FABRICATION AND PERFORMANCE ANALYSIS OF WIND CHILL REFRIGERATION SYSTEM

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Abstract : Refrigeration has wide range of applications ranging from domestic to industrial purposes. Conventional refrigeration systems run on electricity and refrigerants also cause Ozone layer depletion along with Global warming. Thus, there has been need for a solution that is based on the principles of nature such as bio mimicking and that do not require usage of electricity. Keeping these factors in mind a prototype has been made that works on solar energy and provides refrigeration using ambient air as refrigerant.

The wind chill refrigeration uses the principle of convection, conduction and cooling due to evaporation. There are two main stages of cooling one by conduction and convection the other by cooling due to evaporation. A working prototype was fabricated, assembled, and tested. The response parameters that were considered in the experimentation are 1) Time Vs Temperature drop, 2) mass flow rate of air (at constant velocity of wind) Vs Temperature drop and 3) wind velocity Vs Temperature drop (constant mass flow rate). The parameters that have been studied practically have also been calculated and correlated with theoretical parameters, so that required comparisons can be made for better understanding of the functioning of the wind chill refrigeration system.

After conducting experiments on the fabricated prototype under various conditions, it was observed that temperature drop is directly proportional to local wind speed, inversely proportional to mass flow rate and wind chill refrigeration can be a potential alternative for conventional refrigeration systems.

***IndexTerms* – wind chill refrigeration system, bio mimicking, evaporation chamber, non-conventional refrigeration systems.**

I. INTRODUCTION

Refrigeration is defined as the process of cooling a space, substance or system and maintaining its temperature below that of ambient temperature. Refrigeration has wide range of applications from food preservation, medicines storage etc to industrial applications. Initially water and ice were used to refrigerate items. As the time passed engineers developed the existing conventional form of refrigeration using chlorofluorocarbons or better known as CFCs and they proved to be a better alternative in terms of functioning, design and in maintenance thereby making it the most widely used form of refrigeration throughout the world. But it was only in the late 20th century that environmentalists started to observe the potential threats posed by these chlorofluorocarbons in ozone layer depletion and global warming. These drawbacks in the usage of CFCs made everyone to look for other alternatives i.e. non-conventional forms of refrigeration with zero ODP (Ozone depletion potential) and zero GWP (Global warming potential). The various non-conventional refrigeration systems includes pulse Tube, Vortex Tube, Solar, Magnetic, Acoustic, and Bio- mimicking refrigeration systems

The present study “Wind Chill Refrigeration” is a novel method of non-conventional refrigeration which comes under Bio-mimicking refrigerating systems. Bio-mimicking is the process of imitating the natural phenomenon. Refrigerating a given space/substance by natural methods (i.e. evaporation, conduction, convection, and radiation) comes under bio-mimicking refrigerating systems and are generally preferred for their environmental merits when compared with the conventional methods, thereby making the system completely eco-friendly having zero ODP and GWP. Wind chill refrigeration makes ambient air to undergo cooling in two stages and will be used as a refrigerant. The first stage is cooling through convection and the second stage is cooling through evaporation. It is applicable to places where there is a scarcity of electricity and can be a potential alternative as there are no harmful refrigerants involved and moving parts like compressor.

2. LITERATURE REVIEW

Georgios Florides [1] *et al* gives an insight about the variation of temperature with depth into the earth. It was observed from their studies that though the temperature variations at depth of 25m are less but the variation of the temperature of ground at a depth of 2-3 m has been significant. Weather conditions such as rain and ground water level also have a significant impact on the local ground temperature. **J.L. Monteith [2]** discusses the various factors which affect the evaporation on the surfaces of objects and applied Penman formula to various diverse systems and obtained significant success in nearly calculating the rate of evaporation. **S.A. Tassou** [3] et al gives us brief insight on the various forms of refrigeration available in the market for refrigerating food items and explored various other forms of refrigeration like bio-mimicking refrigerating systems, thermo acoustic refrigeration, magnetic refrigeration, Stirling cycle refrigeration, thermoelectric refrigeration, tri generation, adsorption refrigeration systems, ejection cycles and mentioned each method’s driving factors ,applications and limitations in providing refrigeration. **Arshad Ayub** [4] et al explains the process of wind chill refrigeration systems and also the components used in wind chill refrigeration are mentioned in detail.

