Chapter 8

Investigation Of Thermal And Flow Characteristics Of Forced Convection Operating Blankets

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Abstract

In this study, operating theatre blankets, which are one of the measures taken against the risk of the patient's body temperature drop during surgery, were examined from various angles. Textile processing method was applied using spot welding method. Within the scope of the study, the hot air vents coming out of the blankets were analysed in terms of system pressure and air outlet velocity. Instead of performing experiments on real patients, an aluminium plate assembly heated from the bottom under constant temperature conditions in the laboratory environment was used. In the second stage, values such as pressure and velocity were measured with the set-up, but heat transfer calculations could not be performed more precisely. Therefore, some calculations were performed using the ANSYS-CFX package programme. In the third stage, several different models of non-perforated blankets, which have only warm air inside and therefore cover the patient partially or completely, were compared in terms of energy consumption. Finally, different models of blankets were tested on the same plate assembly in terms of the temperature generated on the surface. It was concluded that there are clinically significant differences between forced air heated blankets and other types of blankets

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1. Introduction

Thermoregulation is a process by which our body maintains its core internal temperature. All thermoregulation mechanisms are designed to return our body to a state of homeostasis, or equilibrium. One of the moments when thermoregulation is disrupted in the living body is the moment of surgical intervention. During surgical intervention under general anesthesia, the patient's body experiences a decrease in body temperature due to the effect of the anesthesia drugs used and peripheral vasodilation (dilation of the vessel by relaxation of the smooth muscle in the vessel wall) on the thermoregulatory centers. Therefore, temperature control of the body during surgery is a very important issue.

Medical and biomedical studies have clearly shown that, as general anaesthesia can cause shivering and potentially lower body temperature levels, it may be necessary to warm patients for any procedure requiring anaesthesia to prevent hypothermia. It is vital that the patient is warmed before and, if necessary, during the operation, as there is a danger of the body temperature dropping for various reasons during the operation. Sometimes the body temperature drops more during the operation. During the operation, warming is provided with a blanket and the body temperature can be maintained at the desired level throughout the operation.

In this study, operating room blankets, which are used as a precaution against the danger of the patient's body temperature drop during the operation in operating rooms, are discussed in many aspects. The study consists of 4 chapters. In the first part, there is an introductory section where a brief introduction is made. In the second part, there is a detailed literature review on the medical uses of blankets and thermoregulation. In the third part, some of the blankets with forced air heating (heating of air by forced convection) are compared in terms of determining the pressure and speed values of the blower fan. In the fourth section, some well-known forced air heated blankets are compared with direct contact conduction heated blankets in terms of energy consumption. Finally, in the fifth section, heat transfer analysis of forced air heated blankets is carried out with the help of ANSYS-CFX, which performs computational fluid dynamics analysis. Finally, general evaluations are made in the Results section.

2. Literature Review

2.1. Thermoregulation and Homeostasis

The human body maintains a temperature of 37°C, also called body core temperature or core temperature, by using various physical processes.

These include sweating to lower body temperature, shivering to raise it, and constricting or relaxing blood vessels to change blood flow. If body temperature is not regulated, the body can overheat, leading to "hyperthermia". Hyperthermia, also known as heat stroke or sunstroke, is a condition in which the body's thermoregulatory mechanisms become inadequate and overheat, usually as a result of prolonged exposure to high temperatures, prolonged or intense physical exertion or drug use [1].

The body's thermoregulatory balance is the best illustration of homeostasis. Temperature-sensitive receptors are present in the skin. The control center alerts the blood vessels and sweat glands in our skin to changes in temperature outside, allowing them to adjust appropriately. The body temperature drops when the temperature is too high because the blood vessels dilate, or vasodilatate. In addition, sweat is produced by the sweat glands in tandem with vasodilatation. Vasoconstriction, or the narrowing of blood vessels in response to extreme cold, helps the body retain heat. A flow chart representing thermoregulation in the human body is shown in Figure 2.1 [2].

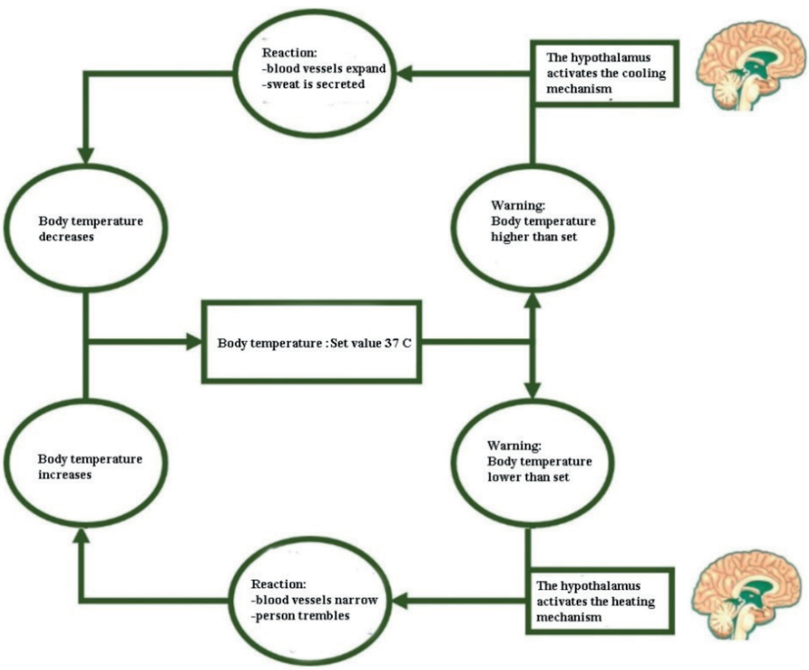


Figure 2.1. Thermoregulation in the human body

The capacity of an organism to retain internal stability in the face of environmental changes is known as homeostasis. The best illustration of homeostasis is thermoregulation, the regulation of the body's internal temperature. The nervous and endocrine systems are essential for preserving the body's homeostasis. Still, other organs are involved in the preservation of homeostasis. A self-regulating mechanism called homeostasis manages the internal factors required to maintain life. Sweating is the body's attempt to remain cool in a hot environment. Furthermore, blood vessels close to the skin's surface enlarge. This aids in reducing body temperature. In contrast, the blood vessels constrict and retain body heat in a cold environment. As a result, the skin keeps its equilibrium [3].

A fundamental understanding of thermoregulation and homeostasis is necessary for many physiological and therapeutic applications. 37°C is the typical core (or center) temperature. It is restricted to a small range (33.2–38.2°C), which gets even smaller when rectal, tympanic, or axillary measurements are substituted for oral measurements [4]. Throughout the day, during the menstrual cycle, and as we age, there are regular fluctuations that happen. The body's thermoregulatory systems will be tested by abnormal core temperature deviations of a few degrees, and temperature swings outside of the normal range can be lethal. For instance, cytotoxicity with protein denaturation and reduced DNA synthesis happens over 42°C [5]. Failure of internal organs follows from thisSerious hypothermia, or a body temperature below 27°C, can also have fatal consequences for the respiratory, cardiovascular, neuromuscular, and haematological systems [6]. Humans are able to push the limits of their thermoregulatory capacity and survive in the most extreme environments, despite the necessity for strict regulation of core temperature. Think about the fact that some people can partake in ice diving, where the water can be just a few degrees above freezing, or the Marathon Des Sables, a 251-kilometer endurance running race held in the Sahara Desert, where daytime temperatures can reach 50°C. Many of us find it incomprehensible that they can do these things and still live. But the reason is obvious. To ensure optimal physiological function and survival, humans must be able to maintain core body temperature (in the head, chest and abdomen) in the face of environmental temperature challenges.

