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Methods for enhancing thermal performances using eco-friendly R1225ye (Z) refrigerant through Nano particles inserted in brine flow evaporator of VCRS

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Abstract

Lot of literature is open on performance enhancement of vapour compression & vapour absorption refrigeration system (VCRS & VARS),in any case, investigators have experienced point by point energetic performances investigation in term of COP of VCRS. Researchers is examined the impact of nanofluids on thermal conductivity enhancement. Nevertheless, researchers had not described exergy principle using entropy generation principle for finding the irreversibilities computation in components and system exergy destruction ratio ($EDR_{rational}$) that can be defined as a rational EDR (i.e. which is a ratio of summation of system's lost work in terms of exergy destruction of all components to exergy of fuel) as well as EDR_{system} (i.e. it is a ratio of total lost work to exergy of product) of VCRS using HFO refrigerants (i.e.R1225ye(Z)) This paper primarily deals with comparison between three nano particles that are utilized in minor circuit of cooling heat exchanger, which improves cooling temperature as a result of enhance in COP. enhancement in first law efficiency (i.e. COP) by using CuO, Al_2O_3, &$TiO_2$was evaluated to be as 18.48%, 17.47%, & 15.95%, respectively alongside enhancement in cooling heat exchanger overall heat transfer coefficient by using CuO, Al_2O_3,&TiO_2 was about 107.66%, 98.6%,&86.4%, respectively. Similarly, enhancement in condenser overall heat transfer coefficient by using CuO, Al_2O_3,& TiO_2 was about 11.24%, 10.77%, & 9.94%, respectively. Also, enhancement in exergetic performance by using CuO, Al_2O_3,&TiO_2 was about 13.93 %, 12.94 %, & 11.49%, respectively. .

Keywords: First & second law efficiency, COP, EDR, ecofriendly refrigerants, nano materials.

1. Introduction

The refrigeration concept is known through heat rejection from a space at a temperature lesser than temperature of surrounding. Now COP can be defined as ratio of effect of refrigeration produced at section of heat absorption to input work through compressor. Also, COP could be enhanced either by declining compressor's input work by multistage compression process/ cascade refrigeration or by increasing effect of refrigeration [1]. Further, HFO refrigerants (i.e. R1234yf & R1234ze) & hydrocarbons like propane (R290) & isobutene (R600a) refrigerants have a low mass flow rate as competed with R134a refrigerant. As can be seen, both specific volume & temperature of refrigerant decreases as mass flow rate going to be decrease. As a result, compressor work also reduces & COP enhances [2]. Besides, environmental safety refrigerant, R600a is whose ozone depletion potential (ODP) & global warming potential (GWP) is less than three [2].

Second method for enhancing COP of Refrigeration system is sub cooling in condensers that result in high heat rejection [3]. It is further possible by arranging more number of fins on condenser, high thermal conductivity material for condenser coil & fins. For reducing the energy consumption in refrigeration systems Mishra [2] introduced Nanoparticle based refrigerant which have refrigerant properties greater that help in improving the performance of heat transfer main refrigerant in VCRS.

The Nano particles utilization in VCRS are a novel, advanced technique to augment effectiveness [2]. In order to enhance rate of heat transfer in VAR system, Nanofluids could be utilized, & as can be seen, their use can remarkably improve thermophysical & heat transfer capabilities. Nanofluids have an ability to show important characteristics, for e.g. high specific surface area due to which more heat transfer surface available

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amongst particles & fluids, dispersion stability can be also high, pumping power could be reduced in contrast to pure liquid & particle clogging could be also reduced [2,38-39].
solid and oxide materials of several types of can be used as the Nano particles were adjourned in the CFC refrigerants. , The effect of the suspended copper oxide (CuO),(TiO_2), (Al_2O_3), into the brine flow in evaporator and eco friendly refrigerants (i.e. HFC-134a, HFC-407c and HFC-404a) investigated by using mathematical modeling [29].
The main constraint in emerging energy-efficient heat transfer fluids for ultrahigh-performance cooling is fundamentally has low thermal conductivity. Therefore metallic or nonmetallic particles of Nanometer dimensions produced by using Nanotechnology due to selected mechanical, optical, electrical, magnetic, and thermal properties. Nanofluids are caused by suspending Nano particles with average sizes below 100 nm in heat transfer fluids such as R-718, oil, refrigerant and ethylene glycol. The current growth of work in this speedily developing area of Nanofluids is most obvious. Although lots of researches have been done investigations on several metallic/ nonmetallic Nanoparticle inserted into the refrigerants to improve the base fluid heat convection properties and carried out performance evaluation. Also some theoretical analysis of inserted Nano material particles of Al_2O_3 in cooling refrigerant.

