Temperature profile of moving belt with direct IR heating using CFD modelling

P Vichaiya and J S Jongyingcharoen
Agricultural Engineering Department, Faculty of Engineering, King Mongkut’s Institute of Technology Ladkrabang, Bangkok, Thailand
Email: patvichaiya@hotmail.com

Abstract. Radiation heat transfer requires no medium, so energy lost is minimal. Infrared wave band is used for heating. However, radiative heating has limitation on the penetration depth. It infiltrated only a few millimetres into an object. IR drying can be used for thin layer drying. Continuous IR drying was an ideal process to use in drying. A pilot continuous IR drying tunnel was constructed. CFD model was used to generate the image of temperature profile of a moving belt which no other mean of temperature measurement can be pursued. The model was compared to measuring points for validation. The result was fair. By varying the IR heating power and speed of the belt, many scenarios can be used to find the optimum condition for drying.

1. Introduction
Radiation is a form of energy transfer without medium; hence, heat loss is minimum. However, only long wave radiation converted to heat. Infrared wave band (0.75 – 1000 µm) is often used for heating. Even though, radiation loss minimal energy, the limitation of heat transfer is distance between heat source and shape of the source which show in term of view factor. Furthermore, radiation is effective only by absorption and can penetrate through object for few millimeters. For drying, use of radiative heating directly on dense object will result in case hardening and water evaporation is obstructed so the radiative heating may be used for thin layer, lose or porous material. Due to this disadvantage, IR heater is used to heat air in order to raise its temperature and use as convective heating.

Computational Fluid Dynamic (CFD) is a numerical base calculation originated in the field of fluid mechanics which fluid is the medium of interest. Conservation of mass, conservation of energy and conservation of momentum were used to exhibit the flow (velocity), the temperature change (energy) and changing of mass (mass transfer) in fluid flow. It gains popularity to solve problems in many engineering disciplines. In chemical Engineering, CFD has been used to simulate concentration of profile in mixing tank [1, 2], in spray dryer [3] and in cyclone separators [4, 5]. CFD was increasingly gained attention in the field of drying. Khodeai et al. [6] use CFD for the analysis of drying in single biomass particle. The prediction demonstrated close agreement with the report data. CFD was also used to simulate the heat and mass transfer of apricots drying [7]. The experiment data agreed with the results predicted by CFD model. With the power of computer generating, CFD image model was visualizes and compared with the thermal imaging. The surface temperature of figs under the effect of infrared heat disinfection from fungal to prolong its shelf life can be seen [8]. Similar idea using CFD was proposed by Zhang [9] to dry animal feed. He found that the thickness of feed layer prevents hot air to pass through; therefore, drying was not effective causing mold and infection to animals. CFD
image generation helped visualized the blinded spot or uneven distribution of drying air. Ability to forecast the results when changing air speed further expand the useful information on the drying of the feed.

In this study, a focus was upon the temperature profile of the continuous moving belt surface of the direct IR heating using CFD simulation. There are 2 objectives.

Objective 1 is to validate the temperature profile of moving belt surface of IR heater using CFD model.

Objective 2 is to investigate the effect of varying IR heaters power to temperature profile of the moving belt.

2. Material and Methods

2.1. Continuous IR drying

A moving belt dryer equipped with 4 ceramic IR heater of 1000 W/m$^2$ were installed. The length of tunnel was 120 cm and the width were 30 cm. Height of 10 cm between heater and belt was set. From preliminary study, at this height, the belt surface temperature was heated to 70-80°C which is suitable for drying of most agricultural product. Schematic drawing of the tunnel was shown in figure 1.

![Figure 1. Schematic drawing of tunnel.](image)

| Case | IR1 (W/m$^2$) | IR2 (W/m$^2$) | IR3 (W/m$^2$) | IR4 (W/m$^2$) | Total (W/m$^2$) | Moving speed (m/s) |
|------|---------------|---------------|---------------|---------------|----------------|------------------|
| A    | 500           | 500           | 500           | 500           | 2000           | 0.02             |
| B    | 500           | 500           | 250           | 250           | 1500           | 0.02             |
| C    | 1000          | 750           | 500           | 250           | 2500           | 0.02             |

2.2. CFD model

The geometry of tunnel and IR heater was drawn with GAMBIT 2.4.6. The grid of hexahedral was generated according to the dimension of the tunnel. For boundary condition, boundary type of both pressure and temperature inlet and outlet was set at 1 atm and 300 K respectively. All the walls, no-slip boundary condition type with adiabatic condition was specified. Only for bottom wall, the adiabatic moving wall with velocity of 0.02 m/s was set. Further, heat flux was specified at IR heater. The values of heat flux corresponded to the values in the experiments.