Jitendra S. Pachbhai [5] et al presented the modified design of the wind chill refrigeration system using CREO software. The authors drafted the CAD model of the wind chill refrigeration for developing the system in terms of design and to ease the difficulties while manufacturing.

In the present study the possibility of a cost effective and eco-friendly refrigeration system for domestic use and for small scale commercial use was carried out by a prototype development. The impact of two important parameters namely (a) Mass flow rate and (b) Wind speed on the system has been considered, which was not considered by previous researchers. These parameters were varied individually and corresponding changes in the temperature drop at the outlet of the apparatus were noted. The results have been tabulated and analyzed thoroughly and the conclusions have been presented.

3. MATERIALS AND METHODOLOGY

In this section the various components used for developing the wind chill refrigeration system along with their specifications and the working process of the prototype was also described. The wind chill refrigerator is made of six major components namely; a Solar Panel, a funnel inlet powered with a DC fan, a U shaped copper coil, a circular copper coil, the Refrigeration chamber, a temperature sensor, Evaporation box.

3.1 Solar panel: the figure 1 represents the photographic view of the solar panel used in the present study. The solar panel is of 5 watt 12 volts and is the source of electricity required to run the DC powered fan.

3.2 The funnel inlet with DC powered Fan

Figure 2 shows the photographic view of the DC powered fan, which rotates at a maximum speed of 500 rpm. The funnel is primarily used as the gateway for the atmospheric air to enter the apparatus. This flow of the air is aided by a DC powered fan provided at the entrance of the funnel which would suck the air and can also be used to control the volumetric flow rate of the atmospheric air into the apparatus by varying its speed. The other end of the funnel is connected to the inlet of the U-shaped copper coil placed underneath the ground at desired depth.

Fig.1. Solar panel

fig.2.The funnel inlet with DC powered Fan

Fig.3. U shaped copper coil

fig.4. Circular copper coil.

fig.5. Refrigeration chamber

Fig.6. Temperature Sensor.

Fig.7. Evaporation Glass box

3.3 U shaped copper coil

Figure 3 shows the photographic view of the U-shaped copper tube used in the prototype. The U-shaped copper coil is placed inside the earth at a depth of 3m, where in the temperature variation of the is between 15 to 25°C on an average and the temperature remains constant at about 22°C. According to this variation the underground temperature is less than the atmospheric temperature, due to this gradient of temperature there is a heat transfer between the air flowing and the soil.

3.4 Circular copper coil

Figure 4 shows the photographic view of the circular copper coil used in the prototype development. The circular copper coil is placed inside the glass compartment which is partially filled in with water up to certain height. The circular copper coil is fixed just above the upper surface of the water in order to initiate evaporative air-cooling phenomena. This copper coil's outlet is attached to the orifice in the workstation.

3.5 Refrigeration chamber

Figure 5 shows the photographic view of the refrigeration chamber used in prototype development. The Refrigeration chamber is the space inside the container where the substances which are desired to be cooled are placed in it. This chamber has a volume of 3 liters.

3.6 Temperature sensor

Figure 6 shows the photographic view of the temperature sensor employed in the present study and is placed inside the refrigerating space to monitor the temperature inside the refrigerating space. The temperature sensor has 36 x 17 mm display, with a 1.5-volt battery.

3.7 Evaporation Glass box

Figure 7 shows the photographic view of the evaporation glass box used in the present study. Four glass plates are cut with the length of 31.5 cm, width 31.5 cm and height of 20.5 cm Once the glass plates are cut, they are placed perpendicular to each other in the shape of a cuboid once the glass plates are aligned properly they are joined with glue and tape is used for extra support.

Copper tube used for air conditioning and refrigeration applications in the field is an almost pure copper material meeting the requirements of ASTM B 280 - Standard Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service. Diameter of the copper tube is 12mm and length of the tube used is 5 metres.

