Firefighter's Garment Based Carbon Foam Fabric

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Background

- The environmental conditions encountered by firefighters impose heat strain through a combination of high ambient temperatures and radiant heat flux .

- Firefighter’s turnout is a composite of three components: an **Outer Shell** (*to take the everyday abuse of firefighting*), a **Moisture Barrier** (protects against the intrusion of water, chemicals or viral agents) and a **Thermal Liner** (provides the most thermal insulation), Fig.1.

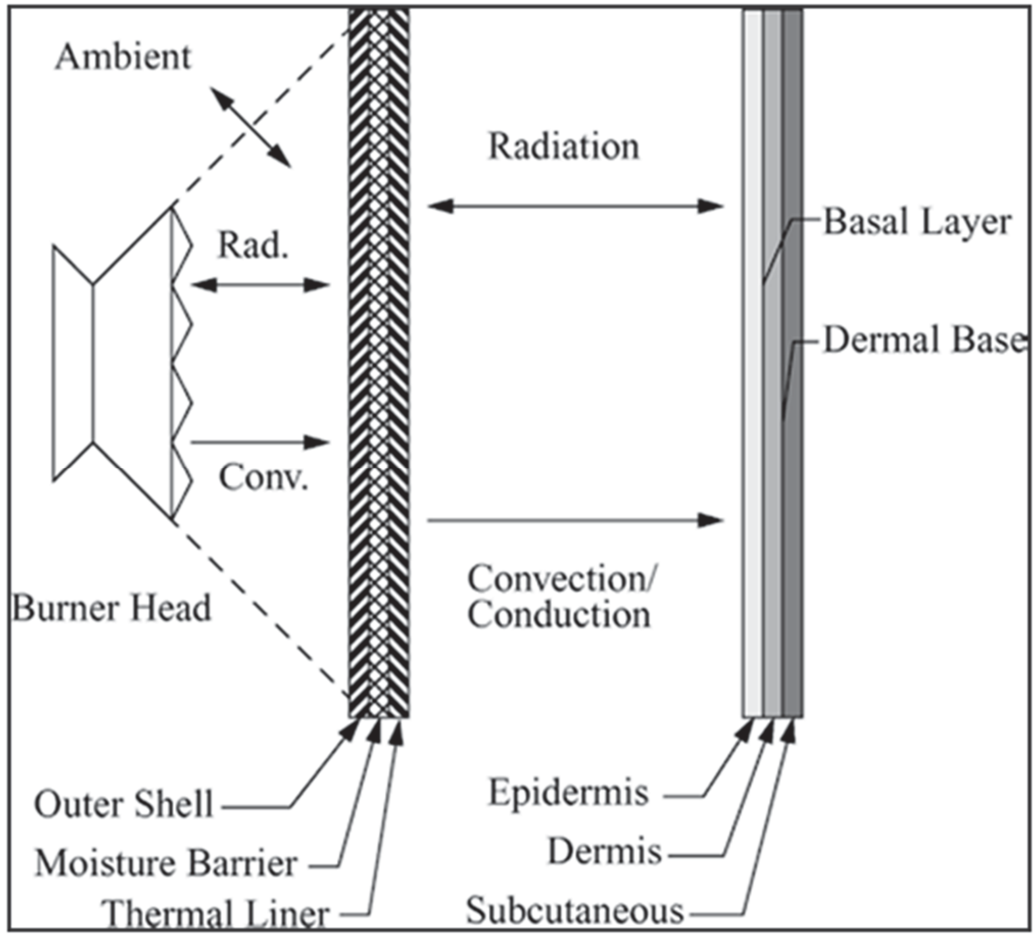

Fig. 1 Firefighter’s turnout components

Turnout Characteristics

-The combination of all three of these components would define the performance characteristics of the entire composite system.

- Thermal protection performance.
- Total heat loss
- System weight
- Durability

Carbon Foams

Carbon foams are cellular materials that have been considered recently in variety of applications due to their:

1- Extremely light weight.

2- Optimum mechanical and thermal properties.

3- Ability to be used in biological applications.

4- Ability to be used as thermal insulators.

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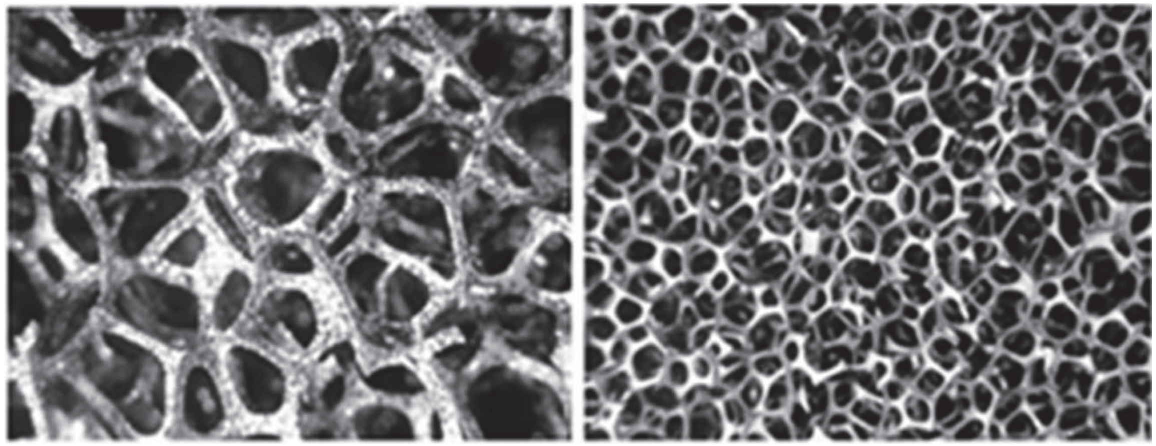

Fig.2 Two samples of carbon foam showing pore structure at different pore sizes

Fig.3 Fig.1 Carbon foam as an insulator

Objectives

The present work is a numerical study to predict and investigate the performance of a thermal protection system for firefighter’s garment consists of carbon foam fabrics in both the outer shell and thermal liner.