Heat input into the body must equal heat output from the body in order to maintain core body temperature. Humans are endothermic, or homeothermic, meaning that they can control their body temperature and produce their own heat. The primary means of achieving a high core temperature is through heat production brought on by metabolism. As will be covered in more detail later, heat transfer always occurs along a thermal gradient, or from hot to cold, via radiation, conduction, and/or convection. Since people are typically the hottest objects in a given environment, heat transfer normally occurs in this direction. Nevertheless, heat loss via evaporation takes over as the main method of heat dissipation when the core temperature rises [3].

The following heat balance equation addresses the internal and external factors that contribute to thermal equilibrium and thus to the maintenance of core temperature:

Heat storage = metabolism - work - evaporation ± radiation ± conduction ± convection here;

- Chemical reactions that take place within the body are referred to as metabolism.
- The working muscle produces a lot of heat when exercising.
- Work is the done external labor.
- As water evaporates from the skin's surface and respiratory tract, heat is lost to the surrounding air.

The following three variables determine the total amount of sweat that evaporates from the skin:

- The body's surface area exposed to the environment.
- The ambient air's temperature and relative humidity.
- and the convective air currents surrounding it.

Radiation, electromagnetic heat transferred to non-contact bodies, including ultraviolet light radiation from the sun penetrating the earth's surface and infrared radiation from the body.

Conduction, is the movement of heat from the body directly to objects in contact with the body. Usually the amount of heat exchanged in this way is minimal.

Convection, is the transfer of heat to a moving gas or liquid. When a body heats up, the air molecules in contact with the body heat up, reducing their density, which causes the molecules to move, rise and are replaced by cooler air. Convective heat exchange is enhanced by the movement of the body in air or water, or by the movement of air or water across the skin.

The core and peripheral shell (skin) temperatures are typically discussed when talking about body temperature. The temperature of the "deep" bodily tissues, or the organs with high basal metabolic rates (the brain, heart, and liver), is reflected in the core temperature. Skin blood flow, which increases with a high core temperature and outside temperature, affects shell temperature. Usually, the skin on the hands and feet is used to measure it. These regions have high surface-to-mass ratios; the hands, for instance, have a ratio of four to five times that of the body [7].

The central integration or coordinating center for thermoregulation is the hypothalamus. The most significant area for autonomic temperature regulation appears to be the hypothalamus [8]. The hypothalamus receives its input from both central and peripheral thermoreceptors. There are two subtypes of thermoreceptors, one for the cold and one for the temperature: peripheral and central. The skin contains peripheral thermoreceptors, with a higher concentration of cold than warm receptors. There are more warm-centered thermoreceptors than cold thermoreceptors in the hypothalamus, spinal cord, internal organs, and large vessels. The most significant impact of central thermoreceptor activation is on core temperature, and it appears that activation of warm thermoreceptors inhibits activation of cold receptors [9].

2.2. Researches on Operating Room Blankets

Under general anesthesia, a surgical procedure results in a 1-3 °C drop in body temperature, which suppresses the thermoregulatory center and causes peripheral vasodilatation [10]. According to reports, hypothermia can raise the risk of bleeding, lengthen hospital stays, increase surgical site infections, and raise medical expenses. It has been demonstrated that maintaining a normal body temperature of ≥36°C during the perioperative period is crucial for postoperative recovery [11]. Studies on preoperative warming and the avoidance of postoperative complications have also been carried out. Decreased hepatic drug metabolizing enzyme activity has been linked to hypothermia [12]. Furthermore, hypothermia may lead to significant complications such as arrhythmias, coagulopathies, increased transfusion requirements, increased susceptibility to infections, and longer hospital stays [13, 14].

As was already mentioned, the human body uses three different forms of heat transfer—radiation, convection, and conduction—to regulate its temperature [15]. By including evaporation, we can actually raise this to four. This surface needs to safely transfer large amounts of heat to the patient, as 90% of heat is conducted through the skin [16]. In the past, specialized patient warming techniques have been employed to circulate hot water and produce heat through radiation and conduction. Hot water circulation heaters only heat the area in contact with the patient; hot air heaters, which surround the patient with warm air and transfer heat by convection, have reportedly been shown to be more effective in recent years [17, 18].

In terms of use, there are two types of warming blankets: over-body blankets, which warm the patient from above, and under-body blankets, which warm the patient from below. However, with the recent development of laparoscopic surgery, the number of operations performed in lithotomy (the position in which the patient is placed and secured in the supine position with the legs raised together and bent at the knees and placed and secured on pre-adjusted footrests) has increased rapidly and the number of cases of hypothermia has risen dramatically. Because lithotomy typically necessitates immobilizing the upper limbs, it is imperative to enhance techniques for controlling body temperature and the body heat field. Nevertheless, the warming field is frequently restricted to the anterior thorax and neck. The patient is heated from the head to the buttocks when an under-body blanket is utilized. This approach is probably going to be more successful in avoiding hypothermia. Without supporting data, it is challenging to adopt the under-body heating system widely due to its higher cost. While prior research has indicated the effectiveness of under-body heating systems for supine surgery [19, 20], no reports of their efficacy for procedures carried out in the lithotomy position exist [21].

The most effective way to prevent hypothermia is to warm the skin. Forced air heating blankets, conduction heating blankets or electric heating blankets can be used for this purpose [22]. However, until recently, the use of electric blankets was restricted due to concerns about electrical hazards and thermal injuries [23].

Active air heating in air heated blankets is done by using fan type forced air heating devices. Passive heating is heating using reflective blankets. The use of active prewarming (active heating before anaesthesia) in combination with intraoperative heating methods has been shown to be more effective than intraoperative heating in isolation in producing higher core temperatures and maintaining normothermia [24, 25].

Active or forced air heating devices rely on convection heating to increase skin temperatures and total body heat content, minimise the heat gradient between core and peripheral tissues and reduce heat redistribution [26]. Forced air heated blankets have a warm air flow that releases the airflow up to 43°C. This extra thermal energy causes temperature gradients that can impede laminar airflow in the operating room [27]. When this unidirectional laminar airflow is disrupted, there is the potential for increased surgical site contamination.

It has been shown that potentially pathogenic organisms can be detected in the tubing of devices connected to forced air heated blankets [28-30]. Although alternatives to forced air heated blankets have been shown to be passive heating devices that utilise a conductive energy mechanism by reflecting radiant body heat to prevent overheating [13], they may not always offer high thermal efficiency [40]. The use of such blankets eliminates any laminar airflow interruption and the absence of reusable parts eliminates the transfer of potentially pathogenic organisms by the device. Although studies have shown that reflective blankets are not as effective as active heating devices in maintaining intraoperative normothermia, none of these studies included the use of preheating of patients [13, 14, 25, 32].

