Liquid Cooling Technology in a High-speed Electrophotographic Process

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Abstract

The authors developed liquid cooling technology for electrophotographic imaging process and put it into practical use for the first time. The thermal design for the liquid cooling system is also established.

The technology, including a liquid cooling jacket for contacting between a development unit and its contact surface, prevents temperature rise in development units for high-speed electrohotographic copiers/printers. The liquid cooling jacket is composed of aluminum plates and a copper pipe, in which liquid circulates without liquid leaks. Liquid temperature is almost the same as room one. Accordingly, it receives the heat from the development unit with low temperature rise and a small cooling space. Besides, a thermal conductive sheet and a PET film on contact surface between the development unit and the liquid cooling jacket, enable the development unit to be attached and removed without lowering high efficiency in liquid cooling. Optimization and selection for a pump, radiators and fans are carried out for the liquid cooling system thermal design by examining thermal resistance between portions with different temperature rise and heat generations in the development unit.

As a result, temperature rise in the development unit in prototype, of 75 pages per minute print speed and 1,320 millimeters wide, is controlled below toner caking temperature.

Introduction

Heat generation in production and office high end electrophotographic copies/printers has been increasing recently because of high image quality, high-speed and long time non-stop printing. Papers are also large heat sources while handled in a machine during duplex printing. On the other hand, the permissible level of temperature rise has been decreasing caused by lowering toner melting temperature for saving energy in fusing process. However, at the same time, downsizing for machines is required.

Heat transfer coefficient for convection is defined as follows,

$$h = (W / \Delta T) / A, \qquad (1)$$

where h is heat transfer coefficient, W is heat, ΔT is temperature rise and A is surface area for convection.[1] Increase in W and decrease in ΔT and A require a high value of h according to eq. (1). In development units, a lower heat transfer coefficient than the necessity causes toner caking and results in streaks in solid images. Figure 1 shows routes of heat transfer in a development unit of office middle and high end machines in RICOH. The heat caused while mixing toners and the one from a photoreceptor drum and an environment around the development unit is transferred to a heat sink, in which the heat is exchanged to cool air. Heat transfer coefficients in our machines are shown in Figure 2 as groups of A and B. It is generally classified into cooling types: natural convection (air cooling), forced convection (air cooling) or liquid cooling, etc based on the ease to cool, though thresholds are not clear. Groups of A and B are located in the area of air cooling by the guide for cooling in semiconductors.[2] In these groups, air cooling is practically chosen because results of air flow simulations and measurements for temperature rise in toners at development units achieved lower one than the permissive level.

For more increase in heat and for more decrease in temperature rise and surface area, higher heat transfer coefficient is required than current level. Group of C shown in Figure 2, for the next RICOH machine, requires higher efficient cooling than air one, e.g. liquid cooling and using latent heat of evaporation. Liquid cooling, which is generally known as high efficient cooling, needs a large system including chilling machines to control liquid temperature and is unsuitable for office uses. Compact liquid cooling systems, however, have recently been applied to cool CPU in personal computers and thermal/LED heads in high-speed printing systems.[3,4,5] No liquid cooling has been applied to development units in a high-speed electrophotographic imaging process at this present so far. Accordingly, liquid cooling technology which supports the group of C and is suitable for development units is needed.

In this paper, we present liquid cooling technology developed in a high-speed electrophotographic imaging process, which controls temperature rise in development units to be less than the permissible level.

