Numerical and experimental analysis of infant radiant warmer.

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Abstract

The main object of this study is to develop 3D model of infant radiant warmer and to understand the heat transfer phenomena between an infant placed in a radiant warmer and the environment. A complete numerical simulation was done by using ANSYS software. The model was used in the Computational Fluid Dynamics (CFD) analysis with the usage of commercial code FLUENT. The analysis involves both the flow, convection and radiation heat transfer as well as the turbulence modeling. The experiments was done to validate a numerical solution. This results will be used to optimise the incubator parameters.

Keywords: *radiant warmer, premature infant, CFD, heat transfer, fluid mechanics*

1. Introduction

According to WHO (World Health Organization) the term of premature infant is a baby who was born between 22nd and 37th week of pregnancy. The lowest chance to stay alive and grow healthy has got the babies who were born before 28th week. This group has the biggest underdevelopment indicator and mortality rate. Premature infants are weaker and their organs are not well developed it strongly depends on weight which is an organ indicator because it verifies if the newborn has a chance to quick recovery Children who were premature born, usually have a low weight Chiswick in 1986 divided birth weight it 4 categories, table 1- shows that schedule [4-6]. The largest problem in neonatology is to keep them alive but it is not the only thing. Very important is 2 or 6 years control and stimulation of the premature birth children, with neurologist, respiration, oculist, etc. rehabilitation, as well.

Table 1. Birth weight categories (Chiswick M. 1986).

Category	Birth-weight (grams)
Low Birth Weight (LBW)	<2500
Very Low Birth Weight (VLBW)	<1500
Extremely Low Birth Weight (ELBW)	<1000
Incredibly Low Birth Weight (ILBW)	<800

One kind of a special rescue device is an incubator: closed – which is well known and open – called a radiant warmer.

The best solution is to place them in a closed incubator and to guarantee the optimal thermal conditions for development. However, in the case of free access to infants is the most important aspect, an open incubator should be used.

A purpose of this project is to build a numerical model and to understand the phenomena of heat transfer between an infant and surrounding environment in a radiant warmer in order to ensure the optimal temperature of body. The attention was paid on natural convection, radiation and conduction only and not on other aspects of the heat transfer. Other possible occurrences-like evaporation, for example are more advanced and will be developed in further work.

2. Fundamentals of thermal control; radiant warmer

2.1. Heat balance equation

The human normal temperature is different in case of skin measured in the stomach: 36.2-37.2°C and on the core body, measured in rectum: 36.5-37.5°C as an effect of energy balance: heat generation and losses into the environment. The heat balance equation is presented by ASHRAE [1]:

$$M-W=Q_{sk}+Q_{res}=(C+R+E_{rsw}+E_{dif})+(C_{res}+E_{res}) \quad (1)$$

Where: M – metabolic energy production; W – mechanical work, Q_{sk} – skin heat loss; Q_{res} – heat loss through respiration; C – convective skin heat loss; R – radiative skin heat loss; E_{rsw} – evaporative skin heat loss (through sweating); E_{dif} – evaporative skin heat loss (through moisture diffusion); C_{res} – convective heat loss from respiration; E_{res} – rate of evaporate heat loss from respiration.

2.2. Infant thermoregulation

Premature infants (born before 32 week) with Very Low Birth Weight (<1500 gram) have handicapped thermoregulation system, so it cannot keep the constant temperature longer than little while, as e.g. grown-up person. Foetal exchanges 85% of heat trough placenta and only 15% through the skin which is thin and not well developed and loses the heat more rapidly that normal baby. Therefore, after delivery there should be ensured a neutral environment with neutral temperature which is not the same for every infant and depends on body weight and birth age. Generally even low fluctuation (even about 1°C) of core body temperature can be dangerous for infants' life. Consequently, closed incubators and radiant warmer are really essential [6].

2.3. Radiant warmer

Model of the open incubator used in the presented study was built on the bases of "Babytherm 8010 Radiant Warmer", constructed by Dräger Medical – Germany, which is installed in "Upper Silesian Child and Mother's Centre of Health" in Katowice [2]. In this project there were analysed two cases

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which do not use a radiator lamp but a mattress only. The full model analyses will be possible in the future because standard models of radiation which are implemented in Fluent Solver solve an diffusion radiation only, while the main part of radiator lamp in this device is an reflector. For this case an own radiation solver is being created basing on the MONTE CARLO method [3]. The Model Design pre-processor was used to create 3D geometry (Figure 1,left), and to discritise the whole domain in the considered region (right) [5]. Due to the restrictions of the hardware and computational time it is important to find a compromise between number of cells and solution accuracy. An unstructured (triangular) mesh which is comprised of 340000 elements was used.

