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Review Article

Magnetic Field Effects on Refrigeration Systems: A Comprehensive Review

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Abstract *- In the midst of the sustainable energy revolution, minimizing energy consumption in refrigeration systems has emerged as a prominent and vital focus area. A substantial quantity of research studies has been conducted on these types of systems in the last few decades. The present research work gives a comprehensive classification and review of available research studies on magnetized refrigeration systems, specifically Vapour Compression Refrigeration Systems (VCRS) and Vapour Absorption Refrigeration Systems (VARS). The influence of magnetic fields on fluid flow interactions is discussed, categorizing studies into Electro-Hydrodynamics (EHD) and Magneto-Hydrodynamics (MHD). The unique effects of magnetization on the thermophysical properties of electrically conducting fluids are highlighted. Furthermore, an important discussion is provided, exploring the fundamental reasons underlying the impacts of magnetic treatment on the thermophysical properties of electrically conducting fluids. The research article typically covers the experimental work conducted on the impact of magnetization on VCRS and VARS in the last two decades.*

Keywords *- MHD, VCRS, VARS, Classification of fluid flow interactions, Energy.*

1. Introduction

Magnetization is well-known for influencing the characteristics of various materials, particularly causing changes in temperature. This phenomenon, known as the Magnetocaloric Effect (MCE), involves an increase in temperature when a magnetic exposure is provided and a subsequent reduction when the exposure is removed, impacting the entropy and heat content of the material. Figure 1 shows stages of the magnetic refrigeration cycle based on MCE. While the effects of magnetization on fluids are not fully understood, it is widely acknowledged that subjecting these fluids to a magnetic field leads to significant alterations.

A plethora of research in the literature supports the idea that magnetic fields can affect thermodynamic properties. Numerous studies have explored the use of magnetization to enhance performance in various applications, such as water treatment, fuel lines, diesel engines, oil, refrigeration, and natural gas furnaces. The influence of magnetic fields on VCRS was initially observed by researcher Samuel Sami in 2003 during an investigational work on the impact of magnetic treatment of refrigerant blends [1].

Over the past two decades, there has been increasing attention to advancing Magnetohydrodynamics (MHD) technology, with both practical and theoretical developments. Despite this attention, commercialization of the technique has been limited.

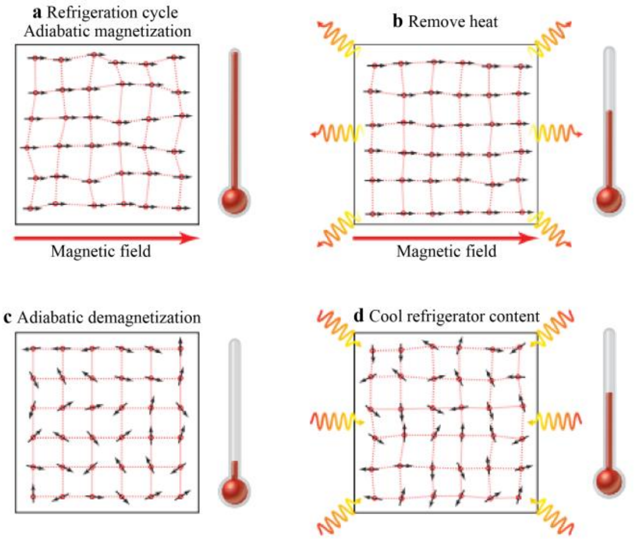

Fig. 1 Stages of magnetic refrigeration cycle based on MCE

Discussing recent advancements in MHD technology is essential to comprehend its progress and laying the groundwork for future developments. Several review papers in the literature detail the influence of different magnetizations on fluid heat transfer characteristics and overall system performance. Table 1 summarizes several of these review studies, highlighting the impacts of various magnetic exposures on fluid interactions in the last decade. Notably, there is a gap in the literature concerning review papers specifically focused on the effects of MHD on refrigerants and the consequent improvements in the performance of refrigeration systems. The magnetic treatment of conducting fluids and its potential for enhancing system performance have attracted considerable attention among researchers in the field of MHD, warranting a comprehensive discussion. Figure 2 provides the year-by-year breakdown of research article quantities reviewed, while Figure 3 illustrates the statistics regarding the number of papers reviewed concerning performance enhancement methods.

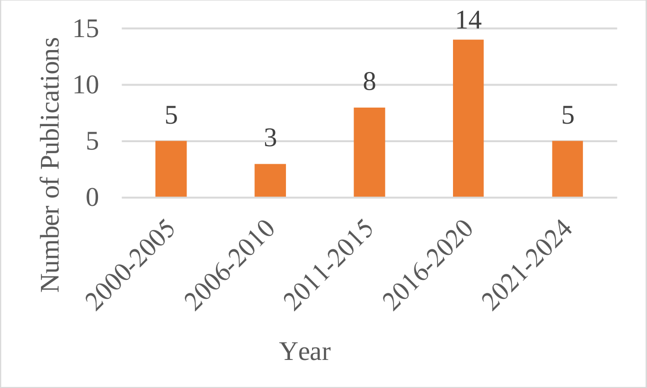

Fig. 2 Year-by-year breakdown of research article quantities reviewed on electrically conducting fluids (In this article)

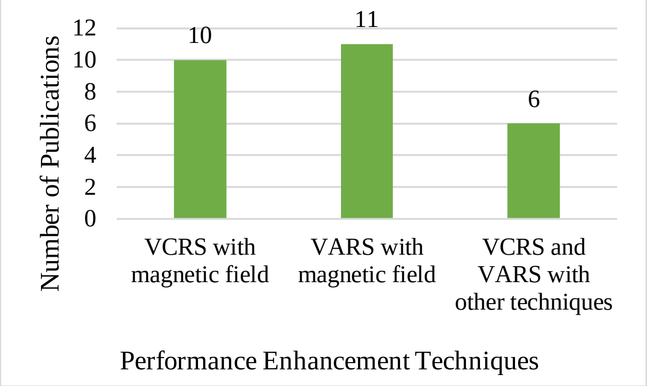

Fig. 3 Statistics of the number of papers reviewed concerning the performance improvement techniques (In this article)

The main objective of this work is to give a thorough categorization of fluid interactions with diverse magnetic fields, offering a comprehensive examination of both experimental and theoretical investigations into the effects of Magnetohydrodynamics (MHD) on electrically conducting fluids in recent years. Additionally, the paper encompasses a detailed review of the application of MHD in refrigeration systems. A comprehensive examination of MHD's impact on weakly electrically conducting fluids is conducted, highlighting their primary advantages and potential avenues for future research. This study serves as a valuable resource, offering profound insights for researchers engaged in this field and presenting a useful foundation for future endeavors.

