DESIGN AND MANUFACTURING OF A CYLINDRICAL REFRIGERATOR

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Abstract - The requirement of refrigeration effect in today's developing world is growing exponentially, enhancing the diversity of cooling applications and their usage. We need an efficient and optimized design to counter the increased rate of CO2 emissions, which leads to global warming. A refrigerator is an appliance used to transfer the heat from its thermally insulated compartment to the external environment. It uses a heat pump to keep the inside temperature lower than the ambient temperature. There is a requirement for continual innovations in the science of refrigeration to make it more efficient. This paper discusses the design and manufacturing of a cylindrical refrigerator with rotating shelves. This design proves to be more efficient in terms of the percentage of useful volume by up to 19.94%. It equips the design with unique features that can improve the refrigerator's efficiency and prove to be more convenient in usage. The model also comprises a bottom-mounted freezer that can enhance its performance compared to the top freezer of conventional design. There is a lot of potential in future developments in this design, which will enhance the vapour compression refrigeration techniques and their use in cooling applications by implementing the optimized design.

Keywords: Cylindrical refrigerator, cooling, design, refrigerator, useful volume

1. INTRODUCTION

The global usage and the requirement of refrigerator cooling techniques have become the fundamental commercial need. They are widely used in domestic households, industries, restaurants and have been a part of many cooling applications. A refrigerator is a thermally insulated compartment which transfers the heat from its inside to the outer atmosphere to keep its temperature lower than the atmospheric temperature. The major components of a refrigerator are a compressor, an evaporator, a condenser and an expansion valve. A domestic refrigerator works on a vapour compression refrigeration cycle. It uses a refrigerant fluid to exchange the heat. A simple Vapour Compression Refrigeration cycle is a theoretical cycle and differs in performance and efficiency from an actual cycle. Sruthi Emani et al. [1] reviewed the refrigerants from different generations that have used in refrigeration techniques and also focusses on the next generation refrigerants that have been eco-friendly because of their less GWP. A simple vapour compression refrigeration cycle comprises four significant steps. In step 1, the low-temperature and low-pressure refrigerant enter the compressor in a gaseous state. The compressor of the refrigerator compresses the refrigerant into high temperature and high-pressure fluid. In step 2, this high-temperature and high-pressure refrigerant enter the condenser, which is a heat exchanger, and the refrigerant gives its heat. In step 3, the coolant expands and releases pressure after passing through an expansion valve which decreases its temperature. The refrigerant leaves the expansion valve in a mixture of liquid and vapour phase. In the last step of the cycle, the refrigerant is at a temperature lower than atmospheric temperature, and it evaporates and absorbs the latent heat of vaporisation and heat extraction takes place at low-temperature and pressure. A lot of experiments have been performed by evaluating the different criteria that can be varied to achieve a more optimized and efficient vapour compression refrigeration system. Hoseyn Sayyaadi et al. [2] investigated optimisation criteria for a cooling tower assisted vapour compression refrigeration system. For multi-stage optimisation of vapour compression refrigeration system with various refrigerant effects, Saleh S. Baakeem et al. [3] performs an investigation using energy, exergy and economic analysis as crucial parameters. The mechanical performance for the vapour compression refrigeration system is measured by the Coefficient of Performance (COP) which is calculated by the ratio between the net refrigeration effect to the external work done (electrical energy):

$$COP = \frac{Unit\ Refrigeration\ Capacity\ (Desired\ Effect)}{Net\ Power\ Input} = \frac{Q_e}{W}$$

The COP magnitude is a parameter which is used to compare the efficiency and effectiveness of a refrigerator. Mustafa M. Kadhim [4] investigated that the COP of a refrigerator can be increase by introducing the heat recovery unit in the system. The relative efficiency can be calculated by dividing the COP of the simple refrigeration cycle to that of the COP of the Carnot cycle.