Research Methods

Several types of carbon foams with different :

- Thermal conductivity.
- Porosity
- Density
- Thickness

Are introduced for the sake of a parametric study.

The new anticipated thermal protection systems are tested numerically at different ranges of heat and temperature.

No	Parameter	Values
1	Thermal Conductivity	0.02, 0.03 and 0.05 W/m-k
2	Density	50 and 150 Kg/m^3
3	Porosity	0.4 and 0.6
4	Thickness	0.0025, 0.00275, 0.003 and 0.00325 m

Table-1 Values for each parameter used in the present study

Model Description

Simulation is conducted for square planar 2D geometry of the clothing comprising of the three fabric layers and Gambit software is used to model the 2D geometry. Quad map meshing scheme is used to mesh the faces and a (300 x 300) grid is used. Simulation is carried out using ANSYS Fluent CFD software.

Model Validation

- The present simulation model has been applied on a case of study introduced by Patirop, and Andrey [7] to ensure its validity. They used KEVLAR/NOMEX blend in the outer shell and Aramid batt quilted to 3.2 oz/〖yd〗^2 NOMEX at the thermal liner.

- Figure 4 shows a good match between the two results.

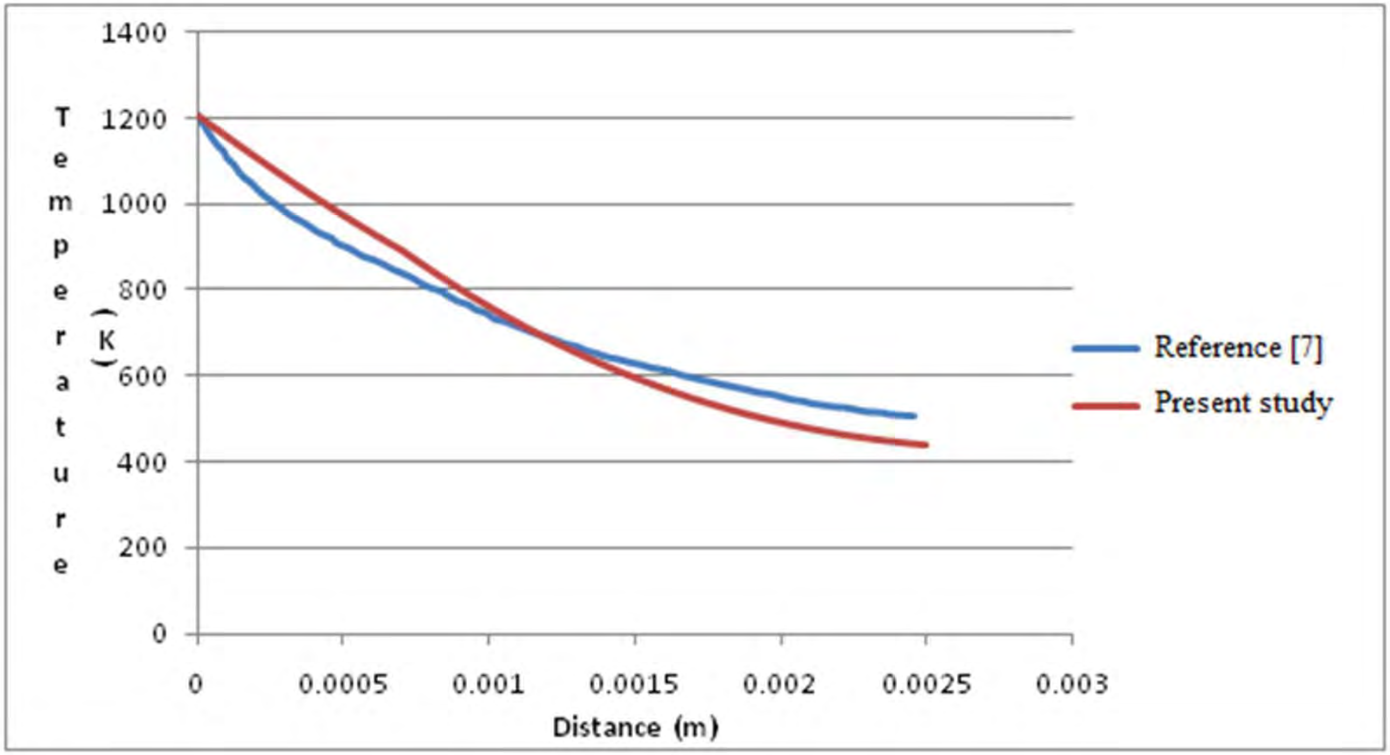

Fig. 4 Validation of present simulation model

Results

1- Effect of thermal conductivity

The first simulation, case-1, has been carried out with a fabric thickness of 0.0025m (outer shell = 0.0007m, moisture barrier = 0.00085 and thermal liner = 0.00095m), thermal conductivity of 0.03 W/m-K, density of 50 kg/m^3 and porosity of 0.6. The fabric has been exposed to a sudden high thermal radiation with a temperature of 1250°K. The temperature has been dropped along the fabric thickness from 1250°K to 472°K. Different thermal conductivities have been used as shown in Figures 5, 6.

