M. DES. PROJECT II

SUBMITTED BY

ASHISH CHANDEL
01613007

GUIDE : PROF G G RAY

IDC . IIT BOMBAY
INDIA .

DESIGN OF THERMAL SUITS FOR INDUSTRIAL WORKERS

Topic	page number
Approval Sheet	3
Abstract	3
Introduction	5
Situation analysis	6
Physiological analysis	7
Thermal regulation	8
Comfort levels	10
Existing products	12
Vortex tube, how it works?	17
Brainstorm	19
Brief	20
Schedule	21
Data collection	22
Test rig	25
User analysis	27
Duct matrix	34
Duct details	39
Understanding workers apathy	41
Donning doffing	42
Concepts	43
Concept evaluation	50
Product integration concepts	52
Harness design	57
Trial	60
The final product	61
Product development	63
Usability	64
Safety	65
Material	70
Aesthetics	71
Acknowledgement	72
Bibliography	73

The project titled "Design of thermal jackets for industrial workers" by Ashish Chandel is approved for the partial fulfillment of the requirement for the degree of ` Masters of Design' Industrial Design.

Project Guide ______________________

Chairperson ______________________

Internal Examiner ______________________

External Examiner ______________________

Date ______________________

Design of thermal suits for industrial, workers working in hot, stressed conditions was a six month product design exercise undertaken by me under the guidance of Prof GG RAY, IDC IIT Bombay. The objective essentially was to use the vortex tube technology and use its specific advantages to create a product which is economically viable and more user friendly then existing technologies. The project was was sponsored by ESSEN ENGINEERS, MUMBAI. The sponsors initially provided us with technological logistics along with a vortex tube and a suit .Henceforth it was left to us to integrate the technology into a user friendly product designed specifically for the target users.

The thermal suit is capable of creating comfortable working conditions for workers working Under high environmental heat stress like in front of blast furnace , molten iron/Metals where the radiant heat load is around 80 degree Celsius and contact temperature is more than 700 degree Celsius.The only input required is compressed air required from an ordinary compressor .The suit can create temperatures conditions close to 10 degrees inside even under high temp loads. The temperature can be easily regulated within a wide range. The suit is designed for easy donning-doffing where in it claims minimum time to wear. The design also respects the highly stressed physical activities of the workers and promises minimum physical stress while using it protecting the worker all the time. The materials selected for the design, down to the zipper are all heat resistant. The suit will also give protection to the worker form occasional splinters and sparks coming out of the furnaces .the worker is also protected from chemical splashes by the suit fabric. The design boasts of added security of workers through its new breakaway coupling which allows the workers to make a quick getaway in case of emergencies. The design also emphasis on special requirements of workers like provision for storage spaces and tool garages. The product can be suitably digressed into avenues like transportation and tourism by adding simple feature bundles since the basics have already been worked out.

The product, which was eventually prototyped, is the result of a planned design process involving inputs from human physiology, fabrics, pneumatics, fashion, and thermodynamics to name some of them. Special care was taken to keep in mind the capabilities of sponsors in actually manufacturing the suit in desired numbers. The suit has to compete with other imported concepts only in terms of cost which were illegitimately high for their poor product packaging. The cost of the suit has been kept optimum in terms of its utility and economics.

The design is dedicated to Indian industrial workers who work in extremely pathetic conditions for meager financial benefits . Their extremely poor working conditions created the passion and urgency in the design process which helped me to reach this stage. Although the design will help them in more then one way but more still needs to be done at the system level where in the administration takes measures to educate their workers on industrial safety.

This report outline the entire design process involved in reaching the final product prototype in the given time frame. The final product is a thermal suit designed for industrial, workers working in extremely hot, stressed conditions. The objective was not only to evolve a technology into a product but also to arrive at a value for money package for the management in the industries who ultimately decide the purchase of such products. The package comes as an incentive wherein it protects the workers from heat stresses, burns and chemical exposures. The product respects the high demand of workers productivity and no way interferes in the same.

The project had its own limitations which were marked out in the start .

these are ,head wear is separate and was not taken into the scope of the project. This became essential because of the extreme intricacies involved which were difficult to accommodate in limited time frame .

the hands will have to be covered with special protection because they are subjected to extreme conditions which require toughened textiles. However cooling the gloves have been attempted in the project.

The thermal suit is capable of creating comfortable working conditions for workers working in ambient temperatures 32 degrees Celsius, and contact temperatures of 700 degrees Celsius .the only input required is compressed air required from an ordinary compressor .The suit can create temperatures conditions close to 10 °C inside even under high temp loads. The temperature can be easily regulated within a wide range. The suit is designed for easy donning-doffing where in it claims minimum time to wear. The design also respects the highly stressed physical activities of the workers and

Promises minimum physical stress while using it protecting the worker all the time. The materials selected for the design, down to the zipper are all heat resistant. The suit will also give protection to the worker form occasional splinters and sparks coming out of the furnaces .the worker is also protected from chemical splashes by the suit fabric. The design boasts of added security of workers through its new breakaway coupling which allows the workers to make a quick getaway in case of emergencies. The design also emphasis on special requirements of workers like provision for storage spaces and tool garages. The product can be suitably digressed into avenues like transportation and tourism by adding simple feature bundles since the basics have already been worked out.

The vortex tube technology which was asked to be used is quite new in the realm of cooling personnel so it had to go through experimentation which have been incorporated in the report .The process involved some extent of visualization of working conditions given the limited scope of documentation of the entire process.

This part dealt with asking questions

How human body does reacts to heat?

Why vortex tube?

Where can it be used ?

How do workers work in their respective environment?

situation analysis is the most important part of the design process which will eventually define the brief of the project so I have taken utmost care to use authentic data for the same.

The situation analysis involved following investigations.

- cost analysis of the exisiting product
- materials exploration
- aesthetcis treatment
- ergonomic analysis
- value addition
- usability analysis
- physiological study
- cost analysis
- detaling the housings and fixtures
- portability
- customer ideantification
- user analysis
- producst analysis
- prototyping concepts
- setting up a test rig .

Worker mobility?

How do workers use their existing protective wear?

How and where workers wear their things?

How long between breaks?

What kind of workers am I targeting?

What are the conditions at the workplace …how hot, how humid ?

This was the first and the foremost part of the design process. This part was to formulate design strategies regarding the proper use of the technology in relation to the human body. It was essential to understand as to how the human body reacts to hot conditions and is the technology capable if facilitating the natural cooling mechanism .What I wanted was to see the technology facilitating the natural cooling mechanism rather than taking it over.This becomes essential lest the natural system becomes lax to the extent of becoming unresponsive to sudden change.

Among the homoeothermic (constant body temperature) , human beings are among the most efficient from view point of mental and physical conditions

All body mechanisms have been tuned to temperature of about 37 deg Celsius. For human beings a fluctuation in this temp will severely affect his her performance .

The human body's thermal regulatory system makes sure that the internal body temperature does not get affected by the external variations ,

The effect of external environmental heat on the human body can be controlled in three ways .

1 controlling at source of origin of heat

2 controlling the conductive medium

3 protecting the human being

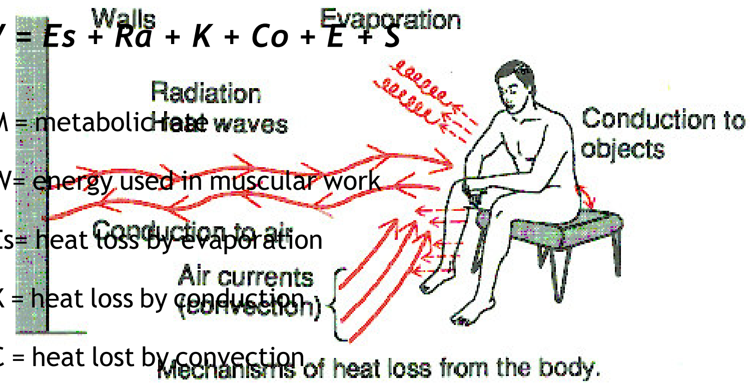
Since, in most cases, controlling the source of heat origin is out of bounds, I shall have to concentrate on regulating the conductive medium and protecting the human being from the surroundings.

Human body temprarature

Normal body temperature recorded from mouth is 98.6 F (37 deg C) Variation in human body temperature happens in human body of the order of ± 2 °C . A difference of 3 °C can be observed in the entire day also.Minimum is observed between 3 to 5 in the morning .Temperature of internal body organs is higher by 1 °C then the temp of the skin.

Human body is beautifully designed to handle external body temperatures . For the project it is essential to know as to how the body naturally cools itself in case of temp rise .This is the model of the human thermal regulatory system wherein there is a balance between the heat received by the body from different sources is equal to amount of heat removed from the body from various sources.

$$M - W = Es + Ra + K + Co + E + S$$



Mechanisms of heat loss from the body.

M = metabolic heat

W= energy used in muscular work

Es= heat loss by evaporation

K = heat loss by conduction

C = heat lost by convection

E = heat lost by respiration

S = heat stored in body

About 90 percent of the body's heat is produced in the torso area by the major organs and muscle groups. The amount of heat generated is increased as the body works harder. In order to maintain a constant core temperature, the body must either give up or retain this heat as necessary. How this is accomplished depends greatly on the ambient temperature and humidity around you.

Convective body cooling.

Under normal conditions 15.5ºC to 26.6° C ambient temperature), the circulatory system carries core heat toward the skin's surface. Since heat always travels from hot to cold, rather than from cold to hot, the body heat is carried away as the cooler outside air passes over the skin. This process is known as convective cooling, since the heat is removed by the movement of air.

Evaporative body cooling.

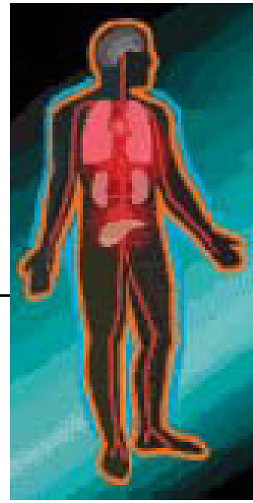
As the temperature outside begins to rise, the difference between normal skin temperature (32.2° C) and the ambient temperature narrows. This difference is known as the delta T. As the ambient temperature rises above26.6ºC, the delta T is not great enough to allow the body's internal heat to flow away from the body by convection.

Instead, the body reacts by cooling itself through a process known as evaporative cooling. When water fluid is exposed to warm, dry air, it will evaporate into water vapor. This change of state is called a phase change and it produces a tremendous cooling effect. The body creates this phase change by secreting perspiration from our sweat glands to the surface of the skin.

When the air surrounding the skin is warm and dry, this is an extremely efficient process. But as the humidity rises, perspiration can no longer evaporate to water vapor, as the air is already saturated. This is a dangerous condition, since the body has no other natural mechanism to give up heat.

Vasoconstriction and the brain.

When the outside temperature drops below 15.5ºC, the body needs to reverse the process and retain its internally generated heat. This is accomplished by a process called vasoconstriction. Vasoconstriction is the restriction of blood flow to the skin surface by contraction of blood vessels. Since the body's organs must always have a flow of blood, vasoconstriction is applied only to those vessels carrying heat to the skin's surface.



when the brain is fooled into thinking the temperature is cool—for example, when ice is applied to the body—vasoconstriction occurs in an effort to prevent loss of heat, even though the core temperature is actually rising. This can lead to dizziness and fainting.

More dangerous is the fact that the cool skin temperature physiologically feels comfortable, so you may actually work harder, creating an even faster rise in core body temperature and the risk of cardiac arrest. This implied the need for providing a temperature control so that worker makes sure that conditions aren't too cool inside .

- There are four components in the workplace which decide the thermal comfort level of human body

Temperature of air

Temperature of surrounding air / surfaces

The humidity of air

Air movements

These four factors are measured by

dry bulb thermometer

whirling psychrometer

and KATA thermometer respectively

- The comfort levels are measured empirically based on these four factors and is called corrective effective temperature (CET) **Recommended values is 28 °C**
- Too much heat conduction away from the body can be unpleasant if it is concentrated at joints especially since it can cause rheumatism and arthritis.
- One needs a control for reaching zone of vasomotor regulation preferably automatic vasomotor regulation.
- **Between 18-24 °C, RH can fluctuate between 30-70 % without causing thermal discomfort**
- Compression and vapor absorber will deliver dry air. The air will have to be humidified above 30%
- Air movements in excess of 0.5 m/s are unpleasant
- Air current from behind and on neck are unpleasant
- P4SR sweat rate (predicted four hour sweat rate).

  Optimal 2.5 liters per 4 hour

  Upper limit 4 liters per 4 hour.

  The air needs to be dry enough (above and close to 30 %) to remove seat to encourage convective heat loss

80% RH and 18 °deg C

60% RH and 24 deg C

End values of thermal comfort

- Maximum heat loss in body is due to radiation, since it will be dramatically reduced if body is covered with protective clothing one needs to concentrate on other factors to increase heat transfer.
- Clothing entraps air next to the skin reducing convection. Here one needs to think about providing drafts inside the suit which will encourage convective heat transfer. This is important given the fact that each person loses unto 600 kcal of heat per day by giving out a liter of sweat.

Air flow

- For standing works air draught at 0.5 m/s are okay. Average requirement is 30 m3 of fresh air per person per hour

Internationally recommended Industrial temperatures

- Range of tolerance is between 20 - 35 deg C
- Under radiant heat load (measured by globe thermometer) 35 deg C

Physiological limits are-

- Heart rate 100-110 per min
- Rectal temp (38 **°C**)
- Evaporation of sweat 0.5 liters per hour.

Today more than ever, safety professionals and plant managers have a wide range of personal cooling technologies from which to pick. It is essential to understand the capabilities of each technology to figure out how the vortex tube technology can be proven as a better option .

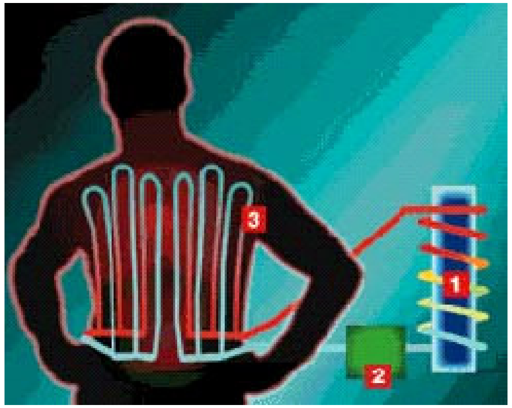
Umbilical *Fluid-chilled systems:*

1. Fluid reservoir holds ice to cool circulating fluid.

2. Variable-speed pump circulates fluid and controls rate of flow.

3. Tube garment carries cool fluid to body and draws away heat toward reservoir.

Fluid-chilled systems consisting of a garment, a fluid reservoir, a circulating pump, and connecting hoses.



The fluid in the reservoir is chilled by ice to .5° to 1.11° C, then circulated by the pump through tubing passages in the vest-like garment. The chilled fluid will rise 6° to 7° C while moving from the pump to the garment. As the fluid passes over the skin, the body transfers heat toward the cooler fluid, which then carries the heat back to the reservoir. As the fluid re-enters the reservoir, it is chilled back down by the ice and the circulation process begins again.

The circulation pump is operated by either batteries or an AC adapter. (Batteries are used when mobility is required. The battery life is typically 4 to 5 hours between recharges. This can create a problem when long-duration cooling is needed, as a change of batteries will be required at least once during the day.

The temperature of the fluid at the body can be controlled somewhat by changing the speed of the pump motor. This regulates the rate of flow, which, in turn, determines the amount of heat drawn from the body.

Fluid-chilled systems are efficient and work well. But mobility is limited because the reservoir and pump are separate from the garment. Some systems operate with a hip pack containing an umbilically attached reservoir and pump. These systems allow greater mobility, but add weight to the body and have limited space for ice, which limits the length of operation.

Another concern with fluid-chilled systems is that they can promote the formation of condensation due to their cool operating temperature range. This can cause some efficiency loss and dampness to the body.

PROS:

Garments are available in all sizes and fit most areas of the body.

Can be worn against the skin and are generally close fitting; uniforms easily fit over garments.

Long-duration cooling.

CONS:

Limited mobility due to umbilically connected circulating reservoir and pump.

formation of condensation can cause efficiency loss and dampness.

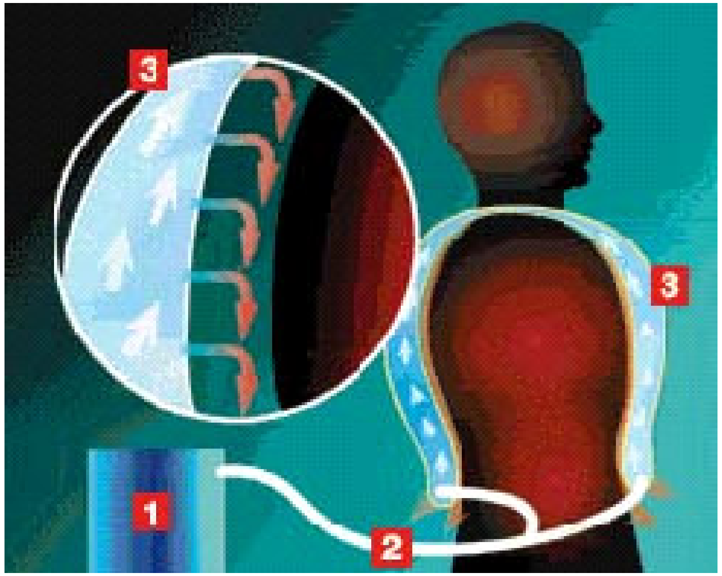
More expensive than other technologies.

Requires electricity or batteries to operate.

Pre-chilled- or forced-air systems:

1. **Vapor compressor pre-chills air and pumps toward vest.**
2. **Umbilical carries chilled air to garment from fixed compressor location.**

Body garment forces chilled air against body and carries heat toward atmosphere via convection.



PROS:

Garments are available in all sizes and fit most areas of the body.

Provides a comfortable cooling temperature range.

Lightweight garment construction.

Long-duration cooling.

Pre-chilled- or forced-air systems consist of a torso garment, a compressor, and an umbilical.

The compressor forces pre-chilled air through the umbilical and into a bladder in the garment. The air is then forced against the body through a series of orifices in the inner surfaces of the garment. As the cooler air passes near the surface of the skin, it convectively draws heat away from the body and into the atmosphere.

These systems are lightweight and provide efficient cooling, but mobility is restricted by the length of the umbilical. They also employ many moving parts in the compressor and require regular maintenance.

CONS:

Mobility is limited and encumbered by the umbilical, which must be attached to a fixed compressor location.

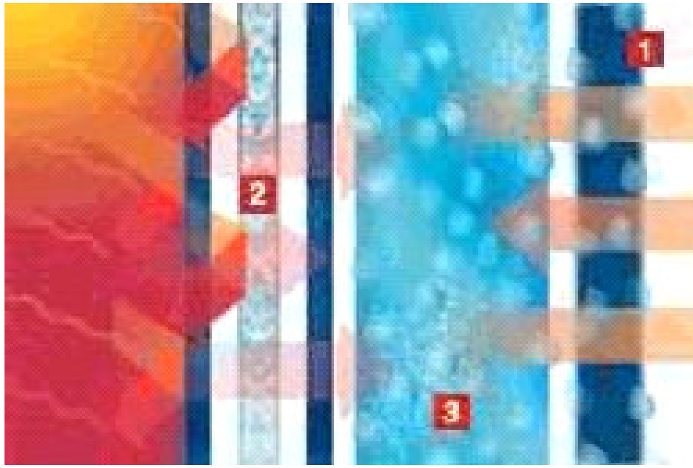
Requires electricity to operate.

Moving parts require regular maintenance.

Passive systems.
Ice or gel pack vests.

1. Carrier holds ice packs against body.
2. Insulation minimizes absorption of ambient heat by ice packs.

Ice packs solidify at 0°C and absorb body heat until saturated.



Ice or gel pack vests consist of a torso garment containing pockets, surrounding the chest cavity, that hold ice packs. Body heat, carried to the surface of the skin by the circulatory system, is absorbed by the ice packs.

The garment fully loaded with packs is heavier than an umbilical-type garment, but is completely unattached to any external devices, making it much more portable. Cooling duration is approximately 1 to 1-3/4 hours between recharges based on average workload and individual metabolic rate. The packs recharge in five hours in a freezer and can be recharged literally thousands of times. once the packs lose their cooling charge, they do nothing but add weight to the wearer.

A concern with this technology is that the ice packs condense, since their temperature is below the typical dew point. The condensation generates heat, which is then absorbed by the pack, reducing the duration before another recharge is needed. Also, the condensation is absorbed by clothing, causing discomfort and adding weight, which creates a greater load on the body.

Ice technology provides a reduction of body core temperature when used for short periods. However, with prolonged exposure (several hours of continuous use) the core temperature can actually begin to rise. This is due to vasoconstriction that occurs in the blood vessels carrying core heat to the surface of the skin. The vasoconstriction is caused by the 0°C temperature of the packs. The continued cold exposure of the packs to the skin fools the brain into thinking it's cold outside. The body then attempts to retain heat when, in reality, it should be giving up heat.

Since workload continues to generate even more heat, the core temperature rises. This condition can cause faintness and dizziness. If full workload continues, there is a serious risk of heat stroke.

