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Applying a magnetic field on liquid line of vapour compression system is a novel technique to increase a performance of the system

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HIGHLIGHTS

- Magnetic field enhances the performance of vapour compression system.
- Magnetic field strength has direct relation with increase in COP.
- There is a limiting field strength till which this improvement is observed.
- Beyond limiting field strength system performance degrades.
- Performance improvement due to change in thermo-physical properties of refrigerant.

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ABSTRACT

This paper presents experimental investigations carried out to study the effect of magnetic field on energy savings in vapour compression system. Application of magnetic field to fluid flow breaks the molecule resulting in a decrease in the viscosity of the fluid. This drop in the viscosity reduces the pumping power required by the compressor as well as enhances the heat transfer rates in the condenser and evaporator due to increased mass flow rates. The net impact is improvement in the COP of the system. Considering the number of refrigerator and air conditioning systems sold globally every year any improvement in the COP could considerably save the energy bills as well as the energy requirement. The main benefit of this investigation is improvement in the system performance improvement in Evaporator capacity or drops in compressor power or increased COP at no cost i.e. no additional input energy. Only cost involved is the initial cost of magnets to be procured for applying suitable magnetic field. The present work was focused on first establishing the effect of magnetic field on the performance of the vapour compression system and then investigating the impact of magnetic-field strength on COP. The magnetic field strength was varied by increasing the number of magnet pairs applied to the liquid line (from condenser outlet to entry of expansion valve). The COP was initially measured without application of magnetic field, and then magnetic field applied to liquid refrigerant was increased by increasing the number of the magnetic pair from 1 to 5. The strength of each magnetic pair was 3000 gauss. The result obtained showed improvement in COP of the system under investigation. The COP of the system increased up to13.13% for R134a and 21.87% for R600a refrigerant.

1. Introduction

Vapour compression cycle is commonly used refrigeration cycle, first reported in 1748 by Professor Williams Cullen of Glasgow University who produced refrigeration by partial vacuum over ethyl ether. This system was further modified to a hand-operated compressor machine working on ether, by Jacob Perkins. This was further improved by motor driven compressor and in present days commonly used in most of the household refrigerators as well as in large commercial refrigeration systems. The implication of CFC (Chlorofluorocarbon) and HCFC (Hydrochlorofluorocarbon) refrigerants has an adverse impact on stratosphere layers of the earth such as ODP (Ozone Depletion potential) and GWP (Global Warming Potential). As per the Montreal protocol and Kyoto these refrigerants need to be phased out and replaced with less harmful

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ones, having ideally zero ODP and GWP. The HFC (Hydrofluorocarbon) refrigerants having zero ozone depletion potential are recommended as alternatives to the CFC and HCFC. R134a is the long term replacement refrigerant for R12 because of its favourable characteristics such as 0 ODP and 0.29 GWP [1,2]. Several studies have reported the use of magnetic elements for the improvement in the VCC (Vapour Compression Cycle). Magnetism is one of the characteristics of materials to respond at an atomic or subatomic level to an applied magnetic field.

The magnetic-field MCE is defined as the heating or cooling of magnetic materials upon magnetic field variation [3,4]. The magnetic field has a strong influence on physical properties such as an entropy, heat capacity, and thermal conductivity of a magnetic material [5–11]. Warburg first discovered the thermal effect of metal iron when applying for it in a varying magnetic field in 1881; known as MCE (Magneto-Caloric Effect) [12]. Debye and Giauque discussed the nature of MCE and suggested achieving an ultra-low temperature by adiabatic demagnetization cooling. The magnitude of MCE of magnetic material is the keyway to cooling capacity [13,14]. Silva et al. numerically studied AMRR (active magnetic regenerative refrigerator); they used a magnetic field to change the thermal conductivity of the magneto caloric material such as gadolinium [15].

The EHD (Electro-Hydrodynamics) technique has shown an improvement of the heat transfer on the refrigerant side [16]. Magnetic refrigeration is an environment-friendly refrigeration technology. The magnetic field required for refrigeration can be supplied by electromagnets, superconductors or permanent magnets. Capital cost required for magnetic field is also less and it does not have any harmful effect on the environment [17]. Bera and Babadagli have briefly explained about the recovery of heavy oil by using electromagnetic heating [18]. Samanta and Guha have carried out analysis on electrically conductive fluid over the horizontal plate under the influence of magnetic field. He studied the effect of magnetic field on different profiles (i.e. velocity, temperature), heat transfer and skin friction coefficient [19].

