Combined Refrigeration And Desalination System Using Vacuum Technology

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Abstract

Energy is the utmost need for the world and energy crisis is likely to be hiked in few decades. So the world turned towards alternative energy and several other new systems are proposed with high efficiency and multipurpose. The output emissions of some process may be utilized to some other applications with additional process. Refrigeration process for cold storage plants are studied and designed using water and vacuum pump. This system works on the basic principle of the boiling point of water decreases when water vapour pressure decreases and with the help of latent heat of vaporization of water. This paper presents the comprehensive review of the bright innovation and future design of the Refrigeration for cold storage along with desalination plant. Distilled water is used for many applications like boiler feed water, drinking purpose and it replaces the RO applications. This study demonstrated that refrigeration for cold storage is achieved along with desalinated water using water and vacuum pump.

Keywords: *Refrigeration, cold storage plants, vacuum pump, desalination, latent heat of vaporization.*

1. Introduction

The demand on fresh water is escalating up to the mark and is becoming the major worldwide challenges. World health organisation (WHO) has undergone a survey in which 20% of world population has inadequate access to potable water. Although world is filled with major part of water, it is in the form salty or in the form of inaccessible one. In order to the necessity of desalination plant, the new design is proposed which eventually cools the refrigerated space. There are technical advances and innovations which are trying to improve both desalination and refrigeration process. Desalination is a promising alternative to equalize the scarcity of drinking water. There are varieties of desalination and refrigeration processes are currently in progress. They fall under the following categories as thermal processes and membrane process and so on. The conventional process which includes phase change is Multi-Effect Distillation (MED), Multi Stage Flash (MSF) [2], Vapour compression distillation (VCD), solar desalination, Vacuum freeze desalination (VFD) and Secondary refrigerant freezing (SRF). The membrane process which does not involve phase change is Reverse Osmosis (RO) [3] and electro dialysis (ED) [4]. The process which includes both phase change and membrane process is membrane distillation (MD). Refrigeration is also vital one for a number of applications. Vapour absorption system, Vapour compression system and phase change cooling are revolving worldwide for refrigeration. Efforts of researchers in coupling refrigeration and desalination are growing worldwide. Pascale Compain [5] studied the most commonly used desalination process (RO, MSF, MED) and come out with an idea of desalination using solar energy and with renewable energy. McDonald [6] investigated the vacuum cooling process of cooked beef product and explained the evacuation rate of vacuum cooling. The evacuation rate plays an major role in efficiency of the overall system and Mc Donald stated the effect of evacuation rate in detail. Xue and Wang [7] studied the vacuum conception and they discussed how to develop the vacuum conception. The main principle is that the temperature which has to be maintained in the cold storage room depends on the surrounding vapour pressure [7]. These concepts build a basic platform for the development of vacuum cooling. Zhou [8] studied the vacuum refrigeration and he performed the design calculations of the vacuum freeze Equipment. John [9] and Van Atta [10] explained about all vacuum cooling process and about vacuum based technologies. Using this technology many products will be developed without harmful to the environment. Kalidasa Murugavela [11] stated about double slope basin which is used for condense steam into desalinated water. He also performed experiments on it and performed the calculations of double slope basin. As said earlier, in our system both vacuum technology and double slope basin are combined to give a new system which performs both refrigeration and desalination.

2. Design and Methodology:

The principle behind the generation of low pressure inside the water tank and operation of the low temperature desalination system was discussed in the previous studies. A schematic arrangement of the refrigeration of cold storage plants along with desalination system based on vacuum pump and pressure - boiling point relationship is shown in Fig.1. Components of refrigeration of cold storage plants along with desalination plants consists of water tank, vacuum pump, storage tank, valves and tubes and Baffle plates. The water tank is mounted inside the insulated cold storage plants and the tank is designed in such way that it has high heat transfer from the room to the tank. Vacuum pumps are installed to reduce the pressure inside the water tank. The vapour pressure of water is directly proportional to the boiling point of water. By decreasing the vapour pressure and making the water to evaporate below room temperature. The heat input can be given by low process heat such as condenser waste heat, room heat or solar energy etc. We are providing heat from the refrigerated space and get evaporated after it gains its latent heat of vaporization. Eventually, if the sea water is used in water tank, still we can get cooling effect and distilled water is produced.

