MEASUREMENT OF HEAT CHARACTERISTICS OF A NEW INCUBATOR WITH A CHEMICAL ENERGY SOURCE

A.H. Kakaee

Department of Industrial Design, Faculty of Fine Arts
Tehran University, Tehran, Iran, kakaee_ah@yahoo.com

B. Farhanieh

School of Mechanical Engineering, Sharif University of Technology
Tehran, Iran, bifa@sharif.ir

Y. Khodadadeh

Department of Industrial Design, Faculty of Fine Arts
Tehran University, Tehran, Iran, yassamankh@hotmail.com
Institute of Science and Technology in Medicine (ISTM), University of Keele
Stoke-on-Trent, ST4 6QG, UK, yassamankh@hotmail.com

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Abstract A heat transfer model was developed for a new non-electric infant's transport incubator. The source of heat comprises a super saturated solution of Sodium Acetate and a metal disk (activator) in a plastic container. Estimating the number of the chemical bags required for different ambient temperature was the goal. First the quantity of heat generated by the chemical was appointed through experiments and use of a parameter estimation method. The number of the chemical bags were also estimated through a numerical-experimental method.

Key Words Non-Electric Incubator, Sodium Acetate, Water Solution, Parameter Estimation, Heat Transfer, Enclosure, Uncertainty

چکیده در این مقاله یک مدل حرارتی برای یک انکوباتور جدید ارائه شده است. این انکوباتور قابل حمل برای نگهداری نوزادان طراحی شده است و بر خلاف انکوباتور های متداول از انرژی الکتریکی در آن استفاده نمی شود. و به صورت غیر فعال کنترل می شود. منبع حرارتی مورد استفاده محلول فوق اشباع استات سدیم می باشد که در کیسه های پلاستیکی با وزن مشخص قرار دارد. این منبع به وسیله یک دیسک ساده فلزی با اشاره یک انگشت فعال می شود. شناسایی رفتار این انکوباتور و پیش بینی تعداد کیسه های مورد نیاز در شرایط مختلف آب و هوایی مورد سوال می باشد. برای این منظور با استفاده از یک سری آزمایشها رفتار منبع حرارتی و رفتار حرارتی انکوباتور مورد بررسی قرار گرفته است. پارامترهای مورد نیاز برای پیش بینی عملکرد با استفاده از روش تعیین پارامتر مورد محاسبه قرار گرفته و میزان عدم قطعیت نتایج ارائه شده است.

1. INTRODUCTION

World - wide every year, over 4 million infants die within the first month of life. 3.9 million of these infants are from the developing world. The main cause of 25% of these deaths is complications associated with prematurely, most often heat and water loss [1]. Keeping babies warm is very important to reduce mortality and morbidity due to hypothermia [2]. Hypothermia is a common problem in neonates, particularly in developing countries [3]. Most babies become hypothermic after birth, due to the limited facilities in developing countries [4]. It is well known that the baby, who gets extremely cold, can suffer irreparable damage and die [5]. Therefore it is essential to have a thermoneutrality control to enhance body growth and to reduce neonatal mortality and morbidity [6]. Generally, babies are kept adequately warm at home and hospital [7] but if it is necessary to transfer the baby, it is also very important to keep it warm

Figure 1. Top view of incubator.

during transportation[8]. Most developing countries are unable to afford the high costs of transport incubators, and do not have sufficient trained personnel to supervise their use and maintenance [9]. A new simple, non-electric transport incubator was designed at Keele University by Yassaman Khodadadeh, which produces heat via an exothermic crystallization reaction initiated by a metal disc in a plastic container [10]. This system is safe, available, low cost and easy to use. A prototype in dimensions of 66x42x33Cm was made of blue Styrofoam, which is classified as a good insulation material with a thermal conductivity of 0.025 W/m°K and low water absorption. The inner layer of the unit was covered with polyester aluminum foil, which prevents heat loss by radiation. The external layer was covered with plastic, which can protect the unit from external damage, moisture, etc. The lid was made of Plexiglas for observing the baby. In order to reduce the heat loss, it was double-glazed. The prototype contained inlets for fresh air, with holes in the back and front of the box. Two plastic panels perforated with holes assisted the transfer of heat to the baby's compartment. This supported the chemical bags as well as separating these bags from the baby's compartment. The chemical bags were located on both sides of the prototype (Figure 1).

