

**DESIGN AND DEVELOPMENT OF
FABRIC ASSEMBLIES FOR EXTREME
COLD WEATHER CLOTHING**

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**DEPARTMENT OF TEXTILE TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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FABRIC ASSEMBLIES FOR EXTREME
COLD WEATHER CLOTHING**

by

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Submitted

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Certificate

This is to certify that the thesis entitled “**Design and development of fabric assemblies for extreme cold weather clothing**” being submitted by **Mr. Gnanauthayan. G.**, to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy** in the Department of Textile Technology is a record of bonafide research work carried out by him. Mr. Gnanauthayan. G. has worked under our guidance and supervision and fulfilled the requirements for the submission of the thesis.

The results contained in the thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Abstract

The extreme cold weather clothing is essential for survival in sub-zero temperatures with uncertain extremities such as wind, rain, snow etc. The main purpose of this research work is to explore a light-weight thermal insulation layer which could provide optimum insulation for the wearer at sub-zero temperatures. The required thermal insulation for a wearer is highly dependent on his/her metabolic heat protection, ambient temperature and other factors such as wind chill. It is also necessary to consider the various heat transfer modes and how they are affected by fabric structure and constituent fibres before designing the insulation layer. An insulation layer having high porosity provides space for air and in turn lower the heat transfer by conduction. However, heat transfer by convection and radiation might increase. The heat loss by convection and radiation would be dominate in windy and low ambient temperature respectively.

In this work the effect of nonwovens' structural parameters such as thickness, areal density, porosity and fibre parameters such as fibre linear density and cross-section on thermal resistance have been studied. Polyester fibres of solid and hollow cross-section were used to prepare thermally bonded nonwovens. Thermal resistance of nonwovens increases with decrease in fibre denier. For a given porosity of nonwoven, the finer fibre nonwovens have smaller mean flow pore size, entrapping more air, thus reducing radiation heat loss. The heat transfer through hollow fibre nonwovens having very high porosities is dominated by radiation and natural convection.

In the case of multilayer nonwovens, finer fibres must be kept at the outer most layer. If the coarser fibres are kept at the outer most layer, then the large open spaces in that layer allows air to move freely thus, reducing the insulating capacity. Finer fibre nonwovens

lose thermal resistance considerably under compression. Multilayer nonwovens with at least two layers of hollow fibres gave higher thermal resistance under compression.

A one dimensional heat transfer model from human body to environment through a porous structure has been developed using a computational fluid dynamics software. The simulation shows that, fine fibres are effective in reducing the total heat loss. In the case of coarse fibre nonwovens, heat losses by convection and radiation are prominent.

An instrument is developed to evaluate heat transfer characteristics of multilayer layer fabrics at sub-zero temperatures. This instrument can be used to evaluate many thermo-physiological characteristics of fabrics and their ensembles such as heat loss, thermal resistance, and also survival time under various combination of metabolic rate, ambient temperatures and thermal resistance. The instrument is found to give good reproducibility in measuring heat loss and thermal resistance across all ambient temperature conditions.

The survival time is highly affected by the metabolic heat productions, ambient temperature and fabric thermal insulation. When the ambient temperature is $-60\text{ }^{\circ}\text{C}$, the hollow fibre nonwovens are prone to more heat loss than the solid fibre nonwovens. A study on measuring temperature gradients across multilayer ensemble has been conducted.

सार

अत्यधिक ठंड के मौसम के कपड़े अनिश्चित चरम सीमाओं जैसे कि हवा, बारिश, बर्फ आदि के साथ उप-शून्य तापमान में जीवित रहने के लिए आवश्यक हैं। इस शोध कार्य का मुख्य उद्देश्य एक हल्के वजन वाले थर्मल इन्सुलेशन परत का पता लगाना है, जो इष्टतम इन्सुलेशन प्रदान कर सकता है उप-शून्य तापमान पर पहनने वाला। एक पहनने वाले के लिए आवश्यक थर्मल इन्सुलेशन उसकी / उसके चयापचय गर्मी सुरक्षा, परिवेश के तापमान और हवा के झोंके जैसे अन्य कारकों पर अत्यधिक निर्भर है। इन्सुलेशन परत को डिजाइन करने से पहले विभिन्न गर्मी हस्तांतरण मोड और कपड़े की संरचना और घटक तंतुओं से कैसे प्रभावित होते हैं, इस पर विचार करना भी आवश्यक है। उच्च छिद्रों वाली एक इन्सुलेशन परत हवा के लिए स्थान प्रदान करती है और बदले में चालन द्वारा गर्मी हस्तांतरण कम करती है। हालांकि, संवहन और विकिरण द्वारा गर्मी हस्तांतरण बढ़ सकता है। संवहन और विकिरण द्वारा गर्मी का नुकसान क्रमशः हवा और कम परिवेश के तापमान पर हावी होगा।

