Surrounding Effects on Temperature and Emissivity Measurement of Equipment in Electrical Distribution System

T. Nunak, N. Nunak, V. Tipsuwanporn, and T. Suesut

***Abstract*—This paper reports the effect of surrounding conditions, e.g. IR radiation through IR window and the reflectivity and temperature of internal surface of chamber on the temperature and emissivity measurement. The results show that the transmission percentage of IR window is about 50 for all IR temperatures, except when the target temperature was the same as the surrounding temperature (T_{sur}). At this condition ($T_s = T_c$), the temperature readings were almost the same for all percentage of IR window. The accurate temperature measurement can be achieved by adjustment of the transmission correction in the IR camera or in the software. Considering the effect of materials surface and temperature of chamber, it can be concluded that the surrounding conditions can affect to the accurate emissivity measurement only with the high reflectance object, whereas the high emissivity object has no effect from the surround.**

***Index Terms*— Temperature and Emissivity measurement, Reflectivity, Infrared thermography, IR window, Electrical distribution system**

I. Introduction

ELECTRICAL distribution system has the main function to deliver the electricity from the transmission system to individual consumers. It consists of the utility electricity production, high voltage distribution, switchyards and substations, service transformers, switchgear, breakers, and meters [1]. The failure of electrical power distribution system can be occurred from many issues, e.g. poor surface contact, under-sized conductors, eddy current, loose connections or excessive current flow, causing to an unusual heat distribution as a hot spot around the equipment, and can be inspected with a contact or non-contact thermometer. For this application, an infrared thermography or thermal image (TI) camera, the non-contact temperature instrument, can be used as an effective tool to inspect the equipment before their failures actually occur in order to maintain the reliability of the system which is the most important topic that needed to be taken into account from the electrical engineer who takes responsibility. This implementation is called the Condition Based Maintenance (CBM) [1] [2] [3].

An accurate temperature measurement of the electrical equipment is an important decision variable for the preventive maintenance of the electrical system. It can be affected from many factors: technical skill of the thermographer; technical factors or specification of an instrument such as thermal image resolution and thermal sensitivity; environmental or surrounding conditions such as relative humidity, temperature, wind speed, electric current load of the targeted equipment, and its emissivity. Several researchers have been studied on the emissivity measurement because it has a significant role to the temperature measurement of an object with TI camera [4] [5]. Emissivity is a surface radiative property, which relates to the amount of radiation emitted by an object [6]. In case the wrong emissivity value is entered into the TI camera, the displayed temperature on screen will be wrong.

Suesut *et al.* [7] and Nunak *et al.* [8] have been proposed the emissivity measurement method and have been reported the emissivity values of several electrical distribution equipment, e.g. terminal lug, bail clamp, driving stud, and insulators, which made of many types of materials, at the temperature range of 30^{o}C to 200^{o}C. They estimated the emissivity of object during the cooling process. The temperature of hot object is decreased with the convective heat transfer between the ambient air and hot object via the prepared aperture in front of the chamber. This may cause to be the source of uncertainty in measurement because it is difficult to maintain the constant temperature. Besides that, they chose the stainless steel to be an internal surface of chamber with the reason for decreasing the radiation from chamber surface to sample. However, this may be not true for all types of materials.

Therefore, the main objective of this paper is to study effect of surrounding conditions i.e. (1) mounting the infrared window (IR window), which is the infrared-transparent window, at the aperture in front of the chamber for controlling the temperature to be constant during the testing and (2) considering the characterization of internal surface of chamber, i.e. reflectivity and temperature of internal surface of chamber on the accurate temperature and emissivity measurement of tested samples.

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II. Theoretical Background

A. Thermal Radiation (Emission and Irradiation)

All objects emit thermal radiation at a temperature above 0 K. The mechanism of emission is related to energy released as a result of oscillations or transitions of electrons within the matter. The amount of radiation or emission (E) depends on its temperature and emissivity (ε), and the magnitude varies with wavelength and direction. Emissivity is defined as the ratio of energy emitted from an object to that of a blackbody at the same temperature. It depends strongly on the nature of the surface, which can be influenced by the method of fabrication, thermal cycling, and chemical reaction with its environment [6].

