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Review Paper

Review On Technology for Improving the Energy Efficiency and Increasing the capacity of Ice Maker by WCR Heat Exchanger

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Abstract

WCR from ice makers is not a novel Concept. WCR equipment is commonly Implemented in industrial ice-making Systems, often in concert with water Purification systems. WCR heat exchangers have periodically been applied to commercial ice makers in the past, according to several industry representatives, with mixed results. Problems with scaling were reported and/or the benefits were not adequate to justify the initial cost. No scaling problems have been reported as yet by users of either the Fast Ice or Maximicer WCR heat exchangers, but water purity and ice maker design and operating settings affecting water purging (key factors affecting the propensity for scaling) have rarely been recorded, so it is difficult to predict safe or unsafe application conditions. Maximicer has incorporated plastic parts to insulate the WCR heat exchanger from any stray electric currents that enhance precipitate formation. However, no consensus has been reached on the preferred WCR heat exchanger design, as indicated by the differences in the Fast Ice and Maximicer units.

1. Introduction: Waste chill recovery (WCR) heat exchangers can be retrofit to commercial-size automatic ice makers to improve the energy efficiency and capacity of the ice maker. Commercial ice cube makers produce ice via a batch process. This ice-making process concentrates any impurities in the residual water, leaving the cube relatively pure and clear. Thus, some portion of the water charged to an ice maker must be purged to avoid scaling within the sump or on other ice maker components and to ensure that clear cubes are produced. The purge water is often near freezing or at least considerably cooler than the makeup water. The WCR device is a type of “shell and tube” heat exchanger that pre cools makeup water being charged to the ice maker with cold purge water being discharged from the ice maker. As a result, the amount of heat that must be removed from the water by the ice maker’s refrigeration system is reduced along with the electricity required to drive the refrigeration system. Reducing the amount of makeup water cooling also reduces the cycle time between harvests, which increase capacity.

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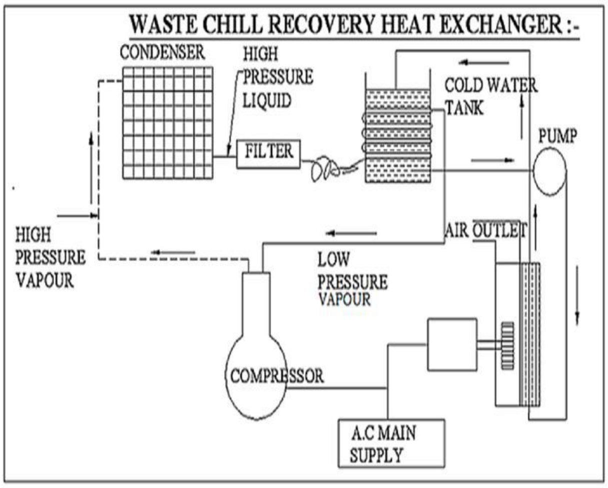

Fig (1): (lay-out WCR Heat Exchanger)

The cost-effectiveness of a WCR heat exchanger varies considerably depending on machine-specific and site-specific operating conditions. This *Federal Technology Alert* (FTA) presents detailed information and procedures that a Federal energy manager can use to evaluate the cost-effectiveness of potential WCR heat exchanger applications. WCR heat exchanger operating principles, design variations, energy-saving mechanisms, and other potential benefits are explained. Specific procedures and equations are provided for estimating energy savings. Proper application, installation, and operation and maintenance impacts are discussed. Two hypothetical case studies are presented to illustrate the evaluation procedures and equations. Manufacturers, users, and additional references are provided for prospective users who may have questions not fully addressed in this FTA. A description of Federal life-cycle costing procedures and a life-cycle cost summary for the Energy Conservation Investment Program are presented in the appendixes.

About the Technology: A waste chill recovery (WCR) heat exchanger could be applied to any ice maker to improve its energy efficiency. The WCR device is basically a type of "shell and tube" heat exchanger that pre cools makeup water being charged to the ice maker with cold waste water being discharged from the ice maker. A simplified, generic flow diagram of the concept is shown in Figure 1. Relatively warm makeup water flows through the tube while the near-freezing waste water flows around the tube within the shell of the heat exchanger. Heat is transferred from the makeup water to the discharge water, which lowers the temperature of the water charged to the ice maker's reservoir. As a result, the amount of heat that must be removed from the water by the ice maker's refrigeration system is reduced along with the electricity required to drive the refrigeration system. The effectiveness of the heat exchanger (i.e., its ability to transfer heat from the makeup water to the discharge water) depends on the amount of heat transfer surface area (tubing surface area) relative to the amount of heat being transferred and the layout of tubing and flow channels within the heat exchanger shell. Increasing heat transfer surface area enhances heat exchanger effectiveness but increases its size, weight, and cost.

