FACTORS AFFECTING THE PERFORMANCE CHARACTERISTICS OF WET COOLING PADS FOR DATA CENTER APPLICATIONS

by

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Abstract

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The energy consumption of data centers in the current US market is fast growing in large numbers by every day. It was reported that in 2013, US data centers almost consumed 91 billion kilowatt-hours of electricity significant enough to power the whole of New York city twice a year [1]. Ever since the explosion of cloud computing, digital content and others the energy consumed by data centers has taken a steep increase and will continue in the coming years.

As a result, there is a growing need to reduce the energy consumption of data centers by employing different cooling techniques which does the balance act by reducing the power consumed and increasing the efficiency. Evaporative cooling in particular is the most sought after cooling techniques in the recent years. This involves the use of evaporative pads for cooling the hot ambient air.

Evaporative cooling media have become an important factor that affect the efficiency of evaporative cooling systems. Typically, different types of media pads have been employed these days in data center environments to maximize the efficient use of outside free air. These pads fitted across the CRAC units are completely saturated with water. To facilitate better cooling, the pads are soaked for a longer time for higher efficiency of direct evaporative cooling.

Various factors affect performance of evaporative cooling media. Many literature papers report on factors that affect performance of cooling pads that are used in greenhouse and poultry farming applications. There is a lack of literature data that discusses the effect of these factors for data center applications. This research work presents the performance characteristics of Cellulose media for two different manufacturers – Munters and KUUL and Munters GLASdek media

Parameters that affect the efficiency of the cooling pads include surface area, thickness of pad, size of perforation of the pad, water flow rate, temperature, and relative humidity of inlet air. The effect of these factors will be studied experimentally. The experimental analysis would include variations of water flow along the length of the pad, changing the frontal air velocity and increasing the inlet air temperature. Based on the test results, it was identified that cellulose based media provides better cooling efficiency over GLASdek media.

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Nomenclature

GPM	Gallons per minute
DEC	Direct evaporative coolers
DBT	Dry-bulb temperature
WBT	Wet-bulb temperature
RH	Relative humidity
WBD	Wet-bulb depression

Chapter 1

INTRODUCTION TO DATA CENTERS, COOLING TECHNIQUES AND LITERATURE REVIEW

1.1. Modular data centers

A Data center is a centralized facility used to contain computer systems and other associated components like telecommunication and storage system. These include back-up power supplies, chillers, cabling, fire suppression system, redundant data connections and security systems. Their primary function is to store, process and exchange digital data and information. The IT equipment which is a combination of compute servers that process data and network equipment used for telecommunication purpose is housed inside a data center. It also houses power consumption units for maintaining the working operation of the data center [2].

With advances in technology, data centers are growing leaps and bounds by every day in terms of energy consumed, power density, size and technology. On average, these data centers require quite a huge amount of cooling energy to reduce the energy consumption and at the same time maintain high efficiency. In addition to this, there is also the initial cost of setting up these data centers and the maintenance needed to prevent them from complete failure.

Expansion of data centers is also extremely difficult when looking at it from the cost stand-point. Capacity expansion is also not a viable option because equipment needs to be purchased, shipped and delivered where it needs to be installed. This process would also require human skill that adds onto the cost apart from the costs incurred for shipping and delivering the equipment.

Modular data center, also known as containerized data centers is a closed box that contains the IT equipment which includes the servers and power distribution units. These data centers are designed for portability, energy efficiency and computing density. All the modules inside this system is built with the necessary equipment, properly configured and then shipped as a fully functional unit. All these data centers need upon deployment is a supply for power, internet connectivity and chilled water supply.

Figure 1.1: Modular Data center, HP Pod [3]

HP Pod is a range of three data centers made by HP. These data centers are 20 or 40 feet in length with the server racks preconfigured, cabling enabled and also has equipment for power and cooling. They can either make use of chilled water cooling or a combination of direct air cooling. HP 20c and 40c are two of its types. Both are water cooled providing higher capacity and consuming less power than conventional air-cooled systems [4]

1.2 Importance of cooling Modular Data centers

Modular data center have gained familiarity over the recent years for their easy deployment, energy efficiency and less maintenance requirement. They come in big sizes ranging from 20 to 40 feet and the IT equipment inside them, servers mainly, consume large amount of power resulting in tremendous amount of heat generation. This very high heat generation can lead to unstable operation of the modular data center.

The servers along with other units inside generate huge amount of heat and hence it is of greater demand to ensure that the air temperature inside these data centers is within the limits to avoid building up of hot spots. Several factors like the ambient air temperature, its humidity, location of the data center and solar loading play an important part in the efficient running of the data center. Also with the size of the micro-chip inside drastically reducing according to Moore's law, there has been an increase in the heat density of these chips. Therefore, from thermal stand-point, cooling and utilizing other resources for cooling is required for the efficient operation of data centers.

Some factors that drive the need for efficient cooling include, increasing number of servers, increasing power density, increasing data center performance and increasing cooling demand. Choosing the right cooling method for data center without compromising on its efficiency has become the go to approach my by manufacturers these days. Precision cooling methods are developed to extract the unwanted heat generated inside the server rooms and release them to the atmosphere to meet the need for high density computing.

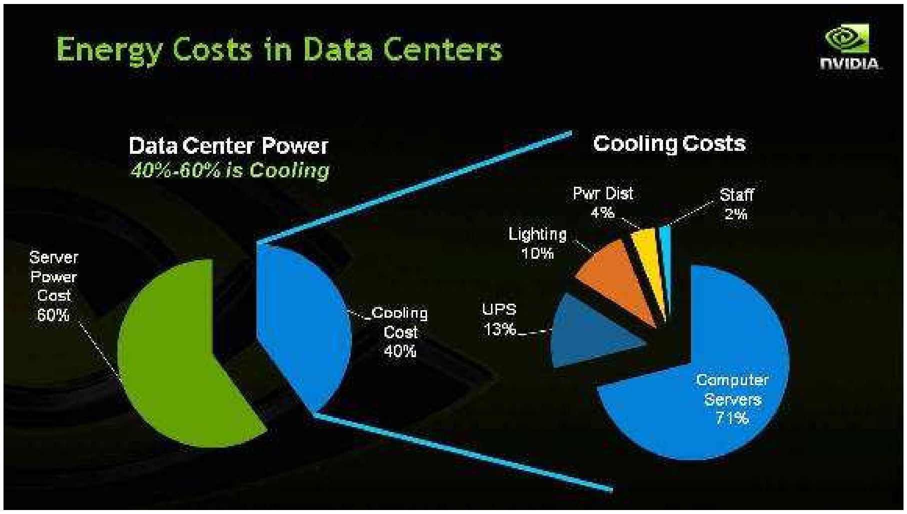


Figure 1.2: Data center energy cost split-up [4]

The above chart shows the break-up of energy costs in a normal, functional data center. It can be seen that cooling resources for the data center alone contributes to about 40% of the total energy consumption. Energy consumed by the cooling resources include the UPS, Power distribution units, lighting, computer servers etc.

1.3 Types of cooling techniques employed in data center

Various types of cooling methods have been in use in data centers to mainly reduce the increase in energy consumption and maintain high efficiency. All the cooling techniques employed revolve around the ASHRAE TC 9.9 standard which has an envelope of operating parameters like temperature and humidity over which the data centers must operate. Depending on the requirement and the outside air conditions, a specific cooling technique or combination of techniques are used to ensure that air is with the envelope of operation of data centers

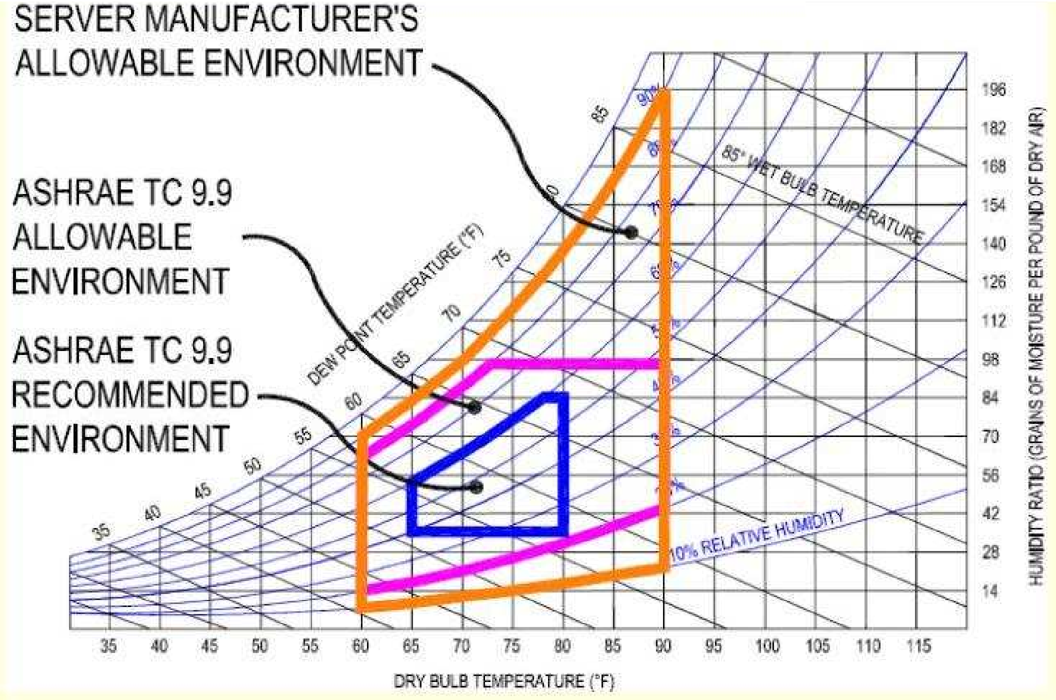


Figure 1.3: Different regions of data center operation [5]

The above chart shows the colored regions of different zones for ASHRAE recommended data center operation. The ASHRAE Technical committee 9.9 has broadened the zone of operation which is shown by the pink region. The allowable environment is shown by the blue one and it can extent all the way till 90° dry-bulb and 50% relative humidity. The orange region is the allowable range for servers operation extending till 90° dry-bulb and 90% relative humidi ty.

Based on the outside air conditions, direct evaporative cooling or indirect evaporative cooling or a combination of both or evaporative cooling with DX cooling can be used to bring in the outside air into the zone of operation. Evaporative cooling is the most sought after technique used by data center manufacturers these days as they are economical, pollution-free and simple to use.

1.3.1 Free Cooling

Mechanical/conventional cooling systems have dominated the operation of traditional data centers with the use of chilled water supply. These cooling systems make use of compressors and condensers to carry the hot air through the chilled water, which during the process absorbs the heat from the air and evaporates into vapor. To ensure that the liquid refrigerant dissipates heat to the outside air, it is compressed by a compressor unit which in turn increases its temperature. As the heat is released into the atmosphere, the liquid is allowed to expand and get back to its initial state resulting in a decrease in its temperature.

This whole process consumes a huge amount of energy which adds to the cooling costs. Free cooling is a cooling technique that makes use of outside ambient air thus reducing the use and energy costs incurred by the mechanical systems. It is economical and viable for cooler regions. There are two types of free cooling namely air side cooling and water side cooling.

Air side cooling involves the use of cold air to cool the electronic components like servers inside the data centers. Cold air is pulled in by the servers through the front and the hot air is expelled from the back of the servers. Although air cooling seems an easier option to cool the components, it does require large volumes of air which in turn increases the fans pumping speed and the contaminants that travel with them. Filters will have to be periodically replaced to reduce the build-up of particulate matter and reduce the air resistance.

Water cooling on the other hand, makes use of water to cool the air and is more efficient in transferring heat per unit volume compared to its counterpart. This cooling system can be integrated with chilled water systems and condensers. Glycol water mixture is used to transfer the heat to the cooling towers without the chillers in operation.

1.3.2 Air-side Economizers

American Society of Heating, Refrigeration and Air-Conditioning Engineers define an air-side economizer as “A device that, on proper variable sensing, initiates control signals or actions to conserve energy” [6] .These systems basically bring in outside air and distribute them to the servers. The return air from the servers is exhausted out into the atmosphere. If the outside air is very cold, these economizer units mix the outside air with the exhaust hot air from the servers so as to have the temperature and humidity fall within the specific range for the data center operation.

