Analytical Investigation of Effects of Thermophysical Properties on Transient Temperature Response of Papers in Thermal Printer

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Abstract

This paper describes the effects of thermophysical properties of printing papers on transient temperature response in the Direct Thermal Printers (DTP). DTP produces printed images by selectively heating thermal papers when a thermal head, which includes dot heaters, contacts thermal papers directly. The printing quality of DTPs is strongly dependent on thermophysical properties of thermal papers. Our study aims to optimize the printing process of DTPs in order to reduce power consumption of DTPs while maintaining printing quality. In this paper, a relationship between thermophysical properties, which are density, specific heat and thermal conductivity of the printing paper, and the transient temperature response of the paper was investigated quantitatively using 3-dimentional thermal conduction analysis. Through the analysis, we clarified the dominant factor in the temperature rise of the papers from the viewpoint of the thermophysical properties.

Introduction

Direct Thermal Printers (DTP) produce printed images by selectively heating thermal papers when a thermal head, which consists of a lot of dot heaters, contacts thermal papers directly. Recently, there is a great demand of DTP technologies to portable POS (Point-of-Sale) terminals because DTP has advantages of compact dimension and running cost over other printing technologies. However, a decrease of a power consumption is strongly needed while improving printing quality in order to apply DTP technologies to the POS terminals. Previous studies have been investigated about the design of thermal printers [1] – [4]. However, in order to optimize the thermal printing process, the further investigation of printing process of DTP should be needed. Especially, the details of thermal conduction process in printing papers which has dominant effects on the power consumption and the printing quality should be investigated.

With this as a background, our study aims to optimize the printing process of DTP in order to reduce the power consumption of the thermal printer while maintaining the printing quality. Generally, thermophysical properties, which are density, specific heat and thermal conductivity, affect the thermal conduction process. In our previous report [5], we investigated the effects of the thermophysical properties and contact resistance between the printing paper and the thermal head of the thermal printer on the temperature transient of the paper experimentally by using the test thermal head and several kinds of the papers. In this report, we did the quantitative investigation of the effect of the thermophysical properties on temperature transient of the paper by using 3-dimentional thermal conduction analysis. We performed the thermal conduction analysis in the paper while changing the thermophysical properties of the paper based on our previous experimental results. Through the analysis, we clarified the dominant factor in the temperature rise of the papers from the viewpoint of the thermophysical properties.

Difference of Thermophysical Properties of Papers [5]

In our previous report, we tried to measure thermophysical properties, which are density, specific heat and thermal conductivity of several kinds of the printing papers as shown in table 1 experimentally by using the apparatuses as shown in Table 2. Five types of the papers were evaluated in order to compare the effects of the type of the papers. Density ρ_{pa} was measured by an analytical balance (TE-64, Sartorius). Specific heat c_{pa} was measured by a differential scanning calorimetry (DSC6220, SII). Thermal conductivity λ_{pa} was measured by using a simple measurement system for measuring one-dimensional thermal conductivity.

Table 1: Test papers

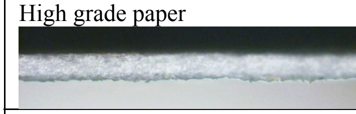
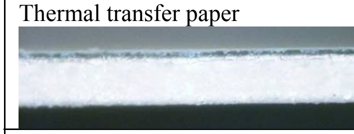
Type of paper	Thickness d_{pa} [mm]
Thermal paper 	0.05
Xerographic paper 	0.065
High grade paper 	0.1
Thermal transfer paper 	0.2
Inkjet paper 	0.3

Table 3 shows the result of the measurement of the thermophysical properties. Here, heat capacity C_{pa} and thermal diffusivity α_{pa} were calculated by using the measurement result and the following formulas.

$$C_{pa} = \rho_{pa} c_{pa} b_{pa} l_{pa} d_{pa} \tag{1}$$

$$\alpha_{pa} = \frac{\lambda_{pa}}{\rho_{pa} c_{pa}} \tag{2}$$

Where b_{pa} [m] is width of the paper, l_{pa} [m] is length of the paper and d_{pa} [m] is thickness of the paper. Here, we listed C_{pa} in Table 3 when b_{pa} and l_{pa} were 1. It can be seen that the thermophysical properties vary according to the kind of the paper. This affects the difference of thermal conduction phenomena in the paper. Heat capacity and thermal diffusivity were also varied according to the thermophysical properties. Here, the heat capacity was also dependent on the thickness of the paper. The heat capacity of the thermal paper was smallest because the thickness of the thermal paper was thinnest. The inkjet paper has the largest heat capacity because the thickness of the inkjet paper was thickest.