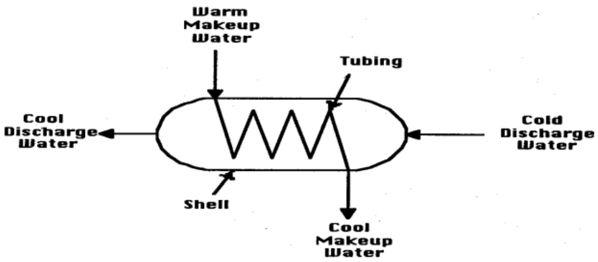

Fig 2.WCR Heat Exchanger Concept [1]

A "counter flow" layout that minimizes the temperature difference between the two fluid streams at any point along the tubing (imagine a smaller pipe [the tubing] within a larger pipe [the shell], with the makeup water entering the smaller pipe at one end and the discharge water entering the larger pipe at the other end) is best for heat transfer, but can result in a cumbersome or complex and costly design.

Application Domain: Currently, about 5,000 WCR heat exchangers have been installed on commercial ice makers, but only a few of these have been in Federal facilities. The current stock of commercial ice cube-making machines (not including flake-ice machines) is reported to be approximately 1.2 million in the U.S. (A.D. Little 1996), with about 1.5% of these estimated to exist in the Federal sector. Whether or not these units represent cost-effective applications depends on several site-specific (a) and machine-specific (b) characteristics each of these and additional factors are discussed in more detail later in this FTA. Fast Ice Products, Inc. and Maximicer Foodservice are the only firms known to offer WCR heat exchangers as auxiliary components for the equipment originally supplied by the ice maker manufacturers.

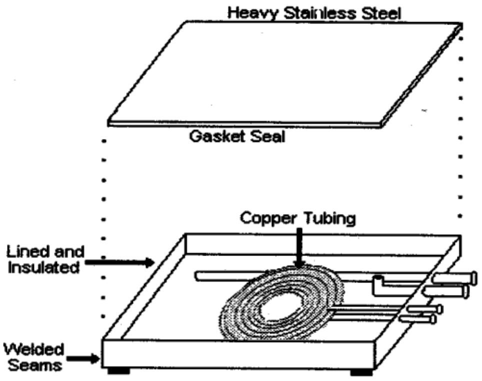

Fig. 3: Fast Ice WCR Heat Exchanger [3]

Similar devices are not currently offered by the ice maker manufacturers themselves as either a standard or optional feature, but Manitowoc plans to offer the Maximicer WCR heat exchanger as an accessory through its distributors in the near future.

Energy-Saving Mechanism: Although ice is made from potable water, the water still contains various impurities at different concentrations depending on the source. Common impurities include sodium, calcium, magnesium, and iron, which occur in the form of salts. In addition to these dissolved solids, the water may contain various suspended solids and microscopic organisms. The process of freezing water tends to concentrate the impurities in the water, resulting in ice that is purer than the original water. In particular, ice formed relatively slowly or by the continuous washing of the ice interface (the technique employed in cube ice makers) results in the purest and clearest product.

While clarity is a highly desirable ice attributes, the resulting concentration of impurities in the residual water will eventually cause precipitation and equipment scaling if allowed to grow unchecked. Thus, a portion of the water charged to an ice-making machine is continuously and/or periodically discharged to keep the impurities within a tolerable level. The problem is similar to that encountered in an evaporative cooling tower, where impurities are concentrated in the residual water not evaporated. In an evaporative cooling tower, “blow down” is the term used to describe water continuously or periodically purged to control impurity concentration.

Water charged to the ice maker must first be cooled to the freezing point before ice will form on the evaporator plates. At the conclusion of the ice making and harvesting cycle, part or all of the residual water, still at or near the freezing point, is purged from the ice maker and the reservoir is then refilled with makeup water that is often much warmer. The objective of the WCR heat exchanger is to capture part of the “chill “otherwise lost with the purge water by first absorbing energy from the charge water. Reducing the temperature of the water charged to the reservoir directly lowers the cooling load that must be served by the ice maker’s refrigeration system and the electricity required to drive the refrigeration system.

For ice makers with condensers located internal to the building, an important secondary energy benefit also accrues. Reducing the cooling load on the ice maker reduces the heat rejected by the ice maker to the building, which reduces the building cooling load (or increases the building heating load). Ice demand tends to be concentrated during the summer and cooling loads tend to dominate heating loads in commercial buildings. Thus, the net effect is almost always a reduction in a building’s HVAC energy loads and energy required to drive the HVAC equipment. Either the primary (ice maker) or secondary (HVAC) energy savings can be greater, depending on the efficiency of the ice maker and HVAC equipment.

