Design and analysis of thermal therapy pad

A DISSERTATION

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IN

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Submitted by:

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CANDIDATE'S DECLARATION

I, Harsh Shyam, Roll No. 2K16/THE/09 of M.Tech (Thermal Engineering), hereby declare that the project Dissertation titled "Design and analysis of thermal therapy pad" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled “Design and analysis of thermal therapy pad” which is submitted by Harsh Shyam, Roll No. 2K16/THE/09, Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Date: **SUPERVISOR**

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ABSTRACT

In medical technology, the advancement of thermal therapy of either heating or cooling gives an extra edge that are intended to improve the quality of healthcare. Thermal therapy pad is a device which can influence blood circulation at an injured site, to a specific area of the body and increase the comfort of the patient. The main purpose of thermal therapy pad is to enhance the heeling process. Localized thermal transfer helps to provide one or more of the therapeutic effects. These effects refers to the acknowledgement after a treatment of any kind, the results of which are judged to be indispensable and effective.

The Mul-T-Pads are disposable thermal transfer devices for use in a Localized Temperature Therapy system. The Mul-T-Pad, disposable pads are intended as thermal transfer devices for use with a Temp Pump Localized Therapy Pump, which supplies warm or cold water at controlled temperatures for the application of localized therapy in situations where a physician determines that temperature therapy is necessary or desirable.

In this dissertation various designs for thermal pad having different flow passage are designed and compared. Their analysis was also performed on simulating software. Also, different fluids and cover fabric material has been studied and compared for the betterment of this product and hence the thermal therapy. Designing was done on SOLIDWORKS 16 and CREO 3.0. Analysis was carried out in ANSYS 18.1 FLUENT. Thermal camera was also used to capture the temperature distribution across passage and result was studied to decide the fabric and fluid for the thermal therapy system.

Keywords- *CFD; heat therapy; thermal therapy pad; heat transfer*

CHAPTER 1

INTRODUCTION

1.1. Background

In medical technology, it is a common practice to treat the injured areas of the patient using thermal therapy pad. This practice involves the application of cold or heat locally to the specified area to heal the injured or operated part. The main purpose of thermal therapy pad is to provide a uniform temperature to the assigned body parts to get the effective and efficient result. For this even distribution of temperature is important at each point of the thermal pad. Moreover, the thermal pad may be used in folded state so the uniform circulation of the fluid is also a desired factor for the effective result.

This thermotherapy basically consists of cold therapy and hot therapy. Both these therapies have their own advantage and it depends on the condition of the patient to apply these therapies. The basic mechanism that exists in this therapy is that it impacts on the tissue exposed to it and soften it or increase the blood flow circulation in the applied area. Both these therapies have opposite effects on the body parts. The purpose of thermotherapy is to adjust tissue temperature in an applied region or localized area to get the desired changes in the tissue and ultimately relieving the person or patient from pain and making them in comfort condition [1].

1.2. Types of thermotherapy

The major types of thermotherapy are heat therapy and cold therapy. This classification depends on the operating condition of therapy.

- **Heat Therapy**

Heat therapy is given the name because of the operating condition of the fluid used in the treatment of the patient. Heating the soft tissue or skin increase the circulation of blood. This increases the metabolic rate and since heating also increases oxygen uptake which acts as a catalyst in the healing process. The activity of destructive enzymes (collagenase) also gains some momentum which eventually increases catabolic rate. The increase in blood circulation is due to vasodilatation which widens the blood vessels. This occurs because of the relaxing of the soft muscle cells within vessel walls. The increase in blood flow is due to the decrease in the vascular resistance. This resistance is the resistance offered by the circulatory system which must be overcome in order to allow the blood flow in the system. This resistance is called as systemic vascular resistance (SVR) and is used in the calculation of blood pressure, blood flow, and cardiac function [2].

When blood vessels dilate, the flow of blood is increased due to a decrease in vascular resistance. Therefore, dilation of arterial blood vessels (mainly the arterioles) decreases blood pressure. The effect may be fundamental due to local processes in the surrounding tissue or superficial due to hormones or the nervous system. Also, the effect may be localized to a specific organ (depending on the metabolic needs of a particular tissue, as during strenuous exercise), or it may be systemic (seen throughout the entire systemic circulation) [2,3].

- **Cold Therapy**

Cold therapy is called so because of the application of cold environment on the localized or targeted area to make the user more comfortable and enhance his/her condition for a better biological response.

The cold therapy decreases the localized temperature of the soft tissue which decreases the blood flow by vasoconstriction. This is followed by vasodilatation which prevents to cause hypoxic damage (hunting reflex: If the cold therapy is done on the skin for more than 10 minutes, the blood vessels will dilate). Moreover, like inflammation, conduction rate, tissue extensibility the tissue metabolism will decrease [2,5].

The effects of both the therapies are given in the table below. Depending on the requirement, need and condition of the patient the doctor or medical staff apply thermotherapy on the required part of the body.

Table 1.1: Effects of cold therapy and heat therapy [4]

Sl. No.	Effects	Cold Therapy	Heat Therapy
1	Pain	Decreases	Decreases
2	Spasm	Decreases	Decreases
3	Metabolism	Decreases	Increases
4	Blood Flow	Decreases	Increases
5	Inflammation	Decreases	Increases
6	Edema	Decreases	Increases
7	Extensibility	Decreases	Increases

1.3. Types of thermal therapy pad

Nowadays, heat therapy application has increased exponentially because of the ease and results it provides with least amount of input required. Many pads are developed so that to help the user in their daily basis and make them comfortable in the least possible time.

1.3.1. Sodium Acetate Heat Pad

This heat pad consists of sodium acetate, metal flat disc, and water. When the metal disc present in the pad is compressed, then heat is produced in the pad via crystallization. Freezing temperature of sodium acetate is 54˚C and hence crystallization occurs at 54˚C. Once the crystallization started by forcing few molecules to turn into solid, it forces other molecules to solidify. When the pad is completely solidified it generates heat while cooling occurs. This heat can last for 30 min to 3 hours depending on the quantity of the liquid present in the pad. It is a reusable pad till the cover is working properly. Once it gets distorted we must dispose of it. It is a safer mode of therapy as sodium acetate is food-additive hence it is non-toxic [7].

(a) **(b)**

Figure 1.1 Sodium Acetate Pad (a) before and (b) after crystallization

1.3.2. Microwavable Heat Pad

This pad consists of fabrics, grains and it requires the application of microwave to generate heat from them. Fabrics used are buckwheat, rice or beans. It can be customized depending on the size requirement and its operating region. It is a home remedy and it requires care and caution during its operation as sometimes they may ignite while being heated in the microwave. They are hard to sterilize. Aromatic scents, flower petals are added for soothing therapeutic effect. The main disadvantage of this pad is that it requires microwave which might be a constraint for the operator [8].

Figure 1.2 Microwavable heat pad

1.3.3. Air Activated Heat Pads

As the name suggest this pad gets activated with the application of air with the desired component to produce heat. This pad consists of charcoal, iron powder and salt. Once these components are exposed to air the oxygen reacts with the iron powder producing heat. The charcoal and salt aids this heat release. The desired temperature is achieved after 30 minutes since the reaction gets started. The main advantage is it does not depend on any external heating device and they are very much convenient to use. The drawback is the time required to reach the desired temperature. It is little costly for daily use as it is not reusable. Also, there are chances that the old stock might not work properly [9].

Figure 1.3 Air Activated Heat Pad

1.3.4. Electric Heating Pad

As the name suggests these pads get charged by the application of electricity by some means of a heat generator e.g. thermostat. This pad consists of the cover, thermostat, silica gel and a charger. When electricity is applied the thermostat generates heat which eventually transmitted to the silica gel which acts as a reservoir for 30-45 minutes depending on the quantity of gel and heating temperature. These pads are portable and can be used conveniently until when the covering layer last. It may have the problem of the lifespan of covering layer. If the leakage occurs we must dispose of the pad. Nowadays it is the easily accessible pad for daily and efficient use [10].

Figure 1.4 Electric Heat Pad

1.3.5. Moist Heat Pads

These packs are usually made from gel packs which are enveloped by a thick fabric. This gel is used to absorb heat from hot water. Heat in the gel is maintained for a longer period but the equal time is required to absorb the heat. Overheating of gel packs may lead to leakage thus making it less commercial for daily use. The moisture from these pads allows heat to penetrate more into the skin and thus the desired biological responses are more prevalent [11].

Figure 1.5 Moist Heat Pad

1.3.6. Far Infrared Ray (FIR) Heat Therapy Wrap

Unlike normal or usual heat therapy these wraps use infrared heat to penetrate more into the body and even to the muscles and bones for effective heat treatment because of their deep heat penetrating property. As FIR heat reaches the bones and muscles it speeds up the healing process. This technology produces even heat which reduces the risk of burns. They have a longer life than other heat pads and have higher operating range. There are some concerns about the application of this wrap which is based on the condition of the patient and the desired result. Some precautions should be taken to ensure the safety of user and device [12].

Figure 1.6 Far Infrared Ray Heat Therapy Wrap

1.4. Types of Heat Therapy

1.4.1. Dry Heat Therapy

This therapy is more popular than the moist therapy because of its several advantages. This requires less maintenance, they are easy to handle, easily accessible, takes less time to heat, provide heat for a longer period. The only demerit of this pads is that it consumes the moisture from the skin thus causing dehydration. This causes irritation and dryness in the skin. Electrical heating pads, microwavable heat pads are some examples that follow this technique [6].

1.4.2. Moist Heat Therapy

In spite that dry heat therapy is more popular, moist heat therapy is preferred by the expert because it does not dehydrate the skin. Also, it increases the elasticity of tissue by penetrating deeper into the skin. This also increases the healing process and it provides more comfort than dry therapy. This is Moist [6].

1.5. Thermal Therapy System

This system consists of a pump, pad, and connecting pipes. This pad is an electrical thermal therapy pad which is kind of electric heating pad. This pad is incorporated with the T-pump. This pump is used as a reservoir to give the desired temperature to the fluid. Then the fluid is circulated through the connecting pipes to the thermal therapy pad. There are two pipes inlet and outlet. These pipes circulate the fluid through the reservoir to the pad by the help of inlet pipe and then again to the reservoir via an outlet pipe. The pump assembly is incorporated with a thermostat to maintain the desired temperature as per requirement. The bottom given at the top of the device is used to set the desired temperature. This takes around 20-30 minutes to reach the desired temperature [13, 14].

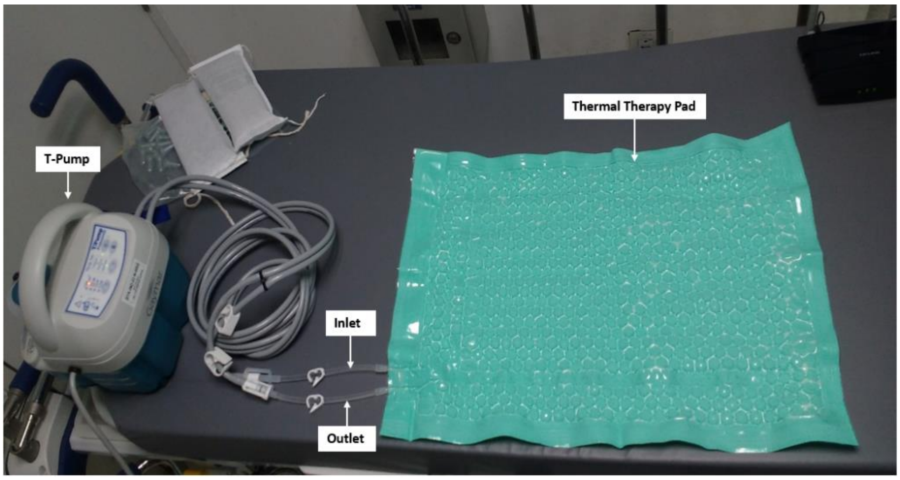
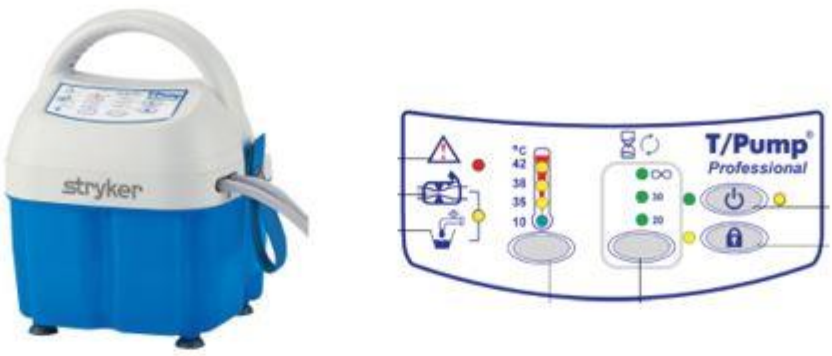


Figure 1.7 Assembly of T-pump, thermal therapy pad, and connecting pipes

1.5.1. T-Pump

Pump acts as reservoir, heat source to the fluid that circulates into the pad. This pump has a switch which is used to operate the pump. The operating temperature varies from 10˚C to 42˚C depending on the requirement and condition of the patient and therapy. The thermostat is used to heat the fluid for heat therapy. But for cold therapy cold water with ice is preserved in the reservoir. After starting the pump, it usually takes 20-30 minutes to reach the desired temperature [14-16].

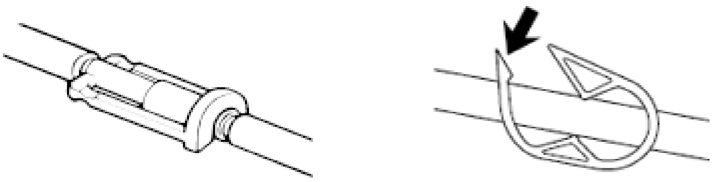


(a) ***(b)***

Figure 1.8 (a) T-Pump and (b) operating switch

1.5.2. Connecting pipes

These are the inlet and outlet pipes which are used to circulate the fluid throughout the system. This pipe has a clik-tite connector and hose pinch clamps which are used to control the flow of fluid manually. By accessing these, pads can be used as a single device once the fluid at desired temperature has been reached. Even it enables to combine two or more pads simultaneously [14-16].



(a) *(b)*

Figure 1.9 Pipe with (a) clik-tite and (b) hose pinch clamps

1.5.3. Thermal Therapy Pad

This pad is used to do the therapy of the user as per the requirement. This is applied to the localized area of the body parts. Wrapping it over the body parts make it isolated from the surrounding and this gives a proper treatment to the required part. The honeycomb-like passage is used to make a continuous flow of the fluid. As this structure gives more passage to the fluid. Some of the passage might get blocked when the pad is wrapped around the body thus the honeycomb structure will give sufficient passage for flow without making fluid stagnant over there. The pad is covered by a polymer polyethylene. This enables it as a recyclable product by sterilizing it after use [14-16].