Maintenance of the patient's normothermia (36°C) during surgery is essential to reduce the risks and complications associated with hypothermia. Several studies have shown that both general and regional anaesthesia can induce hypothermia due to iatrogenic thermoregulatory dysfunction and secondary heat loss from redistribution of core body temperatures. Hypothermia can lead to significant complications such as arrhythmias, increased transfusion requirements, greater susceptibility to infections, and subsequent longer hospital stay [13, 33].

It is appropriate to use upper body blankets during lower limb and abdominal surgeries. The use of upper body blankets suggests a decrease in both heat gain and loss in a relevant area. The enclosed region makes up roughly 0.35 m^2, or 15%–25% of the total surface area. With forced air heating systems and upper body blankets, the heat balance in this area can be adjusted between 46.1 W and 55 W. In conjunction with insulation and fluid heating, forced air heating with upper body blankets can effectively prevent perioperative hypothermia, depending on the type of surgery and the resulting fluid demand [33].

2.3. Blankets Used in the Medical World

The literature review to date has clearly shown that hypothermia is a major problem [34-41]. A number of things, such as the low operating room temperature, the patient's lack of insulating clothing, the application of cold or volatile solutions to the patient's skin to prepare it, and losses from incisions made on the patient, can result in heat loss from the patient. The effects of anesthesia during surgery make it harder for the patient's body to regulate its temperature, which exacerbates the problem. In patients with hypothermia from excessive exposure to cold unrelated to surgery, returning the body temperature to normal is also a concern. It is crucial to warm the patient as soon as possible as a result [42–43].

As mentioned above, the two most common forms of patient warming systems are forced convection air heated blankets and conduction heated blankets [44]. Forced convection air-heated blankets provide a flow of warm air through pores (holes) drilled in the surface in contact with the patient's body. The air coming out of the holes acts like an air jet and hits the patient's body and heats the body. In conduction heating blankets, the mechanism is that a heated pad covering the body maintains the patient's body temperature. Both approaches are effective in preventing hypothermia; however, it has been reported that the use of forced convection air-heated blankets is more effective in increasing the patient's body temperature compared to conduction-heated blankets [44].

Other solutions have been proposed to prevent hypothermia during surgery. Some involve preheating, i.e. providing heat to the patient bed from an external source, such as the application of electric hospital blankets. This is an inexpensive, simple solution, but it has the disadvantage that the heat rapidly decreases, as electricity would be hazardous during surgery and therefore heating would not be available (Figure 2.2).

Figure 2.2. Preoperative bed warming with electric blanket [45]

Blankets through which heated water is passed have also been used with some degree of success. Nonetheless, because of the weight of the liquid, these blankets frequently have an external heat source and are large and bulky (Figure 2.3). Because they are used frequently and eventually begin to leak, water blankets can also be unhygienic. Increase the temperature of the operating room, or at least the area surrounding the patient, with heat lamps is another prior art method for managing the patient's body temperature. The disadvantage of this method is overheating of the surgical team, which is already usually heavily clothed [40].

Figure 2.3. A blanket with hot water inside [46]

Today, forced air blown blankets are preferred in many countries of the world. Hot air is passed through these blankets. Some are laid under the patient and some are laid on top [48]. Figure 2.4 shows an example of a blanket laid under the patient.

Figure 2.4. Example of an air blown blanket with bottom heating [47]

Some of the blanket types that are usually covered on the patient have holes on the face in contact with the patient, through which the air is impinged on the body. In some models, there are no perforations, just heat passing through the blanket fabric to the patient, which is heated by warm air. A disadvantage of this approach is that they are double-walled blankets with an internal chamber for air passage. The natural thickness of the blanket fabric creates a physical barrier to heat transfer. When air is introduced into the blanket, the blanket "puffs" so to speak and can interfere with surgery.

With the emergence of this problem, types that cover the parts of the patient to be operated on and leave the other parts exposed have been produced. Figure 2.5a, and Figure 2.5b show partial area warming blankets, and Figure 2.5c shows an example of a blanket covering the whole body.

a) *b)* *c)*

Şekil 2.5. Examples of top heated air blown blankets [49]

3. Investıgatıon Of The Holes Drılled In Forced Aır Heated Blankets In Terms Of Pressure And Velocıty Accordıng To The Method Of Openıng

As seen in the literature, there are many studies on the use of forced air heated surgical blankets [40-44, 48, 50]. It has been concluded that there are clinically significant differences between forced air heated blankets and other types of blankets [48, 50] and that forced air heating systems are more effective in keeping the body at the desired temperature. In the medical market, there is an ever-increasing number of forced air heated blankets. However, there are few studies investigating the physical background of these devices and aiming to find the most suitable one. For example, the heat flow generated by the power units of a blanket depends on the air temperature at the nozzle and the air flow rate [50]. It is obvious that engineering investigations are required on many subjects such as energy capacity and efficiency, heat transfer, pressure, flow rate and speed settings. Some pioneering studies have already been initiated by the supervisor of this study. For example, Çelik and Bayazıt [51] measured the outlet air pressure of two types of blankets with air holes drilled on the patient contact surface and discussed which blanket would be more efficient. In another study by Bayazıt and Sparrow [52], which also inspired this study, various blanket types were compared in terms of their energy efficiency. Brauer et al. [16] measured the temperature changes on the inanimate model, also called patient surrogate, using various blankets. At this stage of the study, extensive research has been carried out especially in the light of the 3 cited studies, and the stages followed are given below;

Firstly, blankets with hot air coming out of the holes were analysed in terms of system pressure and air outlet velocity. Instead of conducting experiments on real patients, an aluminium plate set up in the laboratory, heated from the bottom under constant temperature conditions, was used.

1. Several different models of blankets, which are not forced air heated, but heated by direct contact conduction, that is, not perforated, but only partially or completely covered on the patient with hot air or other heating system inside, were tested on the installed plate assembly and compared in terms of energy consumption.
2. Although values such as pressure and velocity were measured with the set-up, heat transfer calculations could not be performed accurately. Therefore, some calculations were performed using ANSYS-CFX programme. While performing the calculations, the different geometries of the holes were also compared.
3. Finally, different models of blankets were tested on the same plate assembly, this time in terms of the temperature they caused on the surface.

3.1. System Pressure in Air Blown Blankets

As already emphasised, some surgical blankets with forced heating have some holes under the inner chamber. Through these holes, hot air hits the patient during the operation. A disadvantage of such blankets is that the exhaust of the heated air around the patient may cause the surgical team to overheat. In this case, the air conditioner consumes more energy.

In this part of the study, the effects of opening the air holes with two different methods on the working pressure of the system are analysed. Then, the effects of opening the holes in two different geometries on the working pressure of the system are analysed. The flow rate provided by the blower fan is closely related to the operating pressure. The pressure at the outlet of the fan and the velocity at the inlet of the blanket are the tested parameters of the system.