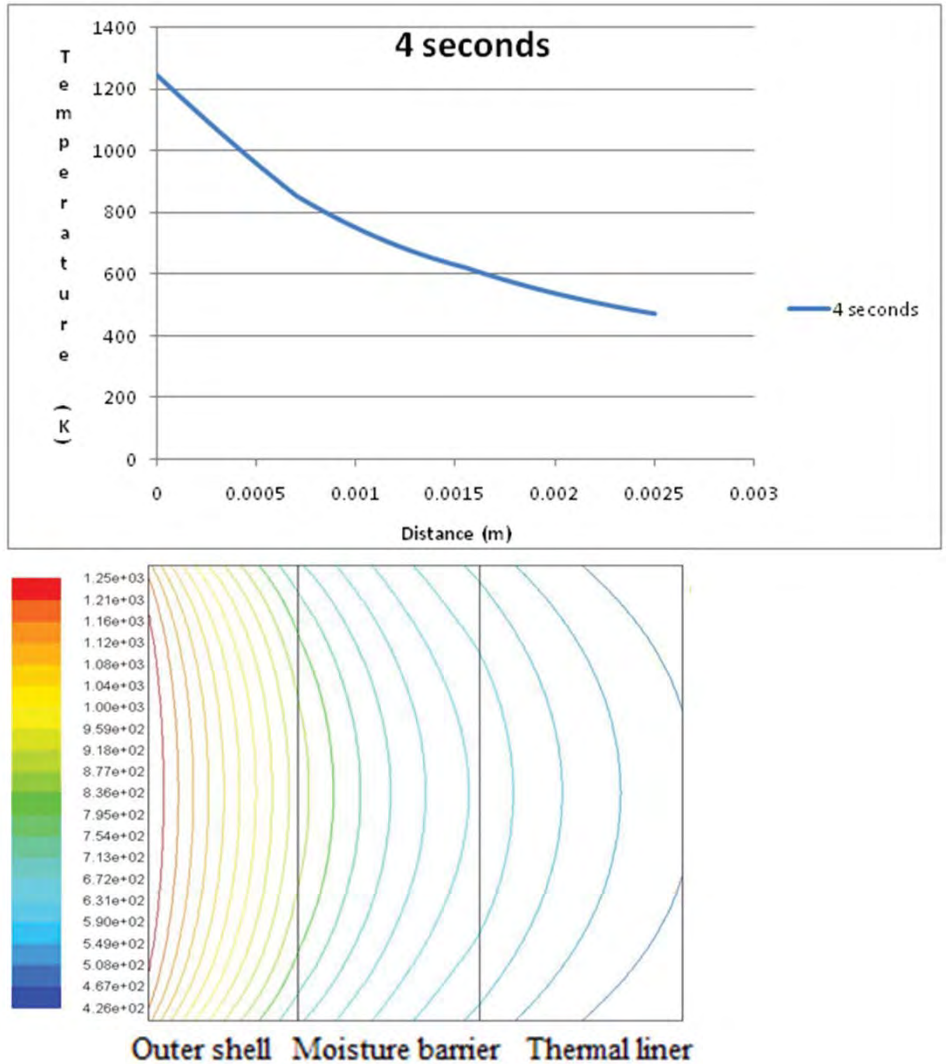

Fig. 5 Temperature drop through fabric thickness, case-1 thermal conductivity of 0.03 W/m-K

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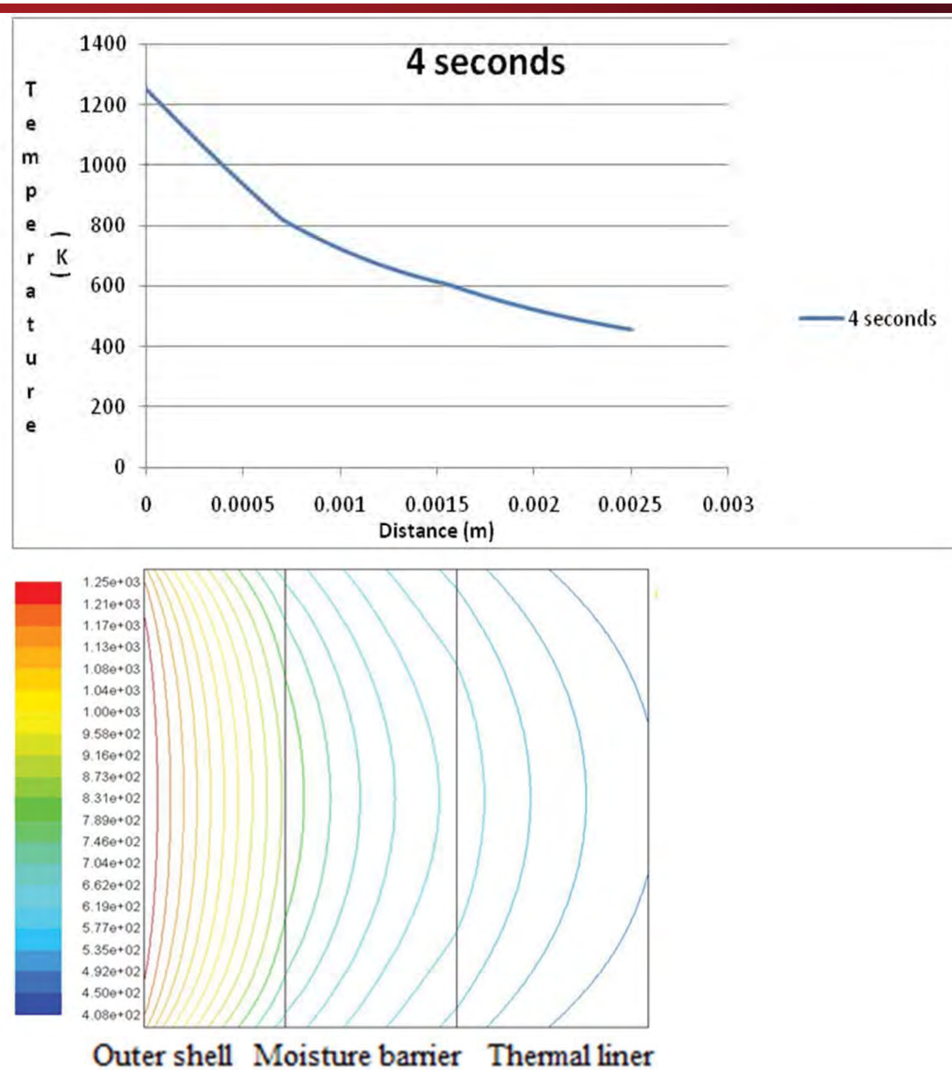

