Temperature Dependence on Distance from Heat Source Objects

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ABSTRACT

The temperature of media surrounding the heat source can be done by a non-contact measurement. Since it is a non-contact measurement, there will be a distance between the measuring instrument and the surface of the object measured in temperature. It is necessary to identify the relationship between measurement distances to measurable temperature readings, both theoretically and experimentally. The main problem that will be solved through this study is how much temperature changes occur due to the difference in position between the temperature gauge against the heat source object so that a model of temperature distribution is obtained in the medium around a heat source, as a function from distance to source. The purpose of this study was to determine the relationship between temperature and distance from the heat source. Research methods included library studies, physics-mathematical analysis of radiation heat transfer processes, experimental tests in the form of media temperature measurements around heat source objects for various distances. The experimental data was then processed by regression analysis, namely Least Square Method, to have the best model for temperature distribution. The result of this study revealed that the model based on radiation heat transfer state that the fourth power of temperatures at any point is inversely proportional to the square of the distance of that point to the heat source. The model obtained from this study turned out to be in accordance with the actual circumstances at a considerable distance from a heat source that is between 4 cm and 10 cm.

Keywords: *temperature, distance, heat radiation, Stefan-Boltzmann law.*

1. INTRODUCTION

Temperature measurement of an object can be done in contact or non-contact. Non-contact measurement has advantages over contact measurement, in terms of response speed as well as technical measurements that avoid contact. Because it is non-contact, there will be a distance between the measuring instrument and the surface of the object measured in temperature. This research studies the relationship between measurement distances to measurable temperature readings, both theoretically and experimentally.

If an object i.e. a source of heat is surrounded by calm air, then the process of heat transfer from the object to the surrounding air is dominated by the radiation process [1, 2].

The amount of radiation energy emitted from the surface of an object is proportional to the fourth power of surface temperatures of an object. This is stated as Stefan-Boltzmann's Radiation Law [2–4]. This law only states the relationship between energy and the temperature of objects; that are sources of heat [5–7]. The relationship between the temperature around an object to a distance is more predicted by the Law of The Inverse of Squares [8]. However, this law is more appropriately applied to the intensity of the energy beam, while the determination of the temperature model to the distance is still doubtful in significance. In addition, it is difficult to determine the direct relationship between the temperature of the object and the surrounding temperature that is a certain distance from the object, because in addition to the factor of heat transfer of radiation from the object of the heat source, there is also an influence of ambient temperature [9, 10].

The main problem that will be solved through this study is how much temperature changes occur due to the difference in position between the temperature gauge against the heat source object so that a model of temperature distribution is obtained in the medium around a heat source, as a function from distance to source. The purpose of this study was to determine the relationship between temperature and distance from the heat source. As a constraint, this study was limited by the assumption that the heat source does not change, so that its emissivity remains. Similarly, the dimensions of objects as a source of heat, as well as the radiation power, are considered fixed. Constant quantities are combined into a constant, which will not be determined in value in this study.

2. METHODOLOGY

Research methods included library studies, physics-mathematical analysis of radiation heat transfer processes, experimental tests in the form of media temperature measurements around heat source objects for various distance variations. The heat source used was an induction stove that has a constant temperature-regulating rheostat with a black glass surface with an emissivity of 0.85 at a spectral response of 8.0 micrometers. While the temperature gauge used was a type K digital thermocouple thermometer. The experimental data was then processed by regression analysis, namely the Least Square Method to get the best model for temperature distribution.

3. RESULT AND DISCUSSION

According to Stefan-Boltzmann's Law, an object with temperature T_B will emit heat to the surroundings, with an intensity of:

$$I_B = \frac{P}{A_B} = e_B \sigma T_B^4 \tag{1}$$

with P is the power (heat emitted per unit of time), A_B is the surface area of the object, e_B is the emissivity of an object, and σ is Stefan – Boltzmann constant.