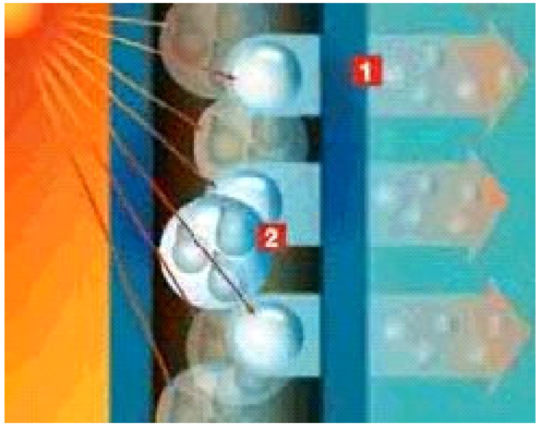
In addition to vasoconstriction and the resultant physical problems, due to extended cold exposure to the skin can cause harm to skin tissue and the development of flu-like symptoms.

Evaporative cooling.

1. Carrier holds water absorption crystals against body.

2. Crystals absorb water when immersed, then evaporate the water to atmosphere to create cooling.

Evaporative technology consists of a garment and a water absorption material. The garment is extremely lightweight and the technology is inexpensive.



To use the garment, simply soak it in water and put it on. The crystals in the cloth swell up and contain water held closely against the body. The process simulates the body's evaporative cooling system as it evaporates the water held in the garment to the atmosphere. The phase change from water fluid to water vapor creates a tremendous cooling energy. There is some efficiency loss over natural perspiration evaporation because the water is not in actual conductive contact with the skin, but is actually cooling air between the absorption crystals and the skin.

The concept is simple, but has several drawbacks. Most obvious is that evaporative technology works well only in warm, dry air. When the humidity is high and the air already saturated with water vapor, the technology cannot work. There is a hybrid version of this technology, which suggests placing the water-saturated crystals in a freezer to solidify. The frozen crystals provide some absorption cooling in high humidity, but only for a very short duration, since the total amount of retained water is minimal.

Another drawback is that the garment is always damp, which can cause skin irritation, bacterial growth, mold, and odor.

PROS:

Most inexpensive.

Extremely lightweight.

Portable; no umbilical device needed.

Longer-duration cooling.

CONS:

Requires the movement of warm, dry air across them to be effective; completely ineffective under any type of protective garment.

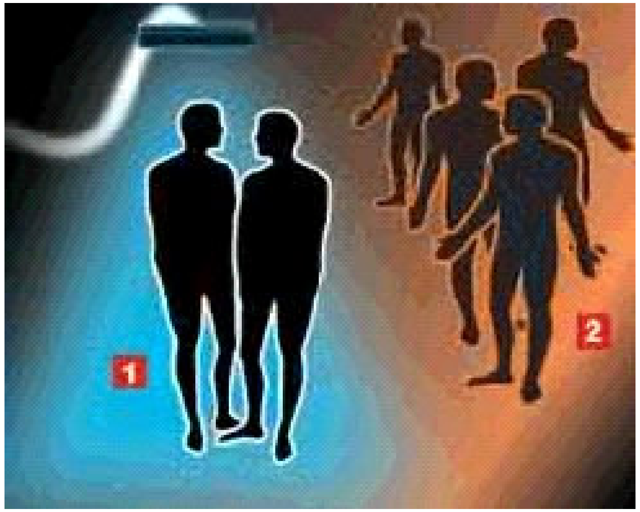
Won't work in high humidity.

Tends to be damp against the body; can cause skin irritation, bacterial growth, mold, and odor.

Environment cooling.

1. Spot-cooled area restricts worker mobility.

2. Workers outside cooled area derive no cooling benefit.



There are many methods of conditioning and ventilating the air around workers. The purpose of this guide is not broad enough to include all methods, but a brief overview of benefits and concerns is presented.

If workers operate in a closed, contained space, it's possible to provide spot environment cooling. There are a number of methods available, and results will vary based upon the ambient temperature, humidity, and mobility of workers.

The simplest method is to provide good ventilation and a flow of fresh outside air. This can be an effective method against lower temperatures of 80° to 90° F, as the air movement will induce evaporation of perspiration. When the temperature rises above 90° F, however, this method is no longer effective, as the differential between circulating air temperature and skin temperature is too small, so body heat can no longer be drawn away.

Another method is to use spot air pre-chillers. This is effective for cooling a small group of workers in higher heat, but is an expensive approach and limits workers mobility to the cooled area. Also, as workers constantly move back and forth between hot and cold areas (e.g., to get parts or to perform other temporary work), they can develop flu-like symptoms over extended periods of exposure.

In addition to the initial expense of these types of environment cooling systems, keep in mind that there will be an ongoing maintenance cost, plus the utility cost to run them.

PROS:

Allows good worker mobility, but only within cooled area.

Temperature is easily controlled.

Can be turned off when not required.

CONS:

Most expensive.

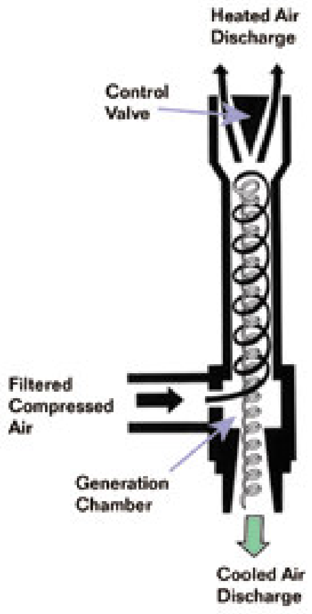
Not effective for outdoor situations.

Not effective for large groups of workers.

The vortex tube system

The vortex tube technology falls in the category of forced air systems in which prechilled air is pumped inside the suit. The main advantage of this system is instant cooling no need for a refrigerant. The vortex tube is about 15 cms in length and 2.5 cm in diameter only . There are no moving parts inside the gadget so one can expect exceptionally long life performance. The technology is explained hence.

, Georges Ranque was the French physicist who invented the Vortex Tube in the 1930's. Vortex Tubes behave in a very predictable and controllable way. When compressed air is released into the tube through the vortex generator, you get hot air out of one end of the tube and cold air out the other. A small valve in the hot end, adjustable with the handy control knob, lets you adjust the volume and temperature of air released from the cold end.



The vortex generator - an interchangeable, stationary part - regulates the volume of compressed air, allowing you to alter the air flows and temperature ranges you can produce with the tube

how it works ?

The vortex generator crates a vortex which flows towards the end of the tube. The impact at the end drives a jet of air through the core of the vortex in the opposite direction. The jet of air at the center exchanges kinetic energy from the outer vortex and cools down substantially. This chilled air is retrieved from the other end and utilized.

"Cold Fraction": an important term for understanding Vortex Tube performance

"Cold Fraction" is the percentage of input compressed air that's released through the cold end of the tube. As a rule of thumb, the less cold air you release, and the colder the air will be. You adjust the cold fraction with the control knob.

Cold fraction is also a function of the type of vortex generator that's in the tube, i.e., a "high cold fraction" or "low cold fraction" generator. Most industrial process applications use a high cold fraction (above 50%). A high cold fraction tube can easily give you cold outputs 50-90°F (28-50°C) BELOW your compressed air temperature.

High cold fractions give you a greater air flow, but they don't give the lowest possible temperatures. The high cold fraction combination of airflow and cold temperature produces the maximum refrigeration capacity, or greatest Btu/H (Kcal/H).

A low cold fraction (below 50%) means a smaller volume of air coming out that's very cold (down to -40°F/-40°C). In short, the less air one releases, the colder the air.

Maximum Btu/H (Kcal/H) capacity (also called maximum cooling or refrigeration) occurs with a high cold fraction tube.

To effectiveness of the vortex tube in localized cooling has been tried and tested.

However to make it a winner among all the alternatives it is desirable to remove all the loopholes in the usability aspect of this technologies.

These are as under

- The umbilical arrangement has to be improvised into a flexible system which does not hamper worker mobility.
- The vortex tube requires huge amounts of air in excess of . If one provide excessive quantities of air inside it will create unnecessary drafts inside the suit which are not desired above a certain speed (3-4 cm /sec) so one has to decide upon the amount of air that has to be pumped inside.
- The tube is weighing 700 grams and needs to be kept close top the body to cut down on convective losses from the conduits.
- The tube has to be cleaned and serviced once a while to remove any chance of rust and deposits on the vortex generator.

Where all this technology can be used ?

The vortex tube technology shows lot of promise given its effectiveness in localized cooling , compactness and minimal parts, affordability and ecofriendliness . I needed to spend some time before I could decide who will be the target users . The major problem facing us was absence of any presets. This tube is mostly used in industries for localized cooling of some machine parts . There are hardly any other users of this technology . So I focused my thinking into areas which involve high heat exposures

Industrial workers were top of our priority list because one they work in extremely poor conditions and second the subjects are readily available which can be extensively studied

Lot of areas open up once we start thinking in terms of portability . a vortex tube arrangement which comes with a portable compressor cane be used by tourists and sportsmen likewise . sportsmen can use this arrangement for long distance running which gets exhaustive due to excessive loss of fluid .It can also be used in sprts like cricket where the players are under severe heat stress. Small suits can also be developed which will instantly cool the injured body parts of sportsman even below 0 °C which is very much possible in case of vortex tube. Ice packs which are currently use are not capable of provising such low temperatures. Also tourists who are not used to handling such high temperatures in India can be provided with such suits which they wear along as they explore the richness of India.

Another lucrative area is long distance truck and bike drivers. These activities involve sitting for long hours while being exposed to hot dry winds or a very hot cabin usually heated by radiation and engine exhausts. Vortex tube comes as a cost effective alternative in place of expensive cabin cooling.

It can also be used very effectively in body temperature management in hospitals under severe clinical disorders.

There are umpteen areas which could be handled by this technology but since the concern was to come to a well worked out product we selected industrial workers working in foundries and casting industries as our target users. Once essential features have been worked out I’m sure that they can be incorporated into other fields also.

After much deliberation the brief was finalized towards Design of thermal jackets suitable for Indian industrial worker in high temperature conditions ,keeping in mind

#Their special thermal comfort criterion. The suit should provide 28°degrees CET

#Their usability issues should be based on work analysis .

Special requirement like fire, chemical retardance

Provision of an effective control mechanism for thermal environment inside

Also , the design should address issues like

Cost effectiveness .

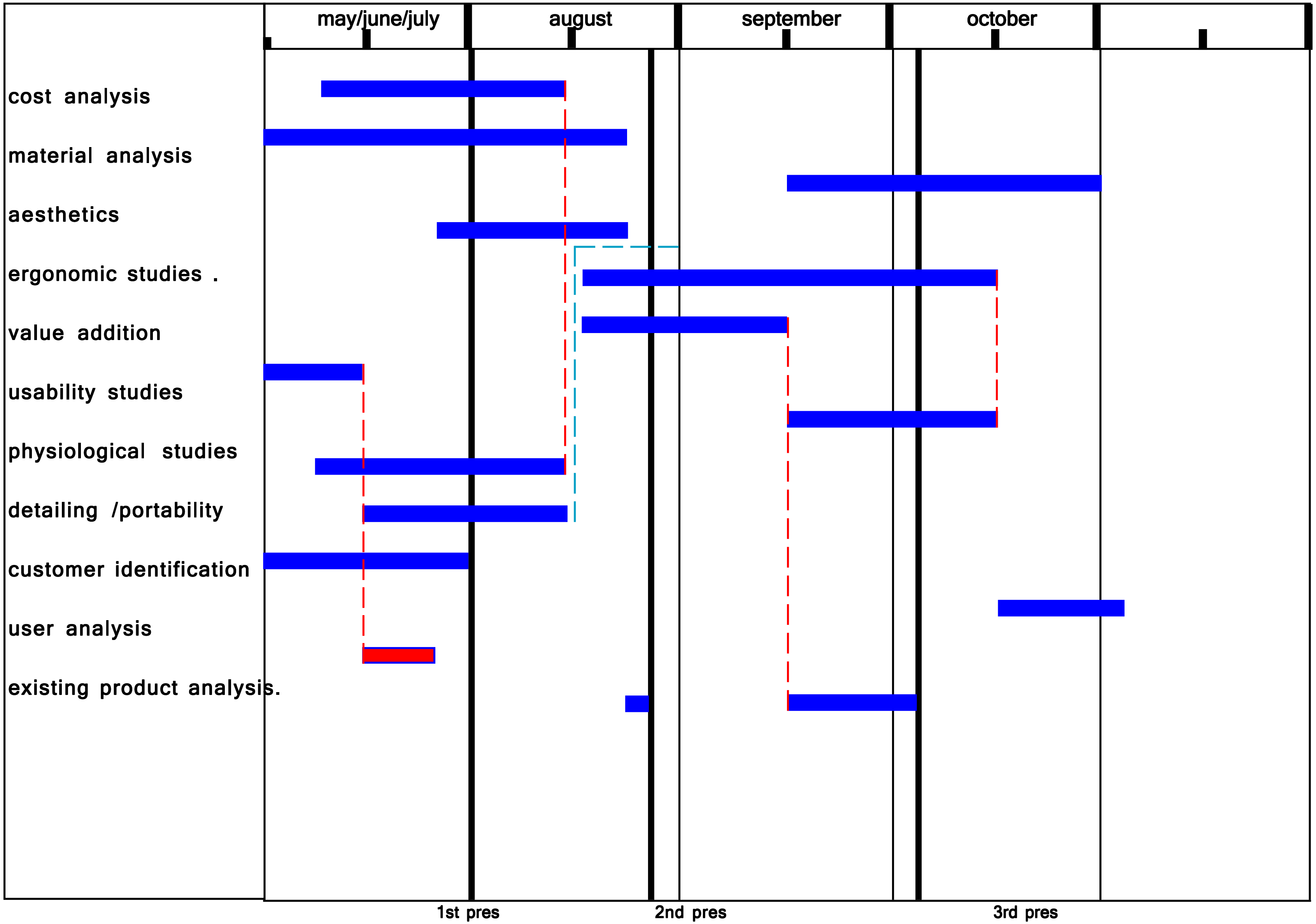
Eco friendliness

Portability, which can usher the design into new areas besides industry .

Asses the scope of the technology in other areas like tourism , sports , Medicare

In all , to come up with a value for money package for thermal comfort

TIME SCHEDULE FOR DESIGN OF THERMAL SUITS



ANALYSIS OF CHEMICAL SUITS USED MY MUMBAI FIRE SERVICE

- **Purpose** : The suit is designed for fire fighters in times of a chemical hazard.
- **Material** : outer lining: Regzine coated with chemical resistive coating. Inner layer is a thermal insulation made of (jute/felt /flannel) .The entire suit consist of the overall, the gloves, boots, head gear, (all are coated for chemical resistance)
- **Weight:** 3.5 kgs
- **Cost:** 75000 Rs

Subjective response: I asked fireman Mahesh Sane to wear the suit so that I can assess various issues. I kept the time as to analyze the entire activity.

- **Wearing the jacket**: The entire suit is made of 6 pieces which have to be worn in steps one after another.

- The entire activity is time consuming and tedious. At the end of it he is sweating profusely. He had to perform the entire activity standing up and sometimes with the help of his mates.
- Inside conditions: inside the jacket the conditions become very humid due to extensive accumulation of sweat. The insulating layer inside which is meant to protect the body from the excessive radiation itself creates lot of heat accumulation and is very uncomfortable to wear. The jacket cannot be worn for more than 15 minutes.
- Mobility: this is hindered by the excessive weight of the jacket which comes to around 3.5 kgs. The jacket which is meant for high risk areas is a risk for the fireman in case of getaway conditions.

However the design has some excellent features like chemical splash protection by use of extra long gloves and vise which extends to the rear neck region.

It has extra big pockets for carrying tools and accessories.

The suit has big fluorescent patches which help in locating the worker in hazy conditions.

MATERIAL : DUPONT TYVEK

COST : (in RS)

Boiler suit	30000
Vortex tube	14000
Fittings (QRC)	200
Wire braided pipe	20/ meter

The existing suit is imported and after all the duties and taxes the price of the concept in India comes to around 45000 Rs.

weight : 1400 grams .

First trial of the tyvek jacket

Procedure

Subjects were asked to wear the jacket and the cold air was pumped in. The users were asked to asses the air flow and cooling patterns in the suit . Also they were asked to perform some activities like walking and stretching. Their responses were noted.

Subject 1

Uday Kumar, student, IDC

Cooling pattern: excessive cooling at the back, wet back, little cooling at the front.

Usability : control is difficult, the horn gets too hot to handle

Movability : difficult to move with the weight of the jackets, walking back is a problem.

Subject 2

Yogesh patankar, student, IDC.

Yogesh is a fairly plump having slight excess in the waist area and sides .some of his observations were

Cooling pattern : Excessive cooling at the back. No cooling in the front.

Usability : Strenuous movements

To authenticate the performance of the concepts I had to ascertain the cooling pattern inside the suit.

Construction of test rig

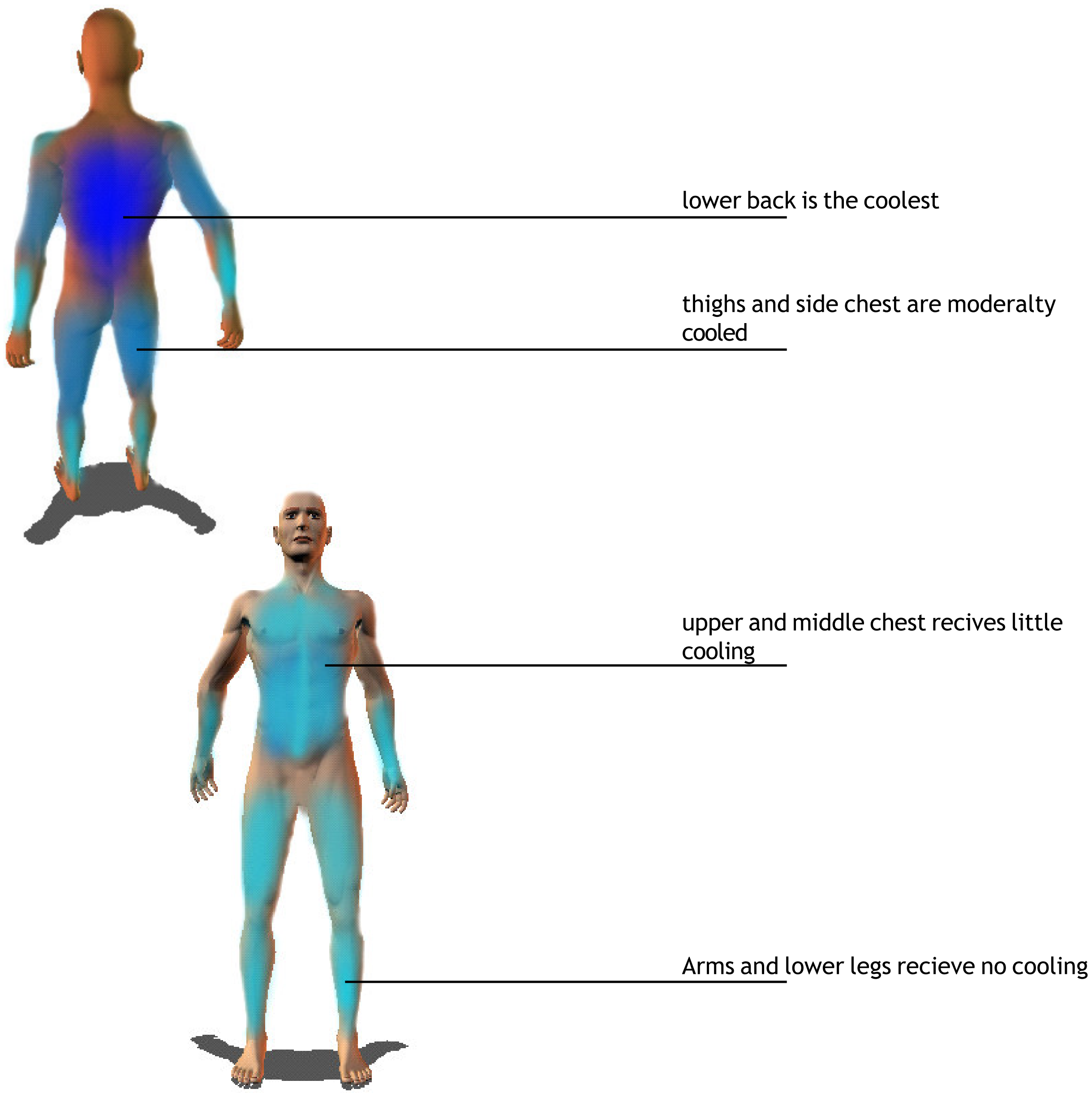
I acquired a FRP mannequin for this purpose. Thermocouple sensors were attached on the surface of the mannequin at pints of interests. The thermocouple gave the readings on a linear scale which was calibrated beforehand.

After donning the suit on the mannequin compressed air at 60 PSI was supplied inside the suit.

Procedure

After the supply of air was resumed, some time (10 minutes) was allowed so that temperature conditions inside the suit were stabilized. After that successive readings were taken and them temperature contours were plotted to ascertain the effectiveness of the concept.

After experiments following observations were obtained .



Since I have to concentrate the design on improving the working conditions of industrial workers, I concentrated my analysis basically on two areas, Foundries and casting units. This was followed by my visits to

Fire station,chembur

ISHA steel, vikhroli

CROMPTON, R&D

BITRA (bombay industrial textiles research association)

Central Labour Institute , Sion

Sardesai Air tools

Boroosil glass

Mukand iron and steel

The aim of the study was to observe the postures adopted and conditions in which the workers undertake different processes. I'm presenting the visit to mukand iron and steel in detail .Observations at other locations have been used in different design problems and have been presented throughout the report .

Following is the study at mukand iron and steel .