इस कार्य में नॉनवेस के संरचनात्मक मापदंडों जैसे मोटाई, क्षेत्र घनत्व, छिद्र और फाइबर मापदंडों जैसे फाइबर रेखिक घनत्व और थर्मल प्रतिरोध पर क्रॉस-सेक्शन के प्रभाव का अध्ययन किया गया है। ठोस और खोखले क्रॉस-सेक्शन के पॉलिएस्टर फाइबर का इस्तेमाल थर्माइज्ड बॉन्डेड नॉनवॉवन तैयार करने के लिए किया जाता था। फाइबर डेवियर में कमी के साथ नॉनवॉवन का थर्मल प्रतिरोध बढ़ता है। नॉनवॉवन के दिए गए पोरसिटी के लिए, महीन फाइबर नॉनवॉवन्स का मतलब छोटी तादाद में छिद्र का आकार होता है, जिससे अधिक हवा फंसती है, जिससे विकिरण गर्मी का नुकसान कम होता है। खोखले फाइबर nonwovens के माध्यम से गर्मी हस्तांतरण बहुत उच्च porosities होने विकिरण और प्राकृतिक संवहन द्वारा हावी है।

बहुपरत nonwovens के मामले में, महीन तंतुओं को सबसे बाहरी परत पर रखा जाना चाहिए। यदि मोटे रेशे को सबसे बाहरी परत पर रखा जाता है, तो उस परत में बड़े खुले स्थान हवा को इस प्रकार स्वतंत्र

रूप से स्थानांतरित करने की अनुमति देते हैं, जिससे इन्सुलेट क्षमता कम हो जाती है। महीन फाइबर nonwovens संपीडन के तहत काफी थर्मल प्रतिरोध खो देते हैं। खोखले फाइबर के कम से कम दो परतों के साथ बहुपरत nonwovens ने संपीडन के तहत उच्च तापीय प्रतिरोध दिया।

एक झरझरा संरचना के माध्यम से मानव शरीर से पर्यावरण तक एक आयामी गर्मी हस्तांतरण मॉडल एक कम्प्यूटेशनल तरल गतिकी सॉफ्टवेयर का उपयोग करके विकसित किया गया है। सिमुलेशन से पता चलता है कि, ठीक फाइबर कुल गर्मी के नुकसान को कम करने में प्रभावी हैं। मोटे फाइबर nonwovens के मामले में, संवहन और विकिरण द्वारा गर्मी के नुकसान प्रमुख हैं।

उप-शून्य तापमान पर बहुपरत परत वस्त्रों की गर्मी हस्तांतरण विशेषताओं का मूल्यांकन करने के लिए एक उपकरण विकसित किया गया है। इस उपकरण का उपयोग कपड़ों की कई थर्मो-फिजियोलॉजिकल विशेषताओं और उनके पहनावा जैसे गर्मी के नुकसान, थर्मल प्रतिरोध, और चयापचय दर, परिवेश के तापमान और थर्मल प्रतिरोध के विभिन्न संयोजन के तहत उत्तरजीविता के समय का मूल्यांकन करने के लिए किया जा सकता है। सभी परिवेश के तापमान की स्थिति में गर्मी के नुकसान और थर्मल प्रतिरोध को मापने के लिए यह उपकरण अच्छा प्रजनन क्षमता प्रदान करता है।

जीवित रहने का समय चयापचय गर्मी प्रस्तुतियों, परिवेश के तापमान और कपड़े थर्मल इन्सुलेशन से अत्यधिक प्रभावित होता है। जब परिवेश का तापमान -60°C होता है, तो खोखले फाइबर नॉनवॉएन्स को ठोस फाइबर नॉनवॉएन्स की तुलना में अधिक गर्मी के नुकसान का खतरा होता है। बहुपरत कलाकारों की टुकड़ी में तापमान ढालों को मापने पर एक अध्ययन आयोजित किया गया है।

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