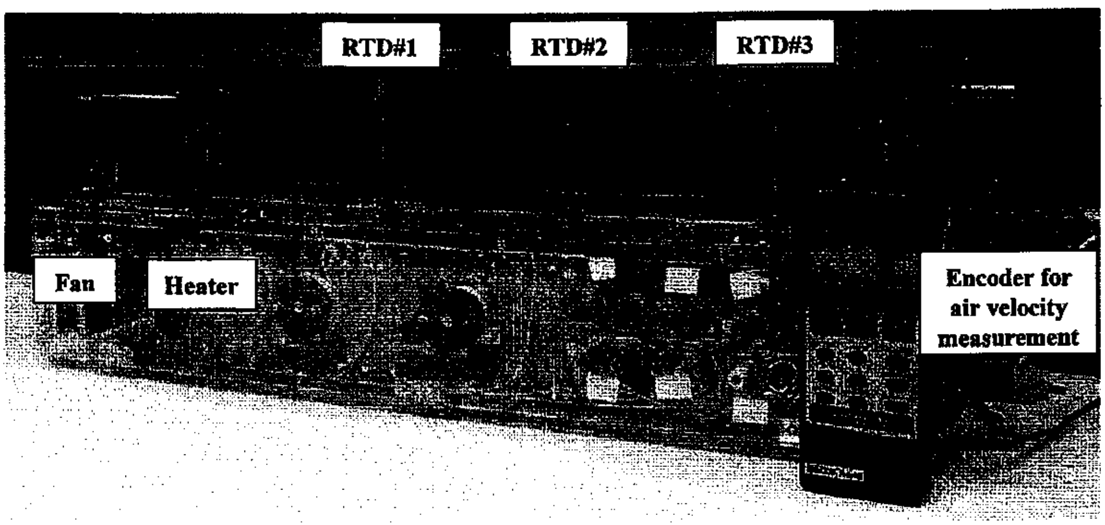

Fig. 1. Experimental apparatus.

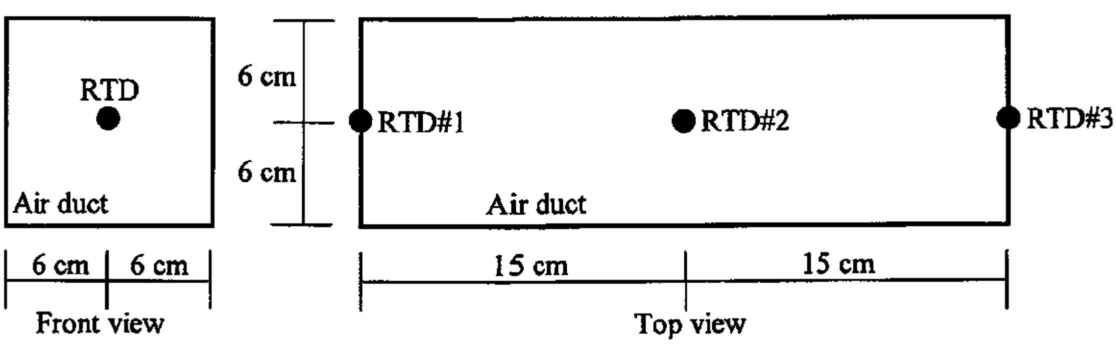

Fig. 2. Position of RTDs in rectangular duct.

Results and Discussion

The temperature and velocity distribution of the hot air flow mainly affects the remove of moisture from food when air is the drying medium. As the need for improving the heating zone which is an important part of drying process is a main idea of this study. In the heating zone, the major apparatuses consisted of the heating element and the air flow generator to produce the forced convection heat transfer in the drying chamber. Therefore, the control design for maintaining the suitably required temperature and air velocity in the heating zone is crucial in order to keep the quality of drying process. In the experimental procedure, the hot air flow temperatures at different three positions of RTDs located in the non-insulated rectangular duct were measured as mentioned above when the electrical power supplying to heating element and the air velocity were varied. Fig. 3 illustrates the effects of heating power supply and air velocity on the temperature at position of the first RTD (RTD#1) in the heating zone. At fixed air velocity, an increase of power supply increased the hot air temperature in the heating zone. At fixed heating power, the hot air temperature decreased as the air velocity increased this is because of the increase of the average convection heat transfer coefficient (as described by Eq.(1)) depending on the velocity of the fluid flow in term of Reynolds number (Re) [12].

$$q = h(T_s - T_b) \quad (1)$$

where q is the heat flux [W/m^2], h the heat transfer coefficient [W/m^{2}K], T_s the surface temperature of heating element [°C] and T_b the bulk temperature [°C].