These difference of the thermophysical properties may affect the thermal conduction in the printing paper. Based on the result of the measurement of the thermophysical properties, we tried to evaluate the quantitative evaluation of the effect of the thermophysical properties on the transient temperature response of the paper by using 3-dimentional thermal conduction analysis.

Table 2: Measurement Method of Thermophysical Properties

Parameter	Apparatus
Density ρ_{pa}	Analytical Balance TE64 (Sartorius)
Specific heat c_{pa}	Differential scanning calorimetry DSC6220 (SII)
Thermal conductivity λ_{pa}	One-dimensional thermal conductivity measurement system (see [5])

Table 3: Measurement Method of Thermophysical Properties

Paper type	Density ρ_{pa} [kg/m^3]	Specific heat c_{pa} [J/(kg·K)]	Thermal conductivity λ_{pa} [W/(m·K)]
Thermal	1114	1240	0.064
Xerographic	909	1330	0.062
High grade	981	1540	0.067
Thermal transfer	1192	1470	0.070
Inkjet	963	1550	0.075

Paper type	Heat capacity C_{pa} [J/K] (when b_{pa}= l_{pa}=1)	Thermal diffusivity α_{pa} [10^{-8} m^2/s]
Thermal	69.1	4.62
Xerographic	78.6	5.15
High grade	151.0	4.42
Thermal transfer	347.4	4.02
Inkjet	447.8	5.03

Investigation of Transient Temperature Response

Analytical Method:

Figure 1 shows the image of the analytical model for evaluating three-dimensional thermal conduction in the paper put on the dot heater. In order to perform the 3-dimentional thermal conduction analysis, Flow Designer version 11, made by Advanced Knowledge Laboratory Inc., was used. The analytical model is composed of the paper, which has the width of 1 mm, the length of 1 mm and the height of 1 mm, and the heating element which has a footprint area of 0.125 mm × 0.125 mm. The heating element simulates the dot heater. The paper was mounted on the heater element. 10^{-3} W of the heat was released from the heater element. Transient conduction analysis was performed and temperature response of the heating point on the paper after 1 second from the start of the heating was evaluated. The number of the mesh was 300,000. Here, we assumed that there is no contact thermal resistance between the paper and the heater element because we targeted to evaluate the effect of thermophysical properties without contact resistance.

Table 4 shows the analytical condition of the thermophysical properties in the analysis. The conduction analysis was performed while changing the value of the thermophysical properties based on the measurement result as shown in the last chapter. Through the analysis, we investigated the relationship between transient temperature rise and each thermophysical property.

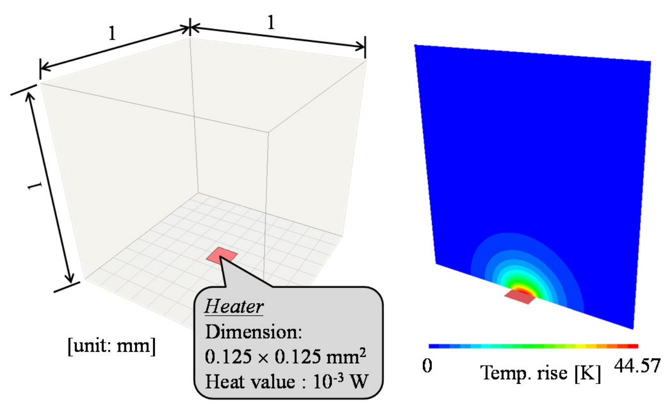


Figure 1. Left : Analytical model which is composed of the test paper and one dot heater, Right : Example of the analytical result (temperature distribution in the paper near the dot heater the dot heater in the case of density of 1200 kg/m^3, specific heat of 1600 J/(kg·K) and thermal conductivity of 0.08 W/(m·K)

Table 4: Analytical Condition of Thermophysical Properties

Thermophysical properties	Conditions
Density ρ_{pa} [kg/m^3]	900 – 1200
Specific heat c_{pa} [J/(kg·K)]	1200 – 1600
Thermal conductivity λ_{pa} [W/(m·K)]	0.06 – 0.08
Heat capacity C_{pa} [×10^{-3} J/K]	1.08 – 1.92
Thermal diffusivity α_{pa} [10^{-8} m^2/s]	4.12 – 5.56

Analytical Result:

Figure 2 shows the relationship between the temperature rise after 1 second from the start of the heating and the thermophysical properties. We can see that the transient temperature at the heating point of the paper was dependent on the thermophysical properties. However, against the effect of the specific heat and the density, the effect of thermal conductivity of the paper is significant. Even if the density or the specific heat was changed, the level of the change of the temperature rise was small. On the other hand, when the thermal conductivity changes 0.01 W/(m·K), at least 5 K of the change of the temperature rise causes.