Fig. 6 Temperature drop through fabric thickness, case-2 thermal conductivity of 0.02 W/m-K

- As it can be seen from Fig. 6, the temperature has been dropped drop from $1250^{o}K$ to $455^{o}K$.

- Yet, the required temperature drop has not been achieved.

2- Effect of density

- To achieve more temperature drop, a carbon foam fabric with higher density of 150 kg/m^3 has been introduced, which is still a very low value compared to the used one by Patirop, and Andrey [7].

- With this density and thermal conductivity of 0.03W/m-K, the temperature drop along the fabric is from 1250°K to 422°K, Fig. 7. Figure 8 shows the results for K = 0.02 W/m-K.

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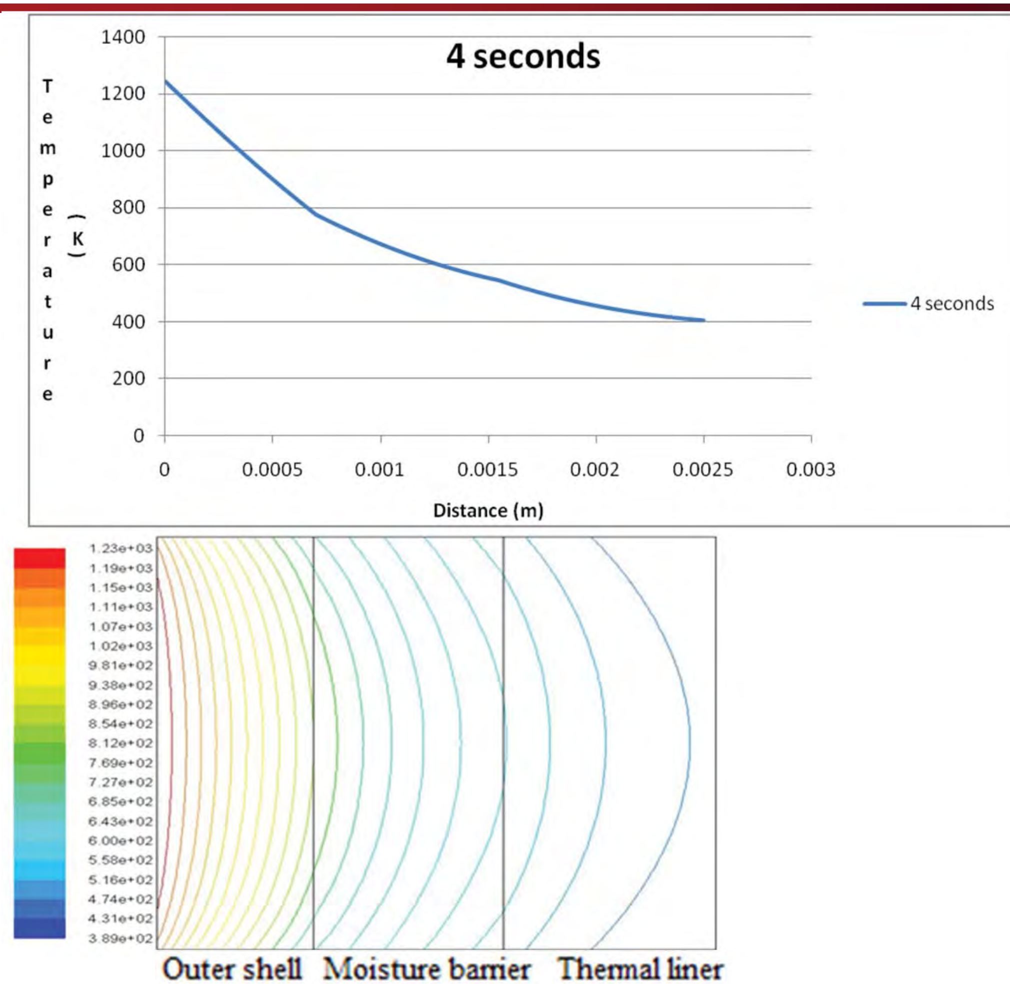

Fig. 7 Temperature drop through fabric thickness, case-3 density 150 kg/m^3 and $K = 0.03 W/m\text{-}K$

