Research Methodology

ERROR ANALYSIS ON DETERMINATION OF SPECIFIC HEAT OF AGRICULTURAL PRODUCTS USING MIXTURE METHOD

Analisis Kesalahan pada Penentuan Panas Jenis Produk Pertanian Menggunakan Metode Pencampuran

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ABSTRACT

This paper reporting method of error analysis in determination of specific heat of agricultural product using mixture method. There are six variables evaluated on error measurement, those are: mass of water, mass of sample, equilibrium temperature, water temperature, sample temperature and calorimeter temperature. As the results of experiment on potatoes and carrot, calorimeter temperature gave biggest error contribution based on simulation conducted using Visual Basic Application (VBA) at Microsoft Word.

Keywords: *error analysis, Specific heat, VBA*

BACKGROUND

The specific heat of a substance is defined as the energy required to raise its temperature to 1°K per weight units (Burghardt and Harbach, 1999). The specific heat denoted the variation of the temperature with the amount of heat stored within the substances. Specific heat depends on the nature of the addition in terms of either a constant pressure process or a constant volume process. One of the common procedures (Siebel's equation, method of mixtures, method of *guarded-plate*, method of comparison calorimeter and method of calculated specific heat) for measurement of constant pressure specific heat is the method of mixtures by calorimeter. In this method, the specimen at a known mass and temperature is dropped into a calorimeter of known specific heat containing water at a known temperature and weight. The unknown specific heat is then computed from a heat balance equation between the heat gained or lost by the water and calorimeter and that lost or gained by the specimen (Mohsenin, 1980).

Selection of measurement concerning with accuracy and precision of measurement must become main concern in order to reduce error of each variable is measured. Therefore, analysis of error in determination of specific heat of agricultural product is discussed in this paper.

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OBJECTIVES

The objectives of this analysis are as follows:

1. To determine of specific heat of agricultural products
2. To determine error model of specific heat
3. To develop a simple program to simulate error of individual variable to overall specific heat measurement.

THEORETICAL REVIEW

A. Specific Heat

To calculate the specific heat by the method of mixtures, the following heat balance equation is used (Mohsenin, 1980):

$$Q_s + Q_c - Q_w \tag{1}$$

$$m_s Cp_s (T_s - T_e) + m_c Cp_c (T_c - T_e) = m_w Cp_w (T_e - T_w) \tag{2}$$

with change of $m_c Cp_c$ become C_c, we get

$$m_s Cp_s (T_s - T_e) + C_c (T_c - T_e) = m_w Cp_w (T_e - T_w) \tag{3}$$

the last result we get

$$Cp_s = \frac{m_w Cp_w (T_e - T_w) - C_c (T_c - T_e)}{m_s (T_s - T_e)} \tag{4}$$

where:

Q_s = Heat energy of sample (J)
Q_c = Heat energy of calorimeter (J)
Q_w = Heat energy of water (J)
Cp_s = Specific heat of sample (J/kg°C)
Cp_w = Specific heat of water (4200 J/kg°C)
C_c = Heat capacity of calorimeter (J/°C)
m_w = Mass of water (kg)
m_s = Mass of sample (kg)
T_e = Equilibrium temperature (°C)
T_w = Temperature of water (°C)
T_s = Temperature of sampel (°C)
T_c = Temperature of calorimeter (°C)

B. Error Analysis

The sum of absolute values of the error terms gives the maximum possible value of the error. However, combining these terms by a root-mean-square and changing to the finite difference form as (Henry, *et al.*, 1991):

$$\Delta Cp_s = \sqrt{\left(\frac{\partial Cp_s}{\partial m_w}\Delta m_w\right)^2 + \left(\frac{\partial Cp_s}{\partial m_s}\Delta m_s\right)^2 + \left(\frac{\partial Cp_s}{\partial T_e}\Delta T_e\right)^2 + \left(\frac{\partial Cp_s}{\partial T_w}\Delta T_w\right)^2 + \left(\frac{\partial Cp_s}{\partial T_s}\Delta T_s\right)^2 + \left(\frac{\partial Cp_s}{\partial T_c}\Delta T_c\right)^2} \tag{5}$$