Table 1. Overview of review papers on fluid interactions with various magnetic fields

S. No.	Description	Year	Reference
1	EHD phenomenon, Flow and heat transfer enhancement, EHD fluid pumps, Drying and evaporation	2014	Fylladitakis et al.
2	Impacts on flow field and heat transfer behaviour, Industrial and medical applications	2015	Kabeel et al.
3	EHD drying	2016	Martynenko et al.
4	The impact of electric fields on the boiling behavior of both insulating and conducting liquids.	2016	Shahriari et al.
5	Simulation studies on the treatment of nanofluid in the presence of magnetization	2017	Sheikholeslami et al.
6	Utilizations of Electrohydrodynamics (EHD) in boiling, condensation, evaporating, solar energy systems	2017	Rashidi et al.
7	Influences of magnetization on pool and flow boiling, impact of electric field on pool and flow boiling	2019	Zonouzi et al.

2. Classification of Performance Enhancement Techniques for Thermal Energy Systems

The performance improvement techniques for thermal energy systems (TES) are broadly classified as active and passive techniques. Further, the application of magnetic fields on thermal energy systems can also be categorized based on the electrical conductivity of fluids.

A broad classification of performance enhancement techniques for TES is shown in Figure 4. The noticeable research study carried out on the performance enhancement techniques for refrigeration in the recent past is explained in the following text.

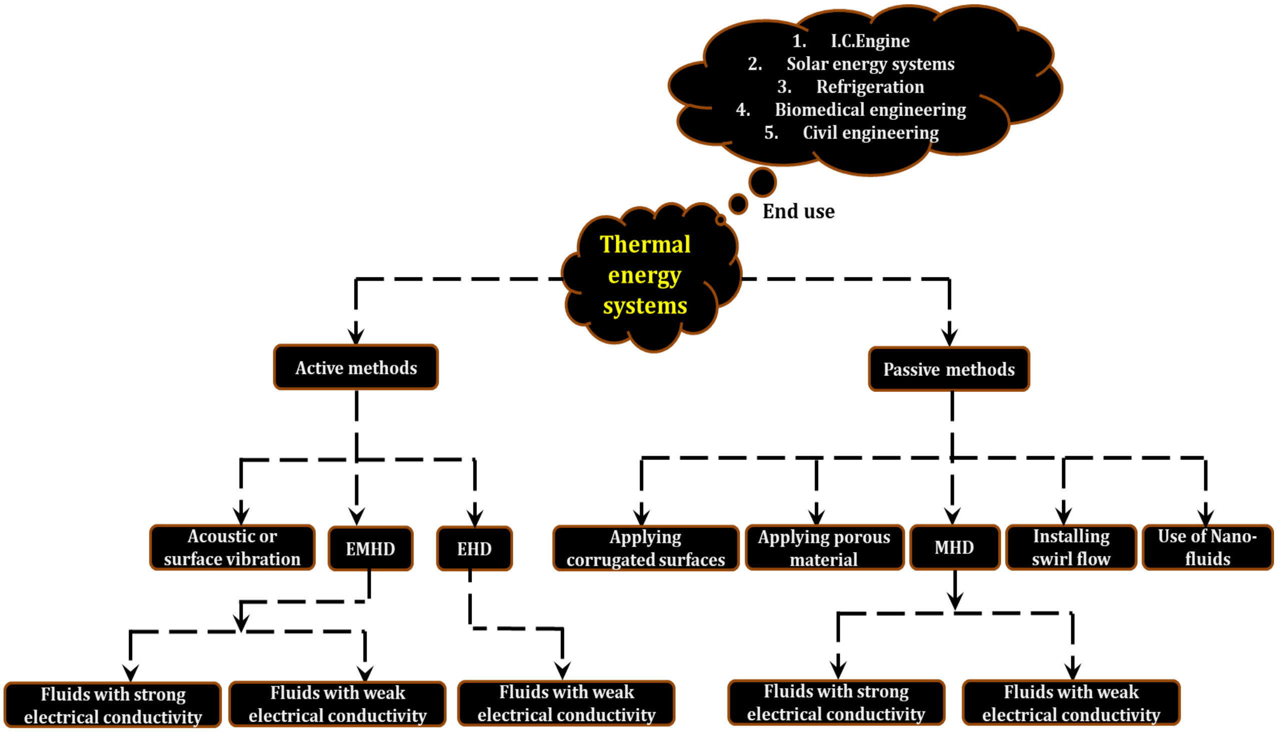

Fig. 4 Classification of performance improvement methods for thermal energy systems

3. Effects of Magnetization on the Behavior of Electrically Conducting Fluids

This section delves into research findings regarding the effect of magnetization on electrically conductive fluids like water, hydrocarbon fuels, and refrigerants and explores their implications for various end applications.

3.1. Categorization of the Interaction between Fluid Flow and Magnetic Fields

The exploration of magnetic field influences on fluids with electrical conductivity is not exhaustive, yet it is well-established that significant transformations occur when these fluids traverse magnetic fields. This study categorizes fluid interactions with magnetic fields into two primary domains: Electro-Hydrodynamics (EHD), focusing on the impact of electric forces, and Magneto-Hydrodynamics (MHD), addressing the effects of magnetization on electrically conducting fluids. Additionally, the investigation into the impacts of both electric field and magnetization on fluid conductors of electricity, or magnetic fluids, falls under Electro-Magneto-Hydro-Dynamics (EMHD) . Classification of fluid flow interaction of electrically conducting fluid with various magnetic exposures is depicted in Figure 5.