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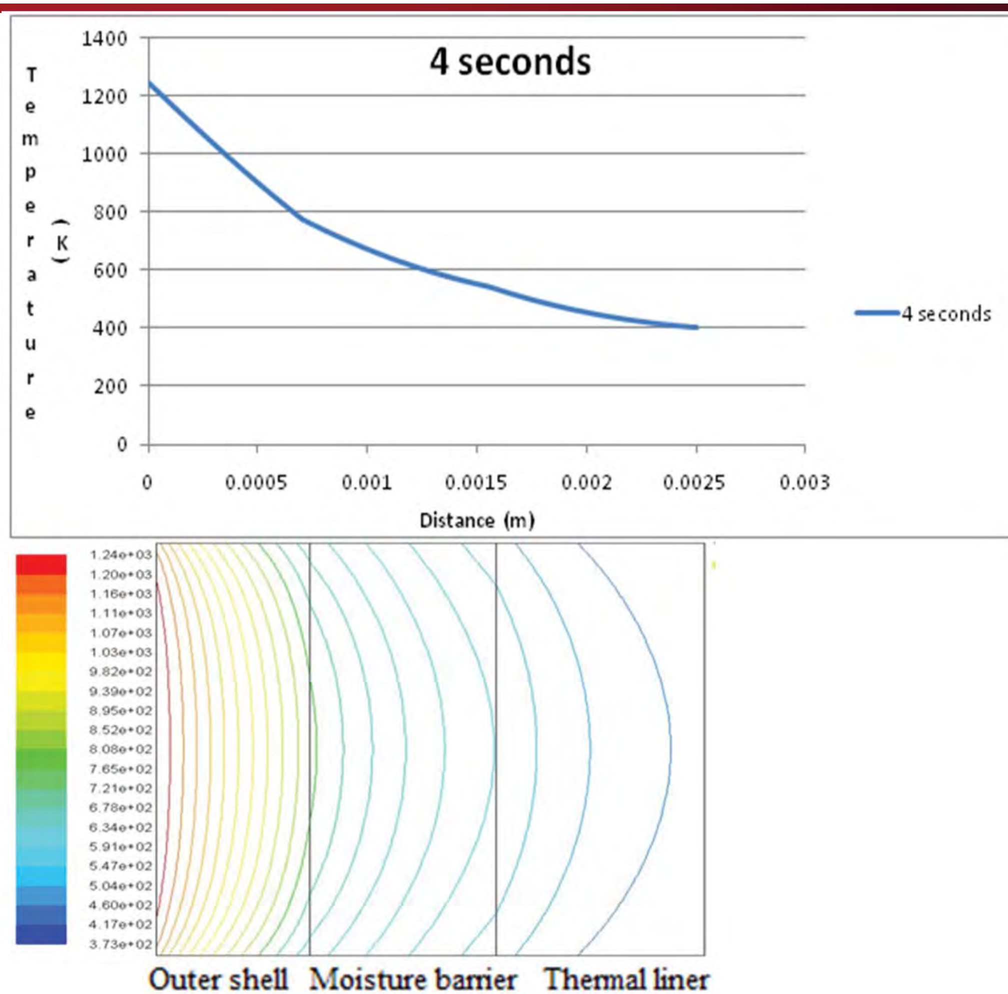

Fig. 8 Temperature drop through fabric thickness, case-4 density 150 kg/m^3 and $K = 0.02 W/m\text{-}K$

The temperature drop in this case is from 1250^{o}k to 405^{o}K. Temperature at the end of the fabric dropped by 34^{o}K from the reference case, [7], which would considered as a satisfactory result

3. Effect of porosity

- The next set of simulations incorporated a porosity value of 0.4 for the carbon foam material in the outer shell and the thermal liner of the fabric. The density of the fabric is considered to be 150 kg/m^3 and its thermal conductivity is 0.03W/m-k. As a result, temperature dropped from 1250^oK to 393^oK. Case-6 has the same properties as Case-5 except that thermal conductivity is considered to be 0.02W/m-k instead of 0.03W/m-k . As a result, temperature dropped from 1250^oK to 370^oK

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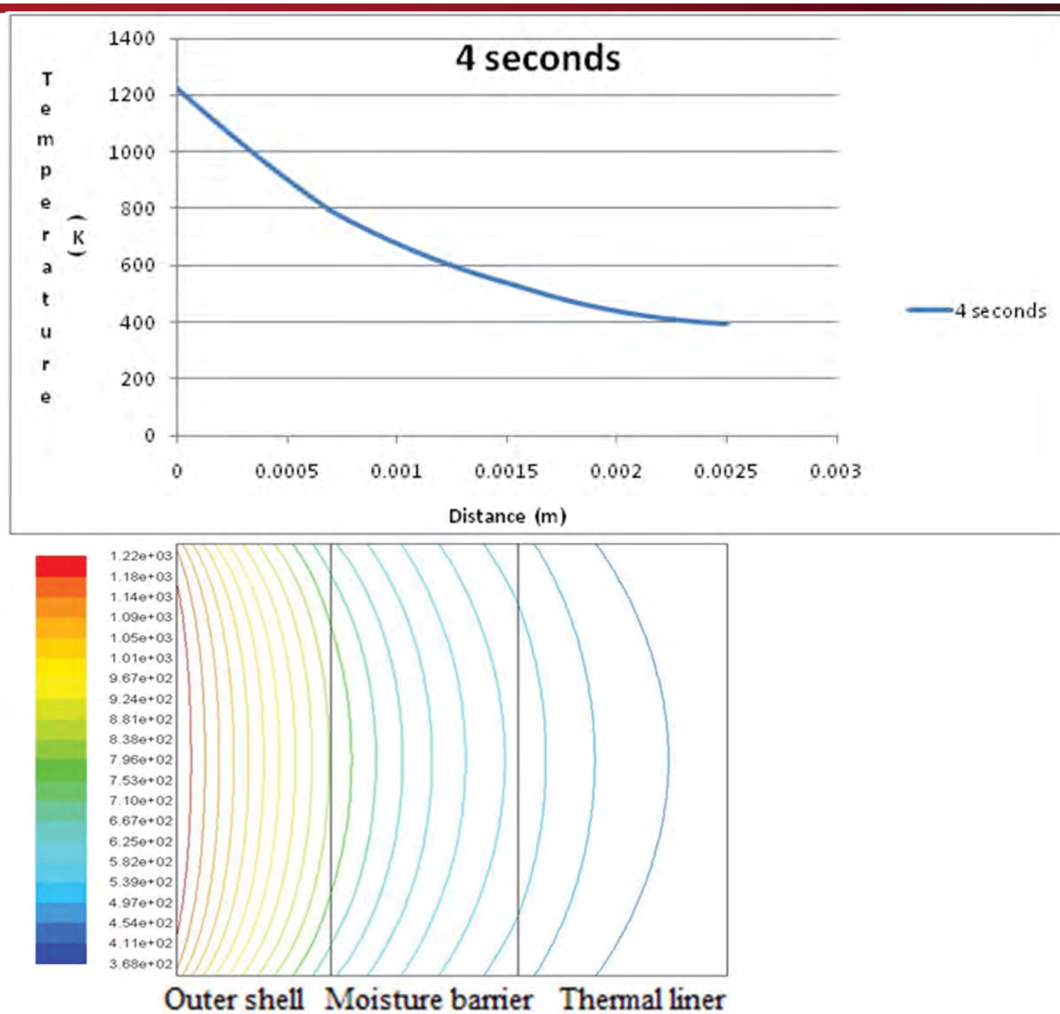