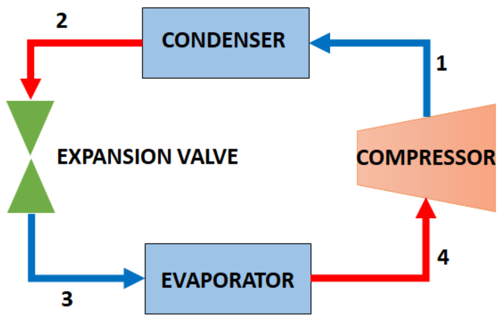

Figure 1: Schematic diagram of a Vapour Compression Refrigeration Cycle

Refrigerator technology has developed in terms of its energy efficiency and COP. Also, the GWP-weighted production of CFC's, HFC's and HCFC's has decreased by 90% between 1988 and 2005 following the Montreal Protocol. James M. Calm [5] analysed the impact of refrigeration systems on emissions and the environment. It shows that a decrease in GWP and ODP of a refrigeration system increases its energy demands because of reduced performance which will lead to an increase in CO2 emissions. Therefore, an existing refrigeration system design requires a balance in its performance and emission criteria. Adriana Greco et al. [6] investigated the reductions of greenhouse gases emissions in refrigerators. In this developing economy, energy demands in the refrigeration and cooling systems application alone are nearly about 20%. HFC's have advantages in terms of their energy and performance but affects the GWP magnitude profoundly. Therefore, a mixture of HFC's, and HFO's will decrease the fluorine emissions and recommended for future applications. The cylindrical design of a refrigerator enhances the compartment useful volume compared to a conventional refrigerator. The model comprises revolving shelves that can freely rotate on their axis. It refines the usability of the fridge. The design also optimises the efficiency for the freezer by placing it at the bottom, which will increase the mechanical energy. CAD software SolidWorks is used in constructing the design. The design has a fibreglass sliding door which will move on the circumference of the body and save the door opening space. The paper discusses the component and manufacturing details of the refrigerator. Though vapour compression refrigeration technology is used from the past 200 years commercially, it requires further innovations and development in its technique to generate a more efficient cooling effect by considering energy consumption, COP, environmental emission and ODP as the factors for future improvements.

2. LITERATURE REVIEW

Nishikant Z. Adkane et al. [7] perform a comparison between air-cooled and water-cooled condenser refrigerator. By considering COP, heat extraction rate and refrigeration effect as the factors for comparative study, they investigated that the COP of a refrigerator equipped with a water-cooled condenser has increased between 55% to 86%. Also, the refrigeration effect and heat extraction rate in the water-cooled condenser system has enhanced at the 40-watt condition. It represented the experimental results in the form of time vs parameter graphs. The study concludes that the refrigerator equipped with a water-cooled condenser will enhance the performance parameters and thus increases the overall efficiency of the fridge.

Hakan DEMIR [8] investigated the method to calculate the optimum thickness distribution of thermal insulation material for a domestic refrigerator by considering various parameters that can vary the performance and results. The investigation includes the consideration of the effect of convection heat transfer coefficients, temperature differences and run-time ratio. This investigated method eliminates the need for an iterative process for the same calculations. Determination of an optimum insulation thickness proves to be more economical by reduction of about 2.2% in electricity consumption.

Reddy Mula et al. [9] performs an experimental analysis to enhance the COP of a refrigerator in a vapour compression refrigeration cycle. The experiment focuses on improving the COP by decreasing the compressor work. The research considers the mass flow rate of the refrigerant, the suction pressure of the compressor delivery pressure of compressor and temperature of evaporator and condenser as the factors for analysis. Further, they introduced a diffuser in between compressor and condenser to reduce the power output and hence enhances the COP. This arrangement increases the COP by 31%. They used CFD simulations for result validation.

Balakrishnan P. et al. [10] investigated that the COP, Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) improves by using an eco-friendly refrigerant instead of using R134a. The refrigerant used for the experiment is a mixture of hydrocarbon refrigerants, i.e. R32/R600a/R290 in the ratio of 70:5:25. They made plots of COP vs time between R134a and the eco-friendly refrigerant while performing the refrigerator at half loading, full loading and loading ON condition. Using the mixture at unloading ON and loading ON condition improves the COP and mass flow rate. Also, it improves the GWP of the mixed refrigerant.

Devidas Matkar et al. [11] investigated that the use of a vertical evaporator refrigerator equipped with R600a refrigerant compressor proves to consume 7-8% less energy in comparison with an upright evaporator refrigerator with R134a as a refrigerant. Also, the usable space of the fridge increased by ~25% by converting the existing freezer into refrigerator space with the help of roll bond vertical evaporator. The experiment analysis proves that the overall refrigerator compartment's 6th-hour temperature of R600a R190L 170CC upright evaporator refrigerator is colder than the R134a refrigerator. Also, the mean shift in the vertical evaporator refrigerator compartment temperature is -14.7 to -4.4 ^{0}C. This refrigerator proves to be 7-8% more energy efficient than the conventional R134a refrigerator.