Mukand Ltd. makes over 450 grades of specialty steels in a wide range of categories that include:

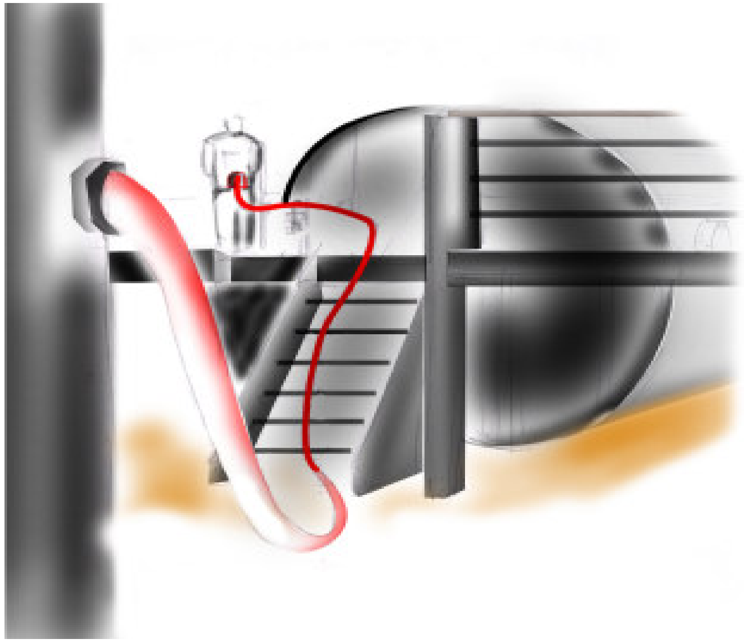
- Alloy constructional steels
- Ball bearing steels
- Carbon constructional steels
- Cold heading quality steels
- Boron steels
- Electrode quality steels
- High carbon steels
- Leaded and sulphurised free-cutting steels
- Semi free-cutting steels
- Spring steels

The Steel Plant of Mukand Ltd. has India's largest and most modern electric arc furnace complex in India. Its ultra high power furnace is one of the world's most modern furnaces of its kind. This plant is equipped with computerized process controls, scrap pre-heating arrangements operating on a waste heat recovery system with facilities for eccentric bottom tapping, oxy fuel burners and ladle refining furnace

The Steel Plant of Mukand Ltd. uses a 10.5-metre radius bloom caster which is the largest in India. Its fume exhaust de-dusting system helps protect the surrounding environment. The bar mill of the steel plant, with its walking beam type cooling bed, is state-of-the-art and so is its fully automatic wire rod mill and its 8-stand, no-twist block mill.

We undertook the visit to assess the conditions the wokers have to work in .

In our visit to mukand we saw workers working in severe heat stress conditions which is derogatory affect on their health. in some circumstances such conditions were unavoidable. however it was felt that there is a need fro better education of worker safety and emphaasis on the same from the managment .
We observed the entire process of steel scarp being converted into blooms. We identified some areas where the workers where workers faced severe heat in absence of proper protection. Our measurements helped us to prove this.



The process starts where the ladles are heated up. The ladle stations are about 10 feet high structure. They have a observation deck where a worker has to operate. The job of the worker is to clean and monitor some valves. **ladle are heated upto 800 degs** During a major part of process the worker has to stand near the heated ladle. The environmental conditions in this area are as under.

WBT : 27 °C

DBT : 35 °C

GLOBE TEMP : 43.5 °C

CET : 31.5 °C

The CET value that we observe over here is well above the thermal comfort level of 28 °C This indicate unsuitable working condition for the worker.

The second point of observation was on the sides of the ladles. The workers have to get close to scorching heat to attach a few cables. The ladles are fired with gas for heating.

Our measurements at the sides gave the following observations.

WBT : 28 °C

DBT : 35 °C

GLOBE TEMP : 65°C

CET : 31.5 °C

KATA TIME : 1 Min 35 Sec

KATA FACTOR : 601

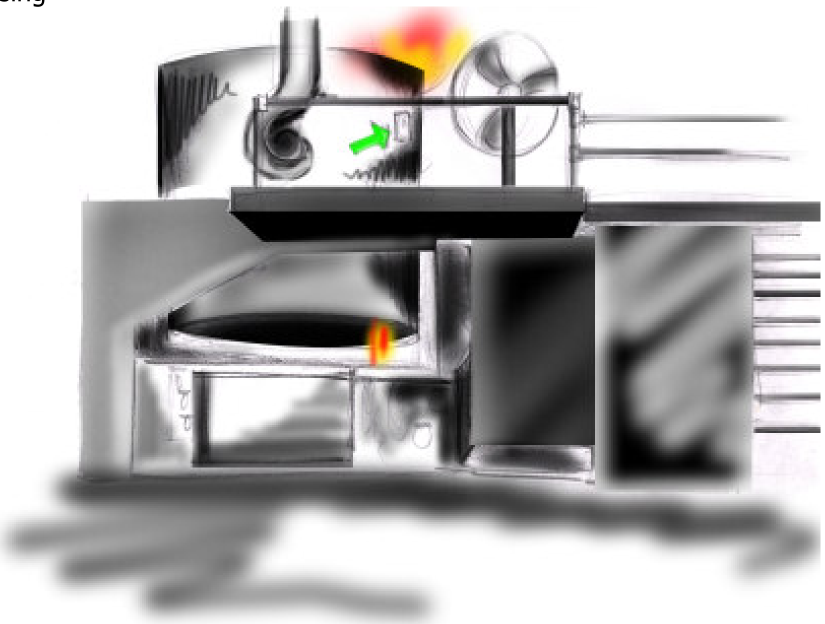
RANGE :145 -150

The sides of the ladles can get hot upto 600 °C

The other observations we took was that the workers are working under protection of a air blower. It is effective to some extent in way that it disperses the heat. But it is ineffective in case of radiation load. Also the fans end up dehydrating the workers.

The Third observation point was the casting column where the melted steel brought from the furnace is continuously casted into blooms. The melted steel is brought in ladles using overhead cranes and placed over the caster.

At this point we observed the activity of workers closely.



Following points were noted:

The worker has to walk unto the ladle lid which and attach a pipe to it which pumps oxygen inside the ladle. The operation is carried under the cover of draft coming from the fan. The platform is in metal and some 10 feet above nearest. The metal floor is a wire mesh to dissipate heat.

The process involves emission on lot of sparks which fly upon the workers leaving holes in their suits and small burns on exposed skin. Since the entire caster is seven storey and casting starts from the top the sparks fly all the way down to the unmarked shop floor and land on the unsuspecting workers working in that area .

The worker in that area has to rely on sound (whistles) and gestures to communicate. However they find it difficult to do it with steam pouring out and sound coming out.

A design area is to find out ways to provide effective communication method for the workers.

The workers have been provided with a water fountain where they rush occasionally to quench their thirst.

The fourth process under observation is the ladle cleaning operation. This involves pouring out the slag, removing the hoses and then lancing the pouring hole.

Our measurements in these areas give the following results.

DBT : 30 °C

WBT: 35°C

GLOBE TEMP : 75 ° C

In this case the globe temperature is much above the prescribed limit of 45 suggesting highly unsuitable conditions for the worker

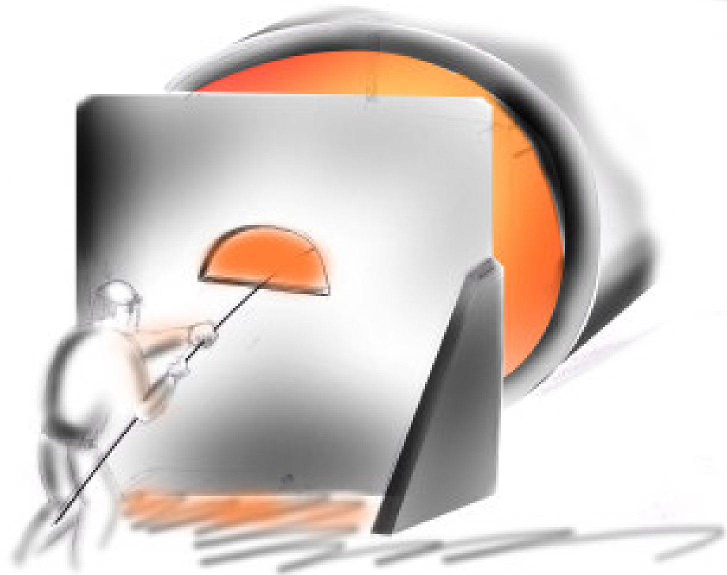
Besides these the following were observed

The workers have to approach the inverted ladle by shielding himself with a tin sheet.

During lancing the worker has to hold a 10 m long lancing tube which is supported on the cutout in the shield .T he process involves heavy pushing and continuous stroking the hot metal.

The workers stands directly in the way of the hot sparks coming thru the hole . Visible burn marks and cloth holes patterns are visible on the skin and the clothing as shown in the sketch.

The workers are provided with shields and goggles for their face and eyes. However their head and back neck region still remains exposed.



The workers show high degree of mobility in such operations, for ex the same worker who had removed the pipe had to do the lancing and then continue to guide the empty ladle to the stationary coach. the coach transfers the ladle to the other end . The same worker guides the coach. This marks his working area to about 20 * 20 meters.

The fourth observation area is the actual melting furnace where the steel is melted and alloyed.

The process involves a huge electric furnace in which metal is alloyed with other properties. The furnace works 24 hours with charge being fed into earlier melted charge . the process of alloying involves a worker sitting inside a lift , which moves close enough to the furnace and inserts a huge block of unspecified metal inside the melt . The worker has to bear extreme radiation and convective currents coming from the furnace .

Meanwhile another worker inserts oxygen pipes into the furnace again using a mobile platform. After this the process is taken over by the electronic controls and switches.

In between using a mechanism fitted on a small truck a worker inserts oxygen pipes into the furnace.

Other observations are ....

There is **substantial emission of UV** which can damage most of the plastics. So a UV resistant polymer coat is absolutely necessary .

The **sparks** are unpredictable and travel at a very high speed towards the workers

The **shop floor is unmarked.**

The workers have been provided with air conditioned cabins where they can rest between shifts.

Water fountains are handy and located at convenient points on the shop floor.

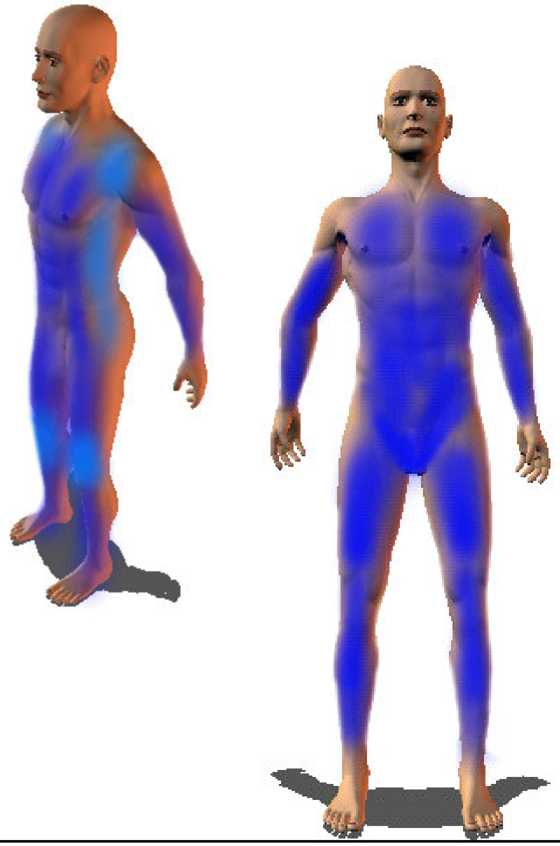
All workers are supposed to wear helmets while they are on the shop floor.

Design of duct matrix.

After the visit to iron industry, observation indicated that the areas that were being exposed to maximum heat were concentrated in the front half of the body. Since the worker has to be attentive to the jobs all the time they seldom get heat exposure on the back

However as the analysis of the existing jacket shows most of the cool air is confined at the back side only. This happens because there is no conduit along the sides for the air to come to the front sides. For subjects like yogesh things are even worse, with little or no communication of air to the front. Also there is no supply of cold air to the front. After sometime subjects invariably felt an urge to roll up their sleeves to wipe the sweat.

Hence I needed to come up with a plan which can convey the air to the front part of body preferably and some part of it to the back also.



Other requirements from any other arrangement were

EASY TO REMOVE SO THAT SUIT CAN BE WASHED

MINIMUM INTERFERENCE IN OPERATIONS

MINIMUM BODY CONTACT

EASY TO WEAR

BIOSENSITIVE

FLEXIBILITY.

The idea of giving ducting was found to be suitable for our requirements because

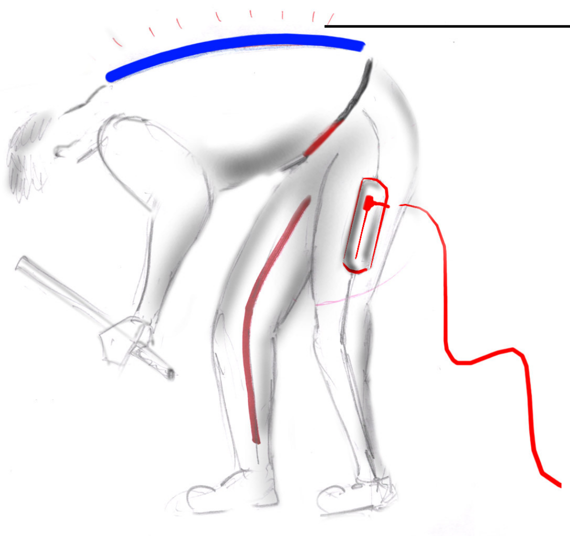
1 it allows for assured and equal distribution of air.

2 air can easily be passed around bends and curves.

3 most of the parts are available off the shelf in this case.

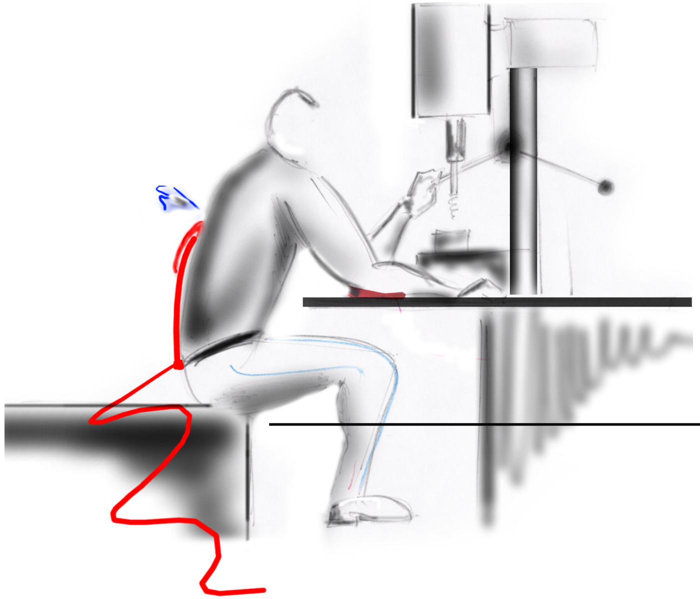
4 ducting being very small in size can be integrated with the suit or can be worn externally also when fixed with a harness

5 ducting are easy to conceal also limiting the scope of cold shock in case the workers touches the chilled pipes.



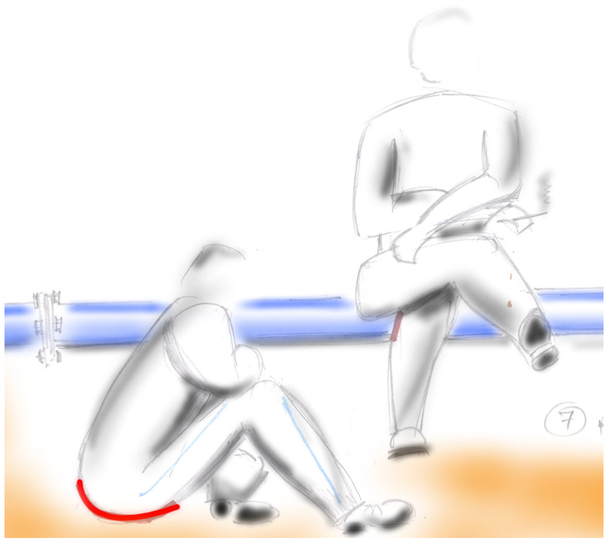
In forward Bending, Spine will be stretched

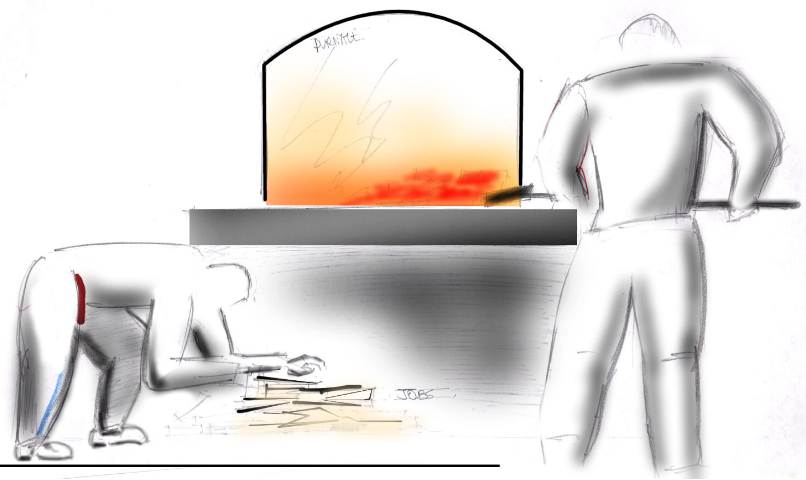
Given these advantages I decided to go ahead and design the ducting plans using conduits which carry the air to different parts of the body. These will insulated on the way and will release diffused air at the end.



during sitting, thigh bottom is blocked

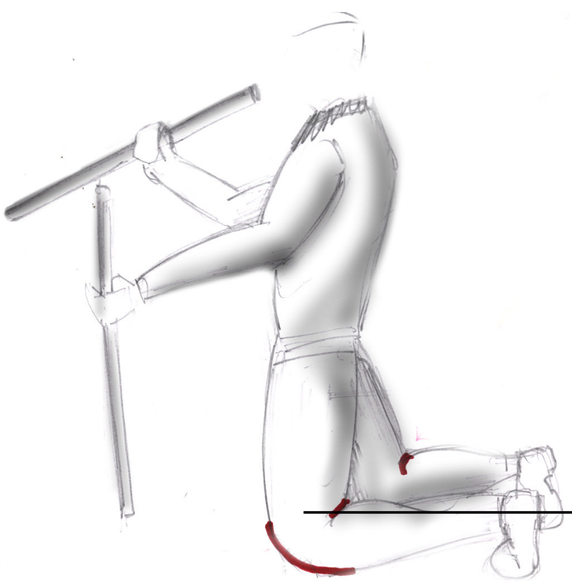
The first step was to identifying the basic activities of workers. Aim of this exercise was to identify the basic matrix of the ducts, This will be a network which will not interfere in regular body activities of the workers and will be flexible enough.