These units are coupled to an air handling system with ducts for both the inlet and exhaust. They have filters to reduce the build-up of particular matter so that air with less impurity enters the data center. Air-side economizers reduce the energy costs of HVAC units (Heating, Ventilation and Air-conditioning) especially in cold climates, improving the quality of outside air but are not most suited for hot and humid climates. Since data centers operate 24/7 and it needs to be cooled 365 days a year, these economizer units find use even in hot climates by making use of cooler evening temperature.

Dampers and sensors are used to allow the desired quantity of air into the data center for cooling purpose. Sensors are mainly used for monitoring the outside air conditions. If the conditions are suitable for fresh free cooling, the control mechanism enables the movement of dampers such that, it opens and closes for the entry of fresh outside air making it and important source of cooling.

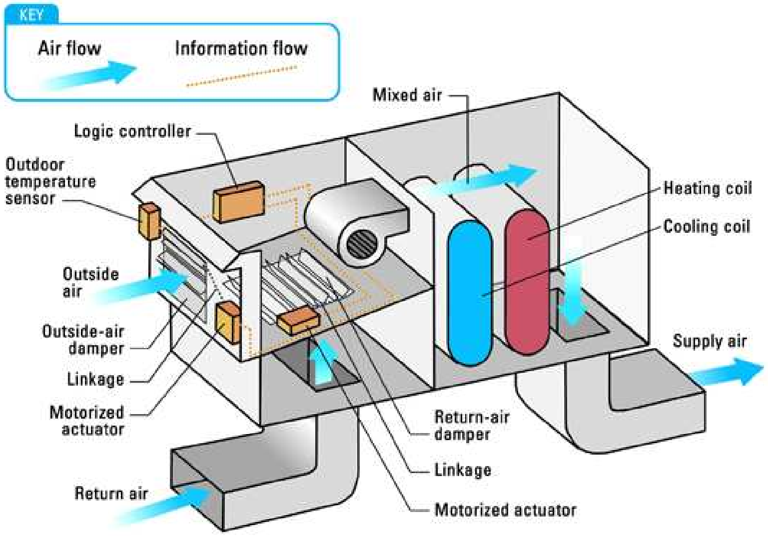


Figure 1.4: Diagram of an air-side Economizer [6]

1.3.3 Direct evaporative cooling

Direct evaporative cooling also known as swamp cooling is a process where the hot and humid outside air is made to pass through a wet cooling media that has water following over it from top to bottom. During this process, as air comes in contact with the cold water, it loses its sensible heat to water, thereby gaining an equal amount of latent heat of vapor. As the water evaporates into vapor, it cools down the temperature of the inlet air simultaneously increasing the air relative humidity.

This is a constant adiabatic saturation process wherein the loss of sensible heat is balanced by an equal gain of latent heat. Also, the wet bulb temperature of the air remains constant throughout the cooling process which is actually the measure of the potential of evaporative cooling. The greater the temperature difference, the higher is the cooling effect.

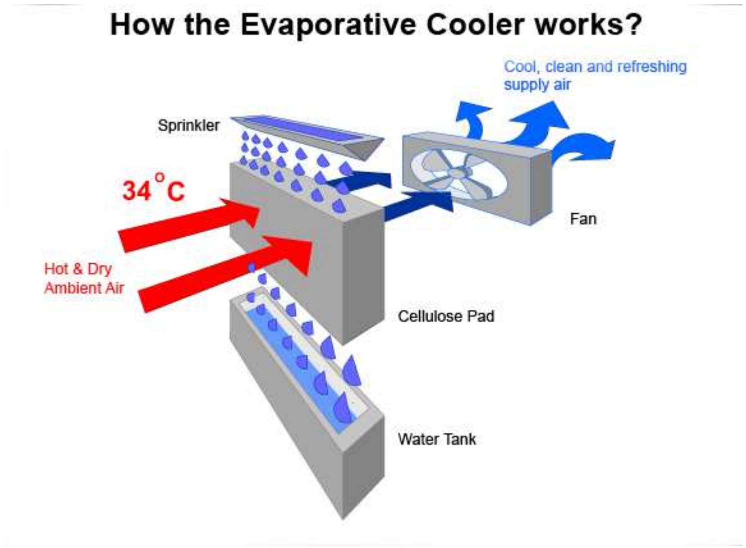


Figure 1.5: Working of an evaporative cooler [7]

The above figure shows the working of an evaporative cooler. It has a water tank from where the water is carried all the way to the top of the cooling pad (cellulose in this case) through a water pump. A water distribution tray with a sprinkler system or a small pipe is used as means for distributing water evenly over the pad surface.

As hot and humid outside air comes in contact with the water flowing over the cooling media, water evaporates thereby reducing its dry-bulb temperature. Blowers or fans units are used to carry this cold air into the data center. Depending on the requirement, the blowers either ramp up or ramp down its speed during the cooling process.

Advantages of direct evaporative cooling

- Consumes minimal energy for cooling than convention refrigeration systems
- Increases the cooling effect by addition of moisture to dry air
- Best suited for hot climates

Disadvantages of direct evaporative cooling

- Water consumption
- High relative humidity
- Maintenance required for replacing pads

1.3.4 Indirect evaporative cooling

This method is similar to the direct evaporative cooling technique causing the water to evaporate and reducing the dry-bulb temperature of inlet air. In this method, the secondary air also called the scavenger air is cooled by the water flowing over the heat exchanger coils. This heat transfer between the secondary air and water provides the necessary cooling effect to reduce the inlet temperature of the primary air. The primary does not come in contact with the water.

Both the dry-bulb and wet-bulb temperatures of the air are reduced and there is no addition of moisture to the incoming air. One of the main differences with the heat exchanger coils is that it can cool the air that is to be supplied to the living room.

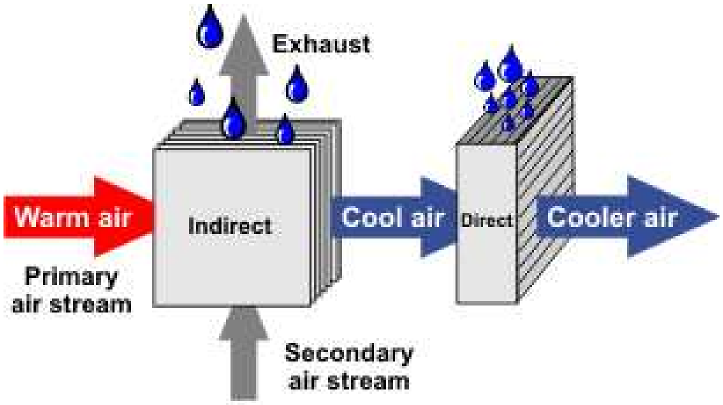


Figure 1.6: Working of an Indirect Evaporative cooler [8]

The above figure shows the working of an indirect evaporative cooler. The cooling process involves,

- Hot outside air (secondary air) drawn across the cooling coils, supplied with water
- Air is cooled as it passes over the tubes
- Moist secondary air is expelled out
- Primary air flowing inside the heat exchanger interiors is cooled by the heat transfer occurring across the tube exteriors
- Finally, the cool air with no humidity addition is blown through a ductwork to the building interiors

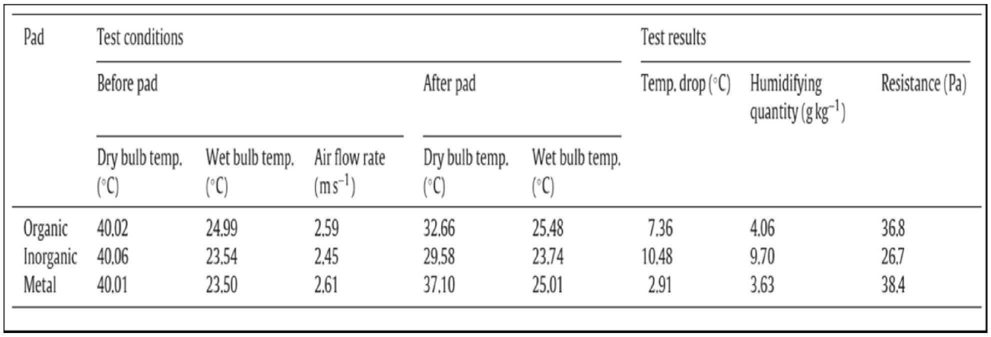
Indirect evaporative cooling is more suitable for areas where humidity is not desirable for the room's air. Because this cooling method consumes more electricity that the direct evaporative cooling, the latter is chosen to study in detail, wherein, the performance characteristics of different cooling media will be studied.

1.4 Literature review

Civilizations throughout the world have tried to look into different ways and techniques to cool the temperature of the ambient air and use it for various purposes. Evaporative cooling method then became a viable option for cooling the hot, humid air with almost minimal expenditure of energy. This technique has been in use for almost more than 100 years where the main purpose was to keep the room cool and comfortable enough for living.

Evaporative cooling pads posed a simple solution wherein the hot outside air was drawn across the cooling media through fans or blowers. This outside air was made to come in contact with the water flowing over the cooling media. This drastically reduced the temperature of the incoming air while simultaneously increasing the room's relative humidity. Over the years, most of the cooling pad research work has been predominantly focused for greenhouses and poultry farming applications.

Y.M. Xuana et al. [9] described about the evaporative cooling techniques in China where the working and thermodynamic principles of evaporative cooling method and its various types were studied in detail. Experimental part of testing included feasibility studies (effect of climate), performance tests of the evaporative cooling equipment, heat and mass transfer analysis and numerical modeling of evaporative cooling. They compared the filter performance of a perforated and corrugated aluminum type DEC pad of 200mm thickness with the commonly available filters and reported that, its performance is equivalent to that of the medium-efficiency air filters, while its pressure drop us lower than that of the low-efficiency air filters.



Pad	Test conditions					Test results		
	Before pad			After pad		Temp. drop (°C)	Humidifying quantity (g kg^{-1})	Resistance (Pa)
	Dry bulb temp. (°C)	Wet bulb temp. (°C)	Air flow rate (m s^{-1})	Dry bulb temp. (°C)	Wet bulb temp. (°C)			
Organic	40.02	24.99	2.59	32.66	25.48	7.36	4.06	36.8
Inorganic	40.06	23.54	2.45	29.58	23.74	10.48	9.70	26.7
Metal	40.01	23.50	2.61	37.10	25.01	2.91	3.63	38.4

Figure 1.7: Cooling performance comparison of different pads

The above figure shows the physical comparison of the cooling performance of the three different media that they tested. Results showed that Inorganic pad material produced higher temperature drop and lesser pressure drop compared to the other pads.

The University of Georgia, College of Agricultural and Environmental Science department [10] reported the misconceptions and myths about the operation of evaporative cooling pads. Common misconceptions included

- Pad produces maximum cooling before it dries out
- Water flowing over the pad reduces the cooling effect
- 10 minute timer interval improves the cooling performance

The experimental results showed that, if the timer cycle is short and the pad remains wet for the entire cycle, the pad produces the same level of cooling and humidity and evaporate the same amount of water. Also, if the water flow over the pad stops, minerals build-up which significantly reduces the pad life and the air-flow entering the house or the data center facility. To improve pads life and the cooling performance, it was found that the cooling pads need to be continuously operated over time.

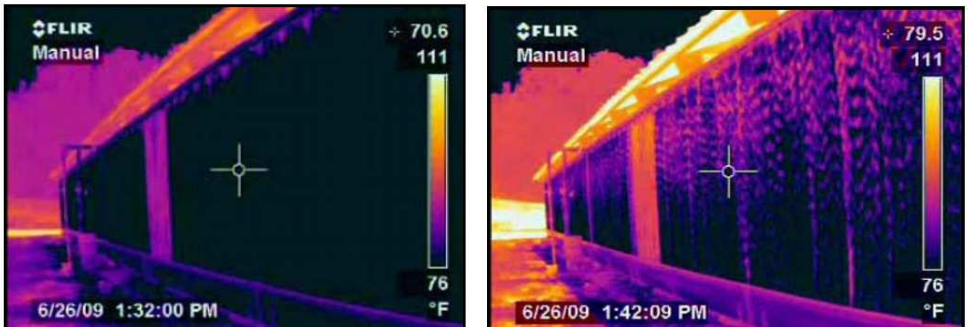


Figure 1.8: Thermal images of cooling pad

The above figure shows the thermal image of cooling pad report by the University of Georgia. It was reported that though the pad surface temperature increased all the way till 80℉, the temperature of the incoming air did not change from what it was at 1.32 P.M

R.W. Koca et al. [11] discussed about the experimental testing of the cooling pads and their evaluation. They observed that pressure drop increases with thickness and steeper pad angle. Also, they reported that the efficiency of the pads follow the same trend with increasing pad thickness, steeper angles and slower air velocities.