Kuie Tien Lin et al. [12] performs a study on bottom-mounted freezer refrigerator. They performed numerical computational simulations to calculate effectively the variables like temperature, air velocity, etc. using SolidWorks. The research shows that by reducing the thermal leakage of the refrigerator, the high operation ratio of the compressor can be improved. An estimated increase of 10mm in the thickness of insulation can save 11.25% of energy. Also, the simulation model of no glass shelves in the compartment proves to be more acceptable. The model enhances the effect of temperature stratification in fresh FSC and decreases the volume flow rate of air circulation.

Mohit Kumar Agarwal et al. [13] investigated the optimisation techniques for a refrigerator using improved cylindrical design and manufacturing. The design comprises the implementation of adjustable shelves which can change heights of the compartment. The proposed design enhances the efficiency of the vapour compression refrigerator by increasing the total overall useful volume compared to the conventional refrigerator. This design saves space and energy. There is a total increase of 12.84% and 2.78% in aggregate and useful volume in this design of the refrigerator. Also, the model saves about 2340.5% of volume in accessing the door.

Rajeev Satsangi et al. [14] reviewed the refrigerants to substitute R134a refrigerant by discussing various chemical and physical properties. The alternative refrigerants considered are CO2, HFC-152a, HFO-1234yf, ammonia and super freeze 134a. The parameters considered for this review were the boiling point, molecular weight, Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). The research established that because of high fluorine content in R134a refrigerant, its GWP is high, which affects global warming. Hydrocarbons and CO2 may enhance future refrigeration processes because of their less GWP and ODP.

3. MATERIAL AND COMPONENTS

The material and components used for the manufacturing of the cylindrical refrigerator are:

Material- Stainless Steel is the primary material used for the construction of the body; sheet thickness - 24 gauge
Refrigerant: R134-a is used as a refrigerant in this model.
Major Components:

Compressor- A compressor is a device which sucks the low pressure and low-temperature refrigerant from the evaporator and compresses the refrigerant to increases the temperature and pressure of the refrigerant. We have used LG MA88LJEM for the manufacturing.

Table 1: Technical specifications of the compressor

Input wattage	212.5 W
Voltage	220-240 V/50 Hz
Power	227 W
Cooling capacity	1/3+ (HP)
COP	1.2
Displacement	8.8 cc

Condenser- The condenser or the cooler consists of coils of pipe in which the high pressure & temperature vapour refrigerant is cooled & condensed. The refrigerant while passing through the condenser, rejects its latent heat to surrounding condensing medium which is usually air or water. Thus, hot refrigerant vapour received from the compressor is converted into liquid form in a condenser. We have used a two-row multi-channel condenser for this purpose.

Evaporator- An evaporator consists of coils of pipes in which the liquid-vapour refrigerant at low pressure and temperature evaporates & extracts heat and then changes into vapour refrigerant at high-pressure and high temperature. During the evaporation process, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium which is to be cooled. We have used a copper tube of 5/16 gauge of approximately 50ft for the evaporator coiling.

Expansion Valve- Expansion Valve is a throttle valve that expands the refrigerant, which decreases its temperature and pressure. It changes the refrigerant into the vapour phase and controls the pressure difference in the circuit.

Other Components:
Receiver: The condensed liquid refrigerant from the condenser is stored in a vessel, known as a receiver, from

where it is supplied to the expansion valve or refrigerant control valve.

Condenser fan: Enhances the heat exchange rate in a condenser. It is located near the condenser, and its rpm is normal to 200.

Circulating fan: Helps in circulating air in the refrigerator so the uniform cooling effect will be generated.

Bearings: We have used 18 ball bearings of Spin Bearings (6004ZZ).

Thermostat: A thermostat is an electronic device that maintains the temperature inside a refrigerator. It has a knob through which we can adjust the desired temperature. When the desired temperature is achieved, the thermostat cuts the compressor's electricity supply, and when the heat increases, it allows electricity to flow. We have used 1.5 ft of a copper tube of 1/4 gauge for thermostat coil.

