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Design, Construction and Performance Studies of a Non-electric Refrigerator Using Eco-friendly Refrigerant Materials

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Abstract

In this study, we describe the design, construction and the performance of an eco-friendly non-electric refrigerator. The refrigerator is made up of stainless steel (SS) chambers, drawers, four different types of insulation materials, refrigerant materials, gaskets, screws, sensors etc. The refrigerant material used herein was the mixture of table salt and ice with an optimum ratio of 1:2. The refrigerant materials were preserved in a stainless steel (SS) chamber of optimal dimension covered by four successive layers of insulation materials. A refrigeration time of about fifty three hours of the preliminary designed refrigerator was attained. The microbiological effects of freezing mixture on foods and food stuffs preserved into the refrigerator have also been studied. The performance of the preliminary setup is found to be promising for developing non-electric low cost refrigerator considering the raw materials used, easy fabrication procedure, temperature control mechanism and health issues. However, further studies are needed for realization of an environmental friendly novel green refrigerator powered by chemical energy from very low cost freezing mixture.

Keywords: Green refrigerator; Freezing mixture; Insulator; Phonon transport; Temperature control and performance.

Introduction

Global warming is one of the major concerns of current world that is directly responsible for climate change. Emission of greenhouse gases is the key factor for this intimidating change. Energy crisis is another big challenge for the survival of human civilization. Over the years, scientists and researchers are trying to resolve these problems by inventing energy efficient devices. As a consequence, there are growing interests among the scientists and technologists in order to develop alternative refrigerator(s) that would be eco-friendly and operated without electricity.

Refrigerator has become an indispensable part of our modern life for keeping food fresh and spoilage free. This household appliance has a long research and development history. Over the years, scientists from different parts of the world had conducted their research for developing the modern refrigerator. The first true refrigerator was invented by Jacob Perkins in 1835 where he used ammonia for a vapor-compression cycle [1,2]. In 1859, Ferdinand Carré developed another refrigerator that used a mixture containing ammonia and water for compression cycle [3]. Another notable progress occurred in 1875, when Carl von Linde invented a portable compressor refrigeration machine using methyl ether [4]. The first mechanical refrigerator, somewhat similar to the modern refrigerator, is patented by Albert T. Marshall in 1899 [5]. In fact, modern refrigerator worked by compressing and expanding of a man-made greenhouse gas called Freon. This Freon is notoriously depleting the ozone layer of the Earth's stratosphere that protects living beings from the harmful UV radiation comes from the sun. Although other refrigerant materials, for examples, ammonia, sulfur dioxide, and non-halogenated hydrocarbons such as propane, have been used in replacement of Freon gas [6] but these materials are also not entirely eco-friendly and have some negative effects on environment. To avoid the use of Freon like greenhouse gases, scientists are trying to invent eco-friendly refrigerator that does not emit any type of harmful greenhouse gases. With this aim in mind, Albert Einstein and Leo Szilard invented an environmentally friendly refrigerator in 1930 that runs without electricity because it had no moving parts and used only pressurized gases to keep things cool [7]. They used ammonia, butane and water and took the advantage of the fact that liquids boil at lower temperatures when the air pressure around them was lower. In recent time, the primitive invention of Albert Einstein has been rebuilt by a group of scientists led by McCulloch at Oxford University who has been trying to develop an environmentally friendly refrigerator that runs without electricity [8]. They have been working on powering their innovated refrigerator with solar energy. Engineers of Camfridge, a Cambridge-based start-up company are using magnetic fields and special metal alloy to cool things [9]. In this paper, we have presented a novel approach for developing eco-friendly refrigerator, where the device is driven by chemical energy from very low cost freezing mixture rather than electrical energy.

Materials and Method

In this work, we have designed and developed a simple and low cost unique type of refrigerator using eco-friendly refrigerant materials. Where temperature of the freezing mixture (~ -20°C) confirms the

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refrigeration environment. This freezing mixture is prepared by allowing a chemical reaction between sodium chloride salt (NaCl) and ice, and preserved in a stainless steel (SS) chamber of optimal dimension. There is a list of freezing mixture in literature [10-12], but the freezing mixture of sodium chloride salt (NaCl) and Ice resulted the best match for attaining desired refrigeration condition, because temperature of this freezing mixture is -20.4°C. This mixture is preserved in a stainless steel (SS) chamber and this SS chamber is covered by four successive layers of insulation materials consisting of cotton layer, cork-sheet, wooden layer and plastic sheet. The temperatures of the drawer-inside were monitored over a period of time and recorded by a commercial digital thermometer (Clock and Hydro-Thermometer: Model# HTC-2) integrated with a thermocouple.