Adbollah Malli et al. [12] investigated the performance characteristics cellulose evaporative cooling pads. Pads of different thickness were tested for its thermal performance like its pressure drop, humidity variation, amount of water evaporated and saturation efficiency. The results showed that pressure drop and amount of water evaporated increased with the frontal air velocity and pad thickness whereas the saturation efficiency and the relative humidity decreased with increasing air velocity.

A. Franco et al. [13] discussed about the influence of water and air on the performance of cellulose pads for greenhouse applications. They reported that water flow rate was a function of the pressure drop and that it increased with greater water flow rates. They also recommended a particular range of air velocity that needed to be blown across the cooling media. Also, they found that the amount of water evaporated from the cooling pads increased with increasing temperature difference between the inlet and the outlet air. A detailed study was also carried out on understanding the geometric characteristics of the cellulose pads that included

- Angle of incidence of the sheets in the pad
- Thickness of the pad
- Number of sheets in the pad
- Porosity
- Characteristic length of the pad

M.F Koseoglu [14] examined the effect of water droplet carryover phenomenon in evaporative cooling applications. Ten different evaporative pads were tested and it was found smaller flute angle pads showed higher pressure drop compared to the ones with bigger flute angle. In addition to that, he concluded that water temperature was not an important factor that affects the cooling efficiency of drip-type evaporative coolers.

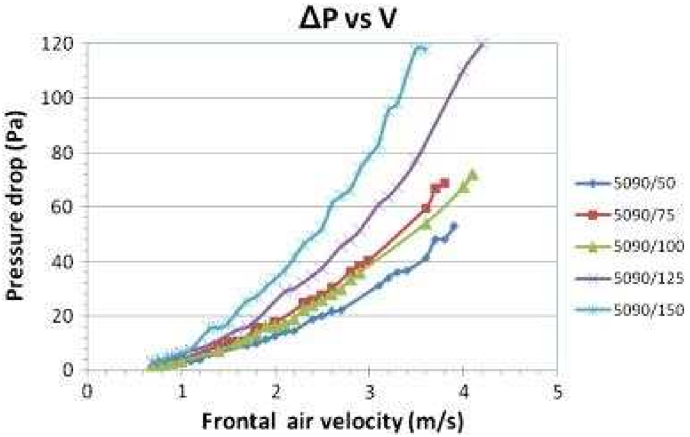


Figure 1.9: Pressure drop characteristics of 5 mm flute height cooling pads [14]

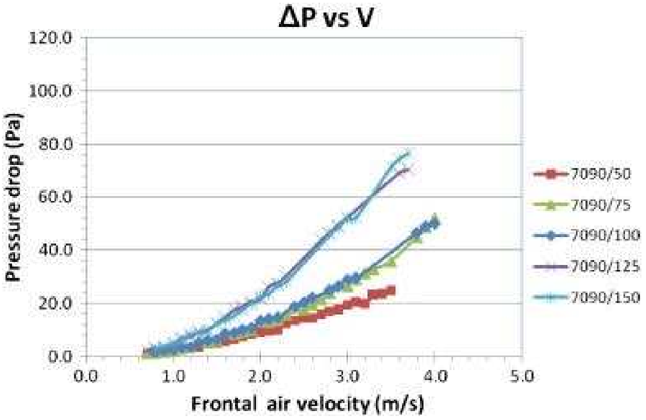


Figure 1.10: Pressure drop characteristics of 7 mm flute height cooling pads [14]

Metin Dagtekin et al. [15] investigated the effect of air velocity on the temperature difference across the cooling pad and its saturation efficiency. They conducted the tests at different time periods which varying air velocities under each chosen period. The effect of temperature drop across the pad and its effectiveness was studied under the chosen time periods. Finally, based on the optimum result obtained, i.e. maximum temperature drop across the pad and higher saturation efficiency, an appropriate air velocity was chosen. In this case study, it was found that the air velocity for the experimental testing must be higher than 0.5m/sec and lower than 1.5m/sec.

Water temperature is an important factor to be considered in evaporative cooling testing and its applications. Each time the ambient temperature changes, the temperature of the water in the sump drastically vary. M.S. Sodha and A. Somwanshi created an analytical model to evaluate the variation of water temperature along the direction of flow of air [16]. They used the model to find out the exit air temperature and the transient temperature of water in the sump. A new concept of using tank water for cooling was proposed and this model was in pretty good agreement with the experimental data.

A simulation model of the pad is always better to understand the air pattern as it comes in contact with the pads, the pressure drop across the cooling media for different flute angle and pad thickness, the material type of the pads and the effectiveness. A. Franco et al. [17] performed an aerodynamics analysis and CFD simulation on several cellulose evaporative pads to study its pressure drop characteristics and the effectiveness. The experimental testing was conducted inside a wind tunnel and was used as a basis to carry out the CFD simulation. The simulation included results for both the dry and the wet pads and good correlation was obtained between the experimental and the simulated ones.

The results also reported that at higher water flow rate the pressure drop across the cellulose media increased. Moreover, the CFD model could be used as a valuable tool for carrying out design optimization on the cooling pads as well as predict the pressure drop that the pad will produce based on the pads design.

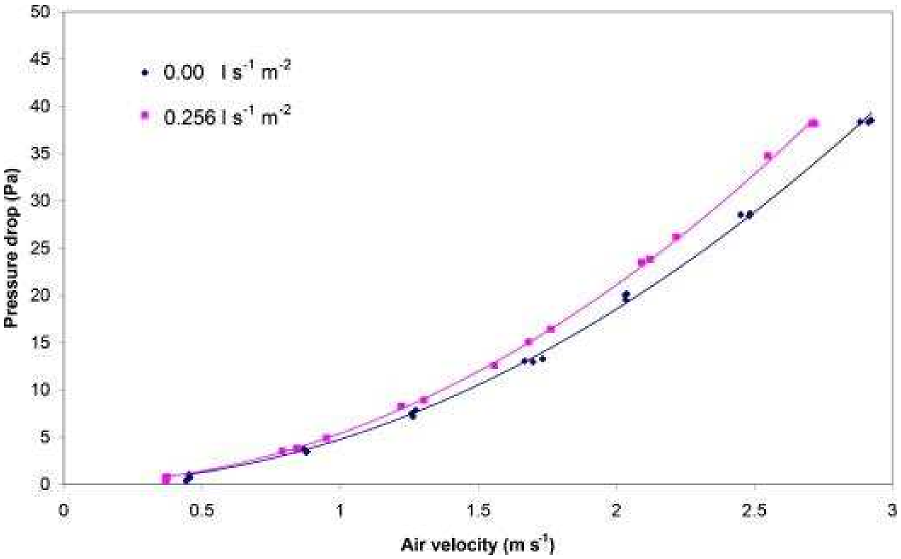


Figure 1.11: Pressure drop against air velocity for two different water flow rates [17]

The above figure presents one of the results reported from by Franco and others on the variation of pressure drop against air velocity. The pink curve with the higher water flow rate of 0.256 l/s/m^2 has much higher pressure drop compared to the other for the same air velocity.

Thus CFD poses a good tool to understand the physical characteristics and the behavior of the cooling pad when subjected to different inlet conditions and parameters like air velocity, water flow rate, material type, temperature and humidity and others.

Chapter 2

EVAPORATIVE COOLING PADS

2.1 Definition

Evaporative cooling pad is a cross-flow arrangement structure that is primarily used for cooling purpose. The structural setup is so designed that it facilitates easy contact of air and water. Cooling pads come in different shapes and sizes and also vary in its material types. The main function of the cooling pads is to cool the hot, outside air and use the resultant product of cool air for cooling the living rooms, data centers, greenhouses and other applications.

This is an evaporative cooling phenomenon wherein hot and humid air with less moisture content is drawn through these cooling pads by fans or blowers and is made to come in contact with the water at the pad’s interface. As air and water interact, it loses its sensible and gains an equal amount of latent heat of vapor. When the velocity of air increases, more and more water is evaporated into the path of the air flow and as a result the temperature of the air decreases. The greater the temperature difference between the inlet and the outlet air, the greater is the cooling effect.

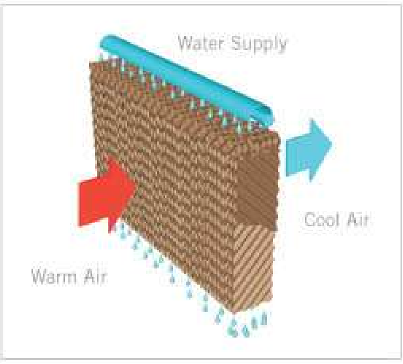


Figure 2.1: Image of air passing through the cooling pad [18]

2.2 Types of evaporative cooling pads

There are different types of cooling pads used my manufacturers based on the need and the type of application. Some of them include Aspen pads, Cellulose pads Glasdek pads. Most of these cooling pads find their applications in poultry farming and greenhouses. Cellulose and Glasdek pads are the commercially used ones for data center applications. Cellulose is made from paper and Glasdek from fiber glass.

Figure 2.2: Aspen pads [19]

Figure 2.3: Cellulose pads [20]

2.3 Factors affecting the cooling pads

There are a number of factors that affect the performance characteristics of evaporative pads. Some of the important factors include

- Surface area of the pad
- Pad thickness
- Pad material
- Size of perforation of the pads
- Flow-rate and relative humidity of air passing through the pads
- Volume of water used
- Number of sheets

Number of sheets is the number of layers that actually made up a complete pad. The more the number of sheets the higher is the pad efficiency. Volume of water used also significant affects the performance of cooling pads. Typically, manufacturers suggest a constant water flow rate of 1.5 gallons per minute of water per square foot of the top surface of the pad [21].

2.4 Material of the pads

Pad material also affects the effectiveness and pressure drop of cooling pads. Some common material that make up a pad include

- Metal
- Cement
- Wood
- Plastic
- Paper

Paper material is preferred over the others because they have very less pressure drop and high saturation efficiency.

Chapter 3

EXPERIMENTAL SETUP AND GUIDELINES FOR TESTING

3.1 Air-flow bench and Test duct

The experimental setup consisted of the air flow bench and the test duct for the evaporative cooling test. Air-flow bench is a device used for testing the thermal resistance of the test sample, testing for fan performance curve and to calculate the air flow rate. It consists of a blast-gate that controls the opening and closing of the chamber for air entry, flow straighteners to channelize the air flow path and nozzles with different diameter sizes to achieve the desired flow rate.

Figure 3.1: Experimental setup side view

The test duct consists of three segments with the cooling pad sitting inside the middle zone. The duct was initially modeled in modeling software, PRO-E and then fabricated for the experimental testing. The three duct segments were 0.6m X 0.6m in dimensions and 1.8m long. It was attached to the downstream end of the air-flow bench with the cooling pad fitted approximately 0.7m away from the downstream.

To prevent air leaks from the test duct and from its sides, duct tapes and water-resistant foams (R-Matte-rigid insulating water-resistant material) were used. Pressure taps were fitted on the upstream and downstream ends of the duct to measure the static pressure across the cooling pads. A water pump was used to carry out the wet media testing. It was connected to the water distribution tray through a long pipe with a water flow meter attached to it.