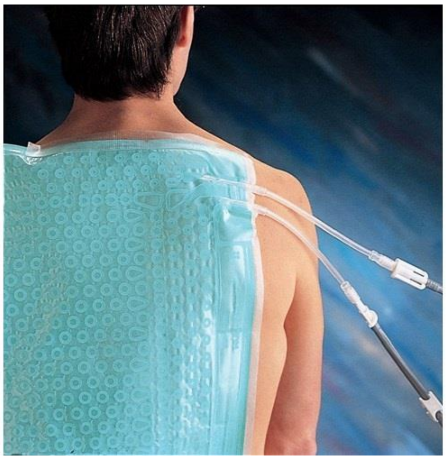


Figure 1.10 Thermal therapy pad

1.6. Designing Software

For manufacturing any product, the initial step is to design the required parts and products in a designing software to get a feel of the product as a base to develop it further as per the requirement. Many designing software is available such as SOLIDWORKS, CREO, AUTOCAD, CATIA and so on. Depending on the need, these software are used by design engineer to design a component. For this dissertation, SOLIDWORKS 16 and CREO 3.0 is used to design the thermal therapy pad.

1.7. Computational Fluid Dynamics (CFD)

There are many designing and simulation software used in today's world to see the actual scenario of the product before manufacturing it. This enables the design engineer to do the necessary modification and analysis for producing the efficient products. All these software's have three major steps i.e. Pre-Processor, Solver, and Post-Processor. Some examples of available CFD software are PHOENICS, STAR-CD, ANSYS CFX, ANSYS FLUENT and so on. For this dissertation, CFD software used is ANSYS 18.1 [33].

1.8. Thermal Camera

Thermal camera is a device to have a look upon the temperature variation over a body or object using the infrared radiation to form the image. Same as in case of normal camera which uses visible light to capture images this device uses infrared radiation to capture image. Depending on the need its application has a wide range from military to the normal moisture inspection in daily life. This camera is manufactured by numbers of company for different purposes with required specification [17].

Figure 1.11 Thermal Camera (a) back view (b) front view

One of the thermal camera is FLUKE TiX560 Infrared camera which has the 5.7-inch LCD screen and 240-degree articulating lens to capture the tough shots. It can measure temperature up to 1200˚Celsius. It has function to save files as per requirement. It offers basic need to the user of editing images, video, background environment condition. It has built-in laser distance meter to measure the targeted object from lens. As it is a rechargeable battery operated it can be used at different locations with an ease [18].

The testing of any thermal therapy pad can be done by this camera. This will provide the temperature distribution of the fluid across the regions of the pad in actual scenario. This will be beneficial for the tester and for the designer to study the distribution and re-develop the product with the necessary iteration in the product.

CHAPTER 2

LITERATURE REVIEW

Living in 21st-century one cannot guess the actual evolution of thermal therapy. But one can surely assist that this was being used from the AD (Anno Domini - Latin for The Year of the Lord) or even BC (Before Christ).

Herndon (1889) was the one whose model of water bandage was first patented infield. Herndon invented some new design and techniques to make the bandage more helpful and efficient by providing different arrangements of tubes i.e. a coiled flexible tube to hold the surface intact, numbers of short tubes being secured to the inner surface and thus hold the surface intact. These improvements also prevent the inflation of the bag or covering [19].

Holland (1903) proposed a hot water bottle design that prevents the accumulation of fluid at some points which were leading to unexpected expansion. He suggested to sandwich the tube of same material between the two surfaces of the bottle at different points and place it in a vulcanizing heat. Vulcanization process unites the short tubes with the bottle surfaces. This makes the bottle more serviceable, serves well even if the bottle is not full as the small pockets thus formed restrict the movement of fluid [20].

Coleman (1963) proposed a personal thermal device comprising of the flexible heat exchanger with inbuilt passages to circulate the liquid by means of thermopump. This thermopump may consist of the electrical heater or some other heat source to heat the liquid and the pump play the role in circulating the heated liquid through the passages provided between the two fabrics of the blanket, garments, mattress cover, or similar items of personal use. Coleman suggested to use the tube of small diameter and connect this to the small junction units rather than using large diameter tubes which may arise problems when the blanket gets folded in operating condition [21].

Bhaskar (1975) invented fluid heating and temperature control unit for a system utilizing a circulating fluid type heating pad or thermal blanket. The unit comprises a bulkhead with a fluid reservoir mounted below and a cover mounted above including means for directing the flow of ventilating air. The bulkhead carries a heater extending into the reservoir, a fluid circulator and a thermostatic temperature control device including a sensor having channels, one of which carries inflowing fluid and the other of which carries outgoing fluid so that the control of temperature is responsive to both inflowing and outflowing fluids, substantially to the average temperature thereof. In this manner, a more satisfactory control of the temperature of the heating pad is achieved than if the control were made responsive either to the temperature of the hotter fluid flowing into the pad or the cooler fluid returning therefrom [25].

Moore et al. (1975) designed a temperature controlled applicator or pad which may be applied to a selected area of application of the body as a covering or dressing; or in the treatment of a wound, incision, bruise, burn or sprain; or as a covering for an organ either in situ or after removal, as in a transplant, to induce hypothermia in the organ. In this pad, a continuous fluid conduit is formed by heat sealing sheets of thermoplastic material together so as to form a conduit layer having a continuous serpentine or meandering flexible tubular conduit for conducting the hot or cold fluid, such as water. Earlier pads are specially designed for use with a companion heating and cooling unit, and the same pad is used over and over again until it is either damaged or wears out. Hence, in order to prevent cross-contamination, the pad must be sterilized. These pads are difficult to sterilize and they may become contaminated during storage between use. So, the inventor designed a disposable pad which may be made of low-cost materials to reduce the overall cost, and it is easily sterilized during manufacture according to conventional technique [26].

Gammons et al. (1979) gave a design of a flexible fluid circulating pad having interconnected internal passages for circulating desired liquid i.e. hot or cold. In this design, there are set of partitions that enable the continuous flow of the fluid to all the areas even if the pad is in a folded condition. This is possible because the liquid can flow randomly in any direction. Suppose the pad gets crimp at any particular area then the liquid will deviate its direction through the most possible passage thus avoiding the accumulation or discontinuity in the flow. This patient treatment pad was named, the Gaymar T-pad. A major concept in designing this pad was to provide a narrow inlet and outlet channel along two adjacent edges by providing a row of closely spaced seal button pattern and the remaining circulating area was covered by randomly placing the round seal buttons to provide random passage to the entire area. This reduces the fluid restriction during the folded condition and fluid will take the path of least resistance and there might be a possibility of no circulation region or little circulation region when the pad is folded but this will not restrict the flow as it will deviate the flow [22].

Ronald et al. (1989) build a liquid circulating thermal therapy system which includes flexible thermal pad and a pump assembly. Pump assembly consists of heater, thermostat, reservoir. A honeycomb-like passage was provided inside the thermal therapy pad. This reduces the fluid’s blocking problem even in a folded condition. The system had a function to control the temperature so that the user gets the desired therapy environment. Thermal pad surface was built with a foam having cushion surface to reduce the risk of ischemia and enhance patient comfort [23].

Kelly et al. (1995) designed a device that enables application of continuous passive motion therapy and thermal therapy simultaneously. In doing so, the therapy pad may face the blockage problems. To overcome this the easiest option is to provide a parallel circuit from the inlet to outlet to maintain continuity of flow, but the heat transfer rate would get affected. So, Inventors provided a spiral cut on the internal conduit. Thus, on the action of radial compression, these spiral cuts get elongated and make a passage for the fluid to escape. This gave the possibility to use a thermal pad in a folded condition, which has increased reliability and improved continuity of flow [24].

Agarwal et al. (2005) designed a new thermal therapy pad having removable layers. The pad has a plurality of layers that may be removed. In a heating pad, this exposes the reactive material in the pad core to more oxygen while simultaneously removing insulation from the pad. In a cooling pad, this removes insulation between the reactive material and the user. The user may thus tailor the rate of heat delivery or removal to his/ her skin to the rate he/she desires. The removal of layers results in increased heat removal or delivery to the skin. The removed layer may be reapplied on the same side from which it was removed or on the side opposite or discarded. The pad may use an iron powder reactive core which reacts exothermically with air to provide heating or water and other reactants that react endothermically. More than one core may be used to further tailor the amount and rapidity of the temperature change [27].

Flick et al. (2005) invented a first conformable material having a three-dimensional shape and a first hypothermia (reduction of the core temperature) and/or hyperthermia (increase in the body core temperature) device. This invention is used as a pad for sleeping, lying down, or sitting, to maintain the desired temperature to the contacting surface of a body to the pad. This pad comprises pad cover and is a first gelatinous elastomeric material having a three-dimensional shape with a top surface, a bottom surface and at least one side surface and a plurality of apertures positioned on the exterior of the top surface, the bottom surface or the at least one side surface and interspaced throughout the first gelatinous elastomeric material. It is a first convective hypothermia and/or hyperthermia device positioned near the first gelatinous elastomeric material to allow the pad to have a desired temperature [28].

Louise (2011) gave a new thermosimulation method using multilayer pads with integrated temperature regulation. The therapeutic method is thermostimulation and includes the steps of applying heat and stimulation via the pad, sensing temperature at the pad with an embedded temperature sensor and regulating the heat current at the pad via the inline control system in response to the output of the temperature sensor. In an alternative embodiment, the embedded sensor is a galvanic skin response sensor for measuring skin conductivity and having output is used by the inline controller in the treatment of dermatological conditions, relaxation treatment, desensitization training or other purposes. In any case, useful data with respect to the performance of and conditions at each pad is displayed either on the inline controller and/ or at the console. In addition, the inline controllers may be adapted to communicate with each other and/ or with other external devices [29].

Kelner et al. (2012) invented a thermal pump for controlling air bubbles, thermal therapy to allow the patient to perceive that thermal therapy is constantly being applied and ensure the appropriate amount of water flows through the thermal pump. This thermal pump system comprises a pump container having a dry compartment that contains a motor, a wet compartment that contains a propeller, and a shaft system that interconnects the motor to the propeller. The wet compartment has a water inlet, the propeller pulls water from a water bath into the wet compartment through the water inlet and pushes the water into a conduit toward a heating block and to a patient application device, the heating block has a heating pad and/or a cooling pad; and a therapy management device that controls the thermal energy provided by the heating pad and/or the cooling pad to direct the water's temperature [30].

Fruitman (2012) invented a comfortably, yet highly efficient therapy pad that is effective in delivering cold or hot thermal therapy for the relief of pain, inflammation, swelling, and muscle stiffness. This invention provides a hot and cold therapy device with a unique material that is simultaneously capable of safely, comfortably and rapidly delivering hot or cold thermal therapy in a highly effective fashion [31].

Woods (2013) provided a multi-layered therapy pad is having a comfortable and supportive structure that houses heat therapy and electrotherapy means for treating back injuries and sores while an individual lies thereon. The pad comprises a first and second outermost layer of low-resilience polyurethane foam sandwiching an internal layer of higher density foam, which also supports electrical connections between the therapy controller, the power source, and the two therapy means within the pad. The electrotherapy means comprises static or tethered electrodes that apply pulsing electric current directly onto the user' s back for stimulation and easing of back pain, while the heat therapy is applied using a resistance heating element within the pad, which heats a majority of the pad for applying heat to the user' s back. The operation of the therapy means is controlled by an external controller, while power is received through an external source or an internal battery pack [32].

CHAPTER 3

RESEARCH OBJECTIVES AND METHODOLOGY

3.1. Design Objectives

The basic function and requirement of therapy are to provide the desired uniform temperature for a longer period. The primary function of heat therapy system is to transfer temperature to the desired body parts. Specifically, the primary design goal is to distribute the fluid and maintain required temperature evenly to the entire surface area, as doing so improve the therapy system ability to efficiently produce uniform temperature and therapeutic effects. The geometric design of the thermal therapy pad affects the efficiency of the therapy system, and thus directly affects the level of comfort. The construction of the passage in thermal pad has a major influence on how the therapy performs at various condition. The challenge, therefore, was to optimize the design of the intake passage system and remap the thermal therapy system. For this, there are various points that need to be taken care of. Points written below are the users need and depending on that the design objectives and inputs were decided.

i. Provides interface for thermal energy transfer to patient
ii. Compliant with applicable Regulatory Requirements
iii. Meet requirements of applicable Standard
iv. Provide appropriate packaging materials, methods, and consideration for modes of transport
v. System will perform reliably throughout its expected life

3.2. Design Input

Since the design of any product is solely based on the application of that product. Any product in market is designed to meet reliability, desired output, customer satisfaction and never the less worth for money. The therapy pad is more of concern to patient and operator safety. Based on users need, major design inputs that plays role in designing this therapy pad are:

- **Provides interface for thermal energy transfer to patient**

  Based on this user need, the main design input is

  i. Pad should provide uniform warming/cooling. The difference between the supply line temperature and the return line temperature must not exceed 4 ºF or 2.22 ºC. The difference between the temperatures at any point on the product must not exceed 4 ºF or 2.22 ºC.

  ii. Minimize fluid spillage when disconnecting. There shall be no flow of water through the product once the connectors are disengaged.

  iii. Compatible with Stryker Controller. Pads shall be able to be used with T-Pump ® Controllers: TP500, 650, and 700 series. So, the pad should be compatible with its other counterpart.

  iv. Resistant to Bio fluids. Product shall show no peeling or cracking after 24-hour test, and should have no leaks, cracks, or peeling when run at 42°C for 20 minutes. Pads shall have no unacceptable visual discoloration after one-hour test as evaluated by marketing

- **Compliant with applicable Regulatory Requirements**

  Pad shall meet regulatory requirements for sale within the United State, Canada, European Union. It shall also meet Labeling standards.

- **Meet requirements of applicable Standards**

i. Pad shall meet applicable Biocompability. It should Meets ISO 10993-1:2009 - Biological Evaluation of Medical Devices − Part 1: Evaluation and testing within a risk management process.

ii. Pad shall meet appropriate ISTA standards for shipping packaged product. For this packaging to be tested in accordance with ISTA 3A with conditioning to winter and summer conditions. The overall packaging must maintain integrity and the internal pad / device must function without leak after completion of the ISTA 3A testing.

iii. Pad shall meet applicable Environmental standards. It Complies with REACH Directive 1907/2006 (ES-0604).