2. Literature review

Mishra [2] carried out experimental studied on evaluation of VCRS thermodynamic performances with low GWP and ultra low ODP refrigerants (HFC-404a, HFC-407c and HFC-134a) in main circuit & Nanofluid (Water Nano particles based) in a minor circuit using water cooled condenser with variable speed compressor and developed thermal model of VCRS and found that the experimental first law efficiency in terms of COP and second law exergetic efficiency values are closed matched with computed values with accuracy under 10% and also observed that using HFC-410a in primary circuit of evaporators , the performances falls drastly. R. S. Mishra [3] carried out **i**rreversibility analysis of multi-evaporators vapour compression refrigeration systems using new & refrigerants: HFC-134a, HFC-290, HFC-600, HFC-600a, HFO-1234yf, CFC-502, HFC-404a & HFC-152a & CFC-12, and found that hydrocarbons gives best thermodynamic performances than HFC refrigerants for replacing R12 and R502 but they are flammable. Therefore HFC refrigerants can be a alternatives for replacing CFC refrigerants. R. S. Mishra [4] developed thermal model for Evaluating thermodynamic Performances of single compressor & single expansion valve & liquid vapour heat exchanger coupled multi-evaporators in VCRS by using low GWP and zero ODP thirteen eco-friendly refrigerants found that model predict experimental behaviour well .
Arora & Kaushik [5] carried out theoretical analysis of actual VCRS with LVHE by using energy, entropy, & exergy in specific temperature range of evaporator & condenser and found that the CFC-502 fluid was best refrigerant as compared to HFC-404A & HFC-507A refrigerant. Getu& Bansal [6] optimized operating parameters of cascaded refrigeration cycle (i.e. temperature of condenser sub cooling, evaporator superheating along with temperature overlapping in cascade heat exchanger) CO2-Ammonia Cycle.. Mohanraj et al. [7] investigated experimentally domestic refrigerator under different temperatures of environmental & they computed cycle’s COP using mixture in ratio of 45.2:54.8 by weight of R290 & R600a fluid & evaluated it up to 3.5% advanced than similar cycle by using HFC-134a. Anand && Tyagi [8] carried out second law exergetic performance of two ton of refrigeration test rig by via HCFC-22 fluid & assessed that compressor’s irreversibility was maximum among other components. Reddy et al. [9] did numerical investigation of VCRS by using several eco-friendly refrigerants (such as HFC 134a, HFC 143a, HFC 152a, HFC 404A, HFC-410A, CFC-502, & R507a) and described that the temperature of evaporator & condenser have crucial effect on both COP & exergetic efficiency. In addition, they assessed that HFC-134a fluid has better performance than HFC-407C . MastaniJoybari et al. [10] done study on a local refrigeration system experimentally & concluded that compressor’s exergetic destruction was highest in contrast to other components. Ahamed et al. [11] carried out exergy based investigation of VCRS & evaluated thermodynamic performance of hydrocarbons, mixture of hydrocarbons, & R134a. Additionally, they evaluated that higher exergy destruction occurred in compressor as rivaled with other VCRS’ components. Elcock [12] employed TiO_2 Nano particles as additives to increased solubility of mineral oil & reported that refrigeration cycles by means of combination of HFC134a fluid & inorganic oil through TiO_2 Nano particles can provide improved thermodynamic performance. Hindawi [13] showed boiling heat transfer performance of R22 cooling fluid with Nano particles made up from Al_2O_3 experimentally & evaluated that Nano particles has an ability to enhance cooling fluid heat transfer performance. Eastman et al. [14] investigated characteristics related to pool boiling heat transfer by using R11 cooling fluid through TiO_2 Nano particles & presented heat transfer improvement. Liu et al. [15] computed nucleate boiling heat transfer of R123 & HFC134a cooling fluidby using properties of carbon Nanotubes and described that carbon Nanotubes can enhanced nucleate boiling heat transfer of cooling fluids. Besides, they noticed that large enhancements can be possible equal to 36.5% at little heat fluxes. Jiang et al. [16] evaluated thermal conductivity of carbon Nanotube Nano refrigerants experimentally and found considerable greater than that of R-113 Nano refrigerants & also assessed that Nanofluid thermal conductivity is correspondingly depends on temperature& size of .Nano particles. Hwang et al. [17] compared thermal conductivity of Nano fluid with base fluid & concluded that multiwall CNT is strikingly advanced thermal conductivity than that of Nano particles in equal base fluid of SiO2.Yoo et al. [18] claimed that ratio of surface area to volume of Nano particles was leading factor that Nano fluids inspired thermal conductivity relatively improved with Nano particles of smaller

