The Relationship Between Measurable Temperature by Infrared Thermometer with the Distance to Heat Source

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ABSTRACT
Temperature measurements can be performed on contact and non-contact basis. In certain situations, direct contact temperature measurement of objects is difficult, so they should be performed without touching the objects. The phenomenon of heat transfer between the objects and their environment causes a difference between the temperature of the objects, especially on the surface of the objects, and the media temperature around the objects. This fact demands a transformation between non-contact measured temperatures with the temperature of the objects. In this study, the problem of heat transfer from heat source objects to surrounding media is developed to determine the media temperature around the object. The results are experimentally tested to determine the transformation between contact object temperature measurement and non-contact temperature measurement. A model was then designed that stated the relationship between measurable temperature and measurement distance from the source. The obtained temperature distribution model was matched with the results of non-contact measurement experiments at the Applied Physics Laboratory of Politeknik Negeri Bandung. Measured temperature readings by infrared thermometers depend on distance from the source, with temperature models inversely proportional to the inverse squared distance. From this study, the correlation coefficient between the measured temperature and the distance of the heat source for non-contact measurements and contact measurements at distances more than 4 cm respectively are 0.96 and 0.92. This shows a strong relationship between the measured temperature and the distance from the heat source.

Keywords: *non-contact temperature measurement, radiation, infrared.*

1. INTRODUCTION

One indicator of the nature or state of an object is temperature. Temperature measurements are divided into two categories: contact and non-contact measurements. In general, contact measurement has a relatively slow response time. While non-contact measurements are performed with instruments that detect the amount of infrared (IR) radiation emitted by objects and have a rapid response [1].

Infrared thermometers measure temperature by sensing the infrared energy which every material or object with temperature above absolute zero (0 K) will radiate. In the simplest configuration, a lens will focus the infrared radiation onto a detector which in turn converts this energy into an electronic signal [2], [3]. This setup enables temperature measurement from a certain distance without requiring contact with the object. The infrared thermometer is thus suitable for measuring tasks for which thermocouples or other types of contact sensors would be inadequate or not sufficiently precise [4]–[6].

The main design of the infrared thermometer is the change of infrared energy into an electrical signal that can be calibrated in temperature units. This temperature gauge facility configuration works remotely without touching the objects.

The main problem that is solved through this study is how large correlation between the temperature of the measured object in contact with the measured temperature in non-contact using the infrared thermometer for various measurement distances.

The purpose of this study is to determine the temperature of the object using noncontact measurement, and the result is then compared to the actual temperature of the object measured using contact measurement. The urgency of this study is closely related to the accuracy of the thermal condition of objects, especially the temperature when it is measured on a non-contact basis, because contact measurements have an extremely high negative risk in addition to technical measurements which are also complicated.

2. METHODOLOGY

A temperature distribution model was developed that was measured using an infrared thermometer around a particular heat source. This temperature distribution model was experimentally tested using non-contact measurements at the Applied Physics Laboratory of Politeknik Negeri Bandung. The device is an infrared thermometer gun with a response time of 500 ms, spectral response 8 μm – 14 μm, and preset emissivity of 0.95.

3. RESULT AND DISCUSSION

The intensity of infrared radiation emitted by the heat source is directly measured by an infrared thermometer Thus, this infrared thermometer acts at once as a transducer as well as a display device. As a transducer, it converts radiation intensity signals into temperatures, which displays as digital readings [7].

If the heat source emits energy per unit of time of P, assuming the dimensional heat source is very small, then the radiation intensity at the distance r from the source is

$$I = \frac{P}{A} = \frac{P}{4\pi r^2} \tag{1}$$

where A states the area of the sphere, equals $4\pi r^2$.

Infrared radiation intensity follows Stefan's Boltzmann Law,

$$I = \frac{P}{A} = \varepsilon\sigma T^4 \tag{2}$$

with ε declares its emissions, σ declares Stefan Boltzmann's constant, and T declares the temperature.