Motor: A Cool-Flow copper quiet motor of 1/35HP is used to make the condenser effective.

Glass: We have constructed three circular glass shelve of thickness roughly 6 mm.

Insulation, fibreglass and wiring: We have used polystyrene for insulation, fibreglass for constructing the door and wiring for the circuits.

4. DESIGN AND VOLUME CALCULATION

The 2-Dimensional drawing of the model is sketched using Autodesk AutoCAD software. The model consists of a total of four compartments in which, the bottom most compartment is utilised to fulfil the requirement of freezer. All the four compartments are separated by using circular glass sleeves which can rotate 360^0 supported by ball bearings which are mounted on the inner circumference of the body. The design is equipped with a sliding door mechanism to access the refrigerated space. The electric circuit is fitted inside the stand cavity at the bottom most section. The figure below represents the schematic of the design and dimensions of a cylindrical refrigerator. The dimensions represented in the figure is in centi-meter unit.

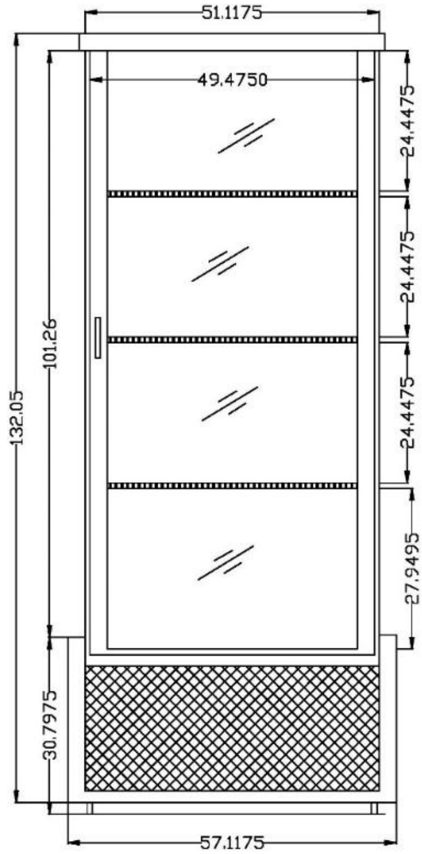

Figure 2: Schematic of the cylindrical refrigerator (dimensions in cm)

Calculation of areas and volume by considering the above dimensions of the model is shown in table 2.

Table 2: Dimensions and calculation of areas and volume

Top Body Radius	255.5 mm
Height	1320.5 mm
Base Radius	285.58 mm
Whole Body Volume	286367290 mm^3 = 286.36 L
Area of Top	204979.985 mm^2
Area of Base	256085.640 mm^2
Curved Surface Area of body	2176803.2 mm^2
Total Surface Area of body	2637868.82 mm^2

5. MANUFACTURING METHODOLOGY

The manufacturing of the proposed design is completed in five steps consists of the making of body, fitting electric circuit arrangement, and testing the final model. The fabrication includes and requires the implementation of different workshops and manufacturing technologies like electron beam welding, sheet metal cutting operations, machining, metal casting, and thermal testing to determine the number of coils turns for the evaporator. The methodology followed-