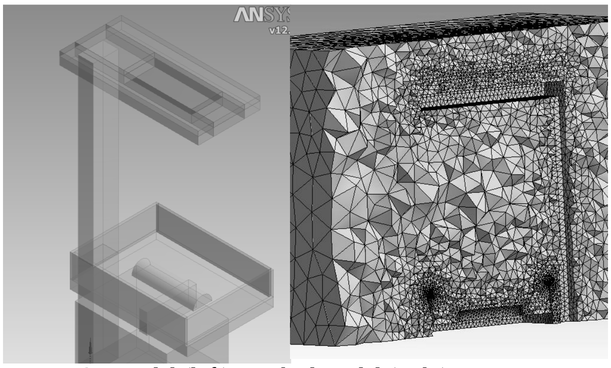

Figure 1: 3D model (left), meshed model (right).

2.4. *Computational fluid dynamics aspects*

FLUENT solver was used to solve heat and flow phenomena. A 3D model was analysed. The following settings were assumed. Firstly, all of processes are considered as a steady–state. The fluid as an in-compressible ideal gas was admitted. Air is viscous and analyzed by $k-\varepsilon$, RNG (renormalization group) turbulence model. Radiation is considered by Discrete Ordinate radiation model [4] which permission describes diffusive radiation between baby skin and surrounded devices.

2.5. *Calculations and their solutions*

The calculations were done in the case of baby who was not thermally-protected. The aim was to observe how much time it takes to obtain the hypothermia. This problem will be solved by comparing two solvers: Fluent – which modelling what is being done in the space surrounding baby and own solver (which is connected to Fluent) which can calculate a core temperature. Numerical solution is shown in Figure 2 where the temperature distribution was presented (left) and temperature

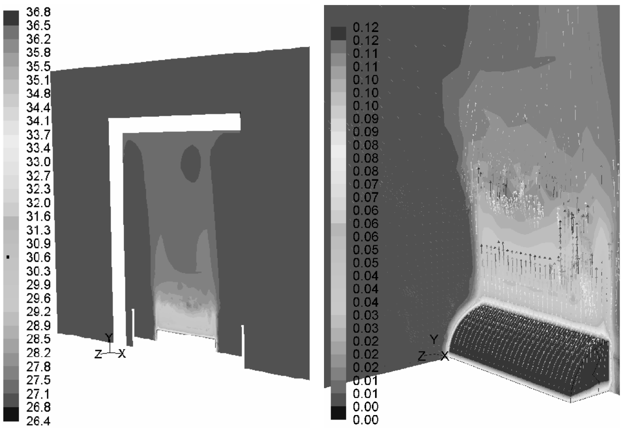

Figure 2: Temperature distribution, whole model °C (left), temperature distribution with vectors m/s (right).

distribution with vectors speed of air (right). In both cases the highest value of temperature and air velocity are the highest above an baby model because of natural convection. The total heat loss through convection and radiation is about 10W.

To validate above numerical simulations a laboratory stand was constructed. The part of the laboratory devices was shown in figure 3. It is a model of a baby (1), with a thermocouples (2) to monitor a temperature in a model and above where is the biggest temperature gradient is. In the figure 4 (left) it is shown the experimental flow field surrounding the heater. In the figure 4 (right) a numerical solution next to the baby model is shown. These experiments show that the temperatures are the same on the body surface as well as above it. In both cases, a duck is shown very well. It is characteristic for a natural convection. Velocity distribution was measured by using a PIV method and it is 0.06 m/s. It means it is almost the same as in the case of numerical model. The additional protection for a baby is the transparent shields in incubator which are also being modelled and tested by laboratory devices.

3. Conclusions

Radiant warmer is a very important device in every delivery room. Nowadays, devices are very sophisticated, but there are still places which should be improved. The optimalisation of this equipment is really important but making experiments within baby is unacceptable. The CFD (Computational Fluid Dynamics) can give a proper solutions with a numerical model without exposing the premature infants. The experiments presented above prove that this numerical model can be used successfully to future researches with MONTE CARLO radiation model to modelling full incubator usage. A full model with a tool to solve core temperature will be presented in a conference.

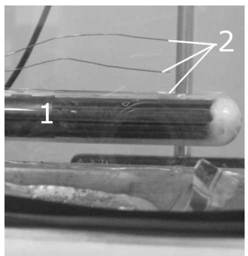

Figure 3: The model of a infant baby (1) with thermocouples (2).

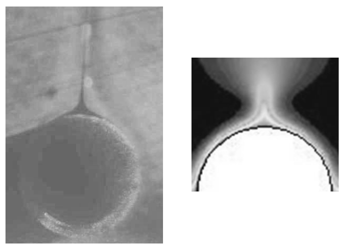

Figure 4: Flow field above infant model. An experimental solution (left), an numerical solution (right).

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