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Indirect evaporative cooling: Past, present and future potentials

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A B S T R A C T

This paper reported a review based study into the Indirect Evaporative Cooling (IEC) technology, which was undertaken from a variety of aspects including background, history, current status, concept, standardisation, system configuration, operational mode, research and industrialisation, market prospect and barriers, as well as the future focuses on R&D and commercialisation. This review work indicated that the IEC technology has potential to be an alternative to conventional mechanical vapour compression refrigeration systems to take up the air conditioning duty for buildings. Owing to the continuous progress in technology innovation, particularly the M-cycle development and associated heat and mass transfer and material optimisation, the IEC systems have obtained significantly enhanced cooling performance over those the decade ago, with the wet-bulb effectiveness of greater than 90% and energy efficiency ratio (EER) up to 80. Structure of the IEC heat and mass exchanger varied from flat-plate-stack, tube, heat pipe and potentially wave-form. Materials used for making the exchanger elements (plate/tube) included fibre sheet with the single side water proofing, aluminium plate/tube with single side wicked setting (grooved, meshed, toughed etc), and ceramic plate/tube with single side water proofing. Counter-current water flow relevant to the primary air is considered the favourite choice; good distribution of the water stream across the wet surface of the exchanger plate (tube) and adequate (matching up the evaporation) control of the water flow rate are critical to achieving the expected system performance. It was noticed that the IEC devices were always in combined operation with other cooling measures and the commonly available IEC related operational modes are (1) IEC/DEC system; (2) IEC/DEC/mechanical vapour compression system; (3) IEC/desiccant system; (4) IEC/chilled water system; and (5) IEC/heat pipe system. The future potential operational modes may also cover the IEC-inclusive fan coil units, air handle units, cooling towers, solar driven desiccant cycle, and Rankine cycle based power generation system etc. Future works on the IEC technology may focus on (1) heat exchanger structure and material; (2) water flowing, distribution and treatment; (3) incorporation of the IEC components into conventional air conditioning products to enable combined operation between the IEC and other cooling devices; (4) economic, environment and social impacts; (5) standardisation and legislation; (6) public awareness and other dissemination measures; and (7) manufacturing and commercialisation. All above addressed efforts may help increase the market ratio of the IEC to around 20% in the next 20 years, which will lead to significant saving of fossil fuel consumption and cut of carbon emission related to buildings.

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1. Introduction

The building sector is responsible for around 30–40% of world total energy consumption and similar proportion of global carbon emission [1]. Heating, Ventilation and Air Conditioning (HVAC) is the major energy user in a building and consumes around 50% of the total supplied energy [1]. Air-conditioning, representing an important function of the HVAC system, is becoming increasingly crucial for many buildings, particularly those public types e.g., office blocks, supermarkets, sport centers, airports, factories etc, owing to recent frequent warm spells, improved building insulation and growth of in-house heat generating appliances. In hot and/or arid regions e.g., Middle East, Far East and North American, air conditioning has become part of the people's life need; whilst its use in mild climatic regions such as UK, Denmark and other European regions is also rapidly growing [2]. During the hottest summer period when air conditioning is in full operation, many cities in China, Kuwait etc. [3], experienced difficult power-overloads that often led to unwanted grid 'cut-off'. Concerning with the extensive need for air conditioning and growing pressure on energy saving and carbon emission in building sector [4], seeking for routes to reduce fossil fuel consumption and increase utilization of natural or renewable energy during air conditioning process is of particular importance.

Air conditioning market is currently dominated by the mechanical vapour compression refrigeration system which, formed as a loop (Fig. 1) comprising an evaporator, a condenser, a compressor and an expansion valve, allows a refrigerant (e.g., R-22, R-134a, R410A) to circulate around. Within the evaporator, the refrigerant absorbs heat from the surrounding causing change of its phase from liquid to vapour and subsequently the cooling of the surrounding medium (e.g., water, air). Afterwards, the refrigerant is fed into the compressor which, through delivering a significant electrical power, enables generation of a high pressure, super-saturated refrigerant vapour. This form of vapour then enters into the condenser; whereas it loses heat to surrounding medium, leading to condensation of the high pressure refrigerant vapour. Leaving off the condenser, the refrigerant comes across an expansion valve which, through the throttle effect, causes reduction of the refrigerant's pressure. This low pressure refrigerant is then back to the evaporator to recollect the heat. This kind of cycle was fully established and has been in practical use for over 100 years. Owing to its relatively long history and massive scale production, the technology presents many advantages e.g., good stability in performance, low cost, long life cycle time and reasonable good energy performance (COP in the range of 2–4). However, this type of system has a major disadvantage that lies in high demand to electricity for operation of the compressor. Owing to the high dependency of fossil fuel burning in current electrical industry, this technology is regarded as neither sustainable nor environmentally friendly [5].

Absorption and adsorption cooling, as a potential alternative to conventional mechanical vapour compression systems, remove need for the power-intensive compressor but add up requirement for high temperature vapour or water. The absorbent system is a liquid desiccant cycle comprising a desiccant absorber, regenerator, condenser, evaporator, expansion vale and piping connections, as shown schematically in Fig. 2. This system would absorb heat on one side (evaporator) to enable cooling of a medium (e.g.,

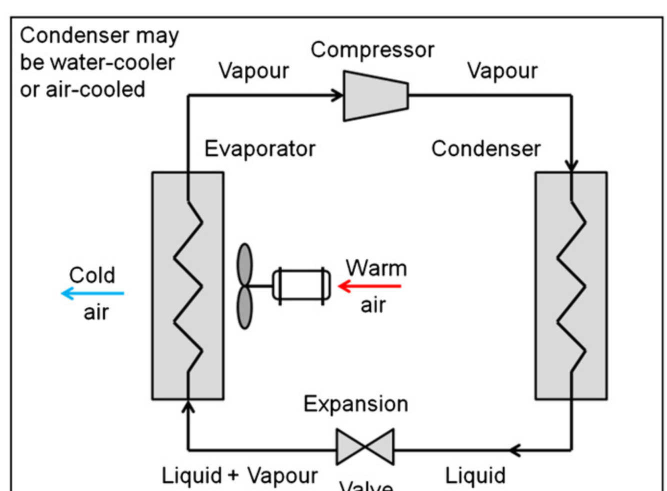

Fig. 1. Conventional vapour compression refrigeration cycle.

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