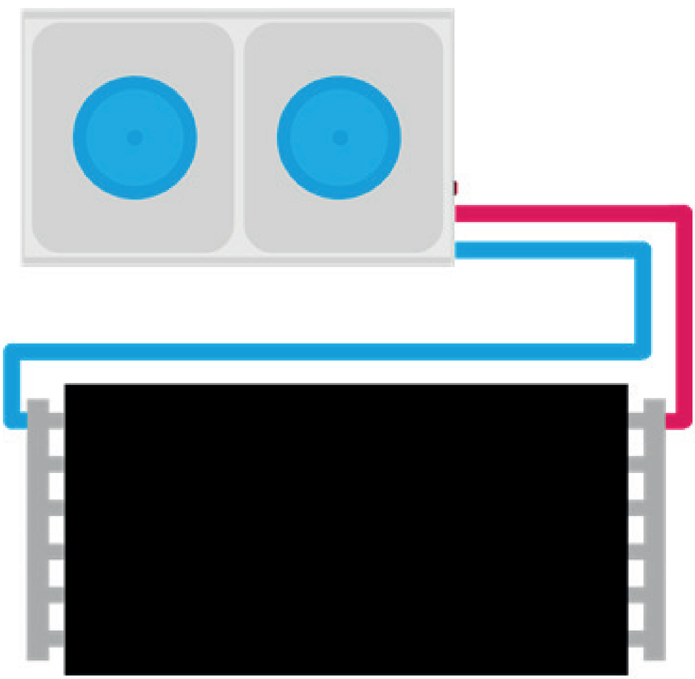
3.1.1. The Effect of the Shape and Geometry of the Air Blowing Holes on Pressure

The blanket used in the experiments has a length of 185 cm and a width of 90 cm. The mass of the blanket is 135 g. In fact, the blanket considered is a forced air heating type that does not blow air, only hot air is sent into it. In order to obtain a blanket that blows air on the surface in contact with the patient, various processes were applied to the blankets. It will be useful to state immediately that such perforated blankets are available in the market. However, in our study, our aim is to test whether the existing holes are efficient. For this reason, circular holes were first drilled under the inner chamber of the blanket sewn with a simple duvet cover technique. The diameter of each hole is 1 mm. The distance between two holes is 3 cm along both length and width. The holes were obtained in two ways: by hot burning and punching. In hot burning, a 1 mm diameter rod heated to a glowing ember was pressed onto the wire fabric and pulled. Air was blown through the hole formed by the burning parts. In the second type, i.e. punching, holes with a diameter of 1 mm were formed with a punching device, which is a textile tool. It was examined whether there was a difference in the pressure and speed of the air blown from the blanket in terms of the formation of the hole.

The geometry of the holes is as important as the way they are formed. Because sending hot air to the patient's body is a real impact jet application. In impinging jets, the geometry of the nozzle or pipe from which the air comes out is an important factor parameter. For this reason, blankets were tested in three different situations such as triangular, square and circular holes. Triangular and square holes were drilled with a hydraulic diameter of 1 mm at 3 cm intervals, just like the circular hole. Thus, their sizes were equalised.

In the experiments, the air from the air-blowing blanket was impinged on a smooth fixed plate called a surrogate patient (manikin) instead of real patients. The use of this plate, schematically illustrated in Figure 3.1, as a surrogate patient was investigated for compliance with the standards. It was found to be accepted by ASTM (F2196-02, 2002) and TS (60601-2-35, 1996) [53].

a)



b)

Figure 3.1. Plane designed as human body a) Front View b) Top View

The plate is made of aluminium sheet 6 mm thick, 1.5 m long and 1 m wide, whose upward facing surface is painted with matt black paint to provide a radiation equal to that of human skin (ε=0.90-0.95). A total of

16 strings of water-carrying copper tubes were placed under the downward facing surface of the plate. In the pressure and velocity experiments, no attention was paid to heating measurements; in the thermal tests to be described later, the constant body temperature condition was ensured by the hot water passing through these pipes. Figure 3.2 shows a photograph of the blanket on the plate. Both pressure and velocity were measured using a small diameter Pitot tube.

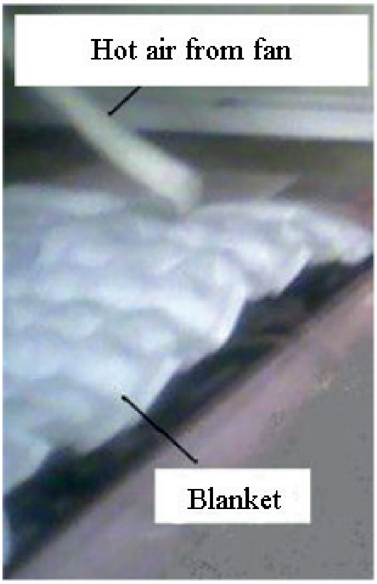


Figure 3.2. Tested Blanket

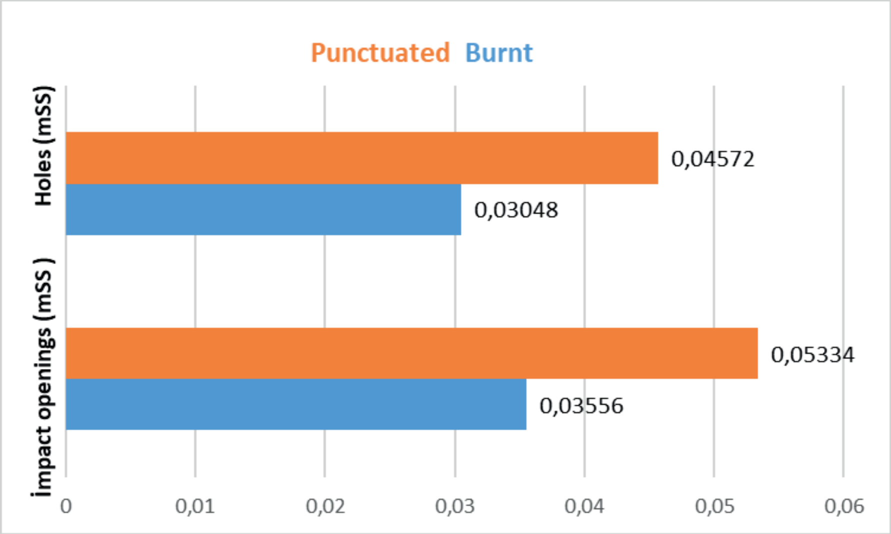
The first motivation for the pressure measurements was the determination of the operating point of the system when making air outlet measurements from the blower fan. The operating point represents the intersection point of the fan curve and the system curve. The variation of the operating pressure in combustion-formed perforated blankets compared to puncture-formed perforated blankets is due to the change in flow resistance.

Measuring the static pressure at the outlet of a blower is a challenging task. This is because the fluid flow lines at that location are by no means straight and mutually parallel. Two approaches have been used to deal with this complexity. One is to place a Pitot tube with the pulse opening facing the direction of flow. The measurement of the pressure at the pulse opening was expected to be a reasonable estimate of the static pressure. The second approach is to measure the pressure in the static orifices of the Pitot tube while the pulse aperture is positioned facing downstream.