3.2. Exploring Magneto-Hydrodynamics (MHD) and its Influence on the Thermophysical Characteristics of Electrically Conducting Fluids

The examination of fluid interactions between electrically conducting fluids and a magnetic field generated by permanent magnets is termed Magneto-Hydrodynamics. When an electrically conducting fluid flows through a static external perpendicular magnetic field, it induces electrical currents within the fluid. These induced currents interact with the applied external magnetic field, giving rise to a magnetic force that consequently modifies the heat transport phenomenon.

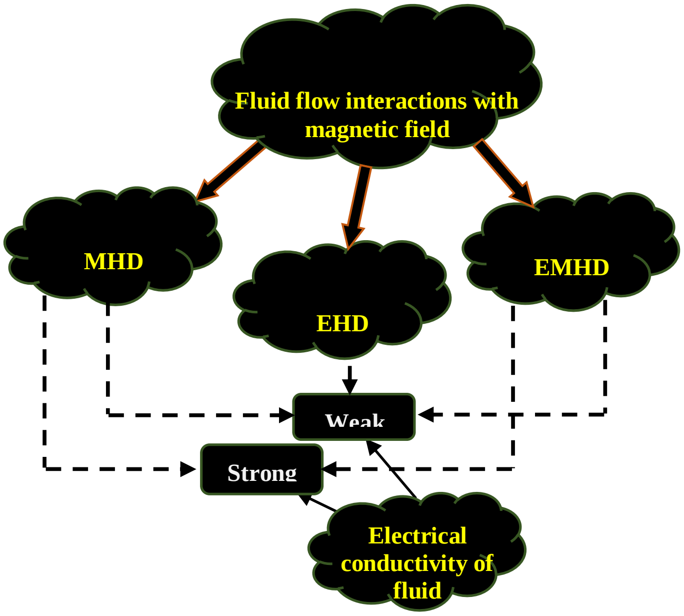

Fig. 5 Classification of fluid flow interaction of electrically conducting fluid with different magnetization

The introduction of magnetization disrupts the clusters of molecules, leading to alterations in the thermophysical characteristics of fluids, including changes in surface tension, boiling point, specific heat, viscosity, thermal conductivity, and more. Table 2 shows the influence of magnetization on the thermo-physical characteristics of some electrically conducting fluids. Figure 6 illustrates the de-clustering of conducting fluids with magnetization, resulting in the generation of smaller particles. Niaki et al. delved into the physical phenomenon behind the loosening of hydrocarbon bonds in robust magnetization, studying the absorption spectrum of ultraviolet light [2]. Magnetization of crude oil and paraffin sample solutions induced changes in the rheological behavior, as demonstrated in Figure 7. Figure 8 shows the significance of covalent bonds in electrically conducting fluids. Figure 9 to Figure 11 illustrates the root cause of variations in thermophysical characteristics of electrically conducting fluids under magnetization.

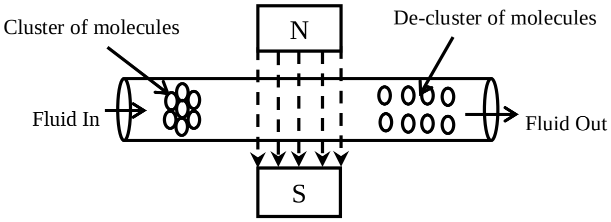

Fig. 6 Breaking of molecular cluster using permanent magnets

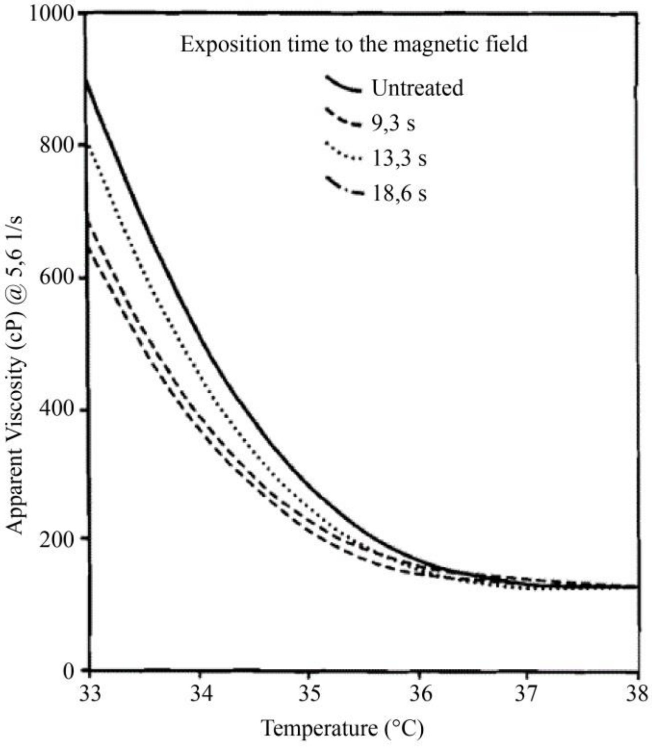

Fig. 7 Graphical representation of rheological properties for crude oil [3]