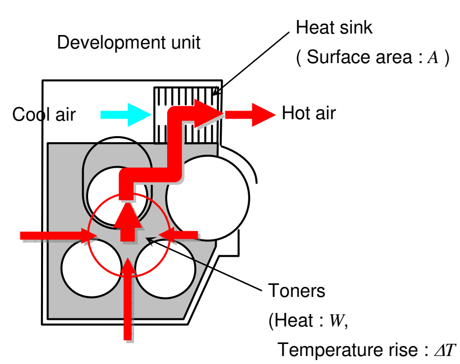

***Figure 1**. Routes of heat transfer in development unit*

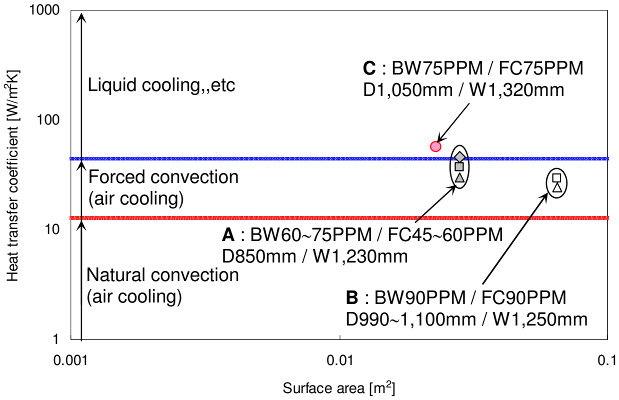

***Figure 2**. Heat transfer coefficient to cool development units*

Liquid cooling technology

Outline of liquid cooling in a development unit

Liquid cooling in a development unit, as shown in Figure 3, receives the heat that occurs due to mixing toner and the one from a photoreceptor drum and an environment around the development unit by attaching a liquid cooling jacket. In the liquid cooling jacket, flow channels are arranged and liquid of low temperature that is almost the same as room one circulates transferring the heat from an imaging process area to radiators and fans. The liquid is mainly of water. Even a small-sized liquid cooling jacket receives much heat with low temperature rise because of higher heat transfer coefficient in liquid than that in air. Besides, not wide ducts but narrow pipes enable much heat to be transferred owing to higher thermal capacity in liquid than that in air. Thus liquid cooling contributes to downsizing in imaging process. Liquid cooling system must be along with radiators and fans, which are larger than ducts and fans in air cooling. However, these can be installed in a free space apart from an imaging process area. As a result, better space factor can be obtained in liquid cooling than air one.

In order to obtain high efficiency in liquid cooling for a less loss, thermal design of liquid cooling system, development, optimization and selection of liquid cooling devices are required. In particular, a liquid cooling jacket and contact surface between the development unit and the liquid cooling jacket are important. In the following section, details of those are explained and evaluation of liquid cooling system including these devices is shown.

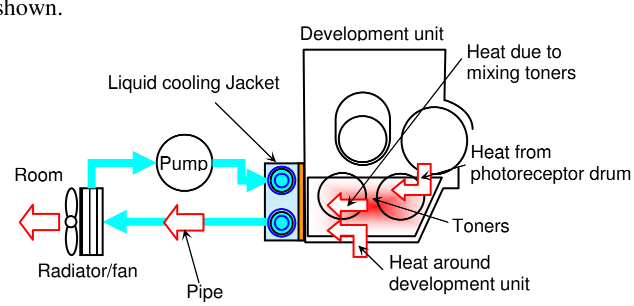

***Figure 3**. Schematic diagram of liquid cooling in development unit*

Liquid cooling jacket

The liquid cooling jacket is the most significant device, in which no liquid leaks and receiving much heat with low temperature rise are needed.

The liquid cooling jacket requires as long flow channels as the length of a development unit and has higher risk of liquid leaks than a short one. Our prototype of liquid cooling jackets, as shown in Figure 4, is composed of a copper pipe bended like a shape of U as seamless flow channels to avoid liquid leaks and two aluminum plates that clamp the pipe.

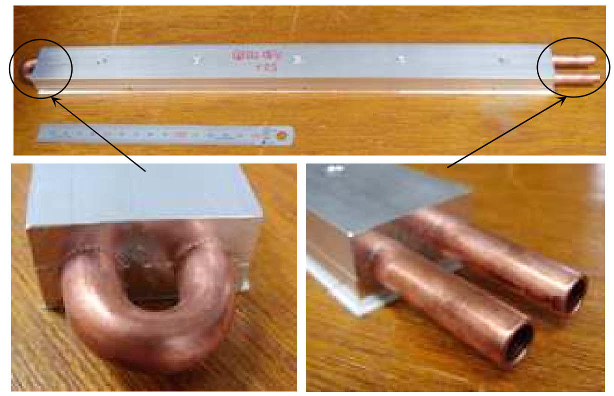

***Figure 4**. Photographs of liquid cooling jacket*

In order to design the liquid cooling jacket with high efficient cooling, thermal resistance and pressure loss defined in Figure 5 and eq. (2) are evaluated by measurements and computer simulations. Figure 6 shows an example of results and provides characteristics for the thermal and flow channel designs. Besides, the simulated results show excellent agreement with measurements. Therefore, simulations can be used for developing liquid cooling devices.

$$R = (T_1 - T_{OUT}) / (\rho Cp Q \times (T_{OUT} - T_{IN})). \qquad (2)$$

Nomenclatures are listed below.