Incident radiation may originate from emission and reflection occurring at other surfaces (Fig. 1). The intensity of the incident radiation may be related to an important radiative flux, terms the irradiation (G), which encompasses radiation incident from all directions. It may be incident from all possible directions, and may originate from several different sources.

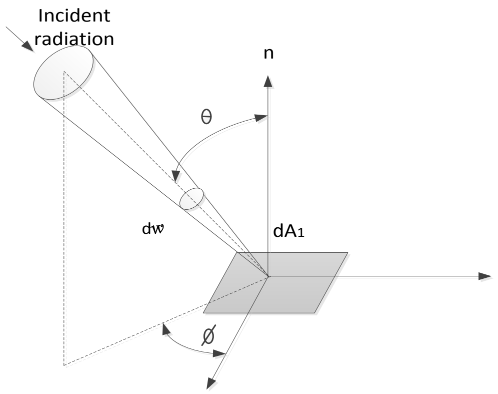


Fig. 1. Incident radiation.
Source: Fundamentals of Heat and Mass Transfer [6]

B. Surface Reflection, Transmission, and Radiosity

Reflectivity (ρ) and transmissivity (τ) are properties to characterize the reflection and transmission (Fig. 2 (a)). In general they depend on surface material and finish, surface temperature, and the wavelength and direction of the incident radiation. The reflectivity is determined as the fraction of the incident radiation reflected by a surface, also depends on the direction of the reflected radiation. Most engineering applications assume the medium to be opaque to the incident radiation (τ =0) and the diffuse reflection (Fig. 2 (b)) [6].

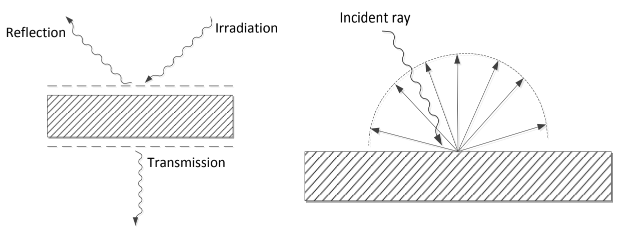


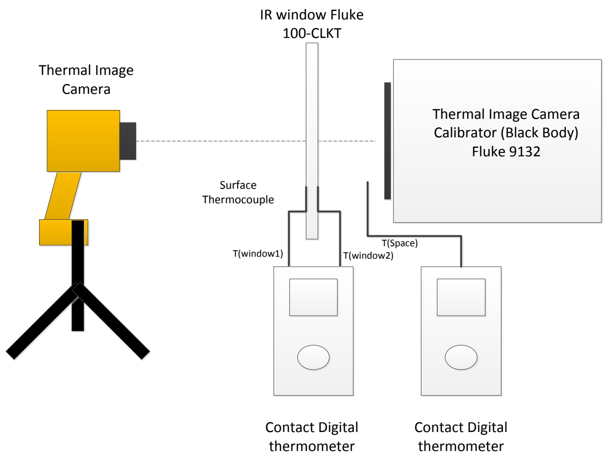
Fig. 2. (a) Refection and transmission of semitransparent medium, (b) diffuse reflection.

Radiosity (J) represents the rate at which radiation leave a unit surface. This radiation includes the reflected portion of the irradiation and the direct emission from the object surface.

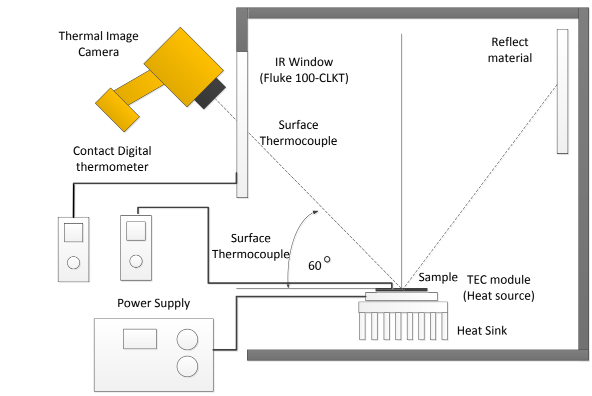
III. Experiments

A. Experimental Setup

There are two sets of the experimental setup (Fig. 3), which consists of five main equipment, e.g. an infrared camera (Ti-400, Fluke Corporation, USA), J-type contact thermocouple, a tripod of camera stand, IR window (Fluke, CLKT Type: 3, 12 indoor/outdoor use) and a heating unit, as explained the detail of some equipment in Nunak *et al*. [5]. Thermal images were analyzed by thermal imager software Fluke SmartView® 3.5. The infrared radiation detector was calibrated before performing the experiment in order to ensure that the obtained results from each experiment had no effect of the instrument.