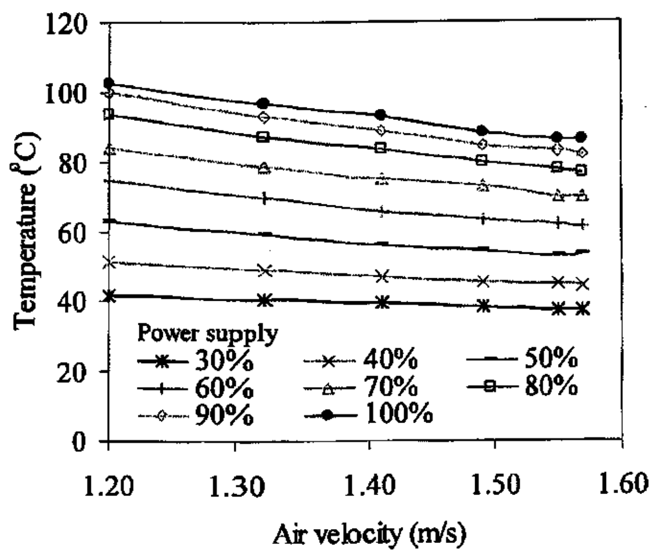

Fig. 3. Temperature measured by RTD#1 as a function of air velocity and heater power supply.

Fig. 4 shows the temperature distribution of the hot air flow in the non-insulated rectangular duct when the air velocity was varied between 1.2 and 1.57 m/s at various value of the heater power supply in the range from 30% to 100% of a 500 W heating coil. In Fig. 4, ΔT represents the difference between the measured temperature and the ambient temperature. The measured temperature was recorded in thermal equilibrium by balancing the heat gained through the energy supplied to it via the heater and the heat lost through convection and conduction. At fixed velocity and heating power supply, the hot air temperature after transferring through air duct deceased with increasing the distance of RTD position that is because of increasing of heat loss being function with the distance. This result showed that it is very important to consider the control design to maintain the desired temperature before entering the drying chamber.

