

DESIGN AND ANALYSIS OF CLOTH DRYER CABINET
BY UTILIZING HEAT REJECTED
FROM AIR CONDITIONING SYSTEM

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Report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2009

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicate to my beloved father, mother and my honour siblings

ACKNOWLEDGEMENTS

First grateful to Allah SWT for making it possible for me to complete this project on time. It is a pleasure to acknowledge the help and support of everyone who concerned with this project. To my father, mother and siblings who have been so keen in helping and supporting me in the period of completing my final year project..

I would like to thank to my supervisor, Mr. Mohd Yusof bin Taib for his help, comments and assists during the progression of this project. I am truly grateful for his progressive vision, tolerance of my mistakes, and his commitment to me. I also sincerely thanks for all of his effort to spent time in assuring my project is complete.

Finally, my sincere thanks go to all my friends that help me especially for those who are under same supervisor with me. Thanks for all the cooperations.

ABSTRACT

Nowadays cabinet dryer is widely use, especially for those who are busy working. Besides that, most of the laundries today have a dryer. It is not just because it can run their operation all the time, but they also can prevent the risk to the cloths that might lost or get dirt. Cabinet dryer in the market nowadays is using electrical power as a source in generating heat. The other alternative in manipulation of heat being study to create a new cabinet dryer that make a benefit of waste. From the study, it found that split air conditioning system had waste heat that rejected from it condensing unit. The rejected heat had bad effect to the environment. This project is the study in manipulation of the heat rejected from air conditioning system to dry cloths inside a cabinet dryer. It cover the design of cabinet, investigation of the effectiveness and comparison to the several kind of other dryer. The comparison been made between natural drying and drying by commercial cabinet dryer According to the comparison, it shows that drying by heat rejected from condensing unit is better compares to the natural drying. But commercial dryer have a better drying rate compares to the cabinet dryer that manipulate the heat from condensing unit. From this project, it prove that the cabinet dryer utilizing heat rejected by air conditioning system is effective and worth even the performance is not good as commercial cabinet dryer, it is free and environmental friendly.

ABSTRAK

Kini cabinet pengering digunakan secara meluas terutamanya pada mereka yang sibuk bekerja. Selain itu, kebanyakan dobi kini juga menggunakan kabinet pengering. Ia bukan kerana cabinet pengering boleh berfungsi setiap masa, tapi dapat mengelakkan risiko kehilangan atau kekotoran pada baju semasa menjemur. Kabinet pengering di pasaran kini menggunakan kuasa elektrik untuk menjana haba. Sumber lain untuk memanipulasikan haba dikaji untuk mencipta sebuah cabinet pengering yang mendatangkan kebaikan daripada pembaziran. Dari kajian yang dijalankan mendapati bahawa system penghawa dingin melepaskan haba ke persekitaran melalui kondenser. Haba yang dilepaskan ini membahayakan persekitaran yang boleh menyebabkan pemanasan global. Projek ini bermatlamet untuk memanipulasikan haba yang dilepaskan itu untuk digunakan untuk mengeringkan baju melalui kabinet pengering. Ia meliputi reka bentuk kabinet, kajian mengenai keberkesanan dan perbandingan dengan proses pengeringan yang lain. Perbandingan ini dibuat dengan pengeringan semulajadi dan pengeringan menggunakan kabinet pengering yang sedia ada dipasaran. Melalui perbandingan ini dilihat pengeringan yang menggunakan haba dari kondenser lebih baik dari pengeringan semulajadi. Namun yang demikian, pengeringan menggunakan kabinet pengering dipasaran kini lebih baik berbanding kedua-dua pengeringan yang lain. Dari projek ini, ia membuktikan yang kabinet pengering yang menggunakan haba dari kondenser paling berbaloi kerana tiada kos diperlukan dalam masa yang sama mesra alam.

