International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 9 Issue 9 ǁ 2021 ǁ PP. 01-17

Development of textiles to combatcold weather in mountain terrains

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Abstract
Technical textiles is a major area in the field of textiles. One aspect of technical textiles is the use in military applications. This article reviews the one area in the use of textiles in military applications. Operation of Armed Forces personnel in harsh military terrains for extended tenure period necessitates protection from elements and battle hazards. Harsh military terrains exert profound effects on the physical and physiological performance of the soldiers and can impart serious health hazards on inadequately protected soldiers resulting in mission failure and avoidable loss of lives. Harsh military terrains can be Mountain environment characterized by treacherous terrains with extreme cold and hypoxia, Deserts characterized by extreme heat stress, Depths of underwater that can pose life threatening situation in case of a distressed submarine, Aviation hazards (such as deadly G-forces faced by fighter pilots during G-manoeuvres and fire hazards that may result from crash) etc. Clothing being the first layer of protection for the wearer, forms an important protective measure in military operation against combat and environmental hazards. A great deal of research is being carried out by military/defence research laboratories worldwide in collaboration with industries to develop technical textiles incorporating suitable smart material finishes for the alleviation of the dangers associated in the combat terrain.

Key words: *Military textiles, weather condition, Mountain environment, Clothing principles, Design, Fit.*

Date of Submission: 21-08-2021 Date of acceptance: 05-09-2021

I. Introduction

Military personnel live in a harsh environment. The harshness of the environment could include extreme cold, hypoxia, fire, extreme heat, depths of sea, aviation hazards, and so on. These conditions could affect the military troops more than the enemy forces. Militaryactions occur in volatile, complex, uncertain, ambiguous environments often coupled with physical exertion, cognitive overload, sleep restriction and caloric deprivation. The natural environment has been highly disastrous for unprepared armies and has influenced planning, conduct and the outcome of many wars. Many great armies in the past have been impacted by terrain specific climatic environmental conditions such as heat, cold, altitude. The landarmy in mountain environment, deserts, hot humid jungle has learned it the hard way through centuries of experience that weather has been a significant, and sometimes decisive, factor for mission success [1].

The discomfort associated with the movement of the Armed Forces and the debilitating impact of cold injuries date back to ancient wars when people made gruelling trips across mountainous routes in the quest of conquering the World (or to carry out scientific experimentations in real world scenario). People travelling treacherous mountainous areas have complained of loss of appetite, breathlessness, tachycardia in addition to blood stained sputum and oedema in pulmonary system induced by the high altitude (HA)which can be fatal if not addressed immediately. More often than not, the efforts of evacuation of the patient to the lower altitude or to the hospitals with adequate medical facilities have been met with little timely success due to the treacherous terrain and inclement weather. Military personnel apart from the difficulties associated with combat platforms, often succumbed to harsh battle conditions. In Northern borders of Kashmir, 40% combatants lose their lives to mountain hazards than to the war while guarding the borders. Mountainous operations are fraught with life-threatening conditions such as hypothermia and hypoxia and other effects such as UV blindness and carbon monoxide poisoning [2]. Efforts have been made to alleviate theproblems associated with military performance in such inhospitable terrains for extended periods mainly due to modified and functionalized technical textiles.

II. Textiles for use in cold conditions in hill regions

During war in cold weather, the adverse conditions cause greater losses of armypersonnel than those of the enemy forces [3,4]. Past records show that in many instances armed forces with good training and numbers failed in war during winter. Deleterious effects of cold weather on the human bodyhave been evident since man first ventured to climates outsideof the tropical. The oldest documented case of frostbite was discoveredin a 5000-year-old mummy in the Chilean mountains.

Classification of cold regions

For military purposes, cold regions are defined as anyregion where cold temperature, unique terrain and snowfallsignificantly affect military operations for at least 1 monthor more in a year. About one quarter of the earth's landmass may be termed severely cold [5].

Cold environment: classification

In many countries, the military personnel deployed in coldregions encounter the harsh cold climates that can be eitherwet cold (þ10^{o}C down to –10^{o}C), very cold (–10^o C downto –30^{o}C), extreme cold (–30^{o}C and below with theextreme lower limit of –60^o C) [6]. The humanbody is not designed for extended stay/operations inextreme cold. Although, there are populations adapted toextreme cold weather (e.g. people living in Ladakh region ofIndia, north arctic Canada, arctic Greenland, north ofRussia, etc.), the vast majority of World's population has noexperience of living in such sub-zero temperatures. ArmedForces personnel from diverse geographical terrains, beingalien to such adverse environment, have to initially acclimatizethemselves to the new climatic conditions and thenneed supplements in the form of protective clothing anddevices to carryout assigned military tasks effectively [7].

Effects of cold

Fast growing research has ensured some relief measures tothe Soldiers working in most violent and fearsome coldenvironment such as Siachen Glacier. This has been realizedthrough the modification of technical textiles either actingas thermal barrier for heat loss from the body or throughheat generating by incorporation of phase change materialstermed as 'thermalcapacitors' by NASA. Electrically heated garments such asgloves, insoles, jackets and trousers are extreme effectivemeans in providing physiologically comfortable warmth andensure that the extremities are safeguarded [8-10].

Cold exposure elicits several defence mechanisms in thebody that try and boost core temperature in chilly weather.The body begins to generate additional heat through tensioningmuscles, leading to involuntary shivering. Shiveringthat begins in the torso region subsequently spreads tolimbs. It has been reported that shivering can raise metabolicheat production up to three times [11]. Involuntary shivering, however, is highlyundesirable for military personnel involved in fine motoractivities (such as deep-sea divers and helicopter pilots). Thehypothalamus, located near pituitary glands, acts as body'sthermostat, reduces blood supply to the extremities throughvasodilation in a bid to keep core warm at any cost – sacrificing the extremities should the need arise [12]. This leaves extremities vulnerable to frostbite, whichin worst case may lead to amputation [13-15]. A case study presents the severity of frostbite as causefor tissue loss, amputation and morbidity in arcticGreenland [16]. Another field study on chilblain at HAHimalayan regions of India delineates the effectiveness ofavailable pharmacological measures [17].Several interesting strategies adopted by living organisms forsurvival in the cold have been reported [18].However, human survival entirely depends on the insulationaround the body.

Response to cold weather by humans andclothing principles

The human body obeys laws of thermodynamics. Energy iseither gained or lost by the body to ambient climate due tonatural direction of flow of heat. The energy generated fromfood (basal metabolism) maintains a constant core temperatureof 37^{o}C, despite external environmental extremes andhence, humans are termed as homeothermic in nature(Greek: Homos-same, therme-heat). The term 'core' refersto the important organs such as heart, lungs, liver and thebrain. The heat that maintains the core body temperature isgenerated from metabolism and is further augmented bymuscular activities.Therefore, humans are classified as warm-blooded animalsor endothermic. The distribution of temperatures inbody's core and shell is represented in Figure 1. A comprehensiveaccount of thermo physical models is elaboratelyreviewed recently [19,20].