sizes. Choi et al. [15] found150% improvement in thermal conductivity of poly (a-olefin) oil by adding of at 1% volume fraction of MWCNT. .Jiang et.al.[16] observed 200% improvement in the thermal conductivity for poly (a-olefin) oil covering 0.35% MWCNT & also evaluated improvement in thermal conductivity over a three order of magnitude for improving viscosity. Eastman et al. [17] assessed 40% improvement in thermal conductivity of ethylene glycol by 0.3% copper Nano particles of 10 nm diameter. Kanget al. [18] reported thermal conductivity improvement of about 75% for ethylene glycol through 1.2% Nano particles concentration of diamond between 30 & 50 nm diameter. Lee et al. [19] evaluated that thermal conductivity of Nanofluids can be affected by pH level & addition of surfactant. They achieved better Nano particles dispersion through adding of sodium dodecylbenzene sulfonate. Moreover, they also stated that best combination of pH & surfactant can primes to enhancement in thermal conductivity. Wu et al. [20] observed that at low concentration of TiO_2 Nano particles in R11 fluid, pool boiling heat transfer might be improved & it might be deteriorated under state of higher concentration of Nano particles. Trisaksri & Wongwises [21] employed HCFC 141b in a cylindrical copper tube by inserting TiO_2& evaluated that nucleate pool boiling heat transfer can be declined with improvement in the in concentration of Nano particles. Hao et al. [22] carried out effect of Nano particles concentration, mass fluxes, heat fluxes, & inlet vapor qualities on characteristics of heat transfer coefficient of refrigerant-based Nanofluid. Also they observed that it was larger than that of pure refrigerant by 29.7% along with 0–0.5 wt% mass fraction of Nano particles. Hao et al. [23] studied refrigerant/oil mixture with diamond Nano particles nucleate pool boiling heat transfer & evaluated that it was greater than that of R113/oil combination by extreme of 63.4%.Wang et al. [24] conducted experimental study of HCFC-22 cooling fluid through Al_2O_3 Nano particles & evaluated of boiling heat transfer and observed that the Nano particles can improve heat transfer phenomenon of the refrigerant. Li et al. [25] observed CFC-11 cooling fluid through TiO_2 Nano particles and computed the pool boiling heat transfer & found that improvement up to 20% heat transfer at a particle filling of 0.01 g/L. Peng et al. [26] examined the effect of heat transfer of cooling based Nano refrigerant & evaluated that heat transfer coefficient was higher by about 29.7% than that of pure refrigerant. Kumar & Elansezhian [27] experimentally observed consequence of concentration of ZnO Nano particles in order of 0.1%, 0.3%, & 0.5% with size of 50 nm particle on VCRS & also evaluated maximum COP of 3.56 & 21% power input declined with 0.5% ZnO concentration. Mahbubul et al. [28] calculated physical properties and pressure drop & investigated thermodynamic performance based Al_2O_3 Nano particles suspended in HFC-134a fluid heat transfer & evaluated Al_2O_3/R-134a Nano-refrigerant thermal conductivity which can be enhance through particle concentration increment. Although, it can be decrease by rise in particle size. In addition, they assessed that a significant enhancement in viscosity, pressure drop, & coefficient of heat transfer of Nano-refrigerant by enhance of volume fractions. Mishra et al. [29] evaluated VCRS' performance by inserting Cu, Al_2O_3, CuO, & TiO_2 Nano particles in the R718 refrigerants in minor circuit of evaporator and HFC-134a, HFC-404a and HFC-407c in the main circuit of evaporator .Their experimental results evaluated that overall C.O.P by using Al_2O_3/HFC-134a Nano fluids was enhanced by 18.5% using CuO/HFC-134a that was highest among all other Nano refrigerants. Similarly first law performance was enhanced 17,5% using Al_2O_3/HFC-134a and 16.0 using TiO_2/HFC-134a and 16.5 in R407c and 14.8 % using R404a using copper oxide particles in R718. Sabareesh et al. [30] improved 17% COP experimentally by by means of TiO_2 Nano fluid in VCRS by way of a lubricant preservative. by volume concentration of 0.01% .Sajadi A.R. et.al. [31] observed Nano inserted TiO_2 detached in water Nano fluid in circular tube and computed turbulent convective heat transfer coefficient along with pressure drop using measured values by conducting experiments along with Nusselt number correlation & concluded that in what way (%) convective heat transfer coefficient can be improved. Huang Dan et al. [32] assessed outcome of hybrid combination of Nano Al_2O_3 inserted in fluid of plate type heat exchanger & evaluated that convective coefficient which was improved as compared without Nano fluid. Zeinali S Heris et.al [33] experimentally evaluated enhancement in convective heat transfer in laminar flow forced convection heat transfer since of improvement in the thermal conductivity of Nano fluid. Shengshan Bi et al. [34] assessed enhancement in performance of VCRS along with reduction in power utilization up to 25% as using lubricant by mixed TiO_2 mineral oil along with R600a refrigerant. Subramani & Prakash [35] observed enhancement in performance of domestic refrigerator via Al_2O_3 at weight in mineral oil of 0.06%. Kumar et al. [36] improved COP of a domestic refrigerator by 19.6% & decline utilization of power by 11.5% due to an enhancement in coefficient of heat transfer by using Nanofluid Al_2O_3 & R600a/mineral oil as working fluid.Abbas et al. [37] carried out the thermodynamic study of an air conditioner through carbon Nano tubes polyester oil concentration of 0.01-0.1wt% by refrigerant R134a & assessed 4.2% enhancement in COP through carbon Nanotube particles with 0.1% by weight concentration. Hussen [38] showed enhancement in conventional refrigeration system with Nano cooling fluid & evaluated that compressor work decreases by about 13.3%. The researchers have carried out detailed study of VCRS with single evaporator. Also, researchers examined Nanofluids effect on simple VCRS; however, they did not go through irreversibility examination in terms of EDR. Mishra [39] developed test rig in the DTU and conducted experiments using R134a, R407c and R404a in main route besides R718, and the minor route of evaporator brine flow and water flow condenser was used on the comparison of results as shown in Fig-1(a) and Fig-1(b). and developed thermal model for predicting thermodynamic energy and exergetic performances.

