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Fuel Saving and Energy Efficiency in the Aviation Catering Systems Using Phase Change Materials (PCMs)

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Abstract : This study investigates the application of Phase Change Materials (PCMs) for enhancing fuel efficiency and energy management in aviation catering systems. Recognizing the challenges posed by conventional heating and cooling methods in aircraft, we explored the use of polymeric and composite PCMs as sustainable alternatives. A series of experimental tests were conducted on a standard aircraft trolley, simulating in-flight conditions, to evaluate the thermal performance of PCMs for both cooling and heating applications. Results demonstrated that PCMs maintained optimal food storage temperatures more effectively and for longer durations compared to traditional dry ice and mechanical chillers, achieving cooling periods of over 7 hours and heating above 60 °C for over 6 hours. Implementing PCM technology offers multiple benefits, including significant weight reduction, lower marginal fuel burn, decreased greenhouse gas emissions, and enhanced operational efficiency. The findings support the feasibility of adopting PCMs in aviation catering logistics, promising economic advantages and environmental sustainability. Further work on full economic feasibility analysis is underway.
Keywords: PCM , cooling period , heat storage ,TES

I. INTRODUCTION

The demand for energy has risen exponentially. Energy consumption defines the economic wealth and technological affordability of countries. Yet remains a huge gap between the energy supply and the energy demand worldwide. This is due to the population growth, urbanization and progressing economies. To conserve energy, reduce dependency on fossil fuels, and lower greenhouse gas emissions, it is crucial to develop efficient and cost-effective energy storage systems [1]. Energy storage can significantly reduce total energy consumption, especially when integrated with sustainable energy sources such as wind and solar power. Thermal energy storage (TES) has become very popular now in different engineering applications. The thermal energy storage is divided to three categories:

- Sensible heat storage which is a single phase -heating or cooling- energy storage. This type of energy storage is limited to some applications due to the requirement of high volume and small temperature range.
- Latent heat energy storage which includes a two-phase melting and solidification thermal energy storage. Latent heat energy storage exceeds the use of other energy storage systems due to high density thermal storage and nearly isothermal phase change.
- Thermochemical heat storage that relies on reversible chemical interaction between reactive components.

Phase change materials are used in thermal energy storage systems to absorb energy from the source when available and release them to the sink when required. A wide variety of PCM materials has been identified and extensive studies have been conducted on this topic. They have been utilized for building construction materials such as wood [2], concrete [3], for building energy efficiency and comfort condition attainment, in electrical appliances like household refrigerators [4] and freezers [5] for efficiency enhancement, thermal management of lithium-ion batteries [6] and solar panel cooling system [7]. Phase change materials can be classified into three categories as organic PCMs (paraffine wax and fatty acids), inorganic PCMs (salt hydrates and metallic) and eutectic which is a combination of both. Figure 1 shows the classification of PCMs for latent heat storage [8].

1.1 Properties of PCM

Depending on the application requirements, it's very important to select the PCM with the suitable properties to achieve the best results in latent heat storage. PCMs show different thermophysical, kinetic and chemical properties. In addition, economic properties are to be taken into consideration for the feasibility of the process and optimal outcomes.

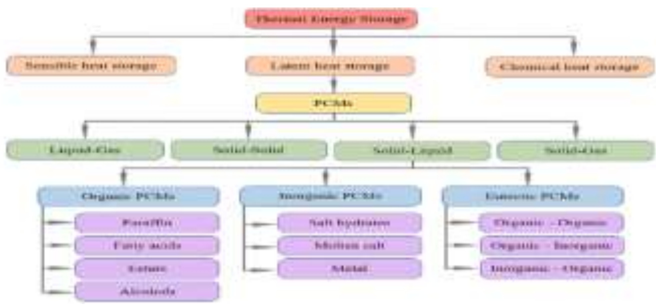

Figure (1): Phase change material classification [8]

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Table 1 lists the thermal properties of different organic and inorganic PCMs at moderate phase transition temperature [9].

1.2 Catering in Aircrafts

Aircraft operator services include catering service for passengers in flight. The catering service undergoes periodic quality and safety assessment by different organizations including the national and international civil aviation authorities. At the same time, food and catering service is an important asset for the airline income and brand advertising. To boost sales, airlines compete in offering the best food service in terms of quality, taste aesthetics.

Maintaining food and beverages at optimal storage temperature stops harmful bacteria from growing. In addition, food and beverages need to be served at a certain range of temperatures to enhance the service and taste. The civil aviation authorities mandate that food should be kept at safe temperatures. Safe temperature in food industries is defined as any temperature beyond the band of danger which is 6-10 °C. Foods between 10 °C to 60 °C set the optimal condition for bad bacteria growth. By minimizing the period that food stays in this temperature band food can be safely maintained.