The results of the pressure measurements are presented in Figure 3.3. The static pressure measured at the blow opening facing the flow direction was 0.05334 mSS for the blanket with holes formed by puncture and approximately 0.03556 mSS for the blanket with holes formed by burning. These numbers were then checked by removing and replacing the Pitot tube at the blower outlet. Although the numerical values were not reproduced per se, the relative differences between the two cases are negligible. The static pressures at the hole mouths were 0.04572 mSS in the case of holes formed by spotting and 0.03048 mSS in the case of holes formed by burning.

The pressures measured in the static holes of the Pitot tube reinforced the trend described in the previous paragraph. In fact, the results are not surprising. Before the experiment, it was observed that the perforated blanket created by combustion produced more regular holes. Problems such as small crumbs on the edges and uneven hole perimeter were observed while drilling holes in punching. For this reason, lower pressure drop was expected for the perforated blanket formed by burning compared to the perforated blanket formed by punctuating. Since this expectation is a visual assumption, it is useful to measure the air velocities at the inlet of the blanket to be sure of the results.

The average velocity calculated from the pitot tube impact pressures are 9.4488 m/s and 10.0584 m/s for the puncture-formed perforated blanket and the burn-formed perforated blanket, respectively. Statistically speaking, the difference between these two numbers should not be considered. This is because the measurements are limited to a single diameter. Since the holes created by burning are smoother, they do not block the air flow, so it is expected that the air velocity will be higher in the blanket with holes created by burning, just like the result of low pressure loss.



Figurel 3.3. Measured pressures at the impact opening and in the bores

Although the types of holes created by burning gave better results among the circular perforated blankets, spotting has been a more preferred method as a textile processing method. For this reason, in this part of the study, air pressure and velocities were measured from the triangular and square hole blankets by spotting method as well as the circular holes. The data were summarised in a single graph. Figure 3.4 shows the pressure drop.

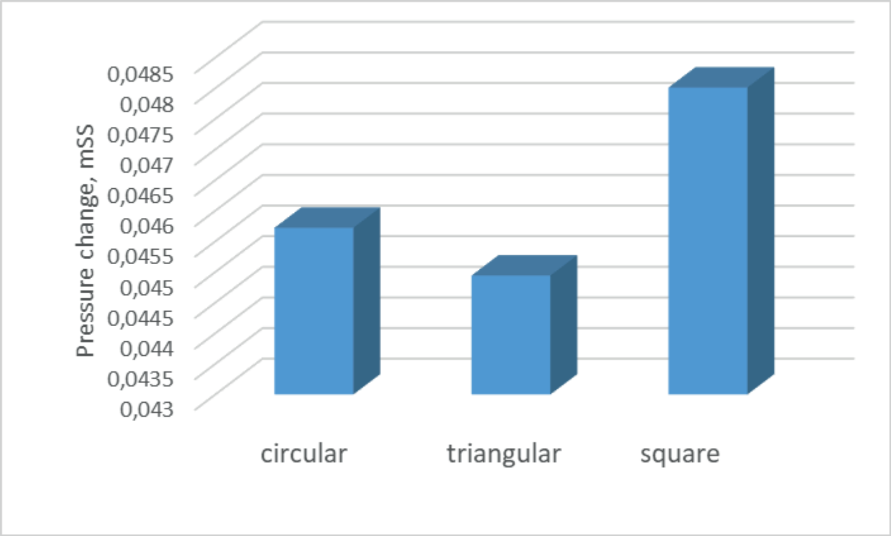


Figure 3.4. Static pressures measured in holes according to geometry type

In the pressure drop tests, the highest pressure difference was detected in the square pipe, then in the circular pipe and finally the lowest pressure difference was detected in the triangular pipe. Similarly, velocity values are given in Figure 3.5.

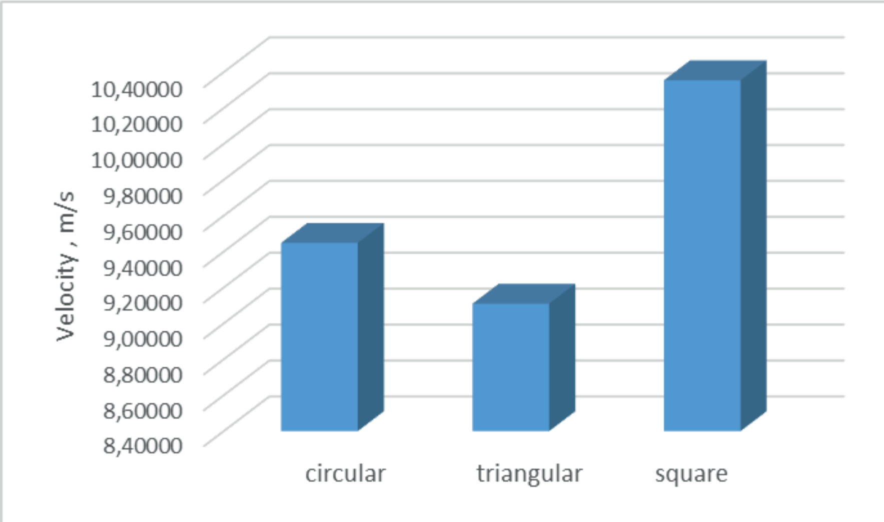
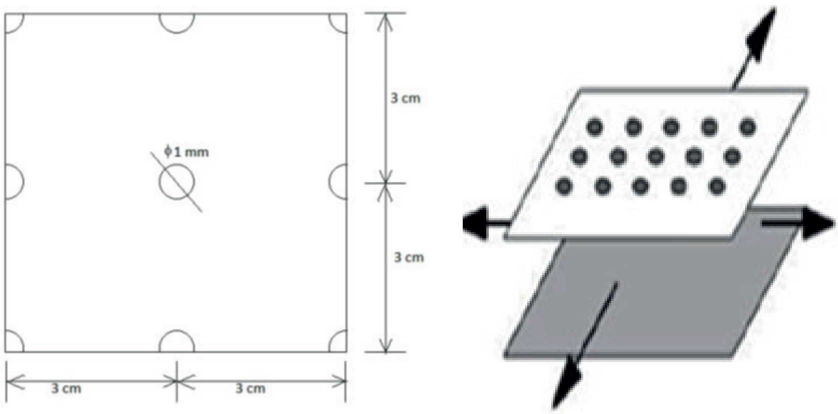


Figure 3.5. Outgoing air velocities by geometry type

As can be seen in the figure, the highest velocities were measured in the square tube, then in the circular tube and then in the triangular tube. This was confirmed by Celik [54], who had previously performed impinging jet studies with three different geometries. The highest velocity and momentum were obtained with square geometry. This was followed by circular and triangular tubes.