$UA(T-T_r)$

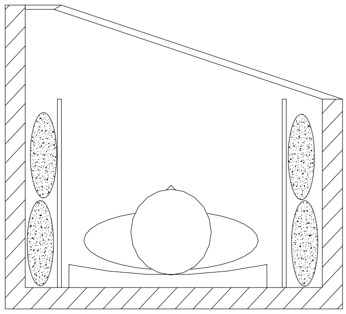

Figure 2. Main control volume

The number of the chemical bags, used in the device, was considered as a mechanism for control of the inside temperature of the incubator. For estimating the number of the chemical bags, there was a need for studying the thermal behavior of the chemical. For investigating this behavior, a mathematical model was developed and unknown parameters were obtained by parameter estimation method, via a numerical-experimental method [11].

2. HEAT TRANSFER MODEL

In order to develop a heat transfer model of this device, which is a prismatic enclosure, the first law of thermodynamics is used. This law must be used to a specified control volume. As the main aim of incubator is keeping the temperature of air in the enclosure at a specified level, the air in the chamber was selected as control volume, see Figure 2
The heat transfer model is formulated as:

$$\left(m c_p\right)_{air} \dot{T} = \left(\sum UA\right)\left(T_r - T\right) + \left(\dot{m} c_p\right)_{in}\left(T_r - T\right) + \dot{q}_s + \dot{q}_b \quad (1)$$

where $\left(m c_p\right)_{air}$ is the heat capacity of the air. T is the temperature of the air inside the control volume. T_r is the ambient temperature. $\dot{q}_b$ is the rate of heat loss from the baby, and $\dot{q}_s$ is the heat transfer rate from the Sodium Acetate water solution bag. $(\dot{m}\, c_p)_{in}$ is the heat capacity rate of the incoming fresh air or oxygen $\sum UA$ is the total heat transfer coefficient of the incubator walls. If all the physical parameters are known, then Equation 1 can be solved for the temperature history in the device. The unknown terms in the above equation are $\dot{q}_s$ and $\sum UA$.

The concentration of the Sodium-Acetate in the water solution and some other physical and chemical properties of the solution and the bag, contribute in $\dot{q}_s$ [12]. Therefore, the value of $\dot{q}_s$ was found, resorting to experiment. The material and the smoothness of the walls strongly affect the value of $\sum UA$. Due to the complex geometry and the heat transfer mechanism in the enclosure, the value of $\sum UA$ cannot be calculated accurately by means of the conventional formula or numerical methods found in open literature [13, 14]. Therefore, $\sum UA$ is also obtained experimentally. The non-linear regression method is used to obtain these unknown parameters.

3. PARAMETER ESTIMATION

One of the fundamental tasks of engineering and science is the derivation of information from data. Non-linear regression or normally known as parameter estimation method is employed for the efficient use of data in the estimation of parameters in mathematical model.