Technical textiles for the alleviation of cold injuries

From foregoing discussion, it is evident that extremitiesbadly suffer during cold exposure. Hands and feet beingmost vulnerable for frostbite require special protection.Hand gloves and mittens are primarily used by the soldiersoperating in extreme cold climate for the protection of fingersand toes. Continuous exposure to the low temperature,however, affects the performance of soldier by diminishingthe gross and fine motor skills [21]. This happensdue to the reduction of nerve conduction velocity,which is temperature dependent lower the temperature,lower will be the nerve condition velocity. The diminishedcognitive ability due to the exposure to the cold temperatureis also reported in soldiers and sojourners in the literature[22].

Principles of military clothing design

Clothing provides resistance to heat and water vapour transfer.Complex interaction that happens between the wearerand environment and their dynamic relationships are notyet fully understood. The effect of clothing often refers tojust insulation (sometimes including water vapour permeability)properties. Much research is conducted to know theimportance of various characteristics of clothing. Factorsthat affect thermal properties and the behaviour of clothinginclude, dry thermal insulation, moisture and water vapourtransfer through the clothing, heat exchange with andwithin clothing by means of conduction, convection, radiation,evaporation and condensation, air penetrationthrough fabrics, vents, openings, pumping effects (caused bybody movements), compression caused by high wind (or bypressure exerted by 'outer layer' clothing/mounted items)and finally on the posture of the wearer.The following two broad principles determine the 'overallinsulation' provided by the clothing ensemble.

Layering – Air has thermal conductivity of 0.02 Watts/m K at 27^{o}C, it reduces as the temperature decreases andtherefore considered as bad conductor of heat. The airtrapped between the layers is responsible for reduction inexchange of temperature between the body and environmentand hence loss of warmth from the body is discouraged to agreater extent if more air is trapped between the layers. Theinsulation provided by clothing can be enhanced by havingmore than one layer of clothing to compensate for the existingclimate and the metabolic activity. Although multilayerclothing system (such as arctic clothing system) may soundan effective way to enhance protection from cold, there aretwo important inferences to be kept in mind.

a. It has been reported that multilayer clothing results in enhanced basalmetabolism and results in enhanced food intake due tohobbling or binding effect caused by clothing layers [23].Therefore, extra 'energy cost' for a given set of activitiesis required with each additional enhanced layering. Theincrease in energy requirement is 4% per layer, whichcan be reduced by avoiding interlayer friction[24].

b. The second inference is that thick layers offer moreprotection than thin layers.

Looseness of Fit – In military clothing, the ability to ventilatethe torso is greatly inhibited while carrying a rucksacor wearing webbing. Therefore, efforts should be made toget as much ventilation as possible without compromisingwaterproofness, both in the jacket and the trousers. To beeffective, any vents allowing air 'in' should have a correspondingvent to allow the ventilating air 'out'. Additionally,sleeves can be pulled up to the elbow to allow increasedheat loss from the lower arms. Full or partial length trouserzips can also be used to aid desired ventilation.

The clo value determines the clothing insulation. Thethermal insulation of a clothing ensemble or a single garmentis expressed by the 'clo' unit introduced by three physiologistsin 1941 [25]. The clo isdefined in SI unit as 1 clo ¼ 0.155m K/W). One cloth is oftendescribed as 'the thermal insulation required to keep a sedentary person comfortable at 21 _C', has an average value of 0.155m2C/W and is typically a representative of the insulationprovided by a typical business suit [26].

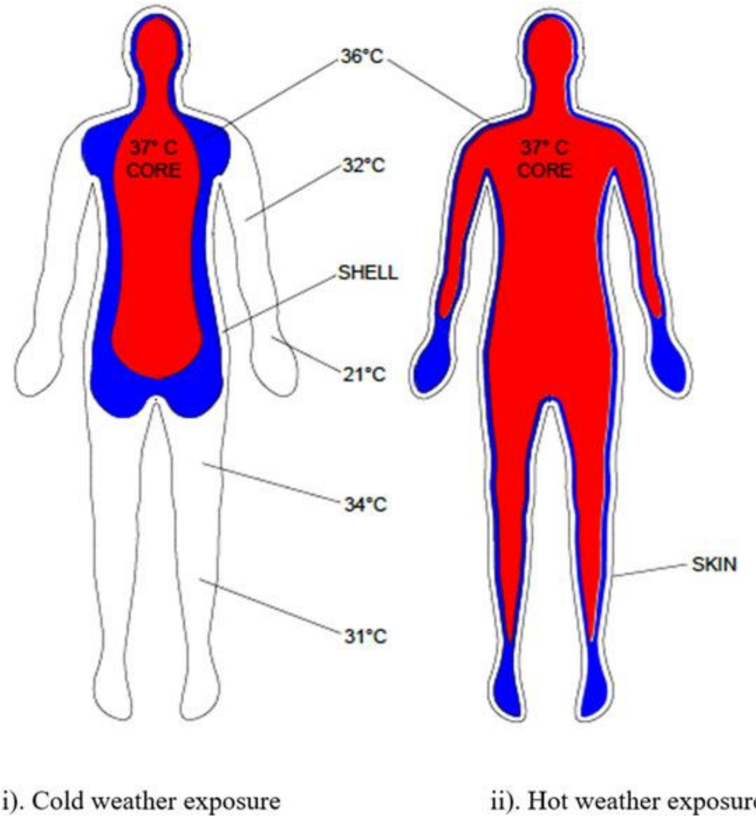

Figure 1 - Temperature distribution in the body's core and shell during cold and hot weather

Estimation of the clothing insulation required

A very useful standard has been developed which estimatesthe thermal insulation required for thermalneutrality in cold environments IREQ neutral (ISO 11070,2007) [27]. The calculation requires inputs such as air temperature,velocity, relative humidity, the air permeability of theouter fabric and the mean radiant temperature. An estimateof the metabolic heat generation (M) has to be made – thiscan be obtained from ISO 8996 (2004) or calculated fromequations developed [28,29].These can predict the metabolic heat generation for soldierswalking and running, carrying rucksacs, and different typesof terrain can be selected. Most data on clothing have beenobtained on standing manikins in relatively still air – whichis the basic thermal insulation.