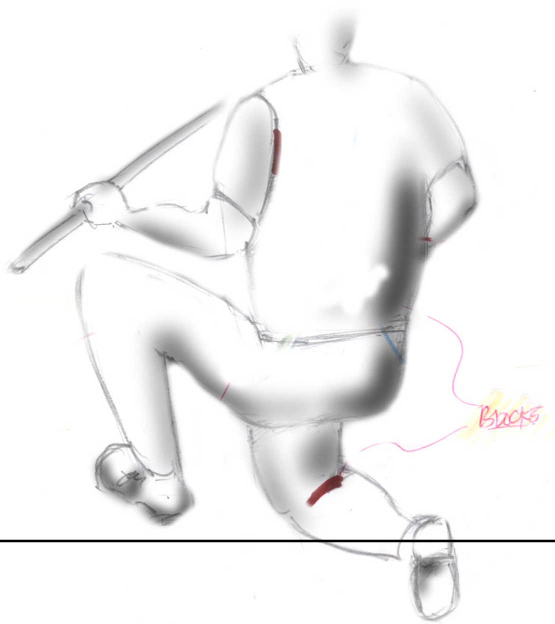




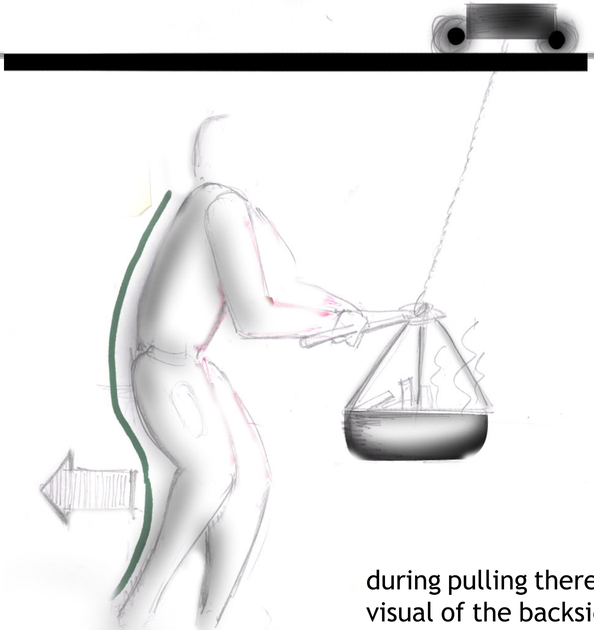
Front half is getting heat exposed.
Tools demand high mobility

during Resting,lower back and leg insides need to be freed

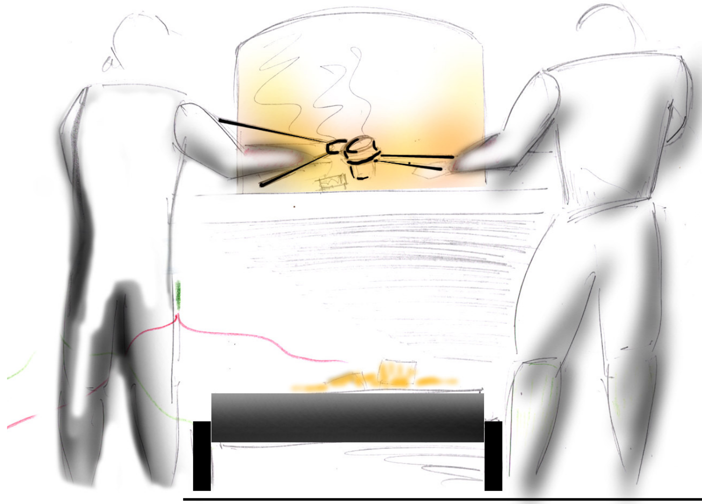




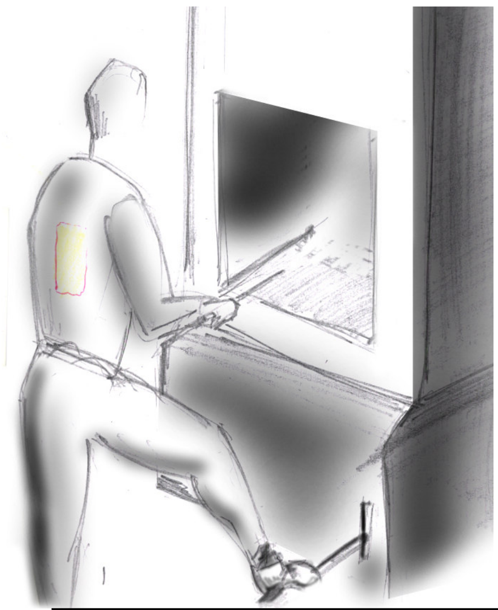
on Kneeling,knees will be blocked.Also
leg pits will be blocked



during pulling there is no visual of the backside visual. Hose can't be brought from back

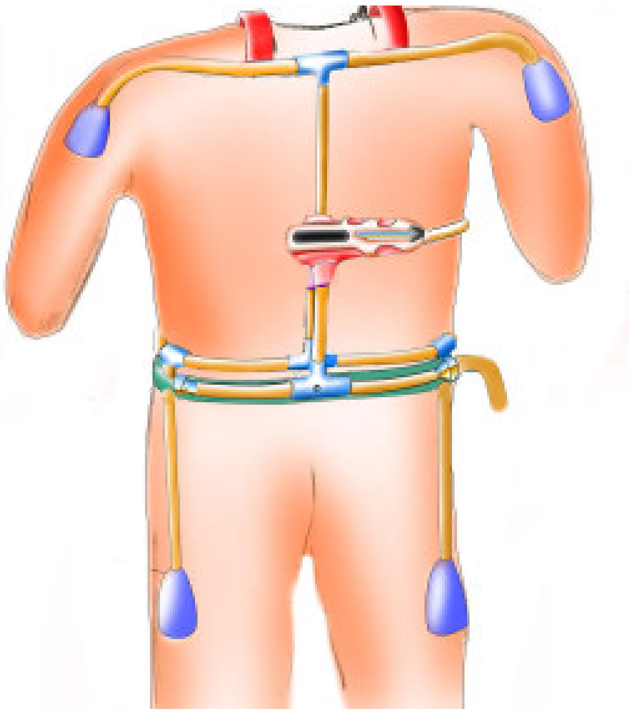


Lower legs are also exposed to high heat



In some operations legs are equally mobile

Keeping all the points in mind the final matrix of the air duct came out like this.



The main features are.

The **ducting avoid lines of normal flexion** in Human beings which run from the mainly on the front ends. They go along the sides.

In case of arms the **ducts move over the joint** but the joint has limited freedom on that axis.

Ducts **circle the waist** and take off along the axis of along the sides and channel the air a few cms above the crotch line.

The ducting which runs along the spine is to be made stretch-able so that it can **accommodate the bending of human body.**

The ducts which go inside the arms will have to **accommodate the decrease in palm to palm length in case of complete vertical stretch**. This will be accommo-dated by giving a slider arrangement inside the arms.

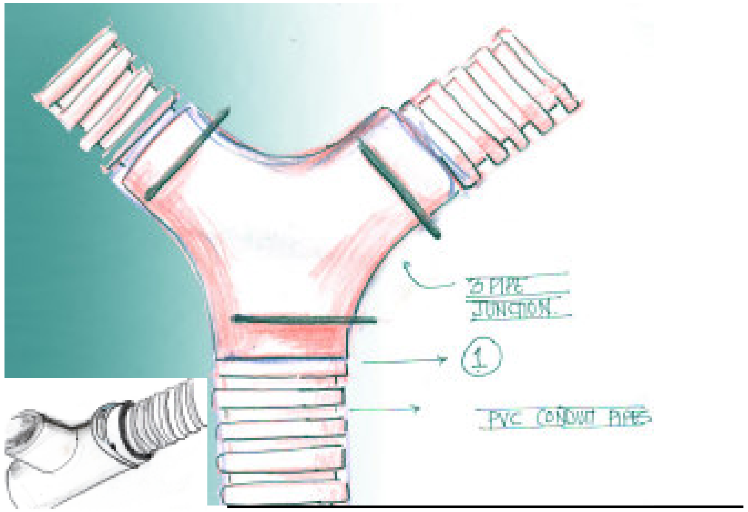
The ducting consist of following parts

One vortex tube

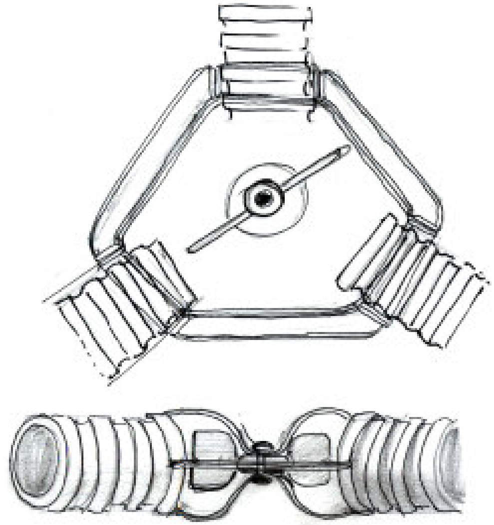
Nipple which connect vortex tube to ducts

PVC Conduit pipes (10mm ID) or PU pipes (6*8)

Junction boxes (Y junctions)

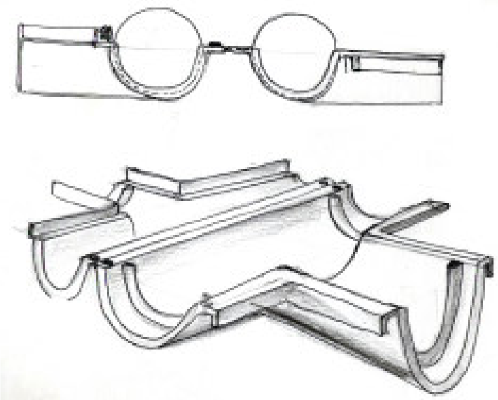


machined out DELRIN junction box



DELRIN junction with flow ratio control

one piece POLYPROPYLENE junction



The initial plan was to use the ordinary PVC pipe joinery available in the market. However there were several problems with the joineries.

1) There was no joinery available which takes less then 25mm pipes
2) The junctions are not designed for conduit pipes. The ends of such pipes get easily damaged and they would have needed special junction boxes.

Another problem was the production volume of the product. Since **the manufacturers are not expecting more than 50 suits per month on the higher side they wanted to use standard details available in the market.**

So I had to replace the conduit pipes with PU pipes which are easily available and are available with all the standard joineries in ABS and stainless steel also . These are used in pneumatics and Hydraulic System and as a fuel pipe in automotive industries.

The sizes available includes 4*2, 4*2.5, 6*4, 8*5, 8*6, 10*8, 12*10

So the new details that were selected to go with the ducting are as under.

Quick Release PY – DIFFERENCE UNION

'Y' coupling PW 0804

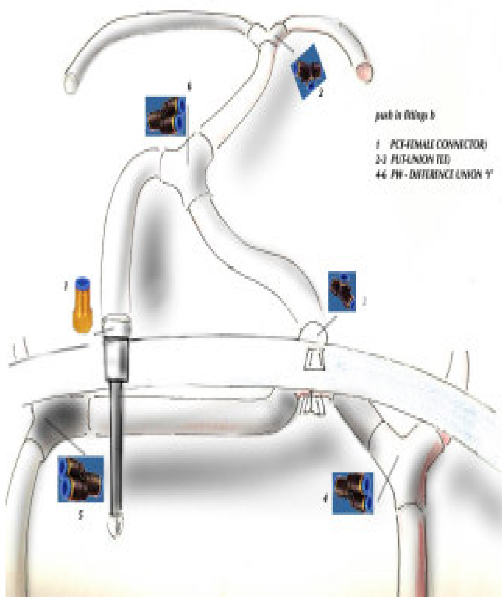
PC–MALE CONNECTOR)

for joining the pipes with vortex tubes

PU pipes 6*8 ID/OD

The Y coupling is the junction point at which the air flow has to be bifurcated. Use of such details allows for easy removal and assembly of the ducting .

Another advantage of such details is their long lasting properties . the details will have to endure lot of condensation inside the pipes . also since the pipes will have to be removed often for cleaning , having easy clamp couplings is definite advantage .



Knowledge and attitudes

Education and training

No awareness of health risk with high temperature and Importance of drinking water

TO WEAR OR NOT TO WEAR??!!

"Perceived" physical effects

Too much weight will cause problems

New fiber may not be good for skin

Co-worker/external influences

Looks funny

Not clean

Forgot to wear

Too busy to wear

It was important to handle such issues to insure that the workers actually feel an inclination to wear the suit while they work.

Inability to communicate with coworkers

Economic factors

Too much wearing time eats into productive time

Being expensive it will remove the casualness with which the workers use their existing clothing. In other word, workers will have to bother about the condition of suit all the time rather then give full attention to his job.

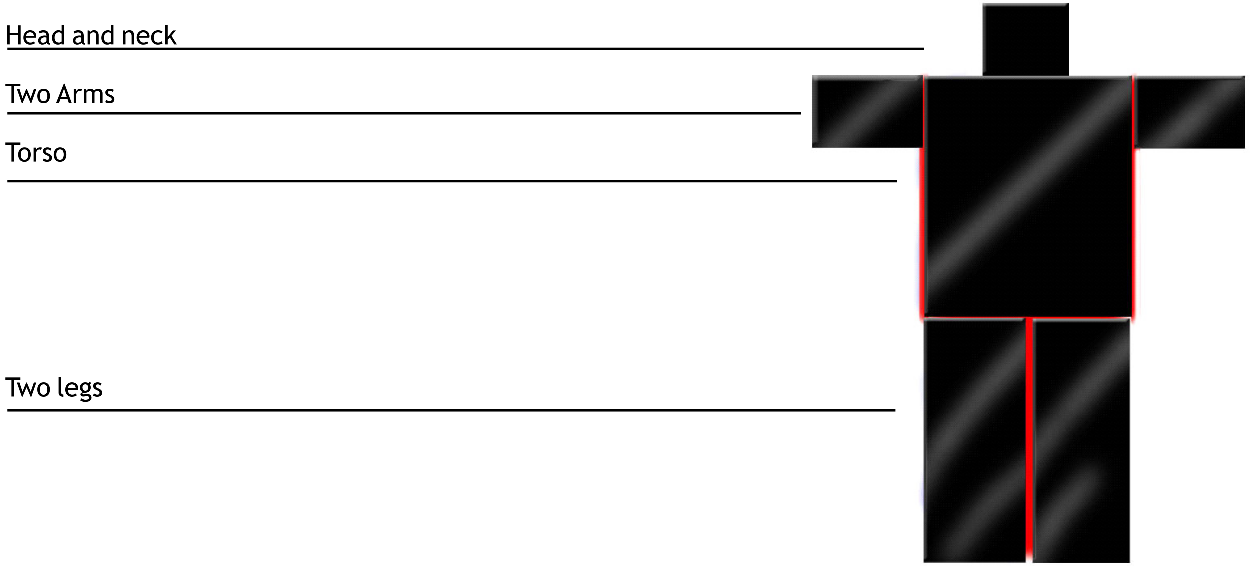
What appeared to be an important issue was the time and effort it took to put on the suit. It was worth investigating the fact the suit will be fitted with lots of details which will make the donning doffing difficult. So it was felt that the suit should have a simplified donning doffing procedure.

simplified donning doffing procedure.

A simplified entry exit procedure for the suit will have following advantages.

- Workers will save lot of time hence productivity.
- A simple act of donning is lucrative enough for a worker who will have to wear the suit everyday
- The existing procedure of donning the suit is visibly taxing for workers who are on the higher percentile.
- Worker will love to explore the newness of the product in their otherwise unfriendly environment. The new suit can generate some sort of play value for the worker.

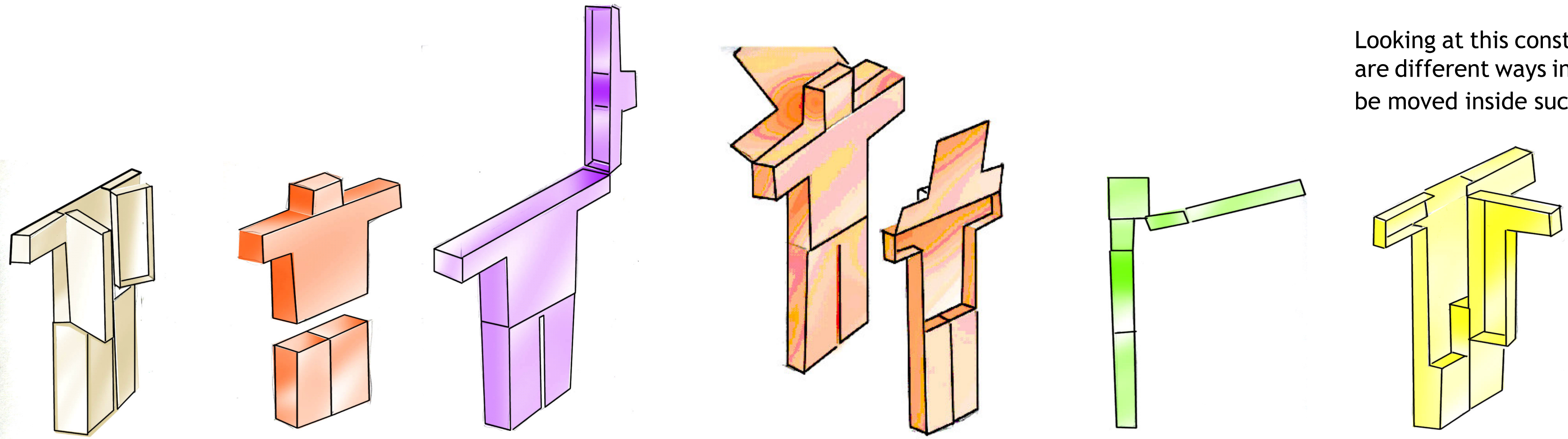
A human body can be seen as six distinct elements.



The first step was to develop the new concepts for donning doffing the suit.

These elements have to be pushed inside the suit in such a way that they do not overstrain themselves.

Looking at this constrained volume there are different ways in which the body can be moved inside such a suit.



these are different ways in which the body can be moved inside such a suit.

Front side zipped entry

Search for elements: extra time is required to locate the second hand which falls back

Difficult body positions: leg lifted above knee to get inside

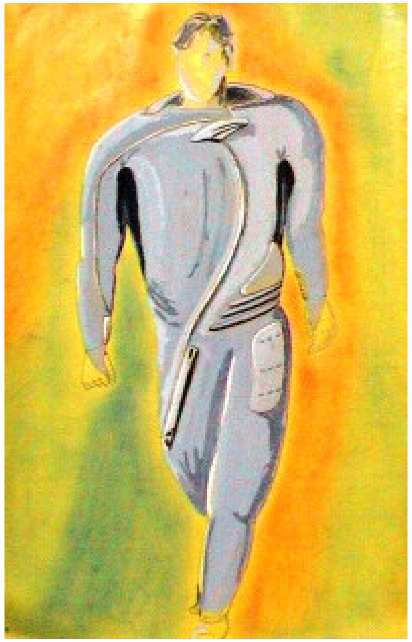
Stretching: arm to pull the chain

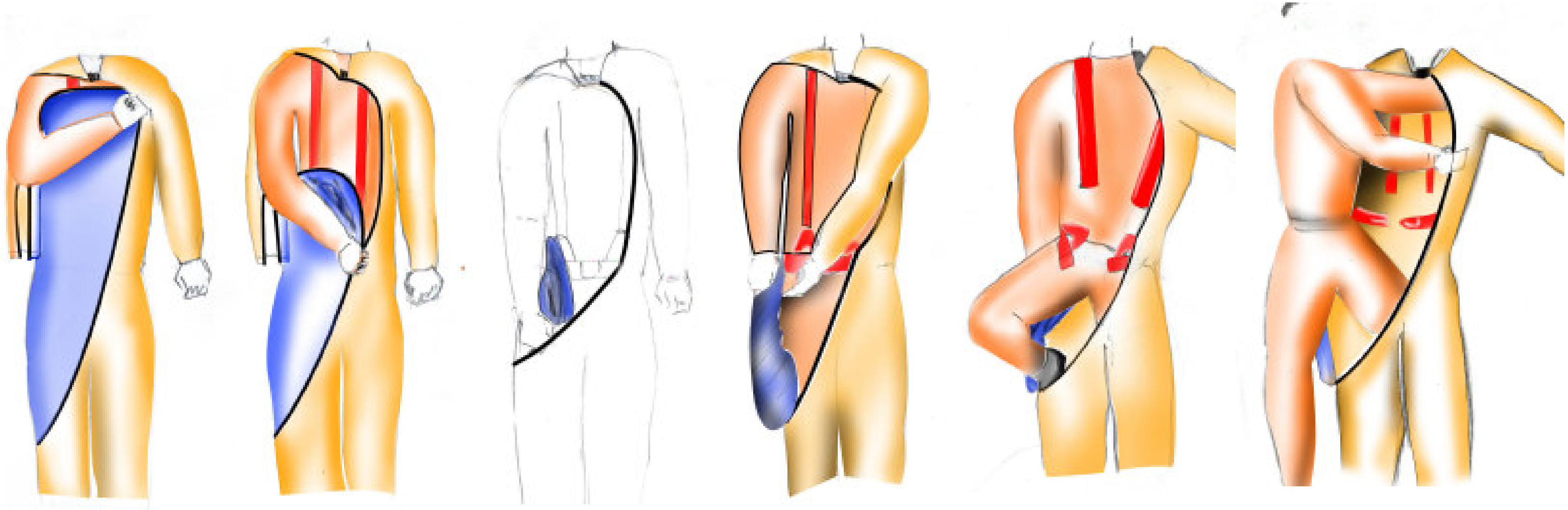
Deadlocks: happen at the turns

Difficult body movements: none

Accommodation of percentiles:

- comfortable for higher percentiles
- Putting in leg can be difficult fro lower percentiles
- Putting in second leg maybe difficult for higher percentiles
- Lower percentiles will find it difficult to grab the chain





Sideways entry

Search for elements: search for other arm and leg is difficult

Difficult body positions:

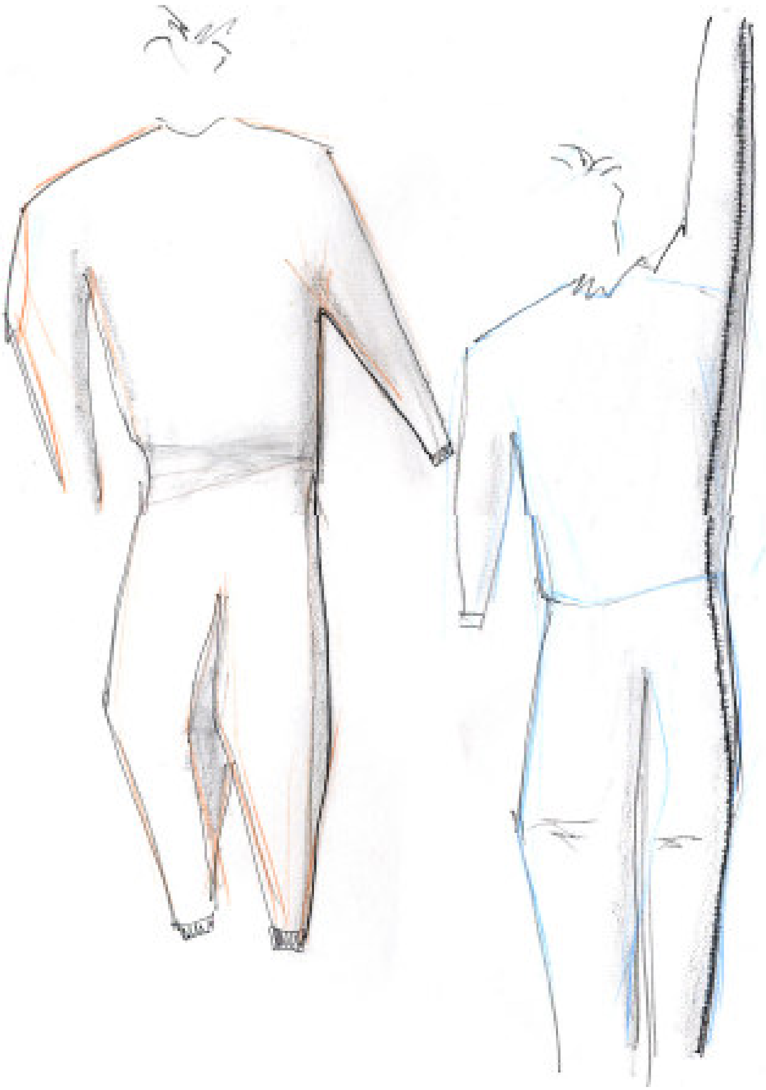
- where one hand has to take over from other
- when hand had to be stretched and caught at end.