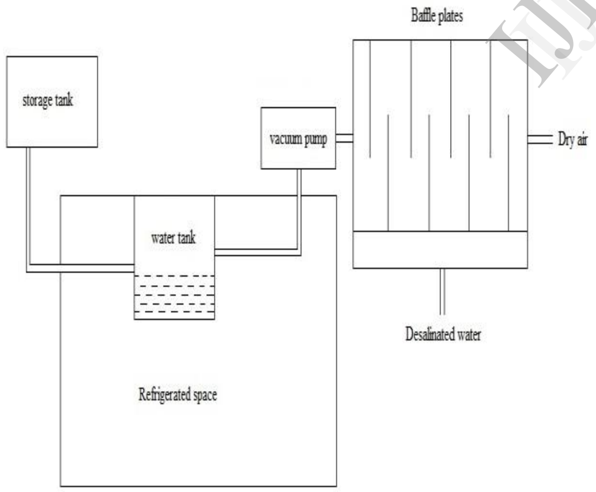

Fig 1 Combined system of refrigeration and desalination

The above figure clearly explains the overall combined system of Refrigeration and desalination. The use of vacuum pump is the power source for the both system. The system works only with water as a working medium and so there is no possibility of environmental pollution. The process gives double efficiency because of the mutual process of two different applications. There are varieties of vacuum pump which are available in the market based on the power and pumping speed. The type of vacuum pump used in the system is roots vacuum pump. The cold storage room is insulated from the surroundings. The Baffle plate structure is used to condense steam into water and the distilled water is used for many applications. The volume of the cold storage room is assumed to calculate cooling load, vacuum pump power and COP of the system.

In calculating the cooling load of the cold storage room [1], we have to consider all the materials and products which are used inside the room. The materials of wall, ceiling, ground and door and their thickness and overall heat transfer coefficients are shown in the below table. The volume of the cold storage room is considered to be 5m * 7m * 5m. There is a door for the room whose dimension is 2.4m * 2m. It is assumed that storage room has 4 lights whose power is 300 W each. The number of persons who enters the room is 3. The period of opening the door of the cold storage room is assumed to be 3 hours for each time inserting the product or removal of the product. The number of air change per hour is assumed to be 4.84. The products have to be stored is vegetables like potato, tomato etc. whose Cp is 3.6 kJ / kg K. The type of box which is used to pack vegetables is chosen as wood. It has the Cp value of 1.38 kJ / kg °C.

Type of walls	Materials	Thickness (mm)	U value (W/m2k)
Wall	Portland Cement + Insulation	270	1.074
Ceiling	Lightweight Concrete	230	0.869
Ground	Reinforced Concrete + Floor tiles	75 + 125	0.350
Door	Wood	50	3.4

3. Calculations:

The cooling load due to the heat transfer between surroundings and inside the cold storage room through walls:

$$Qw = Uw\ Aw\ \Delta T$$

Where Uw is the overall heat transfer coefficient for the construction of walls, Aw is the area of each wall, ΔT is the temperature difference of surroundings and cold storage room. The cooling load due to Heat transfer through Ceiling is as same as that of wall:

$$Qc = Uc\ Ac\ \Delta T$$

Where Uc is the overall heat transfer coefficient for ceiling, Ac is the area of each ceiling, ΔT is the temperature difference between surroundings and cold storage room. The Cooling load due to ground:

$$Qg = Ug\ Ag\ (Tg - To)$$

Where Ug is the overall heat transfer coefficient for all construction of ground, Ag is the area for the ground, Tg is the temperature of ground, To is the temperature of surroundings. The Cooling load due to the door:

$$Qd = Ud\ Ad\ (To - Ti)$$

Where Ud is the overall heat transfer coefficient of door, Ad is the area of the door, To is the outside temperature, Ti is the cold store room temperature. The cooling load due to light and persons are calculated below. The cooling load of light,

$$\frac{QL = n * P * 3.6}{3600}$$

Where n is the number of lights, P is the power for each light. The cooling load of heat gain due to persons:

$$Qperson = m * 753.62 / 3600$$

Where m is the number of persons. The cooling load for natural ventilation:

$$Qnv = ((V*n_1)/\rho) * Cp * (To - Ti)$$

Where V is the volume of the cold storage room, n1 is the number of change air per hour, Cp is the specific heat for air. The cooling load for the product has sensible heat as well as heat of respiration. The cooling load for the sensible heat of the product is

$$Qproduct = (mp * Cp * \Delta T) / t$$

Where mp is the mass of the product, Cp is the specific heat of the product, ΔT is the temperature difference, t is the chilling time. The cooling load for heat of respiration:

$$Qbreath = mp * R$$

Where R is the reaction factor. The summation of all heat loads are the total heat load which is Qtot.The total volume of water needed to provide cooling effect for the total cooling load is given by:

$$Vw = Qtot / L$$

Where Vw is the total volume of water needed, L is the latent heat of vapourisation of water.

Input power of Vacuum pump:

$$P = (So * \Delta P) / \eta mech$$

Where P is the input power of vacuum pump in W, So is the pumping speed in m3 / s, ΔP is the pressure difference, ηmech is the mechanical efficiency of the pump.

COP of Refrigeration:
COP of the cold refrigeration system depends on the input power of the vacuum pump.

$$COP = Qtot / Wpump$$

Where Qtot is the total cooling load of the cold storage room, Wpump is the input power of the vacuum pump.
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4. Results and Discussion:

As mentioned in the formula, we can calculate the cooling load as a total of 27.39kW. For the calculation of amount of water needed, latent heat of vapourisation is taken as 2460 kJ / kg. The amount of water needed for the above cooling load is 11ml per second. For the calculation of vacuum pump input power, pumping speed is taken as 0.025m/s and the mechanical efficiency is 85%. The input power is calculated as 2.921 kW. The COP of the refrigeration system is 9.37 in fact the distilled water gains additionally. Moreover the evaporated water is condensed by a double slope glass arrangement and distilled water is obtained as a side effect. The amount of desalinated water is based on the rate of evaporation of water and refrigeration load.

