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# Modelling and optimisation of the operation of a radiant warmer

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ABSTRACT

This paper presents numerical calculations of the temperature field obtained for the case of a neonate placed under a radiant warmer. The results of the simulations show a very non-uniform temperature distribution on the skin of the neonate, which may cause increased evaporation leading to severe dehydration. For this reason, we propose some modifications on the geometry and operation of the radiant warmer, in order to make the temperature distribution more uniform and prevent the high temperature gradients observed on the surface of the neonate. It is concluded that placing a high conductivity blanket over the neonate and introducing additional screens along the side of the mattress, thus recovering the radiation heat escaping through the side boundaries, helped providing more uniform temperature fields.



## 1. Introduction

Survival of each neonate depends on its ability to regulate its body temperature. While healthy and full-term babies usually have no difficulties in such adaptation, preterm and small neonates often cannot respond to environmental temperature changes. This is due to the immaturity of their thermoregulation system. Without an environment in which a preterm neonate can maintain a normal body temperature (~37 °C) [1], it will risk cold stress and hypothermia, which may cause an increase in their morbidity and mortality [2,3]. This can develop very quickly because a premature baby can receive up to 120 kcal kg$^{-1}$ day$^{-1}$ [4,5] and a wet newborn at birth looses around 200 kcal kg$^{-1}$ min$^{-1}$ [5]. For this reason, maintenance of the neonate's body within a narrow temperature range is essential for their survival and growth. Neonates nursed in an incubator, or under a radiant warmer within the thermo neutral zone, have also shown a more rapid weight gain in comparison to other babies.

The importance of maintaining a newborn within a narrow temperature range is therefore crucial. However, there is one major concern when using radiant warmers, in that neonates may become severely dehydrated when nursed in these devices. Therefore, the main purpose of this paper is to present a numerical model of a neonate placed under a radiant warmer, which includes metabolic heat generation, and propose some modifications to improve the operation of the device.

The results presented in this paper were obtained using 3D numerical simulations performed in ANSYS FLUENT, for a simplified geometry of the neonate, namely when the newborn is modelled in the form of a half-cylinder, as well as for the real neonate geometry. Lastly, two different modifications are introduced to the shape and operation of the radiant warmer. They include placing a high conductivity blanket over the neonate and introducing additional screens along the sides of the mattress in order to recover the radiation that would otherwise escape through the side boundaries, and to re-direct this radiation towards the sides of the newborn.

## 2. Assumptions

The following assumptions have been made in the models described in this paper:

- The geometry and dimensions of the IW930 Series CosyCot™ Infant Warmer (Fisher and Paykel, New Zealand) were used to build the model. This is because this type of radiant warmer was used when gathering the experimental data in the form of thermographic pictures;

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- In some of the calculations, a simplified model of the neonate was used, namely a half-cylinder with the same volume as in the real neonate geometry;
- In the simplified model with a half-cylinder, only a quarter of the geometry is considered due to symmetry. In the model with the real geometry of the neonate, no symmetry planes are assumed;
- The radiant warmer is modelled in the form of a cylindrical filament with a prescribed heat flux. It was assumed that the known power of the radiant warmer is totally transformed into heat, and therefore the total heat flux on the external surface of the filament is equal to the power of the radiant lamp;
- The problem is modelled as steady-state;
- Turbulent flow is assumed and the Reynolds Averaged Navier-Stokes equations are used. The $k$–$\varepsilon$ RNG model is used for the turbulence modelling. This is because the model is effective for both high and low *Re* number turbulent flows and therefore it can produce good quality results even for the situations when the flow is not fully turbulent [6];
- The air density is calculated from the thermal equation of state for an ideal gas. The influence of pressure changes on the calculation of the density was assumed to be negligible in the considered situation, and the density was treated to be solely temperature dependent;
- Except for the density, all other air properties are assumed to be constant;
- The gravitational force is considered as a crucial part of natural convection;
- Radiation is taken into account. The Discrete Ordinates Model (DOM) is used for the radiation modelling because it is the only model in FLUENT that is able of calculating the specular reflection of the radiation occurring on the reflector. Furthermore, DOM is also a very reliable technique for modelling radiative heat transfer.