(a)



(b)

Fig. 3. Schematic of a typical experimental setup.

Fig. 3 (a) shows a schematic of the experimental setup for studying the changes in radiative properties of IR window (emission and transmission) at various surface temperatures. The measured object, in this experiment was Blackbody (model 9132, HART Scientific, USA), which the emissivity is known, i.e. 0.95). An IR camera is placed in front of the Blackbody in order to obtain the normal direction ($\theta = 0^{o}$) to

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the object surface. Fig. 3 (b) shows a schematic of the experimental setup for studying the effect of reflection on the tested sample. An IR camera is placed at the viewing angles 45^o to the normal direction (θ = 45^o) [5]. The sample placed on thermoelectric cooling device (TEC) constructed on the holder for heating the sample. The temperature was controlled by a DC power supply (24 V 2.1 A) with a current regulator circuit. Inside the chamber, the reflective material (very low emissivity) and general material (high emissivity) were placed on the surface of chamber for considering the effect of reflection on the emissivity of test samples.

C. Measurement Method

Two types of experiments were carried out. Firstly, the experiment was studied on the change of emission and transmission through IR window due to variations on surface temperature. From Fig. 3 (a), blackbody was set at the temperature of 50, 100, 150, 200, and 250, respectively. At each blackbody temperature (T_{BB}), three thermocouples were used for recording the temperature of medium (air) between IR window and blackbody, IR window at inside area (closely to blackbody), and IR window at outside area. The T_{BB} was measured using TI camera. The IR detector received the IR radiation of blackbody emitted through IR window and then processed into a thermal image which displayed temperature over an area in form a thermal map [2] [9]. Emissivity in TI camera was set at 0.95 for the blackbody. Percentage of transmission in the TI camera was adjusted from 10 to 100 every 10 percent. The temperature that obtained from TI camera at each percentage of transmission was recorded. The reflection temperature or background temperature (TBG) in TI camera (Fluke) was monitored during experiments for determining the reflection of radiation of the surrounding. In this study, TBG was about 29^{o}C.

The second experiment, effect of reflection on emissivity was investigated by changing the material types placed on the surface chamber at different surface temperatures of internal chamber. Two types of samples were tested in this experiment, i.e. square piece of black painted sheet as a representative of the high emissivity electrical distribution equipment (bail clamp and connector splice compression) and galvanized steel sheet as a representative of the low emissivity equipment in the electrical distribution system such as drop fuse and terminal lug of load break switch SF6. At the internal surface chamber was mounted with two types of materials having the different reflective radiation. The experiment was divided into three groups, i.e. sample temperature (T_s) is lower than internal surface chamber temperature (T_c) (T_s < T_C), T_s = T_C, and T_s > T_C. The experiment was performed at the sample temperature of 30^{o}C (room temperature) and 50^{o}C, and also the chamber temperature was set at the same temperature of tested sample. The infrared radiation emitted from sample was detected by infrared detector through IR window which mounted in front of the tested sample. The percentage of transmission IR window was set at 50 as obtained result from the first experiment. The reflection temperature or background temperature (T_{BG}) in TI camera (Fluke) was set at a temperature of T_C. Thermal image of tested samples from each experimental group was captured by TI and recorded for considering the effect of reflection occurred. The emissivity of each sample as displayed on TI camera, which considered in the infrared radiation area of 0.5 cm^2 locating at the center of each thermal image as a highlighted rectangular frame on the picture in Fig. 5, was adjusted until the presented temperature equal to measured temperature by a thermocouple contacted with the sample surface. Each experiment was repeated three times and the average value was taken from the recorded data.