Multilayer coveralls and military combat suit

Troupes working in extreme cold weather environment cannotwear multiple layers of clothing to protect themselves,as their movement in a combat situation is restricted.Therefore, an ensemble known as Extreme Cold WeatherClothing (ECWC) has been developed to reduce the cumbersomeweight of the older cold weather clothing systems while maintaining required cold protection below –20^{o}C. This clothing ensemble has distinct layers, each with definedpurpose. The outer garment will be generally fleece fabric(such as windstopperVR), which provides protection againstwind chill. The middle layer provides insulation by trappingair (such as ThinsulateVR from 3M, ComfortmaxVR fromDuPont, Hollofil, PolarTec, PolarFleece, and PrimaLoft, etc.,and not limited to these companies alone), which providesmore protection against cold than the conventional insulatingmaterials. The extremely thin microfibers present in thislayer help trap air and reduce radiant heat loss from thewearer. These synthetic insulations are available in variousfinishes such as plain, inherently flame resistant, waterresistant, antimicrobial, etc. The innermost garment shouldensure 'sweat wicking', to wick the moisture away from thebody (which sometimes may form due to enhanced physicalwork even in such cold environment).The condensation of moisture due to perspiration makescloth wet and replaces air by moisture which has muchhigher thermal conductivity (at least 25 times at the sametemperature) leading to greater heat loss from the body.

An example for this is ripstop fabrics based on nylon orpolyester. Ripstop fabrics are a combination of materialsthat are woven into a square pattern. The extra threads ofsynthetic fibre are placed within the weave at certain increments,usually 1/8 inch or smaller. Nylon and polyester arethe two most common ripstop additives. This extra threadstrength is what 'stops a tear or rip from continuing beyondthe first square' and hence the name 'ripstop'. The specialstructure minimizes the damage to a garment in the unfortunatecircumstance during which it may get torn or ripped.

The authors of this review have done pioneering work inthe development of protective clothing based on multi coverallsfor Indian military use (Cold weather clothing)(https://www.drdo.gov.in/drdo/labs1/DEBEL/English/indexnew.jsp?pg=products.jsp). Presently Indian Army is usingthe above protective clothing in extreme cold operations.Although multilayer coveralls provide protection up to–20^{o}C, they become ineffective below certain lower temperatureas the bulkiness impedes the movement of thewearer (soldier). Several clothing systems, developed basedon loading of clothing with PCMs, aerogels etc., aredescribed in the following sections.

PCMs: PCM-based fabrics

Latent heat storage has been the most efficient ways of storingthermal energy, wherein physical change such as freezing/melting/boiling point property is used to store thethermal energy [30,31]. The change being physicalproperty remains constant throughout lifecycle of thematerial and several million cycles can be envisaged, makingthe material robust for the energy storage application. Suchmaterials are known as PCMs. PCMs are finding enormousapplication in enhancing energy efficiency of the buildings,solar water heaters, residential shelters and thermallyenhanced fabrics [32-39]. Based on thephase transitions, PCMs are classified as solid–liquid, liquid–gas, solid–gas orsolid–solid systems and can be organic, inorganic or eutectic[40,41]. (Liquid–gas and solid–gasare generally not considered for energy storage as gas occupieslarge volume). All human activities are energy basedand the PCMs have offered to reduce the energy consumptionof modern buildings and have helped in reducing carbonfootprint. Experimental analysis of utilizing PCM inpassenger cars and vehiclethermal buffering have been carried out [42,43].

PCMs are thermal energy storage materials that can beused to regulate temperature fluctuations. When employedas thermal barriers, they use physical property; the melting/freezing point, to store and release heat and thus control theheat transfer from ambient to the microclimate provided byclothing. Coating, finishing, lamination, melt spinning, bicomponentsynthetic fibre extrusion, injection moulding arethe processes through which PCMs are incorporated into the clothing and structures [44-46]. It has been hypothesized thatPCM embedded clothing (generally in the form of microencapsulatedPCM or mPCM) provides good cold protectionhaving higher insulation to the weight ratio. The PCM technologywas originally developed for NASA to protect astronautsfrom the extreme temperature fluctuation in space touse them as ‘thermal capacitors or thermal flywheels orlatent heat devices’. PCM fabrics are now available in customconfigurations to suit the requirement of industryworkers such as a Chef going inside a cold chamber to pickup an item to the Securities Forces personnel, where briefexposure to temperature fluctuations can be a routine operationalthing. Once PCM absorbs/releases the energy, itneeds to be regenerated either by heating or cooling.The most common PCMs applied to textiles are n-paraffinwaxes having different melting temperature (Tm) such asheptadecane (Tm = 21.1–22.9^{o}C), hexadecane (Tm =18^{o}C), octadecane (Tm = 28–30^{o}C), nonadecane (Tm =32^{o}C) and eicosane (Tm = 36–38^{o}C). The n-octadecane iswidely used due its melting temperature range being relativelycloser to our body temperature [47].

The temperature dependent properties of n-hexadecane,n-octadecane and n-icosane are reported recently [48]. The phase change temperaturesviz, melting temperature (Tm) and crystallizationtemperature (Tc), depend on the number of carbons in theirstructures.PCMs are preferred energy storage materials as theyexhibit high energy storage capacity; 5–14 times more heatper unit volume than sensible storage materials such aswater, masonry or rock [49,50].PCM loaded fabrics have been commercially producedand patented by outlast technologies LLC [51]. A method of preparingmPCM coated polyester fabric by knife over roll and screenprinting and its evaluation has been reported. When PCM encapsulated clothing isexposed to its melting point, the thermal energy is absorbedand PCM melts to liquid, which produces a temporary coolingeffect to the clothing layers (suitable encapsulation ofthe PCM ensures that the molten PCM does not flow awayfrom the clothing system). The thermal energy may comefrom the body or from the environment. Once the PCMcompletely melts, the storage of heat stops and the clothingwill heat up as it would without PCM. On the other hand,when the PCM clothing is exposed to the temperature belowthe freezing point of PCM, the microencapsulated liquidPCM will change back to a solid state, releasing heat energyand generating a temporary warming effect. Afterall encapsulated PCM solidifies, the clothing will ‘see theexternal temperature as normal clothing and PCM on theclothing will act as extra bulk’. There are no reports in theliterature on the employment of PCM clothing alone for theextended cold weather operations. However, there are somereports wherein hybrid approaches have been employed(such as PCM/aerogel and electrical heating) and is discussedin forthcoming section of this review.