- **Provide appropriate packaging materials, methods, and consideration for modes of transport**

i. Storage environmental limits shall be defined. Product shall output flow at a minimum of 12 GPH, when connected to a supply source with an output flow rate of 20 GPH after being submitted to these storage conditions.

Table 3.1: Environment condition for storage

Storage Environment	Range
Temperature	40 ºC - 60 ºC
Humidity	10-95 %

ii. Intended operating environment conditions shall be defined. Product shall output flow at a minimum of 9 GPH, when connected to a supply source with an output flow rate of 13 GPH after being submitted to these operating conditions.

Table 3.2: Operating Condition of pad

Operating Condition	Range
Temperature	10 ºC - 40 ºC
Humidity	30 - 75 %

- **System will perform reliably throughout its expected life**
    i. Pad should withstand the fault max pressure created by controller. It must withstand an internal pressure of 9 psi and a temperature of 109ºF or 315.928 K or 42.7778 ºC for thirty (30) minutes without leakage.

    ii. Product Life and Use of pad shall be easily achievable. Generally, pads life is of 30 / 60 days. The other factors are whether it is a disposable or not and if it can be used for multiple patient or not i.e. if it is reusable or not.

    iii. Product Flow in pad shall meet the desired mass flow rate.

    - Open Flow: Return flow shall be 9 GPH minimum when used with an input supply flow of 13 +/- 1 GPH.

    - Folded Flow: (Through barrier button row when the tube weld bypass channel is clamped closed and the flow path is clamped so that all flow goes through one half of the barrier row): Return flow shall be 3 GPH minimum when used with an input supply flow of 13 GPH.

    iv. Product may be used with X-ray, MRI and CT imaging procedures and equipment. So, the material shall be compatible with X-ray, MRI, and CT imaging procedures and equipment.

3.3. Methodology

To design and analyze the thermal therapy pad the main step is to compare the different types of passage for a specified dimension of the pad. The comparison will include variation in velocity, pressure, the temperature in the various passage scenarios and to find out the best of them for better therapeutic effects. Also, the fluid material and outer pad cover will be a matter of concern. The main i.e. to reach desired and uniform temperature early and to provide this for a longer period should be deciding factor in the selection of design and fluid material. The design part is done in CREO 3.0 and SOLIDWORKS 16. After that, the analysis is carried away in ANSYS FLUENT. The thermal camera was also used to analyze the uniformity in temperature and temperature drop. This result will be compared with the results obtained through software and the decision will be made considering these facts.

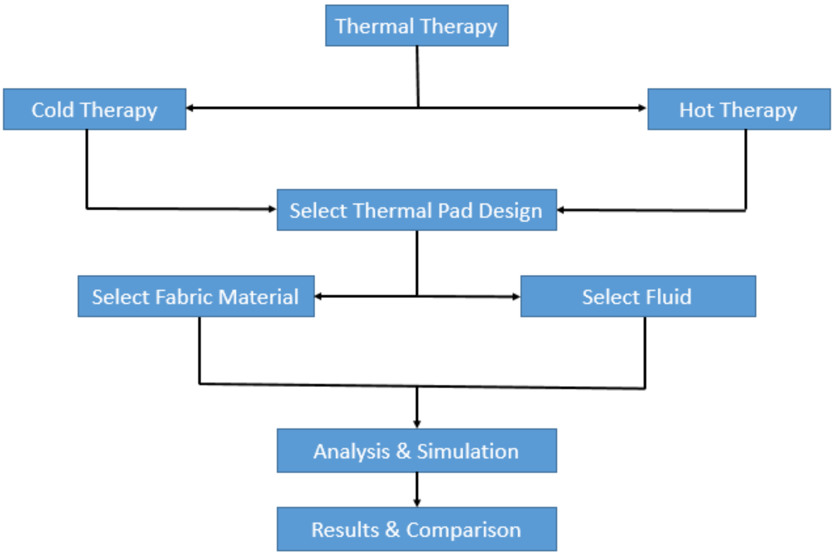


Figure 3.1 Schematic diagram of the methodology

CHAPTER 4

MODELING

4.1. Design

The therapy pad design is configured by first deciding the outer dimension of the pad. The outer boundary or region fixed was 180 cm x 135 cm. This is the smallest dimension of the pad available and hence was used for analysis. The outcome of the analysis will be applied universally as the system is same and the use also. Two basic design was made for the analysis purpose. One having a normal basic linear passage for the flow and other one is a honeycomb-like passage.

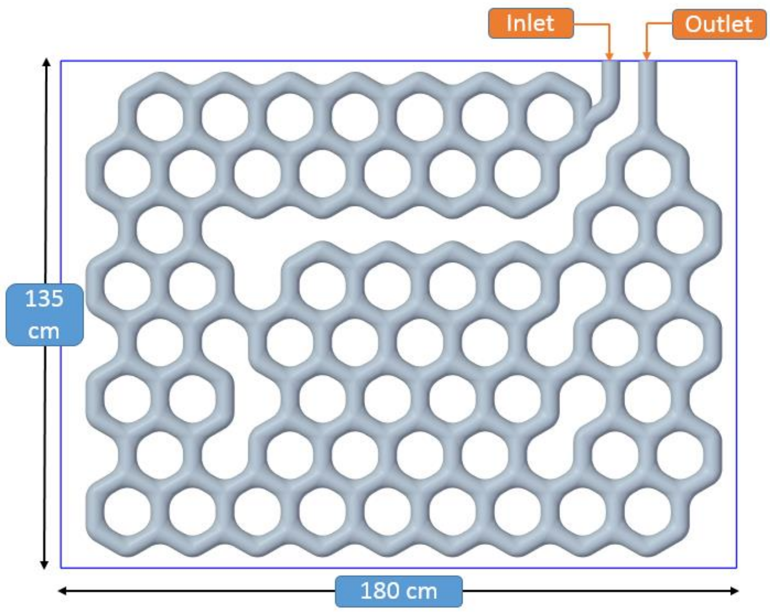


Figure 4.1 Honeycomb structure therapy pad

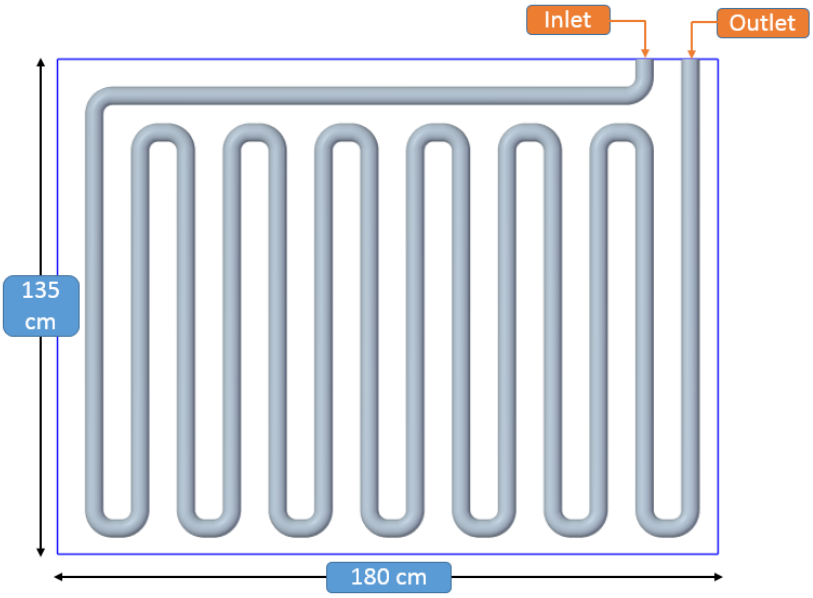


Figure 4.2 Linear passage thermal pad

The cross-section of the passage is made circular to make the analysis easier. The diameter of the cross-section is 1 cm. The concept behind designing honeycomb structure was to provide sufficient passage for fluid at each point. This reduces the chances of blockage and thus prevalent for continuous and uniform flow. On the other hand, the linear passage is made as a comparison purpose. The flow in this will get blocked or the flow uniformity will change if the wrapped pad is applied to the body. In honeycomb structure like passage, the wrapping of the pad will block only some passage. Hence the fluid will take a different route to maintain their flow. This helps in maintaining uniformity in temperature mad circulation. The software used for designing this is CREO 3.0.

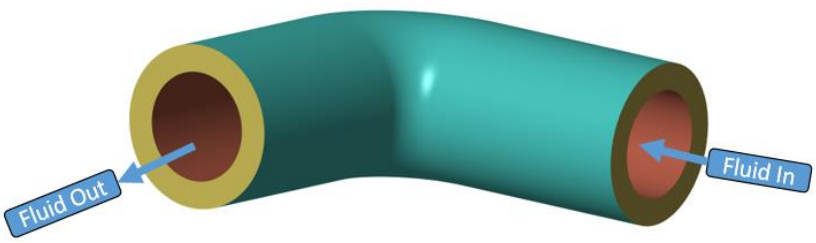


Figure 4.3 Passage cross-section and fabric cover

4.2. Selection of fabric material and fluid

The basic requirement of this device is to maintain the acceptable temperature and transfer the same to the localized area of the body part. The heat transferred to the fluid is based on the heat carried by the fluid which is decided by specific heat capacity. The heat transferred to the body depends on the heat transfer coefficient of the surrounding air which is a fixed parameter for different analysis scenario. Other factors are the body temperature, fabric material properties. Depending on these basic properties some materials are selected for the analysis. The table shown below describe the selected materials and fluids. Apart from these properties, the fluid selection is also dependent on its adaptability with the thermostat and reservoir. Also, the fluid should be used for both cold and hot treatment. So, this is also a point of concern for cold treatment as no such device is incorporated in the pump to decrease the temperature of the fluid to 10˚ C. In case of cold therapy, cold fluid is pore into the reservoir and is used for circulation.

Table 4.1: Selection of Fabric material and Fluid

Sl. No.	**Fabric Material / Fluid**	**Density (Kg/m^3)**	**Specific Heat Capacity (J/Kg-K)**	**Thermal Conductivity (W/m-K)**
1	Polyethylene	950	1900	0.52
2	Rayon	1100	2000	0.25
3	Water	998.2	4182	0.6
4	Silica Liquid	2000	968.4	0.0454

CHAPTER 5

RESULT AND DISCUSSION

Simulation of thermal therapy pad is done for different passage design and contours. Moreover. Separate analysis is performed to decide fabric and fluid of thermal therapy pad. These results are shown below and are compared with each other.

5.1. Analysis of pad

Pad with different passage was analyzed and compared with one another for better output scenario. Main criteria were desired and uniform temperature for longer period, sufficient mass flow, less pressure loss, sustain the internal pressure, less difference in inlet and outlet fluid and not more than 2.22 ºC temperature drop at any point.

5.1.1. Temperature Distribution

Fig 5.1 and Fig 5.2 shows a temperature distribution of hot fluid in a pad with honey-bee structure in k-epsilon model.and k-omega model In this the temperature drop is more in k-e model as compared to k-w model. The temperature at inlet for both the model is kept at 315.15 K. But the outlet temperature is more in k-w model. Also, the temperature at the bottom corners of the pad is dropped by around 2 kelvin in k-e model and around 1 kelvin in k-w model.

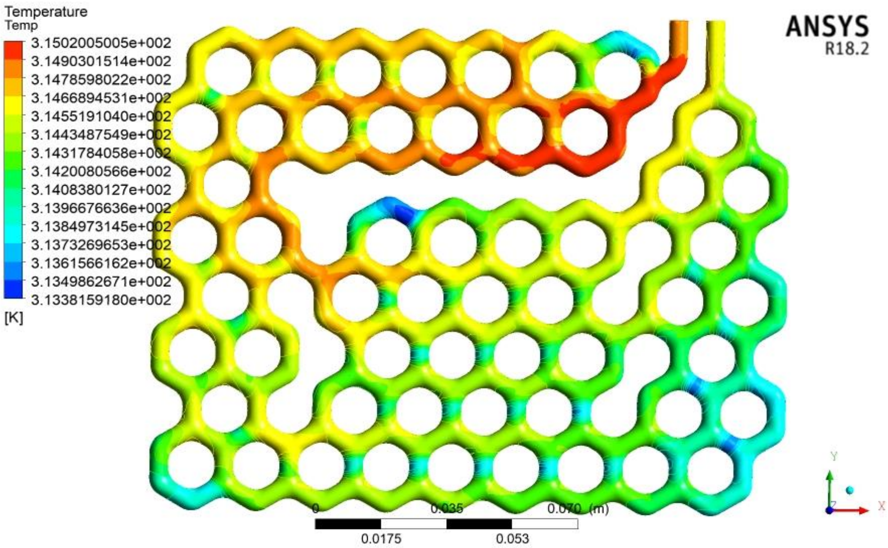


Figure 5.1 Temperature Distribution in honey-bee structure pad (k-e model) for hot fluid

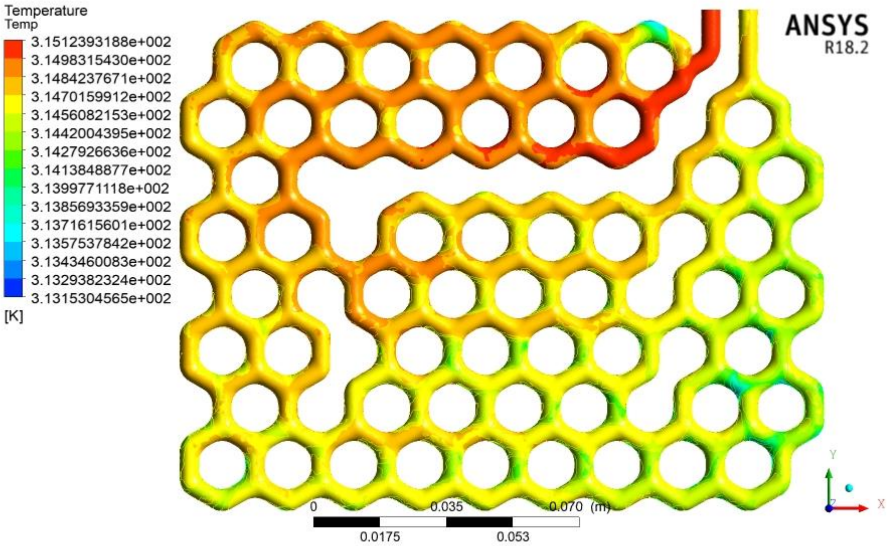


Figure 5.2 Temperature Distribution in honey-bee structure pad (k-w model) for hot fluid

Fig 5.3 and Fig 5.4 shows the temperature distribution of cold fluid in a pad with honey-bee structure in k-epsilon model.and k-omega model. As there is cold fluid is entering at 283.15 K in this model. Heat is transferred from comparatively hot surrounding to fluid and making the users body cool. In k-w model the temperature drop is more uniform and thus providing better cooling treatment to patient. The temperature drop in k-w model is around 0.01 kelvin only.