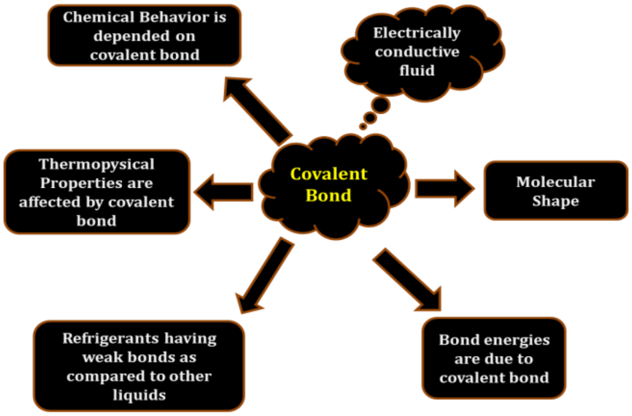

Fig. 8 Significance of covalent bond in electrically conducting fluids

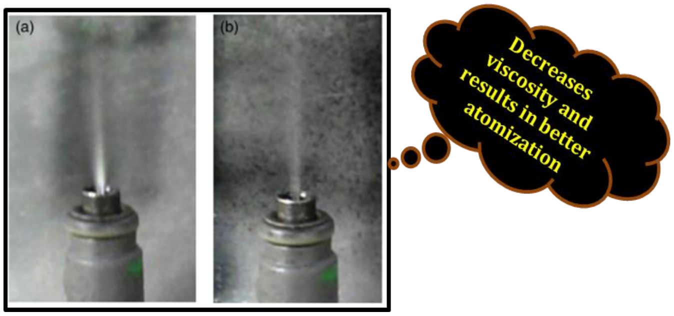

Fig. 9 Impact of magnetization on a spray of fuel from the injector (a) In the absence, and (b) In the presence of magnetization [2].

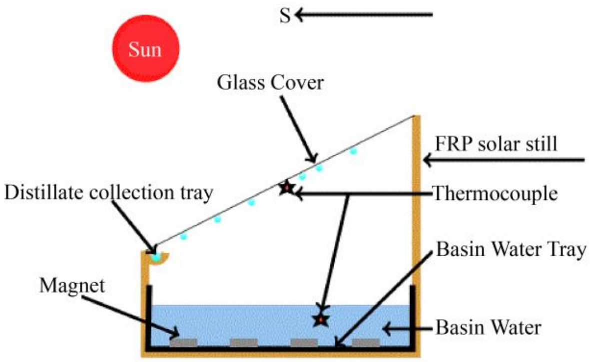

Fig. 10 Schematic representation of magnetized solar still [4]

4. Effect of Magnetic Treatment on Refrigeration System Performance

This section is divided into two parts; the first deals with the impact of magnetization on the performance of VCRS, and the latter deals with magnetic field effects on VARS. Numerous investigational and numerical works have been shown for VCRS and VARS, which are reported in the literature. A summary of several studies on VCRS is presented in the corresponding section. The summary is derived from numerical and experimental outputs, highlighting the important outcomes of various authors. Moreover, a summary of the review paper available on magnetic field impact on VCRS and VARS is provided in Table 3.

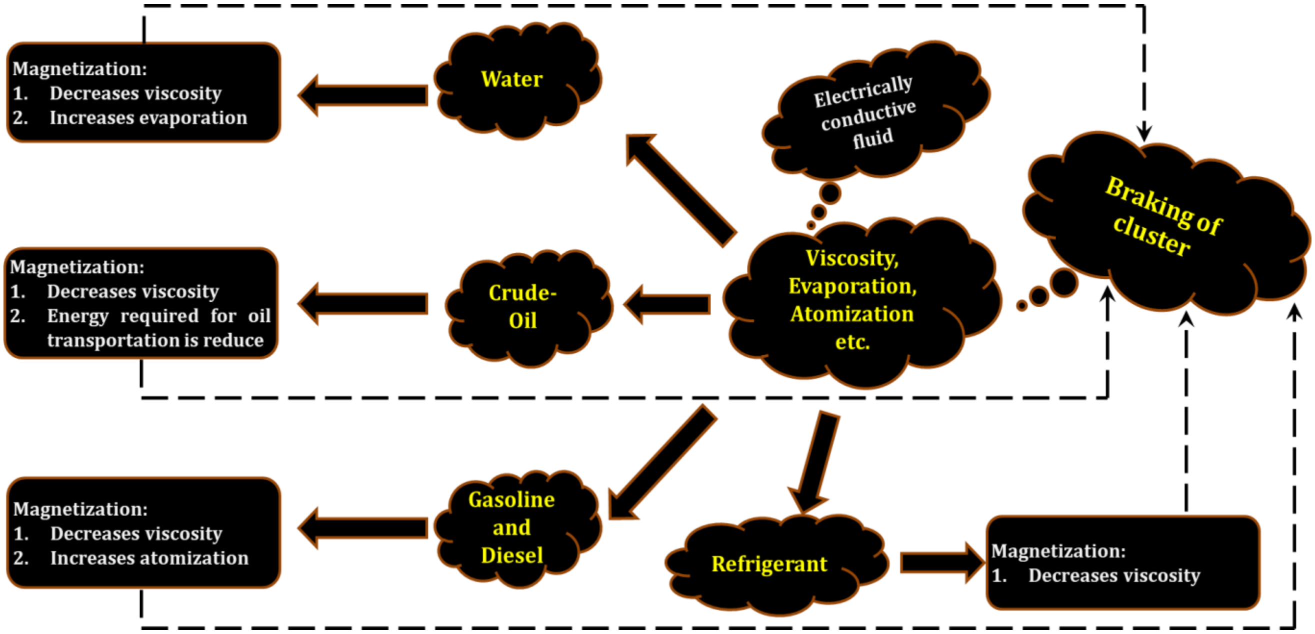

Fig. 11 Root cause of variations in thermophysical characteristics of electrically conducting fluids under magnetization

Table 3. Overview of review papers on magnetized refrigeration systems (VCRS and VARS)

S.N.	Description	Year	Reference
1	Impact of Magnetic Treatment on VCRS	2018	Dangle et al.
2	Performance enhancement methods for VCRS	2018	Deshmukh et al.
3	Influence of magnetization on diffusion absorption refrigeration cycle	2019	Jadhav et al.