3.8 Working Procedure Of Wind Chill Refrigeration Process

The air enters the setup through the funnel with the help of a DC powered fan attached to the funnel. First stage of cooling is Convection. The air then enters the U-shaped copper coil which is embedded in the underground bed (wet), where the air loses its heat to the copper coil by the process of convection, resulting in a drop in temperature. Second stage of cooling is Evaporation. After losing heat, the air enters a circular copper coil which is placed in a glass container filled with water partially. The coil is placed in such a way that it is just immersed or partially floats in the container. Here the air in the coil is cooled by evaporative cooling; the water in the container evaporates and forms a thin layer over the copper coil .This thin layer of water droplets further absorb the heat coming from the hot air in the copper coil and evaporates thereby leading to the chilling phenomenon of air. This process is further accelerated with the help of a DC powered fan connected to a solar panel, resulting in an additional cooling effect which further decreases the temperature of the air.• Finally, the air enters the cooling or evaporation chamber, here the air cools the container (food or beverages) by taking away the heat from it. • The above process continues till the desired temperature is achieved. The readings for the experiment are taken by varying the mass flow rate and wind speed. The mass flow rate varied by covering the funnel opening with help of different diameter caps. The wind speed has been varied by conducting the experiment on different days, by the taking the average wind speed of that day.

3.9 Parameters Considered

Here the parameters like evaporation rate, wind velocity, inlet temperature, intermediate temperature, outlet temperature and mass flow rate have been discussed.

3.9.1 Evaporation rate:

As the temperature of air increases the evaporation rate increases. The below formula has been taken from US EPA Evaporation Equation for pools.

$$\mathbf{E}=[\mathbf{7.4PA(0.447W)^{0.78}}] \div [\mathbf{T+459.67}]$$

Where:

E = Evaporation Rate (Gallons/Day)

A = Pool Surface Area (ft^2)

W = Wind Speed above Pool (mph)

P = Water's Vapor Pressure (mm/Hg) at Ambient Temperature

T = Temperature (°F)

3.9.2 Wind flow rate/ wind velocity

Wind flow speed, is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature. The flow of air can be induced through mechanical means (such as by operating an electric or manual fan) or can take place passively, as a function of pressure differentials present in the environment. Wind flow rate determines the evaporation rate which in turn affects the cooling effect in the circular copper coils.

3.9.3 Inlet temperature

The inlet temperature is the temperature of the air which enters the apparatus through the funnel to undergo drop in temperature. This temperature is basically the ambient temperature which is the measure of temperature of air in the environment surrounding the object. This temperature is affected by topography.

3.9.4 Intermediate temperature

The temperature of the air which enters the evaporation chamber after passing through the U- shaped copper coils and undergoes a change in temperature. It is the temperature of the ambient which has undergone the first stage of cooling in the wind chill system.

3.9.5 Outlet temperature:

This is the final temperature of the air in the refrigerating box. It can be defined as the final temperature of the air which has undergone both stages of cooling in the wind chill refrigerating system.

3.9.6 Mass flow rate

Mass flow rate is the amount of mass of a substance that passes through the area of the cross section taken under consideration per unit of time. Its units are kg/s respectively ($m = \rho AV$, with usual notations)

4. EXPERIMENT AND CALCULATIONS

This section deals about the experimental setup and calculations from the values obtained with the experiments conducted on wind chill refrigeration system.

4.1 Experimental set up:

The experimental setup consists of the funnel which is attached with the fan at the opening for controlling the mass flow rate of the ambient air at the inlet. The other end of the funnel is sent into the underground and is connected to the U- shaped copper coil placed underground at desired depth. This U -shaped copper coil's other end is connected to the circular copper coil which is above the ground in the evaporation chamber. The circular copper coil is placed inside the cuboidal shaped chamber on a raised platform at a height. The evaporation chamber is then filled with water such that the water comes to the level where it just makes contact with the circular copper coil making it conducive for evaporation to occur at the copper coils. This process of evaporation is further aided by placing a fan to control the wind speed over the evaporating box. The other end of the copper coil is connected to the refrigerating space through an orifice. The refrigerating box is insulated properly to prevent the loss of cool air. A temperature sensor is placed inside the refrigerating box to measure the temperature drop with respect to time. The fans present at the funnel and at the evaporation chamber are powered by a solar panel connected to DC battery separately.

Figure 8 shows the photographic view of the actual experimental setup of wind chill refrigeration system.

Fig.8. Experimental Setup.