It was reported by that heat release by PCMs in cold conditions reduced bodyheat loss by an average 6.5W with a one-layer suit (1.5 clo)and 13.2W with a two-layer suit (2.07 clo), compared witha non-PCM control suits (1.48 and 1.95 clo, respectively) [52].Thus PCM incorporated clothing provide small and temporaryheating/cooling relief during temperature changes.However, higher loading of PCM on the fabric ensureshigher heat storage capacity of treated fabrics. It has beenreported that treated fabric with 22.9% add-on is capable ofabsorbing 4.44 J/g of heat if the microcapsules on the fabricundergo a melting process [53].Another important drawback of the PCM loaded clothing isthe difficulties associated with storage in hot/cold environmentfor future use and difficulties associated with‘triggering mechanism’ to initiate the required action ofPCM during the hour of need. However, a plethora of referencesare available on the successfulemployment of PCM as roof boards positioned at appropriateplaces of buildings to store energy during daytime andrelease energy during cold nights or vice versa makingbuildings energy efficient [54-58].It is evident from the foregoing literature evidence thatPCM-based textiles are best employed for temporary thermalswing protection rather than for continuous hot or coldoperations such as military operations lasting for fewmonths. The regeneration of PCM is essential and thereforenecessitates additional logistic regeneration equipment ifemployed in continuous cold or hot operations. If regenerationmeans are not available, PCM will form extra weighton the wearer’s clothing once energy of PCM is utilized.Although PCM textiles enhance thermal properties, fewer PCM clothing is utilized in extreme cold andhot environment due to limitation in regeneration of thePCM. It has been recently reported comforts of PCMloadedbusiness clothing in cold environment ranging from10^{o}C to –5^{o}C [59,60]. Some authors have evaluated the PCMclothing under simulated conditions for their effectiveness[61,62].Many commercial manufactures (e.g. Outlast,ComforTempVR) manufacture PCM clothing for consumerand technical application. The magnitude and duration ofthe heating and cooling effects of PCMs in garments haveto be climate and usage oriented rather than universalsolutions.

Aerogel-based fabrics

Aerogels are third generation insulation materials and consideredto be the best insulation materials ever invented. Interms of warmth retention, air is second to none. The earlierdesign of cold weather clothing relied on clothing layersand capturing ‘insulating air’ between layers. First generation insulation materials from natural origin such asgoose down feathers create air gaps within fluffy structures.

In case of wool and other similar materials, air is trappedinside and between the fibres, which prevents air exchangebetween the layers thereby limiting loss of heat by convection.The wearer is cocooned in a comfortable microenvironment.The second generation of insulation (e.g. syntheticmaterials such as ThinsulateVR or ComfortmaxVR etc.) introducedway back in 1970s also relied upon ‘holding air’within the structure. The buffer zone created by the airbetween the temperature layers worked well in trappingthermal energy efficiently. Most cold weather clothingdesigners tried to have highest loft or air trapping to achievebest insulation. However, in military clothing, enhancedclothing layers impede the movement of the soldiers.

Further, when layers get compressed (during sitting, squattingor crawling activities), the insulating layer air betweenthe layers is lost, replaced by moisture resulting in rapidloss of insulating property of the fabric. Textile structure isessentially a mixture of fibres, air and moisture, each havingdistinctly different thermal properties. Thus, thermal behaviourof the system is the collective and interactive results ofthese three constituents [63].

There was a continued research in development ofinsulating material that does not have the disadvantages oftraditional textile material. To improve the mobility of thewearer, a relatively thin layer having extremely high insulatingperformance to provide adequate protection againstcold was on the lookout. Aerogels were thought to be thesuitable candidates for such applications as they demonstratedvery high thermal conductivities and extreme lowinsulation to weight ratio [64]. Silica, carbon, titaniumand alumina are the prime sources for manufacturingaerogels. Other sources such as polymers, chalcogels andseagels are rarely used. Silica aerogel has been most promising,mainly due to its efficient insulation properties toweight ratios.

An aerogel is an advanced insulating material with anappearance of translucent solid or smoky appearance.Aerogel consists of more than 96% air. The remaining 4% isa wispy matrix of silicon dioxide. Thus, it is one of the lowestdensity solids ever conceived. Sol–gel process is the generalemployed method for the preparation of aerogels,wherein silica and polymer gels are made through chemicalprocesses that create nanoparticle colloids (called ‘sols’),which are then induced to form into a gel in what is calledthe sol–gel process. Specifically, an aerogel is created whenthe chemical process involves removing the liquid used inthe sol–gel process and replacing it with air. This is donethrough a supercritical drying process that utilizes carbondioxide. This drying process avoids the pressures createdwhen liquids attempt to evaporate through the tiny pores ofthe gel. One such method of preparation of aerogel isreported by [64].Properties, features and applications of aerogels have beenreviewed by Hrubresh in as early as 1998 [65].

Fabrication process of multilayer aerogel-encapsulated laminatedfabrics and thermal imaging measurement has beenreported [66].A recent review on polymer-/carbon-based hybrid aerogels’preparation, properties and application describes the methods employed, application envisaged and the insulationproperties [67].

Thermal conductivity of aerogels.

Aerogels havegreat potential in enhancing the thermal insulation with thereduced bulk and weight. Low thermal conductivity of aerogelsis a direct result of two factors viz., (a) their very highporosity of more than 95% and (b) their small pore size ofless than about 100nm that is less than the size of the meanfree path of air molecules at atmospheric pressure. Thesmall pore size of aerogels effectively restricts the collisionof air molecules thus lowering the thermal conductivity ofthe air leading to effective thermal insulation of the aerogels.

The small pore size makes air molecules within any givenparticle more likely to collide with the lattice (and transferenergy to that lattice) than with another air particle, therebylimiting potential gas phase conduction through the material.Aerogel powders and beads known as 'super thermalinsulating aerogels' are reported to have a thermal conductivityof 9 to 20mW/m K (milliWatt per meter Kelvin), visa-vis the value of 25mW/m K for air under atmosphericconditions (about 298.5 K and 101.3 kPa) [68,69]. Biomass-based(citrus and apple pectin) mechanically strong super thermalinsulating aerogels reported havethermal conductivity value of 16–22mW/m K [70]. A new typeof high performance, transparent, mechanically strong liquidcrystalline nanocellulose aerogels from wood cellulose havebeen reported exhibitedthermal conductivity of 18mW/m K at a density of17 mg/cm3[71]. A recent book on biobased aerogels brings stateof the art on polysaccharide/protein,chitin/chitosan, cellulose,starch, alginate/carrageenan, protein, hybrid-greenaerogels with biodegradability, applications and variousproperties such as mechanical, rheological, mechanical, thermal,electrical insulation etc. [72]. Silica–cellulose hybrid aerogels for thermalacoustic insulation application having super hydrophobicproperty with an average water contact angle 151^{o} has beenreported recently [73]. Ternary aerogels usefulfor the absorption of electromagnetic radiation have beenreported, thus aerogels are not onlypromising as insulating materials, they can be employed invarious other applications [74]. Foam, fibrous batting, wool andother commonly used insulating materials have higher thermalconductivity of 40mW/m K and above, a value that ishigher than the conductivity of the air due to the contributionfrom radiation and solid conduction. The advantage ofaerogel powders and beads in particularly having low density(<100 kg/m3) and thermal conductivity is offset by theproblems of handling, shaping and extensive dusting associatedthereby raising safety issues.

Aerogels were primarily developed for NASA spaceexploration, as size, bulk and weight were critical in spacemissions. The trouble NASA had to overcome was the brittlenature of aerogels, which often collapsed under lightpressure. They eventually solved this issue with bettersilicate design and drying processes, which made the silicaflexible and able to withstand pressure.