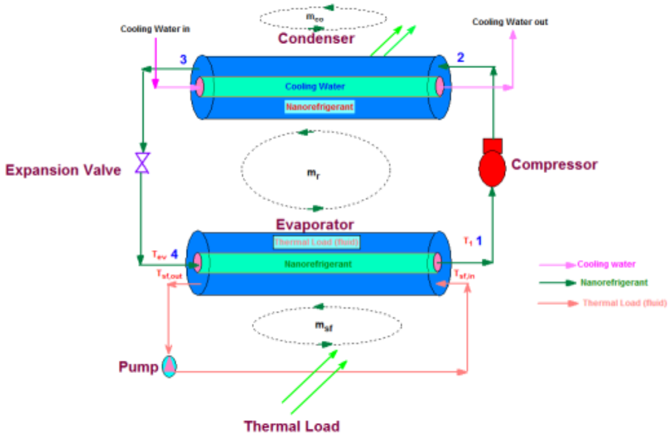

Figure 1(a): schematic of variable-speed vapour compression refrigeration (VCR) system [39]

Fig-1(b): Experimental set of variable-speed vapour compression refrigeration systems[39]

3. Mathematical Modeling

In the modeling of vapour compression refrigeration system, first all we write all the heat balance equation for design of the components in the system. and then substituting inputs as per developed model and for output we assumed some guess values in the software then solved the equations one after one components. First we designed evaporator, then condenser. For design evaporator we "comment" the other components and check the Number. of equations is equal to numbers of variables and then solve the formulation, if there is some error while solving then, we update our guess nearest values of our design. The design of the components set all the inputs like, size of the evaporator and condenser, mass flow rate of brine and water, compressor speed, Temperature of brine and water. So, as per our objective to have constant our inputs data and then we use various nearest replacement of eco-friendly refrigerants on the same configuration and then compare the outputs as per eco-friendly refrigerants used.