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LIST OF SYMBOLS

N_{CRDP} = drying rate in CRDP, kg/s m

N_{FRDP} = drying rate in FRDP, kg/s m

t_{CRDP} = duration of CRDP, min

t_{FRDP} = duration of FRDP, min

W_d = weight of dry material, g

A = area of a drying surface at which heat and mass transfer takes place, m

n = drying index (determined by experiments)

F = free moisture content, g/g

F_{cr} = critical free moisture content, g/g

t_{cr} = time of critical point, min

X = volume-average moisture content (dry basis), g/g

X_{cr} = critical moisture content, g/g

X_0 = initial moisture content, g/g

X_E = equilibrium moisture content, g/g

X_{Ea} = equilibrium moisture content under the ambient condition, g/g

X_{Ed} = equilibrium moisture content under the drying environment, g/g

LIST OF ABBREVIATIONS

CRDP : Critical Rate Drying Process

FRDP : Falling Rate Drying Process

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In the modernization era nowadays, both man and women commute to work. Generally, working hours start from 8am until 5pm, which mean that the extra time from 24 hours per day left only 15 hours. Sadly, this extra time left start from evening until morning where the heat of sun is hard to be manipulated. Human can not avoid from daily job. Either it is personal job or in the workplace. Some of the jobs become routine. Everybody wear a cloth and it is important to keep it clean. Wash a cloths is like a routine and it is necessary that the washed cloths to be dry. For those who are busy commute to work, this routine is one of the challenges in daily life. As long as human have effort to upgrade the quality of lifestyle, the technology will always improve.

Technology has been created to help human job. To make it easy and solve problems that might be faced by human. So many appliances, devices and equipments have been use today, and the appliance which is been use to solve the problem is cabinet dryer. Cabinet dryer is such an appliance that been use to dry cloths or in other word is to remove

moisture from cloths. Commercial dryer that widely use today use a heater as a heat supplier, where the electrical as a main power source to produce a heat, by transformation energy from electric to heat energy.

Nowadays cabinet dryer is widely use, especially for those who are busy working. This is because they can dry their cloths at night and also rainy day. Besides that, most of the laundries today have a dryer. It is not just because it can run their operation all the time, but they also can prevent the customers cloths from lost and also dirt, which is normal problems occur in natural drying when dry it to the sunlight which is open to the environment. There are risks by natural drying, it might be stolen, rain or the cloths become dirty by smoke and dust from air, and also fungi. More and more important, time needed to dry cloths with cabinet dryer is shorter. This can proven by the investigation that been made by Ahmadul Ameen and Saiful Bari between the natural dryer, commercial dryer and heat pump dryer. This benefit is really suitable for human nowadays, where always facing limited time per day. The other benefit for using the cabinet dryer is, save space. For example for those who live in flat or apartment, where the space to dry cloths is limited. By using cabinet dryer that come with many size and just need a small space this problem can be solve. For those countries that hard to manipulate heat from sun, dryer cabinet is necessary.

Even there are many benefit of using cabinet dryer it still has disadvantages. This is because of the cost to buy this appliance. For the commercial dryer nowadays, it follows by monthly electrical bills where the operation needs electrical power to generate heat. Maybe some people love to have cabinet dryer but because of the cost, most of them prefer the natural dryer where have no cost at all. In this era, the technology that can make human job easier, consideration on economic, ergonomic, and environmental friendly are also priority. To overcome these problems, the new type of cabinet dryer will be studied and will be discuss in this project.

1.2 PROBLEM STATEMENT

As being state in the project background, facing the monthly cost is the main problems in using a cabinet dryer. Base on the theory of drying, cabinet dryer need to supply heat to remove the moisture. To generate heat, commercial dryer today use heater that needs electric power, which meant there will be a monthly charge in our electric bill. To overcome this problem is to found other alternative to manipulate heat. The heat must be able for the drying period at the same time free.

A second problem is how to make the cabinet dryer is safe, ergonomic and environmental friendly. Even we have a free heat, the cabinet dryer should be able to perform the operation efficiently and marketable. This mean, the design of this appliance must be attractive and good performance.

Drying process involves two mechanisms. Energy has to be provided to change the water from liquid to vapor and air stream is needed to remove the vapor. According to the kinetic theory, temperature is the expression of the average energy of molecular motion. It means providing heat is necessary as the energy is to change the moisture shape to become vapor. Besides, air flow rate is also a very strong influence to drying rate. So much more water vapor is removed in a rapid air flow. The temperature doesn't change with wind speed but the evaporation rate does. Generally, natural drying has a wind that can ensure that the cloths will not stinky. Just same with the cabinet dryer where that need a mechanism that can ensure the cloth will dry without any bad effect. The air flow in the cabinet dryer must be considered at the same time the heat provided is also one of the main priorities. Hot air must flow through the cloths and directed out from the cabinet and the humid air must be reject from the cabinet dryer.