In recent years, impressive heat insulation property ofaerogel has been successfully employed in diverse fields,such as retrofitting of sensitive building structure thermal insulation of oil and gaspipe lines and industrial/space cryogenic applications [75,76]. However, aerogel in the developmentof insulation clothing application started only veryrecently [77]. This isbecause of the weak strength that results from high porosityand cracking along the drying process, aerogels cannot beeasily applied to conventional applications. A wearer wearingan aerogel trouser would exert enormous compressive forceon the trouser surface, the fragile aerogel would break andthermal insulation offered by it is lost [78]. Therefore, aerogelis generally 'filled into hollow spaces' to enhance insulationproperty. Thus, incorporating aerogels in textile structure,such as woven fabric, spacer fabric and nonwoven is effectiveas aerogels can act as a medium to fill the interstitial spaceavailable amidst fibres [79,80].

Many literature references are available citing methods ofmaking textile-aerogel products used for thermal insulationpurpose. One of the authors of this review has reported anaerogel blanket and a method for the evaluation of the thermalinsulation in a recently published article [81]. LG Chem, Korea Republic has patented amethod of preparing aerogel blanket in 2018 [82]. The properties of laminated silica aerogelblanket along with the schematics of preparation is reportedby a group of researchers from Slovenia [83]. Few research articles have been published oncoating aerogel on wool–aramid blended fabric for thermophysiologicalcomfort for fire fighter's protective clothing[84]. Aramid fibres reinforcedsilica gel composites having high thermal insulation have been prepared with thermal conductivity of22mW/m K having fibre content of 1.5–6.6% [85]. It has been reported that doubling of the thermal insulation observed inSiO2 and fabric composite based on polyurethane [86]. Needlelesselectrospinning and electrospraying of mixture of polymerand on textiles has been attempted to overcome the difficulties associated withother coating methods onto textile fabric base [87].

Some commercial manufacturers have succeeded in themanufacture of high thermalinsulation aerogel clothingmaterials. The usage of these clothing articles as full coldweather ensemble meeting tough military/aviation standardis yet to be realized through research and repeated objectiveevaluation with respect to the insulation performance anddurability in tough military usage. Aspen Aerogel, Cabotcorporation, Oros' aerogel-insulated cold weather gear("Review: Oros' aerogel-insulated cold weather gear", n.d.)are some of the examples. The version of aerogel developedby Oros is called Solarcore, and it's 'the first aerogel suitedfor apparel with its incredible flexibility, hydrophobicity,durability, sound absorbency, and breathability whilemaintaining the incredible insulation that aerogels areknown for'.

The Cabot aerogel Thermal Wrap, an ultrathin nonwovenfabric that retains insulating properties when wet, istwice as warm as leading insulators and up to 12 timeswarmer when compressed. Because the nanosizedpores in aerogel block heat transfer far more efficiently thantraditional fibrous insulators, Thermal

Wrap insulation doesnot have to be bulky to be efficient. This allows outdoorproduct designers to engineer sleeker, ultrathin products,which can increase speed, dexterity and agility for outdoorathletes.

Electrically heated winter clothing

During cold exposure, vasoconstriction takes place andblood supply is reduced to the extremities in a bid to savevital organs present in the torso region (Figure 1:Temperature distribution in the body's core and shell). Thisleaves extremities vulnerable for frostbite, which in worstcase may lead to the amputation. Many soldiers in coldoperations have lost their extremities through amputations[88]. Several electrically heated garmentshave been reported in the literature employing varioustypes of resistive heating element/panels made fromdiverse materials and based on solar-based rechargingmeans for cold application [89-94]. However, very little literature citation isavailable for the heated garments made for the militaryapplications.Many commercially available gloves, mittens, insoles,jackets and trousers are available for cold applications suchas, biking, skiing, mountain sports etc., by some companiessuch as Gerbings, Action HeatTM, Zanier, Hotronic, mobilewarming etc., for consumer application.A foot soldier holding cold weapon and Pilot in anunconditioned cockpit such as helicopter in contact withcold objects are susceptible to greater cold injuries.

Unprotected fingers of the hand and the toes are extremelyvulnerable for frostbite. The passive insulation based gloves,mittens and foot ware do not offer complete protection.Further, in case a downed Fighter Pilot (who has ejected insnow bound mountainous region), the passive winter clothingmay not offer adequate protection if there is fearsomeblizzard or severe cold. The rescue team may take severalhours to reach the spot due to inclement weather. Theseconditions necessitate the development of electrically heatedclothing such as gloves, shoe insoles, jackets and trousers toenhance the survivability. These protective clothing are generallypowered from rechargeable batteries which can bedesigned to offer protection for desired period. The importantfeature of the battery heated clothing is their lightweightcompared to multilayered winter clothing and offer protectionup to –40^{o}C. The main disadvantage will be the heatingduration is limited by the capacity of the battery andhence requires additional batteries. A review describes the effectiveness ofelectrically heated clothing and PCM heated garment ashybrid approach [95].

Hand protection – heated gloves.

Human hand isa complex bioengineering system. If described in engineering terms, it consists of hinges, levers, pulleys,pipes, tunnels, thermostats and its own electrical systems aswell as pressure, pain and temperature sensors. Hand isused to grasp, hold, manipulate and control objects to operateand to position forces. The percentage of skeletal musclein a hand is relatively low which infers that very little heatcan be generated by the hand itself [96].

The total skin surface area of hands is about 400 cm2,which is about 5% body's surface mass (Molnar, 1957) [97]. Theskin of the hand has a strong capability to vasoconstrictionand vasodilatation and hence important in bodily thermalregulation [98].

Hands have a unique combination of dexterity and tactilesensitivity, which are essential in military operation andotherwise. A gloved hand may lose its dexterity and tactilesensitivity and impede the mobility and induce discriminationof an operation in the dark. Therefore, it is pertinentto keep dexterity and tactile sensitivity to the highest possibledegree while designing the gloves. The dexterity refersto fine motor skills, which involves movement of arm, handand fingers to perform a function, which can be tested on a dexterity kit, suchas Roeder or Minnesota manual dexterity kit [99,100]. Better dexterityresults in unstrained movements in a routine workinvolving hand, arm and fingers and helps pilots and soldiers.Tactile sensitivity refers to specific sensitivities such astexture, size, shape etc., which can be sensed with the touch.

Both dexterity and tactile sensitivity are temperaturedependant, and the cold winter leads todiminished speed of movements which iscritically important to perform military duties [101,102]. The effect oflocalized microclimate heating on the manual dexterityreported recently has revealed aninteresting information on manual dexterity [103]. It has beenreported in the literature that thickness of the hand gearaffects the dexterity [104,105]. Critical temperature for manual dexterity is20–22^{o} C (where there is 30% less blood flow) and tactilesensitivity reduces with temperature, as nerve conductionvelocity is temperature dependent. At 4.5^{o}C, there is nonerve conduction, which leads to loss of finger function.Due to the large surface area, hands, especially fingers, theloss of temperature in cold environment is higher. When aperson is exposed to the cold, blood supply to extremitieswill be reduced due to vasoconstriction to discourage heatloss to the surrounding. Decrease in skin blood flow causesa loss in sensitivity and a reduction of manual dexterity andgrip strength, which gets aggravated due to wind chill andcold object contact. Therefore, hand protection is of paramountimportance for armed forces personnel.