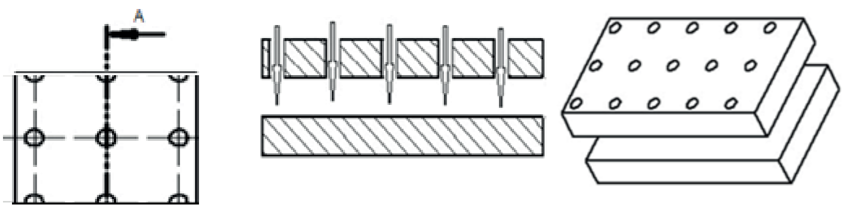
4. Temperature And Heat Transfer Estimates Obtained By Numerıcal Analysis

At this stage of the study, the air jet hitting a flat surface was modelled from a plate with holes drilled on it. The holes were designed as circular, triangular and square. For each geometry, the hydraulic diameter was taken equal to 1 mm. A specific cross-section through the fabric was considered. Figure 4.1a shows the surface (orifice plate) where the circular holes based on the numerical model are located. Figure 4.1b shows the free jet shape between the surface with the holes and the surface that replaces the patient's body. Since the hot air hitting the plate through the holes of the blanket can leak out of the gaps on the edges, the jet stream is considered free, that is, the edges between the opposite orifice plate and the impact surface are open. Figure 4.2 shows the position of the holes and the impact surface from another point of view.



a) *b)*

Figure 4.1. Schematic representation of the modelled drilled surface



a) *b)* *c)*

Figure 4.2. Illustration of the impact surface with holes from various angles

The problem was solved under laminar flow conditions using ANSYS-CFX commercial package programme used in computational fluid dynamics studies. The boundary conditions are defined as the mass flow rate of the air entering through the holes "inlet", the impact surface "wall" with constant 35°C temperature, the edges "opening", the part of the blanket outside the holes "wall" without thermal condition. The problem was solved as time dependent. In this way, it will be possible to find out how long the temperature will become constant in the patient's body. A starting temperature of 35°C was chosen. The total time was determined as 300 s, i.e. 5 min. The initial temperature of 35°C was chosen on the grounds that the patient was about to enter hypothermia. Mass flow rate values are the reference values obtained in the experiments. It was assumed that there was a 6 mm gap between the holes and the impact surface. Since the flow is laminar according to the flow rate values, the following equations were solved under laminar flow conditions:

Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{4.1}$$

Reynolds averaged Navier-Stokes momentum equation:

$$\rho\left(u_i \frac{\partial u_j}{\partial x_i}\right) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) \quad j = 1, 2, 3 \tag{4.2}$$

where μ is the fluid viscosity. Its value at the appropriate temperature for air was found from the tables. Finally, CFX energy equation was used to solve the thermal problem.

$$\rho c_p \left(u_i \frac{\partial T}{\partial x_i}\right) = \frac{\partial}{\partial x_i}\left(k \frac{\partial T}{\partial x_i}\right) \tag{4.3}$$

where k k is thermal conductivity, ρ is density, C_p is specific heat.

The appropriate network structure for the solution domain was found by comparing the temperatures and velocities after several trials. When the results of the tested network structures were close to each other by 0.5%, the final network structure was used. Figure 4.3 shows the network structure.

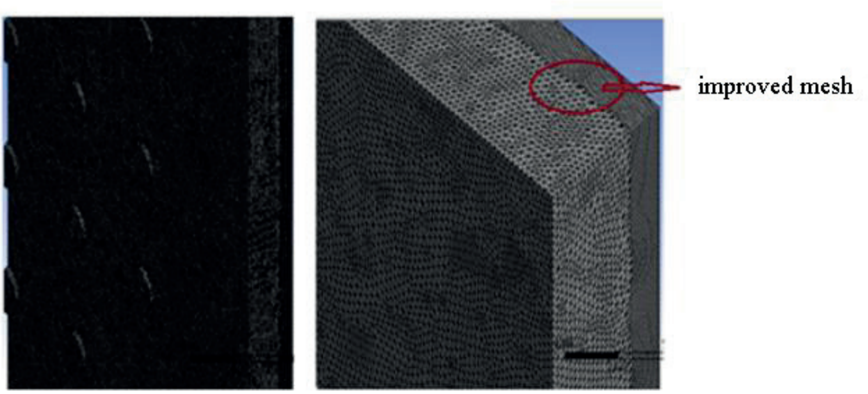


Figure 4.3. Solution area mesh structure

The results will be shown graphically below. However, it should be noted that local values are given by selecting some measurement points on the plate. The 6 cm long plate was assumed to have a line passing through the centre of the plate at a level distance and points were determined at 1 cm intervals on this line. These points are given in Figure 4.4.

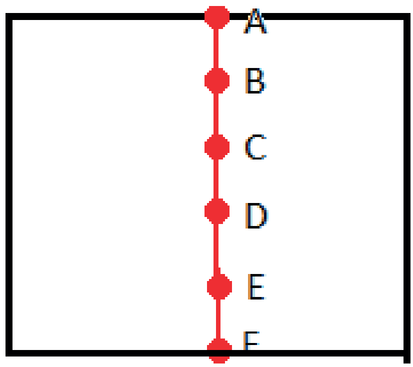


Figure 4.4. Local points

The results will be shown graphically below. However, it should be noted that local values are given by selecting some measurement points on the plate. The 6 cm long plate was assumed to have a line passing through the centre of the plate at a straight distance and points were determined on this line at 1 cm intervals. These points are given in Figure 4.4.

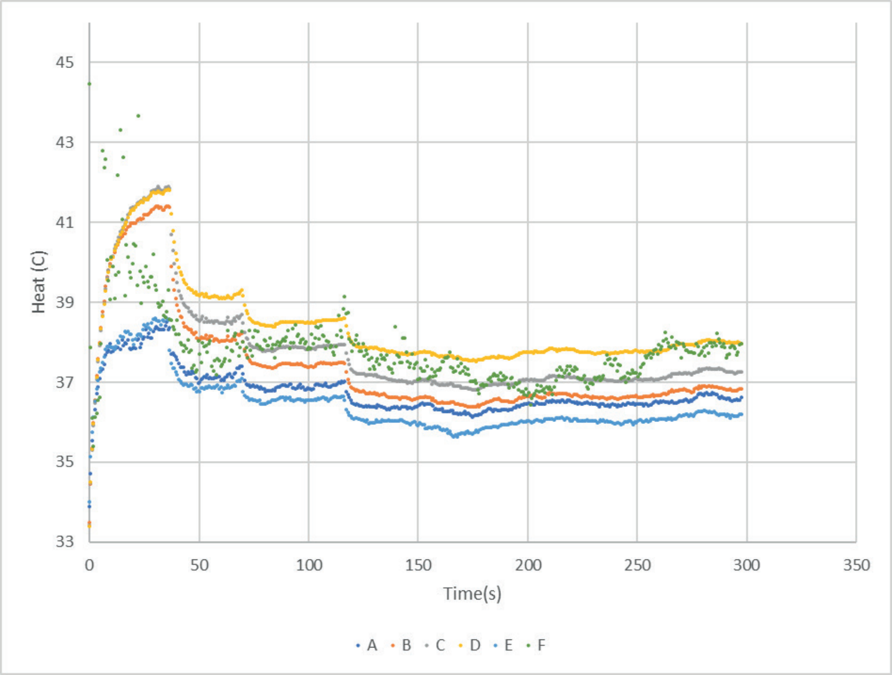


Figure 4.5. Time-dependent temperature change

Table 4.1 shows the variation of temperatures at local points A, B, C, D, E, F when the flow rate of the hot air coming out of the blower fan is increased in case of using a circular hole. The flow rate increase is shown in terms of Reynolds number. In Figure 4.6, the variation of temperature values with Reynolds number is shown graphically.