IV. Results and Discussions

A. Effect of temperature measurement through IR window

As we knows the IR window transmittance is an important parameter for accurate temperature measuring. The more accurately IR window is known, the more accurately temperature is obtained [10]. Figure 4 gives the transmittance results for the IR window at the target temperature from 30^{o}C (room temperature), 50, 100, 150, 200, and 250^{o}C, which IR window temperature was

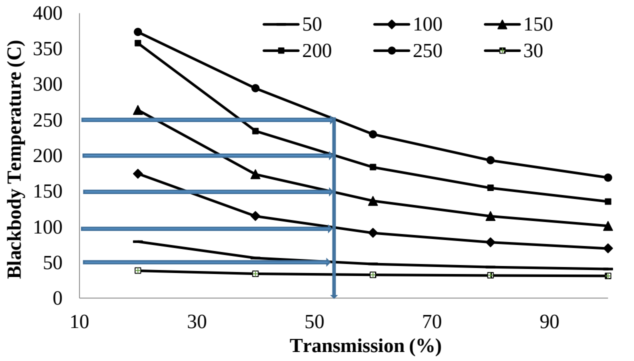

Fig. 4. IR transmission vs. target (blackbody) temperature from 30^{o}C to 250^{o}C.

approximately 32, 35, 41, 50, 57, and 65^{o}C, respectively. It can be seen that the transmission percentage of IR window is in the range of 50 to 55 for all IR window temperatures which related to target temperatures or blackbody temperatures (in this experiment), except when the target temperature was the same as the surrounding temperature (T_{sur}). At this condition (T_s = T_c), the temperature readings were almost the same for all percentage of IR window.

The transmission percentage of IR window at 100% means all energy leaving from the target surface, which is called radiosity, can directly radiate to IR detector. When the infrared energy radiate through IR window, not all of the infrared energy emitted from the objects of interest is transmitted through the optical material in the window. The decreasing of transmission percentage causes the decreasing of the energy emitted to the IR detector. This will affects to the accurate temperature measurement. However, this can be achieved, if the transmission percentage of the window is known. The accuracy of temperature measurement can be obtained by adjustment of the transmission correction in the IR camera or in the software.

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B. Effect of reflection on emissivity measurement

This experiment was carried out to understand how the reflection had an influence to the emissivity measurement. Figure 5 shows the picture of thermal image of tested sample under the different control surrounding conditions, i.e. material reflectivity and temperature. At the target temperature and surrounding temperature or reflection temperature or background temperature being the same ($T_s = T_c$), the pictures of thermal image obtained from the sample having low and high emissivity with the reflection from internal chamber surface having low and high emissivity present the same (pictures not shown). This can be explained from the discussion of previous topic and the theory of radiosity [6]. For this situation, it is impossible to measure the emissivity because the temperature of sample was constant even the emissivity changed. In case of black painted sheet, the measured emissivity had no effect from all surrounding conditions as presented in Table 1. However, Fig. 5 (b) shows the image being colder than others in Fig.5 (a, c, and d) since the sample emission was lower than the reflection. All thermal images of galvanized steel sheet in Fig. 5 shows the non uniform energy radiated to IR detector. Image in Fig. 5 (e and g) represents the low energy radiated to IR window because the emissivity of tested samples is low and the emission from chamber surface is also not much. Considering images among Fig. 5 (e, f, g, and h), image in Fig. 5 (f and h) has the brightness higher than other images or looks warmer than others since the galvanized steel sheet is a low emissivity object and can reflect a lot of IR energy radiated from the high temperature of chamber. Comparing at the same temperature of chamber, it can be seen that the material of chamber surface having a high emissivity Fig.5 (g and h) can affect to the accurate emissivity measurement. This cause to almost IR energy radiated to the IR detector is the reflection from the chamber surface instead of emission from sample surface. In case of galvanized steel sheet having a high reflectance, the measured emissivity was affected from the surrounding conditions, although the infrared energy radiated to IR detector was compensated by setting the condition e.g. surrounding temperature, in the TI camera. Therefore, it can be concluded that the surrounding conditions can affect to the accurate emissivity measurement with the high reflectance object, whereas the high emissivity object has no effect from the surround. The emissivity of tested sample using TI camera at different surrounding conditions is shown in Table 1.