4.2 Calculations

4.2.1 Theoretical Calculations

Heat loss due convection in copper pipe: Q_1=UA ΔT

Q_1 = Heat loss due to convection in copper pipe (W)

U = Overall heat transfer coefficient of copper (W/m^2K)

A = Area of cross-section of copper pipe (m^2)

ΔT = drop in temperature across the pipe (K)

$Q_1 = UA\ \Delta T\ =(13.1)*(\Pi/4*d^{2)}*(35-26) =13.1*\Pi/4*(12*10^{-3})^2*9 =0.013334$ W

Heat loss for an hour = Q_1*3600 = 48.003 J.

Table 1 – Theoretical Temp. drop with respect to mass flow rate

Sl.No	Mass flow rate(kg/hr)	Temperature(^{0}C)
1	0.25 m	20.276
2	0.5 m	10.138
3	0.75 m	6.758
4	1.0 m	5.069

Where m = 5.6673 kg/hr.

Table2. Theoretical Temp. drop with respect to wind speed

S.NO	WIND SPEED (kmph)	MASS FLOW RATE (kg/hr)	TEMPERATURE DROP (℃)
1	8	5.6673	2.71
2	10	5.6673	3.224
3	12	5.6673	3.716
4	14	5.6673	4.189
5	16	5.6673	4.648
6	17.7	5.6673	5.069
7	18	5.6673	5.095
8	20	5.6673	5.530
9	22	5.6673	5.957
10	24	5.6673	6.374

Heat loss due to evaporation:
$E = [7.4*P*A*(0.447*W)^{0.78}] \div [T+459.67]$ m^3/day
E = Evaporation rate (m^3/day)
W = Wind speed above water (kmph)
A = Pool surface area (m^2)

P = Water vapor pressure (m/Hg)
T = Temperature (°C)
From the weather report in Hyderabad:
Water vapor pressure = 5.828 Kpa
5.828= (ρgh) and $h = 4.368*10^{-2} m\ of\ Hg$ or $P = 43.68\ mm$ of Hg
$A = 30.5*30.5 = 930.25*10^{-4}\ m^2$
The wind speed has been taken from the Table 2 ; $W = 17.7$ kmph,, $T = 38.34\ ^{\circ}C$
$E = [7.4*P*A*(0.447*W)^{0.78}] \div [T+459.67]$
$= [7.4*43.68*10^{-3}*930.25*10^{-4}*(0.447*17.7)^{0.78}] \div [38.34+459.67]$
$= 3.0552*10^{-4}\ m^3/$; $E=1.273*10^{-5}$ m^3/hr
Mass rate of evaporation = $\rho*v = 997*1.273*10^{-5} = 0.01269$ kg/hr
Amount of heat loss due to evaporation = mL = 0.01269∗2260 = 28.683 kJ/hr

Total amount of what transferred = Q_E+Q_L = 28683+48.003 = 28731.003J = 28.73KJ
Heat lost by air = m s ΔT ; m = $\rho Av = (1.225)*\Pi/4*(0.025)^2*v$
V=$r\omega$ = 0.05∗ ; $\omega = (2\pi N) \div (60\ ) = [2*\pi*500] \div [60\ ] = 52.35$ rad/sec
Therefore V=0.05∗52.35 =2.61 m/sec
$m=1.225*\pi/4*(0.025)^2*2.61 = 0.003574$ kg/sec = 5.6673 kg/hr
$S = 1*10^3$ J/kg
Theoretical Temperature drop:
Total heat loss by air = Total heat transferred
msΔT = 28.731∗103 ;5.6673∗103∗ΔT=28.731∗103
$\Delta T \approx 5.069\ ^{o}C$
Theoretical C.O.P:
COP = (desired effect) ÷(work done)
$= (ms\Delta T) \div (VI) = [(5.67 \div 3600)*10^3*5.069] \div [5] = 1.596$

4.2.2 Practical calculations

CASE 1:

Table 3. – Time variation of temperature drop

Sl.No	Time Taken (min)	Temperature(^{0}C)
1	0	34.8
2	5	34.4
3	10	33.8
4	15	33.0
5	20	32.3
6	25	31.5
7	30	30.7
8	35	30.2
9	40	29.9
10	45	29.8
11	50	29.8

CASE 2:

Table 4. - Practical variation in temperature drop with respect to mass flow rate