Table 4.1. Reynolds number dependent temperatures of local measurement points for a circular hole

Re	A	B	C	D	E	F
96.76096	36.27778	36.33333	36.33333	36.38889	36.27778	36.33333
105.0534	36.61111	36.66667	36.72222	36.83333	36.66667	36.61111
111.6172	36.72222	36.77778	36.77778	36.88889	36.77778	36.66667
143.5665	36.83333	36.88889	36.94444	37.16667	36.94444	36.77778
175.5732	37.16667	37.22222	37.33333	37.44444	37.22222	37.16667
182.9526	37.27778	37.38889	37.44444	37.72222	37.38889	37.22222
238.6707	37.66667	37.72222	37.77778	37.83333	37.66667	37.61111
245.2231	37.72222	37.77778	37.88889	38.11111	37.83333	37.66667
312.1753	37.88889	37.83333	38.05556	38.27778	38.05556	37.94444
392.1013	37.83333	37.94444	38.22222	38.33333	38.27778	38
436.1178	37.88889	38.11111	38.38889	38.5	38.33333	38.27778
450.819	38.05556	38.27778	38.44444	38.55556	38.33333	38.33333
523.8972	38.38889	38.38889	38.66667	38.77778	38.44444	38.44444
561.6035	38.77778	38.83333	38.88889	38.94444	38.77778	38.77778
667.8714	38.88889	38.94444	39.05556	39.11111	38.88889	38.94444
669.02	39	39.22222	39.11111	39.22222	39.27778	39.33333
689.4064	39.11111	39.11111	39.16667	39.38889	39.11111	39.44444
700.1	39.33333	39.72222	39.44444	39.72222	39.55556	39.5

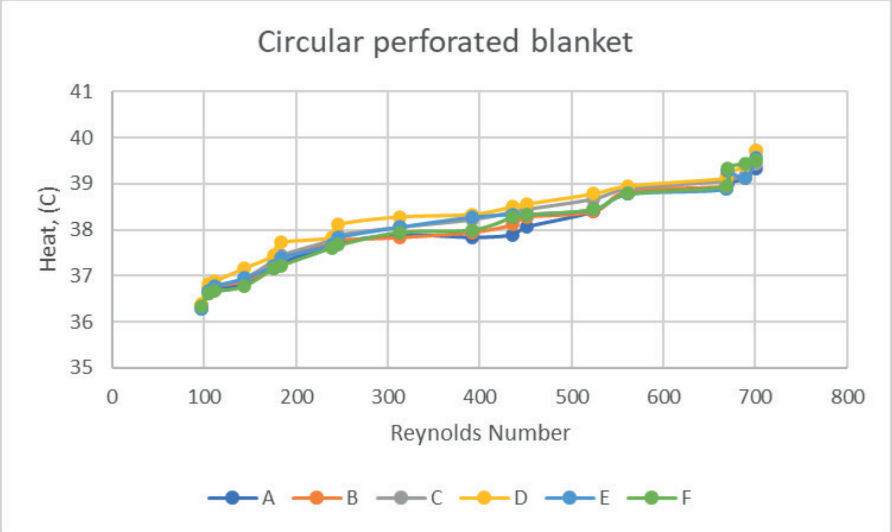


Figure 4.6. Variation of Reynolds number with temperature in case of using circular perforated blanket

It is useful to remember that the temperature here is the constant 35C temperature on the impact surface before the hot air is blown. Accordingly, the temperature rises to a maximum of 39.5°C in the range of approximately 97 to 700 Reynolds number as shown below in the circular perforated blanket. This value may lead to a change from hypothermia to hyperthermia. According to the table, the temperatures corresponding to the values of the Reynolds number between 97 and 500 are within the tolerance limits.

As for the local points, A and F are at the ends, that is, they are closer to the free current called "opening". Points C and D are more in the centre. Therefore, the highest temperatures were obtained at C and D and then at B and E. The lowest temperatures were found at A and F.

Table 4.2 shows the temperatures varying with Reynolds number at the local measurement points for the triangular hole. Similarly, Figure 4.7 shows the graphical representation of the table. As can be seen, the values here are close to the values of the circular hole. However, the temperatures are slightly lower at each point compared to the circular hole. This means that heat transfer is less.

Table 4.2. Reynolds number dependent temperatures of local measurement points for a triangular hole

Re	A	B	C	D	E	F
96.76096	36.12568	36.25479	36.29652	36.30214	36.25123	36.12258
105.0534	36.52121	36.60156	36.70198	36.69845	36.60145	36.51465
111.6172	36.61237	36.69878	36.71249	36.78254	36.69725	36.61789
143.5665	36.73223	36.77658	36.84322	36.83387	36.77554	36.73145
175.5732	37.06557	37.25152	37.36298	37.38456	37.22362	37.07897
182.9526	37.16878	37.43567	37.45944	37.51254	37.42791	37.16978
238.6707	37.58967	37.61489	37.77778	37.78324	37.61112	37.57894
245.2231	37.61232	37.69158	37.70889	37.80154	37.69222	37.59781
312.1753	37.78689	37.71233	37.98716	38.96778	37.75513	37.79258
392.1013	37.72153	37.83159	38.01222	38.09833	37.85778	37.70175
436.1178	37.73149	37.98795	38.39450	38.46664	37.93978	38.01551
450.819	37.99156	38.13597	38.45844	38.44156	38.10145	38.10155
523.8972	38.21589	38.28889	38.66667	38.68554	38.29444	38.35895
561.6035	38.56838	38.67893	38.73322	38.73124	38.65898	38.61245
667.8714	38.78229	38.84788	38.95518	38.99781	38.80889	38.71254
669.02	38.97821	39.00212	39.01166	39.01546	39.02712	38.92891
689.4064	39.00153	39.10122	39.15467	39.38889	39.10250	39.10054
700.1	39.22293	39.50782	39.56328	39.72222	39.60158	39.23548

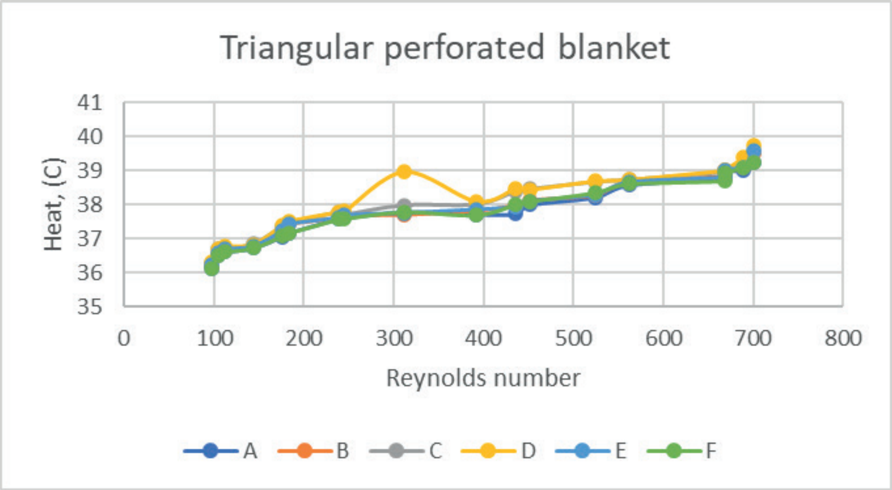


Figure 4.7. Variation of Reynolds number with temperature in a triangular perforated blanket

Table 4.3 shows the temperatures of the local measurement points for the square hole varying with Reynolds number. Figure 5.8 shows the data graphically.