4. Model Validation

For thermodynamic model validation for changed speed compressor refrigeration system with experimental values for changed condition is obtained. The three sets of experimental measurements have been showed by Mishra [2]. The experimental result validation is done with and without using R134a Nano-refrigerant by Mishra [39].

5. Results and Discussion

For numerical computations, following input values have been taken.

- Water mass flow rate in Condenser was varying from 0.007 (kg/sec) to 0.01 (Kg/sec)
- Brine mass flow rate in evaporator minor circuit was s varying from 0.007 (kg/sec) to 0.010 (Kg/sec)
- Inlet temperature in secondary circuit of evaporator is 300K
- Temperature of dead state (ambient condition) =298K
- Brine flow inlet flow temperature in evaporator -300K
- Brine flow inlet pressure of evaporator =2 (bar)
- Water flow inlet pressure of condenser =2 (bar)
- Length of Evaporator = 0.72 m
- Condenser heat exchanger Length = 1.2 m
- Pressure of air = 1.05 (bar)

The Nano fluids thermal properties have been computed by using thermodynamic model is specified in Table-1 respectively

Table 1: Thermal properties of Nano mixed fluid of used in VCRS

Performance Parameters	CuO	Al_2O_3	TiO_2
Effective mixture Density (kg/m^3)	13.93	1145	1155
Effective mixture specific heat (J/KgK)	2965	3590	3558
Mixture Effective Thermal conductivity (W/mK)	31.33	16.62	9.727
Effective mixture viscosity	0.00365	0.00365	0.00365
Prandtl Number of Nano Mixture	0.3457	0.7795	1.336
Effective mixture Density (Kg/m^3)	1393	1145	1155

Table-2(a) : *Variations of Reynolds numbers with Nanomaterials in VCRS*

Reynolds numbers	CuO	Al_2O_3	TiO_2	Without Nano particles
Reynolds number in Capillary Tube	27097	26670	26049	18310
Reynolds number _Condenser Tube	206820	206600	206310	200374
Reynolds number _Brine flow	104.28	104.28	104.28	104.28

Table-2(a) shows capillary tube Reynolds number variations by using Nano materials inserted in brine fluid flowing in minor evaporator route & R1225ye(Z) fluid flowing in main circuit of evaporator. For, comparing results of system's properties with-&- without Nano particles and also observed large improvement in Reynolds number by using CuO& lowest by using TiO_2 and also found improvement in evaporator Reynolds number by inserting Nano particles of CuO, Al_2O_3, & TiO_2 is around 48.0%, 45.7%, & 42.3%, respectively. Similarly, enhancement in Reynolds number for condenser tube by using CuO, Al_2O_3, & TiO_2 is about 3.2%, 3.1%, 2.96%, respectively .Similarly % variation of improvement of Reynolds number in capillary tube and condenser tube is shown in Table-2(b) respectively.

Table-2(b): % Variations of Reynolds numbers using Nano materials in VCRS with witout Nano materials in brine and R1225ye(Z) eco-friendly refrigerant

Reynolds numbers	CuO (%)	Al_2O_3 (%)	TiO_2 (%)	Without Nano particles
Reynolds number in Capillary Tube	47.99	45.67	42.26	18309
Reynolds number in Condenser Tube	3.21	3.1	2.96	200375

Table 3(a): Variations in coefficient of performance and exergetic performance, *parameters of VCRS by using R1225ye(Z) eco-friendly refrigerant*

Performance Parameters	CuO	Al_2O_3	TiO_2	Without Nano-particles
Coefficient of Performance $(COP)_{\_Actual}$	3.507	3.477	3.432	2.96
Exergetic Efficiency	0.392	0.389	0.384	0.3435
Evaporator total heat transfer coefficient $U_{\_Eva}$ (W/m^2K)	1380	1320	1240	665
Condenser total heat transfer coefficient $U_{\_Cond}$ (W/m^2K)	717.6	714	708.6	644.56

Table-3(a) shows variations of coefficient of performance and exergetic performance, by using changed Nano materials assorted with in R718 fluid flowing in minor circuit of evaporator & R134a fluid flowing in primary circuit of evaporator.

Table 3(b): % Variations first law efficiency, second law efficiency, & or performance parameters of VCRS by using R1225ye(Z) eco-friendly refrigerant with and without Nano materials.