Sl.No	Mass flow rate(kg/hr)	Temp. drop (^{0}C)
1	0.25	6.1
2	0.5	5.9
3	0.75	5.6
4	1.0	5.3

CASE 3:

Table 5 - Practical variation in temperature drop with respect to wind speed

Sl.no	Wind speed	Mass flow rate	Temperature drop
1	11	5.6673	3.1
2	8	5.6673	2.9
3	16	5.6673	4.2
4	10	5.6673	3.0
5	13	5.6673	3.8

Practical C.O.P:

COP = (desired effect) ÷(work done) = $[ms\Delta T]\div[V*I]$ = [(5.6673 ÷3600)$*10^3*5$]÷[5] = 1.57

The results obtained from the experiments conducted with the wind chill refrigeration system are discussed subsequently.

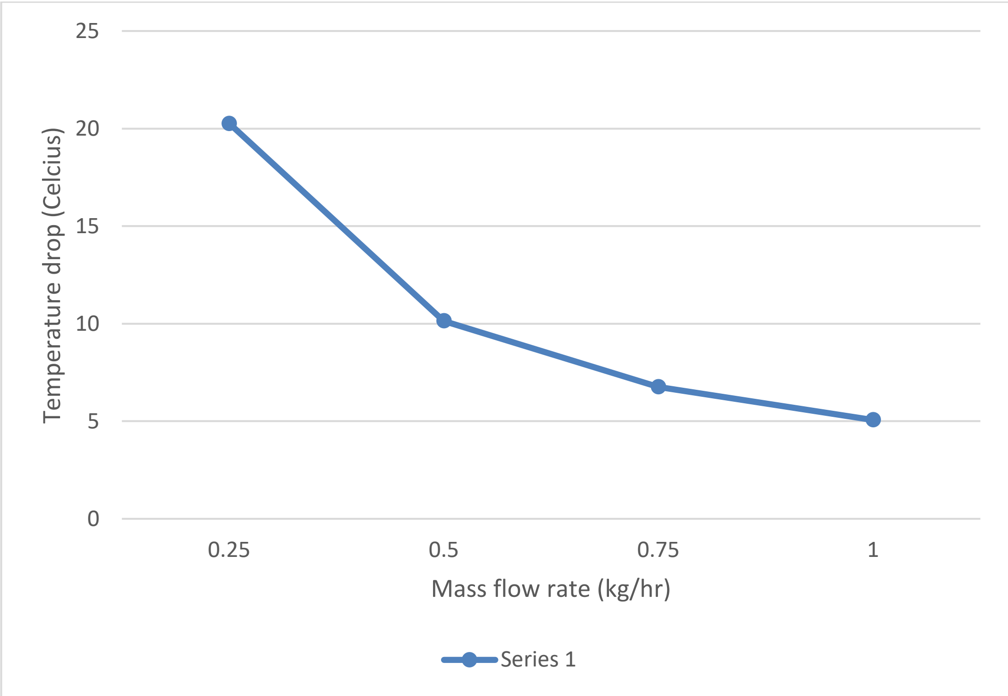
5. RESULTS

After conducting the experiment, and tabulating the results, the performance analysis of wind chill refrigeration system was classified into three cases respectively.

