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COMPUTATIONAL MODEL OF SELECTED TRANSPORT PROCESSES IN AN INFANT INCUBATOR

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Summary The major objective of this study was, using the modern numerical techniques, to investigate transport processes of heat and mass transfer within an infant incubator, were the premature newborn baby is nursed. This investigation consists of calculations of the air flow inside the incubator, including coupled heat transfer due to heat conduction, convection, thermal radiation and evaporation. Obtained results of calculations were numerically verified as well as compared with results published in the subject literature.

INTRODUCTION

Infant incubators are widely used in hospitals to save newborns lives and to provide them with appropriate environmental conditions which are essential for their proper grow in the very early stage of life. In the presented paper results of the applications of the numerical techniques used to describe thermal and flow environmental conditions occurring in the modern neonatal units are discussed. Understanding of these phenomena is absolutely essential for the correct design of comfortable, save and what is the most important, effective medical equipment. Because of the very complex nature of those physical phenomena the whole available information regarding that subject was up-to-now obtained through experimental techniques tested only on neonates animals [2] and adults [1]. Some of these tests were carried out even 40-50 years ago [3]. All that information must be treated as general guidelines and used with certain factor of mistrust. Because of that but also bearing in mind a rapidly growing number of premature births, seems to be essential to develop relevant numerical algorithms capable of examining, with appropriate accuracy, the heat and fluid flow processes and their results in an incubator environment. In this study a commercial CFD (Computational Fluid Dynamics) package called Fluent is applied to build a computational model and calculate results. Computational Fluid Dynamics is the technique which solves problems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation. The technique spans also a wide range of industrial and non-industrial application areas.

Objectives

The main objective of this study was to developed computational model of selected transport processes, including heat transfer due to conduction, convection and radiation as well as heat and mass transfer due to evaporation of moisture from the surface of the newborn skin. In the following projects a sensitivity analysis will be performed in order to find optimal environment conditions for the analyzed newborn baby nursed inside of the modelled incubator. Finally, for a possibility of analyzing different type of medical cases (*i.e.* different shape and weight of patients) parameterization of the geometric model is aimed to be implemented.

METHODOLOGY

In the first stage of this work a parametric three-dimensional geometrical model of the newborn infant, placed inside incubator, was designed. For this purpose a CAD-type software (called Catia [4]), capable of designing even very complex geometrical objects, was applied. Geometry transferred from Catia to CFD package preprocessor is much more flexible and accurate then that created with preprocessor itself.

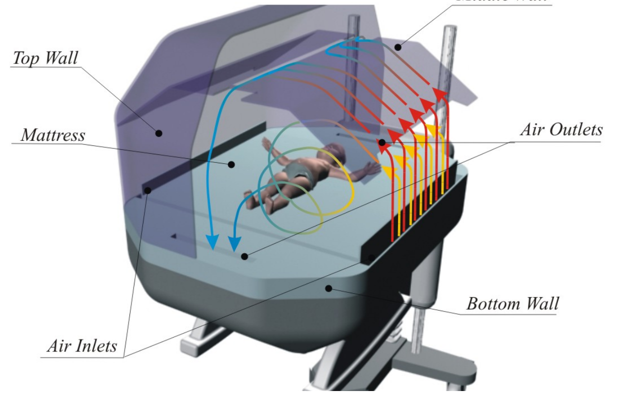

Figure 1. Modelled newborn infant placed within an infant incubator.

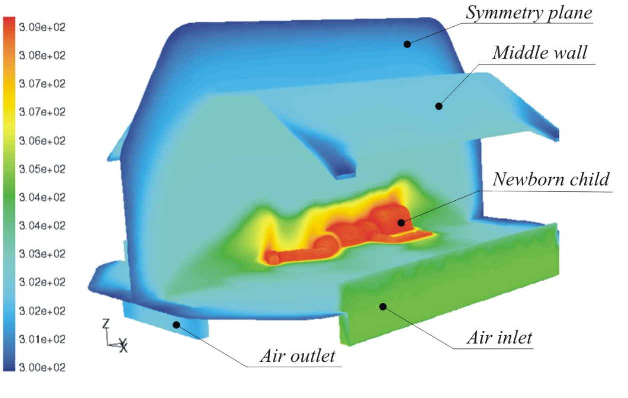

Figure 2. Perspective view of the temperature field.

For all flows, Fluent solves the the energy equation [5]

$$\nabla(k\nabla T) = \varrho\, c\, \frac{\mathrm{D}T}{\mathrm{D}t} \tag{1}$$

where T is the temperature (K), k stands for thermal conductivity (W/mK), ϱ represents the density, c is the specific heat (J/kgK) and t is time (s). The derivative on the right-hand side is the substantial derivative:

$$\frac{\mathrm{D}T}{\mathrm{D}t} = \frac{\partial T}{\partial t} + w_x \frac{\partial T}{\partial x} + w_y \frac{\partial T}{\partial y} + w_z \frac{\partial T}{\partial z} = \frac{\partial T}{\partial t} + \boldsymbol{\nabla} T \cdot \boldsymbol{w} \tag{2}$$

where w_x, w_y, w_z are the velocity components of vector $\boldsymbol{w}$ in the x-, y- and z-direction, respectively (m/s) while x, y and z represent the Cartesian coordinates.

The above equations have to be complemented by the continuity and the momentum equations [5]

$$\boldsymbol{\nabla} \cdot \boldsymbol{w} = 0 \tag{3}$$

$$\varrho \frac{\mathrm{D}\boldsymbol{w}}{\mathrm{D}t} = \boldsymbol{F} - \boldsymbol{\nabla} p + \mu \nabla^2 \boldsymbol{w} \tag{4}$$

where p is the pressure (N/m^2), $\boldsymbol{F}$ represents the body force term which in the present case has only a vertical component $F_z = \varrho g$ in the z-direction (N/m^3), g is gravity acceleration (m/s^2) and μ is the dynamic viscosity (Ns/m^2).

The Boussinesq approximation was adopted for the buoyancy term in the equation (4). Thus, density takes the usual form

$$\varrho = \varrho_0 \left[1 - \beta(T - T_0)\right] \tag{5}$$

where β is the thermal expansion coefficient (1/K), T_0 and ϱ_0 represent the so-called operating parameters.

For flows involving radiative heat transfer or a discrete phase change, additional equations are solved.

CONCLUSIONS

Computational model of selected transport processes presented in this study, provides much more effective and flexible tool compared with previous techniques used in the neonatal intensive care. It can be easily employed for verification of the new technologies, materials and ideas being run with many different input data sets. Proposed procedure can also be useful in testing new medical treatments.

Numerical analysis can provide important and what is the most important, very accurate results without exposing patients at unnecessary risk which is always involved in the medical research. It can also save time and money during the process of developing new medical equipment. This is mainly due to reduction of the number of experimentally tested prototypes.

Sensitivity analysis proved that results obtained from this model are in good agreement to those received from medical literature. Also parameterization of the geometrical inputs proved to be very useful for analyzing individual cases, where one can easily change the weight and shape examined premature newborns.

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