## 3. Geometrical and material properties of the neonate's body

For the purposes of this investigation, the body of the newborn is considered to be one solid material, and therefore all the material properties prescribed to it are averaged values based on information found in the literature.

### 3.1. Volume and surface area

From the geometry of a real neonate it was found that the volume of the newborn is approximately 0.002 $m^3$, and its length is about 40 cm. Therefore the same length was used to construct the geometry of the half-cylinder, for which the radius was worked out in such a way that the volume of the half-cylinder is the same as the volume of the real neonate. Therefore, for a cylinder of radius equal to 0.0573 m and length 40 cm, the surface area of the half-cylinder is 0.128 $m^2$. The surface area of the real neonate model is 0.146 $m^2$.

### 3.2. Mass of the newborn

Three different correlations that relate the surface area of the newborn's body to its mass were employed to work out the mass of the neonate for its given size. Firstly, a linear correlation between the surface area of a neonate and its weight was derived based on two studies [7,8] performed on a group of newborns:

$$m = 14.961 \cdot A - 0.4606, \tag{1}$$

where $m$ is the mass of the newborn, kg, and $A$ is the surface area of the newborn, $m^2$.

Using Eq. (1), the mass obtained for the surface area $A = 0.146\,m^2$ is $m = 1.724$ kg.

The second correlation was found in [9] and is given as follows:

$$A = 0.1 \cdot m^{2/3}, \tag{2}$$

and the third correlation from [8] is given by:

$$A = m^{0.5378} \cdot h^{0.3964} \cdot 0.024265, \tag{3}$$

where $h$ is the newborn's height, cm.

The surface areas of the newborn's body, for a given mass $m = 1.724$ kg, calculated from Eqs. (2) and (3), are $A = 0.144\,m^2$ and $A = 0.140\,m^2$, respectively. This shows good general agreement between the three methods used and gives us confidence that the obtained mass of the newborn, $m = 1.724$ kg, is accurate enough.

It has also been found in [10] that for low birth weight neonates, with a body mass of about 1.5 kg, the average surface area of the body is 0.13 $m^2$. This also confirms that the calculated weight $m = 1.724$ kg of the neonate in the presented model is realistic.

### 3.3. Body tissue conductivity

The average conductivity of the newborn's body has been found in [11] and it is $k = 0.34\,W\,m^{-1}\,K^{-1}$.

### 3.4. Metabolic heat generation

The metabolic heat generation was derived from a formula by Brück [12], which takes the following form:

$$q_v = \frac{m(0.0522 \cdot \tau_n + 1.64)}{V}, \tag{4}$$

where $q_v$ is the metabolic heat generation rate, $W\,m^{-3}$, and $\tau_n$ is the age of the newborn, days.

Taking the values of the newborn's mass $m$ and volume $V$ presented above, as well as assuming that the neonate is, say, one day old, the metabolic heat generation rate obtained is $q_v = 1417.5\,W\,m^{-3}$, which gives $Q = 2.9$ W. This value is consistent with the findings presented in [7], where a newborn weighing 1.6 kg had a metabolic heat production of about 2.8 W.

## 4. Geometry, mesh and boundary conditions

### 4.1. Simplified geometry of a neonate

The geometry used for the initial simulations described in this paper is presented in Fig. 1. The length of the half-cylinder was set to be 0.4 m, since this is the height of the newborn in the real model, and its radius was taken to be 0.0573 m. With such dimensions, the volume of the half-cylinder is equal to the one of a real neonate.

The mesh size used to prepare the grid inside the half-cylinder is 0.008 m, which results in a mesh of 6.5 k elements. The remainder of the domain consists of 258 k elements.

The boundary conditions used in the model are presented in Fig. 2. The side and top boundaries of the model are pressure inlets and a pressure outlet with the air temperature of 22 °C and no gauge pressure prescribed. This is the temperature used in the nursing rooms for neonates where no intensive care is necessary. The temperature in intensive care units is usually about 27 °C. The external blackbody temperature of 20 °C is also prescribed at the inlet and outlet boundaries. By prescribing the external blackbody temperature at the inlets and the outlet, we can take into account the radiation heat losses from such surfaces as the mattress and cylinder to the colder walls of the room.

The mattress is assumed to be an insulated wall and the cylinder has a coupled boundary condition prescribed which is a continuity boundary condition. This was possible because the surface of