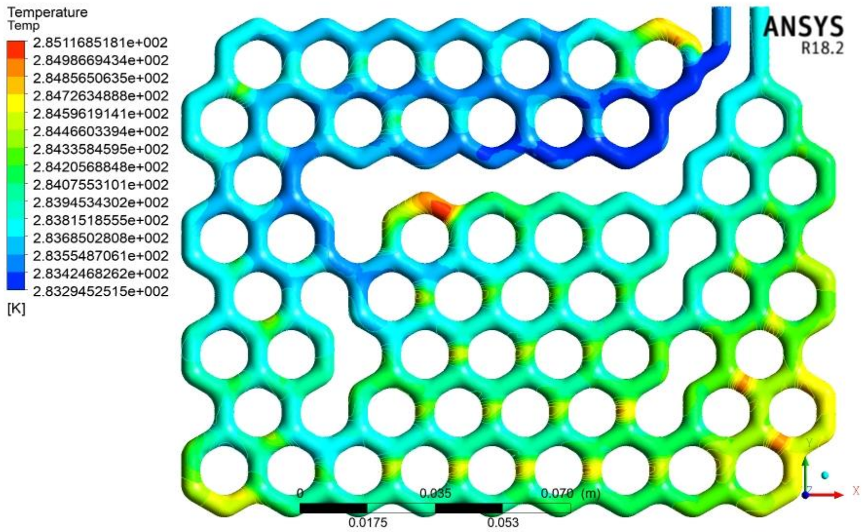


Figure 5.3 Temperature Distribution in honey-bee structure pad (k-e model) for cold fluid

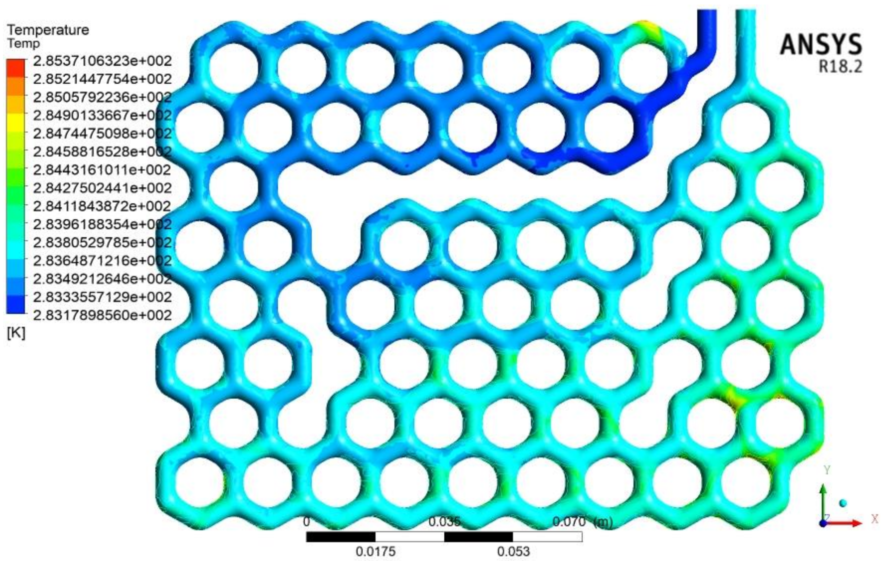


Figure 5.4 Temperature Distribution in honey-bee structure pad (k-w model) for cold fluid

Fig 5.5 and Fig 5.6 shows a temperature distribution of hot fluid in a pad with linear structure in k-epsilon model.and k-omega model In this the temperature drop is more in k-e model as compared to k-w model. The temperature at inlet for both the model is kept at 315.15 K. But the outlet temperature is more in k-w model. Also, the temperature at the end of the pad is dropped by around 1 kelvin in k-e model and around 1 kelvin in k-w model. Since this structure is linear and has a definite path the temperature loss is less as compared to the honey-bee structure. This is because of the increase in surface area in new design which increases the heat loss. This increase in heat loss will give more comfort to the patient is less period. Moreover, the pad with linear structure will not provide uniform temperature to the exposed part of the body and hence the effective result will be more in the honey-bee structure therapy pad. This is because of the uniformity in the temperature distribution across the pad. Also, the application of pad is to heat/cool the required area though direct contact and this will be more in the honey-bee structure pad and therapy effect during wrapping will also be better in the honey-bee structure pad.

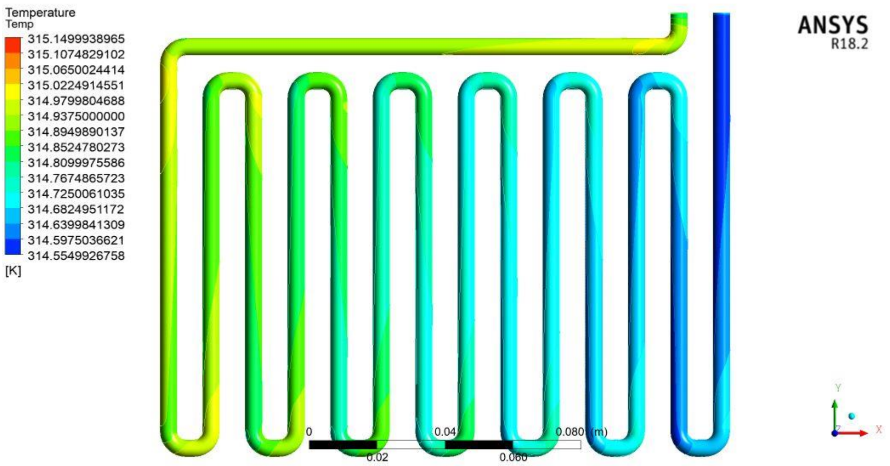


Figure 5.5 Temperature Distribution in linear structure pad (k-e model) for hot fluid

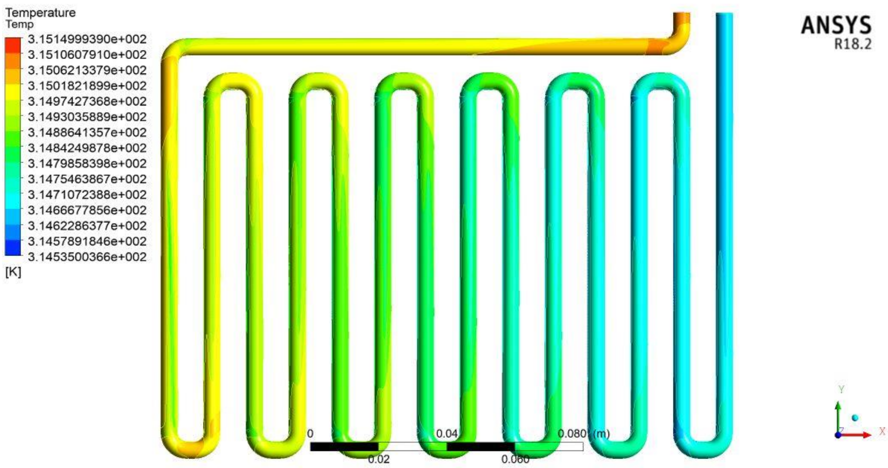


Figure 5.6 Temperature Distribution in linear structure pad (k-w model) for hot fluid

Fig 5.7 and Fig 5.8 shows the temperature distribution of cold fluid in linear structure pad. As this will be cooling therapy, there will be a heat gain in the fluid from the surroundings and the patient will get a cooling effect. The temperature increases as the fluid passes though the passage. Thus, the heat loss will be non-uniform here and it will give a disrupted cooling effect to the patient.

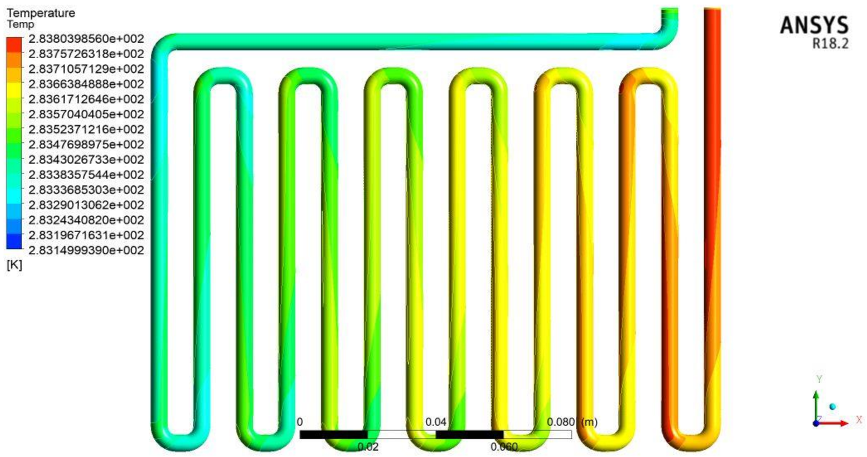


Figure 5.7 Temperature Distribution in linear structure pad (k-e model) for cold fluid

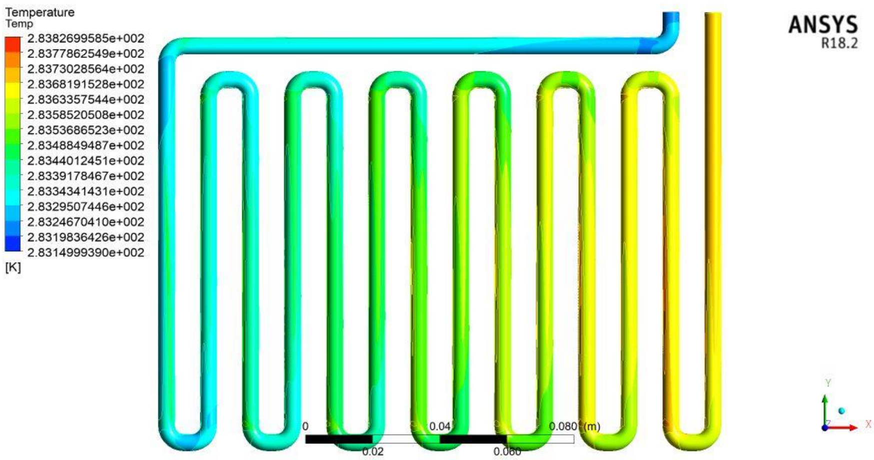


Figure 5.8 Temperature Distribution in linear structure pad (k-w model) for cold fluid

5.1.2. Pressure Distribution

In every flow pressure plays a major role to decide the flow characteristics. More is the number of diversions more will be the pressure loss and more energy will be needed to get the desired flow but if the linear passage is long enough the major loss will be more. Hence the pressure loss depends on the cross section, path and the bends. In the case of thermal therapy pad the main requirement is to maintain a uniform temperature and to have greater heat interaction with the surroundings. In honey-bee structure the flow has to pass through the designed curves which causes the drop-in pressure. Fig 5.9 and Fig 5.10 shows the pressure distribution of hot fluids in k-e model and k-w model respectively. As the fluid passes the pressure reduces due to frictional loss. At inlet the pressure is around 6.7 Mpa but most of the cross section has pressure of around 6.46 Mpa. In k-e model the fluctuation of pressure is from 6.67 MPa to 5.98 Mpa and in k-w model fluctuation of pressure is from 6.88 Mpa to 5.95 Mpa. Fig 5.11 and Fig 5.12 shows the pressure distribution of cold fluids in k-e model and k-w model respectively. The pressure distribution of cold and hot fluids is same as the condition and fluids were kept same and pressure distribution is not a function of temperature here.

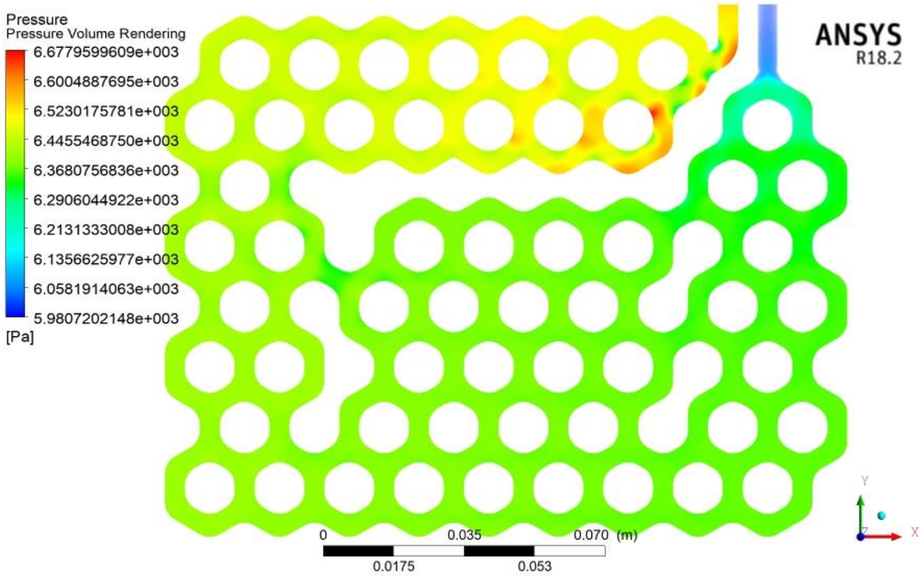


Figure 5.9 Pressure Distribution in honey-bee structure pad (k-e model) for hot fluid

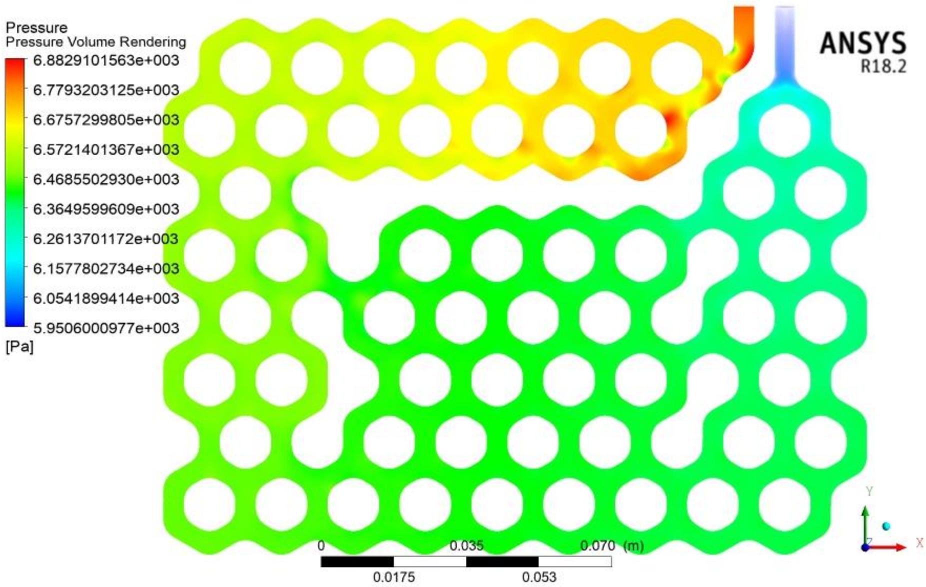


Figure 5.10 Pressure Distribution in honey-bee structure pad (k-w model) for hot fluid