The heat transfer models used in this work are all of first order differential equations:

$$\dot{T} = f(T, p, a_1, a_2, \ldots, a_L, t) \quad T = T_0 \quad @t = 0 \tag{2}$$

where f is a general first order nonlinear function. p is an unknown parameter. $a_l, l = 1,...,L,$ are the known parameters. These parameters may be functions of t or T. T_0 indicates the initial condition. To obtain the unknown parameter, a new set of information is required. Thus, the temperature is measured at each discrete time intervals.

$$t_c, c = 1,...,C: \quad T_c^m = T^m(t_c) \tag{3}$$

The superscript m denotes the measured temperature, whereas the subscript c indicates the time of measurement. Suppose p has a definite value. By solving Equation 2, temperature at discrete times t_c is obtained:

$$T_c^c = T^c(t_c) \tag{4}$$

where superscript c indicates calculated temperature. If p has the correct value T_n^m must equal to $T_n^c,\ n = 1,...,\ N$. However, due to the errors arising from the temperature measurements, this could not be possible in all time intervals [15]. Therefore, the following sum of the squares must be minimize

$$S(p) = \sum_{c=1}^{C} \left(T_C^m - T_C^c\right)^2 \tag{5}$$

This optimization is called the whole domain method. To minimize Equation 5, a linear functional form at each R time step is assumed for p [16]. The vector of unknown p at each discrete time is defined as:

$$\vec{p} = [p_1\ p_2\ \ldots\ p_N]^T \tag{6}$$

where for $n = 1,...,N$, $p_n = p(t_{nR})$. p within the time interval $t_{(n-1)R} < t \le t_{nR}$ could be calculated from the following relation:

$$p = p_n \frac{r}{R} + p_{n-1} \frac{R-r}{r} \quad r = 0,1,\ldots,R \tag{7}$$

For minimizing S, the Gauss-Newton base method is used. The necessary condition for minimizing S is:

$$\frac{\partial S}{\partial \vec{p}} = 2\left[\frac{\partial \vec{T}^c}{\partial \vec{p}}\right]^T \left(\vec{T}^c - \vec{T}^m\right) = 0 \tag{8}$$

Where

$$\vec{T}^{c} = \left[T_1^c \; T_2^c \ldots T_C^c\right]^T \qquad (9)$$

$$\vec{T}^{m} = \left[T_1^m \; T_2^m \ldots T_C^c\right]^T \qquad (10)$$

On the other hand, by using Taylor series for $\vec{T}^c$ the following expression is obtained:

$$\vec{T}^{c,k+1} = \vec{T}^{c,k} + \frac{\partial \vec{T}^{c}}{\partial \vec{p}} \Delta \vec{p} \qquad (11)$$

where k indicates the iteration number, and $\Delta\vec{p}$ is the increment of the parameter. A sensitivity matrix can be defined as:

$$\mathbf{X} = \frac{\partial \vec{T}^{c}}{\partial \vec{p}} \qquad (12)$$

Substituting Equation 11 and 12 into Equation 8 reads:

$$\vec{p}^{k+1} = \vec{p}^{k} + \left(\mathbf{X}^T\mathbf{X}\right)^{-1}\left(\mathbf{X}^T\left(\vec{T}^{m} - \vec{T}^{c,k}\right)\right) \qquad (13)$$

To obtain a stable solution, regularization parameter, υ is introduced into Equation 13:

$$\vec{p}^{k+1} = \vec{p}^{k} + \left(\mathbf{X}^T\mathbf{X} + \upsilon\mathbf{I}\right)^{-1}\left(\mathbf{X}^T\left(\vec{T}^{m} - \vec{T}^{c,k}\right)\right) \qquad (14)$$

where $\mathbf{I}$ is the unit matrix. The sequences of the solution algorithm, in the order of their execution, are:

1. Put $k = 0$ and guess $\vec{p}^0$.
2. Solve Equation 2 for $\vec{T}^{c,k}$.
3. Solve Equation 5 for $S\left(p^k\right)$.
4. The correct solution is obtained if any of the following criteria is full filled.

$$S\left(\vec{p}^{k}\right) < \varepsilon_1 \qquad (15)$$

$$\frac{\left|S\left(\vec{p}^{k}\right) - S\left(\vec{p}^{k-1}\right)\right|}{S\left(\vec{p}^{k-1}\right)} < \varepsilon_2 \qquad (16)$$

Otherwise, calculate $\vec{p}^{k+1}$ from Equation 14. Check the fulfillment of the criteria $\left|\vec{p}^{k+1} - \vec{p}^{k}\right| < \varepsilon_3$. Otherwise, return to step 2, and repeat the whole procedure until a converged solution is obtained. υ is chosen equal to 10^{-3}. Whereas, ε_1, ε_2, and ε_3 are put equal to 10^{-7}, 10^{-7}, and 10^{-10}, respectively.