Fig. 9 Temperature drop through fabric thickness, case-5 porosity 0.4 kg/m^3 and $K = 0.03 W/m\text{-}K$

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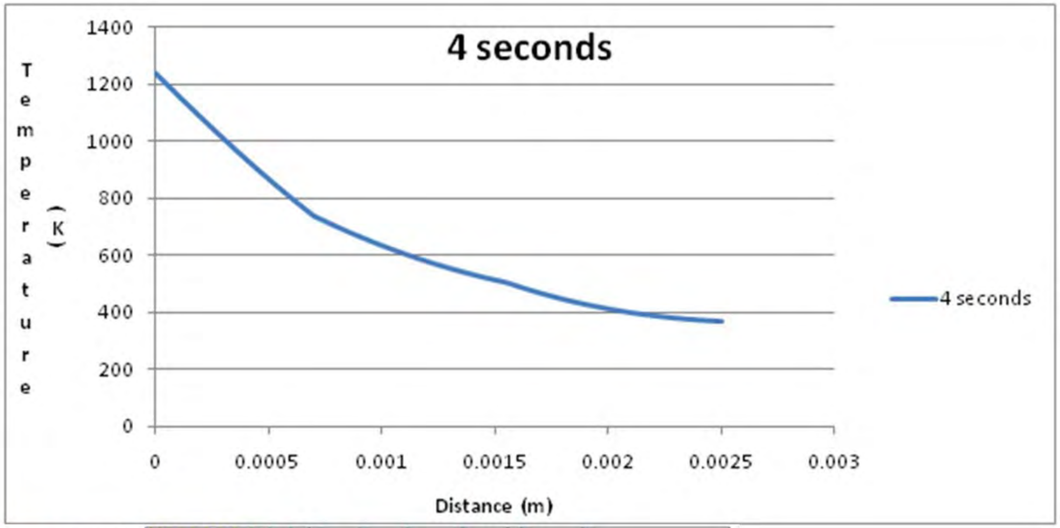

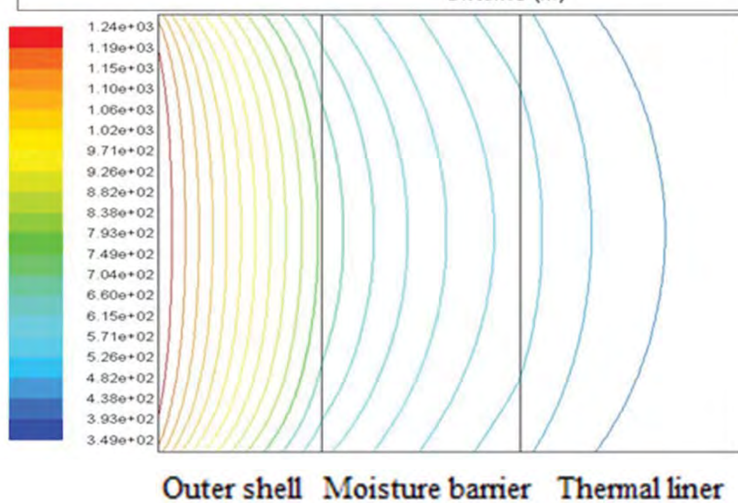

Fig. 10 Temperature drop through fabric thickness, case-6 porosity 0.4 kg/m^3 and K = 0.02W/m-K

4. Effect of thickness

The thickness of the fabric has been increased to be 0.003m (outer shell = 0.001m, moisture barrier = 0.0085 and thermal liner = 0.0015m) and density of 50 kg/m^3 has been employed. This will help to reduce the weight by 75% in the outer shell layer and by 72% in the thermal liner layer. With a thermal conductivity of 0.03 W/m-K, the temperature has been dropped from 1250^oK to 435^oK . With thermal conductivity of 0.02 W/m-K, case-8, the temperature has been dropped from 1250^oK to 417^oK.

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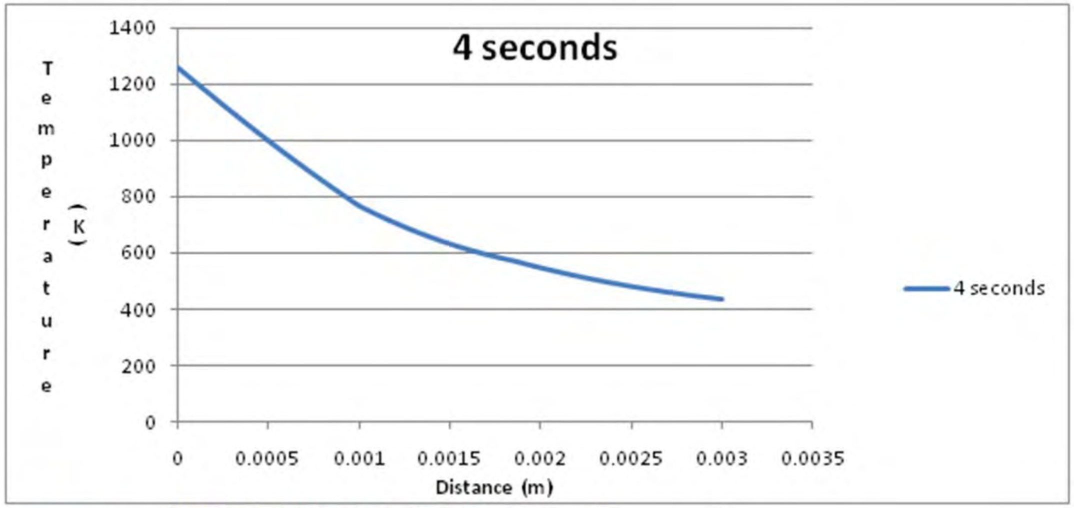