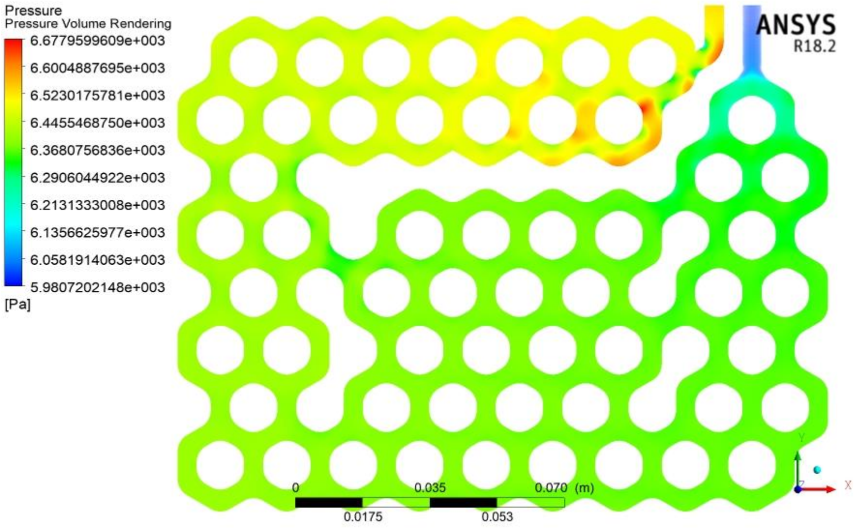


Figure 5.11 Pressure Distribution in honey-bee structure pad (k-e model) for cold fluid

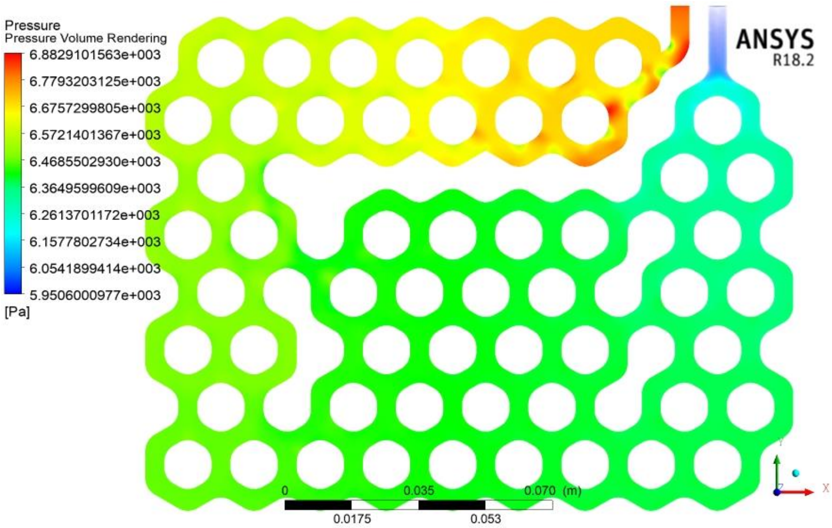


Figure 5.12 Pressure Distribution in honey-bee structure pad (k-w model) for cold fluid

Fig 5.13 and Fig 5.14 shows pressure distribution of hot fluid in linear structure pad in k-e model and k-w model. In this design the pressure drop was observed as the fluid passes through the passage. The loss due to friction was there and over the length it tends to decrease more. The curves in the passage has more pressure drop due to the bends. In k-e model the fluctuation of pressure is from 10.5 MPa to 5.85 Mpa and in k-w model fluctuation of pressure is from 13.16 Mpa to 6.01 Mpa.

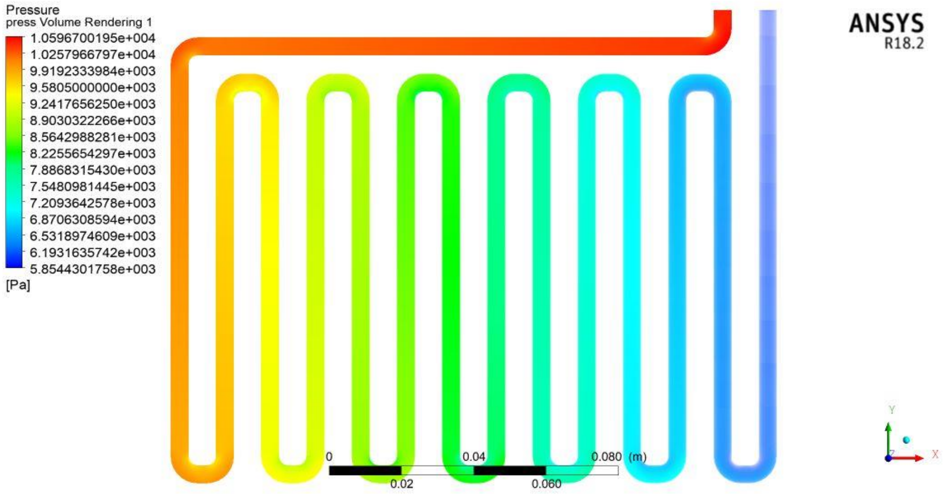


Figure 5.13 Pressure Distribution in linear structure pad (k-e model) for hot fluid

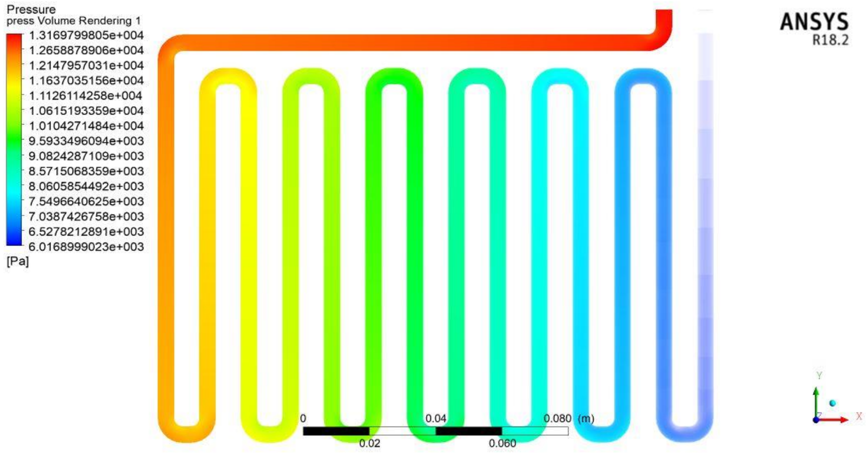


Figure 5.14 Pressure Distribution in linear structure pad (k-w model) for hot fluid

Fig 5.15 and Fig 5.16 shows pressure distribution of cold fluid in linear structure pad in k-e model and k-w model. The pressure distribution of cold and hot fluids is same as the condition and fluids were kept same and pressure distribution is not a function of temperature here.

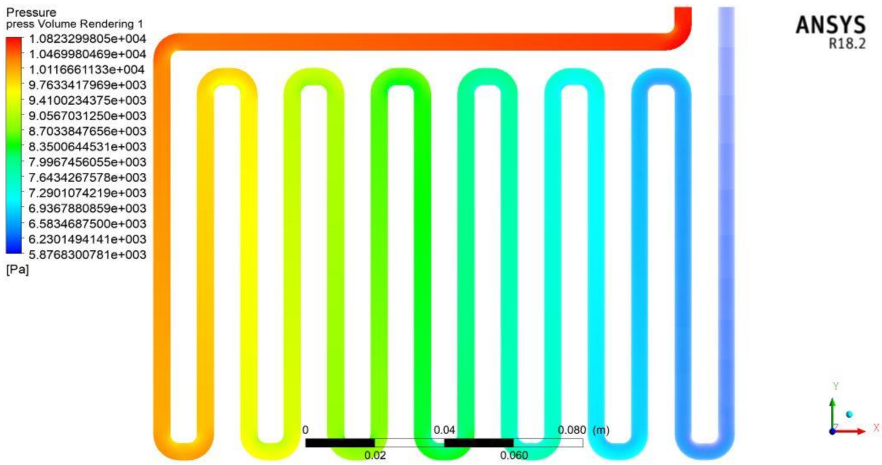


Figure 5.15 Pressure Distribution in linear structure pad (k-e model) for cold fluid

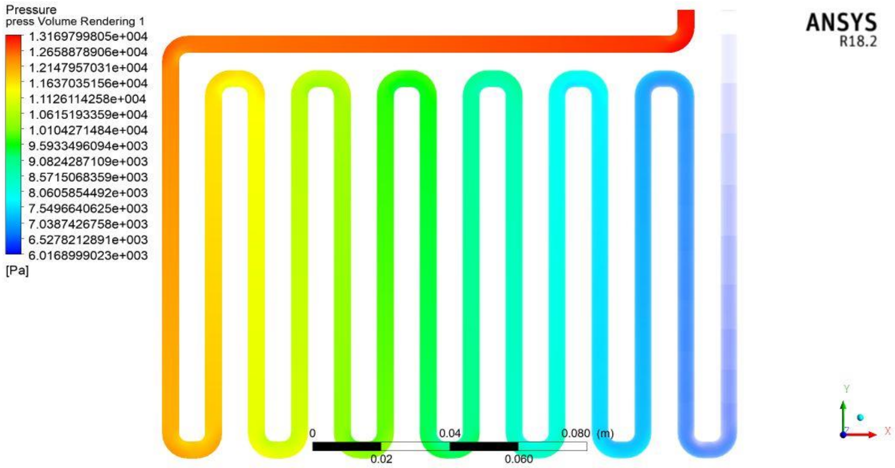


Figure 5.16 Pressure Distribution in linear structure pad (k-w model) for cold fluid

5.1.3. Velocity

The flow of fluid in any condition is a function of velocity. The velocity in thermal therapy pad is due to the pump which circulates the fluid throughout the pad and maintains the desired flow rate. Fig 5.17 shows the velocity vectors of the hot fluid at every point in honey-bee structure in k-e model. In this the fluid is entering at a velocity of 0.69 m/s to target the desired mass flow rate. But due to mixing and reverse flow around the corners and honey bee passage the flow of fluid decreases and leads to the decrease in fluid velocity. But the flow here is a forced flow and pump is helping in achieving the mass flow rate the velocity is of least concerned. The objectives of achieving uniform temperature and providing better effects to the patient has nothing to do with the velocity unless the temperature is decreasing abruptly due to decrease in velocity. This has been tested by the thermal camera on actual therapy pad which is discussed later in this chapter.

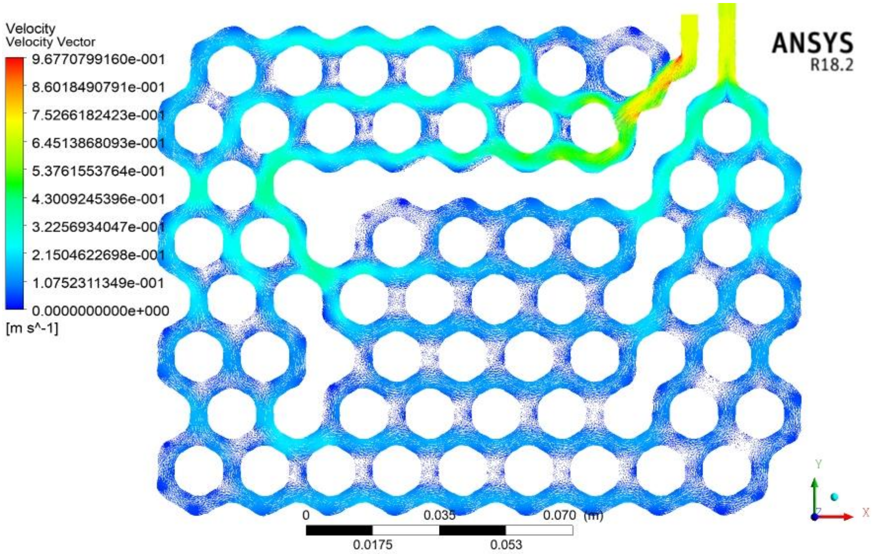


Figure 5.17 Velocity of hot fluid in honey-bee structure pad (k-e model)

Fig 5.18 (a) and (b) shows the velocity of hot fluid at inlet and outlet cross section of the honey-bee structure for k-e model. As there exist a no slip condition at the surface, both the figures have a zero velocity around the surface and comparatively more velocity near the center of the cross section. This effect is due to the wall shear effect and no slip condition.

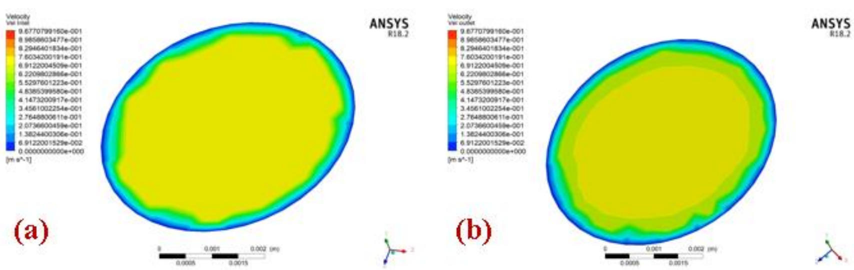


Figure 5.18 Velocity of hot fluid at (a) inlet and (b) outlet cross section of honey-bee structure (k-e model)

Fig 5.19 shows the velocity vectors of the hot fluid at every point in honey-bee structure in k-w model. As it can be observed that the velocity here is better than the k-e model as this model is known to be better to calculate the turbulence of fluid. In this the inlet velocity is 0.69 m/s to target mass flow rate. But due to turbulence, mixing and reverse flow the velocity decreases. But the fluid at slow velocity is kept on going and reaches the outlet cross section at higher velocity due to the pressurized flow.