As a rule, cold food should be kept below 10 °C and hot food on the other hand should be kept at 60 °C [10]. The chilling and heating of food in aircraft is carried out conventionally by use of electrical-mechanical devices which use electricity generated by aircraft engines (Fig. 2).

Table (1): Ranges of Thermal properties for the organic and inorganic PCMs [9]

Property	Organic Paraffin	Organic Non-Paraffin	Inorganic Salt Hydrate	Inorganic Metal Eutectic
h_f (kJ/kg)	230 - 290	120 - 240	170 - 340	30 - 90
h_{fv} ([J/m^3] x 10^6)	190 - 240	140 - 430	250 - 660	300 - 800
ρ (kg/m^3)	~ 810	900 - 1800	900 - 2200	~ 8000
k(W/m°C)	~ 0.25	~ 0.2	0.6 - 1.2	~ 20
Thermal Expansion	High	Moderate	Low	Low
Congruent Melt	Yes	Some Do	Most Do Not	Yes
Supercool	No	No	Most Do	No
Corrosion	Low	Some Are	Highly	Some Are
Toxicity	No	Some Are	Highly	Some Are

Currently, airlines use both mechanical cooling chiller and dry ice. The mechanical cooling chiller is optional, so the dry ice is used in the event of inoperative chiller, or no chiller installed. Dry ice is a type of phase change material used to cool food in aircraft. Thus, precooling of any other alternative phase change material can be planned and carried out similarly to dry ice.

1.3 Phase change materials in logistics

Phase change materials are one of best candidates for cold chain logistics. They can maintain the food temperature at a certain value during transportation period to prevent spoilage of the materials. Liu et al. [11] utilized the preparation and stability analysis of water-based organic PCMs, with a melting temperature range of -4°C to -6°C, modified with potassium sorbate for cold chain logistics. Static stability of a mixture of glycerin and mannitol aqueous solution as a PCM has been improved with adding 0.1 wt% of potassium sorbate. For the optimum values of 6 wt.% glycine, 1.5 wt.% mannitol, and 0.1 wt.% of potassium sorbate the thermal conductivity, melting temperature and heating density of the produced PCM were 0.6017 W/m K, -5.78 °C and 292.64 kJ/kg respectively.

Figure (2): An aircraft trolley [12]

The results after 100 thermal cycles the thermal conductivity, melting temperature, and enthalpy of fusion were 0.5886 W/m K, -5.91 °C, and 290.66 kJ/kg, which proves an acceptable thermal cyclic stability of the PCM and can be used for pre-cooling and short distance cold chain transportation of the perishable foods.

A low temperature mixture two of PCMs containing decyl alcohol and lauric acid with added expanded graphite as thermal conductivity enhancer and melting temperature of 2-8 °C has been produced by vacuum adsorption method by Liu et al. [13] and used for vaccine cold chain logistics. The phase transition temperature, heating density, and thermal conductivity of the PCM have been measured and reported as 2.08 °C, 1.7527 W/m K, and 188.71 kJ/kg respectively. The measured parameters after 500 thermal cycles also proves the thermal stability of the samples.

Stereotyped PCMs consisting of caprylic acid and lauryl alcohol suitable for cold chain logistics have been prepared and modeled by Xu et al. [10] in which expanded graphite has been added for thermal conductivity enhancement. The melting point thermal conductivity and heating density of the composite PCMs have been reported to be -0.7 °C, 1.411 W/m K, and 170.4 kJ/kg respectively. Adding 8% of expanded graphite to the composite PCMs could decrease the mass lose rate up to 7.73% which shows that it could prevent the leakage of PCMs.

Application and optimization of portable PCM-based storage system for cold chain logistic systems using four water, potassium sorbate, tetradecane + docosane, (PCMs and tetradecane) with melting point in the range of -2.5 to 2.5 °C and latent heat of 214 to 334 kJ/kg in three layouts have been

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evaluated and reported by Burgess et al. [14]. They exprimental and analytical results reveal that the best PCM layout to enhance the threshold time was performed with 2 kg of PCM distributed 25% top, 25% bottom, and 25% each long side. Also water with heat density of 334.1 kJ/kg and zero melting temperature was the best among other materials followed by the water-tetradecane + docosane configurations.