The studied of air conditioning system shown there are waste heat being rejected from the condenser to ambient air. This mean free heat is just being waste without any benefit. There is badness in releasing heat to the environment that will cause of global warming. This problem can overcome by manipulate the waste heat to flow into a cabinet

dryer and remove the moisture from cloths. This heat will cost zero, which mean no monthly charge for using cabinet dryer. Cost for the air conditioning system usage can be separate to two functions which are also to dry cloths. This mean the cost that we spend is worth compared to the usage that only for air conditioning system without cabinet dryer.

1.3 PROJECT OBJECTIVES

There are several objectives regarding to the title of Design and Development of Cloth Dryer Cabinet by Utilizing Heat Rejected from Air conditioning System:

- i. To design cloth dryer cabinet by utilizing heat rejected from air conditioning system.
- ii. To analysis a cloth dryer cabinet by utilizing heat rejected from air conditioning system.

1.4 PROJECT SCOPES

Project scopes are very important to start this project. This is because, the objective is not enough to widely cover the project all about. The scopes for Design and Development of Cloth Dryer Cabinet by Utilizing Heat Rejected from Air conditioning System is:

- i. Study about air conditioning system. The information of each part involve in air conditioning system. How it work, temperature and pressure involve in the air condensing unit should be notice.
- ii. Study about the cloths drying process. It cover all the mechanism involve, calculation in determining the rate of drying and also all the factors that influence the process.
- iii. Analyze the air flow into and outgoing the cabinet dryer. The air flow need to be simulated and how the flow influences the temperature inside the cabinet. The result of the of the flow simulation need to be interpret into heat distribution figure, where it can show the effectiveness of the design.

- iv. Design an ergonomic, safe, economic and environmental friendly cabinet dryer. Several design need to be done and being evaluated to choose the best design base on it performance.
- v. Testing and compared the drying process performance for natural drying and drying by heat waste from air conditioning system.