Deadlocks: search for arms is very difficult

Difficult body movements: when person has to pull himself out of suit

Accommodation of percentiles:

- Inserting first leg is difficult for lower percentiles
- Head insertion is a problem fro all
- Chain will not be tight enough for lower percentiles
- Large entry is good for higher percentiles



Back entry

Search for elements: grabbing the flap and flipping it over to other side where it catches the Velcro is difficult

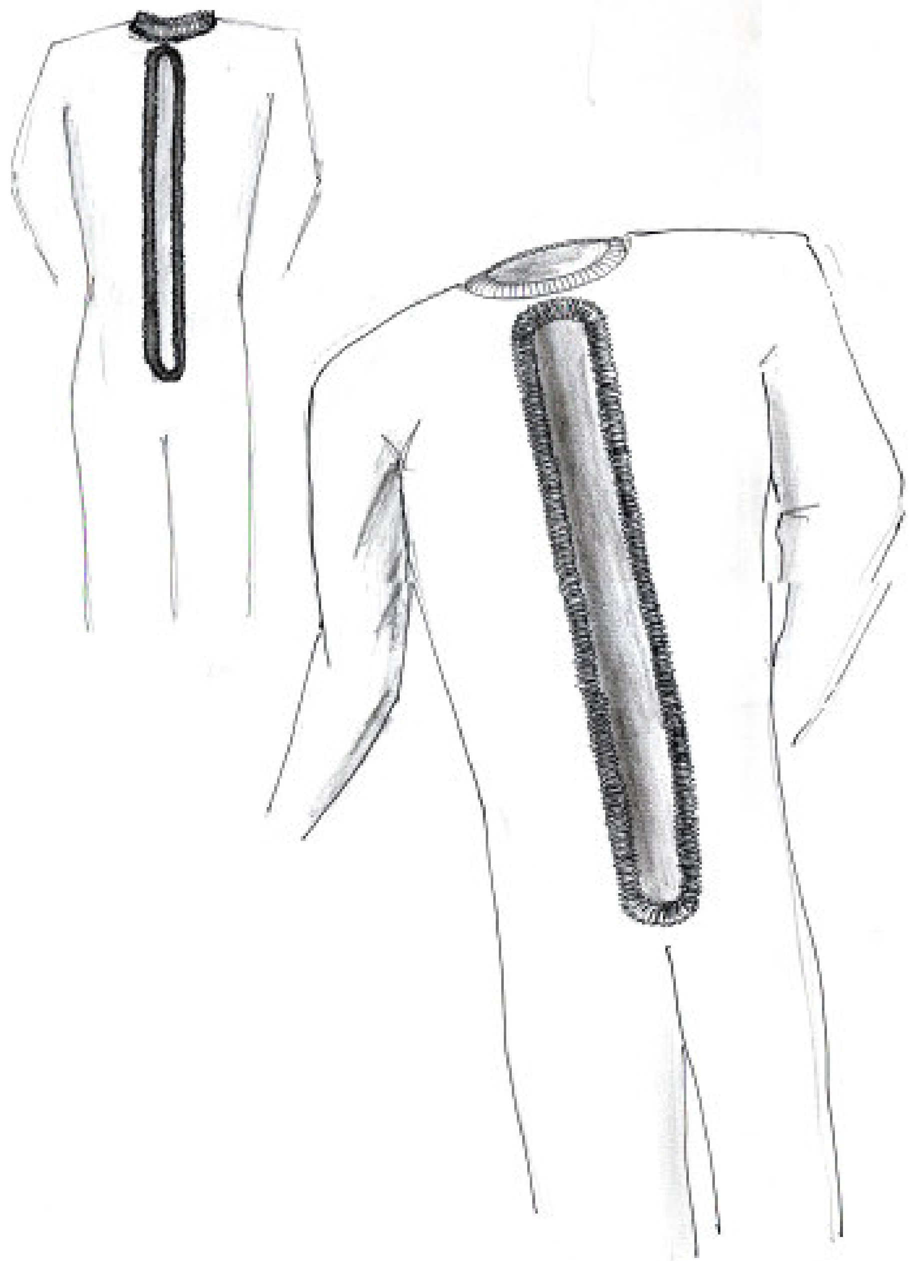
Difficult body positions: stretching hand backwards

Deadlocks: none

Difficult body movements: none

Accommodation of percentiles:

- low cut back suit can accommodate lower percentiles in case of putting leg inside
- Higher percentiles have difficulty in stretching elastic over the head
- People with broader profile will have difficulty in getting hands to back.



Spilt suit

Search for elements: all elements are fairly visible

Difficult body positions:

- When one end is hanging down it is difficult to pull up.
- Sliding shoes inside too much prepositioning is required.

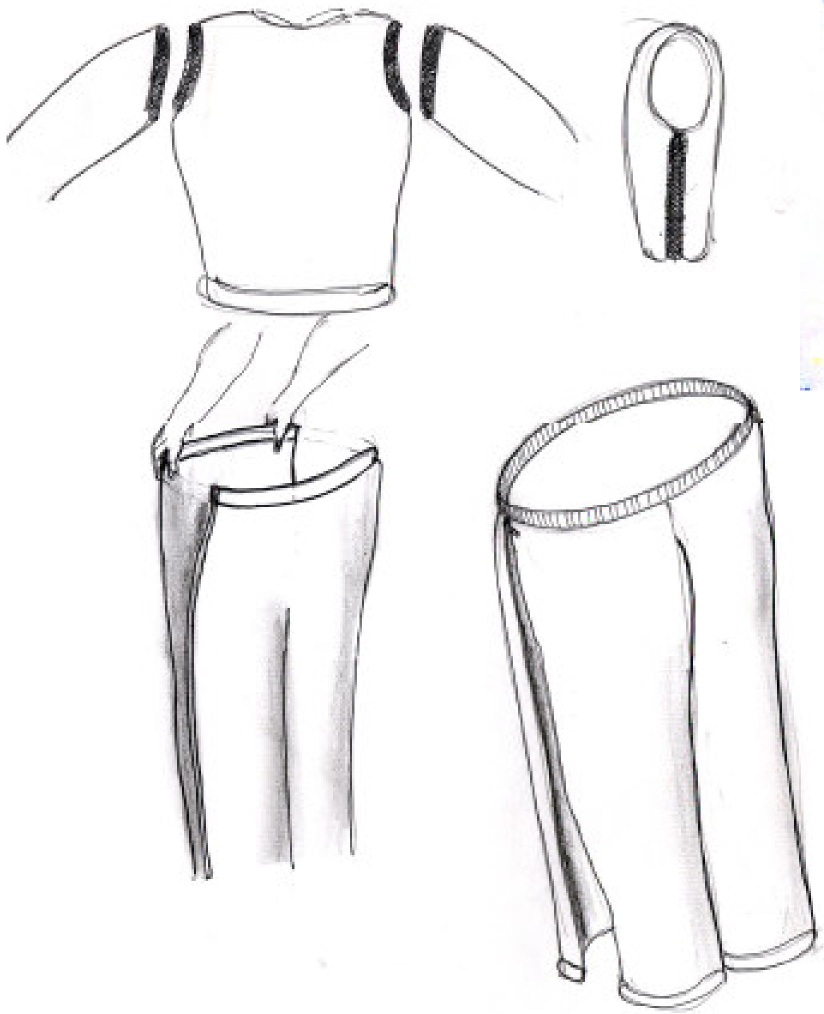
Difficult body movements:

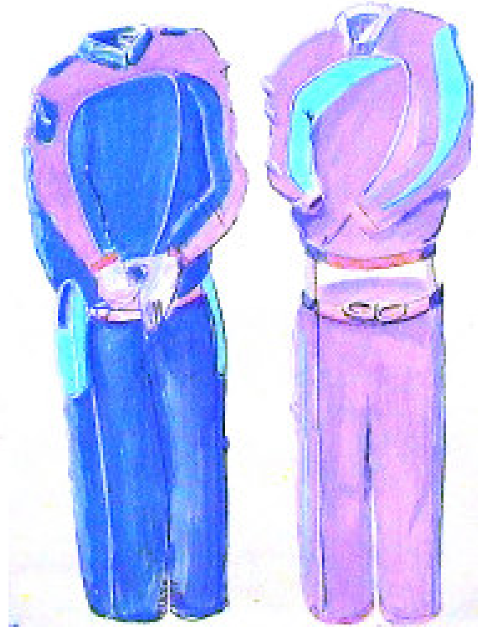
- pulling up the zip while bent down
- Dancing on one foot to pull the leg out

Accommodation of percentiles:

- Lower percentiles find it easy to wear
- Can accommodate most of the percentile because of split at the centre
- Elastic at waist might bother higher percentiles
- Pants are suited more for higher percentiles
- Chain lengths can be bothersome fro lower percentiles

Deadlocks: bulge at the shoulder stops the chain





Backside entry

Search for elements: finding the other arm

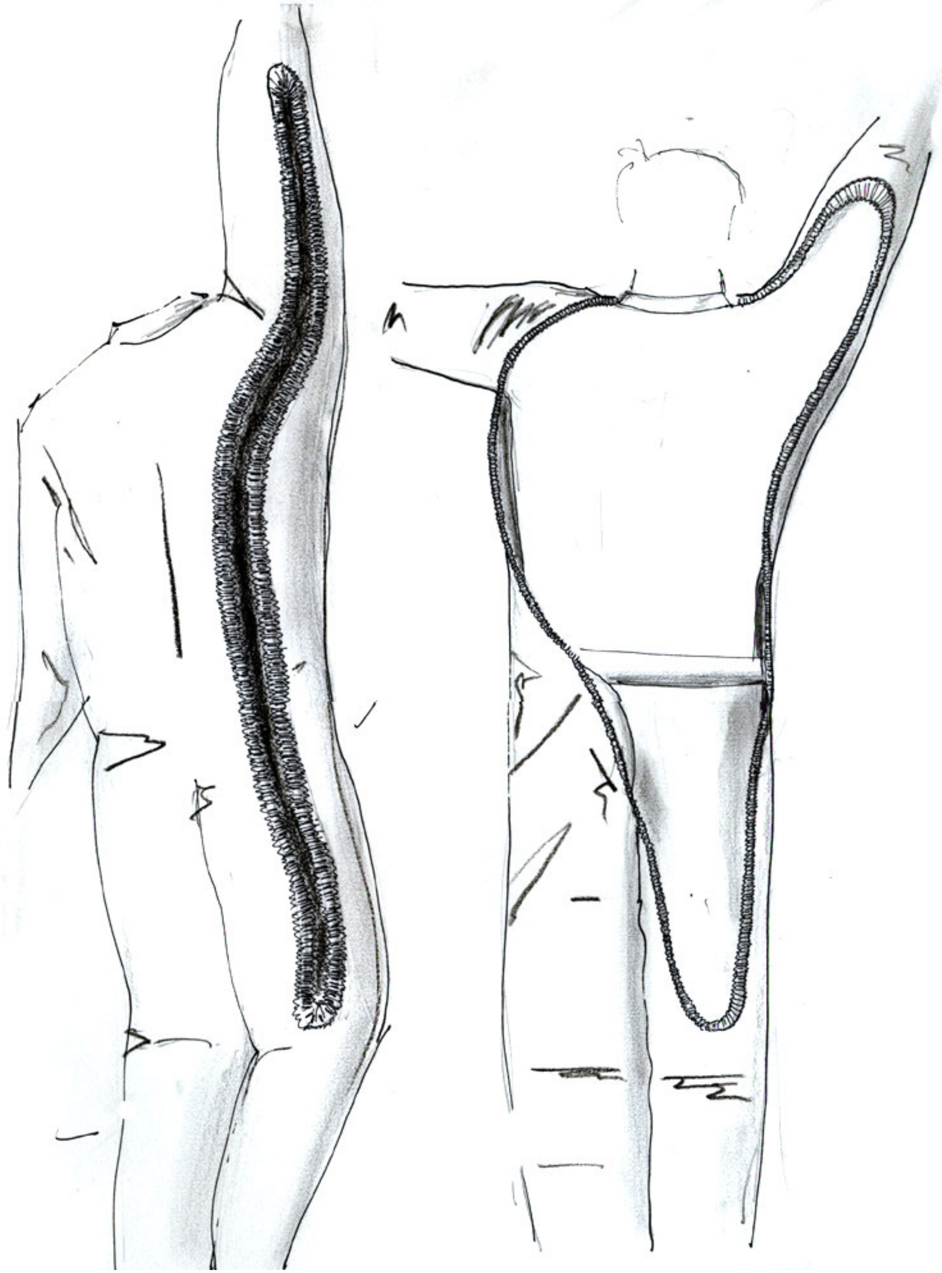
Difficult body positions: putting the head in, one need to full arm and leg inside

Deadlocks: Search fro Velcro

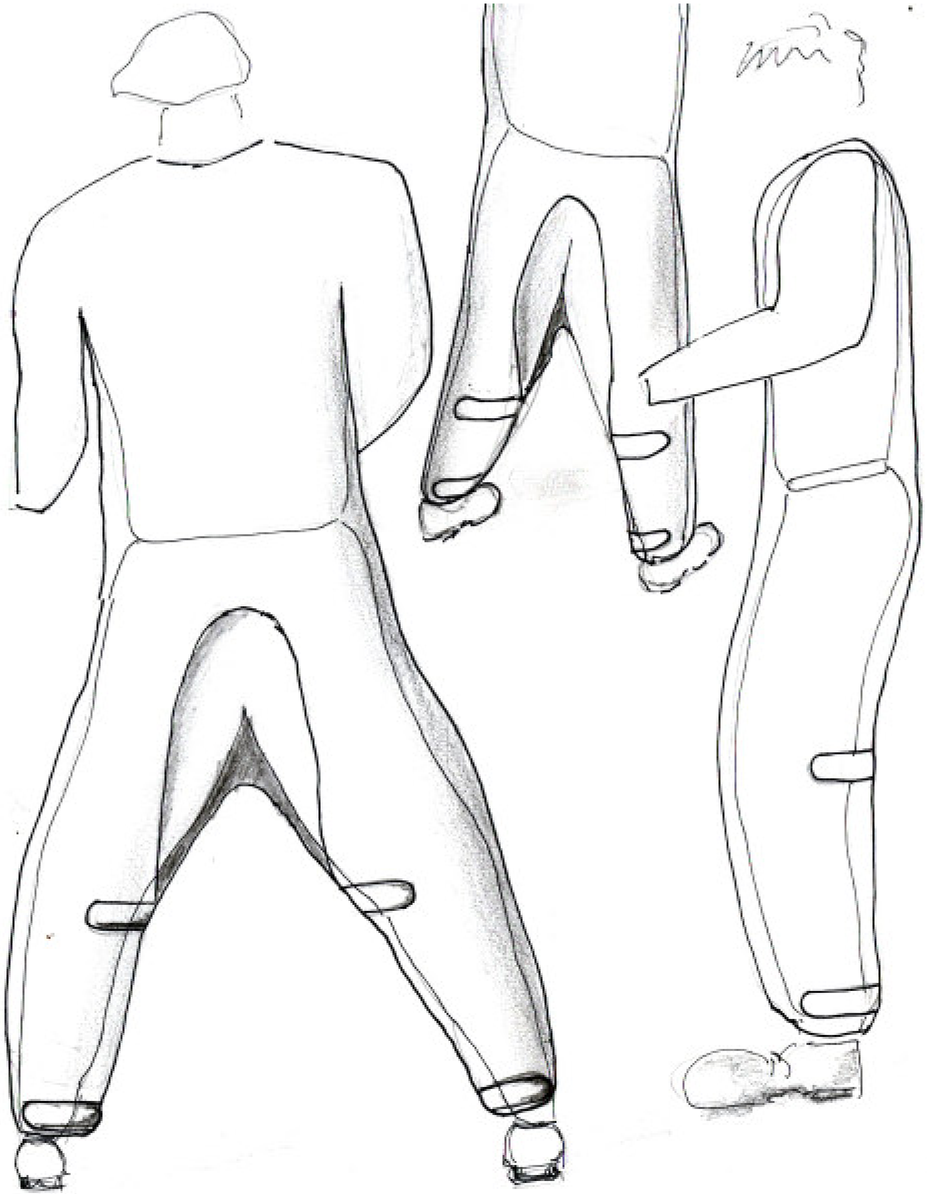
Difficult body movements: stretching down to put head inside

Accommodation of percentiles:

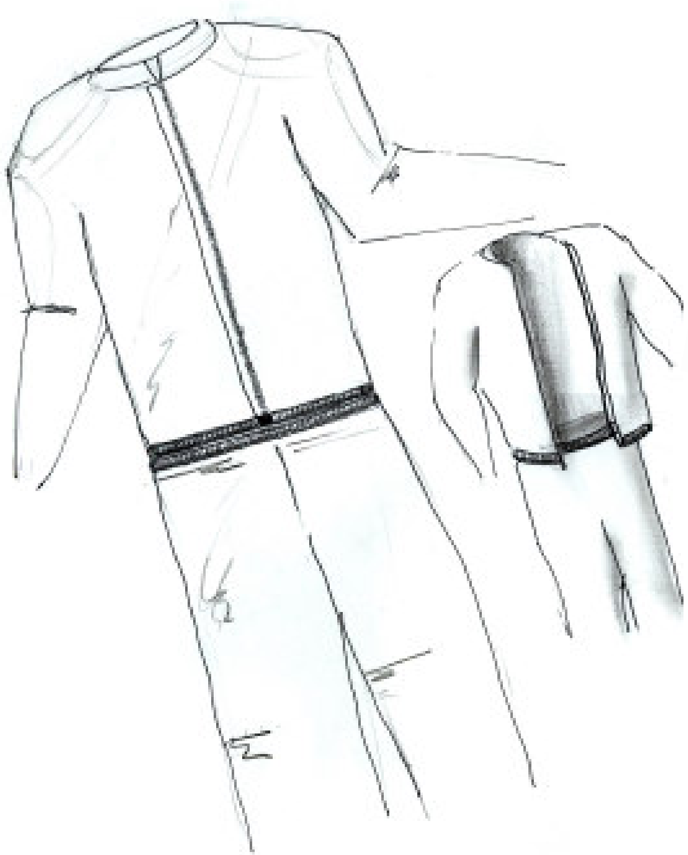
- without flexion, the suit is good enough for lower percentiles only
- Locating the strap at the back is difficult for higher percentiles

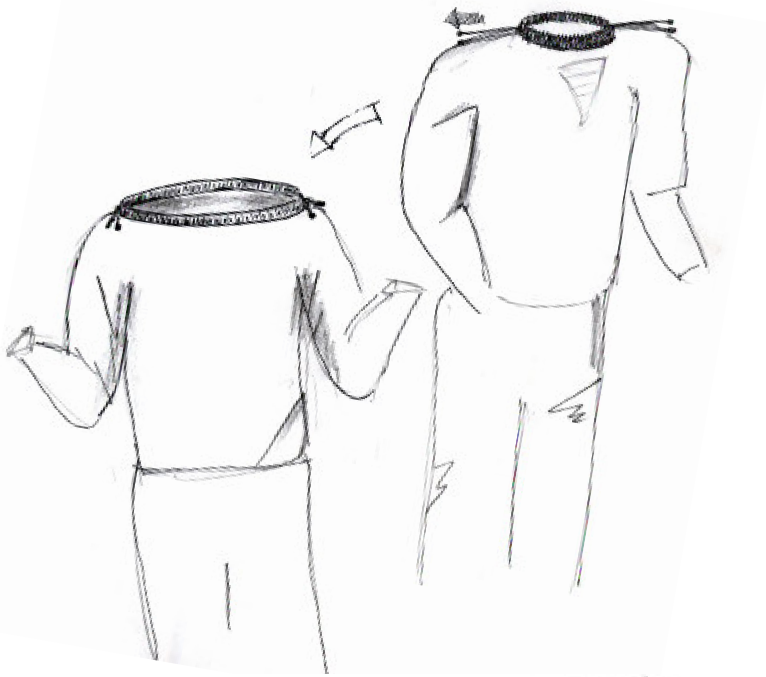


Some other concepts

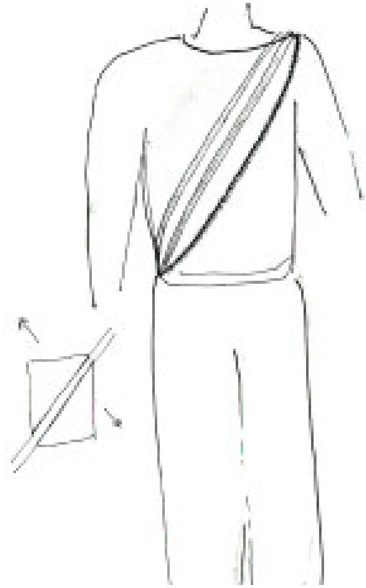


Entry from the bottom

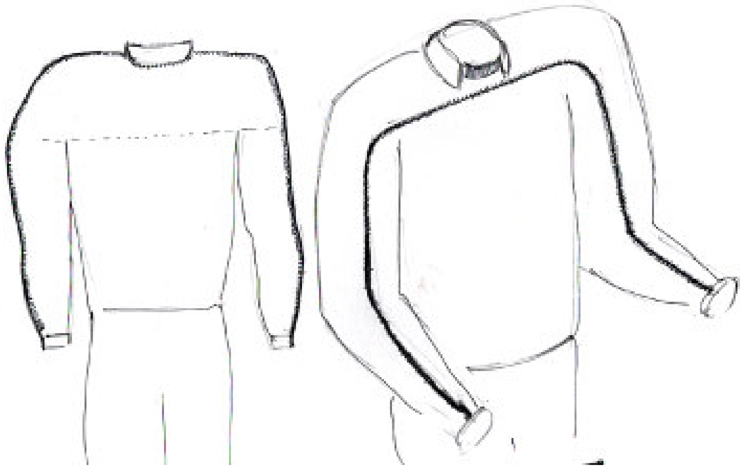




Entry from top



Diagonal split



For selecting the right concept it was important to actually try them out. Five concepts were selected to be tried out. They were made out of cotton boiler suits with some modifications. Some things like molded chains were simulated with ordinary chains because one needs to specify the length of chain in such cases. The subjects were selected to cover the percentile range from 75 to 99.