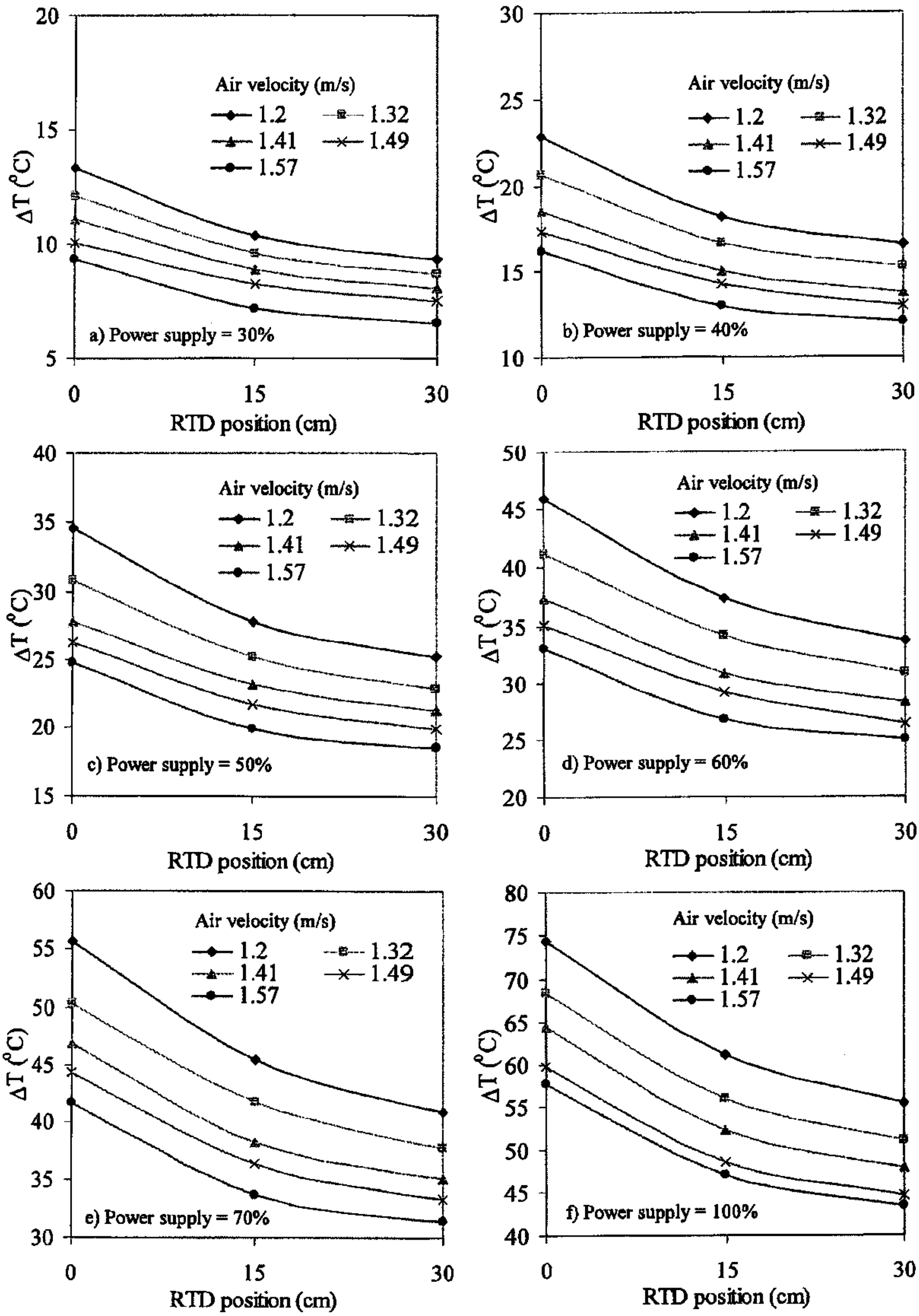

Fig.4. Temperature as a function of RTD position for various air velocities at different heater power supply: a) 30%, b) 40%, c) 50%, d) 60%, e) 70% and f) 100%.

Conclusion

Because successful drying depends on enough heat and air circulation to remove the moisture, the design of heating zone that generate the hot air flow passing through the drying zone is very vital in order to retain the quality of drying process. In this study, the temperature distribution of hot air flow generated by heating zone in a rectangular duct was investigated for drying application. In the experimental set-up, a heater and a fan were used to produce the hot air flow in the range of temperature from about 40 to 100°C by varying the heater power supplying to the heating coil and the range of air velocity between 1.20 and 1.57 m/s. The equilibrium temperatures at three positions in the rectangular duct were measured by using RTDs. The experimental results showed that at fixed air velocity, the hot air temperature increased as the heater power supply increased while at fixed power supply, the temperature decreased with increasing the air velocity. The temperature distribution was reported that the hot air temperature after transferring through air duct was decreased with increasing distance of the rectangular duct. These results are very important for the control approach design of air flow temperature and velocity for heating zone design in the future.