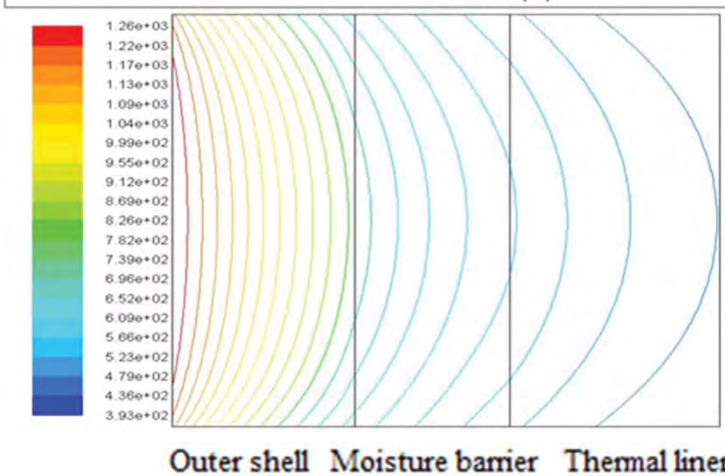

Fig. 11 Temperature drop through fabric thickness, 0.003m, case-7 density 50 kg/m^3 and K = 0.03W/m-K

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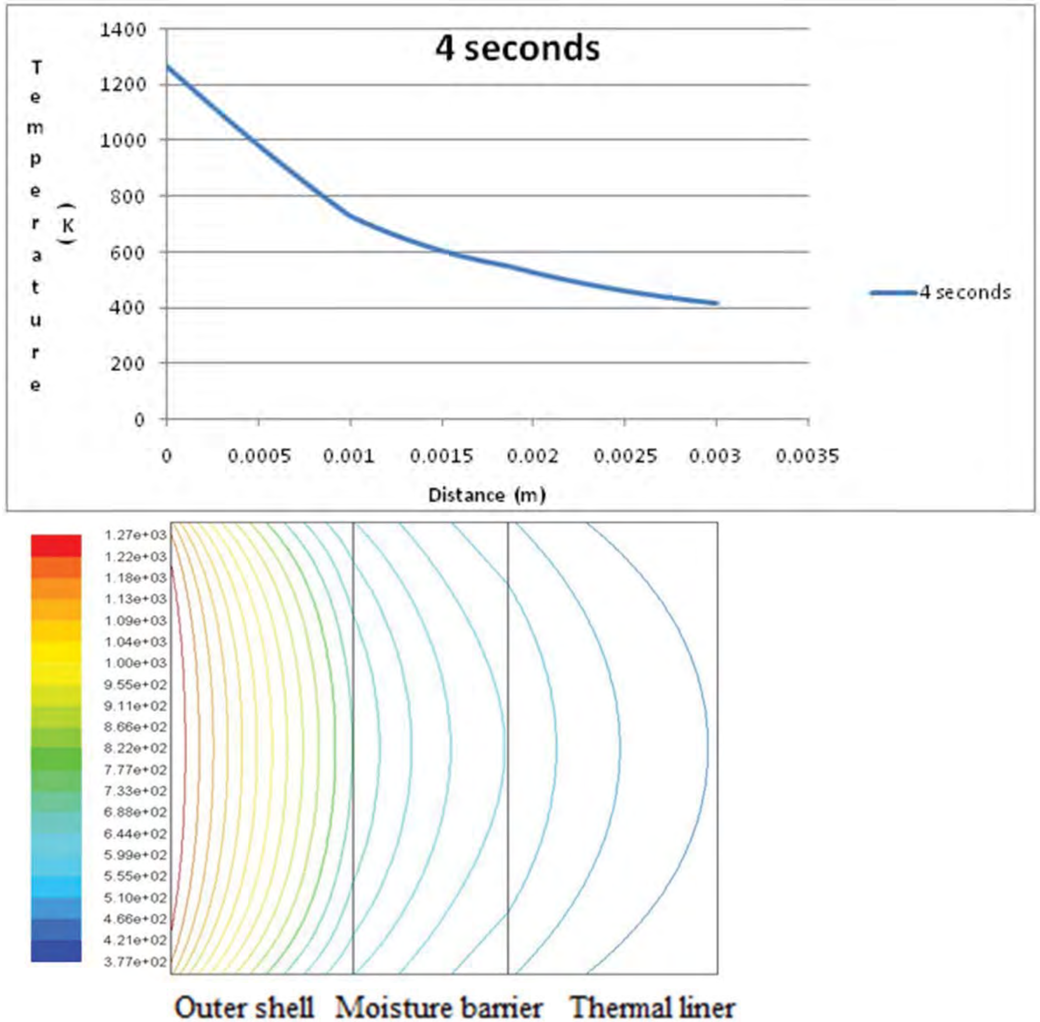

Fig. 12 Temperature drop through fabric thickness, 0.003m, case-8 density 50 kg/m^3 and K = 0.02W/m-K

To improve the effectiveness of the proposed carbon foam fabric, a further increase in the fabric thickness has been made. The total thickness of the three layered fabric = 0.00325m. With a density of 50 kg/m^3, the weight reduced by 70% in the outer shell layer and by 71% in the thermal liner. With constant porosity of 0.6, simulations have been run for two different values of thermal conductivity, 0.03 W/m-K and 0.02 W/m-K. With thermal conductivity of 0.02 W/m-K, case-9, the temperature has been dropped from 1250°K to 401°K. The temperature at the end of fabric drops by 38 °K from the reference temperature [7], which is a significant drop.