4.1. Impact of Magnetization on the Performance of VCRS

The energy consumption of households is profoundly impacted by refrigeration and air-conditioning systems. Even a marginal enhancement in their efficiency, quantified by the COP, can lead to considerable energy conservation. Therefore, it is essential to investigate solutions that reduce compressor power utilization, thereby enhancing the overall efficiency of the thermal energy system. An encouraging approach in this regard is the implementation of a magnetic field, renowned for its cost-effectiveness, low maintenance, and the advantage of not requiring additional modifications to the conventional system's existing components. A summary of magnetization impacts on VCRS is provided in Table 4.

Multiple investigations, including works by Sami and Aucoin [1], Mani and Selladurai [11], Sami and Kita [6], and Tipole et al. [12], have underscored the effectiveness of utilizing magnetization to improve VCRS. The use of magnetic treatment in refrigeration can be accomplished through superconducting magnets or electrical energy. Significantly, the reported low principal cost associated with implementing magnetic treatment and its environmentally benign impact make it a noteworthy consideration.

Sami and Aucoin [1] explored the impact of magnetization on several refrigerant mixtures flowing via enhanced surface tubes in air-cooled heat exchangers. Employing three magnetizers, each producing a magnetic exposure of strength 0.4 T, they investigated blends such as R507, R404A, R410A, and R407C.

A diagram illustrating the experimental test-rig setup can be found in Figure 12. The experimental results revealed that applying a magnetic exposure at the condenser outlet led to efficiency enhancements in both the condenser and evaporator, consequently boosting the performance of VCRS.

Sami and Kita [6] explored the influences of magnetization on substitute refrigerant blends, specifically R-410A, R-507, R-407C, and R-404A, in the context of an air-source heat pump. The refrigerant mixtures underwent exposure to a 4000 Gauss magnetic field applied through three magnetic elements in the liquid line of the condenser.

The study's findings indicated that the reply of refrigerant mixtures to magnetization is contingent on the composition, boiling point, and thermophysical properties of the blend. Refrigerant mixtures with higher viscosity demonstrated a greater likelihood of responding to magnetic treatment, while those with higher specific heat and thermal conductivity exhibited lower responsiveness. Notably, the application of magnetization had a considerable impression on the overall efficiency of the system.

Table 2. Influence of magnetization on thermophysical characteristics of different fluids with weak electrical conductivity

S. No.	Researchers	Fluid	Magnetization	Main Properties	Outcomes
01	Tung et al. [5]	Crude Oil	NdFeB magnets (8500 G)	1. Viscosity.	1. Decrement in the flow resistance of oil.
02	Sami and Kita [6]	R507, R404A, R 410A, and difluoromethylene	NdFeB magnets (400 mT)	1. Specific heat 2. Thermal conductivity 3. Viscosity	1. Refrigerants with higher thermal properties exhibit a diminished reaction to magnetic exposure. 2. Refrigerants with higher viscosity tend to exhibit a more pronounced response to magnetic exposure.
03	Tipole et al. [7]	Diesel fuel	NdFeB magnets (300 mT).	1. Viscosity	1. Breaking molecular clusters reduces the viscosity of the fuel.
04	Niu, Kai, and Xiao [8]	NH_4OH solution	Electromagnet (1326.4 to 2613.5 Gauss)	1. Viscosity 2. Heat conductivity	1. Decrement in the flow resistance, on the other hand increment in the heat conductivity.
05	Wang, Wei, and Zhuangwen [9]	Tap water	NdFeB magnets (100 mT, 200 mT, 300 mT, & 400 mT).	1. Specific heat 2. Boiling point	1. Reduction in the specific heat and boiling point of tap water
08	Oommen and N [10]	Gasoline fuel	Neo-delta magnets (320 mT, 480 mT, and 640 mT)	1. Viscosity.	1. Decrement in the flow resistance of oil.
09	Previous Study	Tetrafluroethane	NdFeB magnets (300mT-720mT)	1. Viscosity	1. Magnetization decreases the viscosity of refrigerant.

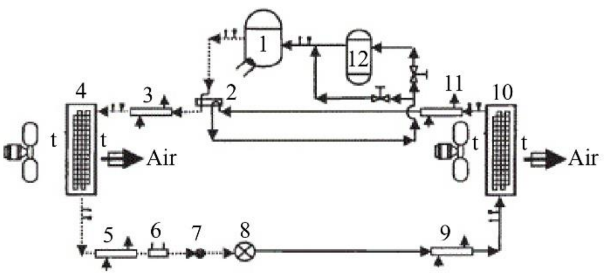

Fig. 12 Schematic representation of experimental test-rig [1]

Mani and Selladurai [11] conducted an experimental investigation on the feasibility of using the R290/R600a refrigerant fusion as a replacement for R12 and R134a, both with and without magnetization, without altering the components of VCRS. The tests utilized a reciprocating-type compressor originally designed for R12 operation, and a detailed schematic diagram is provided in the figure. The results indicated that using a magnetic exposure at the condenser liquid line led to a drop in energy utilization by the compressor across all operating conditions, compared to scenarios without a magnetization. Consequently, there was an enhancement in the efficiency of the system. The study further concluded that the R290/R600a mixture could be deemed an excellent alternative refrigerant for R12 and R134a systems.

Tipole et al. [12] performed an investigational examination to find the impact of magnetization on a drop-in replacement of VCRS. The results showed that the COP of VCRS demonstrated a positive correlation with the application of a magnetic exposure, showing growth with the quantity of magnetizers, up to 3 magnetizers.

However, beyond 3 magnetic pairs, a decline in COP occurred due to entropy generation. Notably, R600a exhibited a significant response to the magnetization compared to R134a, attributed to its higher electrical conductivity. The COP improvement ranged from 6.55% to 13.13% for R134a and 6.57% to 21.87% for R600a. For the critical magnetic pairs (3 pairs), the COP of the system with R600a was 66.56% higher than that of R134a.