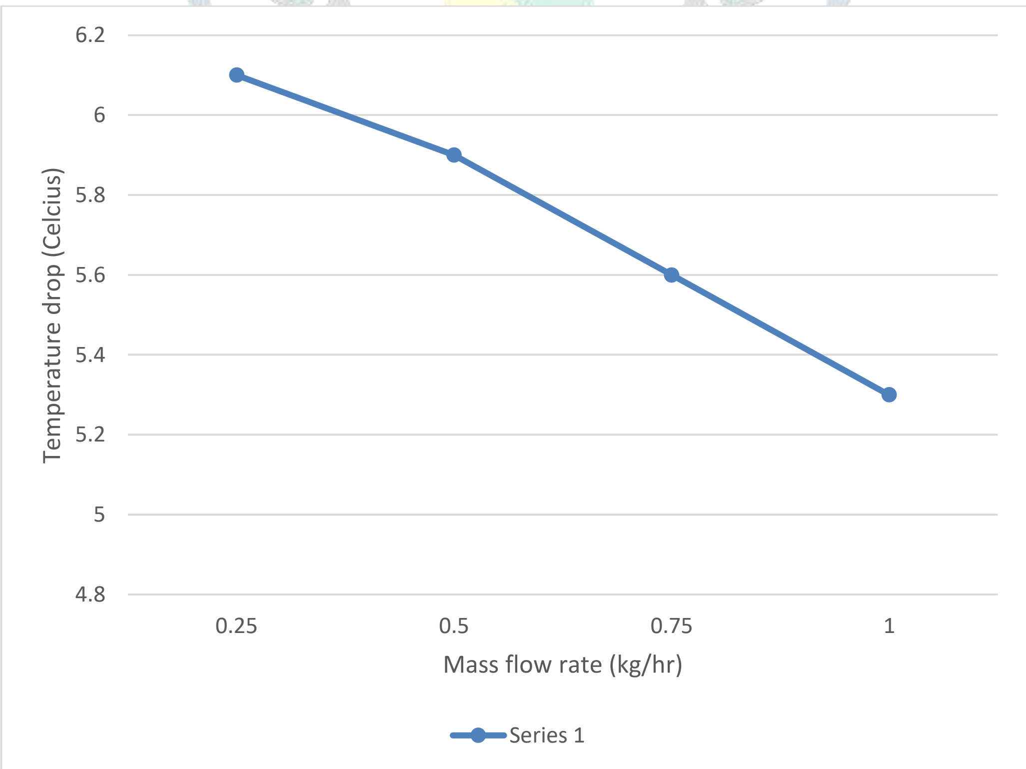
Case 1:

When the wind speed is kept constant and the mass flow rate of the system is varied by changing the area of cross section as presented in the tables 1 and 4

Graph 1 shows the theoretical variation of temperature drop with respect to mass flow rate whereas Graph 2 shows the practical variation of temperature drop with respect to mass flow rate



Graph.1 – Theoretical Variation in temperature drop with respect to mass flow rate

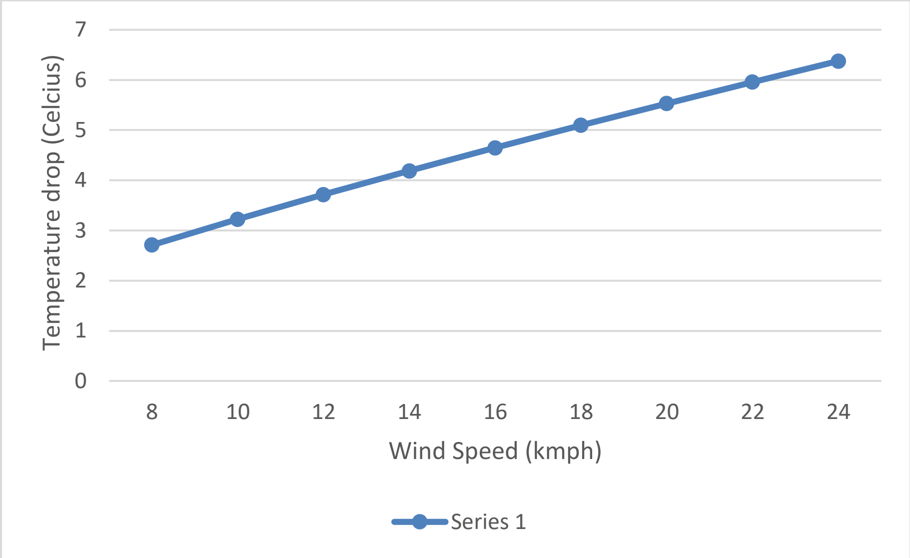


Graph .2 – Practical variation in temperature drop with respect to mass flow rate