Performance Parameters	CuO (%)	Al_2O_3 (%)	TiO_2 (%)	Without Nano-particles
First Law efficiency $(COP)_{\_Actual}$	18.48	17.466	15.98	2.96
Exergetic Efficiency	14.17	13.27	11.81	0.3436
evaporator total heat transfer coefficient $U_{\_Eva}$ (W/m^2K)	107.63	98.60	86.42	664.62
condenser total heat transfer coefficient $U_{\_Cond}$ (W/m^2K)	11.333	10.7732	9.942	644.56

By comparing results of system's properties with-&- without Nano particles, higher COP was observed by using CuO& lowest by using TiO_2. It has also been evaluated that enhancement in COP by using CuO, Al_2O_3, & TiO_2 is about 18.48%, 17.47%, & 15.95%, respectively. Similarly, enhancement in exergetic efficiency in condenser tube is by using CuO, Al_2O_3, & TiO_2 is about 13.92%, 12.94%, & 11.49%.

Table 4 variations of compressor efficiencies with Nano particles mixed with in brine Flow in evaporator;s minor route using R1225ye(Z) *fluid flowing in primary circuit of evaporator.*

Compressor efficiency	CuO	Al_2O_3	TiO_2
Isentropic Efficiency	0.8169	0.8131	0.8094
Volumetric Efficiency	0.6299	0.6289	0.6275

Table-4 demonstrates variations of compressor efficiencies with Nano particles mixed with brine water (i.e. R718) flowing in secondary circuit of evaporator & R134a fluid flowing in primary circuit of evaporator. It has been evaluated that compressor efficiencies by using CuO is highest & by mixing TiO_2 is lowest that significantly affecting first & second law efficiency of VCR system.

Table 5: variations in enhancement in Performance parameters VCRS

% Enhancement in performance Parameters	CuO	Al_2O_3	TiO_2
Coefficient of performance	18.5	17.47	15.9
Exergetic Efficiency	13.93	12.94	11.5
E.D.R.(based on exergy of product)	6.07	6.8334	6.06
Evaporator total heat transfer coefficient (W/m^2K)	107.66	98.628	86.4
Condenser total heat transfer coefficient (W/m^2K)	11.239	10.773	9.94

Apart from this, Table 5 illustrates variation in evaporator heat transfer coefficient, condenser heat transfer coefficient first & second law efficiencies, EDR of system, & rational EDR percentage enhancement by using CuO, Al_2O_3, & TiO_2.

Table 5: variations in enhancement in Performance parameters VCR system

% Enhancement in performance Parameters	Copper oxide	Aluminum Oxide	Titanium oxides
Coefficient of Performance (COP)	18.48	17.46	15.98
Exergetic Efficiency	14.17	13.27	11.81
E.D.R. based on exergy of product	6.1	6.83	6.05
Evaporator total heat transfer coefficient (W/m^2K)	107.64	98.60	86.42
condenser total heat transfer coefficient (W/m^2K)	11.33	10.77	9.94
Reynolds number in Capillary Tube	47.99	45.67	42.26
Reynolds number in Condenser Tube	3.216	3.1072	2.963

6. Conclusions & Recommendations

Therefore present investigation has been carried out with aim of overall performance enhancement in terms of first law efficiency & second law efficiency along with various efficiencies of compressor using ultra low GWP eco-friendly non toxicnon flammable R1225ye(Z) in the main circuit of evaporator and Nano mixed brine flow in the minor circuit of evaporator.

- The enhancement in coefficient of performance by mixing CuO, Al_2O_3, & TiO_2 in brine R718 flowed in minor route in evaporator and R1225ye (Z) in main route in evaporator is about 18.48%, 13.27%, & 15.98%, respectively.
- The, enhancement overall heat transfer coefficient of evaporator by using CuO, Al_2O_3, & TiO_2 inserted in brine flow water in minor route of evaporator and R1225ye(Z) in main evaporator circuit of is about 107.64%, 98.61%, & 86.4%, respectively.
- The enhancement overall heat transfer coefficient of condenser by using CuO, Al_2O_3, & TiO_2 mixed in brine flow R-718 in minor route of evaporator and R1225ye(Z) in main circuit of evaporator is about 11.33%, 10.77%, & 9.94%, respectively.
- The exergetic efficiency enhancement by using CuO, Al_2O_3, & TiO_2 mixed in brine flow R-718 in minor route of evaporator and R1225ye(Z) in main circuit of evaporator is about 14.17%, 12.94%, & 11.81%, respectively.

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