According to Huygens's principle, on the waves that propagate in free space, all points of a wavefront in a vacuum or transparent medium may be regarded as new sources of wavelets that expand in every direction at a rate depending on their velocities [11]. At a point that is r from the source, assuming that it is a heat wavefront, which means it can be a new source of waves, heat emission with an intensity I, the magnitude of which:

$$I_B = \frac{P}{A} = e\sigma T^4 \tag{2}$$

with *A* is the surface area of the field through the review point, *e* is the medium emissivity at the point of review, and *T* is the temperature at the point of review. The power emitted, *P*, is the same as the power emitted by the heat source, it means:

$$P = e_B\, \sigma\, T_B^4\, A_B = e\, \sigma\, T^4 A \tag{3}$$

If the environment has ambient temperature T_L, then the environment emits heat that will then be absorbed by the object, so that the total net of heat emitted by the object is the same as the heat emitted assuming the temperature of the zero ambient temperature subtracted by heat absorbed from the environment. So, the magnitude of intensity is

$$I = \frac{P}{A} = e\, \sigma\, (T^4 - T_L^4) \tag{4}$$

If the dimension of a heat source object is much smaller than the dimension of the reviewed space, then the heat source object can be considered a point, so that the surface area of the plane through the point of review, A, can be considered a sphere which is forming a group of points which have the same distance to the source point. Because the distance is *r*, the surface area $A = 4\pi r^2$, so obtained:

$$\frac{P}{4\pi r^2} = e\, \sigma (T^4 - T_L^4) \tag{5}$$

The study was limited to determining the dependence between measurable temperatures to distances from heat sources. Thus, it is assumed that the heat source does not change, so that its emissivity remains. Similarly, the dimensions of objects as a source of heat, as well as the radiation power, are considered fixed. Constant quantities are combined into a certain constant, which will not be determined in value in this study.

Thus, it is obtained the relationship between the temperature of the review point (*T*) to the distance of the point to the heat source (*r*), as:

$$T^4 = B(r^{-2}) + T_L^4 \tag{6}$$

Or

$$T = [B(r^{-2}) + T_L^4]^{1/4} \tag{7}$$

with $B = \frac{P}{4\pi\sigma e}$

The experiment on temperature measurements with variations in the distance of measuring points to heat sources was conducted in the Applied Physics Laboratory of Politeknik Negeri Bandung. Temperature is measured using a thermocouple metal thermometer with digital readings.

From equation (6), if a graph is made between r^{-2} (abscissa) against T^4 (ordinate), it will be obtained a straight line, with linear regression equations $y = A + Bx$, and by Least Square Method, obtaining parameter A equals T_L^4, and B equals $P/(4\pi\sigma e)$.

Measurement result can be seen in Figure 1, Figure 2, and Figure 3.

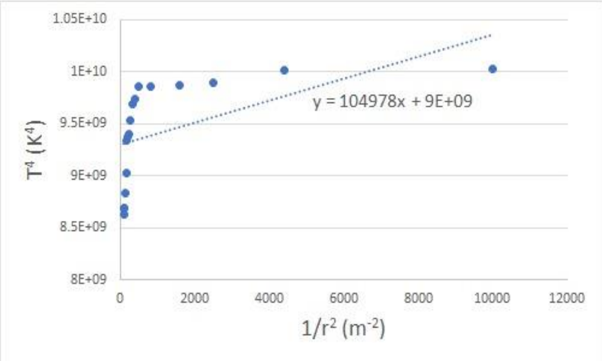

Figure 1 Graph between T^4 (y) against r^{-2} (x)
Source: Data Processing

Data obtained from the temperature measurements results to the distance from the heat source is depicted in the graph in figure 1 above. To be compared to the theoretical model presented in equations 6 and 7, the graph coordinate is chosen not temperature (T) against distance (r), but the power of four of temperatures (T^4) against the inverse of the square of the distance ($1/r^2$).

From the empirical data on the graph, it appears that there are two tendencies of data regularity, namely for abscissa data smaller than 625 m^{-2} (or distance r more than 4 cm) and abscissa data greater than 625 m-2 (or distance r less than 4 cm). That is why two graphs between T^4 and $1/r^2$ are made, namely Figure 2 for r between 4 cm and 10 cm, and Figure 3 for r smaller than 4 cm. The maximum distance is chosen to be 10 cm (means that $1/r^2$ equals 100 m^{-2}) because for a distance more than 10 cm, thermometer reading is almost constant due to dominant environment influence [10].