An extensive review articles on the application of PCM as energy storage for cold chain logistics for aquatic food stuff, agricultural products and other types of food transportatin have been reported in the literature [15-18] but based on the literature survey and information of the authors there is no study on the application of PCM for heating/cooling purposes in the aircrafts for aviation catering systems. Therefore, the main goal of this research study is to apply PCM technology in the aircarft food supply chain as an alternative to the conventional cooling and heating process. Since airline managments are competing in cost rduction and fuel saving in a very competitive market, this research work can assist in achieving cost reduction and fuel savings by:

- Reducing direct costs of cooling and heating
- Weight reduction of the chillers and heaters which directly contributes to fuel consumption reduction (as a rule of thumb a n additional of 2 -3 kg of fuel per 1000 km is needed for every 100 kg weight added which is known as a marginal fuel burn rate (MFB).
- Electrical consumption redu ction by eliminating electrical chillers and heaters which is related to the fuel consumption
- Gas emission reduction for fleet by reducting fuel consuption which makes the airline as an eco -friendly carrier option

This paper examines the use of two types of phase change materials as alternatives to traditional cooling and heating methods in aviation catering systems onboard aircraft during flights. The materials will be prepared on the ground with required temperatrue and utilized during the flight.

II. MATERIALS AND METHODS

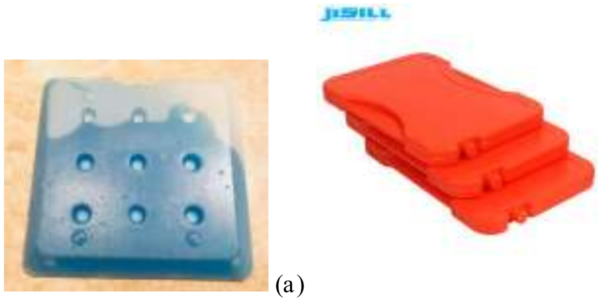
2.1 Phase Change Materials (PCMs)

A polymeric PCM mixture of 1.67 wt.% of polymer water-absorbing resine and 98.33 wt.% of water with melting point of -5 °C, specific heat capacity of 4500 kJ/kg °C and heating density of 176.4 kJ/kg with weight of 1.028 kg encapsulated in high density polyethylene (HDPE) with dimensions of 24.4cm x 24.2cm x 2.5cm has been suppied by Changzhou Jisi Chain Technology Company in China for cooling purposes as shown in Fig. 3. a. HDPE has been seleted as a PCM container due to its hardness to hold the PCM weight, very good sealing and light weight in comparison to matallic containers. A composite PCMs consisting of sodium acetate trihydrate 90%, disodium hygrogen phosphate dodecahydrate, 5.8%, and gelatin 4.2% with melting point of 59.1 °C has been packed in HDPE with size of 17.8cm x 12.2cm x 1.4cm and weight of 2.60 kg provided with the same company for the heating purposes as depicted in Fig. 3.b. Both composition of phase change materials classified as non-corrosive, non-falammable and non-toxic and are environmental friendly type of phase change materials.

2.2 Measurement techniques

The method of testing the PCM cooling and heating requires practical application of the PCM in catering container that resembles the actual working environment. Except for the pressure difference - aircraft altitude ranging between 0 to 21000 meter – all other parameters are set to match the actual environment.

Many parameters are measured for comparison including temperature which is the main factor for the study. The temperature sensing, while easy to obtain, is challenging over the period of the test which can extend up to 15 consecutive hours. In addition, the test must be carried out multiple times for accuracy purposes.



(a) (b)

Figure (3): Plates of PCMs for cooling (a) and heating processes (b)

The manual recording of the temperature in cycles extended to a few minutes is impractical. Thus, the use of another method was unavoidable. A system comprising of set of sensors, microcontroller development board ESP32, breadboard and a power source. All thermocouples have been calibrated with a reference temperature. The NodeMCU-ESP32 allows for easy prototyping with simple programming using Lua scripts or the Arduino IDE, and its breadboard-compatible design. This board features a 2.4 GHz dual-mode Wi-Fi and Bluetooth wireless connection. Additionally, it includes 512 KB of SRAM, and 4 MB of flash memory integrated into the microcontroller development board. It has 21 interface connection pins, including I2C, SPI, and UART.

2.3 PCM weight calculation

The selected operator of the case study is a local airline (Salam Air in Oman) operating a fleet of fifteen Airbus 320 narrow body aircrafts with operation connect to several airports that varies seasonally. The passive cooling/heating system has been considered for one of the trolleys during the Salam Air flights. Each trolley is a mobile storage and transport unit used for food and beverages storage with parking brakes. There are service-related trolleys and waste-related trolleys in two different sizes: full-size and half-size trolleys. The operation of both trolleys is the same. The trolleys (aircraft cart) are made of aluminum sandwich panel to an aluminum frame. The aluminum sandwich panel typically includes PVC foam. This structure ensures good

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heat storage and insulation. For the sake of this article, an aluminum standard cart is used to conduct the experiment, and the temperature sensor is installed to record the temperature.