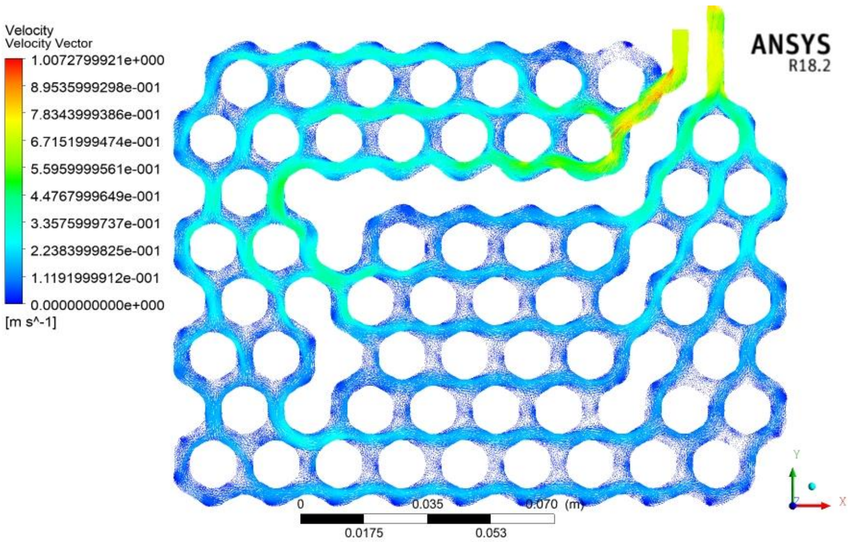


Figure 5.19 Velocity of hot fluid in honey-bee structure pad (k-w model)

Fig 5.20 (a) and (b) shows the velocity of hot fluid at inlet and outlet cross section of the honey-bee structure for k-w model. As compared to the k-e model, the velocity at inlet is relatively more. At outlet condition also, the velocity seems to be better in this model. The no slip effect can be seen in both the models and the velocity is increasing in the central region of the cross section.

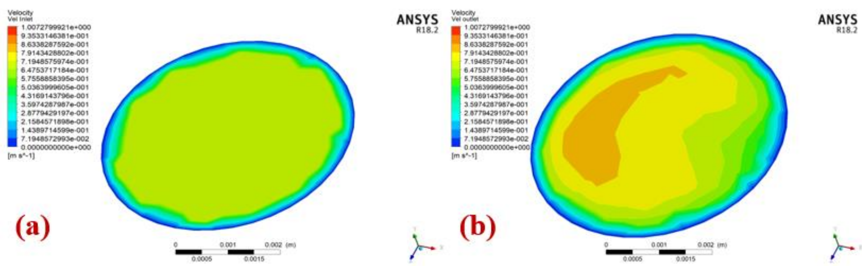


Figure 5.20 Velocity of hot fluid at (a) inlet and (b) outlet cross section of honey-bee structure (k-w model)

Fig 5.21 shows the velocity vectors of the cold fluid at every point in honey-bee structure in k-e model. As in case of hot fluid, here also the velocity is decreasing due to the mixing and turbulence. But pressurized flow is maintaining the mass flow rate at the inlet and outlet.

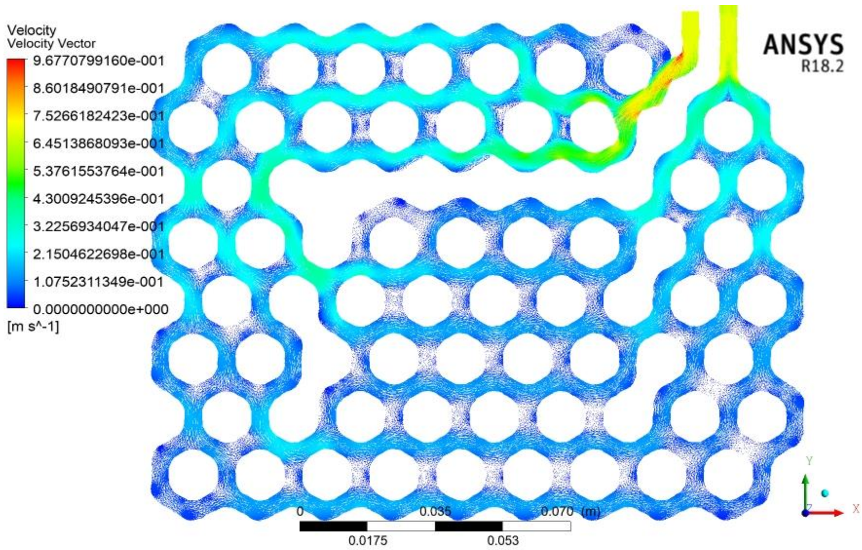


Figure 5.21 Velocity of cold fluid in honey-bee structure pad (k-e model)

Fig 5.22 (a) and (b) shows the velocity of cold fluid at inlet and outlet cross section of the honey-bee structure for k-e model. It can be observed that at center is more in comparison to the velocity at surfaces due to the shear and viscosity of the fluid.

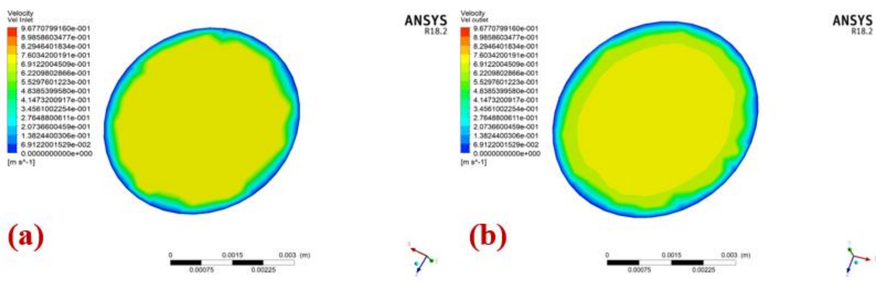


Figure 5.22 Velocity of cold fluid at (a) inlet and (b) outlet cross section of honey-bee structure (k-e model)

Fig 5.23 shows the velocity vectors of the cold fluid at every point in honey-bee structure in k-w model. In comparison to the k-e model the velocity here is more and gives the better flow velocity. As the passage gets the direction in its flow it has a better velocity but if the direction is diverted then the flow velocity decreases and further mixing is further decreasing it.

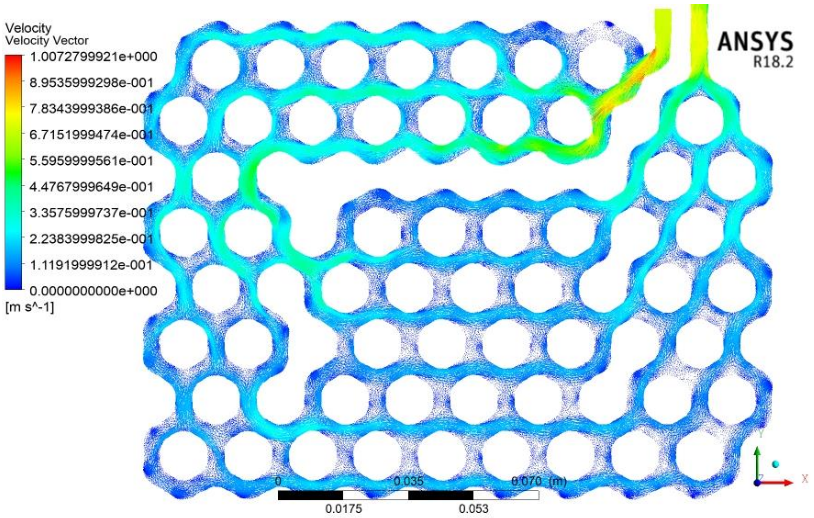


Figure 5.23 Velocity of cold fluid in honey-bee structure pad (k-w model)

Fig 5.24 (a) and (b) shows the velocity of cold fluid at inlet and outlet cross section of the honey-bee structure for k-w model. The velocity at inlet is more uniform as the flow is developing. The velocity at outlet is less uniform due to the turbulence and pump pressure.

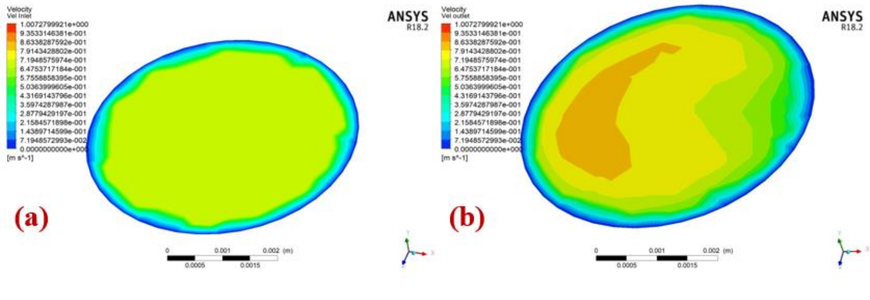


Figure 5.24 Velocity of cold fluid at (a) inlet and (b) outlet cross section of honey-bee structure (k-w model)

The other design analyzed in this project is the linear and simple passage pad. It has a circular cross section with defined path for the fluid to flow under pressurized pressure. Fig 5.25 shows the velocity of hot fluid in linear structure pad for k-e model. Here the inlet velocity is 0.69 m/s. The velocity of fluid here remains almost same throughout its flow due to the defined path and pressurized flow. It can be observed little variation at the corners or bends parts due to the cross-section change. In this design the velocity is uniform and turbulence zone is less as compared to the previous design. This is the traditional and old which was the base of this product. From velocity consideration this gives the better result and would be the first choice. But other aspects like the usability during wrapping condition and across complex body parts are also a factor to decide the design.

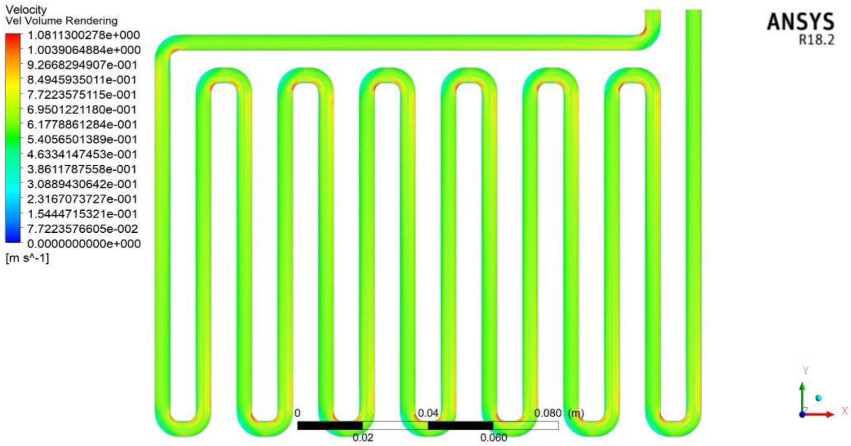


Figure 5.25 Velocity of hot fluid in linear structure pad (k-e model)

Fig 5.26 (a) and (b) shows the velocity of hot fluid at inlet and outlet cross section of the linear structure for k-e model. As there exist a no slip condition at the surface, both the figures have a zero velocity around the surface and comparatively more velocity near the center of the cross section. This design has a uniformity in its velocity all over the cross section at inlet and at outlet velocity at center is more due to wall shear effect.

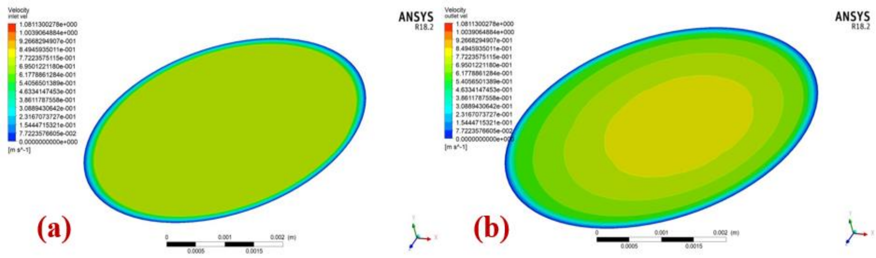


Figure 5.26 Velocity of hot fluid at (a) inlet and (b) outlet cross section of linear structure (k-e model)

Fig 5.27 shows the velocity of hot fluid in linear structure pad for k-w model. Here also the inlet velocity is 0.69 m/s. The velocity of fluid here is changing at the bends due to the turbulence effect but the uniformity is observed same as in k-e model.

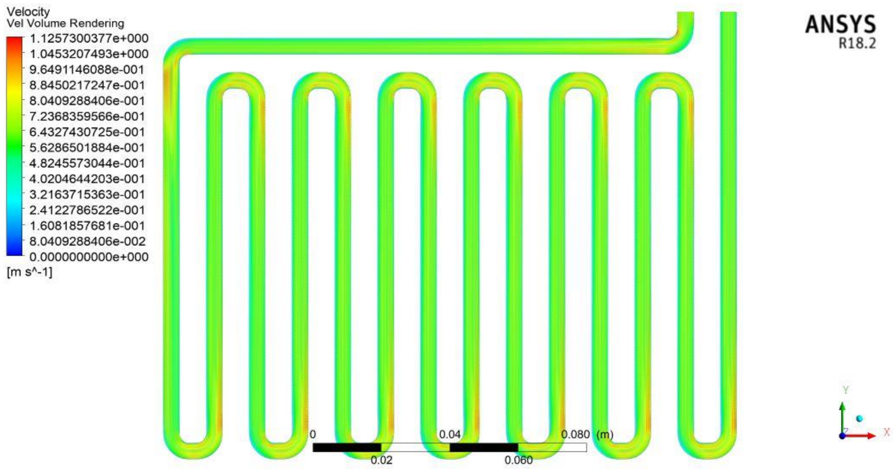


Figure 5.27 Velocity of hot fluid in linear structure pad (k-w model)

Fig 5.28 (a) and (b) shows the velocity of hot fluid at inlet and outlet cross section of the linear structure for k-w model. The velocity at the center is more and at the surface is zero due to wall shear effect and no slip condition.

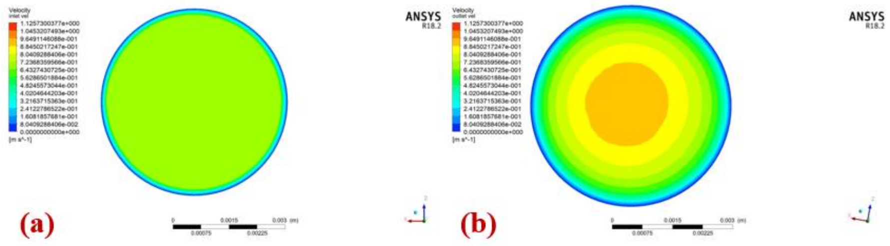


Figure 5.28 Velocity of hot fluid at (a) inlet and (b) outlet cross section of linear structure (k-w model)

Fig 5.29 shows the velocity of cold fluid in linear structure pad for k-e model. As the passage is completely defined, here also the flow is uniform as the temperature hardly affects the velocity of pressurized fluid. Average temperature of velocity is 0.69 m/s. Slight change in the velocity at the bends can be observed due to eddy formation and turbulence.