As this infrared thermometer displays a reading of the magnitude of the temperature, then the temperature that reads is proportional to the intensity of radiation captured by the thermometer, meaning the temperature in that position is inversely proportional to the square of the distance from that position to the heat source, or

$$T = C + B\left(\frac{1}{r^2}\right) \tag{3}$$

with B and C are constant values that depend on the source power, as well as the radiation properties of the medium and thermometer device as a gauge. The B and C values in the equation (3) can be determined by the Least Square Method in linear regression.

Since the temperature reading on the thermometer is only a description of the intensity of radiation, not directly connected to a particular formulation, it is sensible if in this case the unit of temperature remains expressed in degrees Celsius, and not in degrees Kelvin.

From experimental data conducted for temperature measurements using infrared thermometers for various distance variations from heat sources, graphs such as in Figures 1, 2, and 3 are obtained. It is known that the temperature of the heat source object is 60°C and the ambient temperature is 28.3°C.

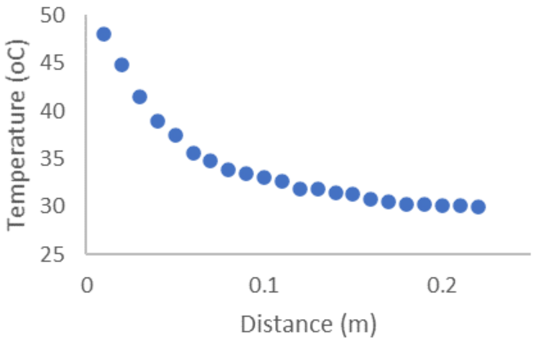

Figure 1 Graph Temperature vs Distance.

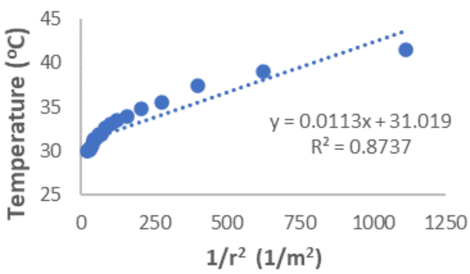

Figure 2 Graph T vs $1/r^2$, for r < 4 cm.

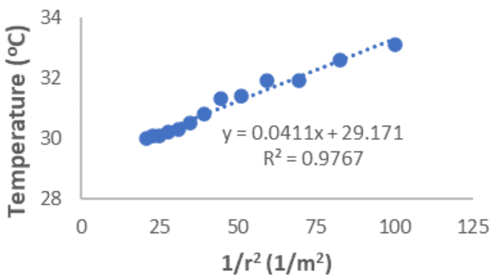

Figure 3 Graph T vs $1/r^2$ for r > 4 cm.

Figure 1 presents the relationship between measurable temperature (T) to distance from the source (r). Figures 2 and 3 are graphical visualizations of measured temperature models (T, y-axis) against the inverse of squared distances ($\frac{1}{r^2}$, x-axis). Figure 2 applies to the entire distance attempted, while Figure 3 applies only to distances more than 4.0 cm. From

Figures 2 and 3, it appears that the designed model applies satisfactorily for a large distance (r > 4.0 cm). This can be seen from the value of the coefficient of determination for distance r > 4 cm is 0.9767, while for r < 4 cm is 0.8737.

In equation (3), C represents the measured temperature value for a sufficiently large distance value or r approach ∞. Thus, the C value will be close to the magnitude of the ambient temperature. From Figure 3, with the Least Square Method, it is obtained that the magnitude of the ambient temperature is $29.2°C$, which the value is close enough to the actual measured ambient temperature of $28.3°C$, so the deviation equals 3 %.

Figures 4 and 5 show that the results of non-contact temperature measurements (using infrared thermometers) are in line with contact temperature measurements (using thermocouple thermometers).