4. STATISTICAL CRITERIA

Investigation of the statistical parameters, such as mean value μ, and standard deviation σ give some criteria to evaluate the accuracy of the estimated parameters. The errors of the measured temperatures are assumed to have normal distribution with zero mean and σ^m standard deviation. To obtain the standard deviation of the estimated parameter $\vec{p}$, it is necessary to investigate its variance-covariance matrix:

$$Cov(\vec{p}) = E\left\{\left[\vec{p} - E(\vec{p})\right]\left[\vec{p} - E(\vec{p})\right]^T\right\} \qquad (17)$$

where E is the expected value. This equation is a non-linear system for the determination of the variance- covariance matrix. For linearization of this equation, the Taylor expansion can be employed, and with neglecting the higher order terms, the following equation is obtained [17]:

$$Cov(\vec{p}) = \left[\frac{\partial \vec{p}}{\partial \vec{T}^{M}}\right]^T E\left\{\left[\vec{T}^{m} - E\left(\vec{T}^{m}\right)\right]\left[\vec{T}^{m} - E\left(\vec{T}^{m}\right)\right]^T\right\}\left[\frac{\partial \vec{p}}{\partial \vec{T}^{M}}\right] \qquad (18)$$

Bates and Watts showed that [18]:

$$E\left\{\left[\vec{T}^{m}-E\left(\vec{T}^{m}\right)\right]\left[\vec{T}^{m}-E\left(\vec{T}^{m}\right)\right]^{T}\right\}=\sigma^{m^{2}}\mathbf{I} \tag{19}$$

Substituting Equation 19 into Equation 18 gives:

$$Cov\,(\vec{p})=\sigma^{m^{2}}\left[\frac{\partial\vec{p}}{\partial\vec{T}^{M}}\right]^{T}\left[\frac{\partial\vec{p}}{\partial\vec{T}^{M}}\right] \tag{20}$$

The sum of squares with zeroth order regularization is as follow:

$$S(p)=\left(\vec{T}^{c}-\vec{T}^{m}\right)^{T}\left(\vec{T}^{c}-\vec{T}^{m}\right)+\upsilon\mathbf{I} \tag{21}$$

The variance-covariance of $\vec{p}$ can be expressed as [19]:

$$Cov(\vec{p})=\sigma^{m^{2}}\left\{\left[\frac{\partial\vec{T}^{c}}{\partial T}\right]^{T}\left[\frac{\partial\vec{T}^{c}}{\partial\vec{p}}\right]+\upsilon\mathbf{I}\right\}^{-1} \tag{22}$$

Assuming independent errors in the estimated parameters, the nondiagonal elements in the $Cov(\vec{p})$ vanish:

$$Cov(\vec{p})=\begin{bmatrix}\sigma_{p_1}^{2} & 0 & \dots & 0\\ 0 & \sigma_{p_2}^{2} & \dots & 0\\ \vdots & \vdots & & \\ 0 & 0 & \dots & \sigma_{p_N}\end{bmatrix} \tag{23}$$

Comparing Equation 23 with Equation 22 gives:

$$\sigma_{p_m}=\sigma^{m}\sqrt{a_{mm}} \tag{24}$$

where

$UA(T-T_r)$

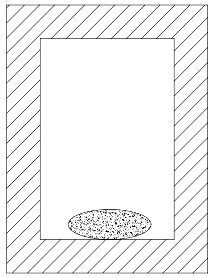

Figure 3. Schematic diagram of the insulated flask.