An assumption was made for daily flights depending on most frequent flight times throughout the year. This assumption will have a negligible if not at all effect on the results of the study. The average flying time is required to ensure adequate cooling method for the food and drinks on board.

Depending on the flight time it is decided whether a specific method of cooling/heating is a feasible option. The average daily flight schedule of the airline is listed in Table 2.

Table (2): Average daily flight time of the airline [19]

Aircraft Code (IATA)	Flight time (hr.)	Airport (IATA)	Flight time (hr.)
SKT	5	SLL	4
BAH	4	CMB	15
JED	8	SAW	12
DAC	12	IKA	2.2
KHI	8	DOH	2
FJR	2.2	SYZ	4
CMB	15	KWI	5
DQM	3	FAU	2
KUL	15	IST	12
DMM	5	MUC	15
HKT	12	UKH	3
BKK	12	DXB	3
Flight time	6.587 hours		

The flight hours per flight cycle of the fleet which is calculated from the annual reliability report of 2022 for the airline are listed in Table 3.

Table (3): Average flight hours per cycle [19]

	Registration	Flight Hours	Flight Cycles	Hrs/Cycs Ratio
1	A4O-	1060.7	526	2.02
2	A4O-	1133	543	2.09
3	A4O-	1181.53	561	2.11
4	A4O-	1167.28	564	2.07
5	A4O-	1051.27	511	2.06
6	A4O-	999.7	491	2.04
7	A4O-	1156.82	401	2.88
8	A4O-	1286.98	417	3.09
9	A4O-	1109.88	451	2.46
10	A4O-	643.03	302	2.13
	Fleet Total	10790.2	4767	2.26

Thus, the average cooling time can be calculated from the average above. It can also be noted that 30 % of the flights are over 6 hours flight time. The aircraft chiller is an optional feature and in our case study airline and it's only installed in two aircraft. The remaining aircraft rely on ice. Air chiller is used to cool galley trolleys at constant supply with the help of air conditioning. As fruits and beverages that have been stored on galley trolley for the whole flight must be cooled before been prepared for serving. Aircraft that are not equipped with chillers or have inoperative chillers have their food contents cooled in a different manner. Dry ice is provided by the catering company prior to each flight. It is up to the catering company to provide ice bags for the aircraft trollies. Dry ice is one of the oldest phase change materials known by humans. However, the cold storage performance and thermal conductivity is not the best among PCM when compared to other organic and non-organic PCM.

The Steam Oven/High Speed Oven is installed in a galley. It is supplied by the aircraft electrical system. The oven has a control box to select the temperature and time of operation, to heat the meals. During the cooking program, the heating element will energize and de-energize constantly to keep the oven cavity at the correct temperature, while the motor and the fan circulate the heat and steam. When the pressure in the oven cavity is more than 100 millibar ± 25 millibar [1.45 psi ± 0.36 psi], the internal pressure relief valve of the door assembly opens to release the pressure from the oven cavity. Each aircraft is equipped with four steam ovens distributed between forward and aft galley, each weighing between 16 to 19 kg as depicted in Figure 4.

Based on the flight time the amount of PCM has been calculated from the following two equations for the cooling and heating purposes:

$$Q = m \cdot Cp_s \cdot (T_m - T_i) + m\lambda + mCp_l.(T_f - T_i) \quad (1)$$

For sensible and latent heat calculation and:

$$Q = m\lambda \quad (2)$$

for latent heat calculation.

Figure (4): Aircraft steam oven [13]

Where T_m is the melting temperature of phase change material, $C_{p,s}$ is the solid specific heat capacity in J/kg K, $C_{p,l}$ in J/kg K is heat capacity of liquid PCM, λ is latent heat per mass unit in J/kg. The first term in equation (1) represents sensible heat transfer between the storage material and foods before PCM melts, the second term shows the energy produced during the phase change and the last term indicates

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the sensible heat transferred between the PCM and the foods after PCM melts.

III. RESULTS AND DISCUSSIONS

3.1 Cooling system

For the cooling process the PCM plates have been pre-frozen inside the freezer and have been located inside the trolley for temperature measurement.

The first cooling cycle was carried out using PCM for a total duration of 9.5 hours. 4 plates of cooling PCM were frozen in the freezer to a temperature below its freezing temperature and then moved to the trolley and fitted around the food basket including fruits and beverages as shown in Fig. 5.

Figure (5): PCM plates configurations in the trolley

Figure 6 illustrates temperature distribution during the cooling process. The initial temperature of the foods is ambient temperature at 18 °C when the cooling process started. As seen from the temperature profile the temperature reached 10 °C after one hour due to the measurement of air temperature inside the container. It is also observed from the curve that the temperature remained below 10 °C for a period of 6 hours and 40 minutes of cooling process. This will ensure a safe environment for the food to be stored and ensure quality preservation. The same is applied for the drinks that are preferably served cold where the temperature remains almost steady at 4 °C for more than 5 hours.