Error analysis every variables (individual errors) are done with partial differential equations in every variables which will be analysed. Measurement of variables are: (1) m_s and m_w is measured by digital weighting machine with accuration is 0.0001 kg, (2) T_e, T_w, T_c dan T_s is measured by thermocouple with accuration is 0.1 °C.

$$\frac{\partial Cp_s}{\partial m_w} = \frac{Cp_w (T_e - T_w)}{m_s (T_s - T_e)} \tag{6}$$

$$\frac{\partial Cp_s}{\partial m_s} = \frac{C_c (T_c - T_e) - m_w Cp_w (T_e - T_w)}{m_s^2 (T_s - T_e)} \tag{7}$$

$$\frac{\partial Cp_s}{\partial T_e} = \frac{m_w Cp_w + C_c}{m_s T_s} - \frac{m_w Cp_w T_w + C_c T_c}{m_s T_e^2} \tag{8}$$

$$\frac{\partial Cp_s}{\partial T_w} = -\frac{m_w Cp_w}{m_s (T_s - T_e)} \tag{9}$$

$$\frac{\partial Cp_s}{\partial T_s} = \frac{C_c (T_c - T_e) - m_w Cp_w (T_e - T_w)}{m_s T_s^2} \tag{10}$$

$$\frac{\partial Cp_s}{\partial T_c} = -\frac{C_c}{m_s (T_s - T_e)} \tag{11}$$

C. Rejecting Bad Data

Henry, *et al.* (1991) described that the impossibility of ever being able to replicate an experiment or measurement exactly presents a dilemma for the analysis and interpretation of the results of experimental studies. Generalizing this concept to N observations, let and be those points of f(X) such that:

$$P\{X_l < X < X_u\} = 1 - \frac{1}{N} \quad (12)$$

and then the range of acceptable X-values may be computed as:

$$\bar{X} \pm t\,.\,s \quad (13)$$

the variance of a predicted individual y for a given X, as presented by Ostle (1963) in Henry, *et al.* (1991) may be computed as:

$$S_y^2 = S_E^2\left[1 + \frac{1}{N} + \frac{(X-\bar{X})^2}{\sum(X-\bar{X})^2}\right] \quad (14)$$

where:
S_E^2 = the mean square for deviation about regression, i.e. the residual mean square.

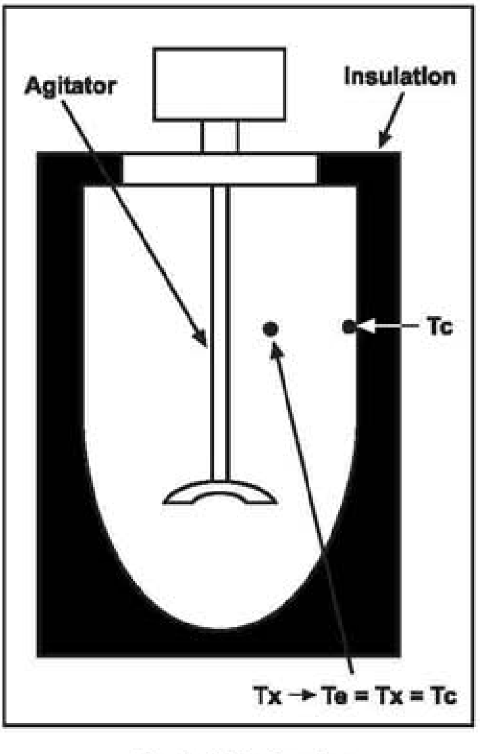

Fig. 1. Calorimeter

EXPERIMENTAL DESIGN

Measurement is done in Laboratory of Energy and Agricultural Electrification, Department of Agricultural Engineering IPB, Bogor.