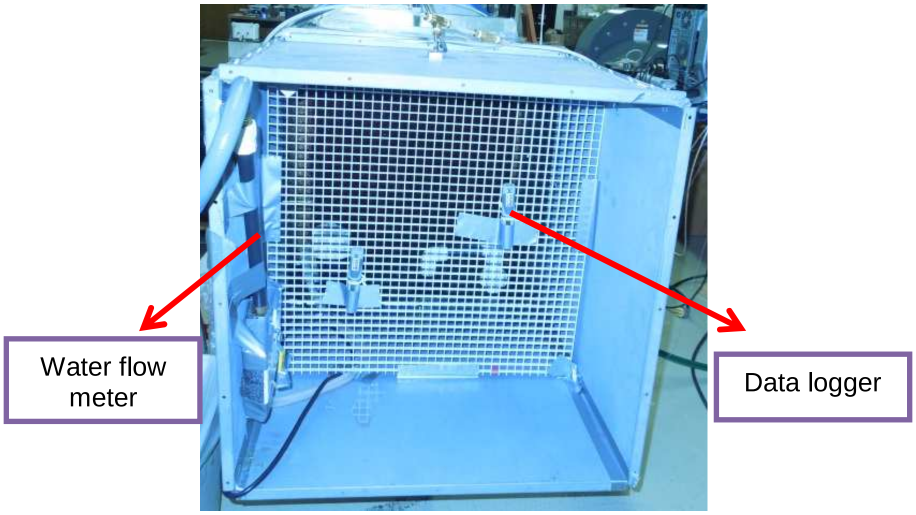


Figure 3.2: Downstream end of the test duct

The above figure shows the downstream end of the test duct to which the water flow meter and the data logger were attached. The data loggers reported the dry-bulb temperature, dew-point temperature and relative humidity. Inside the middle test duct the water pump was placed together with a float valve that regulated the level of water inside the sump. In order to maintain continuous supply of water for the cooling pad test, a garden hose pipe was attached to the outer end of the test duct whose other end was connected to a tap water.

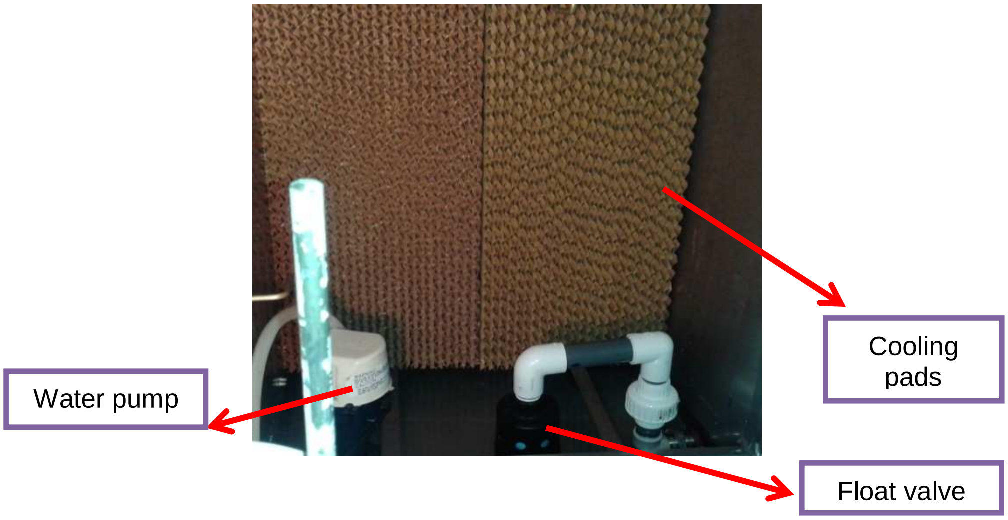


Figure 3.3: Test duct with the cooling pads, float valve and water pump

The ambient airflow to the test setup was provided my means of a centrifugal fan that was capable of delivering power ranging from 0-3000rpm. The flow rate needed for the experimental analysis was controlled by adjusting the motor for various speeds and the difference in pressure drop across the inlet and the outlet was noted.

To control the relative humidity of the room during the wet media tests, couple of dehumidifiers was used to keep the humidity with desired limits. In addition using data loggers for recording humidity and temperature, RF Code sensors were also used to get a more averaged and precise measurement. To ensure that water evenly distributes across the cooling media, a water distribution tray was fitted over them.

Figure 3.4: Water distribution tray

3.2 Guidelines for evaporative cooling testing

The ASHRAE technical committee has laid down a standard for the testing of direct evaporative coolers. The guidelines specified in the standard are specific to data center applications. Some of the important points to be followed while doing the testing include,

- Inlet air- temperature : 46℃ (115℉) maximum
- Wet-bulb temperature : 5℃ (41℉) minimum
- Wet-bulb depression : 11℃ (20℉) minimum
- During the testing, difference between the upstream wet-bulb temperature and the downstream wet-bulb temperature should not be more than 1℃ (2℉)
- To ensure that equilibrium is maintained, trail recording is carried out until steady readings are obtained

ASHRAE standard 133-2008, “Method of testing direct evaporative air coolers was the followed for the evaporative media testing [22]. These guidelines were used to benchmark our test analysis and later were compared to tests carried out standard room conditions of temperature and pressure.

To maintain the higher inlet air temperature, two heaters each of 3.6KW rating capacity were used to carry out the tests on the cooling pads. To maintain the wet-bulb temperature of 11℃ minimum, chilled water was constantly added to the sump during testing. Care was taken to ensure that the water temperature in the sump was maintained close to the wet-bulb temperature of the ambient air.

3.3 Cooling pad – Test setup

The cooling media tests were conducted at room temperature and at higher ambient temperature(according to the standards). Three 45°/15° flute angle pads were used for testing. The cellulose media which is of dimensions 0.6m X 0.6m tightly sits inside the middle segment of the duct with a water distribution tray on its top. Two mesh setups were used upstream and downstream of the cooling pad to which thermocouples and RF Code sensors were attached. All possible gaps were tightly sealed. The test setup remains common for all the cooling media testing.

Figure 3.5: Front view of the pad inside the test duct

Figure 3.6: Rear view of the cooling pad (with both the pads fitted)

Chapter 4

ANALYSIS AND INSTRUMENTATION

4.1 Data recording and measurement

The testing part of the experiment was carried out in closed lab environment. The dry-bulb temperature of the room was maintained constant for the test conducted at room conditions and increased to a higher temperature for the test conducted according to the standards.For every test analysis carried out on the cooling media, the pressure in the room was measured from the manometer. For measuring the pressure drop across the pads, eight pressure taps were fitted with four upstream and four downstream ducts to measure static pressure .

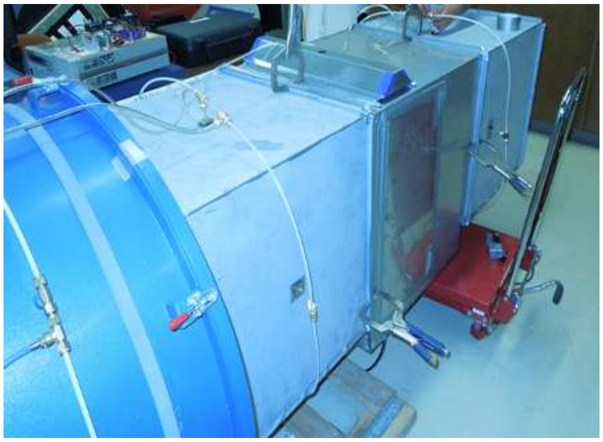


Figure 4.1: Test duct fitted with pressure taps

From these pressure taps a common tube was connected to the pressure transducer sitting on the upstream of the air-flow bench. The pressure taps were connected to metal tee connectors which were perfectly tested well-in-hand for air leakage. Four relative humidity data loggers were actually used for measuring the humidity, one to record the relative humidity of the room and the other three for the upstream and downstream. T-type thermocouples with accuracy ±0.1˚C were affixed to the setup to record the dry-bulb temperature. The temperature readings were measured off of a data acquisition unit named AGILENT connected to the computer. The unit read the static pressure and the differential pressure across the test chamber, as well as the thermocouple readings placed at different locations across the test unit. RF Code temperature and humidity sensors were also used with nine upstream and nine downstream to read the inlet and outlet air temperatures as well as relative humidity.

Figure 4.2: RF Code sensors fitted to the mesh setup

The humidity data logger recorded the dry-bulb temperatures, relative humidity and the dew-point temperatures at both the upstream and the downstream of the cooling media. Once the data’s were collected off of the data logger, its recordings were taken down by plugging it to a computer. The data logger is capable of recording data for a time-span of 48 hours. All the thermocouples have been installed in a grid format nine on the upstream and nine on the downstream. Before the actual start of the experiments, the humidity data logger and the thermocouples were carefully calibrated and then attached to the setup at its respective positions.

Chapter 5

TESTS AND RESULTS

5.1 Benchmarking tests

Two different pads manufactured by Munters Corporation namely Cellulose and GlasDek pads were tested according to the ASHRAE-133 standards and the results were compared against the manufacturer's supplied data. Cellulose pads are made from paper material and its counterpart from fiber glass. Two types of tests dry media and wet media tests were conducted on both the pads to determine its pressure drop and saturation efficiency. Tests were repeated for validation purpose and two heaters were used to perform the testing according to the standards.

5.2 Case 1 : MUNTERS 6560/15 cellulose cooling pads

Two 12in Munters 6560/15 cellulose cooling pads were tested for its pressure drop and its saturation efficiency.

Figure 5.1: Two 12 inch Munters cellulose pads

5.2.1 Dry tests and results

Two dry media tests were conducted, one at room temperature and at higher inlet air temperature. The tests were repeated for validation and consistency with manufacturers supplied data.

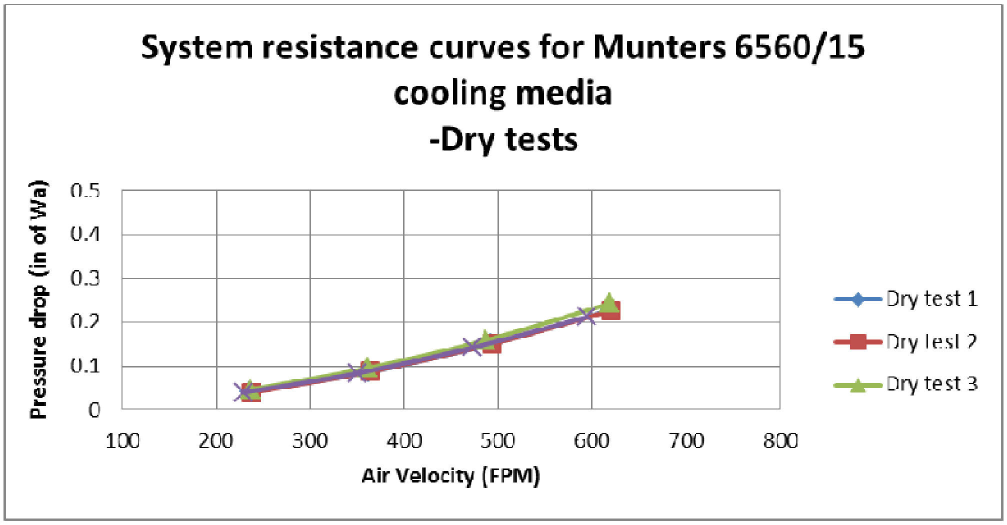


Figure 5.2: Pressure drop curves for the dry test at room temperature

The above figure shows the variation of pressure drop against the air velocity for three different dry media tests conducted at room temperature. It was observed that the pressure drop increases with increasing air velocity over the entire range of testing. Tests were repeated for consistency and very good agreement was observed seen by the overlapping of the test results. The tests were performed at room temperature of 24℃ (75.2℉) and room pressure of almost 1bar (99898.4Pa)

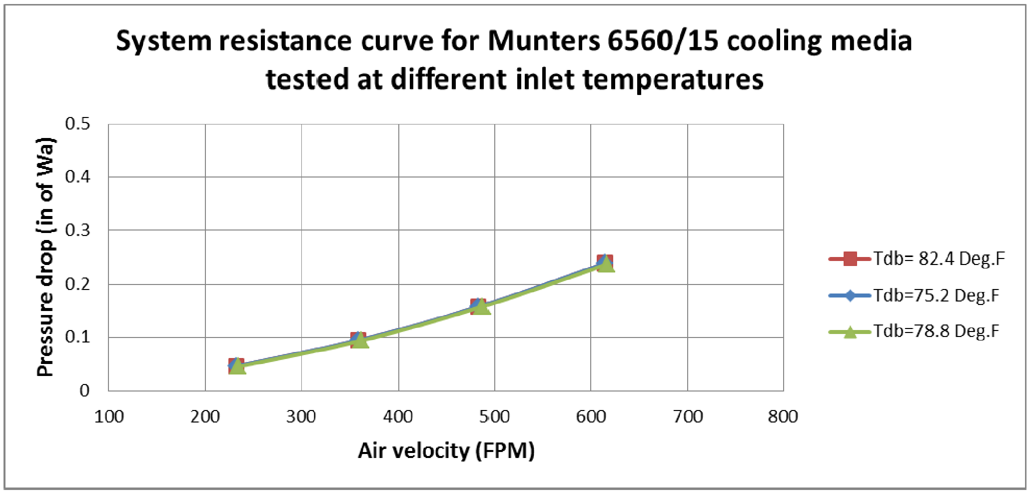


Figure 5.3: Pressure drop curves for the dry test at higher inlet air temperature

The above figure shows the same test results carried at higher inlet air temperature using the heaters. It was observed that increasing the temperature had no effect on the pressure drop across the cooling pad. At 600FPM, pressure drop at room temperature is about 0.23 in of H_2O which the same as the pressure drop at higher inlet air temperature.