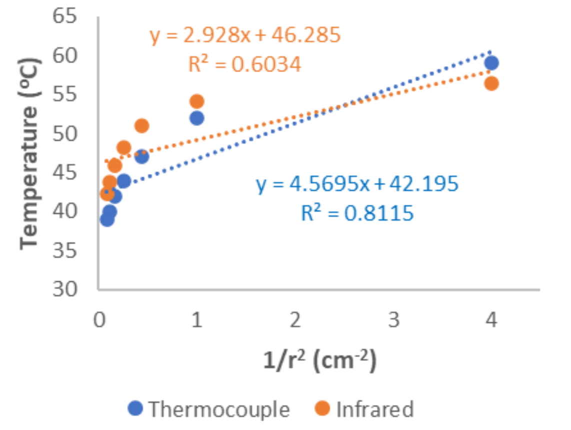

Figure 4 Graph T (measured by IR thermometer as well as by thermocouple) vs $1/r^2$ for r < 4 cm.

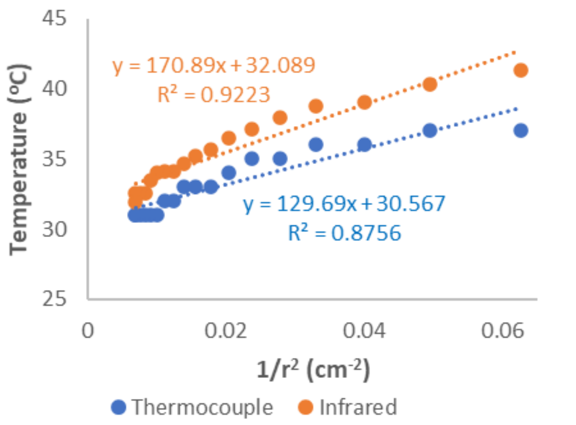

Figure 5 Graph T (measured by IR thermometer as well as by thermocouple) vs $1/r^2$ for r > 4 cm.

From the data presented in Figures 4 and 5, it is seen that models which predict linear relationships between temperature readings to the inverse of distance squares are quite appropriate, especially for distances to sources greater than 4 cm.

In addition, from the data using the Least Square Method, it concludes regression coefficients that correspond to equation (3) are B = 170.89 ^{o}C.cm^2 and C = 32,089^{o}C.

Since a T-reading by an infrared thermometer is a measurement of intensity, $P/(4\pi r^2)$ equals B/r^2, or $P = 4\pi B$. If this is substituted to equation (2) (Stefan-Boltzmann's Law), it is obtained the absolute temperature of the heat source object, T_m (in units of degrees Kelvin), as:

$$T_m = [B/\varepsilon\sigma r^2]^{1/4} \quad (4)$$

By equation (4), using the results of regression calculations and taking the maximum emissivity of objects (= 1) and radius of object (r) is moderately smaller than the measurable distance (r = 0.5 cm), then obtained the temperature of the heat source object in line with the experimental temperature data, is

T_m = 331.4 K = 58.26 ^{o}C

Compared to the actual temperature of the object (i.e., 60^{o}C), there is a small deviation of 2.9%. Thus, the model predicted through this study can be used to determine the temperature of the heat source object through non-contact measurement of the temperature around the object.

From Figure 5, it is obtained the coefficient of determination (R^2) of non-contact temperature measurements (using infrared thermometers) and the coefficient of determination of contact temperature measurements (using thermocouple thermometers) respectively are 0.9223 and 0.8756. Thus, the correlation coefficient between the measured temperature and the distance of the heat source for non-contact measurements and contact measurements at distances more than 4 cm respectively are 0.96 and 0.92. This shows that there is a strong relationship between the measured temperature and the distance from the heat source.

4. CONCLUSION

Non-contact temperature measurements using infrared thermometers do not accurately state the actual temperature of an object. Temperature readings by infrared thermometers depend on distance from the source, with temperature readings proportional to the inverse squared distance from the heat source. From the data of infrared thermometer readings around the heat source, the regression coefficient can be calculated. From this coefficient, radiation power emitted by the heat source can be found, so that the temperature of the heat source as well as the ambient temperature can be calculated. From this research, the correlation coefficient between the measured temperature and the distance of the heat source is 0.96 for non-contact measurements and 0.92 for contact measurements at distances more than 4 cm.

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