In Previous study, an experimental analysis to examine the impact of magnetic exposure on the efficiency of VCRS. The magnetic configurations employed were a magnetic pair and a Halbach array, generating magnetic field stretch of 0.3 and 0.72 Tesla, respectively. The investigational outcomes specify that the magnetization strength and magnetic treatment time impact the VCRS performance.

In the same operating conditions, the COP of VCRS was enhanced by up to 8.38% for magnetic pair using 2 pairs and 9.94% for Halbach array using 1 array. Furthermore, the Total Equivalent Warming Impact (TEWI) analysis for the magnetic pair and Halbach array was found to be lower than the conventional system, ranging from 0.72% to 2.11% and 1.83% to 3.39%, respectively.

Previously conducted experimental work on the influence of magnetization on convective heat transport as R134a condenses in a pipe with a radius of 0.419 cm. Four magnetizers with a 3000 Gauss intensity each were employed in the tests, maintaining a mean dryness fraction between 0.4 and 0.5 for saturation temperatures ranging from 40 to 45. The results revealed a significant impact of the magnetization, saturation temperature, and mean dryness fraction on the coefficient of heat transfer.

Regardless of the number of magnetizers, the heat transfer coefficient generally decreased with rising saturation temperature. The magnetic field exhibited a more pronounced impact at lower saturation temperatures and higher mean dryness fraction. The investigation identified two magnetizers as the limiting factor for heat transfer coefficient improvement, showing an increase of 15.2% for the critical number of magnetic elements at a saturation temperature and mean vapor quality of 40 and 0.5 and an 8.65% increase at a saturation temperature and mean dryness fraction of 45 and 0.5.

4.2. Impact of Magnetic Exposure on the Performance of VARS

Absorption refrigeration technology stands out as a promising alternative to conventional VCRS, garnering increased attention from scientists and engineers in recent years. This thermally powered refrigeration technique utilizes heat energy, sourced from low-grade energy reservoirs or solar energy, to deliver cooling, making it versatile, such as by utilizing the exhaust of an Internal Combustion (IC) engine [15]. The components comprising VARS include the generator, pump, absorber, solution heat exchanger, condenser, expansion valves, and evaporator, as depicted in Figure 13.

Various investigations, including works by Niu et al. [16], Niu et al. [17], Niu et al. [18] and Jadhav et al. [19], have highlighted the usefulness of employing magnetic fields to enhance the performance of VARS. A summary of magnetization impacts on VARS is provided in Table 5.