$$a_{mm}=\left[\mathbf{X}^{T}\mathbf{X}+\upsilon\ \mathbf{I}\right]_{mm}^{-1} \tag{25}$$

Considering the above arguments, the 99% confidence bounds can be determined from the following expression [20]:

$$\Pr ob\left\{\vec{p}-2.576\sigma_{\vec{p}}\le P_{mean}\le\vec{p}+2.576\sigma_{\vec{p}}\right\}=0.99 \tag{26}$$

where "Prob" stands for probability. Using the statistical criteria expressed in Equation 26, the accuracy of the solutions can be determined in each experiment if the measurement errors are known. For this reason, all the experiments were performed using calibrated sensors.

5. HEAT PRODUCTION BY THE CHEMICAL

The rate of heat released by the chemical, $\dot{q}_s$, is partly due to the heat generation from crystallization process, and partly due to the heat capacity of the chemical. As the rate of heat transfer of the chemical is time dependent, thus the conventional calorimeter method [21,22] is not appropriate for this purpose. Therefore, the parameter estimation method is

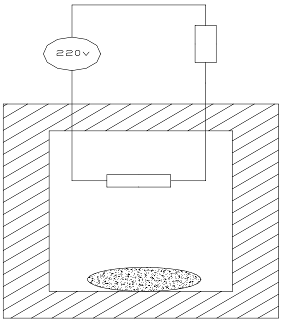

Figure 4. Controlled Heat Generation

used to find the time dependent behavior of $\dot{q}_s$.

In order to obtain $\dot{q}_s$, an insulated flask is used. The heat transfer model of the air in the flask, Figure 3 can be written as:

$$mc_p \frac{dT}{dt} = UA(T_r - T) + \dot{q}_s \qquad (27)$$

where mc_p is the heat capacity of the air. UA is the total heat transfer coefficient from the air inside the flask to the environment. T_r is the ambient temperature and T is the temperature of the air inside the flask.

There are two unknowns, UA and $\dot{q}_s$, in Equation 27. To determine these unknowns, the following experiment is performed in two different stages.

For both stages the temperature was measured using thermocouples and a Pico TC-08 data logger. The accuracy of the device was checked against a standard thermometer (LSW, type BS593 A40C with the certificate number 5852). A temperature probe was attached to the bag and another one was placed inside the calorimeter to measure the internal air temperature. A third probe was measured the ambient temperature. Temperatures were recorded for two hours. The interval time was set on 30 seconds. A solution of 100g Sodium Acetate plus 20ml pure water was made and sealed in a plastic bag for use in stage 2. A similar bag was filled with 100ml of pure water for use in stage 1. The volume of the calorimeter, the bag and the air inside the calorimeter were measured by water displacement method.

6. STAGE 1: DETERMINATION OF *UA*

To obtain the heat transfer coefficient *(UA)*, a known amount of heat is supplied to the air inside the flask by means of a thermal coil. The heat generation by the coil is controlled by a rheostatic circuit, Figure 4.

Variation in the resistance of the circuit causes changes in the electrical current and the voltage of the coil. Therefore the amount of produced heat by the coil could be change and controlled. Prior to the experiments, the chemical bag is examined in the flask to obtain estimation about the equilibrium temperature, which is about 33°C. Therefore attempts are made to achieve an equilibrium temperature around 33°C inside the calorimeter. For this aim, the resistance of the rheostat is changed and stage of changing is continued, until by try and error method the optimal range is achieved, in which the amount of the heat production of coil caused equilibrium in the air temperature of the flask. A Hioki voltmeter from Japan with the accuracy of 0.01 volt is used to measure the amount of *V*. The voltmeter is checked for accuracy prior to the experiments. The amount of heat generation of electrical coil, q_e, is calculated from:

$$q_e = \frac{V^2}{R} \qquad (28)$$

where V is the voltage of heat generator and R is the resistance of the the heat generator. Knowing V (60.3v) and R (1737Ω), q_e is calculated to be:

$$\dot{q}_e = 2.09W \qquad (29)$$

As the total heat transfer coefficient may

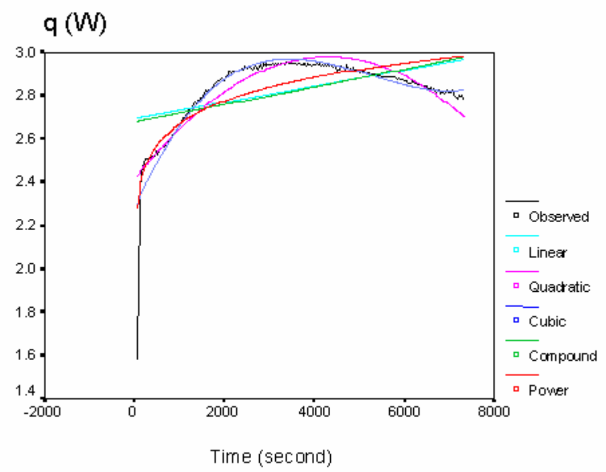

Figure 5. Heat generation vs. time with curve fitting.

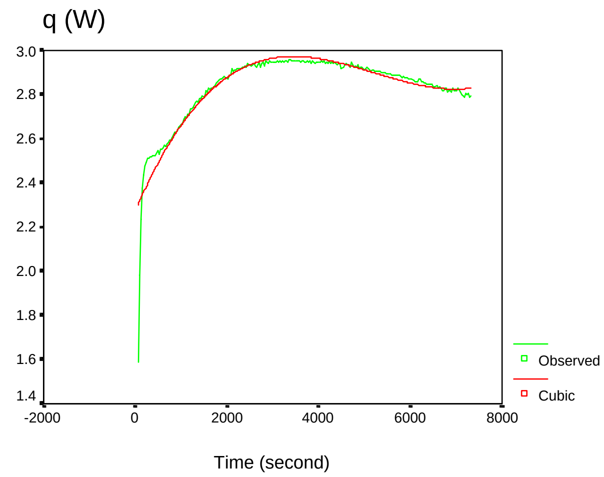

Figure 6. Heat generation and best curve fitting.

change under different condition, attempts are made to provide a similar situation to stage 2 (when the rate of heat generation by the chemical is measured) for temperature recording. Therefore, a water bag in temperature 50°C was used in the flask to make the volume of the air and thermal condition inside the calorimeter similar to stage 2. The temperature of the water bag is adjusted to 50°C, by placing it in a water bath for about one hour. It is then placed in the insulated flask and temperature recording is carried out. By using the temperature history obtained from the experiment and *parameter estimation method* the amount of UA was found. The experiment is repeated three times, and the average calculated UA is equal to:

$$UA = 0.23 \pm 4.19 \times 10^{-2}\ W/°K \tag{30}$$

7. STAGE 2: DETERMINATION OF HEAT GENERATION RATE

The chemical bag is inserted into the flask after attaching a temperature probe to it. It is activated and the temperature changes are recorded over two hours.

The quantity of heat output by the chemical bag is calculated for each 30 seconds from Equation 27 by *parameter estimation method.* The variation of the heat generation with is presented in Figure 5.

As the results show, the amount of heat generation of Sodium Acetate in the first few seconds is different from the amount of heat generation later in the experiment. In the first 120 seconds it shows a very rapid rise, however the rate of rise decreases significantly by time. When it reaches its maximum, it gradually decreases. Using ***SPSS*** software, five different methods of curve fitting, such as linear, quadratic, cubic, compound, and power are examined to obtain an expression for describing $\dot{q}_s$. As it can be seen in Figure 6, among five kinds of curves, the observed graph ($\dot{q}_s$ vs. time) could best fit in cubic. Therefore:

$$\dot{q}_s = 2.27 + 5 \times 10^{-4} t - 10^{-7} t^2 + 6.7 \times 10^{-12} t^3 \tag{31}$$