Next, Fig. 3 shows the relationship between the thermal diffusivity and the temperature rise. Figure 4 denotes the relation between the heat capacity of the paper and the temperature rise. As we can see, the temperature rise changes dependent on the thermal diffusivity and the heat capacity. When the thermal diffusivity increases, the level of the temperature rise slightly increases. When the heat capacity increases, the level of the temperature rise decreases because the dissipation of the heat is inhibited by the storage of the heat in the paper. However, against the effect of the heat capacity and the thermal diffusivity, the effect of the thermal conductivity on the temperature rise is dominant. In our analytical result, even if the density or the specific heat is changed, if the thermal conductivity is same, the difference of the transient temperature rise of the paper becomes less than 4 %. However, if the thermal conductivity is changed, the level of the temperature rise is significantly changed.

These tendency may be caused by the special thermophysical characteristic of the papers. The value of the thermal diffusivity of the paper is relatively small. Therefore the heat dissipation in the paper is inhibited when the heat is applied from the heater. Therefore, temperature transient near the heater is strongly affected by thermal conductivity of the paper because the paper receives more heat from the surface of the heater when thermal conductivity becomes higher. However, from the viewpoint of the thermal printing process, the transient temperature response very near the heater only becomes important because a leuco dye and a developer is coated on the surface of the thermal paper. In addition, the printing speed of the DTP process should be shortened as fast as possible.

Therefore, from the result in this paper, we conclude that the

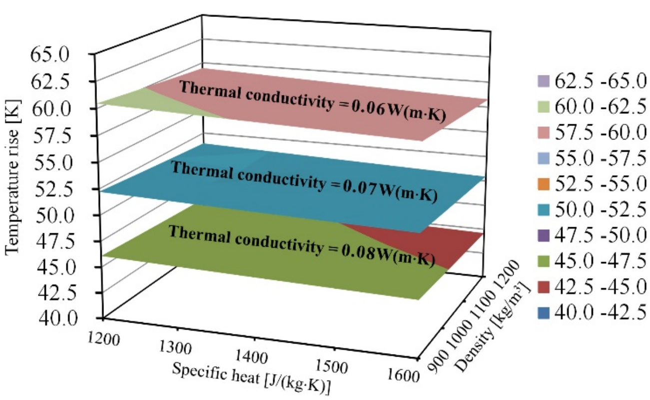


***Figure 2**. Relationship between thermophysical properties and transient temperature rise after 1 second from the start of the heating*

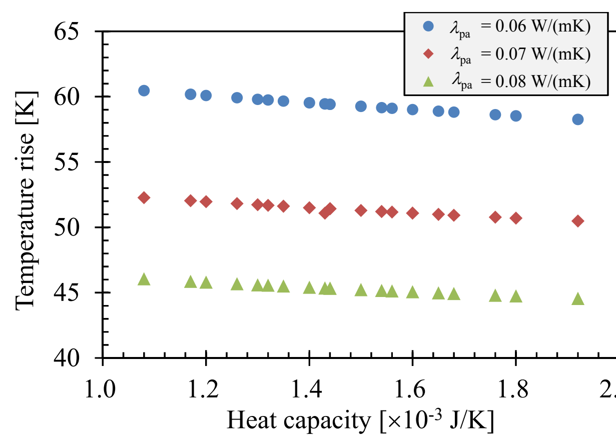


***Figure 4**. Relationship between transient temperature rise after 1 second from the start of the heating and heat capacity*

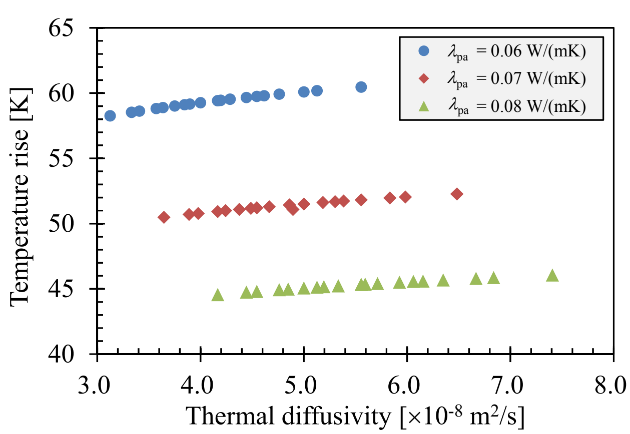


***Figure 3**. Relationship between thermal diffusivity and transient temperature rise after 1 second from the start of the heating*