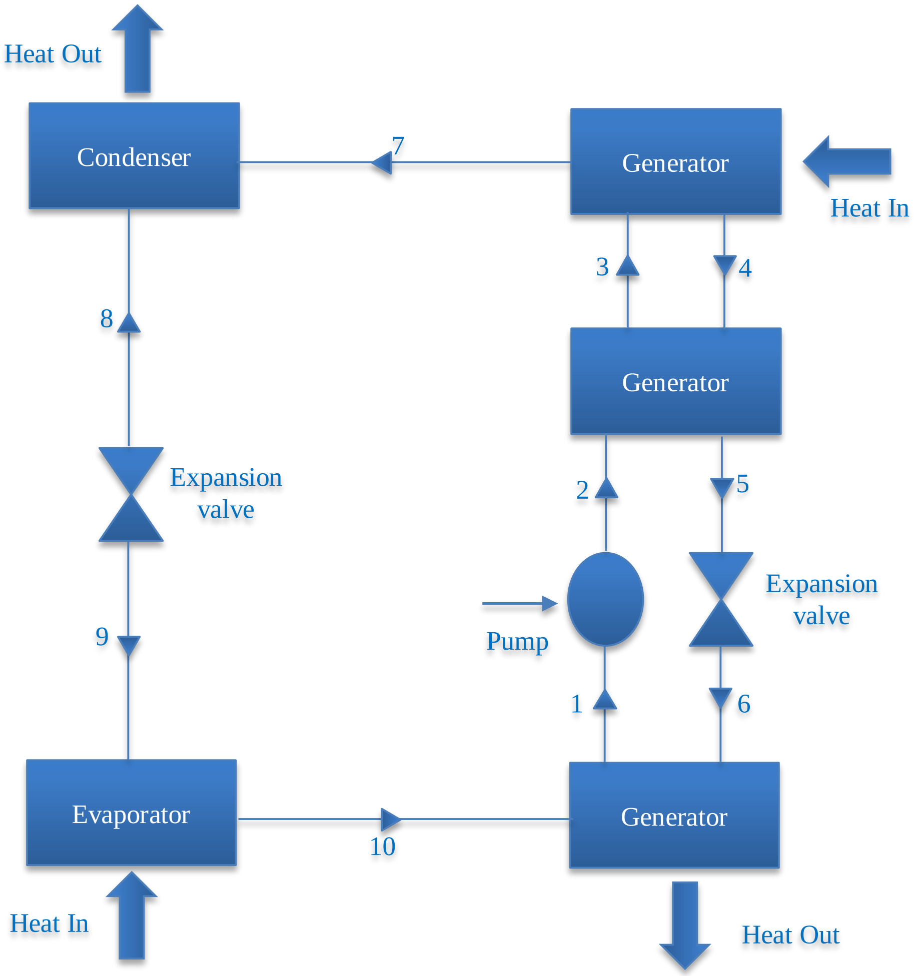

Fig. 13 Schematic of VARS

Table 4. Impact of magnetic treatment on performance of VCRS

S. No.	Author	Refrigerant	Source of Magnetic Field	Parameters	Magnetic Field Effects
1	Samin and Aucoin [1]	R-410A, R-507, R-407C, and R-404A	NdFeB permanent magnets (400 mT)	1. Condenser COP 2. Evaporator COP 3. Compressor Capacity 4. Condenser capacity 5. Evaporator capacity 6. Pressure ratio 7. Compressor discharge pressure	1. The existence of magnetization accelerated the enhancement of both the condenser and evaporator COP compared to results without a magnetic field. 2. Power consumption of the compressor was decreased slightly under the external magnetic field. 3. A marginal enhancement in condenser capacity was noted. 4. The rise in the quantity of magnetizers has led to a slight increase in the pressure ratio. 5. Slightly reduced discharge pressure was observed with higher field strength.
2	Sami and Comeau [13]	R-507, R-407C, and R-404A	NdFeB permanent magnets (400 mT)	1. Boiling pressure drop	1. Insignificant impact on the pressure drop.
3	Samuel Sami [14]	R-410A, R-507, R-407C, and R-404A	NdFeB permanent magnets (400 mT)	1. Evaporator COP 2. Evaporator capacity 3. Pressure ratio 4. Cycle COP	1. Boosts the evaporator capacity and improves the compressor efficiency and COP.
4	Mani and Selladurai [11]	R290/R600a, R12, and R134a	NdFeB permanent magnets (400 mT)	1. Cycle COP	1. Enhances the COP with R290/R600a as compared with others
5	Tipole et al. [12]	R134a and R600a	NdFeB permanent magnets (300 mT)	1. Power consumption 2. Refrigeration effect 3. Mass flow rate 4. COP	1. Decreases the energy utilization 2. Advances in the cooling effect 3. Enhancement in refrigerant mass flow rate 4. Enhances the COP
8	Previous Study	R134a	NdFeB permanent magnets (300 mT and 720 mT)	1. Power consumption 2. Refrigeration effect 3. Mass flow rate 4. COP	1. Decreases the energy utilization 2. Advances in the cooling effect 3. Enhancement in refrigerant mass flow rate 4. Enhances the COP
9	Previous Study	R134a	NdFeB permanent magnets (300 mT)	1. Condenser heat transfer coefficient	1. Enhancement in heat transfer coefficient

Niu et al. [16] conducted a numerical investigation on the impact of magnetization on the absorption process via a mathematical absorption model for NH_3-H_2O falling film absorption. The mathematical model incorporates a macroscopic magnetic field force, considering variations in the physical characteristics of ammonia–water solution during absorption, variations in falling film thickness, and convection in the direction of the liquid film thickness.

Numerical results indicate a positive impact of the magnetization on NH_3-H_2O falling film absorption. Specifically, at a magnetization strength of 3 T at the solution's inlet, there is a 1.3% increase in the concentration of the NH_3-H_2O solution at the exit, resulting in a 5.9% enhancement in absorbability. In a simple NH_3-H_2O absorption refrigeration system, the COP experiences a 4.73% increase, accompanied by an 8.3% reduction in the circulation ratio.

Niu et al. [17] carried out an experimental investigation of NH_3-H_2O falling film absorption under magnetic exposure of varying field strengths, orientations, and operating conditions. The experimental findings revealed that in a downward magnetic field, the outlet concentration of NH_3-H_2O, cooling water outlet temperature, and absorption heat and mass were higher compared to a non-magnetic field. Conversely, these parameters decreased in an upward magnetic field. This suggests that a magnetic field aligned with the falling film direction enhances absorption, while a magnetic field opposing the falling film weakens the absorption of NH_3-H_2O. The study also indicated that the impact of the magnetization on absorption is more pronounced in solutions with low inlet concentration.

Niu et al. [18] explored the impact of magnetiztion on ammonia absorption in an NH_3-H_2O absorption refrigeration system. The study experimentally explored the changes in the viscosity and heat conductivity of NH_3-H_2O under a magnetic field. The magnetization was achieved using an electromagnet with intensities ranging from 1326.4 to 2613.5 Gauss, and magnetization times of 10, 20, and 30 minutes were examined.

Results revealed that magnetization led to a decrease in the viscosity of the NH_3-H_2O solution, with a more significant reduction observed under stronger magnetic fields and longer magnetization times. Conversely, heat conductivity increased with prolonged magnetization time and higher magnetizing intensity. These changes in viscosity and heat conductivity were attributed to the Lorentz force and the breaking of hydrogen bonds in the microstructure of magnetized NH_3-H_2O.

Odunfa et al. [20] explored absorption improvement as a prominent means of enhancing the performance of refrigeration systems, with a focus on enhancement using magnetization. This paper presents a model for magnetization improvement in ammonia-water absorption systems, employing a theoretical model developed based on conservation equations and mass transport relationships. The momentum equation was enriched with a macroscopic magnetization force.

Validation of the model was performed using literature data. The study investigated changes in the physical properties of NH_3-H_2O solution during absorption in both the direction of the falling film and across its thickness. The magnetization demonstrated a considerable influence on NH_3-H_2O falling film absorption, with enhanced absorption performance correlating with increased magnetization strength. Notably, the performance of a simple NH_3-H_2O solution absorption refrigeration system exhibited a 1.9% and 3.6% increase for magnetization strength of 14000 and 30000 Gauss, respectively.

Triché et al. [21] conducted comprehensive investigational and numerical investigations on heat and mass transfer in a falling film absorber, utilizing a plate heat exchanger configured for falling film absorption with an NH_3-H_2O solution. The study employed a prototype of an NH_3-H_2O absorption chiller (as shown in Figure 14) to examine absorber behaviour under actual operating conditions. The falling film of the NH_3-H_2O solution moved along the plates with co-current vapour flow and counter-current coolant fluid flow. A brief work of the absorber, along with native analyses derived from temperature measurements along the falling film, were offered.

A mathematical model and simulation tool were established to complement the investigational work, with a parametric study focusing on the impact of coolant mass flow rate. The model's validation with investigational data demonstrated the highest relative error of 15%. The outcomes propose that, in the absorption process, mass transfers are primarily constrained by the falling film mass transfer resistance, while the liquid-side heat transfer resistance is insignificant.

Wu and Ortiz et al. [22] conducted an investigational study exploring the enhancement of VARS with the help of magnetization, which generates slip movement of nanoparticles in a nanofluid. The experiments were conducted in an adiabatic falling film absorber using a blend of lithium bromide-water solution and Iron (III) nanopowder, with particles less than 50nm at a mass fraction of 0.17% in the fluid.