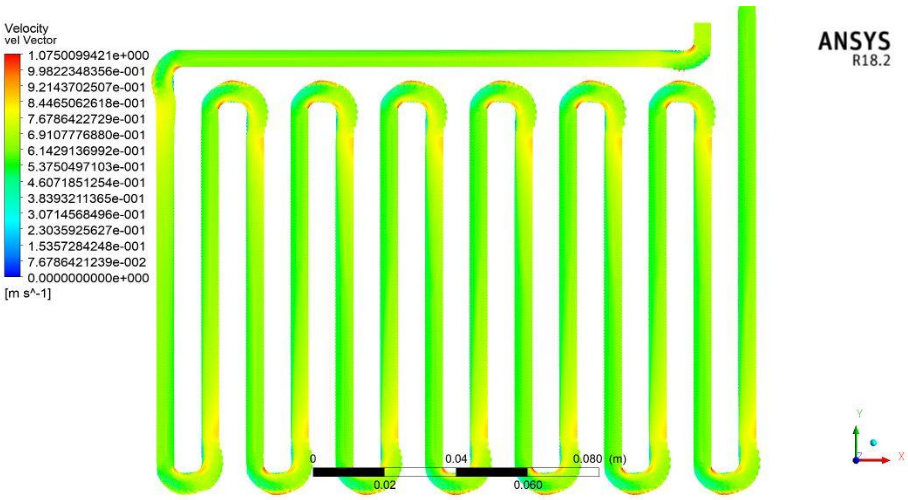


Figure 5.29 Velocity of cold fluid in linear structure pad (k-e model)

Fig 5.30 (a) and (b) shows the velocity of cold fluid at inlet and outlet cross section of the linear structure for k-e model. At inlet the velocity is uniform at the center and zero at the surface. At outlet the velocity is more at the center because the flow is in the developed region.

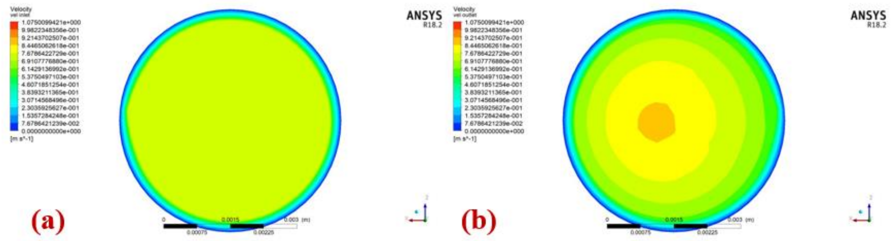


Figure 5.30 Velocity of cold fluid at (a) inlet and (b) outlet cross section of linear structure (k-e model)

Fig 5.31 shows the velocity of cold fluid in linear structure pad for k-w model. The velocity in this model is more uniform as compared to the velocity in the k-e model. The turbulence effect can be observed near bends and curves. Here the average velocity is around 0.7 m/s which gives maintains the desired flow rate.

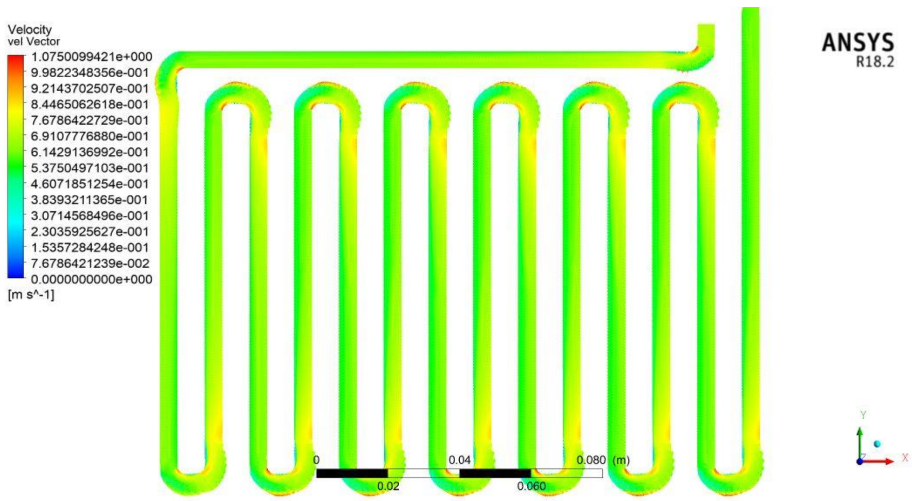


Figure 5.31 Velocity of cold fluid in linear structure pad (k-w model)

Fig 5.32 (a) and (b) shows the velocity of cold fluid at inlet and outlet cross section of the linear structure for k-w model. The velocity at the center is more as compared to the k-e model. The velocity contours are decreasing radially around the center of the cross section. At inlet the velocity is uniform and changes are observed near the surface contours.

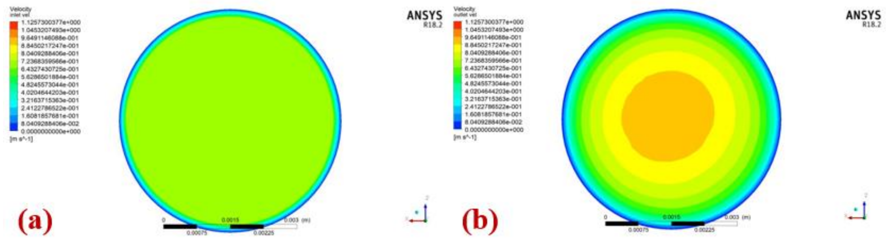


Figure 5.32 Velocity of cold fluid at (a) inlet and (b) outlet cross section of linear structure (k-w model)

5.2. Analysis of passage

A thermal therapy pad is applied directly to the body and its application of serving the desired effects is done by direct contact to the localized area of body. For this the material of the thermal pad is of high importance and the selecting the fluid is also a factor of concern. Depending on the all the safety issues, rules and regulation few materials for cover were proposed such as polyethylene, rayon, nylon etc. Talking about fluid the best would be water as it can be used for both hot and cold effects. But research and development is all about creating opportunities for betterment of the product. So, the proposed fluid for this dissertation is silica as it I already in use with the other pads. Only difference is that in this therapy pad the fluid need to be circulated though the direct contact of pump. This pump works completely fine with the water and test is to be done for silica as fluid. The analysis part of different combination of cover material and fluid has been done and are compared below.

5.2.1. Temperature Distribution

Temperature distribution of all the combinations were analyzed and they should be compared see the difference in the outcome. As seen earlier the k-w model gives better result in all aspect we have performed this analysis on k-w model only. Fig 5.33, Fig 5.34 and Fig 5.35 shows the different combinations of cover and fluid i.e. polyethylene surface in contact with water, polyethylene surface in contact with silica liquid and rayon surface in contact with silica respectively.

Fig 5.33 (a) shows the variation in temperature in polyethylene surface in contact with the hot water flowing in the passage provided. It can be observed that the temperature decreases slightly when the heat is transferred from fluid to the inner surface of the polyethylene. Fig 5.33 (b) shows the outer layer temperature of the polyethylene cover. The temperature drop in the inner and outer surface is around 1 kelvin. Fig 5.33 (c) shows the complete variation of temperature from fluid to the inner surface and then to the outer surface. This variation depends on the cross section of the tube and the thermal properties of the polyethylene and water. Fig 5.34 (d) is the front view of the complete variation showing the radial transfer of heat from inner surface to outer surface.

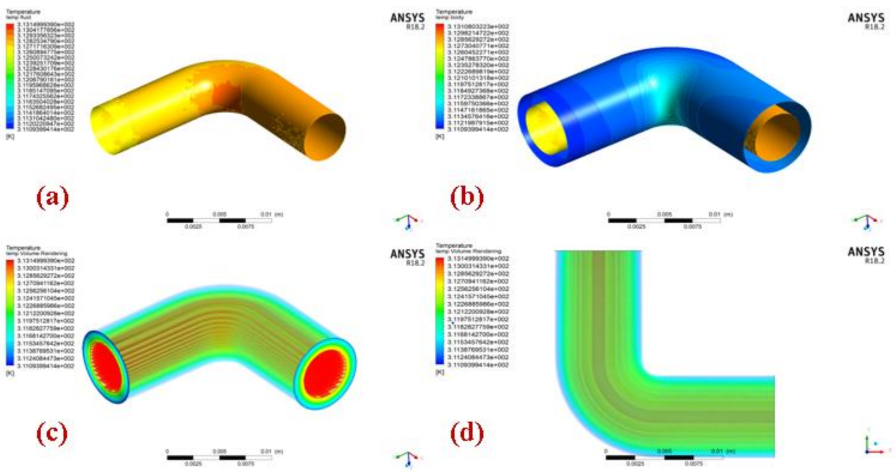


Figure 5.33 Temperature Distribution of (a) polyethylene surface in contact with water, (b) outer surface of fabric and overall passage temperature (c) isometric view (d) front view

Fig 5.34 (a) shows the variation in temperature in polyethylene surface in contact with the hot silica liquid flowing in the passage provided. It can be observed that the temperature decreases slightly when the heat is transferred from fluid to the inner surface of the polyethylene. But the drop-in temperature here is slightly less as compared to the water as fluid. Fig 5.34 (b) shows the outer layer temperature of the polyethylene cover. At outer surface also, the temperature drop is less providing a high temperature at outer surface. The temperature drop in the inner and outer surface is around 0.5 kelvin. Fig 5.34 (c) shows the complete variation of temperature from fluid to the inner surface and then to the outer surface. This variation depends on the cross section of the tube and the thermal properties of the polyethylene and silica liquid. Fig 5.34 (d) is the front view of the complete variation showing the radial transfer of heat from inner surface to outer surface.

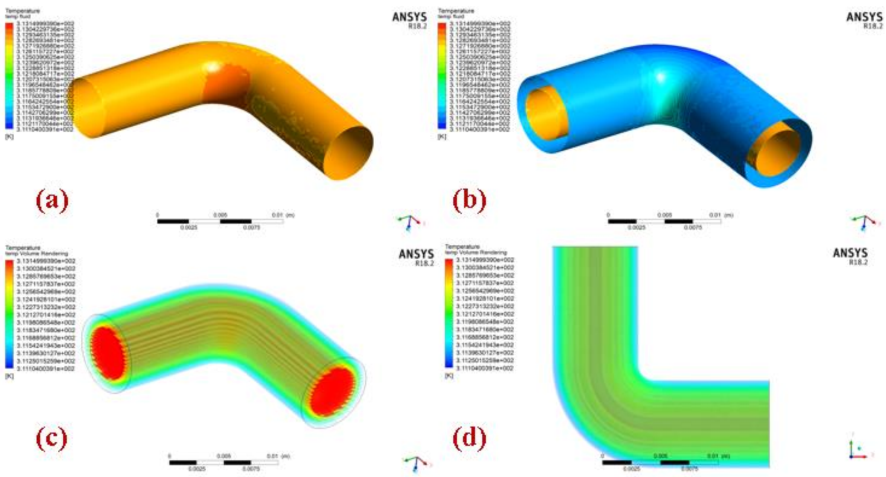


Figure 5.34 Temperature Distribution of (a) polyethylene surface in contact with silica, (b) outer surface of fabric and overall passage temperature (c) isometric view (d) front view

Fig 5.35 (a) shows the variation in temperature in rayon surface in contact with the hot silica liquid flowing in the passage provided. It can be observed that the temperature decreases slightly when the heat is transferred from fluid to the inner surface of the rayon. But the drop-in temperature here is slightly more as compared to the polyethylene as a cover material. Fig 5.35 (b) shows the outer layer temperature of the rayon cover. At outer surface also, the temperature drop is more providing a less temperature at outer surface of rayon. The temperature drop in the inner and outer surface is around 1.5 kelvin. Fig 5.35 (c) shows the complete variation of temperature from fluid to the inner surface and then to the outer surface. This variation depends on the cross section of the tube and the thermal properties of the rayon and silica liquid. Fig 5.35 (d) is the front view of the complete variation showing the radial transfer of heat from inner surface to outer surface.

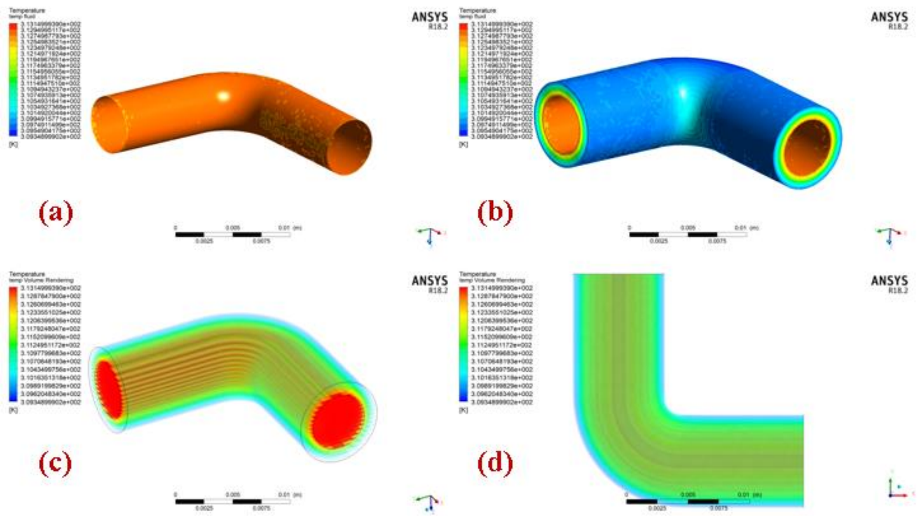


Figure 5.35 Temperature Distribution of (a) rayon surface in contact with silica, (b) outer surface of fabric and overall passage temperature (c) isometric view (d) front view

5.2.2. Pressure Distribution

Pressure variation inside a tube is a function of head loss due to the major and minor loss in the tube. Depending on the property of the fluid and tube surface the pressure varies. This was analyzed for different combination made and is discussed below.

Fig 5.36 (a) shows the variation in pressure across the passage with polyethylene as a cover and water as fluid. In this flow the pressure is more or less constant for this selected passage. The pressure increases at the outer radius of the bend passage and decreases at the inner radius of the bend passage. The pressure dropped by 0.05MPa from inlet to outlet. Fig 5.36 (b) is the front view of the pressure distribution for polyethylene as cover and water as fluid.