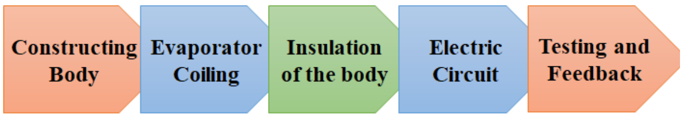

Figure 3: Manufacturing methodology

1. Constructing the body: Stainless Steel is used for manufacturing the outer shape of the refrigerator. Sheet metal cutting operation was performed on a 24-gauge sheet with a weight of 433 gm for 1 square foot. The total sheet used approximately equals to 50 feet. The hydraulic die is used for constructing the desired cylindrical shape with the designed dimensions. The sliding door slot is specially designed to fit the door further. For the implementation of 360^0 revolving sleeves, 18 ball bearings are installed inside to compartment at their designated positions, which divides the refrigerator into four compartments. Six ball bearings support each glass sleeve. The above three compartments are used as a standard cooling space, and the bottom chamber will serve the purpose of the freezer.
2. Evaporator coiling: A copper tube of 5/16 gauge of approximately 50ft is used for the evaporator coiling. The number of turns for the above three standard cooling compartments is one which will create a temperature of 10^0 C in each compartment, and the number of turns for the bottom chamber is six, which will create a temperature of -10^0 C and serve the purpose of the freezer. The one end of the evaporator coil is connected to the compressor inlet, and the other end is connected to the throttle valve outlet.
3. Insulating the body: The layer polystyrene material is used for thermal insulation of the evaporator coil and the refrigerator body. Also, the thermal paste is used in the coiling and insulation process. The final insulation layer is made, which covers the whole body and prevents any thermal leakage.
4. Electric circuit: The electrical circuit consists of the compressor, condenser, expansion valve, evaporator, condenser motor, thermostat, condenser fan, and the lighting arrangement for the refrigerator. A thermostat knob is provided through which the temperature inside the fridge can be controlled. An electromagnetic relay serves to connect auxiliary winding on the start and disconnect it when the motor picks up the speed. Thermal overload release is joined in the circuit to prevent the motor from drawing heavy currents. A voltage regulator must be used to avoid the motor from under-voltage.

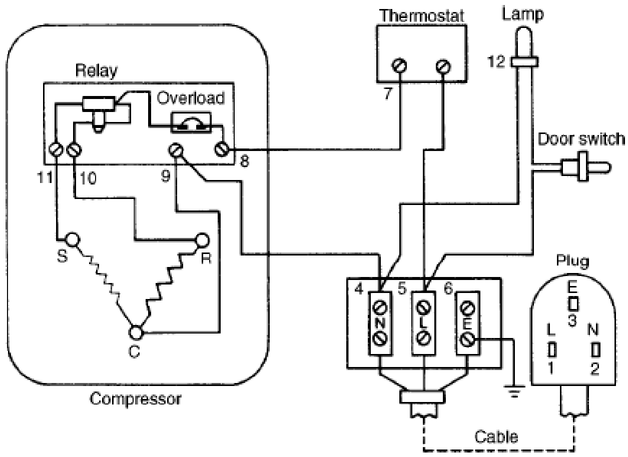

Figure 4: Electric circuit [15]

5. Testing and feedback: The electric circuit is checked for any faults in the connections. The temperature indicator sensors were used to check whether every refrigerator compartment attains the desired temperatures. The ice formation for the freezer chamber is tested, and slight adjustments in the thermostat variables were performed to calibrate with desired results. The temperature measurements were recorded to test the proper functionality of the refrigerator.

Figure 5: Steps of manufacturing

6. COST ESTIMATION

The following table provides the approximate cost distribution (in) of the manufacturing. The machine components along with their costs are listed below.

Table 3: Cost Estimation

S. No	Component	Cost (in ₹) approx.
1	Stainless steel	5000
2	Compressor	3000
3	Condenser	1200
4	Evaporator	1000
5	Insulation	1000
6	Ball bearing*18	1000
7	Fibre glass	1000
8	Stand	1000
9	Temp. indicator	500
10	Fan	800
11	Fabric sheet	1500
12	Bulb	300
13	Refrigerants	800
14	Shelves*3	2000
15	Motor	1000
16	Wiring	1000
17	Thermostat	1000
18	Installation	2000
19	Expansion valve	2000
	TOTAL	**27000**

7. COMPARISON FOR USEFUL VOLUME

The main objective of this design is to increase the total effective useful volume. The cylindrical design proves to more efficient in terms of the % useful volume compared to the conventional rectangular design. Considering the dimensions of the proposed design and the conventional design, the whole-body volume and useful volume is calculated in the following table-

Table 4: Comparison of useful volume for cylindrical and conventional refrigerator

	Cylindrical Refrigerator	**Conventional Refrigerator (LG GL-B201APZY) (1172 x 633 x 534) mm**
Body Volume	286367290 mm^3 = 286.36 L	396161784 mm^3 = 396.16 L
Usable Compartment Volume	194453517 mm^3 = 194.45 L	190 L
% of Useful Volume	67.90%	47.96%
Difference	**19.94%**	
Decrease in % whole body volume of cylindrical refrigerator compared to the conventional design	**27.71%**	

The useful volume percentage in the cylindrical design is 19.94% more than the conventional design. An increase in useful volume makes the design more efficient in terms of space-saving and decreases the overall weight of the appliance for the same effective capacity. The design also saves about an area of 49062.5 mm^2 while accessing the door. Thus, the manufacturing and production of a cylindrical refrigerator becomes easy and uses less material than a conventional rectangular fridge.