75 percentile subject was short in height (5'1") but slightly plump. The 99 percentile is tall (6'1") but on the thinner side. Other three are average built and height.

Since the new designs are competing with a design which has been for sometime and its usage comes with a element of practice. The practice reduces the donning time substantially for the existing front entry suits. However since this is expected the time comparison was done only between the new concepts. The subjects were extensively briefed about the procedure for wearing the new concepts and were asked to rehearse the act 3-4 times before they were shot for the camera. The subjective responses of the subjects were noted and have been tabulated.

		1	2	3	4	5	6
no of steps	ingress/egress	5/5	7/7	6/6	6/7	15/13	6/6
Time taken	ingress/egress	21.4/18.2	42/22.6	29.8/28.2	23/16.2	72/54.6	53.4/18.5
Ease of locating elements in donning		6.8	7.8	5.8	8.8	5.2	4.6
Ease of positioning body for certain operation		5.8	6.6	6.2	8	5.6	5.4
Maneuvering through awkward body positions		4.8	6.6	6	8.2	6.6	5.6
Operating chain/Velcro		8.8	6.2	5.4	5.4	4.2	4.4
Accommodation of percentiles		5	8	7	6	8	5
Accommodation of gadgetry		8	7	8	5	5	4
Balance		5.8	8	7.4	8	6.2	5
Visual appeal		7	6	8.4	4.8	8	4.6

Final selection

As seen from the score the first three concepts shared equal points but the finally selection was based on the issue of manufacturability and integration with the matrix for ducting.

Since the fourth concept was in direct interference with the matrix it was outright rejected

	1	2	3	4	5	6
Ease of locating elements in donning	3	4	4	1	5	6
Ease of positioning body for certain operation	4	2	3	1	5	6
Maneuvering through awkward body positions	6	2	3	1	2	5
Operating chain/Velcro	1	3	2	4	6	5
Accommodation of percentiles	4	1	2	3	1	4
Balance	4	1	2	1	3	5
Visual appeal	3	4	1	5	2	6
Accommodation of gadgetry	1	2	1	3	3	4
Time taken	1	3	2	1	4	3
Total of ranks (minimum will be the best)	27	20	20	20	31	45

The concepts 2 and 3 were selected for further development

Three options are possible in such scenarios

Integral suit

(ducts fitted with the fabric)

External ducting

(independent and placed over the suit fitted in a harness)

Internal ducting

(fitted on a harness inside the suit)

It has already become clear after these experiments that the designs will work best when there is equal weight distribution all over the suit. Because as we see what was happening in the first prototype. A strap running over the shoulder and connecting the front and back half of the belt had to be provided to counterbalance the weight of the suit. There were other issues also. Also it has been decided that since the selected fabric for the outer suit is not comfortable to wear directly it has been given an inner layer of fabric for that reason. Whatever be ducting plan it will have to be developed keeping this plan in mind.

The details will be subjected to lot of condensation so they'll be needed to be dismantled and cleaned occasionally. This called for an arrangement which can be removed from the suit and kept aside for cleaning. This will also be the case when the suit has to be given for washing and sterilization.

The issues which had to be analyzed to select the right arrangement are

- The ducting will have to be removed form time to time to clean and repair.
- The ductings are made of thermoplastics which will not be able to sustain high temperature.
- The ducting should not interfere or cause discomfort to the worker.
- The condensation happening inside the ducting should be taken care of
- The product needs to be stored and tucked away properly.
- The suit should be able to sustain some extent of manhandling
- The suit should have an aesthetic appeal
- The arrangement should leave scope for value additions like storage spaces etc,
- The arrangement should take care of the safety of workers in case of freak accidents

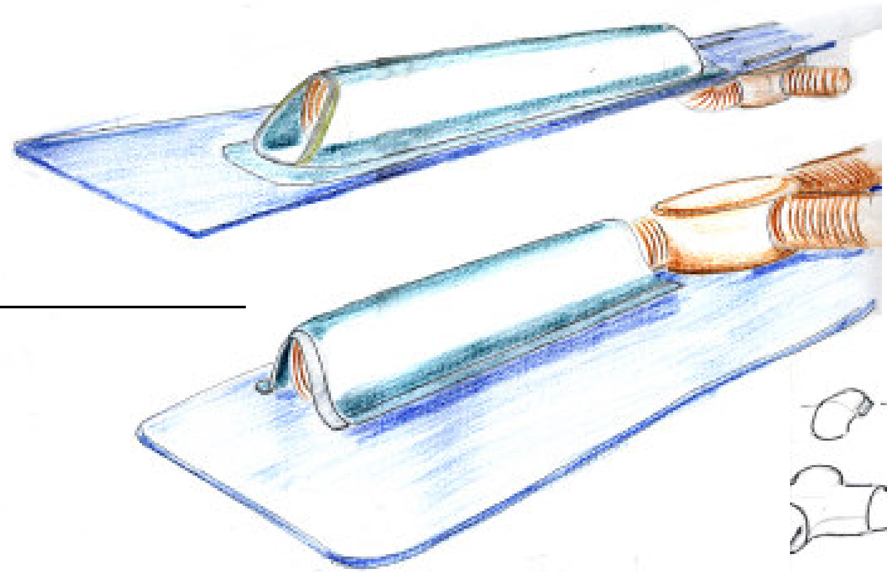
Keeping these in mind three concepts were developed to certain extent before one of them was favored in favor of other.

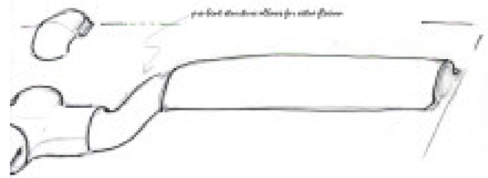
Integral suit

There are several options for mating the fabric with the outer insulating fabric.

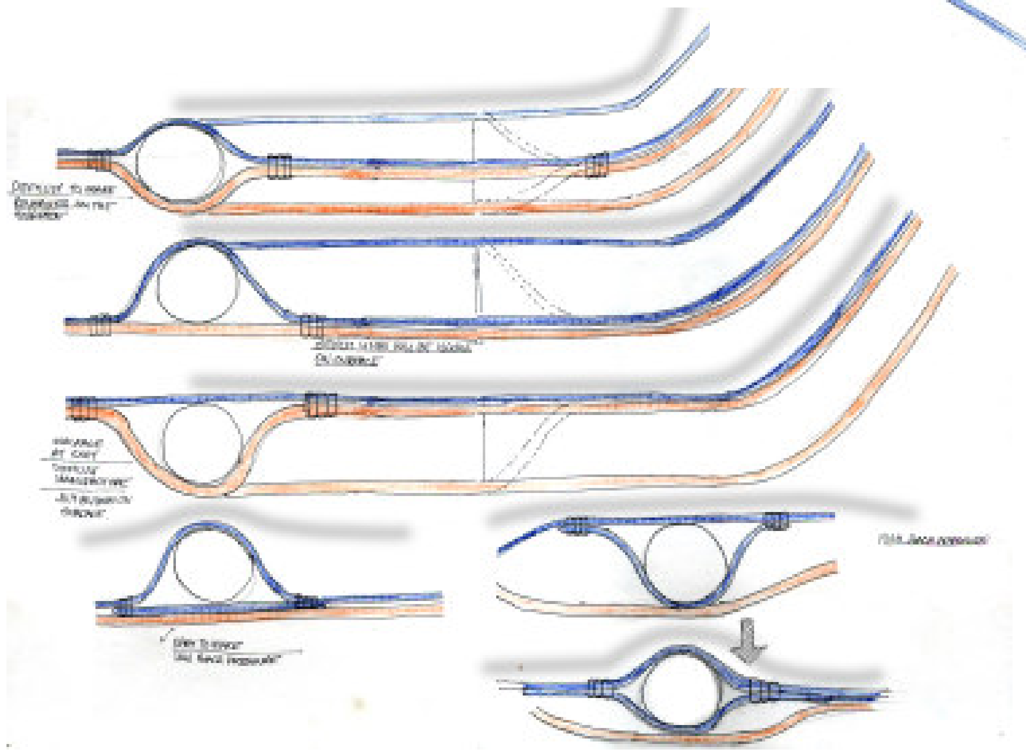
The ducting can be either stitched on the inner fabric or it can be inserted inside the two layers of fabric. There is also a possibility of removing these ducting from the suit by using Velcro.

The details can be either provided garages stitched on the fabric or they can be sandwiched between the two layers with suitable padding inside.





possible ways of stitching



Advantages

- The integration of the suit with the suit allows for easier maintenance of the product
- The ducting is designed to be easily removable from the suit so that the suit can be cleaned and sterilized.
- The sandwiched cross section of the stitching helps to isolate ducting from skin, hence negating the possibly of cold shock.
- The sandwiched structure allows stiffening of suit around the back and front sides of suit which is helpful is circulation of air inside.
- The fact that the ducting will be loosely strung inside the suit with limited mobility helps in accommodating awkward movements and postures of workers.

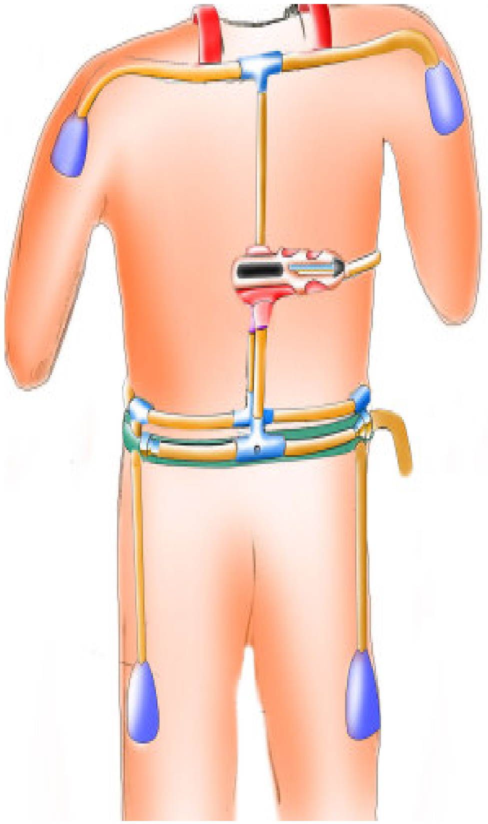
However some experimentation and study of the scenario reveals some serious disadvantages.

- The suit develops a structural rigidity which can get uncomfortable to workers.
- The fabric which insulates the skin from cold ducting will get wet due to excessive condensation and create moist conditions inside the suit.
- The presence of ducts inhibits provision of other features like pockets and clamp fixtures.
- The ducting in contact with the outer heat resistant fabric will have to bear some conductive heat load also. This reduces the efficiency of the mechanism.
- The ducts create bumps on the surface of the suit which will ask for aesthetic treatment again.
- In case of impacts the details are not protected and will bear somewhat direct impact.

Suit with External ducting

This suit has the advantage that the suit will be a system level solution to the problem. The ducting will be concealed inside a harness which is worn over the suit. Here lies the possibility that the suit can be a unit which can be provided to all the workers in the factory and harness is given to the worker who needs cooling inside. This is a more lucrative proposition for the management which can cut down on the cost of purchasing the cooling unit with each protective suit.

The suit is worn like a harness which houses the ducting. After wearing the worker simply attached the blue pods in the Velcro. There are four entry points which duct the air inside the suit.



However, this concept banks on certain feeble possibilities

- Easy availability of heat resistant details like pipes and coupling coming outside
- The suit which will have to bear some level of radiant load.
- Management which is willing to either modify the clothing of all the workers or purchase some quantity of such suits. Purchasing just one or a small number is an underutilization of the idea.

This plan had some advantages as mentioned above. However it had some drawbacks also.

- The low pressure air will have to pumped inside like in existing suits which reduces its efficiency
- The external ducts can be hassle for constrained environments. They might get entangled with machin-ery and become a hazard also.
- The proposal of purchasing several suits made out of the selected fabric is a costly proposition

Internal ducting arrangement with a harness

After exploring possibility of putting ducts within or outside the suit the possibility left was to place the ducting inside the suit on a harness.

This area seems promising for these reasons

- The ducting can be firmly strapped on the body and free up the suit which can now easily adopt the body contours.
- The firm grasp on somewhat heavy parts like vortex tube (700 grams) allows workers to concentrate on their job rather than bother for dangling weight on his body.
- The ducts will be effectively insulated from the conductive load .also the skin can be easily insulated now from the cold pipes avoiding cold shocks.
- Since the suit requires frequent cleaning in comparison to the ducts, this concept as two separate elements works out much better as compared to earlier concepts where the entire ducting arrangement will have to be dismantled for cleaning
- Two separate elements allows for easy storage because the suit can be easily folded now.

After analyzing the advantages and disadvantages the decision went in favor of internal ducting arrangement.

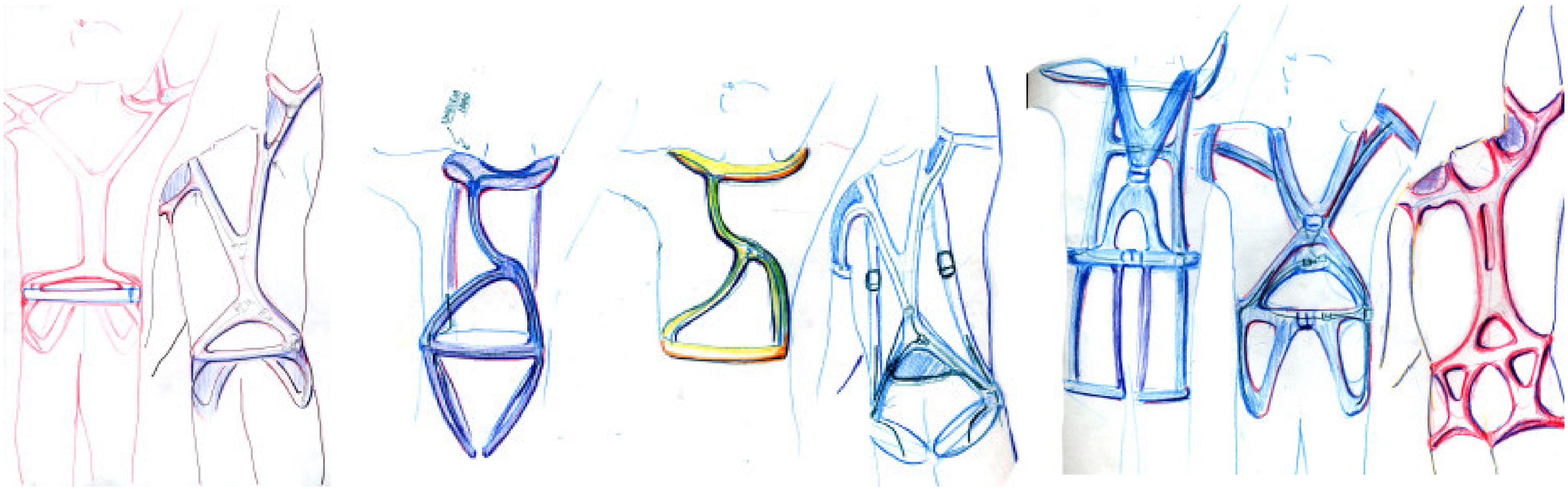
Since the matrix has already been worked out the basic architecture of the harness was already there. What needed to be done was

How can the harness accommodate maximum percentiles without many adjustments?

This becomes necessary given the fact that the worker still needs to wear the suit from here. If he spends too much time on finding his way in and then moving inside the jacket he will develop the sort of apathy which I discussed in earlier chapters (refer page)

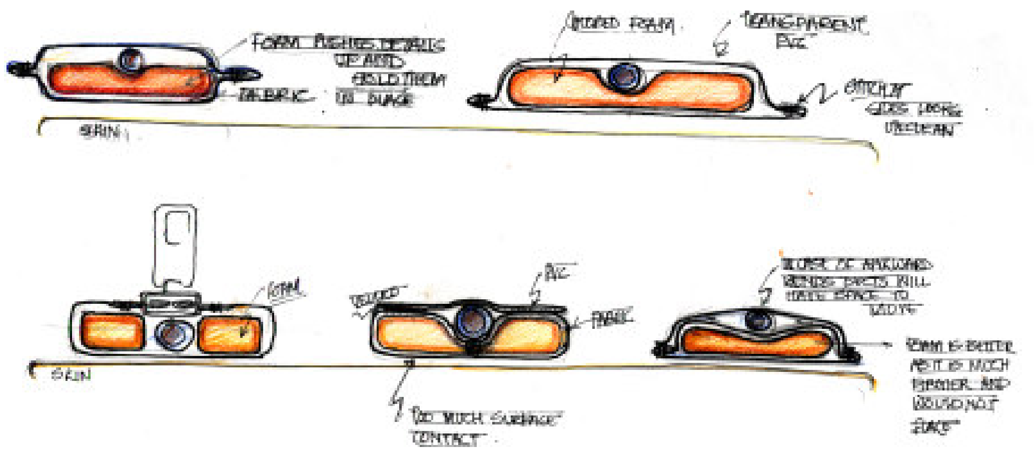
With little imagination I saw scope for creating sculptural value in the harness. It was an effective tool to highlight the body parts like muscles and arms. Also some intrigue was developed due to use of transparent PVC on some lengths.

Aesthetics.

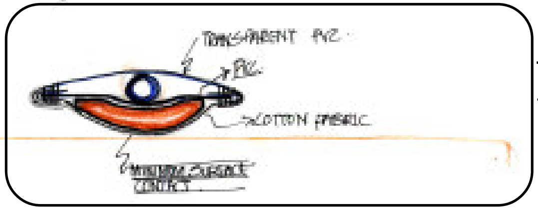


What should be the sort of cross-sections which will not only insulate the pipes from the skin but also provide for easy assembly of ducts? Also desired was housing for details with easy access.

Cross-sections



Since the basic matrix has already been finalized what was needed was to identify features in all the designs integrate them in the final design. Some of the features identified were



This is the cross section selected for its easy manufacturability and minimal skin contact

Split arms which expand with the size of arms.

Shoulder rest which spread the weight of harness and suit over the shoulders.

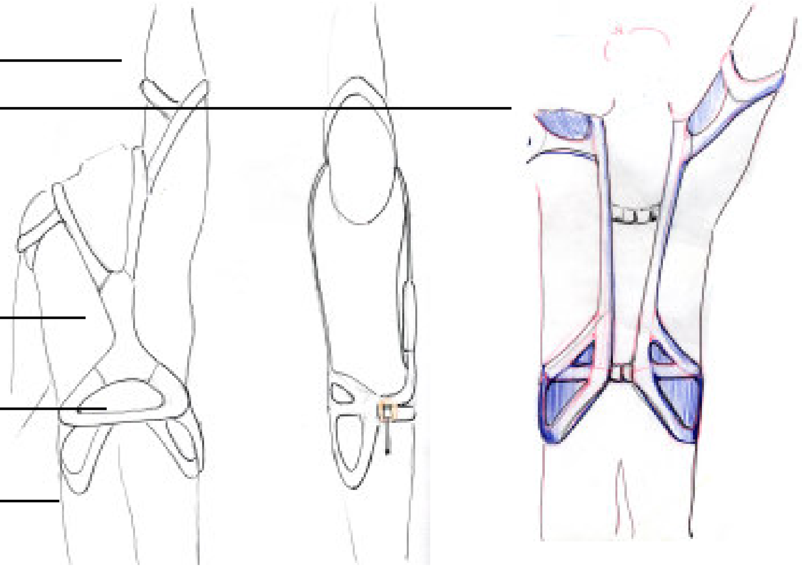
Single point access to nearly ail the details.

Easy assembly

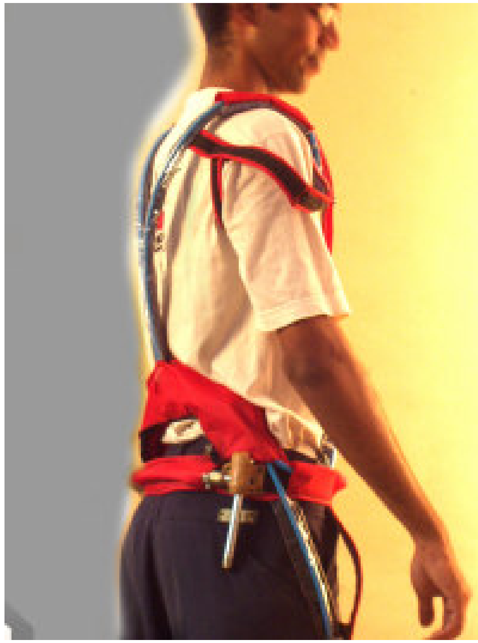
Ample space for attaching details. Ample space for attaching details.