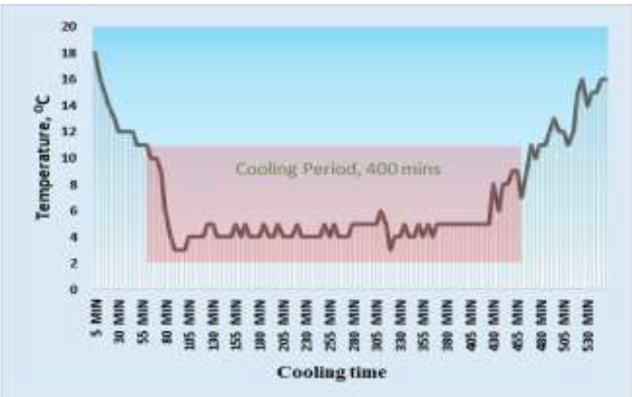

Figure (6): Temperature distribution for cooling process with 4 plates

The second experiment has been carried out using only two cooling packs around the foods with the same environmental conditions and the results are shown in Fig. 7 which indicates that the temperature remains below 10 °C for almost 7 hours. This is due to the fact that in this experiment we have more food on the basket that can provide more cooling time in comparison to the previous experiment. This proves that even half the weight of the PCM plates can provide enough cooling environment during one flight. Cooling temperature from ambient (18 °C) to 10 °C reached at 50 minutes and returns to ambient in 2 hours and 10 minutes.

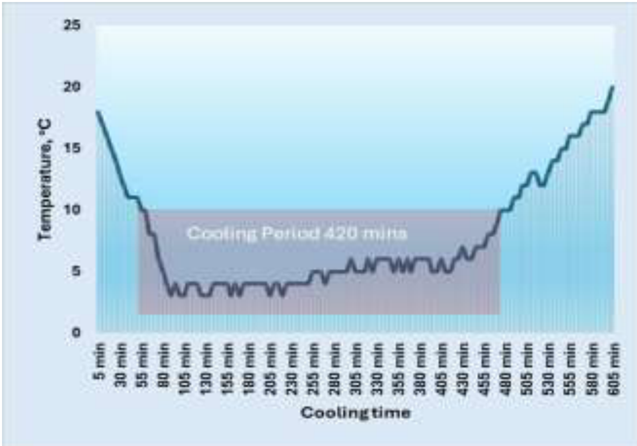

Figure (7): Temperature distribution for cooling process with 2 plates

The third experiment has been carried out by placing food and beverages on the top shelf of the trolley and the cooling plates have been adjusted at the sides and top of the shelf. The temperature distribution for this condition is shown in Fig. 8, which proves that the temperature was below 10 °C for more than 7 hours. Noticeably, the starting temperature in this experiment is lower than the previous two experiments. This might be due to a cooler overall ambient temperature inside the trolley compared to the previous experiments.

In addition, the container position on the top shelf might have expedited the cooling time. On the other hand, the temperature curve after reaching 10 °C exhibits slightly slower ascent when compared to the previous cooling curves. Overall, it is safe to say at this stage that the optimal location for the PCM is on the top shelf of the trolley. This obviously provides enhanced performance and efficiency and may extend the cooling period noticeably.

In the final cooling experiment ice was used for the cooling process. Ice while having a simple making process and economical but is not very practical. The distribution of the ice packs cannot be optimized in the current packing method. This significantly affected the cooling curve shown in Fig. 9. The temperature profile shows a significant drop of temperature from 16 °C to 4 °C after 50 minutes from the beginning of the experiment.

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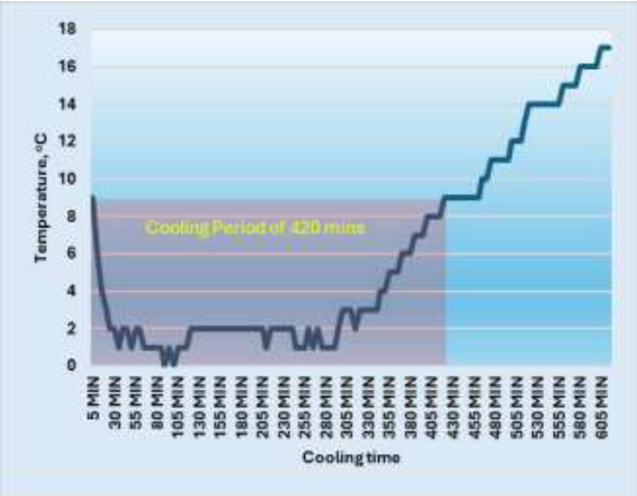

Figure 8: Cooling temperature for the top shelf of the trolley

This is due to phase transitioning. The temperature drops to 4 °C and almost remains constant at this temperature during the cooling process for 2 hours and 20 minutes followed by a gradual temperature rise to the room temperature.
Unlike the PCM curve, the gradual rise in temperature was a slow incline which was on a duration of 3 hours. The entire cycle represented in cooling curve was 6 hours 30 minutes long. This is noticeably shorter than the PCM cycle.