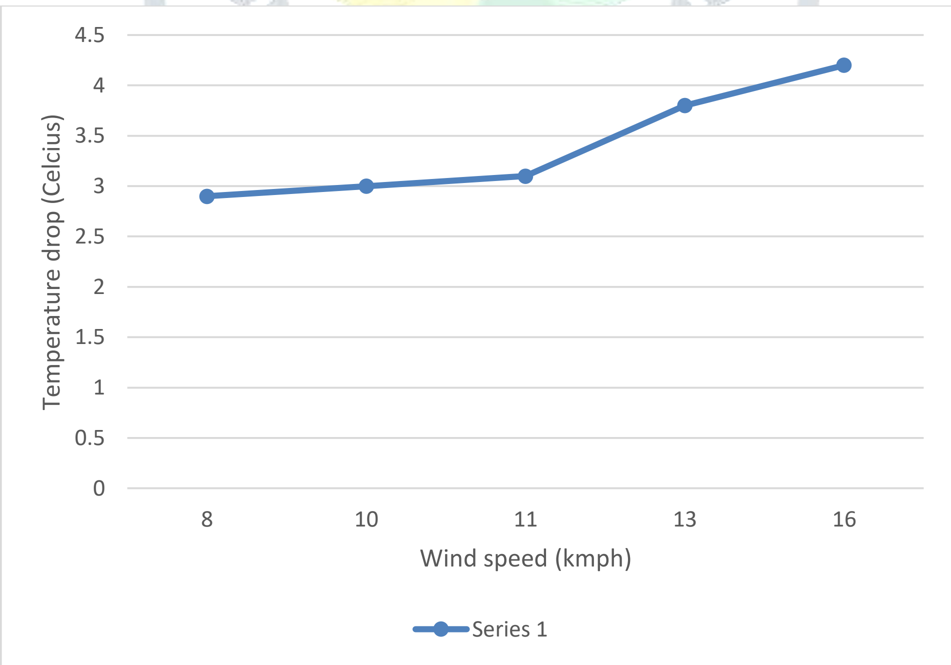
From the above graphs it is evident that with the decrease in the mass flow rate there is a small increase in the temperature drop observed. This temperature drop is since the amount of air which is to be cooled is getting reduced thereby making the drop in temperature even higher than the maximum mass flow rate case.When compared with theoretical values of varying mass flow rate at constant wind speed there is a significant difference observed ranging from 0.069 ℃ to 14.2 ℃. This difference is due to the fact that the time of contact of air with the copper coil is not enough for obtaining the theoretical temperature drop and also in real atmospheric conditions wind speed always changes its pace rather than remaining constant and this phenomenon significantly impacts the evaporation rate leading to the lower drop in temperature in experimental readings.

Case 2:

When mass flow rate is kept constant at m=5.6673 kg/hr and the wind speed is kept varying by performing the experiment on different days over a period. (refer table 2 and 5).Graph 3 shows the theoretical variation of temperature drop with respect to wind speed and Graph 4 shows the practical variation of temperature drop with respect to wind speed.



Graph 3 – Theoretical Variation of temperature drop with respect to wind speed



Graph 4 – Practical variation in temperature drop with respect to wind speed

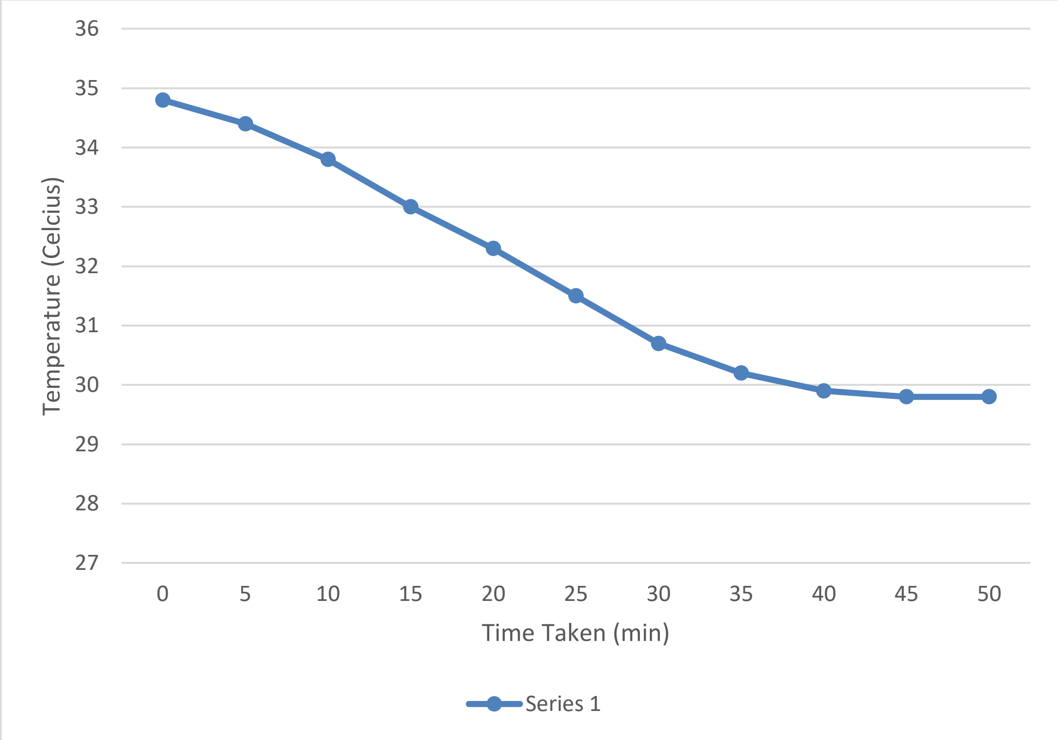
The above graphs depict the variation in temperature drop with different wind speeds. From the graph it can be inferred that the drop in temperature is directly proportional to the wind speed. This is because with the increase in the wind speed, the rate of evaporation is increased leading to more heat loss in the air in pipes ultimately causing the increased drop in temperature, respectively.