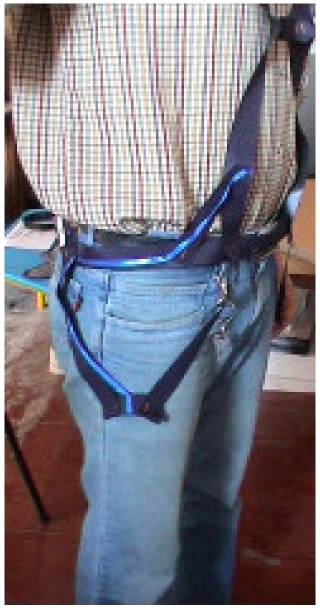
The curved structure at the back allows for forward back stretching during work.

The harness on the leg has been replaced by a structure which laps over the legs and makes it rigid enough to stay in place.

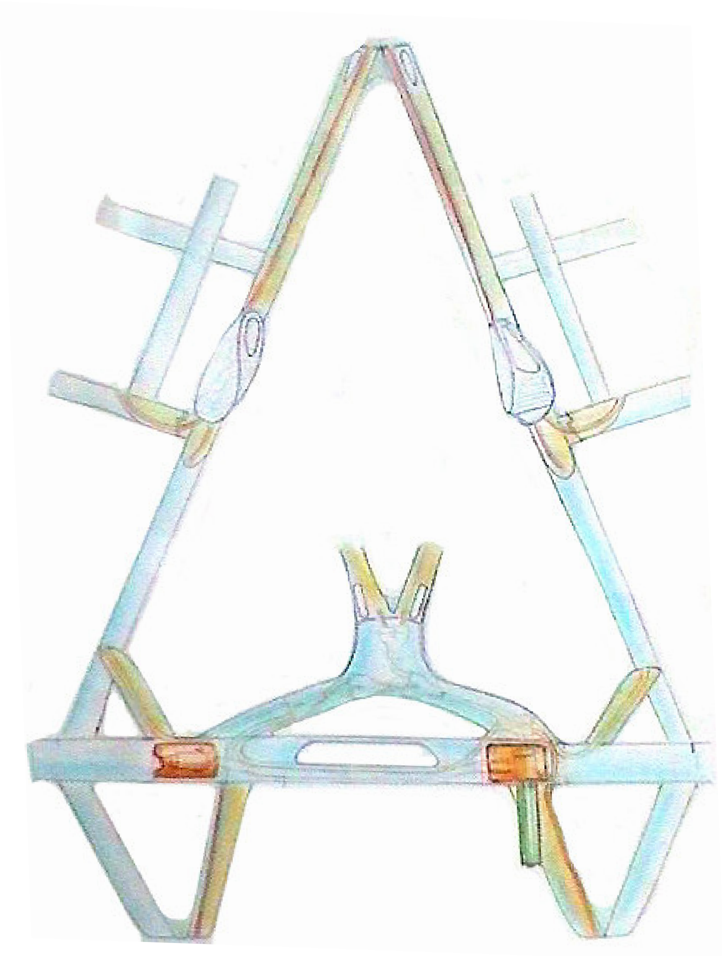


The concept was tried out in stripes of nylon.

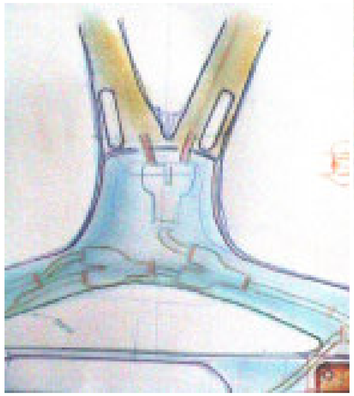


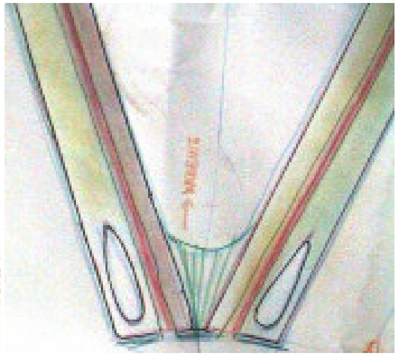


The development drawing with all the details look like this.



Single storage for details, located in lumbar region

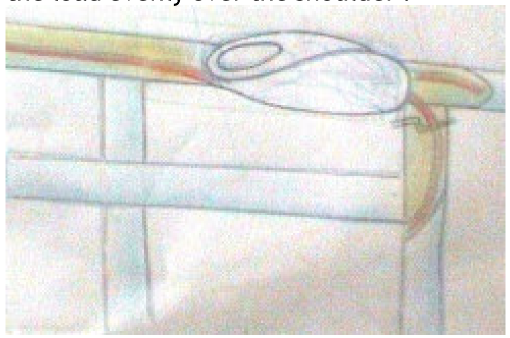


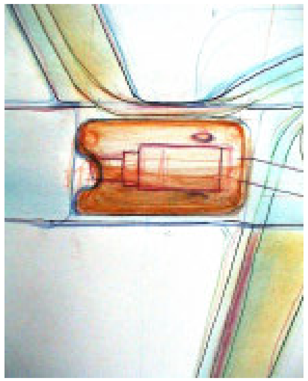


Bellow structure for flexibility

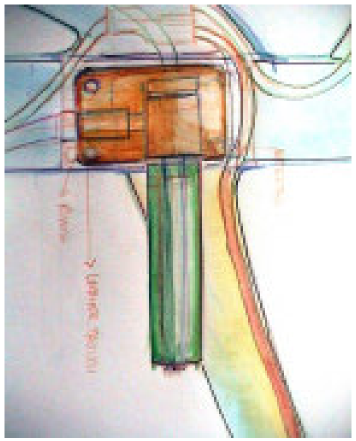
Arched structure for flexing in forward bend.

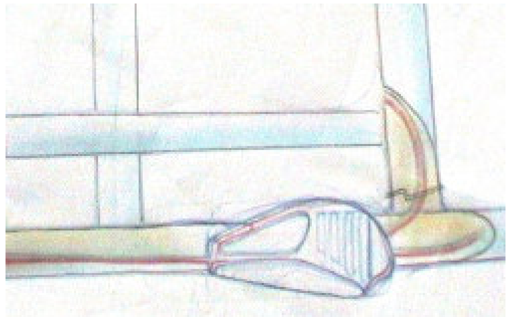
Options in Shoulder rest for distributing the load evenly over the shoulder .





Safety details strung below a leather trough





The final dimension are being worked out to accomodate 50th percentile

Features

- Single piece outer protective suit capable of withstanding 1000 deg Celsius done in silica fiber.
- Internal cooling arrangement worn with a harness capable of cooling the insides of the suit unto 10 deg Celsius(designed to create 28 degrees CET)
- Uniform cooling throughout the body including arms and legs with preference over high heat exposure and high sweat rate areas.
- Patches of reflective surfaces to reflect radiant heat
- Controllable cooling (temperature control available)
- Unique fastening arrangement for stress frees donning doffing.
- Design of duct matrix is keeping in mind to cause minimum interference in work
- Unique light weight details fro minimum weight of the harness
- Provision to accommodate large number of percentiles with use of flexible joints in both suit and harness.
- Provision of gussets and bellows over joints to allow easy worker movements.
- Designed for easy and economical production with simple and straight cutting pattern and easy assembly of details
- Easy to maintain and store. The suit is washable and harness can be disassembled easily for washing thanks to unique quick release details
- Provision of inner voile liner inside the suit for absorbing sweat and condensate from the skin
- Heat resistant zippers further protected by the flap and zipper garages
- Multiple hooking points allow for customization according to workers need
- Refractory and Abrasion resistive surface of suit protects workers from sparks and splinters while withstanding wear and tear
- Design details like upright collars and arm catches for optimum utilization of cool air

- Provision of sufficient clearance between the fabric and skin to allow ample air circulation
- Provision for carrying small tools and accessories like I Cards
- The umbilical arrangement improvised to snap off at two points in case worker wants to make a quick exit
- Provision of fluorescent graphics for easily marking the worker in case of low visibility
- Provision of a special clamp cum hook for bearing the weight of the pipe
- Suit will be anchored at two points to distribute the load
- Insulated ducts to protect from cold shocks
- Smart looks with concealed stitch lines.

The product at this stage had all the basics worked out what remains to be done now was to handle issues which will add USP to the product . These issues came up all through the design process and collected. What needs to be done now was to consolidate them into tangible solutions to individual problems and issues related with the final product. Some of these issues were.

Fluorescent graphics

Heat sealed pockets

Multi utility waist belt

Multiple hooking points

Balanced arrangement

Provision for hanging the suit

Latching device to attach pipes.

Provision for attaching air tools

Isolating zippers from radiant load

Diversion of some amount of air towards head.

Catches for easy removal of legs from the suit.

Multi utility cleaning cloth for workers, inspired form gamcha.

Place for keeping tools like hammers, pliers, poking rod etc.

Heat sealed gloves air cooled by excess air coming out of suit

predictable folding pattern for easy storage for easier storage

Pockets designed to carry tobacco and cigarettes.

Sufficient clearance between body and suit to allow for effective air circulation.

Hot parts of the vortex tube have to be isolated. Self cooling arrangements and reduction of noise from the exhaust

Closer resemblance to casual wear.

Place for keeping goggles and earmuffs

How will the worker bear the load of the pipe?

What will happen in case of a flash fire or a chemical splash?

Provision for regulation of temperature and air flow inside the suit

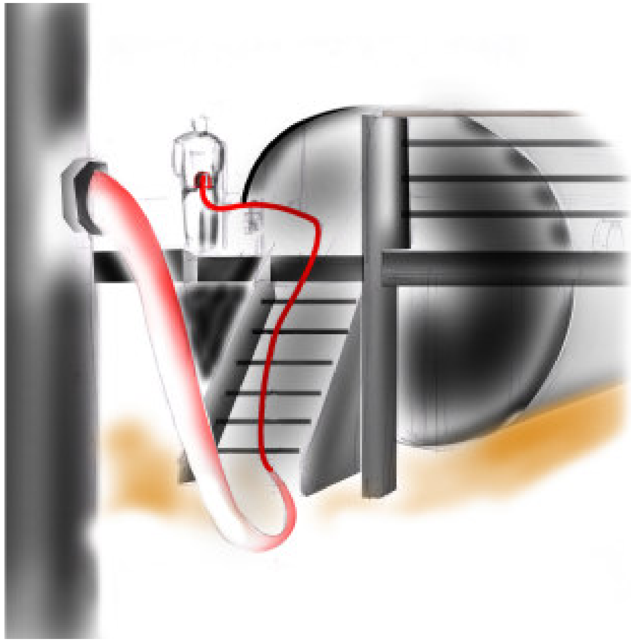
Chains and fasteners which arte able to sustain the excessive temperature load.

Catches provided at the ends of the chain which help to stretch the chain for easy fastening.

Provision for inner cloth liner which is suitable for skin. Minimal contact with synthetic fibers.

How will the worker bear the load of the pipe?

The pipe which is used to conduit the compressed air to the suit is a metal braided reinforced PVC hoses. Such hoses are fairly heavy and dead weight of a 20 foot hose came to around 6 kgs. This could have been tolerated but for situations like these.



This scenario came into picture at the mukand iron where the worker has to climb up the ladle station to keep an eye on the process. Here as shown in the graphics the weight of a substantial length of pipe bears on him. This will be highly undesirable as

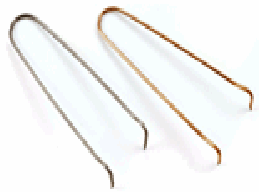
1 it will create a constant back pull for the worker which can be hazardous.

2 it will reduce the effectiveness of proposed quick snap mechanism.

3 it will cause physiological damage as most of the weight will be bore down on the spine.

To tackle this problem ... ded which will bear the weight of pipe and lea... ight on the worker.

Several standard opti... ..

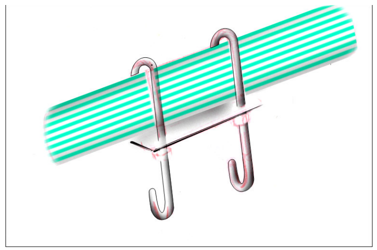


Clamps

Hooks

Pipe straps

Special clamps

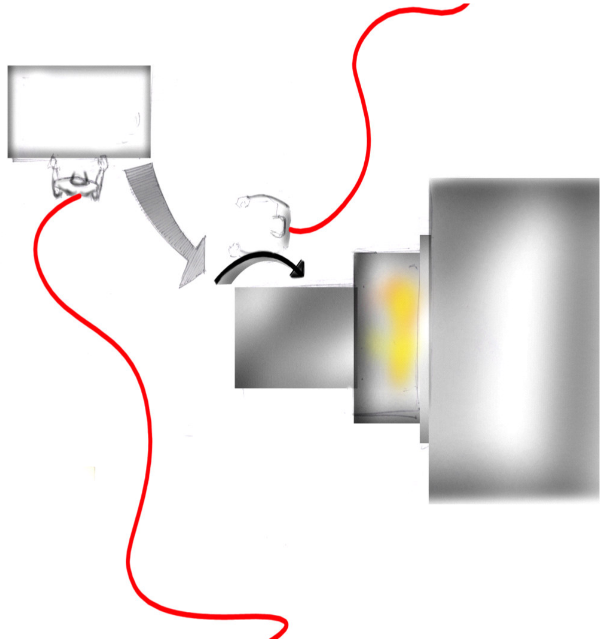


However closer investigation reveals that there are two clamping variables.

1 the distance of the available clamping point from the worker.

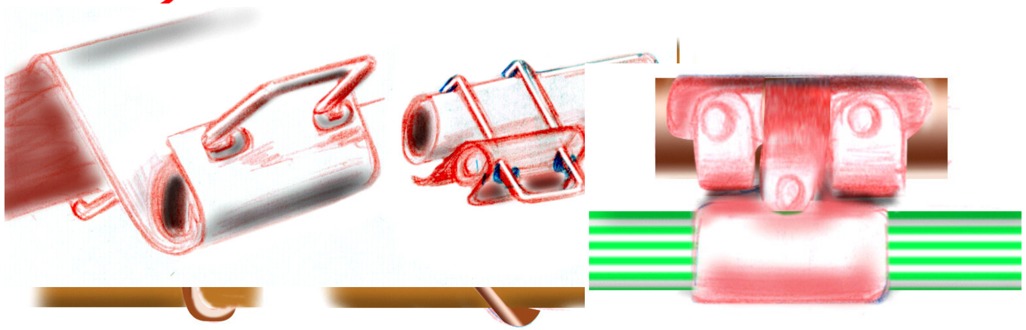
2 the length of pipe from the worker to the clamping point.

These two variables change in different scenarios and it is desired that a clamp should be able to adjust to both of them.



This is a situation in a foundry where the workers have to transport hot material from trolley to furnace .if we look at the worker he has to move a long distance all the while dragging his pipe . but if he gets to clamp his pipe at X then not only he reduces lot of drag but also ensures that the pipe doesn't gets in his way.

These were the option generated



1 twist to lock clamp

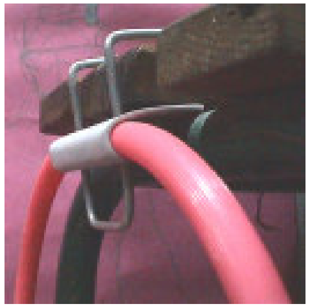
2 clamp and hook combined

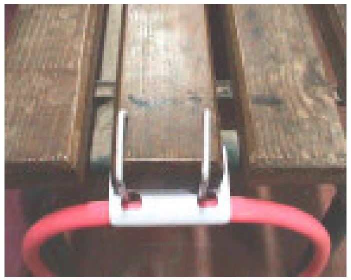
3 leather strap

4 sprung metal clamp

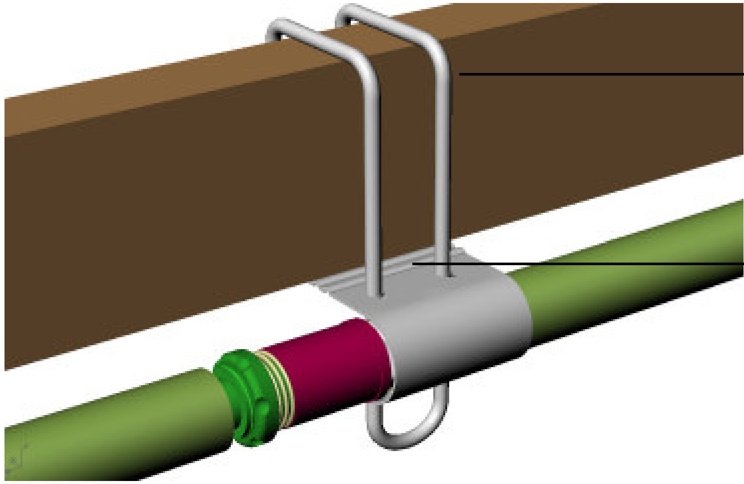
Option 2 was selected for following reasons

1) This will be most cost effective as it requires only a sheet metal strip and a rod.
2) The springing property of pipe itself and its rough surface have been utilized to substitute for spring and clutch.
3) It can alternately become a hook and a clamp.
4) It easily accommodates the safety mechanism also.
5) It will be lot sturdier and reliable than other options





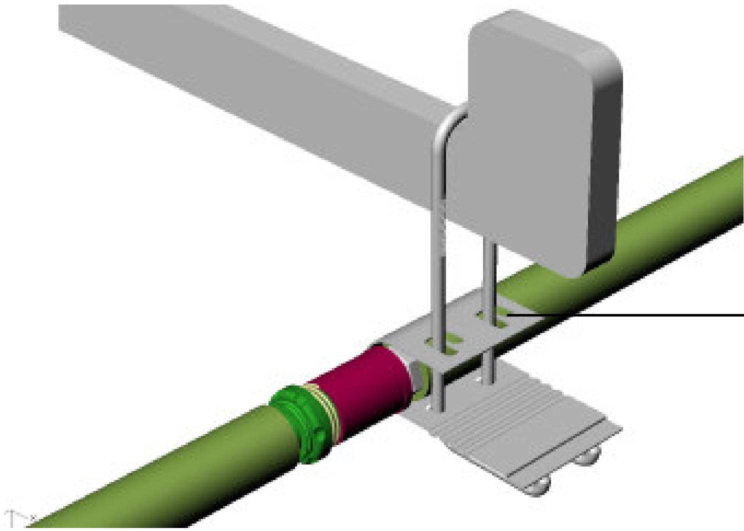
Features



Double clamps for better grip

Nibbled surface for extra grip

Pipe itself is used as a spring



Knurled rods will help to grip the locking edges

Built in locks

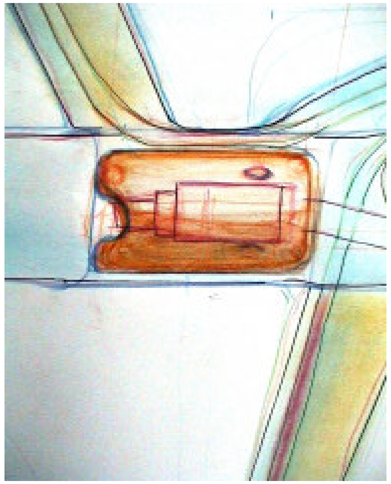
What will happen in case of a flash fire or a chemical splash?

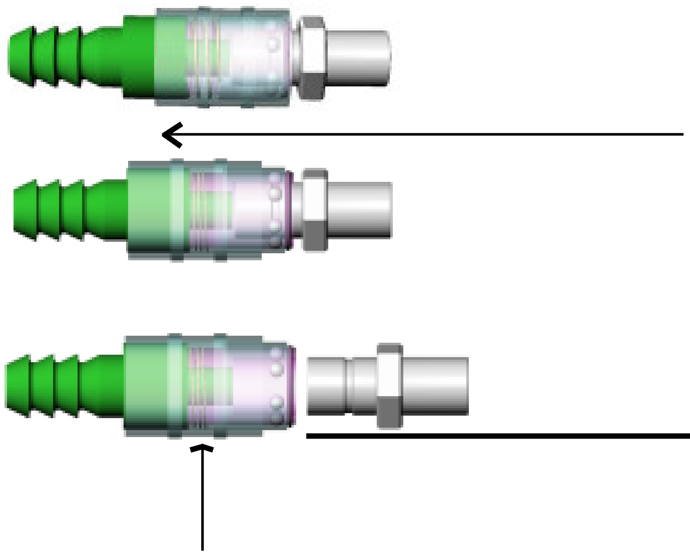
The first and immediate response of the worker would be to run away from the scene. the existing design asks for a pipe which is connected from the suit to the compressor .one end is connected directly inside on the harness . with this umbilical arrangement there is a huge probability that in case of eventuality the worker may not be able to disengage the quick release coupling in time .this is because of the imminent chaos in such situation .

So I need to provide a safety arrangement where in the worker is able to break free from the umbilical arrangement in case of emergency. This was achieved by the small improvisation in the existing quick release coupling.

The details of this arrangement are as shown below.