1.5 PROJECT FLOW CHART

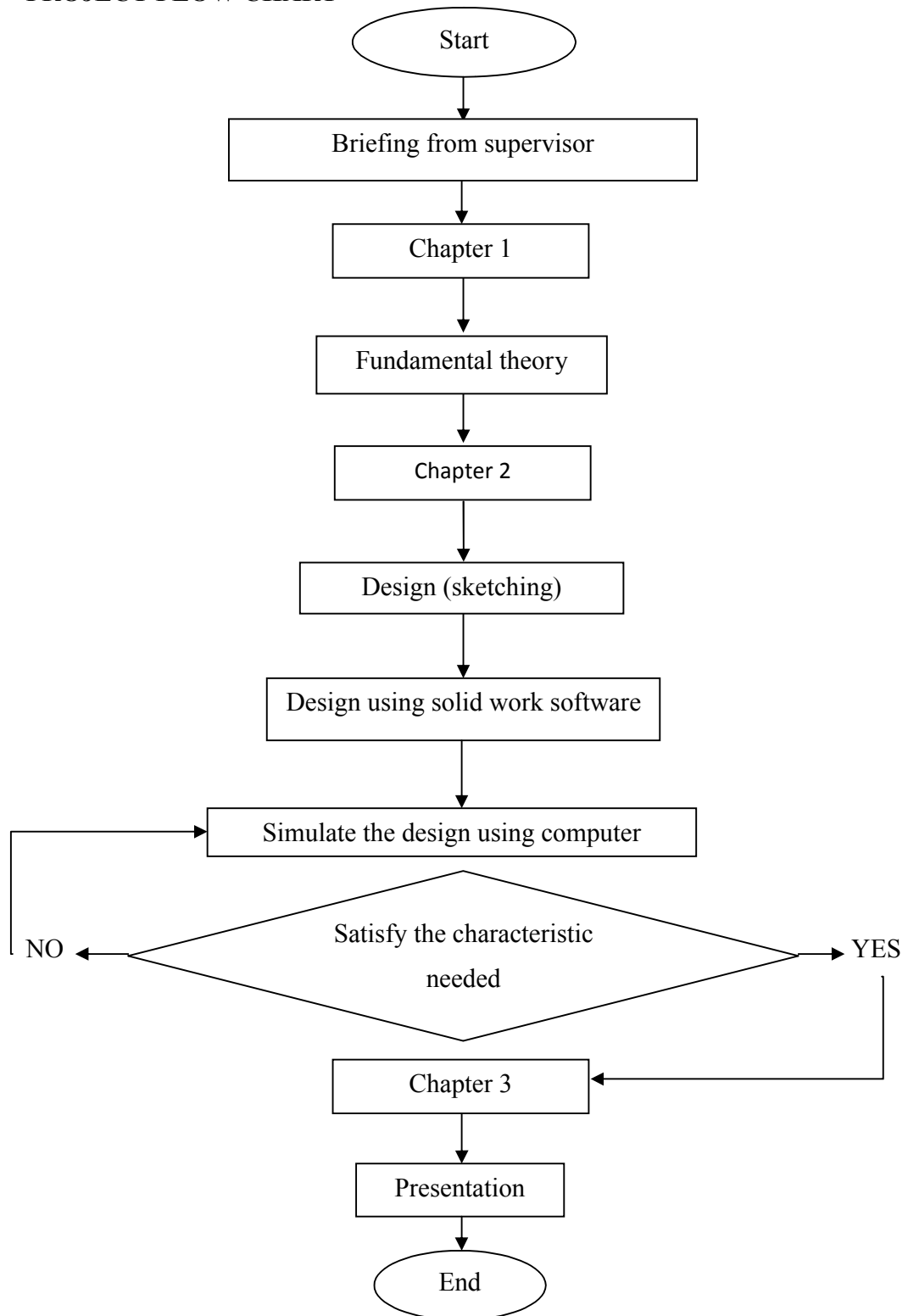


Figure 1.1: Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 SPIT SYSTEM AIRCONDITIONING SYSTEM

Most of people think that air conditioners lower the temperature in their homes simply by pumping cool air in. What is really happening is the warm air is being removed and cycled back in as cooler air. This cycle continues until your thermostat reaches the desired temperature. An air conditioner is basically a refrigerator without the insulated box. It uses the evaporation of a refrigerant, like Freon, to provide cooling. The mechanics of the Freon evaporation cycle are the same in a refrigerator as in an air conditioner. The compressor compresses cool gas, causing it to become hot, high-pressure gas (red in the diagram **Figure 2.1** below). This hot gas runs through a set of coils so it can dissipate its heat, and it condenses into a liquid. The liquid runs through an expansion valve, and in the process it evaporates to become cold, low-pressure gas (light blue in the diagram **Figure 2.1** below). This cold gas runs through a set of coils that allow the gas to absorb heat and cool down the air inside the building. The **Figure 2.1** shows the movement of the hot fluid and cool fluid inside the air conditioning system. The concepts of thermal balance make it possible to release and absorb heat. The physical property of the fluid inside air conditioning system which has very low melting point is one of the reasons for the functioning air conditioner. This is because this fluid is easily change it forms at the same time be able to absorb and releasing heat. Split air conditioning system which separate the system make it possible to be apply to work at the same time.

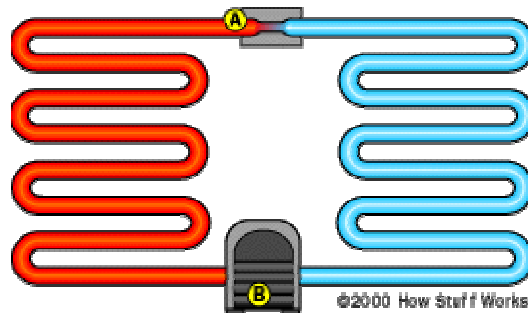


Figure 2.1: Diagram of a typical air conditioner (Danny Parker and John Sherwin 2004)

A split-system air conditioner as shown in **Figure 2.2** splits the hot side from the cold side of the system. The cold side, consisting of the expansion valve and evaporator, lives inside the building. The hot side, which lives outside the building, is known as the condensing unit, as shown in **Figure 2.3**. The major elements that exist in this unit are the condenser and compressor. The condenser, which is at a high temperature, will extract heat to have a balance with its surroundings. This means that the high inlet temperature of the condenser, around $40\text{ }^{\circ}\text{C}$ to $50\text{ }^{\circ}\text{C}$, will transfer heat to the environment and reach a balance temperature with it. This process is helped by the air blown by a fan that exists in the condensing unit.