Fabrication procedure

A three cubic foot (cft) green refrigerator has been designed and constructed as shown in Figure 1. The dimension of the refrigeration chambers is 14″ L × 14″ W × 26.5″ H. The shape of the constructed refrigerator is similar with the widely used modern refrigerator where food preservation chambers and opening door are similar with the conventional electromechanical refrigerator. Food preservation chambers were made of stainless steel (SS) sheet which were made in a shape just like indoor shape of conventional fridge. This SS steel chamber is surrounded by another SS sheet from all five sides (except the door side) that makes up a storage container for the freezing mixture. A schematic diagram of this green refrigerator is shown in Figure1.

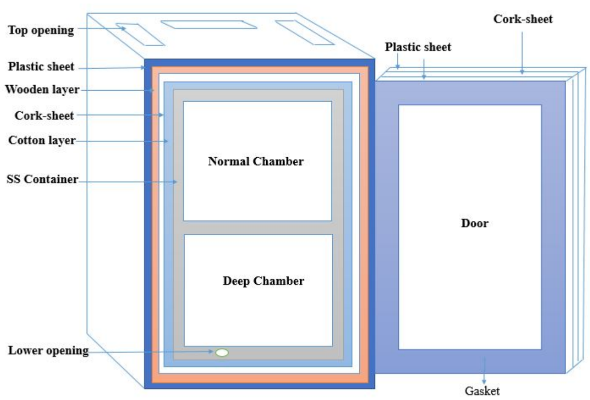

Figure 1: Schematic diagram of a green refrigerator.

The distance between every two adjacent SS sheets of this container is two inches, i.e., the gap in between every two sides of the container is two inches. The topmost surface of the container contains three identical openings and the lower front portion contains another one opening tube. As mentioned earlier, refrigerant materials or freezing mixtures are kept into this container. Here, the topmost openings of the refrigerator are used for pouring the refrigerant materials and front lower opening is used for pulling-out the neutralized liquid. In Figures 2 and 3, openings of this refrigerator are shown. For this opening management, two different mechanisms are applied.

Figure 2: SS container (middle) and SS drawer chambers for food preservation.

To preserve the temperature of freezing mixture for longtime operation, some insulation layers are introduced in between the outer environment and SS chamber where the mixture is kept. The cotton is a low cost but a very good insulation material and it could prevent the adhesion effect of moisture to the container. For thermal insulation of the system, all five sides of the container (except the door portion) are tightly wrapped by 1″ width cotton layer at first. Then, this cotton layer has been successively wrapped by two 1″ width cork-sheet layers and this cork-sheet layer has been further wrapped by 0.5″ lightweight wooden layer. For wrapping, different types of glues such as super glue, aica gum and silicone glue including different types of scotch tape, where necessary, were used.

Figure 3: A photograph of our constructed refrigerator showing the openings in the different stages of the construction.

Our primary aim was to encapsulate the freezing mixture container from the outer environment; in other word, minimizing the phonon transmission from inside and outside environment. Phonon particle is a transient particle that is only generated when two systems are in temperature gradient. However, the door of this refrigerator was prepared by one inch cork-sheet which is sandwiched by two light weight wooden layers of 1″ width. This door was again wrapped by a 0.25″ width insulating plastic sheet. The door of our refrigerator is

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attached by screw and gasket that is almost similar way as the door is connected with the conventional refrigerator. Two temperature sensors (first sensor is attached to the normal chamber and second sensor attached to the deep chamber) are connected with this device for measuring two different temperature of normal and deep portion of this refrigerator. Finally, all five sides of the refrigerator are wrapped by 0.25″ width insulator plastic sheet except the door as shown in Figure 4.

Figure 4: Energy efficient Green Refrigerator.

On the other hand, for the fabrication of the steel container, soldering of every two edges of SS sheet were done with special care to make it leak-proof properly. Every insulating layer of the refrigerator body was wrapped for making air tight.