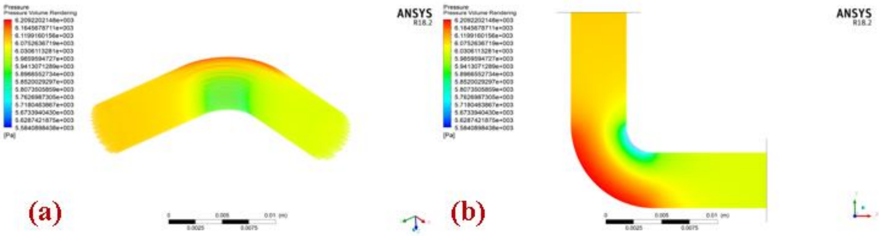


Figure 5.36 Pressure Distribution in polyethylene surface with water as fluid

Fig 5.37 (a) shows the variation in pressure across the passage with polyethylene as a cover and silica liquid as fluid. In this flow the pressure remains constant for this selected passage with slight variation across the bend surfaces. The pressure increases at the outer radius of the bend passage and decreases at the inner radius of the bend passage. The pressure dropped by 0.02MPa from inlet to outlet. Fig 5.37 (b) is the front view of the pressure distribution for polyethylene as cover and silica liquid as fluid.

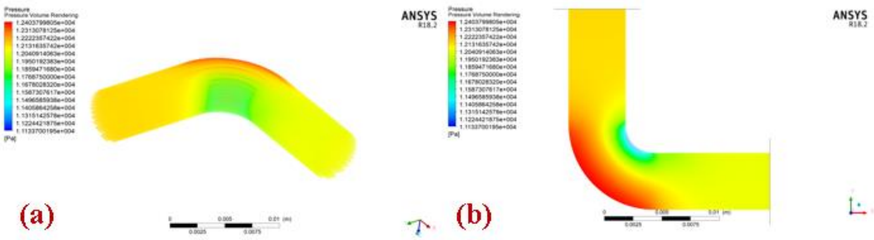


Figure 5.37 Pressure Distribution in polyethylene surface with silica as fluid

Fig 5.38 (a) shows the variation in pressure across the passage with rayon as a cover and silica liquid as fluid. In this flow the pressure somewhat constant for this selected passage. It has also a same effect at the bend surfaces i.e. the pressure increases at the outer radius of the bend passage and decreases at the inner radius of the bend passage. The pressure dropped by 0.02MPa from inlet to outlet. Fig 5.38 (b) is the front view of the pressure distribution for rayon as cover and silica liquid as fluid.

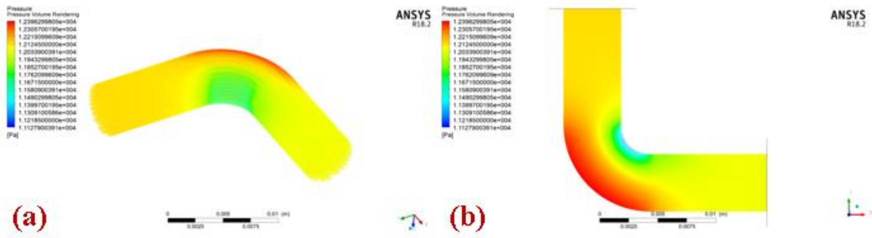


Figure 5.38 Pressure Distribution in rayon surface with silica as fluid

5.2.3. Velocity

Velocity of fluid inside the cover passage depends on the flow property of the fluid and the surface property of the tube. The velocity of fluid for this small cross section will not vary much but for comparison purpose it has been included and the variation has been compared subsequently.

Fig 5.39 (a) shows the variation in velocity of water in polyethylene passage. The velocity increases at the inner radius of the bend passage and decreases at the outer bend radius. This variation is opposite to the variation seen in pressure distribution across the inner and outer bend radius. Fig 5.39 (b) shows the front view of the velocity variation.

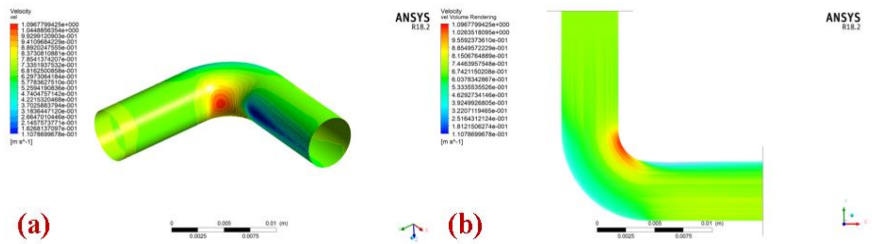


Figure 5.39 Velocity of water in polyethylene passage a) isometric view and (b) front view

Fig 5.40 (a) shows the variation in velocity of silica liquid in polyethylene passage. As seen in previous case, the velocity increases at the inner radius of the bend passage and decreases at the outer bend radius. Fig 5.39 (b) shows the front view of the velocity variation.

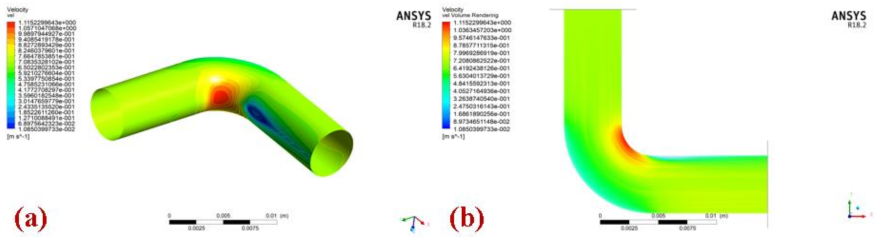


Figure 5.40 Velocity of silica in polyethylene passage (a) isometric view and (b) front view

Fig 5.41 (a) shows the variation in velocity of silica liquid in rayon passage. As seen in previous cases, the velocity increases at the inner radius of the bend passage and decreases at the outer bend radius. Fig 5.39 (b) shows the front view of the velocity variation.

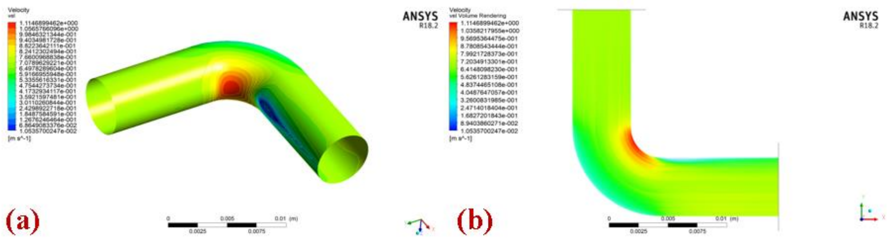


Figure 5.41 Velocity of silica in rayon passage (a) isometric view and (b) front view

5.3. Thermal camera results

As mentioned in the section 1.8, thermal camera is used to measure the temperature of the object by using the infrared radiation. Fluke thermal camera has been used here to capture the thermal image of the pad and measure the temperature of fluid and pad at different locations. The ambient condition was kept at room temperature and pad was allowed to reach the steady state. For this the flow was allowed to circulate the through the pad for 20 minutes. After the time lapse of 20 minutes thermal camera was used to capture the image of thermal pad and is studied for the reference purposes. Fig 5.42 shows the experimental setup of the thermal camera and therapy pad connected with the pump. The Fig 5.42 was captured during the initial stage, after 3 minutes. Hence the temperature displaying by the thermal camera is around 309.6 K. This indicates that the steady state condition has not reached yet.

Figure 5.42 Experimental setup of thermal camera and pad

Fig 5.43 shows the thermal image of therapy pad when steady state was reached. The thermal scale at the right side shows the temperature variation in the included image. Since the pump was set to 315 K but here maximum temperature is only 313.9 K. This clearly indicates the temperature drop of around 1 kelvin when the heat is being transferred from water to the polyethylene cover. The fluke camera provides a function to measure temperature at each point and in desired area of the pad. Starting with the inlet the average temperature is around 313.77 K. In the upper left corner, the average temperature is 313.59 K. This slight loss in temperature is due to the convective heat loss though the passage that has been covered. The center of the pad has average temperature of 313.97 K. The lower left corner has slightly less average temperature of 313.31 K and the lower right corner has average temperature of 313.40 K. As observed there is only slight change in the temperature of fluid at corners. This fluctuation is within a range of 0.08 kelvin. The outlet of the pad has average temperature of 312.62 K. It can be observed that the temperature difference is of around 1 kelvin in inlet and outlet fluid.

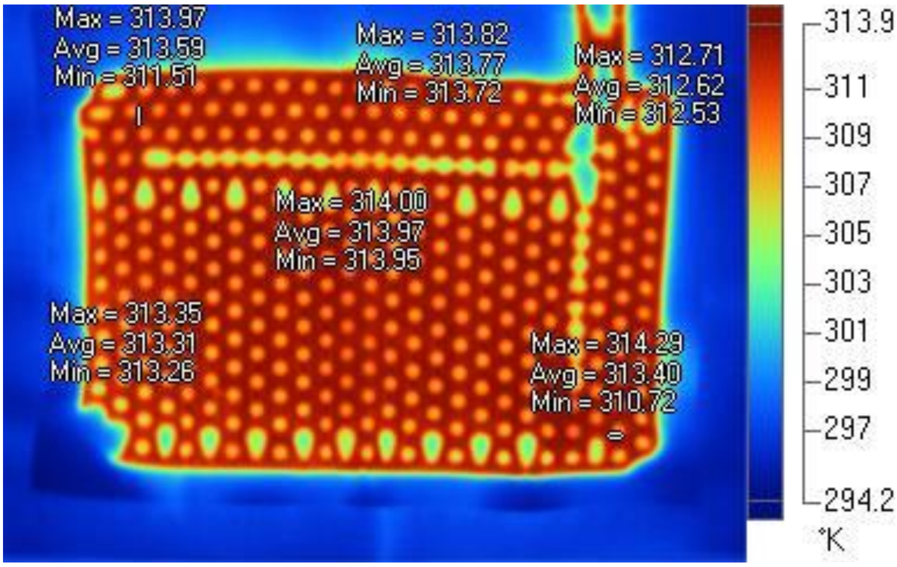


Figure 5.43 Thermal image of therapy pad after reaching steady state

Fig 5.44 shows the variation of temperature with time for different fabric material and fluid combination. Fig 5.44 (a) shows the variation of polyethylene as fabric material and water as fluid. In this the temperature variation is quite uniform and is providing high temperature for longer period. Fig 5.44 (b) shows the temperature distribution of polyethylene as fabric material and silica liquid as fluid. In this the temperature drop is little more as compared to the previous one. Fig. 5.44 (c) shows the temperature distribution of the rayon as a fabric material and silica liquid as a fluid. The temperature in this reduces further thus providing low temperature gradient for the patient.

Fig 5.44 (d) shows the comparison of different combinations. From this it can be observed that the highest temperature is given by polyethylene as fabric material and water as fluid. The other two combinations are giving low temperature compared to the first one.

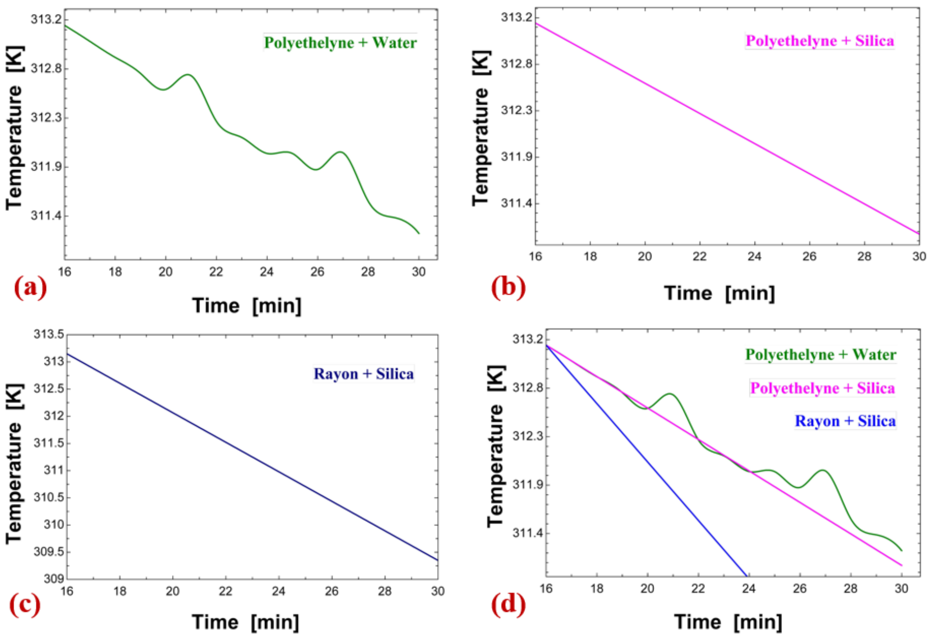


Figure 5.44 Temperature Vs Time graph for different fabric and fluid

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

6.1. Conclusion

The project work encompasses the need of development of thermal therapy pad and to do necessary modification in the passage of the flow. In this dissertation, the flow work in different structure was carried out and the comparisons were made. Seeing those comparison and considering the need and requirements of medical rules and regulations the pad with honey-bee structure will be favored. The main reason would be the allowing of pad to be used in any condition with wrapping. The temperature and pressure drop in both the passage was same. The velocity in honey-bee structure is less as compared to the linear structure but here it is of less concern. The priority is to make the patient comfortable within less time with an ease.

The fabric and fluid are also compared in this project. All fabric and fluid combination reduces the temperature by 1 kelvin and transfer the heat though convection and conduction. The fabric chosen is polyethylene as it has been tested and verified and is biocompatible and gives the highest temperature available for therapy. The water is chosen as fluid as it provides both heat and cold therapy. Thus the combination of polyethylene and water gives the best possible result as per need.

6.2. Future Scope

As discussed in conclusion section, the product can be design with more efficient flow passage and heat transfer mechanism. The fluid used right now is water which is due to limitations of cold therapy. In future this fluid can be replaced by some fluid containing nano particles to enhance the thermal effect. Silica liquid can also be used with some different material. The T-pump specification can also be altered to make the therapy better. At present the portability of thermal pad is issue if thermal pad alone is needed for more than 1 hour of application. This can be overcome by changing the fluid and material of cover. Moreover, some design concept may be changed. This will be based with an objective to make the wrapping of the thermal pad easy. These results can be utilized for the betterment of other products like mattress, wrapping blanket etc.

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