Variations: As noted above and illustrated by Figures 2 and 3, the design approaches for constructing a WCR heat exchanger are nearly endless. The Fast Ice unit consists of a flat spiral of tubing within a rectangular shell. The Maximicer consists of a cylindrical shell within another cylindrical shell, with a helical spiral tube contained within the outer shell and a straight tube contained within the inner shell. The “counter flow” design of the Maximicer unit should result in Better heat exchange between the two fluids, but its purchase price is greater than the Fast Ice unit as well.

A comparison of these two or any other WCR heat exchangers must consider the expected reductions in reservoir water temperature and the benefits derived (e.g., reduced electricity consumption, increased ice-making capacity) from the reduced temperatures, as well as the initial costs of the units.

Installation: Both the Maximicer and Fast Ice heat exchangers are compact devices designed to fit behind, adjacent, and underneath the ice maker and its storage bin. Retrofit is relatively simple because the interface occurs outside of the ice maker and storage bin walls. Either unit requires four connections; both supply and discharge water lines are cut and deplumed to route each line through the heat exchanger. The discharge line entering the heat exchanger and the supply line leaving the heat exchanger should be insulated to prevent warming of the chilled water and potential water condensation on the outside of the tubing.

Application: The cost-effectiveness of a WCR heat exchanger is extremely site-specific; the payback period could be less than 1 year or greater than 100 years. The bulleted items listed below summarize the key favorable conditions that will most likely result in a cost-effective application. Not all of these conditions necessarily need to exist for an application to be cost-effective. Still, if the majority of these conditions do not exist, it is unlikely a WCR heat exchanger will be cost-effective.

- The annual demand for ice is relatively high, generally greater than 30% of its annual production capacity, if operated continuously throughout the year.

- The ice maker operates in a "purge" mode (as described in more detail in the body of the FTA) to charge and discharge its water reservoir.

- The average annual makeup water temperature is relatively high, generally greater than 60°F.

- The ice maker's condenser is located indoors.

Potential Benefits: As noted above, the direct benefit of the WCR heat exchanger is to reduce the temperature of the water charged to the ice maker's reservoir, lowering the cooling load served by the ice maker's refrigeration system and the electricity required to drive the refrigeration system.

Reducing the cooling load on the ice maker reduces the heat rejected by the ice maker to the building, which reduces the building cooling load (or increases the building heating load). Because ice demand tends to be concentrated during the summer and cooling loads tend to dominate heating loads in commercial buildings. Lowering the initial water temperature in the ice maker's reservoir also reduces the time required to cool the water to the freezing point, which reduces the entire ice making and harvesting cycle. In fact, the increased production rate may be the most valuable impact to users with inadequate ice-making capacity who may otherwise be forced to buy supplemental ice, purchase a supplemental refrigeration unit, or buy an additional ice maker.

Literature Summary: The present chapter includes the review of different literature in the field of *Technology for Improving the Energy Efficiency and Increasing the Capacity in the* refrigeration *and ice making industries*. The chapter is concluded with selection of proper method for determination of waste heat recovery heat exchanger for the commercial size ice makers.

WCR heat exchanger Related Literature Review:

In December 1997,The U.S. Department of Energy, have presented that the WCR heat exchanger can be the *Federal Technology Alert*(FTA), one in a series on new technologies, describes the theory of operation, energy-saving mechanism, and field experience for the technology, and presents a detailed methodology, including example case studies, for conducting a site-specific evaluation.

In May 2003, B.B. Saha, S. Koyama, T. Kashiwagi, A. Akisawa, K.C. Ng, H.T. Chua, have presented that Over the past few decades there have been considerable efforts to use adsorption (solid/vapour) for cooling and heat pump applications, but intensified efforts were initiated only since the imposition of international restrictions on the production and utilization of CFCs and HCFCs. In this paper, a dual-mode silica gel–water adsorption chiller design is outlined along with the performance evaluation of the innovative chiller. This adsorption chiller utilizes effectively low temperature solar or waste heat sources of temperature between 40 and 95 _C. Two operation modes are possible for the advanced chiller. The first operation mode will be to work as a highly efficient conventional chiller where the driving source temperature is between 60 and 95 _C. The second operation mode will be to work as an advanced three stage adsorption chiller where the available driving source temperature is very low (between 40 and 60 _C). With this very low driving source temperature in combination with a coolant at 30 _C, no other cycle except an advanced adsorption cycle with staged regeneration will be operational. The drawback of this operational mode is its poor efficiency in terms of cooling capacity and COP. Simulation results show that the optimum COP values are obtained at driving source temperatures between 50 and 55 _C in three-stage mode, and between 80 and 85 _C in single-stage, multi-bed mode.