This calculation can be applied for the detailed computing. However, for practical engineering use, an average amount of $\dot{q}_s$ could be sufficient. The experiment was repeated three times, an average $\dot{q}_s$ was

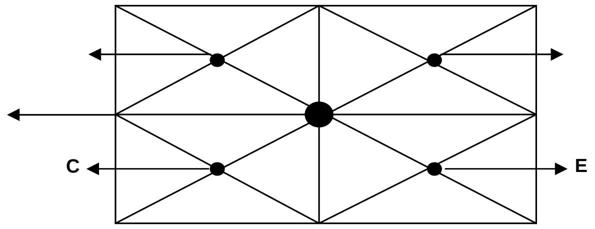

Figure 7. A schematic top view of the mattress

calculated which is:

$$\dot{q}_s = 2.75 \pm 0.26W \quad (32)$$

As the standard deviation is small (0.26), the average amount of $\dot{q}_s$ is sufficient for engineering application.

8. EXPERIMENTS FOR OBTAINING THE TOTAL HEAT TRANSFER COEFFICIENT OF THE WALLS OF INCUBATOR

To obtain the unknown parameters, there was a need for some experiments and a plan was required. Appointing the distribution of the temperature in the canopy was the first task. For this aim, different experiments carried out by placing the thermocouples in the canopy. The experiments are designed in four groups. The placements of the thermocouples were different in each group. Thermocouples were placed:

1. In length of the canopy, 10cm above the mattress. As the canopy has a symmetric shape in length, the probes were placed at one side of the canopy. The first probe was placed in the centre of the prototype and the three other probes were placed at a distance of 8cm distance from each other.
2. In width of the canopy, the first probe was placed at a distance of 3cm from the back wall and the other three probes were placed at a distance of 5cm from each other. All the probes had a vertical position of 10cm above the mattress.
3. In vertical axis, the first probe was placed in the centre of the prototype, 10cm above the mattress and three others at a distance of 4cm from each other.
5. Scattered in the canopy, five temperature probes were placed in the canopy according to the British Standard [23].The probes were placed 10cm above the mattress, at the centre of the canopy and at the centers of four assumed rectangles, on every side. A schematic presentation of the top view of the mattress is shown in Figure 7 to indicate the five standard points of placing the probes. These points were named A, B, C, D, and E showing the placement of the temperature probes

TABLE 1. UA for Canopy.

NO. OF BAGS	3	4	7
UA(W/K)	**1.94±0.30**	**3.62±0.42**	**5.24±0.66**

For each group four type of experiments performed by changing the number of the chemical bags and their placement. The number of the bags is three, four or seven and their placement either in the back or in the front of the prototype. The ambient temperature is similar for each group of the experiments, but it is varied between 12 and 23°C during the study with different groups.

The thermocouples are recorded the temperature through the TC-08 data logger. The interval time is adjusted on one minute. The experiments carried out over four hours. Each test is repeated three times. For all the experiments one thermocouple is is attached to the bag to record the temperature of the chemical bag. Another four thermocouples are placed in the canopy. The ventilation holes are recorded the ambient temperature and another one closed during these experiments.

The obtained results from the experiments are used in calculations. The total heat transfer coefficient of the canopy was calculated for each minute by *parameter estimation* method. In each test, the average temperature of the thermocouples is placed instead of average temperature of the canopy in the Equation 1. By analysing the results and calculating the heat transfer coefficient, it is

TABLE 2. The Number of Chemical Bags.