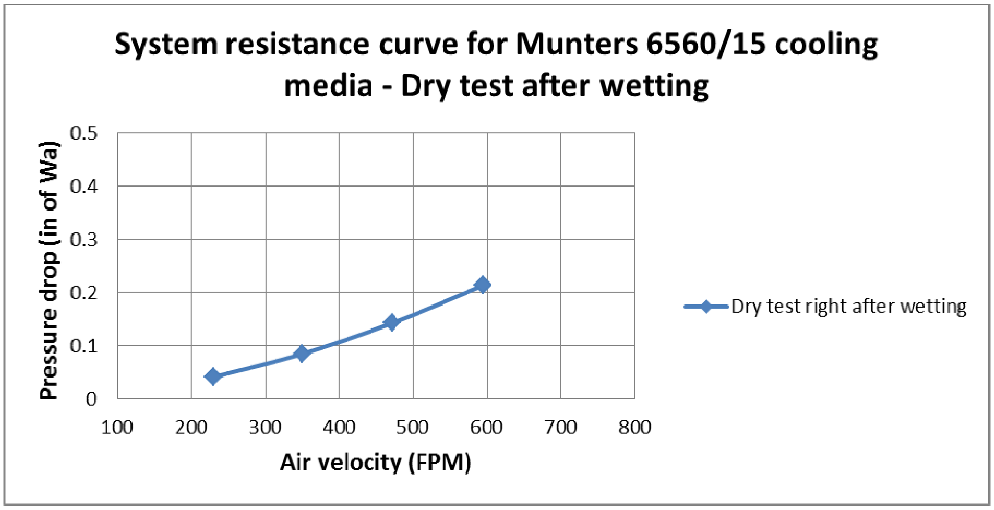


Figure 5.4: Pressure drop curves for the dry test right after the wet media testing

The above figure shows the pressure drop results for the dry media test that was performed right after the wet media test. The cooling pads after the wet media testing were completely blown dry before this test was performed. Results showed that there was a slight decrease in pressure drop across the media for the same air velocity. At 600FPM, the pressure drop read 0.22 in of H_2O. This concludes that temperature has no effect on the pressure drop of the cooling media.

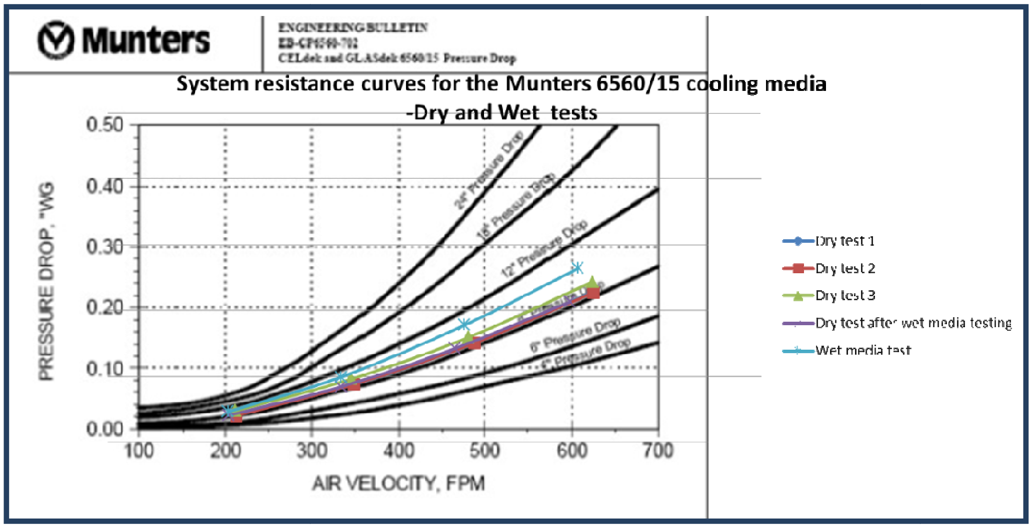


Figure 5.5: Comparison of pressure drop curves for the dry and wet media with the manufacturer data [23]

The above figure shows the comparison of the pressure drop test results for both the dry and the wet media with the manufacturer data. Test results were superimposed on the manufacturer data to study the variation of pressure drop with air velocity. Good agreement was observed in the test results.

5.2.2 Wet media test and results

The wet media test was carried out at higher inlet air temperature by operating both the heaters. Tests were conducted to study the wetting characteristics of the cooling media as well as its effectiveness. During the wet media test, a constant water flow rate of 3GPM (i.e. 1.5GPM per square surface of the top face of the pad) was applied to the pads.

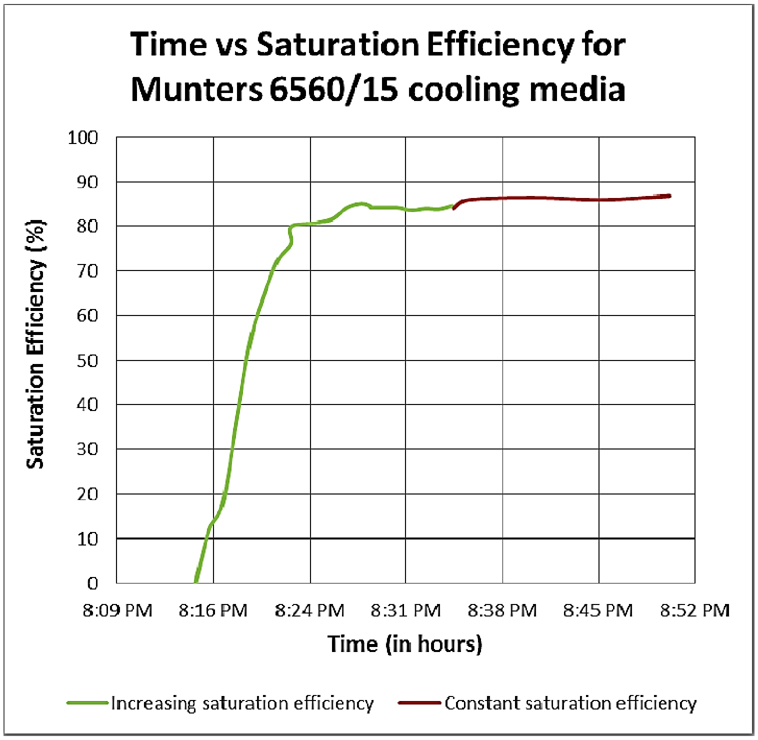


Figure 5.6: Wetting characteristics of the cooling pad

The above figure shows the wetting characteristics of the cooling pad obtained through the testing. It can be observed that it takes about 13-15 minutes for the pads to reach complete saturation of about 85% which is shown by the green curve. The brown curve that follows it shows the period of constant saturation efficiency.

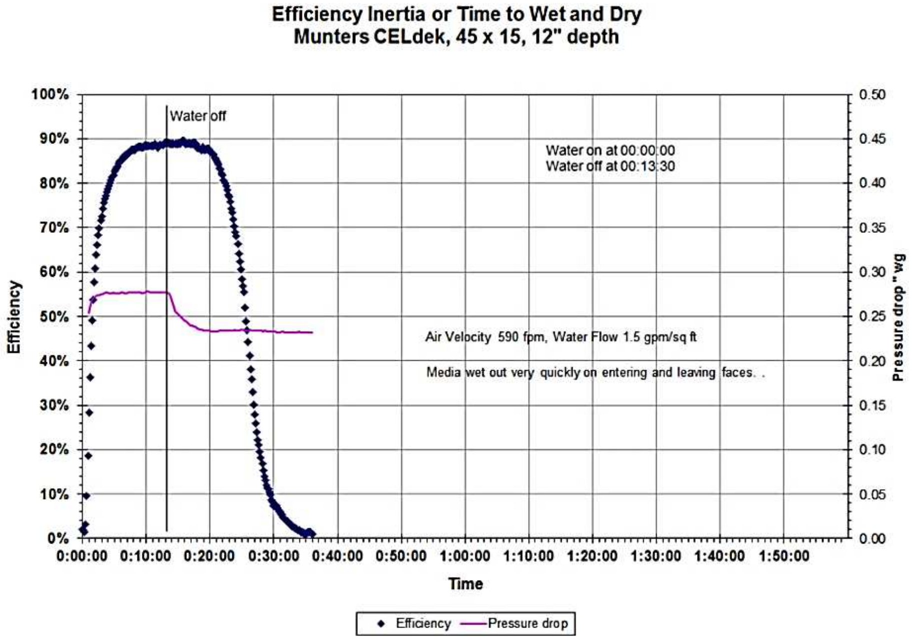


Figure 5.7: Munters manufacturer data for wetting and drying of the cooling media [24]

The above figure shows the manufacturer data for the wetting and drying of the Munters 6560/15 cooling pad. The blue curve denoting the efficiency gradually increases and reaches 90% in about 13 minutes. This shows that the pads have reached its saturation point. After 13 minutes, the water flow rate to the pads was stopped and thus the saturation efficiency decreases shown by the falling of the blue curve. The pink curve on the chart shows the pressure drop for the wet and dry media tests.

At 590FPM, the pressure drop for the wet media was about 0.28 in of H_2O and for the dry media at 0.23 in of H_2O. Comparing the manufacturer data pressure drop data with the rest results, it was observed that at the same air velocity of 590-600FPM, the pressure drop for the wet media was about 0.27 in of H_2O and for the dry media is about 0.23 in of H_2O. This shows that the test results were in good agreement with the manufacturer data.

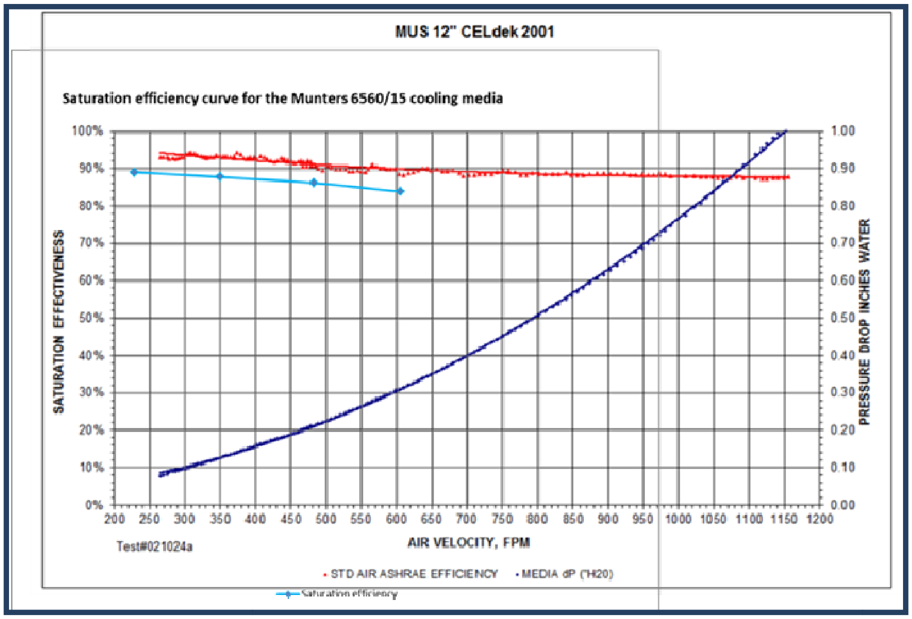


Figure 5.8: Saturation efficiency comparison with manufacturer data [25]

The above curve shows the saturation efficiency comparison of the test results with the manufacturer supplied data. The red curve shows the manufacturer saturation efficiency and blue curve was the efficiency obtained through the wet media testing. At 600FPM, the efficiency is about 85%. Comparing with the manufacturer spec, the efficiency at 600FPM is about 86-88%. The error is less than 5%. This showed that our results were in good agreement with the manufacturer data.

