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# Measuring heat transfer coefficient in convection reflow ovens

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ABSTRACT

In this paper, the evaluation of a measurement method is discussed which can determine the heat transfer coefficient in convection reflow ovens. Nowadays the reflow ovens apply forced convection heating with nozzle-matrix blower system. In these ovens the heat transfer coefficients of the heater gas streams determine mainly the efficiency of heating. A method is presented which has two steps: in the first step, the heat transfer coefficient of the heater gas streams is studied above the assembly in function of height; in the second step, the heating efficiency of the nozzle-lines is compared as a distribution of the heat transfer coefficient in the oven. The heat transfer coefficients are calculated from the heat equation of the reflow oven. It is also presented with the distributions of the heat transfer coefficient that how the contamination of the nozzles affects the heating efficiency of the reflow oven.

## 1. Introduction

Reflow soldering is an important step of surface mounted technology (SMT). This process is applied to enable the attachment of surface mount devices (SMDs) to printed wiring boards (PWBs). The preparatory steps of the process are the solder paste printing to the contact surfaces (pads) of the PWB, and the component placement onto the solder paste deposit. The reflow process then heats the entire assembly to a temperature above the melting point (reflow temperature) of the solder alloy. This allows the individual solder particles in the paste to melt into a single volume which can wet the soldering surfaces and form the solder joints. The homogeneity and the efficiency of the heat transport have strong influence on the solder joints, because an inhomogeneous temperature profile can cause reflow soldering failures.

Usually the industrial reflow ovens contain a number of independently controllable heating zones [1]. During the soldering, the assemblies are transported through the oven by a conveyor line. The heating method of the ovens evaluated during the times. The first reflow ovens applied pure Infra Radiation (IR) heating, so the first reflow models dealt with these [2–4]. These models were based on simplified expressions of heat radiation and conduction, and used only two dimensions. The mapping of IR ovens' capability started with simple temperature distribution measurements. These types of measurement systems had low resolution and accuracy [2,5], therefore these are out of date. The models in the "next generation" examined the reflow ovens which applied mixed heating (radiation & convection) [1,6,7]. These were still 2D, and sometimes applied the expression of convection heat transfer with wrong derivations (see in [1]).

Actually, the latest reflow ovens use pure forced convection heating. In this type of heater system, the efficiency is described by the forced convection heat transfer coefficient ($\alpha$), [W/m$^2$ K]. Generally in a convection heat transport process the convection heat flow rate is calculated:

$$F_c = \alpha \cdot A \cdot (T_2 - T_1) \quad [\mathrm{W}] \tag{1}$$

where $A$ is the heated surface [m$^2$] and $T_2 - T_1$ is the temperature difference [K] between the heater gas and the heated surface. The convection heat is calculated by the integration of (1) over the time of the heating.

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Useful simulations and numerical analysis of the forced convection [8–10] exist but not for reflow soldering environment. Although, a method for optimizing the heating capability of forced convection reflow ovens was published in [11], but it was based on a wrong correlation between $\alpha$ and the heater temperature. Several newer thermal models of the reflow soldering process [12,13] still use an average or some different values of $\alpha$ for the whole oven, but this is a wrong approach. The value of $\alpha$ highly depends on the location in each heater zones. This is caused by the changes of the gas flow parameters, the inhomogeneity of the gas circulation system and the different contamination level of the blower system. Therefore the distribution of $\alpha$ in the reflow oven gives us valuable information about the capability of the oven.