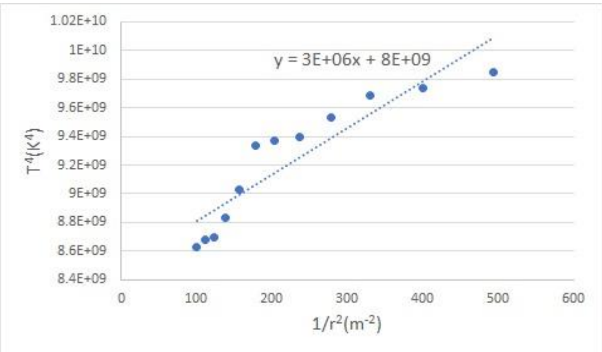

Figure 2 The graph between T^4 (y) against r^{-2} (x), for 4 cm $\leq r \leq$ 10 cm. Source: Data Processing

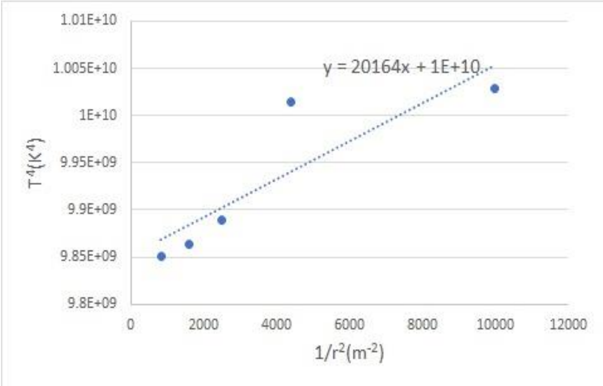

Figure 3 The graph between T^4 (y) against r^{-2} (x) for $r \leq 4$ cm. Source: Data Processing

From the visualizations shown through the graphs in Figures 1, 2, and 3, it appears that the theoretical approach through the formula presented in equation (6) can be used to express empirical representations of temperature against distance to heat source, especially for distances between 4 cm and 10 cm (figure 2).

Using regression analysis, namely Least Square Method, regression parameters A and B can be found from the data. Both figures obtain the value of parameter *A*. From this, we can calculate the ambient temperature T_L. From Figure 1 ($r \geq 4$ cm), it is obtained that T_L equals 299.10 K or 25.95 °C, and from figure 2 ($r \leq 4$ cm), it is obtained that ambient temperature value T_L equals 316.20 K or 43.05 °C. Thus, the first condition (*r* large) obtains better results because it is closer to the real value of factual ambient temperature (25.3 °C or 298.45 K).

Reviewed from the results of ambient temperature obtained, the deviation of the results from the data for distance to source (r) less than 4 cm, is 5.94 %. While deviation of the result of the data for distance to source (r) more than 4 cm, is 0.22 %. So the model obtained through this study, as mentioned in equation 6 or 7, is quite precise if the distances to heat sources are greater than 4 cm, but less than 10 cm. It is estimated that for a fairly small distance (r < 4.0 cm), the model must be recorrected because it concerns the difference in contrast between the emissivity of heat source objects and the emissivity of medium-sized infrared. Thus, the intensity of infrared radiation is measured not only because of emission but also because of absorbance. This is in accordance with what M Novak has stated [2], that the reading of thermometer is a superposition of radiation sensitivity, source emissivity, environmental emissivity, and the emissivity of thermometer materials.

4. CONCLUSION

The thermal behavior of the medium around the heat source object can be expressed by the temperature distribution model around the object. This study obtain that the model based on radiation heat transfer state that the fourth power of temperatures at any point is inversely proportional to the square of the distance of that point to the heat source. This model is relatively significant if it is applied to a distance from the point of the review to the heat source between 4,0 cm and 10 cm.

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