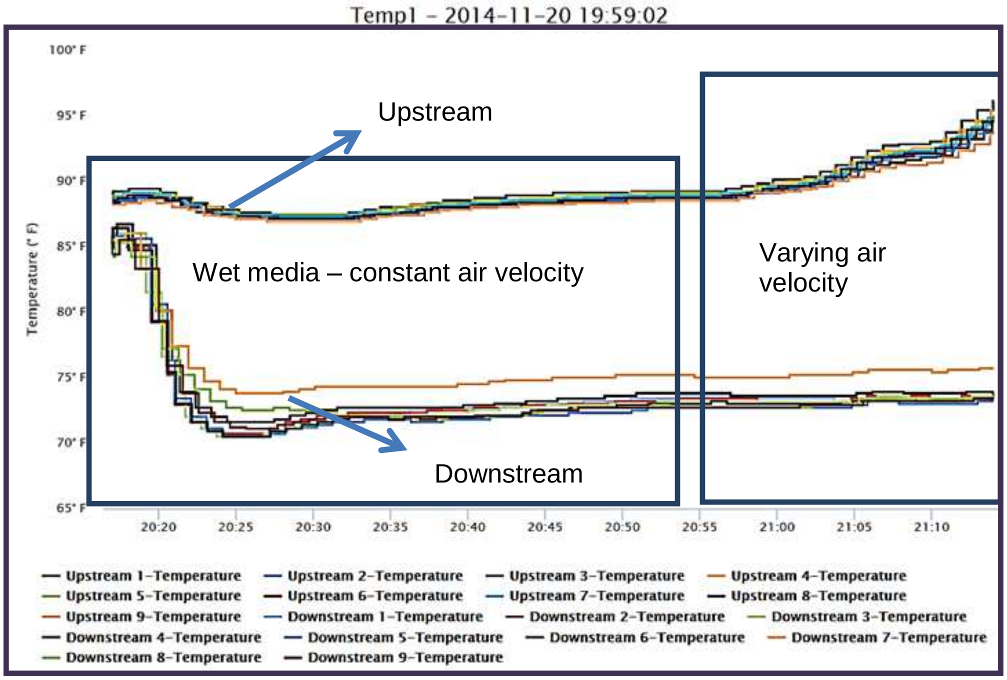


Figure 5.9: Temperature variation of RF Code sensors with time

The above figure shows the temperature variations of the RF code sensors upstream and downstream during the wet media testing. It was observed that the upstream temperature rose all the way up to 95℉ (35℃) from 90℉ (32℃). The downstream temperature readings decreased all the way till 70℉ (21℃). The initial period was performed at constant air velocity of 590FPM for the observing the wetting characteristics of the pad. The second period was performed at varying air velocity to calculate the pressure drop for the wet media test. The maximum reduction in temperature was 35℃ - 21℃ = 14℃.

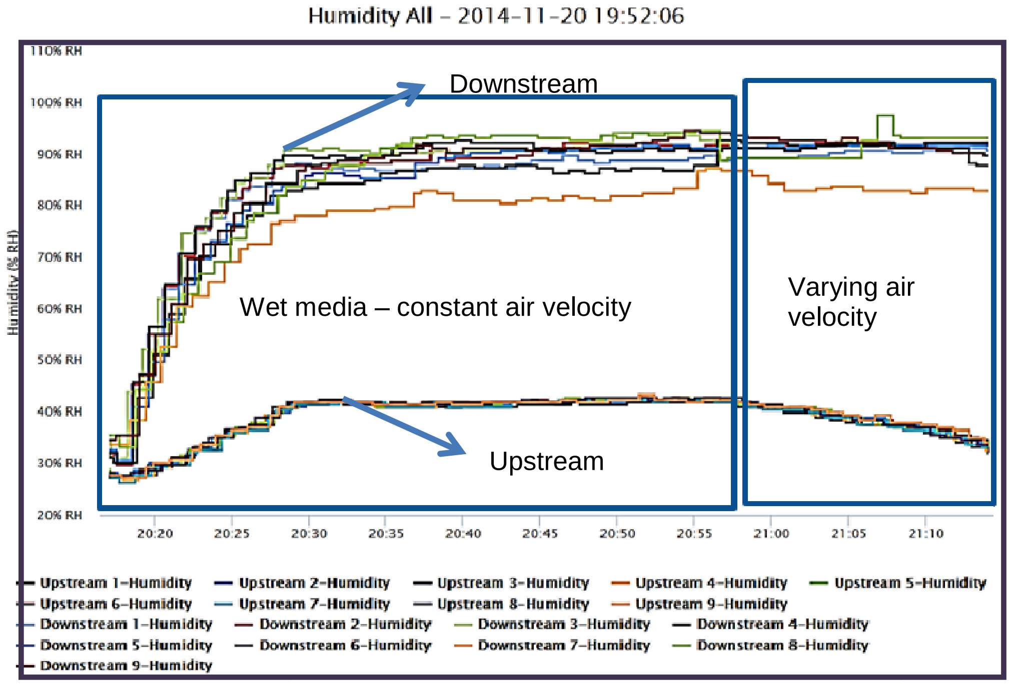


Figure 5.10: Humidity variation of the RF Code sensors for the wet media test

The above figure shows the humidity variations of the RF code sensors upstream and downstream during the wet media testing. It was observed that the downstream humidity went all the way up to 90% from 32%. The upstream humidity readings increased from 27% to 40% during the wetting phase (constant air velocity) and then decreased back to 27% for the varying air velocity test. The downstream humidity on the contrary, increased during the wetting phase all the way till 90% and then remained constant during the varying air velocity test.

5.3 Case 2 : GLASdek 6560/15 cooling pad

Two 12***in*** Munters 6560/15 GLASdek cooling pads were tested for its pressure drop and its saturation efficiency.

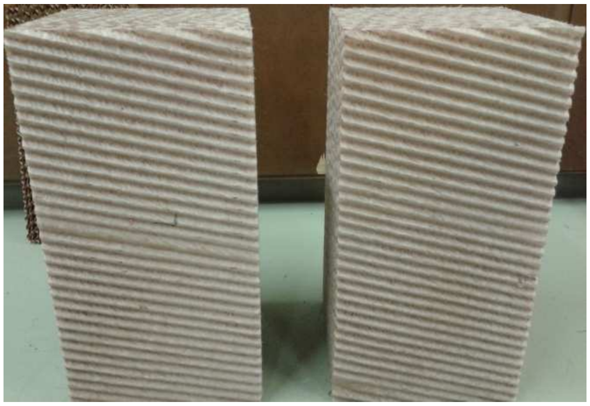


Figure 5.11: Two 12 inch Munters GLASdek pads

5.3.1 Dry tests and results

Two dry media tests were conducted, one at room temperature and at higher inlet air temperature. The tests were repeated for validation and consistency.

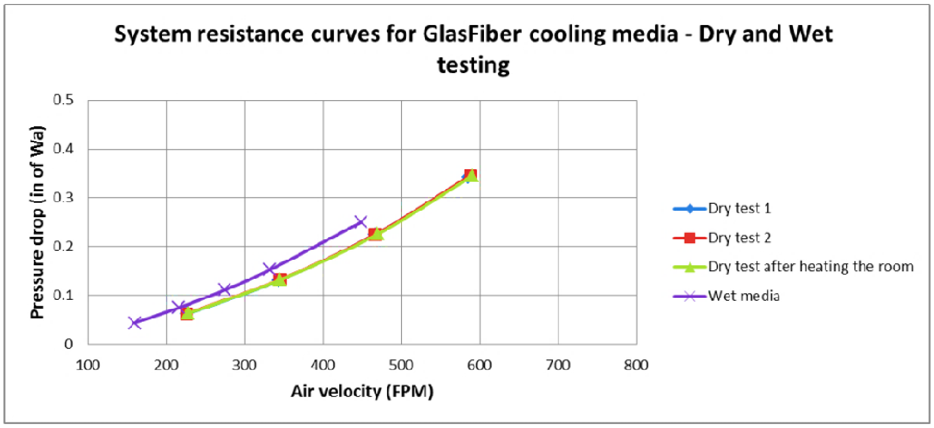


Figure 5.12: Pressure drop curves for the GLASdek media at room and at higher temperature

The above figure represents the pressure drop results for both the GLASdek's dry and wet media tests. As observed earlier for the cellulose media, it was seen that increase in temperature had negligible effect on the pressure drop of the GLASdek media. However the pressure drop for the wet media test was observed to be higher than the dry one mainly due to the effect of water flowing over it.

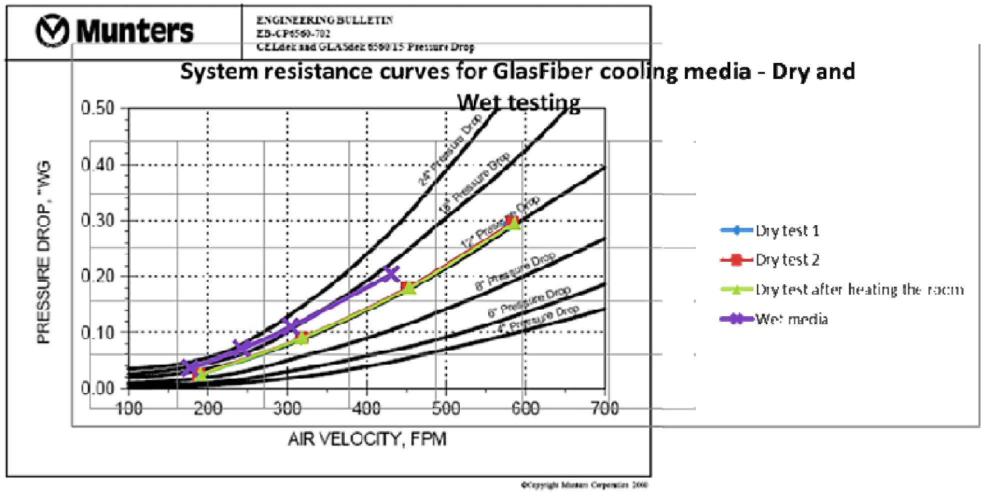


Figure 5.13: Pressure drop curves superimposed on the Munters manufacturer data for GLASdek media [26]

The above figure represents the pressure drop curves comparison with the GLASdek manufacturer data. Results were superimposed and good agreement was observed for the pressure drop characteristics. The pressure drop for the wet media is a bit higher than others mainly due to the effect of pad material (fibre-glass) and due to the water flow rate flowing over the pads.

5.3.2 Wet media test and results

The wet media test was carried out at higher inlet air temperature by operating both the heaters. Tests were conducted to study the wetting characteristics of the cooling media as well as its effectiveness. During the wet media test, a constant water flow rate of 3GPM (i.e. 1.5GPM per square surface of the top face of the pad) was applied to the pads.