There are two different methods to determine the $\alpha$ parameter, by measurement or by calculation. A well worked out measurement method for the natural convection heat transfer was published recently [14,15]. The values of $\alpha$ in reflow ovens can be calculated using the following expression which was derived from systematic series of experiments:

$$\alpha = \frac{\lambda}{2 \cdot d} \cdot G\left(g, \frac{H}{d}\right) \cdot \mathrm{Re}^{\frac{2}{3}} \cdot \left[1 + \left(\frac{H/d}{0.6/\sqrt{g}}\right)^{6}\right]^{-0.05} \cdot \mathrm{Pr}^{0.42} \tag{2}$$

where $G$ and $g$ are assistant functions depending on the geometry of the oven, $\lambda$ is the thermal conductivity of the gas, Re is the Reynolds number and Pr is the Prandtl number of the gas [6]. Although it is difficult to determine some parameters (e.g. the gas flow rate and density) which are needed for Re and Pr numbers. Therefore measuring methods was developed to determine the heat transfer coefficient in convection reflow ovens.

## 2. Experimental

As it was mentioned, the industrial reflow ovens contain a number of independently controllable heating zones [1]. The schematic cross-sectional view of a general convection reflow oven, which applies the nozzle-matrix blow-in system, can be seen in Fig. 1. This contains seven heater zones (the first five are pre-heater zones and then two are peak zones from the seven) and one cooling zone. The main parts of the heater zones are the followings:

- an electrical heaters which heat the gas,
- a fan which moves the gas,
- a nozzle-matrix (Fig. 2) which distributes the moving gas above the assembly and generates the gas streams.

(The construction of the heater and the cooling zones is the same but the cooling zone does not contain electrical heaters.)

The nozzle-matrix contains parallel nozzle-lines which are also parallel with the moving direction of the assembly. These generate numerous heater gas streams. The assembled PCB passes under the nozzle-lines during the soldering. Therefore two important parameters of the oven can be studied: the $\alpha$ parameter of the heater gas streams; and the heating efficiency of the nozzle-lines.

Primary factors affect the $\alpha$ parameter are the gas flow parameters: flow rate, density and pressure of the heater gas. The exact measurement of these parameters is too complicated because of the extreme circumstances in the reflow oven (small space, high temperature, etc.). The alternative solution is to examine the heating capability of the oven. Temperature changes are measured and $\alpha$ values are then calculated from the heat equation of the applied probe:

$$Q_a = Q_c - Q_k \tag{3}$$

where $Q_a$ is the absorbed thermal energy during the soldering, $Q_c$ is the convection heat and $Q_k$ is the parasite conduction heat. In forced convection reflow ovens, the

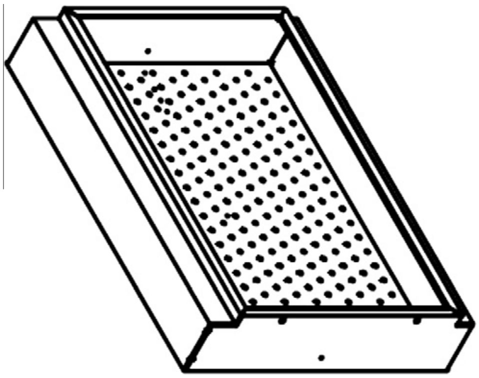

**Fig. 2.** Nozzle-matrix of a heater zone.

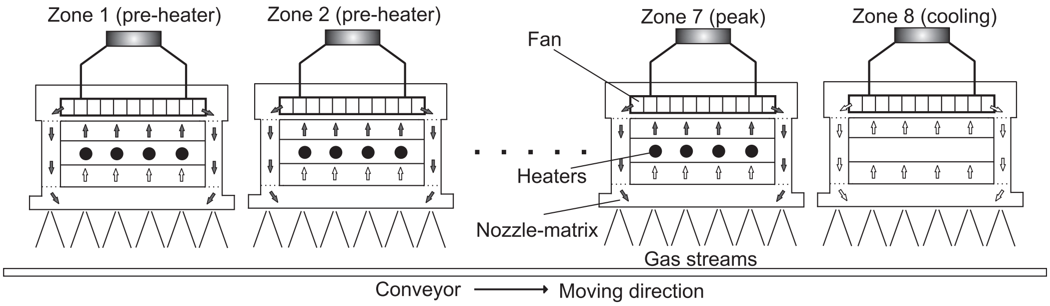

**Fig. 1.** Cross-section view of a convection reflow oven.