The results demonstrated an increase in vapour absorption rates by 17.6% and 4.9% when the nanofluid circulated at 3L per min and 3.5L per min, respectively, in comparison with the reference fluid. Notably, a further enhancement was observed when external magnetic fields influenced the movement of nanoparticles in the fluid. With the magnetization in place, the vapour absorption rates were 1.58 times and 1.32 times more developed than those in the absence of the nanofluid circulating at 3.5L per min and 3.0L per min, respectively.

Jadhav et al. [19] present a simulation model aimed at analysing and forecasting magnetization patterns along with magnetic flux density on pipes. Various magnet arrangements, including series, parallel, and Halbach arrays, are examined, and their respective magnetization flux density and magnetization strength are related to the pipes. Utilizing electromagnetic field simulation software, the study computes diverse magnetization patterns and circuit parameters, allowing for precise outcomes in terms of optimal magnet arrangements.

Neodymium-35-type magnets with stable magnetic strength are employed for the experimentation. The findings from different magnetic arrangements are expected to be highly beneficial in selecting the appropriate magnet arrangement for diffusion absorption refrigeration systems, offering potential alternatives to conventional vapour compression refrigeration systems in domestic cooling applications.

Table 5. Impact of magnetic treatment on performance of VARS

S. No.	Author	Refrigerant	Source of Magnetic Field	Parameters	Magnetic Field Effects
1	Niu et al. [16]	Ammonia–water	0 to 3 T	1. Absorbability 2. COP 3. Circulation ratio	1. 5.9% enhancement in absorbability 2. COP experiences a 4.73% increase 3. Reduction in circulation ratio by 8.3%
2	Niu et al. [17]	Ammonia–water	0 to 0.2 T	1. Outlet concentration of NH_3-H_2O 2. Cooling water outlet temperature, 3. Absorption of heat and mass	1. In downside magnetization, the outlet concentration of NH_3-H_2O, cooling water outlet temperature, and absorption heat and mass are higher in comparison with no magnetization.
3	Niu et al. [18]	Ammonia–water	1326.4 to 2613.5 Gauss	1.Viscosity 2. Heat conductivity	1. Decrement in flow resistance 2. Increment in heat conductivity
4.	Jadhav et al. [19]	Ammonia–water	0.1 to 0.6 T	1. Heat absorption	1. Halbach array enhances heat absorption in comparison with other arrangements
5	Odunfa et al. [20]	Ammonia–water	1.4 T and 3 T	1. Cycle COP	1. Performance of a simple NH_3-H_2O solution absorption refrigeration system exhibited a 1.9% and 3.6% increase for magnetic inductions of 14000 and 30000 Gauss, respectively
6	Wu and Ortiz et al. [22]	Ammonia–water	--------	1. Vapour absorption rates	1. Boost in vapour absorption rate

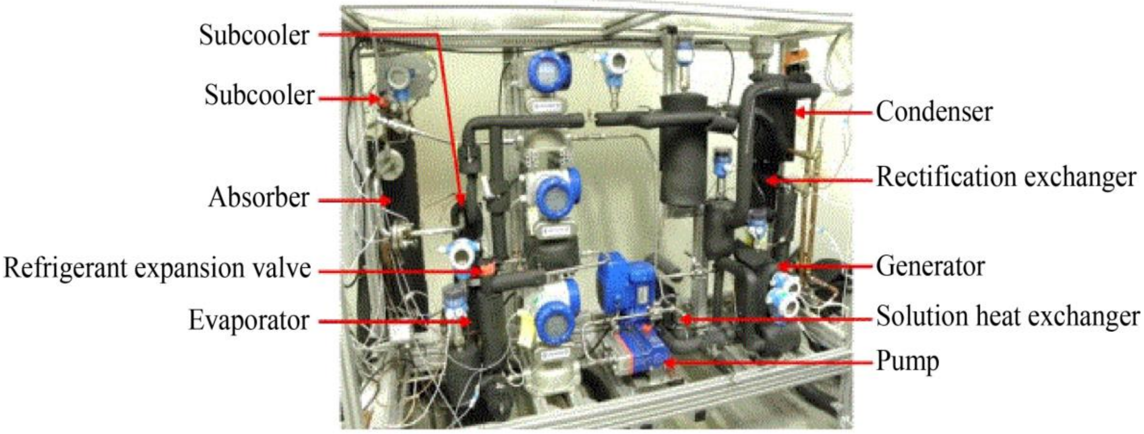

Fig. 14 Prototype of an ammonia-water absorption chiller [23]

5. Conclusion

This review paper comprehensively explores the impact of magnetization on electrically conducting fluids, with a focus on their applications in VCRS and VARS. The paper also explores the root cause of changes in the thermophysical properties of fluids.

Some of the specific conclusions identified in this article are:

1. Many applications, specifically VCRS and VARS, have the benefit of magnetization on heat transfer, refrigerant properties, and overall performance, thereby motivating researchers to delve further into this promising field.
2. More emphasis should be placed on experimental investigations concerning the impact of magnetic exposure on refrigerants.

3. Greater importance should be provided on the mathematical modelling aspect of magnetized VCRS systems, as none of the reviewed papers have presented a comprehensive mathematical model considering the influence of magnetic fields.
4. The influence of magnetic treatment on refrigerant flow has gained relatively little consideration in existing research activities.
5. Numerous researchers have explored the impact of magnetic pairs on refrigeration system performance; there is a need for increased focus on investigating the effects of alternative configurations such as ring magnets and Halbach arrays.
6. The majority of research efforts have concentrated on enhancing system performance, and there has been insufficient emphasis on the environmental aspect. Consequently, greater attention should be directed towards developing eco-friendly magnetized refrigeration systems.
7. The influence of magnetism and magnetization on refrigeration systems is still regarded as a relatively unexplored and not well-understood subject.

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