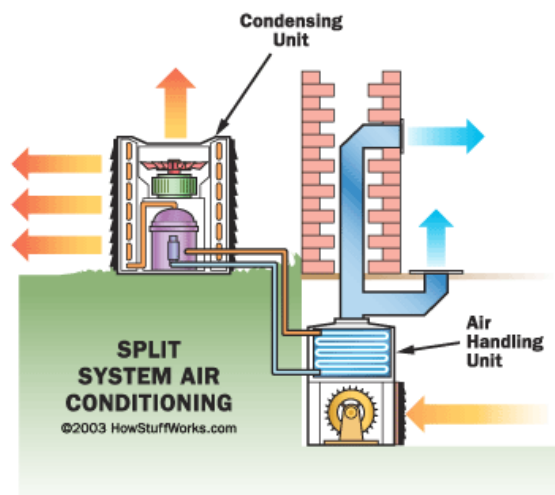


Figure 2.2: Split air conditioning system (Danny Parker and John Sherwin 2004)



Figure 2.3: Condensing unit (Danny Parker and John Sherwin 2004)

2.1.1 Evaporator

A device used to vaporize part or all of the solvent from a solution. Any of many devices in which liquid is changed to the vapor state by the addition of heat, for example, distiller, still, dryer, water purifier, or refrigeration system element where evaporation proceeds at low pressure and consequent low temperature. The solution containing the desired product is fed into the evaporator and passes a heat source. The applied heat converts the water in the solution into vapor. The most common medium consists of parallel tubes but others have plates or coils. Inside the evaporator, refrigerant is changing state from a liquid to a vapor, at a temperature that's about 15° to 20° below the desired final temperature of the space or product being cooled. The saturated gas enters the evaporator where it is changed to a cool dry gas. **Figure 2.4** shows one of the evaporator uses for air conditioning system nowadays.



Figure 2.4: Evaporator (Danny Parker and John Sherwin 2004)

2.1.2 Condenser

Condenser is a device or unit used to condense vapor into liquid typically by cooling it. For air conditioning system the condenser changes the refrigerant from a high temperature gas to a warm temperature liquid. Condensers are used in power plants to condense exhaust steam from turbines and in refrigeration plants to condense refrigerant vapors, such as ammonia and Freon. The petroleum and chemical industries use condensers for hydrocarbons and other chemical vapors. In distillation, a condenser transforms vapors to liquid. All condensers work by removing heat from the gas or vapor. In some, the gas passes through a long tube of heat-conductive metal, such as copper (usually arranged in a coil or other compact shape), and heat escapes into the surrounding air. Inlet temperature of condenser for conditioning system is about 40°C to 50°C and the outlet temperature is around 30°C which is same to the ambient temperature. **Figure 2.5** shows the example of condenser use for air conditioning system nowadays.



Figure 2.5: Condenser (Danny Parker and John Sherwin 2004)

2.1.3 Expansion Valve

A thermostatic expansion valve is a component in air conditioning systems that control the amount of superheat at the outlet of the condenser. The expansion valve meters the proper amount of refrigerant into the evaporator. The expansion valve takes the high pressure liquid and changes it to a low pressure cold saturated gas. This is accomplished by

use of a temperature sensing bulb filled with a similar gas as in the system that causes the valve to open against the spring pressure in the valve body as the temperature on the bulb increases. When temperatures in the evaporator decrease so does the pressure in the bulb and therefore on the spring causing the valve to close. A thermostatic expansion valve is a key element to refrigeration cycle where the cycle that makes air conditioning, or air cooling, possible. Figure 2.6 shows example of expansion valve.