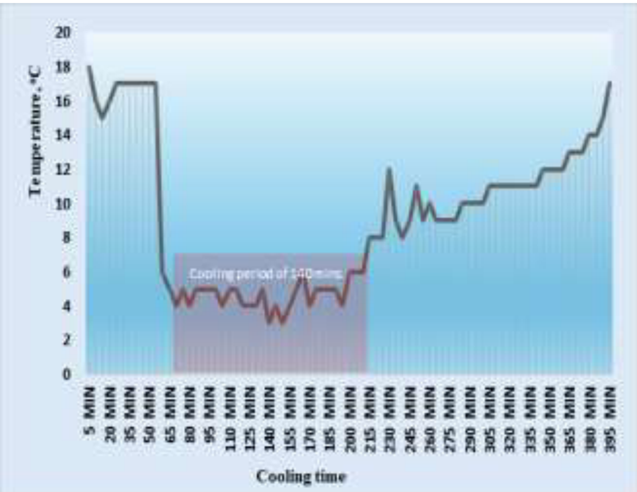

Figure (9): Cooling system using ice

For the comparison of the phase change material cooling and conventional cooling method using air chiller, temperature distribution of a chiller has been recorded during one of the actual flights and the results are presented in Fig. 10. As shown in the temperature profile starts from 18 °C and gradually decreased to the minimum temperature that could be achieved for the cooling process i.e. 14 °C which was unexpected for such a cooling process. This error may be due to the measurement conditions such as pressure difference during the flight.

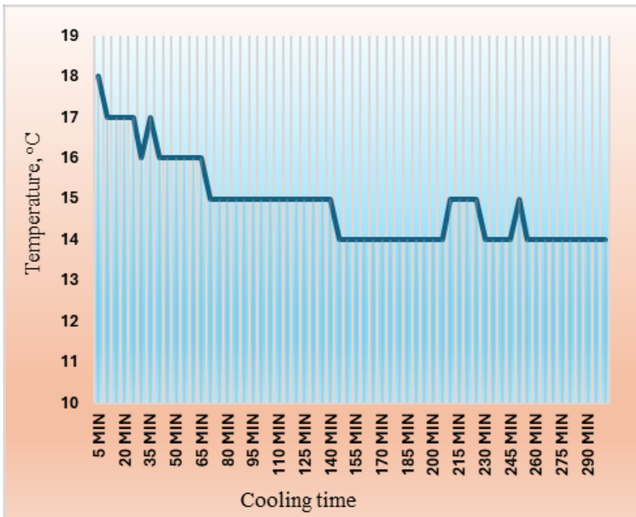

Figure 10: Cooling temperature distribution for the chiller

3.2 Comparison of the PCM and conventional cooling methods

As can be seen from the temperature distributions for cooling process the PCM presented promising results.

There is a preference for organic materials such as paraffins over water in application of thermal energy storage for higher heat density [20]. Here both ice and a composite cold PCM including 93 wt.% of water show approximately the same thermal properties including the heat density. In addition, the cost over the long run favors the PCM over ice usage. This is due to the reusability of PCM and high life cycle. Two Salam Air aircraft are equipped with three aircraft chillers with the weight of 34 kg (total weight of 102 kg) in each and the remaining are based on ice cooling. The PCM plates used can provide steady cooling maintaining a 4 °C to 10 °C temperature range during the 6-hour flight. In the cases of flight time exceeding 6 hours, the flight cycle end for a transit check can be used to change the PCM installed with new ready to use PCM. This can be coordinated with the catering company at the airport of arrival. In conclusion, the utilization of PCM in the fleet for cold supply chain is feasible and can be practically adopted.

3.3 Heating system

For the heating process a preliminary test has been carried out using an insulated box including four hot PCM plates filled with composite PCMs of acetate trihydrate 90 wt.%, disodium hydrogen phosphate Dodecahydrate 5.8 wt.% and gelatin 4.2 wt.%. The plates have been heated to the melting temperature using hot water or microwave to be sure that the PCM in the plates have melted completely. The food pack with a weight of 1 kg, is also preheated to 40 °C in the heater before putting it inside the heating box. Temperature profile of the preliminary hearing process is shown in Fig. 11. As illustrated in the temperature distribution there is a rapid rise in temperature after 25 minutes of the heating process reaching the temperature to 60 °C and remains at this

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temperature for one hour and 15 minutes. After that, the profile shows a steady slow decline in temperature. The decline took a little over 3 hours to reach the initial temperature of the experiment.