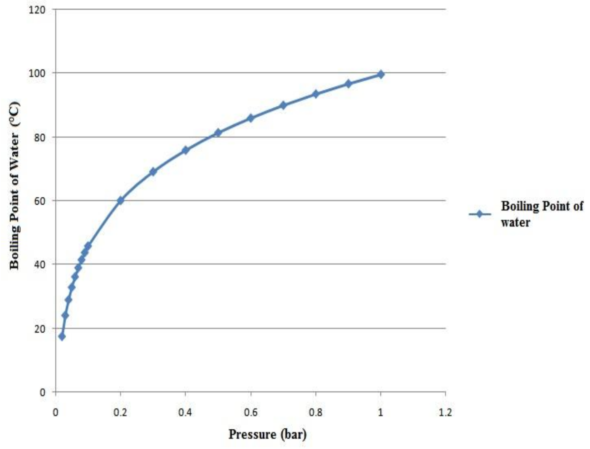

Fig 2 Variation of boiling point with pressure

The above figure explained the variation of boiling point of water with respect to pressure. By this concept we developed the refrigeration system with the COP of 9.37 and it contains combined desalination system.

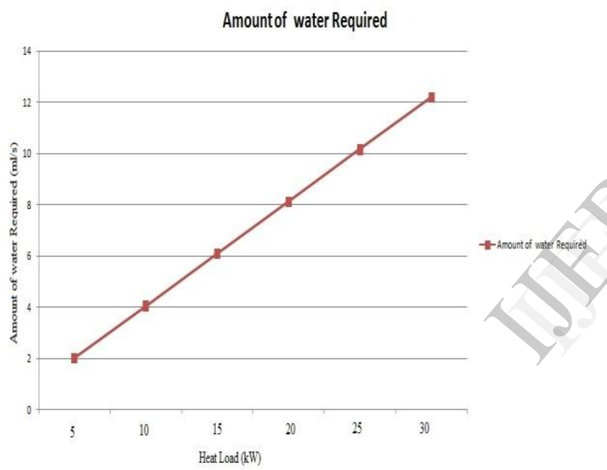

Fig 3 Variation of amount of water required with heat load

The above figure explained the variation of amount of water required with respect to heat load. Using this, we can calculate the amount of water to be filled per day. The filled water will be desalinated to get distilled water by evaporation and condensation using baffle plates.

5. Conclusion:

A vacuum cooling system is developed and designed with the considerations of room heat load, vacuum pump power and pumping speed. As the system is combined with desalination system which further increases the efficiency of the system. Vacuum cooling is the new concept and it is emerging now. So the combined system of refrigeration with desalination is widespread and familiar in the mere future.

6. References

[1] A.Al-Salaymeh, M.R. Abdelkader, " Efficiency of free cooling technique in air refrigeration systems" Jordan Journal of Mechanical and Industrial Engineering, Volume 5, Number 4, Aug. 2011, Pages 325 – 333.

[2] Hala Al-Fulaij, Andrea Cipollina, Hisham Ettouney, David Bogle, Simulation of stability and dynamics of multistage flash desalination, Desalination 281 (2011) 404–412.

[3] Baltasar Peńate, Lourdes GarcÍa-RodÍguez, Current trends and future prospects in the design of sweater reverse osmosis desalination technology, Desalination 284 (2012) 1–8.

[4] Sreekumaran Thampy, Girish R. Desale, Vinod K. Shahi, Babubhai S. Makwana, Pushpito K. Ghosh, Development of hybrid electrodialysis-reverse osmosis domestic desalination unit for high recovery of product water, Desalination 282 (2011) 104–108.

[5] Pascale Compain, "Solar Energy for Water desalination", Procedia Engineering 46 (2012) 220 – 227.

[6] McDonald, K. and Sun, D. W., 2001, Effect of Evacuation Rate on the Vacuum Cooling Process of a Cooked Beef Product, Journal of Food Engineering, 48: 195-202

[7] Xue, X. Z. and Wang, Z. J., 1993, Studies of Development of Vacuum Conception, Natural Communication, 1: 59-66.

[8] Zhou, Y. A. and Wang, Y. F., 1999, Design and Calculation of Vacuum Proceeding Freeze Equipment, Refrigeration, 56(3): 36-40.

[9] John, F.O., 2005, Pumping Speed, A User's Guild to Vacuum Technology, 123-132.

[10] Van Atta, C. M. and Hablanian, M., 1991, Vacuum and Vacuum Technology, Encyclopaedia of Physics, 2: 1330-1333.

[11] K. Kalidasa Murugavela, 2009, Modeling and Verification of Double Slope Single Basin Solar Still Using Laboratory and Actual Solar Conditions,JJMIE, Volume 3, Number 3, September 2009 ISSN 1995-6665.