8. ADVANTAGES OF THE DESIGN

Cylindrical Body:

Cylindrical body design has many advantages compared to the conventional rectangular design. The design saves about 19.94% in useful refrigerator volume. Also, the design can be easily manufactured, requiring less material, and implementing less manufacturing technology. The design proves to be lighter in weight compared to a conventional fridge. The design is more optimized, considering the % of active area for the same volume and size. Because of lesser joining corner points, the possibility of cracks, wear & tear has dramatically reduced. The compartments of this refrigerator give the user the flexibility to decide the number of compartments. The glass shelves can be removed entirely to adjust the individual compartment capacity and volume of the refrigerator. This design proves to be 27.71% more efficient in terms of total occupied volume for the same useful volume.

Bottom Freezer:

A bottom freezer can be more efficient and convenient to implement compared to the top freezer approach. A bottom freezer design has both mechanical and ergonomic advantages. As the warm air rises, it is best to keep the coldest items at the bottom of the appliance. In the conventional design, the warmer air from the bottom standard cooling compartments rises and affects the working efficiency of the freezer mounted at the top of the appliance. Thus, the machine will need to work more to overcome to maintain the optimum desired freezer temperature. By implementing the bottom freezer approach, this problem can be easily tackled as the warm air will rise above, creating no interference in the freezer efficiency. This design proves to be more convenient in terms of ergonomic perspective. The amount of freezer usage and accessibility is less compared to the standard cooling area. Therefore, it is best to keep it at the bottom so that the refrigerator cooling space can be easily accessible to the user because its position will be at the eye and chest level.

Rotating Glass Shelves:

In the conventional rigid compartment platform (shelve) design, the user often faces the problem in accessing the items kept at the back of the compartment. With the modified design, the shelves can now rotate 360^0, enabling the user to easily access any item by moving the shelve towards the front position. The shelves are supported by ball bearings that help in the movement of the shelves. This design enhances the ergonomic perspective of the design by consuming no extra energy for this purpose. Rotating glass shelves also enhances the attractiveness of the machine.

Sliding Glass Door:

The purpose of implementing a sliding door in the design is to optimize the space requirement while accessing the refrigerator. This design saves about an area of 49062.5 mm2 while accessing the door. The design also enables the user to see through the door, which somehow decreases the number of door openings, increasing energy efficiency, and making the design more attractive. The door slides into the specially constructed slot in the cylinder body itself, eliminating any additional requirement of space while opening. It is equipped with a switch for lighting purposes that turns ON the light while opening.

9. CONCLUSION

The cylindrical body design proves to be efficient in many parameters compared to the conventional design. The adjustable and rotating shelves prove to enhance the flexibility and ergonomic convenience for the user. The appliance body occupies less storage space for the same amount of refrigerator capacity compared to a conventional rectangular shape. The total useful volume is increased by 19.94%, and the decrease in % whole body volume of cylindrical refrigerator compared to the conventional design is 27.71%. The sliding door design saves about an area of 49062.5 mm^2 while accessing the door. Also, the bottom freezer approach enhances the efficiency of the freezer and decreases the compressor work of the machine. The implementation of cylindrical design for cooling appliances will ease the production process and will use lesser manufacturing technologies. Also, it saves the total amount of material to be used for manufacturing, decreasing the overall weight of the machine. This design proves to be a refinement factor in terms of efficiency and ergonomic parameters. The requirement for vapour compression refrigeration techniques is estimated to be increased exponentially in the future, considering the innovations in the state-of-the-art cooling and heating applications. The necessity to refine the vapour compression refrigeration systems will surely challenge the researches in the future to better optimize the modern cooling systems for lesser emissions and global warming perspectives. Also, the need to enhance the energy consumption in these systems is always a factor of continual consideration. Future work towards the direction of newly optimized design for a refrigerator is an engaging topic for researches, and many developments in sophisticated systems considering the implementation of electronic sensors and actuators in cooling systems will hopefully further refines these cooling systems.

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