Critical design issues.

While designing the heatedhand gear, care should be exercised about not losing handdexterity and finger tactile sensitivity. This can be achievedusing 'thin fabrics' having superior insulation. Care shouldalso be exercised on wind chill effects coupled with cold ascombined effects aggravate ‘feel of cold’. The wind chilleffects can be discouraged by the use of fleece fabric (suchas WindstopperVR fabric). The resistive heating elements(wires or the tapes) should withstand the flexing that handis subjected during routine operations. The heating elementshould withstand at least 30,000 flexing cycles to last anentire season. The heat generated by heating elementsshould be trapped in an efficient insulation system. The temperaturehas to be cleverly tuned inside the glove so as not to wastethe limited energy source; the rechargeable batteries. Thebattery pack should function at the lowest operation temperatureof the gloves and should ensure higher number ofrecharge cycles while maintaining highest capacity densityratio. A suitably positioned temperature sensor inside gloveshould disconnect the battery after reaching a pre-determinedtemperature. If sweating takes place, due to excessivephysical activity, the whole ensemble should wick out sweat.Otherwise, moisture will replace the insulating air of theinsulating layer leading to higher thermal losses and overalldecrease in the efficiency of the ensemble (as water hasabout 25 times higher thermal conductivity than air at thesame temperature).

Feet protection.

Human feet take highest brunt ofcold in winter operations. Feet being away from the heartreceive less blood supply. Hands can be protected by foldingbeneath armpit in an extreme case. Absence of such protectionmakes feet and toes highly vulnerable for frostbite.

The authors have developed electronically controlledactive heating clothing based on sound military physiologyprinciples. The heated gloves and heated shoe insoles havealready been bulk produced for the Indian Air Force Pilotsand are used by Aircrew since 2010. The gloves are lightweight,offer excellent dexterity and tactile sensitivity andinsoles are designed on an anti-slip antimicrobial substrate. The gloves and insoles provide a physiologicallycomfortable warmth of 22–28^{o}C to the wearer while providingprotection up to –40^{o}C. The items have beenpatented. The principle has also been extended to heatedjackets and trousers, which are being used by the ArmedForces personnel working in extreme cold mountainousregions.

Authors have also extended the principle of heating andby incorporating Patented-heating Tape towards the development of heated jacket, trousersand heated blankets for Indian Military personneloperating in Himalayan border [106].

Working principle.

The heated garments developedby the authors work automatically without requiring humanintervention once done and connected to the battery. A suitablypositioned temperature sensor senses ambient temperatureinside the garment and initiates heating until a certainceiling temperature is attained, at which point, heatingstops. As the temperature falls below the temperature criticalfor dexterity/tactile sensitivity (in case of glove), heating isinitiated again. This ensures the garment as ‘Plug and Play device’ and the soldier/pilot need not pay attention towardsoperation of the heated garments. The heating principles arebased on sound military/aviation physiology principles andthe same has been ensured through several trials inside awalk-in chamber capable of simulating the conditions of acold battlefield.

Hybrid approach

All clothing designs have inherent deficiencies. Multilayercoveralls are bulky and impede the motion of the wearerand do not provide effective protection below –20^{o}C. PCMbasedclothing offer limited protection and are not useful inextended cold weather application and the requirement of aPCM regeneration device leads to additional logistic burdenin a military operation. Aerogels, though promising andexhibit super insulation abilities, are expensive and completeclothing ensemble for military application is yet to be realized.Battery heated clothing, although lightweight offerphysiologically comfortable warmth even at extreme lowtemperature, have limited period usage depending on thebattery capacity. Therefore, there is a need to develophybrid technologies utilizing combinationof technologies such as aerogel insulation in conjunctionwith battery heating to extend the endurance of thebattery life [107]. Such activities are going on at DefenceBioengineering and Electromedical Laboratory and authorsare involved in the development of technical textiles formilitary applications.

Future work

Development of protective clothing for military purpose is achallenging task. In an ever-changing war scenario, warfighters need complex clothing solution to perform optimallyin difficult environment. Research in this field hasyielded complex and intelligent clothing ensemble. A lotmore is yet to be achieved by incorporation of lightweightsuper insulating clothing ensemble, which employs hybridtechnical solutions.

Protection from hypoxic mountain environment

Before taking up activities in mountain environment, it ispertinent to know characteristics of the terrain and knowledgeof how these terrains can affect men and machinery.Mountain environments are complex and pose seriousthreat to the health of the soldiers [108]. Mountain environments are characterized byhyperbaric hypoxia, cold weather, low humidity, high velocitywind, UV radiation etc. The problems associated withcold weather and the remediation is discussed in the precedingsection. This section deals with the effects of hypoxicenvironment on the health and well-beingness of the soldiersand sojourners.

Classification of HA

HA is classified into the following depending on the altitude;8000–12,000 feet is considered as HA, 12,000 to18,000 feet is considered as very HA and 18,000þ feet isconsidered as extreme HA where permanent residence isconsidered impossible. The physiological effects associatedwith these heights are published in recent medical reviewarticles [109-111]. Lowlanders can go up to 8000 feet altitudewith minimal reversible effects. When journeys aretaken up above 8000 feet caution needs to be exercised.

Sufficient acclimatization time should be allowed to avoidserious altitude related illness. Environmental conditions atHAs present reduced barometric pressure to lungs. The oxygen

partial pressure is low and becomes lower as the heightof the terrain increases. Body takes time to adjust to thesechanges. This time is known as acclimatization time.Acclimatization refers to a series of adaptive changes inrespiratory, cardiovascular, haemtologic systems, enhancesoxygen delivery to the tissues and augments oxygen uptake. The lake Louise ConsensusCommittee based scoring system for symptoms and signs ofacute mountain sickness (AMS) has been a useful researchtool since first published in 1991 [112].Indian Army has laid down 14 days of acclimatizationschedule for the deployment of soldiers to very HA.

Effects of HA – AMS and high altitude pulmonaryoedema

As we travel higher ground from mean sea level, the barometricpressure deceases. Although the ratio of oxygen inair remains nearly 21% at all altitudes, the partial pressureof oxygen reduces with respect to the height. Higher thealtitude, lower will be the partial pressure of oxygen[113]. This should be an important factor fortroupes as soldiers reside and perform activities during theirentire tenure of residence. The mountain terrain is generallyunpaved and tortuous in nature, demands more energy thanwould be required to perform similar activities at lower altitudes.Therefore, energy requirement will be higher for routine activities. However, due to lower oxygen partial pressure, the body will not be able to supply same amountof energy.