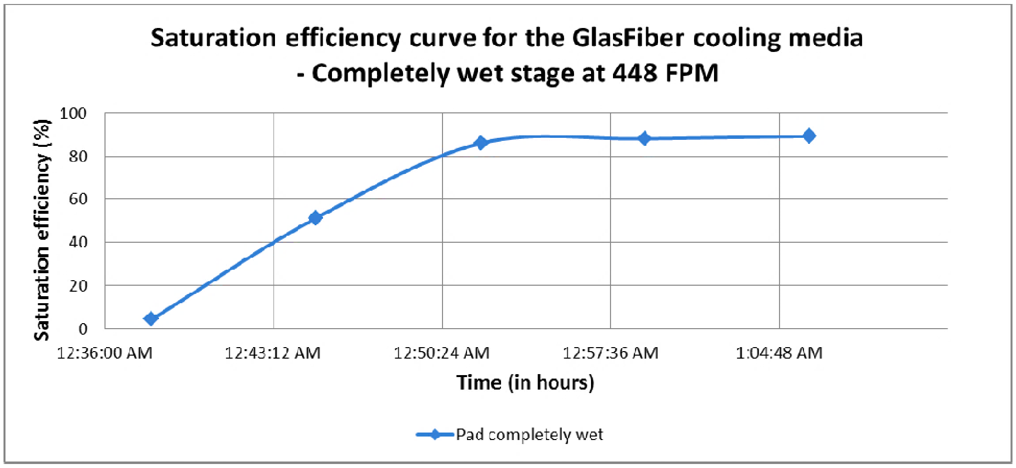


Figure 5.14: Wetting characteristics of GLASdek media

The above curve shows the wetting characteristics of the GLASdek cooling media. It was observed that the pads reach complete saturation of 85% in about 20 minutes and then its saturation efficiency flattens out over time. This test was carried out 448FPM much less than the air velocity used for the cellulose media because at higher velocities, in the case of GLASdek media, water started splashing on the downstream end. Thus, the pads were made to run constantly at 448FPM during the initial wetting phase and then its velocity was reduced to calculate the pressure drop across the media.

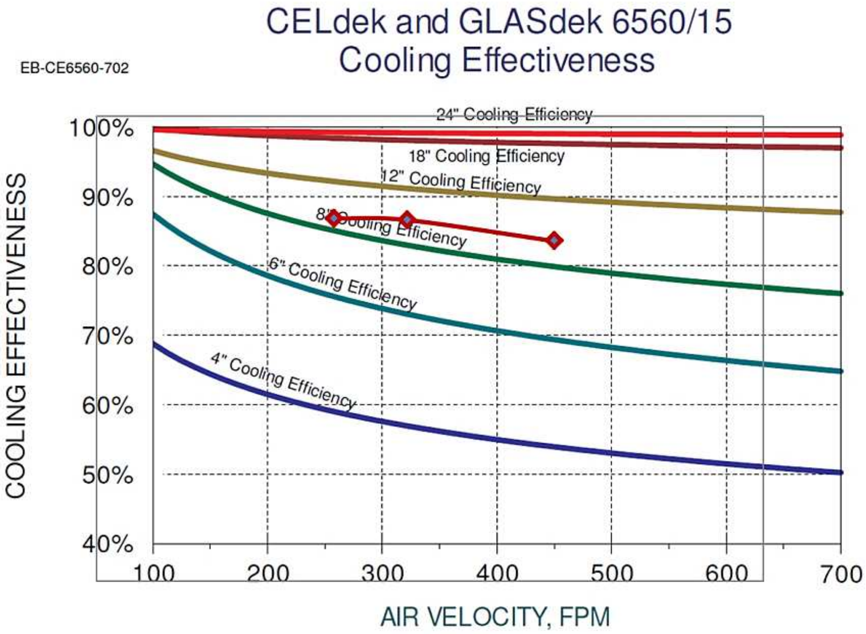


Figure 5.15: Saturation efficiency curve superimposed on the manufacturer data [27]

The above figure shows the saturation efficiency test results superimposed on the manufacturer supplied data. The red curve in the middle shows the results obtained from the test analysis. The pad reaches a maximum efficiency of about 88% and a minimum efficiency of 85%. This concludes that the test results are in good agreement with the manufacturer supplied data. Typically, GLASdek pads exhibited comparatively lesser saturation efficiency compared to the cellulose pads.

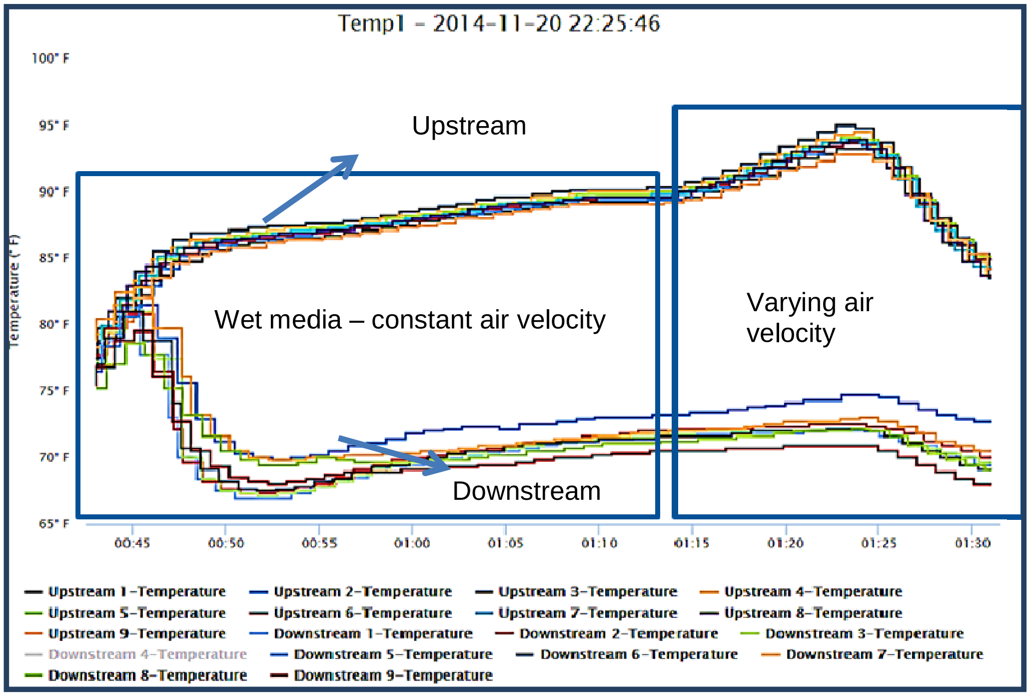


Figure 5.16: Temperature variation of RF Code sensors with time

The above figure shows the temperature variations of the RF code sensors upstream and downstream during the wet media testing. It was observed that the upstream temperature rose all the way up to 95℉ (35℃) from 77℉ (25 ℃) and then decreased to 85℉ (29℃) . The downstream temperature readings decreased all the way till 65℉ (18 ℃). The initial period was performed at constant air velocity of 448FPM for the observing the wetting characteristics of the pad. The second period was performed at varying air velocity to calculate the pressure drop for the wet media test. The maximum reduction in temperature was 35℃ - 18℃ = 17℃

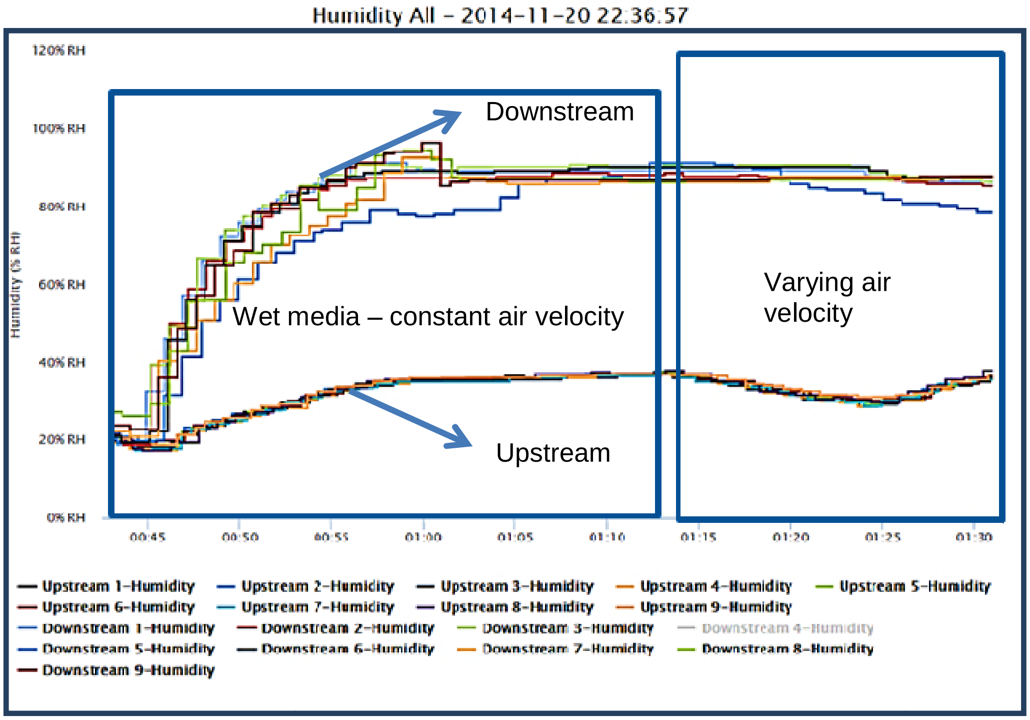


Figure 5.17: Humidity variation of the RF Code sensors for the wet media test

The above figure shows the humidity variations of the RF code sensors upstream and downstream during the wet media testing. It was observed that the downstream humidity went all the way up to 85% from 22%. The upstream humidity readings increased from 20% to 35% during the wetting phase (constant air velocity) and then decreased back to 30% for the varying air velocity test. The downstream humidity on the contrary, increased during the wetting phase all the way till 85% and then remained constant during the varying air velocity test.

5.4 Case 3: KUUL cellulose pads tested at room conditions

Two 12***in*** KUUL cellulose cooling pads were tested for its pressure drop and its saturation efficiency at standard conditions of temperature and pressure.

Temperature : 76°F (24.4°C) ; Pressure : 29.8 in of Hg (almost 1bar)

Figure 5.18: Image of KUUL cellulose media

5.4.1 Dry media tests and results

Two dry media tests were conducted; both at room temperature. The tests were repeated for validation and consistency. No heaters were used for this test. The pressure drop curves from the test results were superimposed on the manufacturer supplied data to verify the accuracy and consistency of the test results. The test setup used for testing the Munters cellulose and GLASdek pads was also used for testing the KUUL pads.

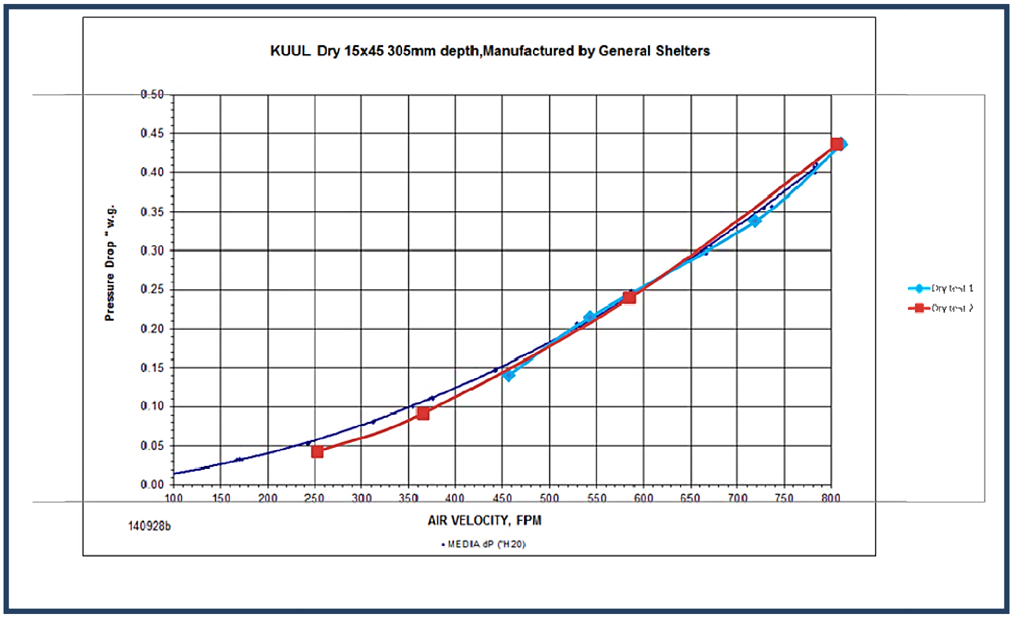


Figure 5.19: Pressure drop curves of the KUUL pads superimposed on the manufacturer data [28]

The above figure shows the pressure drop test results for the KUUL pads superimposed on its manufacturer supplied data. Two dry tests were performed and both the result almost coincided with the manufacturer data. At 600FPM, the pressure drop from both the dry test results was about 0.23 in of H_2O. Comparing with the manufacturer data for the same air velocity, the pressure drop was found to be 0.24 in of H_2O. This proves that the results are in good agreement with the manufacturer data.