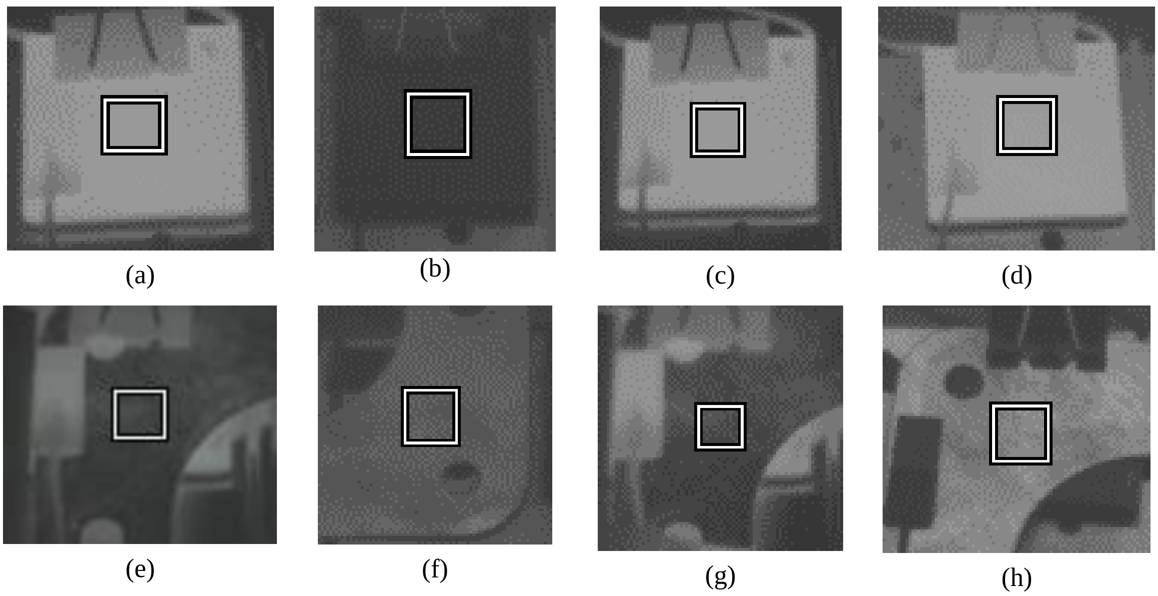

Fig. 5. Typical thermal images of black painted sheet (a, b) at $T_s > T_c$, and (c, d) $T_s < T_c$; and galvanized steel sheet (e, f) at $T_s > T_c$, and (g, h) $T_s < T_c$.

TABLE I
EMISSIVITY OF TARGET SAMPLE AT VARIOUS SURROUNDING CONDITIONS

Types of materials	Temperature	Chamber surface: High reflectance 30^{O}C	High reflectance 50^{O}C	Low reflectance 30^{O}C	Low reflectance 50^{O}C
Black painted sheet	30^{O}C	-	0.96 (b)	-	0.96 (d)
	50^{O}C	0.96 (a)	-	0.96 (c)	-
Galvanized steel sheet	30^{O}C	-	0.27 (f)	-	0.26 (h)
	50^{O}C	0.24 (e)	-	0.21 (g)	-

[Remark] alphabet (a, b, c, d, e, f, g, and h) presented in table referred to pictures in Fig. 5

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V. CONCLUSION

As thermography or thermal image (TI) camera, the non-contact temperature instrument, can be used as an effective tool to inspect the electrical distribution equipment before their failures actually occur in order to maintain the reliability of the system. An accurate temperature measurement of the electrical equipment, based on the emissivity of each object, is an important decision variable for this applications. This paper reports the effect of surrounding conditions, e.g. IR radiation through IR window and the reflectivity and temperature of internal surface of chamber on the temperature and emissivity measurement. The results show that the transmission percentage of IR window is about 50 for all IR temperatures. The accurate temperature measurement can be achieved by adjustment of the transmission correction in the IR camera or in the software. Considering the effect of materials surface and temperature of chamber, it can be concluded that the surrounding conditions can affect to the accurate measurement of the high reflectance object, whereas the high emissivity object has no effect from the surround.

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