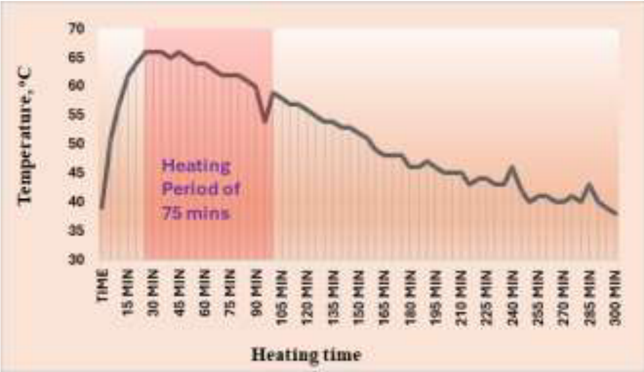

Figure (11): Preliminary results of the heating process using four plates

The main heating experiment has been carried out by adding food inside the box containing eight hot plates to enhance the heating period. The temperature distribution result is presented in Fig. 12. As illustrated in the figure the initial heating process took place between 15 to 20 minutes when the temperature reaches 60 °C and then there is a sharp increase to the peak value of 72 °C and gradually decreases to 60 °C. The maximum temperature reached in this experience exceeds the previous experiment by 8 degrees. This is a considerable improvement in the heating process. Another excellent indication is the totally effective heating time. The curve shows a steady heating temperature above 60 °C for over 6 hours.

It is worth noticing that due to the limited options provided by the manufacturer, the hot PCM plates used were smaller than the cold PCM. To compensate for that more plates were used, and the results are excellent. Temperature profile of the heating process in this experiment shows a very slow decline in temperature. For the last hour and half the temperature remained above 55 °C. This indicates that even after continuous operation of 6 hours the food served can still be provided at a suitable eating temperature which ensures customers satisfaction covering the maximum flight time. As the results show from the graph of the first experiment, heating using less PCM plates (less weight of PCM) than recommended is providing heat less than 1 hour and 30 minutes above 60 °C which is still falling behind the practical implementation for heating purpose onboard of the aircraft. By providing prolonged heating and sufficient PCM plates, it can compete with conventional instant heating and provide a feasible and economic substitute for the conventional heating method.

The experimental testing resulted in a total effective heating time reaching 6 hours under controlled conditions and good thermal insulation. More studies should be carried out to compare the two methods.

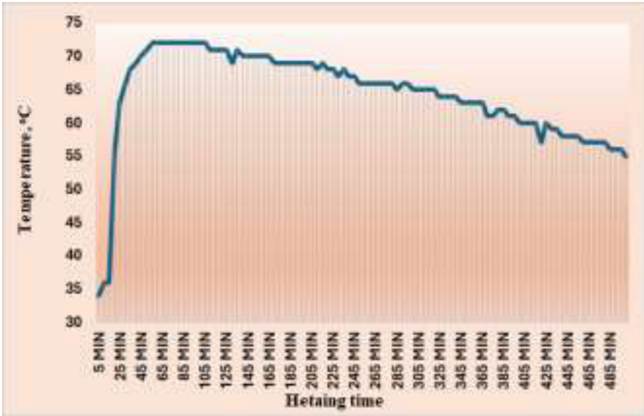

Figure (12): Temperature distribution for the heating process

PCM studies are increasing rapidly, and new materials worth studying are arising. The current method of heating is sufficient for aviation purposes, but soon PCM can take over the process with prolonged heating time and efficiently.

3.3 Fuel consumption impacts

Fuel efficiency is related to many parameters from which one of the important is weight. It means that the more weight added to the aircraft, the more fuel it needs to fly it. This relationship is called cost of weight and defined as the amount of fuel in kilogram or pound that is required to transport one kilogram/pound of weight and is widely used to evaluate the impact of weight on fuel consumption. As an example, United Airlines studied the reduction of weight by using lighted papers in the inflight magazine and found that this slight change in weight can lead to saving 643000 kg of fuel a year in their aircraft.