R : Thermal resistance
T_1 : Temperature on surface contacting with development unit
T_{IN} : Temperature in inlet liquid
T_{OUT} : Temperature in outlet liquid
ρ : Density of liquid
Cp : Specific heat of liquid
Q : Flow rate

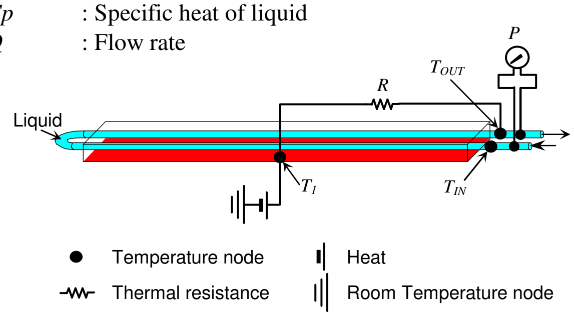

***Figure 5**. Schematic diagram of measuring liquid cooling jacket*

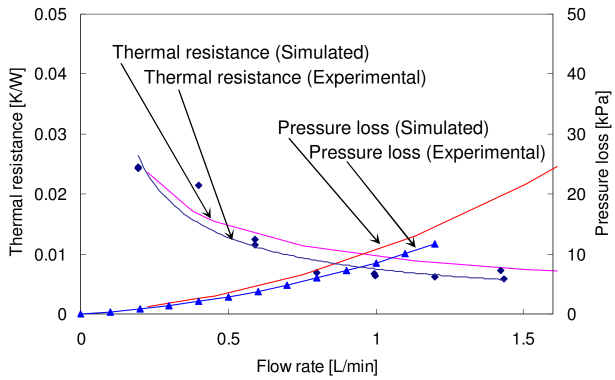

***Figure 6**. Thermal resistance and pressure loss in liquid cooling jacket*

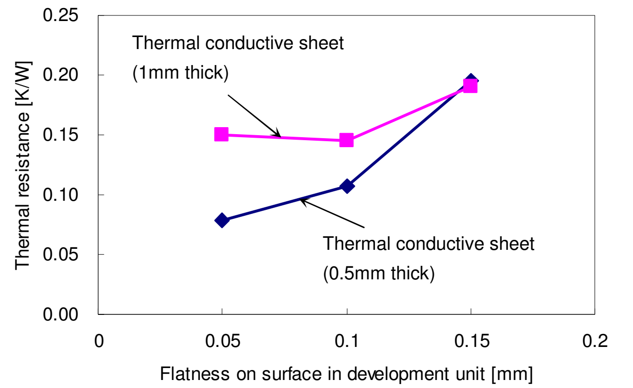

***Figure 8**. Thermal resistance between development unit and liquid cooling jacket*

Contact surface between development unit and liquid cooling jacket

Contact surface between the development unit and the liquid cooling jacket to keep low thermal resistance is needed in spite of attaching and removing the development unit repeatedly. As a contact surface with low thermal resistance, a thermal conductive sheet and a PET film are set as shown in Figure 7. Flexibility involved in thermal conductive sheet is easy to deform and small air gaps on contact layer are filled during being pushed. As a result, the thermal resistance is reduced. Stickiness in thermal conductive sheet, however, has the possibility of peeling it off on removing the development unit. The PET film produces the effect of covering the thermal conductive sheet and suppressing its stickiness. The thermal conductive sheet can be occasionally torn because of its brittleness. The PET film also offers the effect of protecting the thermal conductive sheet. Thermal conductivity of the PET film, however, is considerably low and disturbs high efficiency in liquid cooling. Accordingly, the thickness of the PET film should be as thin as possible. Thermal resistance between the development unit and the liquid cooling jacket also depends on flatness on both surfaces. Figure 8 shows measured results of thermal resistance between the surfaces to the flatness.