Aiboud-saouli et al. have carried out experiments on application of transverse magnetic field on two parallel heated plates through which liquid was allowed to flow. Studies have reported that of magnetic field affects thermophysical properties (i.e. temperature, viscous dissipation on velocity and entropy generation) of the fluid [20,21]. Jia developed a mechanism by using the electromagnetic field containing the change in characteristics of graphenes in the presence of ice water boundary; the results showed electromagnetic field was encouraging graphene engulfment [22]. Applying magnetic field introduces a dynamic environment by which the fluids are influenced on boundary resulting in breaking of molecular cluster (de-clusters), with dynamic result (reduction in viscosity) which decreases the pumping power or compressor input [23].

Globally energy usage for building is 40%. India is 6th ranked place in the world in terms of energy requirement, consumes 3.5% of the world energy which is used for commercial purpose. Most of developing countries in the world face difficult challenges to meet their energy needs and also to provide sufficient amount of energy at reasonable price. To face these challenges government, industries and civil organisations should promote the rapid deployment of the energy efficient technologies. One of the promising directions to achieve this goal is to accelerate the adoption of energy efficient HVAC systems [24].

Heat pumps are used for space heating or cooling in buildings. Heat pump is the main technology used for space cooling either by air conditioner or chillers. Worldwide around 800 millions of heat pumps were installed for different applications. Numbers of researchers are interested to develop more efficient components of the system heat pump rather we will say to develop integrated and hybrid (includes other energy technologies) heat pumps. They kept the milestones that 20% improvement on COP of the heat pump by 2020; 50% up to 2030 [25,26]. More than 24% of Energy utilized for heating, ventilation and cooling, out of this energy more than 50% goes for cooling. Creating more efficient heat pump is a main aspect to reduce operating cost of building [27].

A chiller is heat transfer device that runs on vapour compression or absorption cycle and removes heat from water or non freezing mixture. Water can be cooled up to 2 °C; however required temperature of water depends upon the application. In air-conditioning machines, Chilled water is used in the devices to cool and dehumidify the air flow. Chillers often used for industrial applications such as injection moulding, welding, food processing, paper industries and chilled drinking water dispensing units. Chillers can be classified in two types. (I) Centralized (only one chiller satisfy multiple cooling requirements). (II) Decentralized (for each purpose have its own chiller). Decentralized chillers are small in size and capacity compared to centralized chillers. The cooling capacity of decentralized chillers is up to 10 tons. The various approaches can be used to increase the efficiency of chillers. (I) Controlling the chilled water supply by sensing cooling load, (II) by lowering the condenser temperature, (III) chiller sequencing (in case of multi-chillers, system ensures that proper combination of the chillers is running near to maximum efficiency for set load), (Iv) maintenance.

Vapour compression chillers consists of four key components (i.e. Compressor, condenser, expansion or refrigerant metering device and evaporator). Compressors used in chillers are reciprocating, scroll, screw driven and centrifugal type, electric motor is used as a drive for compressor. Condenser rejects the latent heat of refrigerant to air or water and converts into liquid form. Therefore there are two types air cooled and water cooled condenser. In air cooled condenser heat is rejected to air, the heat rejected in water cooled condenser in two steps first refrigerant rejects the heat to the water, then hot water is pumped to cooling tower where hot water ultimately reject the heat to surrounding. Air cooled condenser is often selected in case off less operating and maintenance cost, also in freezing environment. If the large water temperature differential is available the cold water is not directly sent to application, but it is stored as a buffer [27,28]. In the current research work hermetic reciprocating compressor and air cooled condenser were employed.

Some researchers have studied dynamic model of vapour compression system. Yao et al. developed state space model to investigate the dynamic performance of chiller under transient conditions and design was optimized under controlled strategies for efficient heating, ventilation and cooling system (HVAC) [29]. Shing Lee and Lu evaluated six empirically based models in the year of 2010 and eleven in 2012 for forecasting chiller performance from available data sets. These models are used for energy analysis, energy efficiency improvements, performance prediction and fault detection of chillers [30,31]. Monfet and Zmeureanu proposed two models, Artificial Neural Network (ANN) and co-relation based model for comparison of energy performance of water cooled electric chillers [32]. Power imbalance in grid operation is increases due to integration of renewable energies. To achieve the grid balance end users must have to reduce their power demands. Conventional strategy directly shut downs the important operating chillers, due to this inadequate cooling supply will occur. Xue et al. have developed power demand response control strategy for buildings to overcome this problem [33]. Combined systems are used to improve an efficiency of the chillers, combined system uses the waste heat rejected by the condenser for preheating of water and water can be used for another purpose. Gong et al. studied the performance of components combined system of chiller [34]. Kitanovski et al. presented technical analysis on liquid magnetic chillers. They also presented the correlations of the COP and cooling capacity of the