A. Materials and Equipments

Several potatoes and carrots samples were used on measurement of specific heat. The equipments used were a calorimeter, digital weighting machine, copper-constantan thermocouples, and hybrid recorder.

B. Methods of Measurement

First, determination of Q calorimeter; Prepare 0.5 kg cold water, measure its temperature and pour into the calorimeter, stir using the agitator and record again the temperature by the thermocouple, add 0.5 kg hot water whose temperature has been measured previously, stir the agitator, record the mixing temperature until the equilibrium has been reached. Calculate Q calorimeter in the equation (1) and (3).

Second, determination of the Specific Heat of sample; Prepare 0.5 kg cold water, measure its temperature and pour into the calorimeter, stir using the agitator and record again the temperature by the thermocouple, prepare 0.1 – 0.2 kg specimens of the samples, take one specimen and put into the calorimeter, stir the agitator, record the mixing temperature until the equilibrium has been reached. Calculate the specific heat of sample using equation (4).

RESULT AND DISCUSSION

A. Specific Heat

Table 1. Measurement of Specific Heat (Cp) of Potatoes

No	T_c (°C)	T_w (°C)	T_s (°C)	T_e (°C)	m_w (g)	m_s (g)	Cp (J/kgK)
1	29.7	29.5	30.4	29.9	500.0	320.0	66,856.137
2	29.6	29.5	30.7	30.0	459.5	288.7	102,325.271
3	29.6	29.6	30.2	29.8	500.0	200.0	128,462.275
4	29.7	29.6	31.3	29.9	500.0	150.0	49,938.010
5	29.3	29.4	30.3	29.6	500.0	150.0	144,814.029
Average							98,479.144

Table 2. Specific Heat (Cp) of Carrot

No	T_c (°C)	T_w (°C)	T_s (°C)	T_e (°C)	m_w (g)	m_s (g)	Cp (J/kgK)
1	30.1	30.0	30.7	30.3	500.0	150.0	174,783.033
2	29.9	29.9	31.4	30.5	500.0	150.0	228,377.378
3	30.1	29.8	30.9	30.4	500.0	150.0	213,939.640
4	30.3	30.2	29.6	30.5	500.0	150.0	77,681.348
5	29.8	29.6	30.0	29.9	500.0	150.0	370,566.067
Average							213,069.493

B. Error Analysis

Average of individual error on Cp measurement of Potato and Carrot very small. Average error to potato is 3.95% and carrot is 8.87% respectively. Increasing error is occurred when Cp increase. While overall error is very small.

Calculation on the individual error is showed that Tc give highest error on potato and carrot measurement. On potato is 3.95% and carrot is 8.87%. If instrument accuration to measure Tc is increased, then Tc error could be decreased (as presented in error analysis chart). To decrease measurement error, instrument accuration to measure Tc had to be increased to be 0.01 or more.

C. Rejecting Bad Data

There are no bad data during measurement for potato and carrot, because data obtained are still in range of value and . Where is -180,221.14 and -78,477.47 and is 467,875.07 and 557,115.32 for potato and carrots measurement respectively.

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CONCLUSION

Specific heat (Cp) of agricultural product (i.e.: potato and Carrot) can be measured by calorimeter using mixture method. Equilibrium temperature (Te) contributed the biggest error. Therefore measurement Tc is recommended using thermometer/thermocouple having good sensitivity with accuration; i.e.: 0.01, 0.005, or more. Visual Basic Application (VBA) can be develop in Microsoft Word to simulate about error analysis.