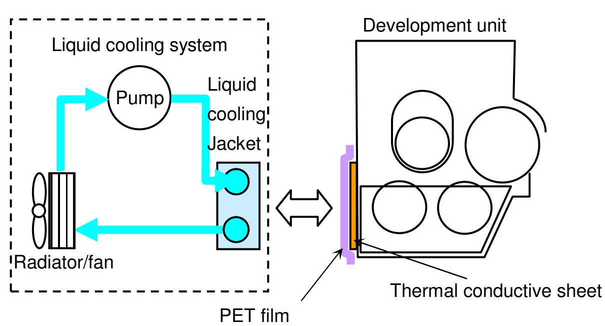

***Figure 7**. Schematic diagram of contact surface between development unit and liquid cooling jacket*

Thermal design in liquid cooling system

As shown in Figure 9, liquid cooling system is set to the prototype of 75 pages per minute print speed and 1,320 millimeters wide, in which four liquid cooling jackets are connected in a series circuit and liquid flows in order of yellow, magenta, cyan and black. The liquid cooling system is designed and optimized using thermal network and hydraulic circuit methods. Figure 10 shows the thermal network in the liquid cooling system in Figure 9. Thermal network method formulates thermal flows in Figure 10, in which thermal resistance and heat generations in the development unit, thermal resistance in radiators and fans and heat generation in the pump have individually been measured in advance. Then, the thermal resistance of liquid cooling jackets and radiators/fans in Figure 10 require specifying a flow rate as a parameter. Hydraulic circuit method obtains it by selecting a pump for the total pressure loss in liquid cooling system and optimizing flow channels in liquid cooling jackets, pipes and radiators. Accordingly, the thermal flows are solved and temperature rises in toners and cases at development units, liquid, and liquid cooling jackets are calculated.

Experimental results and prediction errors in liquid cooling system

Table 1 shows the difference between the measured temperature rise and the permissive level in black toners at the black development unit in Figure 9. Black toners can be the highest temperature in four color toners because liquid of the highest temperature in four color development units flows in the black development unit. The difference is large enough to avoid toner caking. Table 1 also shows prediction errors between the measured temperature rise and simulations in the black toners and liquid at the pump, in which temperature rise is the highest in the liquid cooling system. The prediction errors are very small to show that the liquid cooling system performs target functions.

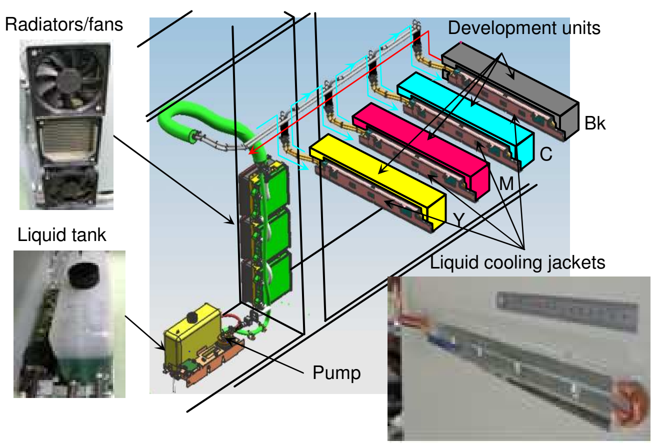

***Figure 9**. Schematic diagram of liquid cooling system in machine*

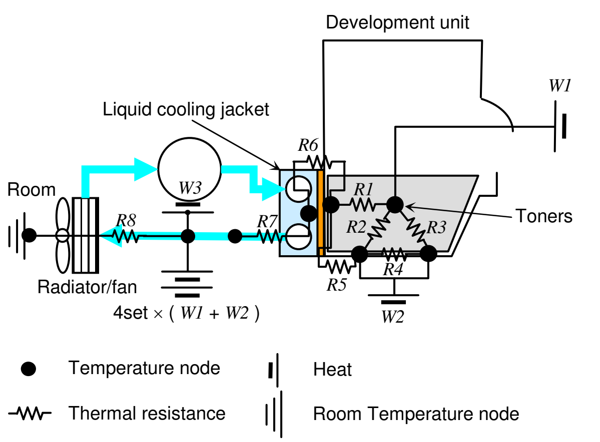

***Figure 10**. Schematic diagram of thermal network in development unit and liquid cooling system*

Table 1. Experimental results and prediction errors.

	Difference between measured temperature rise and permissive level	Prediction errors of temperature rise
Black toners	-2.0[degrees]	+0.5[degrees]
Liquid at pump	-	+0.6[degrees]

Conclusion

The liquid cooling technologies for development units in a high-speed electrophotographic imaging process have been developed for the first practical use. We confirmed that the measured temperature rise achieved lower level than the permissive level in black toners of the prototype of 75 pages per minute print speed and 1,320 millimeters wide with liquid cooling. The technologies provide prevention of temperature rise in development units and avoiding toner caking. Then, the thermal design for the liquid cooling system is established.

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Author Biography

Satoshi Okano received his Bachelor of Science and Engineering degree in physics from Chuo University, Japan in 1991. He joined Ricoh in 1991 and has been engaged in R&D of printing technologies. He has recently focused on the development for environmental technologies in electrophotography.