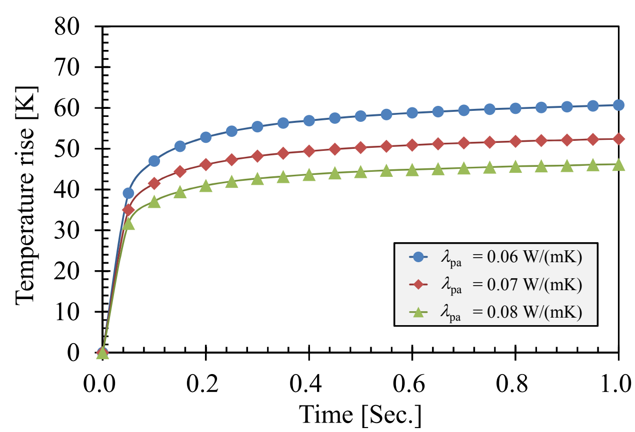


***Figure 5**. Effect of thermal conductivity on transient temperature rise of the paper in the case of ρ_{pa} = 900 kg/m^3 and c_{pa} = 1200 J/(kg·K)*

accurate understanding of the thermal conductivity of the paper becomes most important in order to optimize the printing process of the DTP.

Figure 5 shows the history of temperature of the paper from the start of the heating. As we can see, temperature rise is also affected by the thermal conductivity. However, temperature on the paper significantly increases soon after the start of the heating. In between 0.05 seconds and 1 second, the increase of temperature is small. Temperature rise on the paper surface when the heat is imputed by the heater is also affected by the heat value. Therefore, in order to control the transient temperature rise soon after the start of the heating, the optimization of the released heat and the accurate database of the thermal conductivity may become most important.

Summaries

In this report, the relationship between the thermophysical properties of the papers and the temperature response when the heat is applied from the heater was investigated by using the three dimensional thermal conduction analysis in order to obtain information for optimizing the printing process of DTP. The thermal conduction analysis in the printing paper when the heat is supplied from the heating element which simulated the dot heater was performed while changing thermophysical properties of the paper based on the measurement result.

From the result of the thermal conduction analysis, we concluded that the temperature transient on the heater surface, which the leuco die and the developer is coated for the printing, is significantly dependent on the thermal conductivity of the paper. In addition, temperature on the paper surface is almost decided soon after the start of the heating.

From the viewpoint of the fast printing process, the printing speed of the DTP process should be shortened as fast as possible. The optimization of the released heat and the accurate database of the thermal conductivity may become most important. Therefore, the development of the accurate evaluation method of thermal conductivity of the printing paper may become most important problem in order to control heating process of the thermal printer. In order to optimize the heating process of DTP, some accurate evaluation method of thermal conductivity of printing papers should be investigated. In addition, contact resistance between the paper and the heating element also affects to the temperature response on the paper surface [5]. A further investigation about the evaluation of the contact resistance will be performed as our future research.

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Author Biography

Takashi Fukue received his PhD. (2012) from Toyama Prefectural Univ., Japan. Currently, Assistant Professor of Department of Mechanical Engineering at Iwate University, Japan. His current interests include flow and heat transfer phenomena in electronic equipment.

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Koichi Hirose received his PhD. (1984) from Tohoku University, Japan. Currently, Professor of Department of Mechanical Engineering at Iwate University, Japan. He is a specialist of heat transfer, especially, convection, control of water freezing process and mold injection.

Tomoko Wauke received her master of science degree in of Faculty of Science & Graduate School of Science, Ryukyu Univ. (1988). She has worked at ALPS Electric Co., Ltd. since 1991, and is currently an engineer in the engineering department. She is developing and designing a thermal print head, and Key technology of small and making to thin type printer system. She interests are in research and development of Saving Energy system like power saving technology.

Hisashi Hoshino received his master of engineering degree in graduate school of Information Systems, the Univ. of Electro-Communications (1997). He has worked at Alps Electric Co., Ltd. System Devices Division since 1997 and is currently an engineer in the engineering department. He is designing an energizing control for thermal transfer printing and developing a thermal print head. He is interested in recreating the print process with simulation model.