As a rule of thumbs empirical analysis indicates that it takes on average 20 kg of fuel to transport 100 kg of weight over 1000 km [21]. This calculation is based on the constant flight altitude, speed and other operational conditions of the aircraft. An additional 2 kg to 3 kg of fuel per 1000 km is needed for every 100 kg weight added which is known as a marginal fuel burn rate (MFB). The opposite is also true which shows that a reduction in weight by one kg saves roughly 0.02 to 0.03 kg fuel per 100 km. Thus, saving 102 kilograms of weight on chiller by replacing PCMs including the PCMs weights can lead to saving of 2 kilograms of fuel for 1000 km flight. While this figure may appear to be negligible, a great deal of saving can be achieved considering the number of flights per day for a whole year. As for the electrical consumption reduction, it is a different approach. The IDGs govern the consumption rate. The Integrated Drive Generators (IDGs) on an aircraft like the Airbus A320 are mechanically connected to the engines and produce electrical power as a byproduct of the engine's operation. The IDG's speed is directly tied to the speed of the engine, and its primary purpose is to generate a consistent and stable electrical output. While reducing the electrical demand on the A320 could potentially reduce the load on the generators and associated electrical systems, the impact on fuel consumption is generally minimal. The IDGs

are mechanically coupled to the engine and operate at a speed determined by the engine's requirements for mechanical power, not directly by the electrical load.
In other words, the IDGs are driven by the engine's power, and the electrical power generated is a byproduct of this mechanical connection. Adjusting the electrical load may influence the efficiency of electrical systems, but the primary factor affecting fuel consumption is the overall operation of the engines.

3.4 Environmental effects

Using phase change materials (PCMs) for cooling and heating food in aircraft instead of traditional ovens and chillers can have both positive and negative environmental impacts. Here are some considerations:
Positive Environmental Impacts:

- Energy Efficiency: PCMs can potentially be more energy-efficient than traditional heating and cooling methods. They can absorb and release energy during phase transitions (melting and solidification) with minimal temperature fluctuations, reducing the need for constant energy input.
- Reduced Energy Consumption: PCMs may lead to reduced overall energy consumption compared to traditional ovens and chillers, especially if the energy required for phase change processes is lower than that needed for conventional heating and cooling.
- Weight Reduction: PCMs can be designed to be lightweight, which could contribute to fuel efficiency in aircraft. Reduced weight c an result in lower fuel consumption and, consequently, lower greenhouse gas emissions.

Negative Environmental Impacts:

- Material Production: The production of PCMs may involve the use of materials and processes that have environmental impacts. Depending on the specific PCM used, the production process could contribute to resource depletion, emissions, or pollution.
- End-of-Life Disposal: The disposal of PCMs at the end of their lifecycle needs careful consideration. Some PCMs may contain substances that could be environmentally harmful if not handled properly.
- Complex Manufacturing: The manufacturing process for some advanced PCMs may be complex and energy - intensive, potentially offsetting the energy savings achieved during use.
- Supply Chain Impacts: The suppl y chain for PCM production might involve transportation and other processes that contribute to environmental impacts. This includes the extraction and transportation of raw materials.
- Compatibility Issues: The integration of PCMs into existing systems may require modifications or replacements, and these changes could have environmental implications.
- Regulatory Considerations: Some PCMs may contain substances subject to regulations due to environmental or health concerns. Compliance with such regulations is important to minimize negative impacts.

When evaluating the environmental impacts of using PCMs for food cooling and heating in aircraft, it's essential to conduct life cycle assessment (LCA). This assessment should consider factors such as raw material extraction, manufacturing, transportation, usage, and end-of-life disposal. It's also important to compare these impacts to the conventional methods being replaced to determine the overall environmental benefit. The specific type of PCM, its composition, and the production processes involved will play a significant role in determining the environmental profile of the technology.

VI. CONCLUSION

The aim of the study was to prove the feasibility application of Phase Change Material PCM in aviation catering for the purpose of cooling and heating food and beverages. Although Phase Change Material is increasingly becoming popular for its various applications, this study sheds light on the applicability in aviation.
By experimental testing, PCM proved reliable applicability and feasibility. For the cooling process, the results proved better outcomes from PCM when compared to other existing methods such as ice and chiller cooling. In the traditional systems a chiller is required for the cooling process during the flight while using PCM this can be done on the ground using a refrigerant cooling cycle to solidify the PCM to be utilized during the flight. It surpassed the conventional cooling in parameters of thermal capacity and customizability. Performance output exceeds the expectation for the cooling process. It is recommended that the aviation industry should consider the application of PCM in the field of supply chain to be ahead of competition. The economic benefits, if properly implemented, outweigh any obstacles that may arise. The benefits go beyond being economically feasible to participating in the reduction of CO_2 emissions by saving hundreds of tons of fuel annually. On the other hand, the heating of catering food using PCMs showed promising results. Perhaps better outcomes can be achieved considering different material selection options and enhancement of the trolley design. Yet it remains promising and can be improved. Full economic feasibility studies is under progress and will be presented in our next publication. Due to the limited length of pages of the paper this is not included in the paper.

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