AMBIENT TEMPERATURE (°C)	5-10	10-15	15-20	20-25	25-30
NUMBER OF CHEMICAL BAGS (WITHOUT AIR INLET)	14	10	6	4	2
NUMBER OF CHEMICAL BAGS (WITH AIR INLET)	25	18	12	8	4

found that the amount of *UA* increases by increasing the amount of the chemical bags. However, other factors such as ambient temperature, placement of the probes and the location of the bags do not significantly influence the *UA*. Therefore, the average amount of *UA* was calculated in concern with different amount of bag, which is presented in Table 1.

9. ESTIMATION OF THE NUMBER OF BAGS

The final aim was to provide a condition for the baby in which he or she receives enough heat and oxygen for three hours without becoming hypothermic. The baby also generates some heat. Therefore, in the calculation it should be taken into account as a source of heat. Oxygen is normally provided by supplying a number of holes in the canopy. If a baby requires additional oxygen, it is supplied through a mask from an oxygen supply.

The heat production of the baby in Equation1, $\dot{q}_b$, can be calculated from oxygen consumption In addition, it is possible to calculate the amount of essential fresh air [24] and consequently the amount of heat required by the term $\left(\dot{m}c_p\right)_{in}\left(T_r - T\right)$. Also base on Equation 31, $\dot{q}_s$, can be calculated for each bags. The number of chemical bags required for keeping the temperature of the canopy at 35±2°C for about three hours was calculated from the final Equation 1 in steady form:

$$n\dot{q}_s = \left(\sum UA\right)\left(T - T_r\right) + \left(\dot{m}c_p\right)_{in}\left(T - T_r\right) - \dot{q}_b \quad (33)$$

The baby is placed in the device after warm-up time when the device has achieved a steady state condition. The temperature during steady state is nearly constant. Hence, the left part of the Equation 1, which is the rate of temperature variation during time, can be ignored. Also transient terms regarding qs can be omitted and the average amount of Qs can be replaced in the equation. In addition, T can be replaced by TD, which is the desired temperature (35±2°C). With these considerations, Equation 33 can be simplified to give an expression for “n” as given in Equation 34, which is sufficient for practical engineering use and estimating the number of the chemical bags.

$$n = \frac{\left(\sum UA\right)\left(T - T_r\right) + \left(\dot{m}c_p\right)_{in}\left(T - T_r\right) - \dot{q}_b}{\dot{Q}_s} \quad (34)$$

There is a relationship between the oxygen consumption and the infant’s weight and age. In a constant ambient temperature (thermal neutral range), a larger baby requires more oxygen [25]. In theory, by increasing oxygen consumption, the amount of inlet air increases and consequently more heat is required to warm more air. In reality, as the prototype is not controlled by a very accurate system, and it is not possible to have a specific control for each baby, the amount of inlet air needs to be suitable for the highest possible oxygen consumption. The oxygen consumption was calculated by using the data Ref. [25] for a baby weighing 2250g and with an age of 18-22 days. Most babies will require less oxygen.

The number of chemical bags required at different ambient temperatures was calculated from Equation 34. The results are presented in

Table 2 firstly without considering the inlet air and secondly with inlet air added to the calculations.

In order to keep the temperature at the desired level for more than three hours, it was sometimes necessary to add extra chemical bags required for different ambient temperature each bag contained 500g Sodium Acetate & 50ml pure water

10. DISCUSSION

When the design of a thermal control device is the goal, the source of heat has a vital role. In this research, attempts are made to model the heat transfer behavior of Sodium Acetate under conditions very similar to the real conditions of use. A heat transfer model is developed and, according to the principles of heat transfer, the quantity of heat generation is calculated. The amount of heat generation is then used in the heat transfer modeling of the device.

As explained, many factors associated with the temperature control of the canopy. Attempts were made to consider all the details. Investigations were placed to study the chamber in relation with the baby and the chemical source of heat. The total heat transfer coefficient ($\sum UA$) could be calculated for different ambient temperature. The result of calculating the number of chemical bags gives estimation for using the prototype under different conditions. Obviously, this estimation is not sufficient for using the device by users and there is a need for more experimental and numerical work.

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