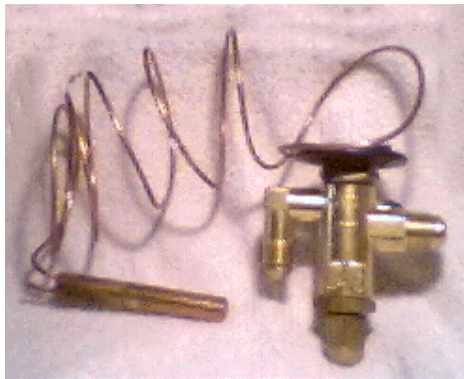


Figure 2.6: Expansion valve (Danny Parker and John Sherwin 2004)

2.1.4 Compressor

Compressor is a machine that increases the pressure of a gas. The pressure of the fluid is increased by reducing the fluid specific volume during passage of the fluid through the compressor. When compared with centrifugal or axial-flow fans on the basis of discharge pressure, compressors are generally classed as high-pressure and fans as low-pressure machines. Compressors are used to increase the pressure of a wide variety of gases and vapors for a multitude of purposes. A common application is the air compressor used to supply high-pressure air for conveying, paint spraying, tire inflating, cleaning, pneumatic tools, and rock drills. The air conditioning compressor is used to compress the gas formed in the evaporator. Compressor will compress the gas and sent out of the compressor as a high temperature, high pressure, superheated gas. **Figure 2.7** shows an example for compressor.



Figure 2.7: Compressor (Danny Parker and John Sherwin 2004)

2.2 DRYING PROCESS

The kinetics of the clothes-drying process inside the dryer involves continuous variation in the values of the temperature and moisture content with respect to time. Assumptions are necessary for successful modeling of various processes occurring inside the dryer. The assumptions are:

- The thermo-physical properties the fabric materials are uniform throughout the volume occupied.
- Dispersion of moisture content within the fabric material is homogenous.
- Instantaneous distribution of moisture within the working fluid is uniform.
- The temperature of the fabric material and the wet-bulb temperature of the working fluid are the same.
- Instantaneous temperature distribution within the bulk of the fabric material is uniform.
- Transfer of moisture from the fabric material to the working fluid takes place inside a cylindrical enclosure, where the material is placed.
- The cylindrical enclosure and the material being dried may be static or in motion; both cases are considered.

- The hot fluid with low moisture-content enters from one of the axial direction and leaves from another.
- For the model implementation purpose, all thermo-physical properties of the working fluid are considered to be the same as those of air.

A complete drying process can generally be divided into three periods namely a pre-heat period, constant-rate drying period (CRDP) and a falling-rate drying period (FRDP). Normally, clothes are mechanically dried (spin) before subjecting to thermal drying. Thus, a pre-heat period will not exist since the initial surface temperature is ready for constant-rate drying, therefore, only the modeling of a CRDP and a FRDP has been considered.

$$N_{CRDP} = \frac{(\quad)}{\quad}$$

Equation above is used to determine the drying rate in a CRDP. After determining the drying rate in a CRDP, its duration can be calculated by the following equation:

$$t_{CRDP} = t_{cr} = \frac{\quad}{\quad} (X_o - X_{cr})$$

After determining the drying rate in a CRDP, we now need to calculate the drying rate in FRDP. The equation below is to determine the drying rate in FRDP.

$$N_{FRDP} = N_{CRDP} \frac{E}{E}$$

After determining the drying rate in FRDP its duration can be calculated by the equation below:

$$t_{FRDP} = \frac{\quad}{(\quad)} [F^{(\quad)} - F_{cr}^{(\quad)}]$$

2.3 AIR FLOW THEORY

Flow of air or any other fluid is caused by a pressure differential between two points. Flow will originate from an area of high energy, or pressure, and proceed to area(s) of lower energy or pressure.