In September 2004, Y.L. Liu, R.Z. Wang*1, Z.Z. Xia, have presented that A newly developed adsorption water chiller is introduced and tested. In the new adsorption refrigeration system, there are no refrigerant valves, the problem of mass transfer resistance resulting in pressure drop along refrigerant passage in conventional systems when methanol or water is used as refrigerant can be absolutely solved. Silica-gel–water is used as working pair and mass recovery-like process is adopted in order to use low temperature heat source ranging from 70 to 85 8C effectively. The experiment results demonstrate that the chiller (26.4 kg silica-gel in each absorber) has a cooling capacity of 2–7.3 kW and COP ranging 0.2–0.42 according to different evaporating temperatures. Based on the experimental tests of the first prototype, the second prototype is designed and tested; the experimental data demonstrate that the chiller performance has been greatly improved, with a heat source temperature of 80 8C, a COP over 0.5 and cooling capacity of 9 kW has been achieved at evaporating temperature of 13 8C.

In December 1990, R.Z. Wang*, J.Y. Wu, Y.X. Xu, W. Wang, have presented that A heat regenerative adsorption refrigerator using spiral plate heat exchangers as absorbers' and an adsorption heat pump for air conditioning using plate ®n heat exchangers or plate ®n shell and tube type heat exchangers as absorbers have been developed and researched. Experimental research results are shown. The activated carbon methanol adsorption pair is used for the two kinds of adsorption systems. With a heat source temperature of 1008C, the refrigerator achieved a refrigeration power density of more than 2.6 kg ice per day per kg activated carbon with a co-efficient of performance (COP) of 0.13, and the heat pump achieved 150 W/kg activated carbon for air conditioning with a COP of about 0.4.

In February 2001, A.O. Dieng*, R.Z. Wang, have presented that the primary objective of this review is to provide fundamental understandings of the solar adsorption systems and to give useful guidelines regarding designs parameters of adsorbent bed reactors, and the applicability of solar adsorption both in air-conditioning and refrigeration with the improvement of the coefficient of performance. Solar adsorption heat pump and refrigeration devices are of significance to meet the needs for cooling requirements such as air-conditioning and ice-making and medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. For these reasons the research activities in this sector are still increasing to solve the crucial points that make these systems not yet ready to compete with the well-known vapor compression system. There is an increasing interest in the development and use of adsorption chillers due to their various economic and impressive environmental benefits, enabling solar energy or waste heat to be used for applications such as district networks and cogeneration plants. Compared to adsorption systems that require heat sources with temperatures above 100°C (zeolite–water systems, activated carbon–methanol systems) or conventional compressor chillers, a silica gel/water adsorption refrigerator uses waste heat with temperature below 100°C. This creates new possibilities for utilizing low temperature energy.

In *March 1998*, R. Z. WANG*, Y. X. XU, J. Y. WU AND W. WANG, have presented A heat-regenerative adsorption refrigerator using spiral plate heat exchangers as absorbers and an adsorption heat pump for air conditioning using plate Þn heat exchangers as absorbers have been developed and researched, experimental research results are shown. The activated carbon methanol adsorption pair is used for the two adsorption systems, which yield a refrigeration power density of more than 2)6 kg ice per day per kg activated carbon and 150Wkg~1 activated carbon for air conditioning, respectively.

In 2008, S.Gh. Etemad, B. Farajollahi, have presented that In the present experimental study heat transfer behavior of γ-Al2O3/water nano fluid in a shell and tube heat exchanger was investigated. The experiments were done for the results obtained for a range of Peclet number and nano particle concentrations.

The experimental results indicate that the heat transfer characteristics of nano fluid enhance significantly with increasing Peclet number. For example nano fluid with 0.5% nano particle volume concentration possesses about 20%, 56%, and 54% higher overall heat transfer coefficient, convective heat transfer coefficient and Nusselt number, respectively. Also there is an optimum for volume concentration in which the nano fluid shows the maximum heat enhancement.

Conclusion: The WCR heat exchanger can be Lowering the initial water temperature in the ice maker's reservoir reduces the time required to cool the water to the freezing point, which reduces the entire ice making.

The increased production rate may be the most valuable impact to users with inadequate ice-making capacity.

Reducing the cooling load on the ice maker should result in less "wear and tear," resulting in lower maintenance costs and longer equipment life.

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