Results and Discussion

To evaluate the refrigeration performance of our developed non-electric fridge, a set of experimental studies have been conducted. It is worth mentioning that refrigerators create an environment which retards bacteria and fungi to trespass from environment and indigenous microbes remain dormant. Therefore, foods and food stuffs are remained fresh and edible condition for longtime compared to those remain in the natural environment condition. Microbes are generally active in the temperature range 13°C -70°C. For this reason, in conventional refrigerators usually two temperature levels are provided, namely, between 2°C to 8°C for normal fridge cooling operation and -20°C for deep fridge cooling operation. In general, food stuffs are required to preserve bellow 13°C temperature for preventing from the spoilage microbes. From our studies, we confirm that the our newly developed refrigerator is capable of providing the desired temperature(s) generated by the chemical energy of a freezing mixture composed of widely available and very low cost materials. The freezing mixture used during this study was made up of NaCl salt and ice with a ratio of 1:2. As the salt and ice both are solid materials, so it is easily possible to put them into the container through the three topmost openings such that the three sides (left, back and right portion) of the container is completely occupied with this refrigerants. Then, topmost openings are shut down manually. Mixture of NaCl salt and ice reacts with each other immediately after brought them into contact and produces liquid freezing mixture. Temperature of the mixture is gradually decreased and this liquid mixture percolates to the bottom portion of the SS chamber over the time. When reaction is completed, all the solid refrigerant materials are converted to liquid freezing mixture that gradually occupy the lower half portion of the refrigerator and vertically upper half portion become empty.

S. No	Time (min)	Temperature (°C)		S. No	Time min	Temperature (°C)		S.No	Time (min)	Temperature(°C)	
		Normal	Deep			Normal	Deep			Normal	Deep
1	0 (10.11 am)	12.9		28	85	-0.1	-0.9	55	275	-2.8	-4.8
2	1	12.4		29	90	-0.3	-1.1	56	280	-2.8	-4.7
3	2	11.4		30	95	-0.5	-1.2	57	290(3.22pm)	-2.9	-4.9
4	5	8.9		31	100	-.07	-1.5	58	302	-2.9	-4.8
5	7	8.2		32	105	-0.8	-1.6	59	308	-2.9	-5.0
6	9	7.4		33	110	-1.1	-1.8	60	325(3.45pm)	-2.9	-4.9
7	14	6.9		34	115	-1.2	-1.9	61	340	-2.9	-4.9
8	15	6.5		35	120	-1.5	-2.3	62	355	-2.6	-4.6
9	17	6.1		36	135	-1.9	-2.9	63	410	-2.2	-4.6
10	21	6.1	4.8	37	145	-1.5	-3.1	64	1960	-0.2	-4.0
11	22	5.9	4.8	38	160	-1.6	-3.2	65	1400	-0.1	-4.2
12	25	5.6	4.2	39	170	-1.7	-3.4	66	1430	0.1	-4.3
13	27	5.4	3.8	40	175	-1.9	-3.5	67	1460	0.1	-4.5
14	29	5.1	3.5	41	180	-1.9	-3.6	68	1490	0.2	-4.6

15	32	4.4	3.2	42	185	-2.1	-3.7	69	1505	0.2	-4.6
16	34	4.0	3.0	43	190	-2.2	-3.8	70	1520	0.3	-4.6
17	36	3.6	2.7	44	195	-2.3	-3.9	71	1550	0.8	-4.5
18	40	3.2	2.2	45	200	-2.5	-3.9	72	1575	0.8	-4.5
19	46	2.4	1.7	46	205	-2.5	-3.9	73	1665	0.9	-4.2
20	52	2.1	1.2	47	210	-2.6	-4.0	74	1695	1.0	-4.2
21	52	1.9	0.9	48	215	-2.6	-4.1	75	1725	1.20	-4.2
22	55	1.5	0.7	49	220	-2.7	-4.1	76	1755	4.40	-4.2
23	60	1.1	0.3	50	225	-2.7	-4.2	77	1785	4.50	-4.2
24	65	0.9	0.0	51	230	-2.7	-4.4	78	1815	5.20	-1.7
25	70	0.7	-0.2	52	235	-2.8	-4.5	79	2775	5.90	-0.8
26	75	0.4	-0.5	53	250	-2.8	-4.6	80	2870	6.50	-0.2
27	80	0.1	-0.7	54	265	-2.8	-4.6	81	3170(4.00pm)	7.0	0.2

Table 1: Recorded Time Vs. temperature data.