Table 4.3. Reynolds number varying temperatures of local measurement points for square hole

Re	A	B	C	D	E	F
96.76096	36.381212	36.40785	36.45673	36.45789	36.3727	36.35478
105.0534	36.73884	36.70667	36.72222	36.73333	36.72452	36.71652
111.6172	36.85112	36.98425	36.97456	36.98889	36.85122	36.84458
143.5665	36.92312	37.01248	37.14444	37.16667	36.92128	36.92148
175.5732	37.23357	37.34582	37.44548	37.46878	37.35445	37.23455
182.9526	37.38764	37.45769	37.64545	37.66789	37.78929	37.44667
238.6707	37.78555	37.91245	37.92545	37.92154	37.83137	37.75445
245.2231	37.98454	37.99238	38.10045	38.10011	37.91245	37.76454
312.1753	38.01245	38.01984	38.10556	38.10725	38.10524	38.08478
392.1013	37.83333	38.12533	38.24544	38.24978	38.36787	38.21555
436.1178	38.10454	38.20111	38.56889	38.55121	38.43158	38.45178
450.819	38.21544	38.36645	38.67244	38.6756	38.34578	38.39971
523.8972	38.48889	38.69458	38.76667	38.79778	38.49551	38.49754
561.6035	38.89454	38.90122	38.91240	39.00012	38.81234	38.81245
667.8714	39.10545	39.12544	39.05556	39.10123	39.01889	38.94444
669.02	39.45878	39.51298	39.12545	39.25787	39.43258	39.48981
689.4064	40.01455	40.10111	39.36667	39.38381	39.25445	39.24454
700.1	40.32455	40.42128	39.54648	39.54789	39.34555	39.38785

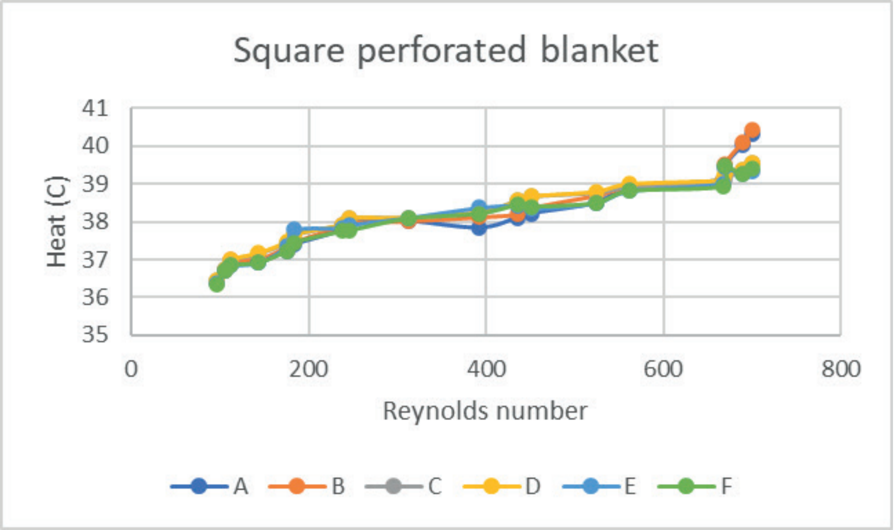


Figure 4.8. Variation of Reynolds number with temperature in case of using square hole blanket

It is obvious from both tables and figures that the highest body temperature values in terms of temperature were obtained from the square hole blanket. A serious temperature increase was observed in the square hole blanket, especially at Reynolds number values above 500, which could damage healthy tissues and even put the body into an unwanted hyperthermia.

The relationship between heat transfer coefficient and Reynolds number is shown in Figure 4.9, which is drawn to make a comparison in terms of heat transfer in the system. It is seen that the highest heat transfer is observed for the blanket with square holes. However, it should be remembered that the thermal problem considered here is not a problem where continuous increase in temperature is desired. After a certain temperature, increasing temperature is not beneficial but harmful.

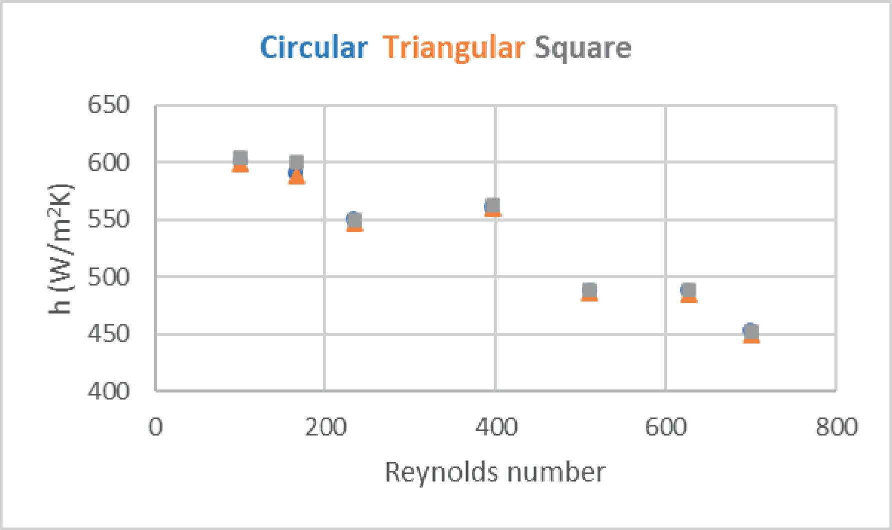


Figure 4.9. Variation of the Reynolds number with the coefficient of heat transfer

5. Results

This work is believed to be one of the pioneering investigations considering the energy efficiency of therapeutic heating devices. An operating room has several energy-using apparatus and their energy inefficiencies are compounded by the need to remove energy from the operating room that is not used for therapeutic purposes.

The equipment used to extract the wasted energy is itself highly energy-intensive. At a time when energy saving issues are being taken seriously, considerations such as the one made here are important. Indeed, there is considerable interest in whether new technologies in the operating room are cost-effective from society's perspective [12]. For the specific heating devices studied here, which serve to defend against hypothermia, the experimental results show a wide range of energy efficiency among the various products investigated. In order to achieve a level playing field, care was taken to study two commercial versions of each of the selected categories of heating devices, convection heating using preheated air and direct contact conduction heating, respectively. The primary expectation was that direct contact conduction devices as a category would be more energy efficient than convective air heating as a category. The experimental data reveal that the characteristics of the individual devices play a greater role in terms of energy efficiency than the category. In particular, the most efficient device was a direct contact heating device, the second most efficient device was a convective heating device, the third device was a direct contact device and the last was a convection heating device. These findings suggest that the use of appropriate insulation and the suppression of external heat loss pathways should be considered in the design of patient heating devices. It is these factors that create significant differences in the energy use efficiencies of the analysed devices in the same category.

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