5.4.2 Wet media test and results

The wet media test was also performed at room conditions of temperature and pressure. Four different water flow rates were applied over the cooling pads namely 1GPM, 2GPM, 3GPM and 4GPM. The effectiveness of the pads and its variation with different water flow rates was carefully studied.

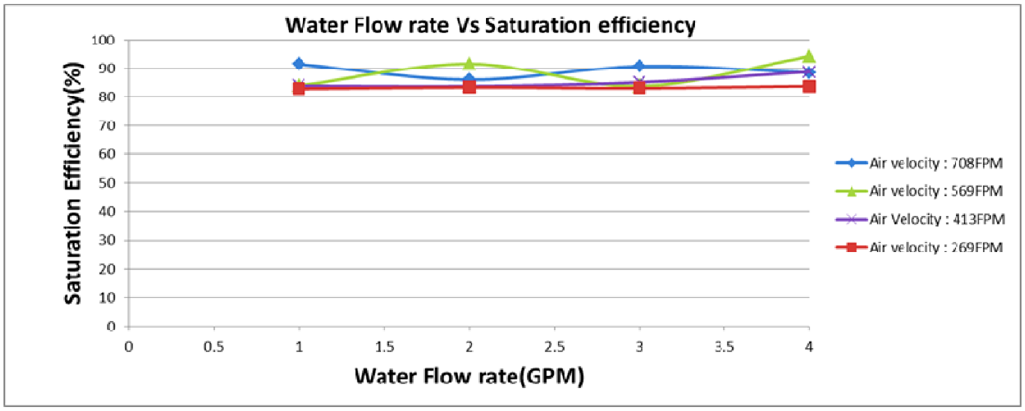


Figure 5.20: Variation of water flow rates with saturation efficiency

The above graph shows the variation of water flow rate with saturation efficiency for different air velocities. It was observed that saturation efficiency remains constant when the water flow rate applied over the pad varied. This result was in accordance with the literature data and thus proved that water flow rate has no effect on the saturation efficiency of the cooling pad.

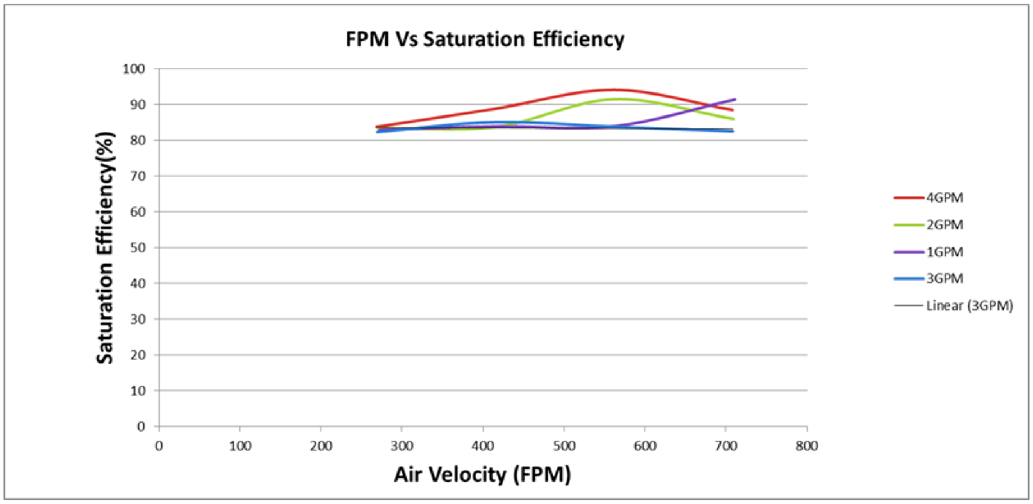


Figure 5.21: Variation of saturation efficiency against air velocity for different water flow rates

The above figure shows the variation of air velocity against saturation efficiency for different water flow rates. It was observed from the tests that the saturation efficiency for 3GPM was found to decrease with increasing air velocity. Its maximum efficiency was observed at 400FPM with 85% and gradually decreased to 80% at 700FPM. However, at 540FPM, 2GPM and 4GPM showed higher saturation efficiency compared to 1GPM and 3GPM. Typically, manufacturers from the evaporative cooling industry recommend a constant water flow rate of 3GPM for doing the wet media test.

Chapter 6

CONCLUSION

Two different factors that affect the performance characteristics of evaporative cooling pads, namely the pressure drop and saturation efficiency was studied in detail for three different types of cooling pads. Experimental tests were carried out according to ASHRAE-133 standard to perform benchmarking analysis. Based on the results from benchmarking, a test was also carried out at room conditions to observe the same effect. Pressure drop characteristics of the cooling media and the saturation efficiency were compared with the manufacturer supplied data to validate the correctness of testing. Three different pads namely, Munters cellulose and GLASdek pads and KUUL cellulose pads were tested for its performance characteristics. The results can be divided into two categories,

- Condition 1 : No heating (air at room temperature)
  - Test : KUUL pads
  - Results : Pressure drop is less at room temperature and the saturation efficiency decreases
- Condition 2 : Pre-heating the inlet air temperature
  - Test : Munters cellulose media and Munters GLASdek media
  - Results
    - Munters cellulose media
      - Pressure drop remains unchanged for dry test and increases with the wet one
      - Saturation efficiency of the media reaches about 90% within a short span of time (15 minutes)
    - Munters GLASdek media

- Pressure drop increases for the dry media and wet media test
- Saturation efficiency of the pad reaches about 85% within 20 minutes

Based on the tests conducted at higher inlet air temperature, it can be concluded that the Munters 6560/15 has a much higher saturation efficiency and higher pressure drop than the GLASdek pads. But preferably for data center applications where fire hazards are easily prone to happen, GLASdek pads are a suitable choice because they are flame retardant and provide good cooling efficiency. Cellulose pads on the other hand, though they have very high saturation efficiency and greater tendency to retain water, they are not preferred because paper material easily catches on fire. Looking from the cost perspective, cellulose pads are much cheaper than the GLASdek ones.

Chapter 7

FUTURE WORK

Testing or gauging the performance characteristics of cooling pads is an important concern and an ongoing research for many data center cooling companies. In this current research work only the two very essential characteristics namely; the pressure drop and the effectiveness of the cooling pads were studied in detail. Some of the future work includes,

- ✓ Looking into other factors that affect the pads efficiency like thickness, surface area and so on
- ✓ Simulating the real-time conditions in a CFD platform
- ✓ Moving towards composite type pad materials

References

[1] P.Delforge, 25 September 2015.[Online].Available:http://www.nrdc.org/energy/data-center-efficiency-assessment.asp.

[2] N.Shah, “CFD Analysis of direct evaporative cooling zone of air-side economizer for containerized data center”, ProQuest, 2012.

[3] “HP”, Wikipedia, [Online]. Available:http://en.wikipedia.org/wiki/HP_Performance_Optimized_Datacenter.

[4] Ellis G.Guiles, Jr. P.E, “Contracting business, “1May 2007.[Online]. Available:http://contractingbusiness.com/commercial-hvac/airside-economizers-are-they-doing-what-we-what-them-do.

[5] Mestex, Evaporative cooling of data centers,Webinar,Dallas,2010.

[6] “Energy star,”[Online]. Available:http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_economizer-zirside

[7] “Ekonair,” 2013. [Online]. Available:http://evaporative-cooling24.co.uk/how-it-works/.

[8] “Wescor,” 2012. [Online] Available:http://www.wescorhvac.com/Evaportive%20cooling%20white%20paper.htm.

[9] Y.M. Xuan, F. Xiao, X.F. Niu, X. Huang, S.W. Wang, ”Research and application of evaporative cooling in China: A review (I)- Research, “ Renewable and Sustainable Energy, vol.16,no.5,p.3535-3546, 2012.

[10] B.F. Michael Czarick, “Evaporative Cooling Myths and Facts” 7 June 2009.[Online]. Available:http:www.poultryventilation.com/sites/default/files/tips/2009/vol21n7.pdf.

[11] R.W. Koca, W.C. Hughes, L.L. Christianson, “Evaporative Cooling Pads: Test Procedures and Evaluation,” in ASABE, 1991.

[12] Adbollah Malli, Hamid Reza Seyf, Mohammed Layeghi, Seyedmehdi Sharifian, Hamid Behravesh, “Investigating the performance of cellulose evaporative cooling pads,”Energy Conversion and Management,vol.52,no.7,p.2598-2603,2011.

[13] A. Franco, D.L. Valera, A. Madueno, A. Pena, ”Influence of water and air-flow on the performance of cellulose evaporative cooling pads used in Mediterranean greenhouses,” ASABE,vol.53,no.2,pp.565-576, 2010.

[14] M.Koseoglu, “Investigation of water droplet carryover phenomena in industrial evaporative air-conditioning systems,” International Communications in Heat and Mass Transfer,vol.47,pp.92-97, 2012.

[15] Metin Dagtekin, Cengiz Karaca, Y ilmaz Yildiz, Ali Bascetincelik and Omar Paydak, “The effects of air velocity on the performance of pad evaporative cooling systems,” African Journal of Agricultural research,vol.6,no.7,pp. 1813-1822, 2011.

[16] M.S. Sodha and A. Somwanshi, “Variation of water temperature along the direction of flow: Effect on performance of an evaporative cooler,” Journal of Fundamentals of Renewable Energy and Applications,vol.2,p.6, 2012.

[17] A. Franco, D.L. Valera, A. Pena, A.M. Perez, “Aerodynamic analysis and CFD simulation of several cellulose evaporative cooling pads used in Mediterranean greenhouses, “ Computer and Electronics in Agriculture,vol.76,no.2,pp.218-230, 2011.

[18] “Nature Cool,” [Online].Available :http://www.nature-cool.com/.

[19] “Indoor comfort supply,” 2009.[Online]. Available: http//www.indoorcomfortsupply.com/cgibin/commerce.exe?preadd=action&key=2838.

[20] “Made in China,” [Online]. Available:http://jiumualon.en.made-in-china.com/produce/CMPmNIUDbsra/China-Cellulose-Paper-Pad-Evaporative-Cooling-Pad-for-Poultry-and-Greenhouse-Cooling-System.html.

[21] “HumiCool Division,” Munters, 2003. [Online]. Available: http://www.haveacoolday.com/docs/default-document-library/2011/04/26/Munters%20CELdek%20Literature%20MB-CDB-0305-ATEC.pdf?Status=Master.

[22] ASHRAE-133:2008, “Method of testing direct evaporative air coolers,” American Society for Heating, Refrigeration and Air-Conditioning Engineers, 2008.

[23] Munters, Pressure drop curves for the cellulose 6560/15 cooling pad, Munters.

[24] Munters, Efficiency inertia or time to wet and dry the media, Munters.

[25] Munters, Saturation efficiency curves for the cellulose 6560/15 cooling pad, Munters.

[26] Munters, Pressure drop curves for the GLASdek 6560/15 cooling pad, Munters.

[27] Munters, Saturation efficiency curves for the GLASdek 6560/15 cooling pad, Munters.

[28] KUUL, Dry pressure drop curve for the KUUL pads 15X45(Flute angle), 305mm.

Biographical Information

Vishnu Sreeram was born in Chennai, India. He received his Bachelor’s degree in Mechanical Engineering from Anna University, India in 2013. He completed his Master of Science degree in Mechanical Engineering at the University of Texas at Arlington in December 2014.

Vishnu has been involved in a number of projects ranging from device level to room level. His primary research areas include electronic cooling, data center cooling and modular data centers.

He has been working in a number of projects related to Air-side economization and data center cooling for a company called Mestex. The projects included, “ CFD Modeling of an Aztec Cooling unit and an IT-Pod, CFD Modeling of ASC-15 direct/indirect cooling unit, testing of evaporative cooling pads and so on. He is also currently a member of the I/UCRC Project 4 titled “Maximizing the use if efficient air-side economization in modular, large data centers and Datacom housing units”.

He joined EMNSPC research team under Dr. Agonafer in spring 2013 and is a member of ASME and ASHRAE.