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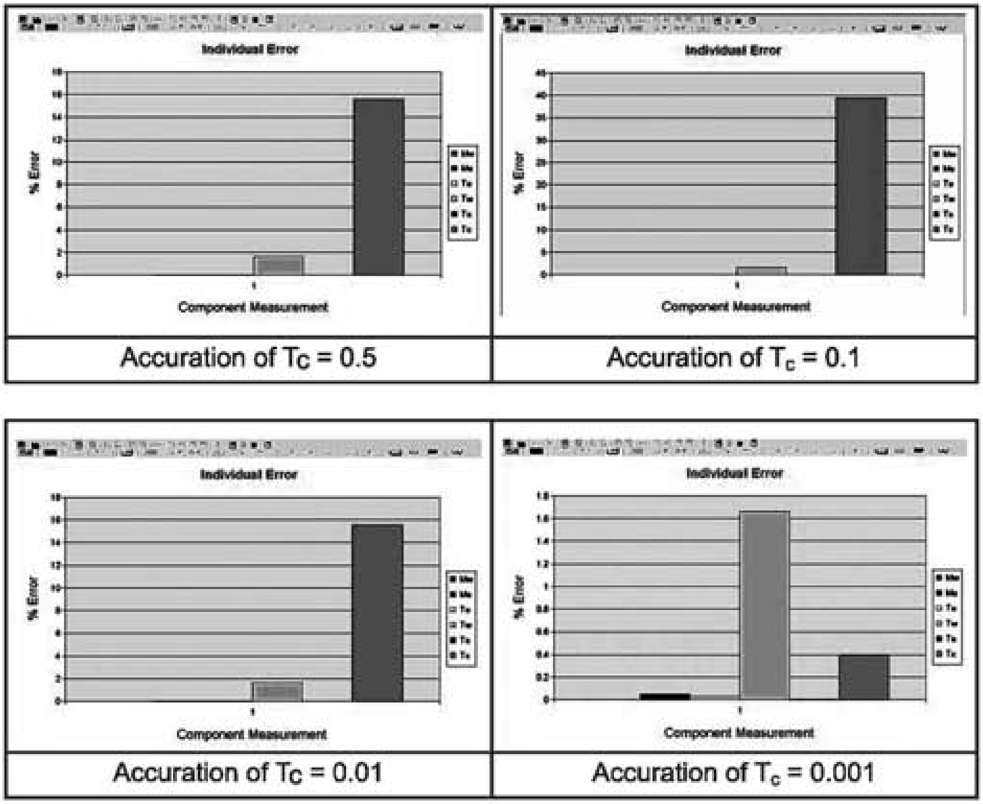

Fig. 2. Contribution of T_c to error measurement of specific heat

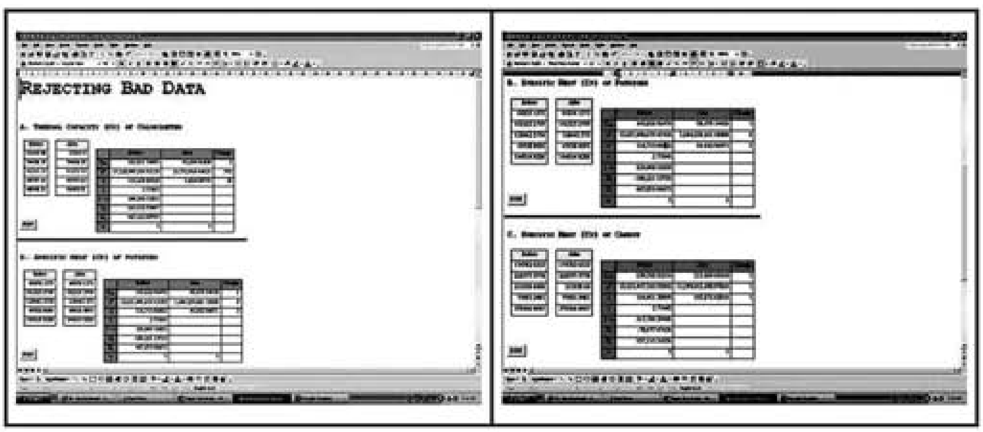

Fig. 3. Bad data rejection

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Appendix 1.

Simulation Program to Analysis the Error Measurement on Determination of Specific Heat of Agricultural Products using Mixture Method