When the experimental readings are compared with the theoretical values, it has been observed there is small difference in between them. This difference is since as in theory where the wind speed is kept constant, it is slightly difficult to maintain the wind speed constant over a long period of time. Hence, there is a small temperature difference observed between the theoretical and experimental readings.

Case 3:

The drop in temperature with respect to time. The wind speed is noted to be 17.7 kmph and the mass flow rate is kept m=5.6673kg/hr respectively. The experiment is conducted, and the readings are noted down in the table 3.

Graph 5 shows the variation of temperature drop with respect to time.



Graph 5 – Time variation of temperature drop

From the above graph, it can be inferred that the initial drop in temperature with respect to time is higher than compared with the latter values. This is due to the fact that the temperature difference between the copper pipes and the air is more in the beginning of the experiment than in the latter stages. As the time goes on the temperature drop in the system comes down to zero indicating that the system has attained steady state. The initial temperature obtained is 34.8^0C.The final temperature obtained is 29.8^0C.

6. CONCLUSIONS

The following conclusions were drawn after developing the prototype and conducting studies by varying different parameters as discussed.

1) The highest theoretical temperature drop in each case is 1) 20.3℃, 2) 6.4℃ and 3) 5.1℃.
2) The highest practical temperature drop in each case is 1)6.1℃ 2)4.2℃ 3)5℃.
3) It has been observed that the difference between theoretical and practical values is due to the fact that many climatic factors like relative humidity, wind speed of air, rate of evaporation are assumed to be constant. These factors are always changing from time to time and from location to location.
4) It has been concluded from the experiment that the temperature drop of the air is directly proportional to the wind speed in the surroundings.
5) It has been concluded that with decrease in the mass rate of flow there is an increase in temperature drop. As there is less quantity of air is to be refrigerated, leading to a higher temperature drop.
6) As the experiment was conducted with a miniaturised version of the original setup the drop in temperature was also observed to be proportionally less. If the scale of the apparatus increases correspondingly there is an increase in the temperature drop.
7) By performing subsequent research/studies in the design and fabrication parts we can obtain the necessary temperature drop while maintaining the compact size of the equipment.

7. FUTURE SCOPE OF WORK

. One of the potential areas of research in the field of refrigeration is Bio-mimicking which 100% eco-friendly in functioning. The design of wind chill refrigeration is only suitable when the size of the apparatus is large. Therefore, changes should be done in the design aspect of the apparatus such that the process of evaporation and convection are maximized, at the same time making the apparatus compact such that it can be used to refrigerate spaces which aren't easily accessible. The wind chill apparatus can be upgraded by changing the copper tubes with materials having higher thermal conductivity and diffusivities keeping in view the structural strength. Finally, the wind chill refrigerating system can be automated by using sensors which monitor the temperature drop, the mass rate of flows and can vary them automatically according to the user's needs for the refrigerating space.

8. REFEENCES.

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