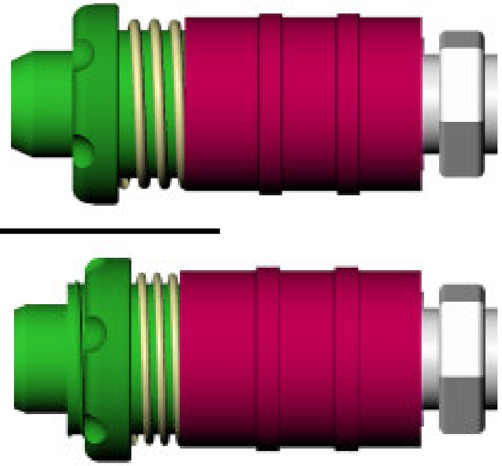
Two such QRCs will be used. One is housed in the harness while the other will be placed after the clamp. If the first coupling in housing doesn't snap, the second coupling will get hooked in the clamp and will snap off. This will complete the **double level of security** for the worker in case of fire.



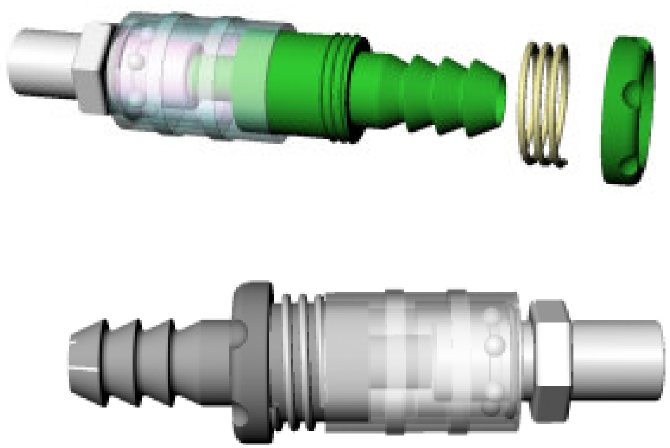


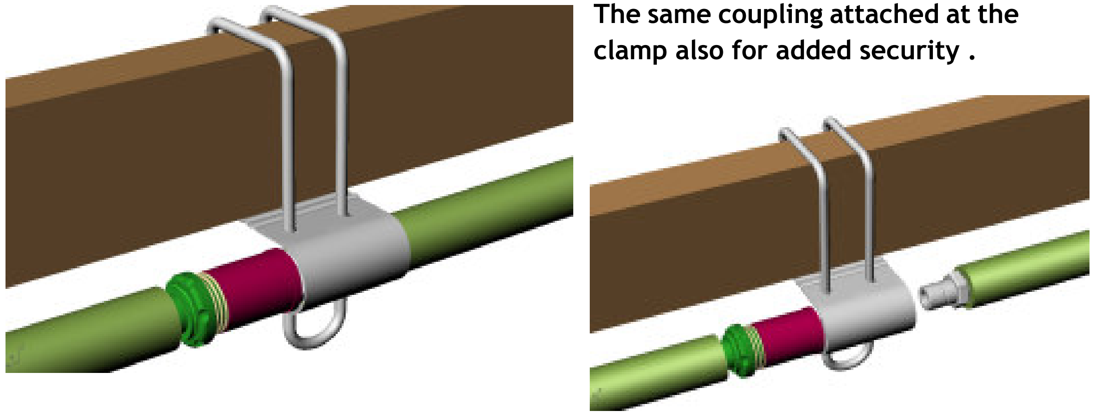
A normal QRC is released by pushing back the collar which is held forward by the spring on the inner core. The female plug is pulled out from the other end easily since the balls which were supported on the collar are now free. Fro this process the collar is simply pulled back while the QRC is pulled from the ends. however if we grab the QRC from the collar and try to pull out the plug it comes out only after application of certain fixed force which depends on the spring coefficient (k) of the spring . This sequence can very well be utilized as a safety device. We need a coupling which will give away on application of a given force. This force is a little higher then what worker will apply in normal work but low enough so that the coupling comes out when needed. The improvised use of QRC in this case is to grab it by the collar when it is installed in the harness. Also the spring needs to be loaded to the right force which needs to be calibrated.

An another improvement of this arrangement will be to allow for worker himself to adjust the coupling if he sees that it coming out easily in normal work. This is done by increasing the size of inner core by a centimeter and putting a spring on it which can be in addition to inner spring and giving a knob like collar which runs over a screw. This arrangement will allow adjustment of spring tension as and when required.



The assembly is simple as shown. The spring is pushed in on the collar and knob is screwed behind it.

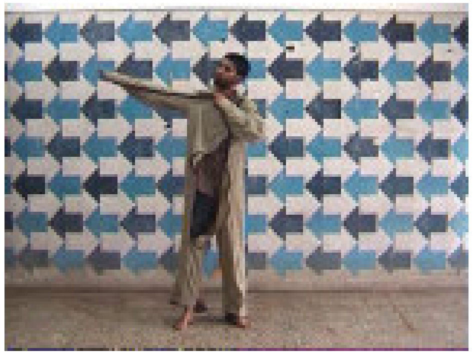




The same coupling attached at the clamp also for added security .

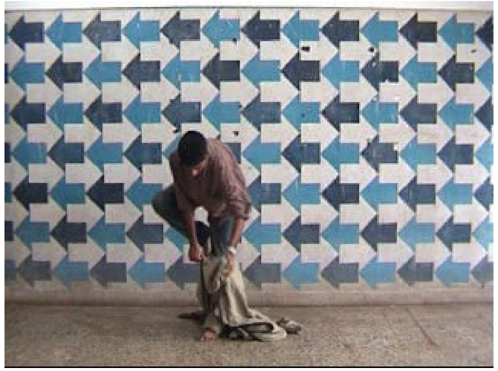
What improvements can be made in the suit?

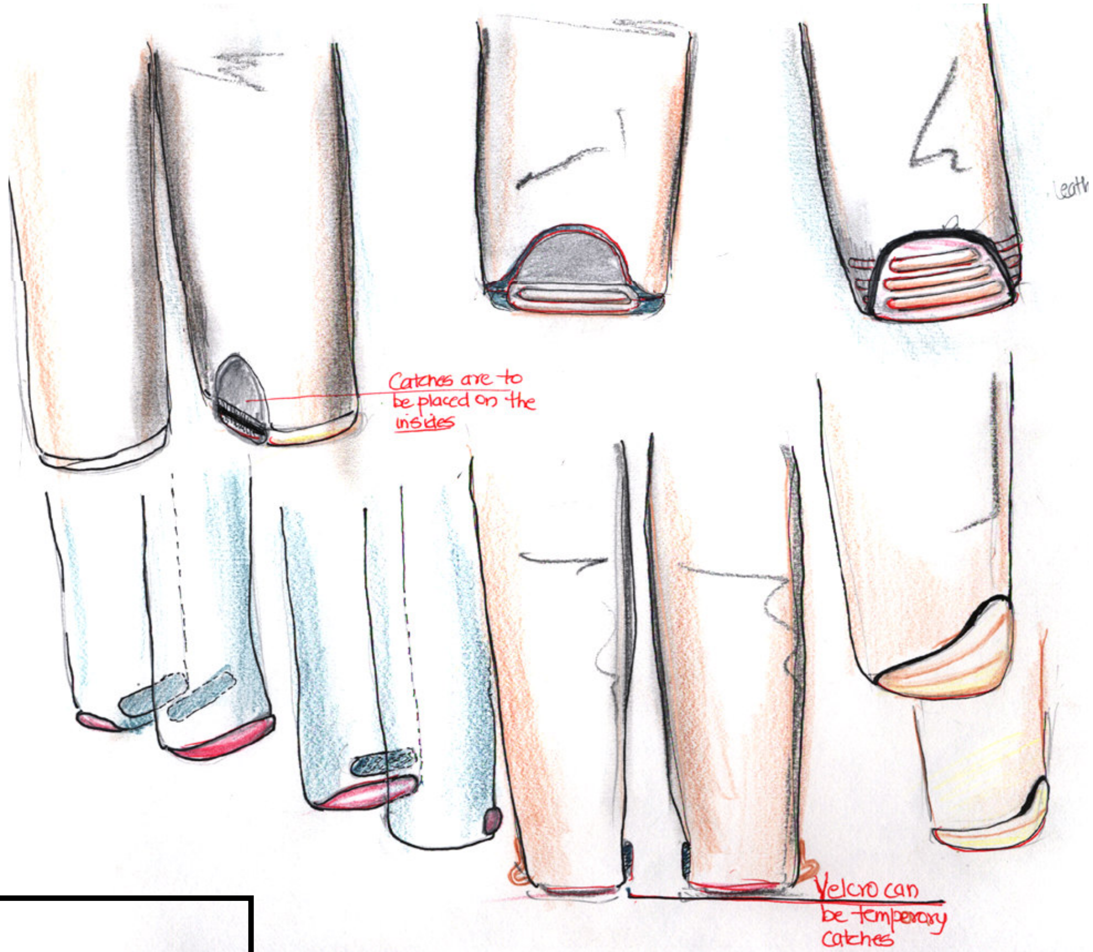
This came to my notice during step by step study of donning doffing concepts. In case of longer chains use finds it very difficult to stretch the chain at the palm end because the edge usually runs up in such cases. What was needed a suitable catch which allows for easy stretching of chain



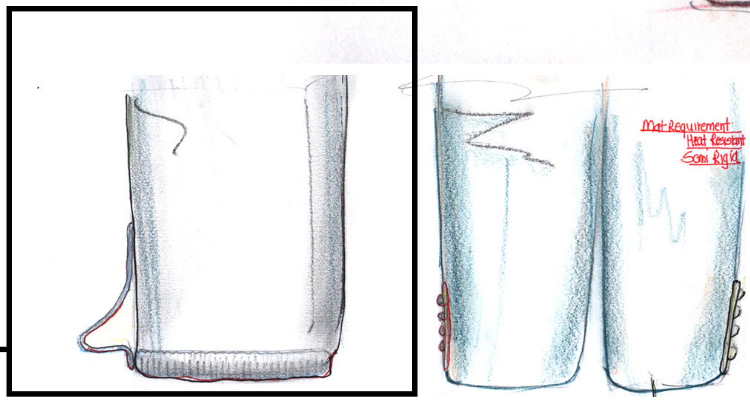
This concept was selected because not only is this very positive and comfortable but is has the added advantage that it has a slit which allows some air to move into the gloves which will also be cooled.

Similarly, some difficulty is observed when the worker has to pull his leg out of the suit. Most of the times the users have to bend down and grab the suit and pull their leg out. Otherwise, some of the users used their other foot to grab the suit and pull their leg out. This is unacceptable as this not only makes the suit dirty but also destroys the edges in the long run. Some concepts were developed for such catches for legs to be made in the same fire proof material.





This concept was selected for its ease in manufacturing and minimal use of expensive material .



Material selected for the fabric .

We needed a outer material which

1) can sustain outer temperatures close to 1000 degrees
2) is fairly abrasion resistive
3) has a reflective silvery outer finish
4) is available easily
5) is cost effective

Some of the criterion for selection was laid out by the sponsors themselves as they were keen for a fabric which does not have to go through import barriers thereby increasing hassle and cost.

URJA PRODUCTS Pvt. Ltd. is marketing High Silica products manufactured by leading American Company on exclusive arrangement. These are engineered textiles having Silicone Dioxide content (Sio2) of minimum 96%. The main feature is their capability to withstand temperature in the range of 1000C to 1200C.

Products include:

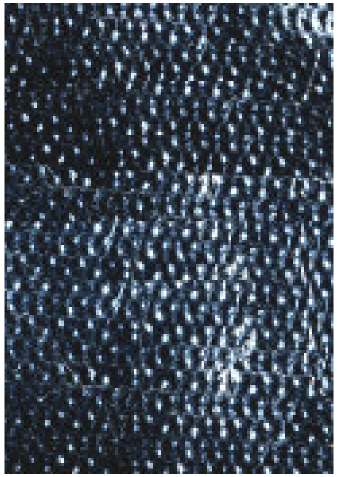
1. Fabrics.
2. Tapes.
3. Ropes.
4. Sleeves etc.

Unique as they are in their characteristic for being non-carcinogenic, they are the best alternative for asbestos

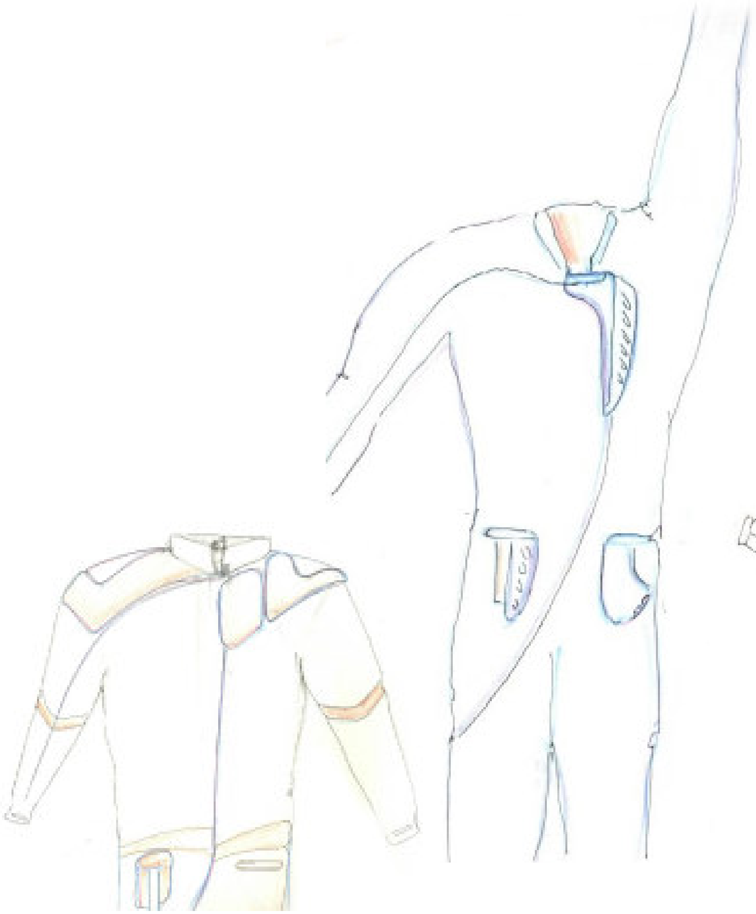
Aluminized Silica fabric (ALUM 84 CH) is Aluminized to reflect heat as well as Rubberized fabric (SILRUB 84 CH) is extensively used in Expansion Joints to convey hot flue gases. Both these are coated Silica fabrics which essentially find use in areas exposed to atmosphere. These fabrics are used on the outermost layer.

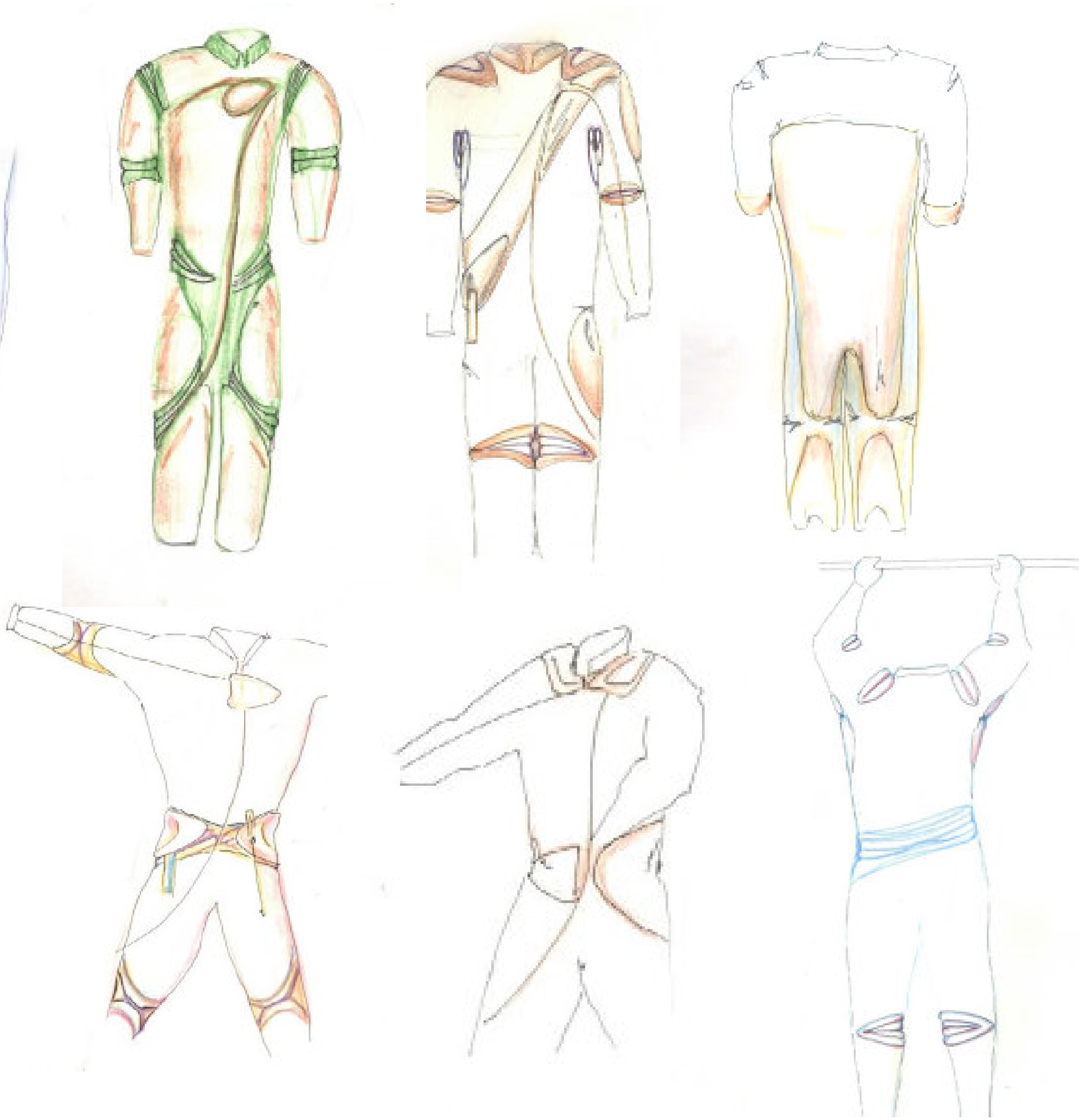
SILRUB and ALUM had their own desirable properties. Since SILRUB is softer it is a good option for fabric which runs over the joints. While ALUM is a fabric which is reflective on the outside. so it was decided to go ahead with both the fabrics and come up with a cost effective cutting pattern which will economize the cost of fabric .

the inner liner for the suit will be 1*1 or 1*2 cotton or voile.



After finalizing the basic design the scope pf the project shifted to aesthetics where in this product was to be finished into a marketable appeal. I'm outlining my initial forays in this area. The constraints and scope of this exercise were uncovered at this stage.





I would like to thank my guide Prof G G Ray for his constant support and encouragement in this difficult project.

I thank the entire IDC faculty for being kind enough to lend their precious time and giving valuable inputs.

My sincere thanks to our sponsors Mr. Satish Shenoy, ESSEN Engineers for sponsoring the vortex tube and their consistent technical feedback and support.

I also extend my gratitude towards Mrs. Usha Batra , HOD , Deptt of apparel design and manufacture, SNDT and her staff for their feedbacks on the manufacturing aspects of the design.

I wish to thank Prof (Retd.) S K Chatterjee, MR P C Ghosh (CLI, Sion) for providing me valuable physiological data.

sincere thanks to Dr. Amit ganguly, Chief R&D and TQM , for allowing us to visit the facilities of MUKAND IRON LTD. and interact with the workers.

We thank the worker of MUKAND IRON LTD for providing us valauable feedback .

I wish to thank all my classmates for standing by me whenever I needed them most.

I also extend my gratitude towards the staff of IDC for their help

- Ashish

Books/Journal

1 **“Fluid mechanics”**

24th edition: R K Khurmi

Gupta publishers

2 **“the physiological basis of medical practice”**

Eight edition: Charles Herbert best and Norman burke Taylor

The William and Wilkins co.

Baltimore 1966. Scientific book agency, Calcutta

3 **“Textbook of Medical Physiology (Textbook of Medical physiology”**

10th Ed, Arthur C., M.D. Guyton, John E. Hall

4 **“heat stress study in an iron and steel plant in southern India”**

Study conducted by Central labor institute

Dr. S K SENSARMA

JOINT DIRECTOR (PHYSIOLOGY)

5 **“Study of accidents and physical environmental working conditions in iron and steel plants forging plants”**

A multi disciplinary scientific approach, evaluation of thermal stress in a forging plant and its impact on the physiological responses of the workmen.

Dr. S K SENSARMA, Dr S K DATTA

6 **fashion illustrations**, Nicholas drake

7 **“Design of thermal insulation ware for industrial workers”**

Poornima K Shenoy, IDC, IIT Bombay.

Useful websites

Thermal comfort

http://www.unl.ac.uk/LEARN/port/1998/mulcom/web/comfort/index.html
http://www.glaciertek.com/cooling.htm
http://www.osha-slc.gov/dts/osta/otm/otm_iii/otm_iii_4.html#6

Material/technology

http://www.tyvek.com/
http://www.artxltd.com/vortex/principle.shtml

http://www.neumaticshoppe.com/html/hydraulic.htm

Industrial wear, sports wear

http://www.arcteryx.com/chooser.html?1
http://www.nflstore.net/cgi-bin/nflgen.pl?tm=HT

Contemporary designs

http://www.inductotherm.com/safety/safety5.htm
http://www.kazafire.com/kaza/special_globe1.html
http://www.surplusandoutdoors.com/ishop/877/shopscr1.html

http://www.tasco-safety.com/ergonomic-safety-products.html