2.3. Experiments

For moving of belt in the drying tunnel, it is almost impossible to measure its surface temperature by all mean. However, thermocouples (K type) were attached to rods which hanged about 1 cm above the belt. It measured the moving air which was influenced by the moving belt. Temperature of each
measuring point was compared to the CFD model for validation. Figure 2 (A) showed the position of thermocouples. One thermocouple (Point 2) was placed at the middle of the belt and other two were placed at 10 cm apart.

Power of IR heater can be adjusted by current controlled input. Speed of the belt can also be varied as showed in table 1.

![Figure 2](image)

**Figure 2.** (A) Temperature measuring points on belt, (B) Points marked of temperature for validation of CFD model.

3. Results and discussion

3.1. Validation of CFD model

After the belt and the heater were turn on, the temperature detected by thermocouple was rising. Until it reached steady state which was around 15 min, the temperature was then recorded and averaged for entire time of another 40 min. In figure 3, the temperature profile can be seen by the color map between the ranges of 27°C to 541°C. The surface temperature profile was from 27°C to 189°C. The temperature appeared to be high in the middle of the belt which was the result of the position of the heaters.

As the belt moves toward the outlet, it pulled the heat signature to the outlet. Top view of the belt showed that the temperature in the middle part of the belt was higher than the edge of the belt. As belt moved, shear of the belt drawn air into the tunnel, so the temperature of the first IR heater was reduced.

CFD model was validated using case A (table 1), equally powered of 500 W/m² for all heater. Since thermocouples were hanged about 1 cm above the belt; therefore, the predicted temperature obtained from CFD model was also 1 cm above the surface. Temperature profile of the model in figure 2 (B) showed that moving belt dragged the heat toward the outlet. The heaters were situated at the middle of the tunnel; therefore, temperature in the middle part of the surface was higher than at the edge. Table 2 also showed that both temperatures measured, and temperature predicted by the CFD model exhibited the same tendency that the temperature at the middle part was higher than at the edges of the belt.

While inlet and outlet temperature of the model was fixed at 300 K (27°C), the temperature in the experimental room was not. Moreover, the initial condition of the model was set to eliminate IR effect,
so the prediction values was underestimated. As a result, the model prediction was fair and reasonable accepted.

![Temperature profile of the belt and IR heater.](image)

**Figure 3.** Temperature profile of the belt and IR heater.

**Table 2.** Measured and predicted temperature of belt surface.

| Point (Pt) | Measured temperature (°C) | CFD Predicted temperature (°C) | Different percentage |
|------------|-----------------------------|--------------------------------|---------------------|
| 1          | 75.68                       | 62.09                          | 17.33               |
| 2          | 77.65                       | 74.66                          | 3.85                |
| 3          | 72.26                       | 62.09                          | 14.07               |

### 3.2. The effect of different IR power

Table 1 shows three cases of IR power generated. It seemed that in case A, the temperature of the IR3 and IR4 were high and as a result, temperature of the belt was also high (figure 4 (A)). Case B was provided with IR power of 500 W/m² for IR1 and IR2 and reduce to 250 W/m² for IR3 and IR4. The result of the simulation suggested that temperature profile of the belt was not different from case A, but the energy can be reduced to 1500 W/m² (figure 4 (B)). However, the goal is not achieved since more than half of the belt surface was only at 27°C. Case C was simulated starting with IR1 at 1000 W/m² and gradually reduced every 250 W/m². The goal was to maintain steady temperature over the entire surface of the belt at 70-80°C. Figure 4 (C) showed that higher temperature was shifted toward the inlet but homogenous distributed was not yet fulfilled. And again, the last heater with less power still resulted in a high temperature signature on the belt.
4. Conclusions
Validation of a CFD model of surface temperature under IR heater with moving belt was studied. The CFD model predicted and measured temperature were compared. The result showed that the model can reasonably predict the temperature profile of the belt.

Additional experiment on different IR heater was investigated. Case B, the reduction of the power of the heater close to the outlet had the same effect on belt temperature as in case A. So, the energy could be reduced to get the same temperature profile. It was shown in case C that heating at the front of the tunnel has more effect to raise the belt temperature. The result suggested that high temperature should be used at the entrance of the tunnel and possibly, heating at the end of the tunnel may be omitted. Furthermore, speed of the belt may be reduced to increase heating time of the belt.

This experiment showed that CFD model may be used to simulate the temperature profile of the belt inside the tunnel. This way, a number of experiments to acquire homogenous temperature distribution of the belt surface in the tunnel can be reduced which also reduce cost, time and manpower due to trial and error experiment.

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