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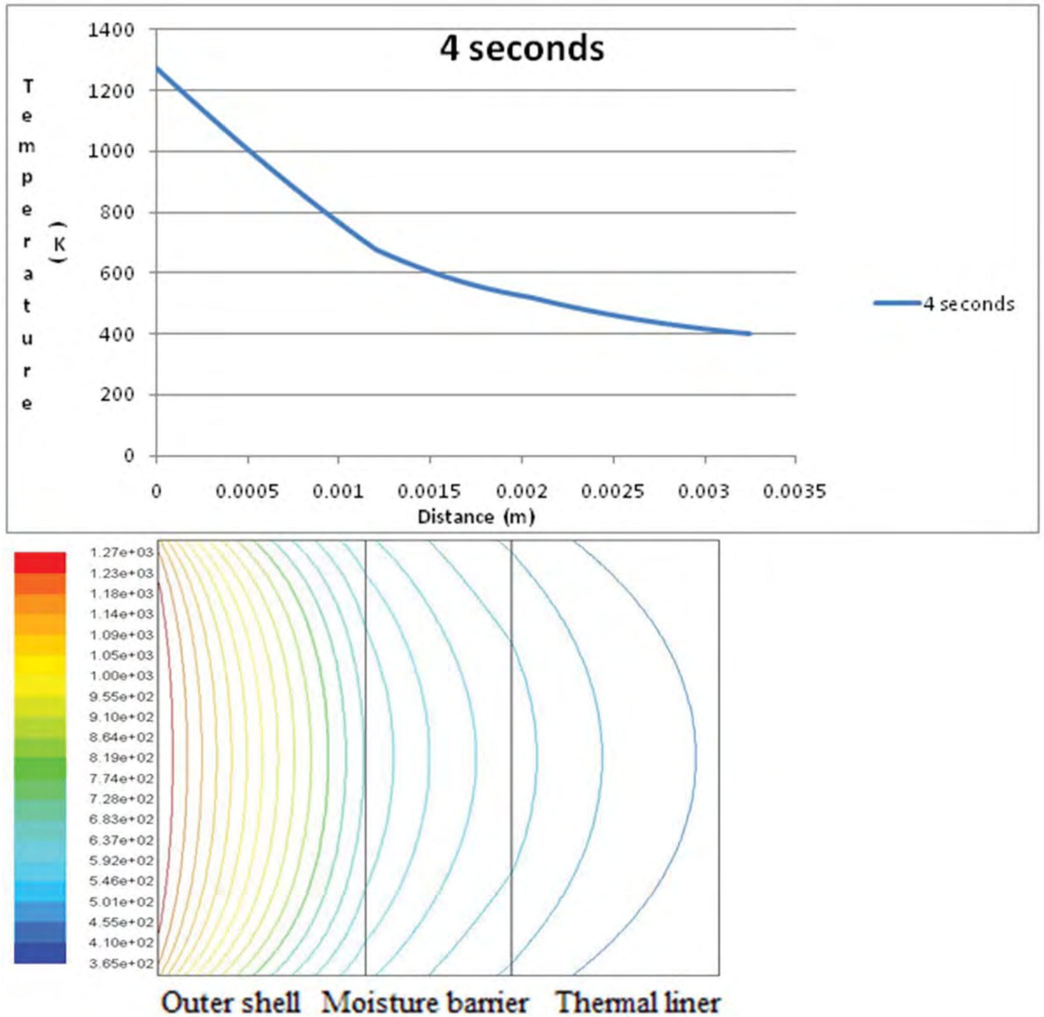

Fig. 13 Temperature drop through fabric thickness, 0.00325m, case-9 density 50 kg/m^3 and K = 0.02W/m-K

Conclusions and discussion

-The results show that with a total thickness of the fabric of 0.003m, density of 50 kg/m^3, and thermal conductivity of 0.03 W/m-K, the weight has been reduced by 75% in the outer shell layer and by 72% in the thermal liner layer.

-On the other hand, the temperature has been dropped to 435^{o}K at the end of the fabric, which is lower than the level of temperature achieved by previous study [7].

Conclusions and discussion

-With carbon foam fabric thickness of 0.00325m and same previous conditions, weight reduction of 70% in the outer shell layer, and 71% in the thermal liner has been achieved.

-the temperature has been dropped at the end of the fabric to 401oK declaring a reduction in the temperature level by (8.6%) compared to previous study [7]

Conclusions and discussion

The results declare that carbon foam with low thermal conductivity and low density can be very effective in preparing clothing for firefighters. Present parametric study provides good combinations of carbon foam properties and fabric thickness in order to achieve good temperature drop along with a low weighing clothing.

Publications

1- Elgafy A., and Mishra S., "Deployment of Advanced Materials in Firefighter's Garment", ***Accepted*** for publication, Proceeding of INTERTECH'2012 Conference, March 2012, Dili - EAST TIMOR.

2- Elgafy A., and Mishra S., "Merits of Employing Carbon Foam Fabrics in Firefighter's Garment", Fire Technology Journal, ***Under Review***, August, 2011.

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Thank You

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