AMS is most common problem in HAs, which is characterizedby headache, nausea, vomiting, lethargy, disinclinationtowards work and general tiredness. AMS can occurto un-acclimatized lowlanders who ascend quickly to mountains.AMS can also occur to well-acclimatized soldier whoperforms physically taxing activities at HAs. AMS is generallyself-limiting and gets resolved after 2–3 days bed rest.The pathophysiology, prevention and treatment of AMS ispublished [114].The serious form of altitude sickness is high altitude pulmonaryoedema (HAPO), which is considered fatal[115].Although HAPO is known to occur to at higher altitude, ithas been reported to occur at moderate altitudes also[116]. The pathogenesisof HAPO is still unknown, but strong evidence indicatesthat it is triggered by pulmonary hypertension as aresult of hypoxic pulmonary vasoconstriction. Systemicblood vessels on exposure to hypoxic conditions dilate. Incontrast, pulmonary blood vessels constrict during hypoxicexposure. This constriction is non-homogenous, probablyreflects the distribution of smooth muscle in the walls of thearteries. It has been reported that HAPO is caused by anincrease in capillary pressure [117]. It islikely that the hypoxic pulmonary vasoconstriction is patchy,with the result that some pulmonary capillaries are exposedto the high pressure. This causes damage to the capillarywalls (stress failure), and they leak a high-protein oedemafluid with erythrocytes. Studies of alveolar fluid obtained bybronchoalveolar lavage in high-altitude pulmonary oedemahave convincingly shown that this is a high-permeabilitytype of oedema.

It is said that out of all mountain-related casualties inHimalayan Borders about 40% soldiers succumb to HAPOalone. Altitude, speed and mode of ascent and, above all,individual susceptibility are the most important determinantsfor the occurrence of high-altitude pulmonary oedema[118]. HAPO is characterized by symptoms ofAMS and additionally tachycardia, tachypnea, mild fevertemperature generally not exceeding 38.5^{o}C, blood stained sputum and collection of fluid in thelungs are also seen. The latter reduces the oxygenation capacityof lungs and aggravates the condition of the patient.

HAPO was earlier misdiagnosed for centuries as pneumonia,frequently reported as young, vigorous men suddenly dyingof ‘pneumonia’ within days of arriving at HA. The death ofDr.Jacottet, ‘a robust, broad-shouldered young man’, onMont Blanc in 1891 who refused descent so that he could‘observe the acclimatization process’ within himself mayhave provided the first autopsy report of HAPO[119].

The best treatment to HAPO is to move the patient tolower altitudes, preferably near sea level wherein theenhanced barometric pressure will cure the condition. Thisis however, not possible in real military situation where soldier’sevacuation to nearby hospital or lower altitude is generallyaffected by terrain conditions and inclement weather.

The best treatment is considered on-site treatment, whichforms a kind first-aid to save the life. Some of the remedialmeasures have been the development of HAPE or HAPOchambers, which are basically foldable mummy shaped fabricchambers, wherein an ailing soldier is cocooned insidethe airproof the chamber and the fabric chamber is pressurizedto simulate descent. The enhanced barometric pressuresoothes the conditions of AMS and HAPO. Apart from this,inhalation of nitric oxide has been shown to be beneficialfor the treatment of HAPO [120,121]. Supplemental oxygenadministration to achieve an arterial saturation above 90%yields good results, treatment with nifedipine is recommendedas prophylactic drug. But thesemethods heavily depend on logistic burden of stockpilingthe required gas cylinders and can be present only in unithospitals. The treatment of AMS and HAPO without drugsis described in a short review. The HAPOchambers are used as 'life saving devices' in remote and austerelocations such as soldiers in bunkers where immediatedescent is not possible and supplemental oxygen is notavailable. An algorithm for the prevention and treatment ofHAPO and pathophysiology of HAPO are published elsewhere[122,123]. An interestingcase of medicalmismanagement of a porter suffering from HAPO/HACEairlifted to a hospital in Kathmandu was presented to 7thWorld congress of mountains and wilderness Medicine,Telluride, CO [124]. The wilderness Medical Societyhas released an update in 2014 on practical guidelines forthe prevention and treatment of Acute altitude illness suchas AMS, HAPO and HACE, in which useof HAPO chambers are given the grade 1B vis-_a-vis grade1A given to the descent and nifedipine [125]. A mini review onHA-related health problems in the Ladakh region of Indiadescribes several case studies [126]. Thequantitative details on the mountain fatalities faced by the large troupes deployed by India and Pakistan in theseregions are obscure. However, it is believed that about 40%non-combat casualties results only due to mountain illnesssuch as HAPO.

Coated technical textiles for HAPO alleviation

Variety of high performance fabrics are used in the fabricationof HAPO chambers used for treating sojourners, mountaineersand soldiers. HAPO chambers have been developedon need-basis and are sold by many companies around theworld. The prominent commercially available HAPO chambersare: Gamow bag, Portable Altitude Chamber, CertecBag and One man HAPO Chamber designed and developedby DEBEL, DRDO, India by the authors of this review. AllHAPO chambers are basically foldable (slightly air permeablefabric chambers) that are inflated manually using a footor hand pump to a pressure generally above 2 PSI, to simulatea descent of 5000–9000 feet of descent depending uponthe altitude and chamber pressure, as each chamber has itsown pressure limitation. An altimeter inside the chamberwill indicate the 'virtual altitude' achieved by the chamber.The patient's pulse rate and blood oxygen saturation levelcan be continuously monitored with a finger pulseoximeter.

The chief disadvantages of these chambers are: tympanicmembrane barotrauma, confined space induced claustrophobiain some individuals and non-suitability for vomitingpatients. The patient has to sleep in one position due tospace constraint. As a result the treatment cannot continuefor more than 1–2 h at a stretch. To avoid CO2 build upinside, the attendant should keep on pumping fresh air asper the instruction of the manufacturer. Further, manualinflation may lead a healthy individual to develop AMS/HAPO conditions as 1–2 h of continuous pumping air withfoot or hand pump is a physically taxing activity, whichshould be generally avoided at HA. Hans-Rudolf Keller et alcarried out a comparison of simulated descent versus dexamethasonetreatment in 1995.

However, the HAPO chambers are trusted life-saving andfirst aid devices used by most mountaineers and soldiersdeployed for HA military operations. The first fabric chamberfor the treatment of HA illness was designed in Germany, it is widely regarded that Gamow bag was laboratorytested hyperbaric bag. Some advances in the treatment ofHA illness has been reported [127].