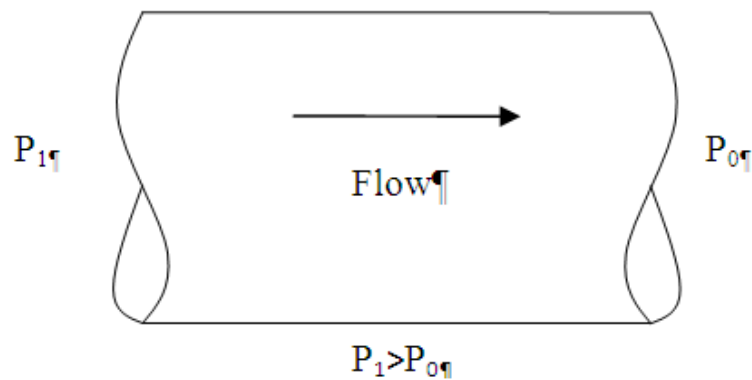


Figure 2.8: Conservation of momentum

Duct air moves shows by the **Figure 2.8** according to three fundamental laws of physics: conservation of mass, conservation of energy, and conservation of momentum.

Conservation of mass simply states that an air mass is neither created nor destroyed. From this principle it follows that the amount of air mass coming into a junction in a ductwork system is equal to the amount of air mass leaving the junction, or the sum of air masses at each junction is equal to zero. In most cases the air in a duct is assumed to be incompressible, an assumption that overlooks the change of air density that occurs as a result of pressure loss and flow in the ductwork. In ductwork, the law of conservation of mass means a duct size can be recalculated for a new air velocity using the simple equation:

$$V_2 = (V_1 * A_1)/A_2$$

The law of energy conservation states that energy cannot disappear; it is only converted from one form to another. This is the basis of one of the main expression of aerodynamics, the Bernoulli equation. Bernoulli's equation in its simple form shows that,

for an elemental flow stream, the difference in total pressures between any two points in a duct is equal to the pressure loss between these points, or:

$$(\text{Pressure loss})_{1-2} = (\text{Total pressure})_1 - (\text{Total pressure})_2$$

Conservation of momentum is based on Newton's law that a body will maintain its state of rest or uniform motion unless compelled by another force to change that state. This law is useful to explain flow behavior in a duct system's fitting.

2.3.1 Types of Flow

Laminar Flow

Flow parallel to a boundary layer. In HVAC system the plenum is a duct.

Turbulent Flow

Turbulent flow is perpendicular and near to the center of duct and parallel and near to the outer edges of duct. Most HVAC applications fall in the transition range between laminar and turbulent flow.

2.3.2 Types of Pressure Losses or Resistance to Flow

Pressure loss in ductwork has three components, frictional losses along duct walls and dynamic losses in fittings and component losses in duct-mounted equipment. Component pressure due to physical items with known pressure drops, such as hoods, filters, louvers or dampers.

Dynamic Pressure

Dynamic losses are the result of changes in direction and velocity of air flow. Dynamic losses occur whenever an air stream makes turns, diverges, converges, narrows, widens, enters, exits, or passes dampers, gates, orifices, coils, filters, or sound attenuators. Velocity profiles are reorganized at these places by the development of vortices that cause the transformation of mechanical energy into heat. The disturbance of the velocity profile starts at some distance before the air reaches a fitting. The straightening of a flow stream ends some distance after the air passes the fitting. This distance is usually assumed to be no shorter than six duct diameters for a straight duct. Dynamic losses are proportional to dynamic pressure and can be calculated using the equation:

$$\text{Dynamic loss} = (\text{Local loss coefficient}) * (\text{Dynamic pressure})$$

Where the local loss coefficient, known as a C-coefficient, represents flow disturbances for particular fittings or for duct-mounted equipment as a function of their type and ratio of dimensions. Coefficients can be found in the ASHRAE Fittings diagrams. A local loss coefficient can be related to different velocities. It is important to know which part of the velocity profile is relevant. The relevant part of the velocity profile is usually the highest velocity in a narrow part of a fitting cross section or a straight/branch section in a junction.

Frictional Pressure

Frictional losses in duct sections are result from air viscosity and momentum exchange among particles moving with different velocities. These losses also contribute negligible losses or gains in air systems unless there are extremely long duct runs or there are significant sections using flex duct.

2.3.3 System Effect

There are some variable which is effect the air flow. The **Table 2.1** below shows the system effect table that been consider in investigation of flow inside duct.