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	Abstract—The paper presents the results of investigations regarding surface roughness measurements in ultrasonic assisted grinding of selected ZrO_2 based ceramic material. There are different results, in the area of surface roughness measurements, presented in the literature. The entry data of hybrid machining process (e.g. grinding wheel type, feed, machining strategy or process variant) may influence these results. The analysis of literature encourages to take up the investigations of surface quality in ultrasonic assisted machining. These investigations may be performed for specific ceramic products and technological tasks which are commonly applied in ceramic machining processes. The knowledge about the machining of ceramic materials in different sintering states is very limited. Based on this finding, ultrasonic assisted and conventional machining processes of ZrO_2 based ceramic material in different sintering states were investigated. *Index Terms*—ultrasonic assisted grinding, surface roughness, ceramic materials, hybrid machining
E1003	Durability performance of concrete containing CFBC fly ash and coal-fired fly ash ***Maochieh Chi and Ran Huang*** WuFeng University, Taiwan
	Abstract—This study presents an investigation into durability performance of concrete with various combinations of circulating fluidized bed combustion (CFBC) fly ash and coal-fired fly ash. All cylindrical specimens with the same binder content of 420 kg/m^3 and water/binder ratio of 0.5 were cast and cured in the saturated limewater. Permeability test, sulfate attack resistance test, rapid chloride ion penetration test (RCPT) and carbonization test were performed. Test results demonstrate that the adding of CFBC fly ash and coal-fired fly ash would reduce the water permeability and chloride ions penetration, and increase the sulfate attack resistance, but an increase in carbonization depth. The carbonization depth increases with an increasing contents of CFBC fly ash and coal-fired fly ash. There exists a negative relationship between compressive strength and carbonization rate. Based on the test results, CFBC fly ash and coal-fired fly ash can be considered as cement replacement materials and employed in concrete. *Index Terms*—Durability, CFBC fly ash, coal-fired fly ash, carbonation depth

Session III–Authors' Oral Presentation
(ICAME 2014, ICIAE 2014)
15:50pm-18:30pm, Conference Room III

Session Chair: *Dr. Eng Hwa Yap,*
University College London, Australia

E011	Development of Computerized Preventive Maintenance Management System with Failure Mode and Effect Analysis for CNC Machine ***Em-ardchaya Rungsa and Somkiat Tangjitsitcharoen*** Faculty of Engineering, Department of Industrial Engineering, Chulalongkorn University, Thailand

	ceramic parts. ***Index Terms***—coordinate measuring technique, ultrasonic assisted grinding, ceramic materials
E052	Temperature Distribution of Hot Air Flow in Heating Zone for Drying Application ***Nawadee Srisiriwat*** *and Chananchai Wutthithanyawat* Pathumwan Institute of Technology, Thailand ***Abstract***—The temperature distribution of hot air flow in heating zone of a rectangular duct has been investigated for drying application. The experimental set-up consists of a heater and a fan to generate the hot air flow in the range of temperature from 40 to 100°C and the range of air velocity between 1.20 and 1.57 m/s. An increase of the heater power supply increases the hot air temperature in the heating zone while an increase of air velocity forced by fan decreases the initial temperature at the same power supply provided to generate the hot air flow. The temperature distribution shows that the hot air temperature after transferring through air duct decreases with an increase of the length of the rectangular duct. These results are very important for the air flow temperature and velocity control strategy to apply for heating zone design in the drying process. ***Index Terms***—Drying, Heating zone, Hot air flow, Rectangular duct, Temperature distribution.
E053	Internal Model Control Design for Autothermal Reforming System ***Chananchai Wutthithanyawat*** *and Nawadee Srisiriwat* Pathumwan Institute of Technology, Thailand ***Abstract***—This paper focuses on the control system design for a process of autothermal reforming (ATR) of ethanol. The targeted application is within an on-board fuel processor of ATR operating at the adiabatic reaction temperature for hydrogen production. An internal model control (IMC) method is designed for controlling the adiabatic reaction temperature of ATR reactor by manipulating the input air flow rate. Two strategies of controller design with and without the feed temperature control of the preheater unit are proposed in order to determine the suitable controller system as the surrounding temperature is a major disturbance for cold weather. Theoretical analysis demonstrates that IMC strategy can achieve desired performance. Two loops of control system of the ATR process combined with the feed temperature control can compensate the surrounding temperature better than without the feed temperature control. ***Index Terms***—Autothermal reforming, Ethanol, Hydrogen production, Internal Model Control, IMC.
E060	A Design of Launching Pattern for Final Inspection of Assembled Cars in Mixed Model Assembly Line *P. Vinitsorn and* ***Suksan Prombanpong*** King Mongkut's University of Technology Thonburi, Thailand ***Abstract***—The objective of this paper is aimed at determining the sequential pattern of a newly mixed -models assembled cars entering into the final inspection lines so that the required production rate of each model can be obtained as specified. The inspection lines are consisted of three parallel conveyor lines and each line is