The protocols for using portable hyperbaric chambers fortreating HA disorders have been provided [128].Critical design issues faced by the manufacturer of theHAPO chambers are the choice of materials that can withstandextreme cold operation, non-degradation on exposureto UV radiation at the HA, reliability of the componentsetc. The fabric material used in the construction of thechamber should withstand temperature up to –40^{o}C andundulated rough terrain. Therefore, while designing thecoated fabric, the glass transition temperature determinesthe vulnerability to sub-zero temperature. The fabric shouldnot crack upon repeated folding that occurs during its lifetime.The valves, hoses and pumps are required towithstand extreme low temperature and exhibit robustness,as these items are considered as 'pressure shells and life critical'in difficult times in the absence of medical facilities.

Should one component fail, the whole bag becomes unserviceable,and therefore, enough caution is required to beexercised to choose the correct material.When descent is not possible, due to inclement weatheror other reasons, HAPO victims can be treated using HAPObags. The pressure inside HAPO bag creates virtual descentto allow patient to recover. Care must be taken to ensureadequate ventilation to avoid carbon dioxide build-up insidethe bag by intermittently pumping air into the bag to 'leakout' carbon dioxide as per the instruction of the manufacturer.

When HAPO victims are removed from the bag, theyare back to their original elevation, but symptoms do notreturn immediately, thereby providing time to descent ontheir own or through other means [129].

HAPO chambers

The Gamow bag.

Pronounced as Gam-off bag wasdeveloped [130]. This is first of hyperbaric fabricchambers developed at theUniversity of Chicago. It is constructedout of an acoustically transparent, non-permeable,lightweight, polyurethane-coated nylon fabric which islargely unaffected by temperature extremes. The bag isbright red coloured, which aids visibility in snow boundregions to an aerial rescue team. The fabric chamber has along zipper through which ingress and egress of patienttakes place. Two transparent windows allow visual examinationof the patient and illuminate the bag to reduce theclaustrophobia. The chamber is inflated using a foot pumpto a pressure of 103mm of Hg, which translates to a descentof several thousand feet depending upon the altitude.

Careful studies were carried out by Igor and his team toknow the relationship between the volume of air introducedinto the chamber and the concentration of CO2 build-upinside the bag by following the pumping instruction of themanual, the CO2 level can be restricted within 1%.Several case studies have been reported on the successfulusage of the Gamow bag for treatment of HAPO and in one case study, Gamow bag was alsoemployed for the treatment of high altitude cerebral oedema(HACO) [131,132].

CERTECVR bag.

Certec hyperbaricbag was designed [133]. Earlier design featured orange coloured bag and thecurrent bag is yellow-blue. The Certec bag adopts differentdesign; it features two bags in one. The outer PVC bag (850gsm) is strong material to withstand abrasion [134]. The innerpolyurethane bag is for the airtightness.All items including the valves are duplicated. Two fulllengthzippers on both inner and outer bag allow the ingressand egress of the patient. The Certec bag can reach 3-PSIpressure creating a descent of 2500 m. The inflation iseffected using an efficient double effect hand pump, wherein3.7 L of air is pumped during both downward and upwardstrokes. After reaching 3 PSI, pumping of air should bedone at regular intervals to avoid build-up of carbon dioxideinside the bag during patient treatment. A large transparentwindow facilitates light inside the bag and aids in visualexamination of the patient.

Portable altitude chamber.

The portable altitudechamber is designed and developed. The developers beingexperienced climbers themselves and Dr. Jim an expeditionphysician himself succeeded in developing an alternativechamber to Gamow and Certec bags. The PAC is amummy-shaped bag made from tough and durable PVC,which can withstand all abuses of HA terrains usage. Thischamber has a circumferential zipper (compared to longitudinalzippers of othercommercially available bags), allowseasy entry and egress of patient. The bag can be pressurizedto 2 PSI pressure with the help of a foot pump, which translatesto a descent of approximately 6500 feet at of 16,500feet altitude.

Portable one man HAPO chamber developed.

The HAPO Chamber developed by authorsis based on the qualitative requirement of theIndian Army [135]. The HAPO chamber employsdouble texture nylon fabric with Neoprene coating to ensureair and water proofness. A longitudinal zipper ensures theeasy ingress and egress of the patient. The chamber can becarried around along with patient to short distances withthe help of lightweight aluminium carry rods (sheathed insilicone rubber sleeves at the ends to avoid frostbite in coldenvironment). The inflation of the chamber can be donewith a foot pump in a strenuous manner or through a fieldinflation automation unit powered by a compressor, whichruns on the built-in rechargeable battery. The automationunit works with AC mains and can charge the battery whileon AC mains operation. Based on the request of the IndianArmy, a foldable solar panel capable of charging battery isalso provided. The field inflation unit continuously measuresthe pressure inside the battery and cuts off power tothe compressor when pre-set pressure of 130mm Hg pressureis reached. An intentional leak valve situated near theface of the patient continuously leaks air from the chamberat a predetermined rate to avoid the build-up of carbondioxide inside the HAPO chamber. Three large transparentwindows allow visual inspection. One of the mesh-coveredwindows can hold necessary medical equipment and a portablealtimeter. All protection measures have been built intothe system. Should the pressure of the chamber exceed apredetermine value, a pressure relief valve gets activated andstarts to release air and an audible whistle sound createddue to the activation of the valve. The chamber has beentrial evaluated by Indian Army and Indo Tibetan BorderPolice (ITBP, an Indian Paramilitary force that operatesnear Himalayan Borders) in the rugged terrains of HAs,during which several HAPO patients weretreated. Two sessions of 1–2 h of treatment was found toprovide great relief to the patients. The HAPO chamber utilizesa compact lightweight filled inflation automation unit,which continuously monitors pressure inside chamber infully automatic manner, comes with additional voice operatedsmall walkie-talkie for patient–doctor/attendant communication.

Since strenuous manual inflation is avoided, asingle attendant can attend to many HAPO chambers. TheHAPO chamber comes with a pressure gauge and an altimeteras a double check to reassure the functioning of theequipment. The recent lightweight version of the HAPOchamber is patent pending design andhas been bulk produced for Indian Army and ITBP [136]. HAPOdeveloped by the authors is also commercially available formountaineers through partner industries in India who havetaken transfer of technology.

III. Conclusion

It is beyond doubt that technical textiles provide primarybarrier from the elements to the war fighters. The everchanging war strategies and widening war theatres havenecessitated the development of lightweight, high performancetextiles and protective gears. The technical textiles haveimmensely contributed towards the retention of cognisance,enhanced mission endurance and effectiveness of militarymission. It has been stated throughout the review thatunprotected men and animals of great armies have lost livesto the hostile environment in the past despite being superiorin number or training. Today's war is fought not just by thesoldier, but also with 'soldier as system' and 'system as soldier'.The importance of man behind the machine has beenborne out through the tragedies that have struck unprotectedsoldiers and have led to the realization that'protecting the protector' is the important part of combatpreparedness. Today's technical textiles are embedded withmodern technologies to enhance the capabilities of the soldiers.The promising research in the recent nanotechnologyis yet to be implemented in the military combat gears andresearch in this area has to pick the pace to replace conventionaltechnical textiles with nano-based capabilityenhancement.

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