Table 2.1: System effect table

Distance between Riser and Elbow	System Effect Coefficient (K)
2 feet	1.75
3 feet	1.5
4 feet	1.3
5 feet	1.2

2.4 HEAT PUMP THEORY BASE ON DRYING PROCESS

The possibility of using a vapor compression refrigeration cycle for both spaces cooling and drying of clothes is considered and the system is referred to an integrated heat pump system (IHPS). A line diagram of the IHPS is shown in **Figure 2.9** below, which shows the air circuit for space cooling (B–C–D), the alternative circuit for drying (d–e–f) and the refrigerant circuit (1–2–3–4). A p–h diagram of the refrigerant circuit (1–2–3–4) is shown in figure shows that the theoretical energy available for heating or drying is (h_2-h_3) , for space cooling is (h_4-h_1) and the work energy input to the compressor is (h_2-h_1) .

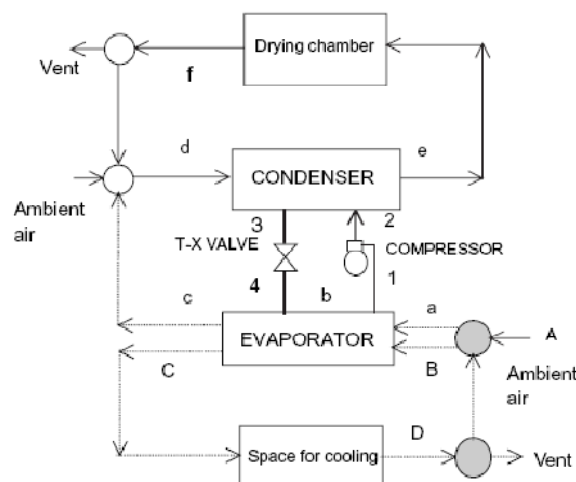


Figure 2.9: Modular configuration of the simple IHPS for drying (Ahmadul Ameen and Saiful Bari 2003)

Figure 2.10 below shows the psychometric chart of the air circuits for drying with dehumidification (a–b–c–d–e–f) and without dehumidification (d–e–f). In the present investigation, only drying without dehumidification is considered. When the humid air from the atmosphere is passed through the condenser coil (d–e), the air is heated with a reduction in relative humidity. This air is used for drying clothes at constant enthalpy. A typical drying curve as shows in **Figure 2.11**, where the drying rate (kg/s) is plotted against moisture content is shown in the figure, which has an initial heating stage (A–B), unhindered or constant drying period (B–C), or hindered drying or falling rate drying period (C–D–E).

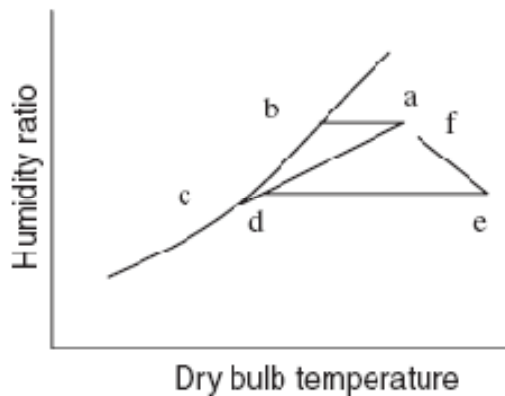


Figure 2.10: Psychrometric chart for drying air circuit (Ahmadul Ameen and Saiful Bari 2003)

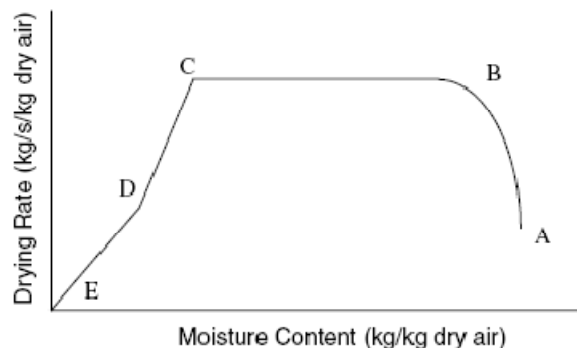


Figure 2.11: Typical drying rate curve (Ahmadul Ameen and Saiful Bari 2003)