Inside the chamber of this empty upper portion of the refrigerator is functioned as a normal fridge like a conventional refrigerator and the inside of the lower portion of the refrigerator containing the freezing mixture is functioned as a deep fridge. The temperatures of the drawer-inside (both normal and deep) were recorded at an interval of 5 minutes with time variation from the starting point to the end and shown in Table 1. This experiment was conducted at the ambient temperature ~18.2°C.

After filling the refrigerant material into the container, we recorded the temperature data by using thermal sensors from 10.11 am. Initially we recorded the temperature of the normal fridge chamber and found that temperature was decreasing very rapidly. After 20 minute, we started to record the temperature of the both normal and deep fridge chamber. After ~ 70 minutes, the sensor of the deep chamber showed the minus temperature for the first time and its' temperatures were found to be decreasing slowly. The minimum temperature of the deep fridge portion recorded was -5.5°C and normal fridge portion -2.5°C respectively. This system was found to be functioning as refrigerator for around fifty three hours. Then its temperature gradually increased and reached towards the atmospheric condition that is in active bacterial range. It is worth to mention here that to confirm refrigeration environment, we have tried to control and maintain the low temperature of the freezing mixture that was remained in the SS container. For this reason, outer portion of this container has been wrapped by four successive insulating layers, because these layers impede the heat transfer from the high temperature (environment) to the low temperature (freezing mixture). According to the law of thermodynamics, heat transfer continues until the equilibrium condition of these two environmental condition (i.e., outer atmosphere and SS container) is reached. Therefore, after a certain period of time, temperature of the freezing mixture inside the chamber becomes equal to the temperature of the outside ambient and this freezing mixture is called neutralized liquid. The neutralized liquid substance is then pulled out through the front lower opening and collected for re-use. The neutral solution can easily be heated for 1 hour at ~100°C to produce fresh solid NaCl and this salt is again mixed with the ice (that is produced in a separate chamber of ~ -37°C that contains calcium chloride ($CaCl_2$) and ice [10,12] and entered into the refrigerator through topmost opening and this recycling procedure can be continued for further refrigeration.

Although our aim was to create a flawless air tight and thermal leak proof refrigeration system, however, there were a list of mechanical slits and defects as we fabricated this refrigerator manually. We think that the duration of recycling time can be extended over more than ~53 hours by resolving heat loss/gain due to defects. For slower phonon transmission through the insulation materials which is responsible for shorter recycling time, composite insulation materials could be applied for longer recycling time. So it should be mentioned that, in a separate mini-scale experimental setup, the minimum temperature has been recorded was -20.4°C. Our ultimate goal is to maintain the temperature of deep-fridge portion is -20.4°C and recycling period is extended up to fifteen days by continuous research and development. Further studies on this issue will be carried out in our laboratories in near future and will be presented in a separate scientific communication.

We expect that our newly developed technology may help the people who are still living below poverty line, out of the national grid transmission line network and unable to buy a high priced refrigerator. For example, in Bangladesh, a significant percentage of population is still outside from the national grid coverage. Since the raw materials of our green refrigerator is inexpensive, fabrication technique is simple, therefore, we expect that the price of our fridge could be affordable for this group of people. The main target of this project is to provide the low cost refrigeration facility to the rural root level people who are still unable to afford a modern fridge and the rural shopkeepers as well as confectionary stores where refrigerator is required to store ice-cream, beverage, sweet etc. On the other hand, our refrigerator has no moving part, so environmental hazardous refrigerant material such as Freon gas does not required. As we used NaCl and ice for refrigeration operation, there is no harmful effect of these material, so we can conclude that out system is environmental friendly and it does not require electricity from national grid.

Future Prospect

Extensive research work will be conducted for developing the low cost freezing mixtures and composite insulation materials for refrigeration time extension. Recycling system of freezing mixture of this device will be user friendly. The ultimate goal of this project is to develop a modern hybrid green refrigerator that is operated by solar electricity in sunny time and in dark period this device will be operated by chemical energy from the freezing mixture.

Conclusion

In this work, we have design and constructed a non-electric refrigerator using eco-friendly low cost refrigerant materials and demonstrated its refrigeration performance. The refrigeration of these appliances can be operated seamlessly up to ~53 hours without electricity. The easy fabrication procedure and low cost materials used for developing this refrigerator is expected to be in great help for poor people worldwide who otherwise could not afford buying modern fridge as well as out of the reach of electricity facility.

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