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Nanotechnology applied to Ground Heat Exchanger Pipes: A review

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ABSTRACT

During the last decades, the use of Geothermal Source Heat Pumps (GSHP) has growth exponential around the world, since it has been considered as the best technology available for the air conditioning of residential or commercial spaces (Lund and Boyd, 2016). The GSHP offers important benefits, e.g. reduction of electricity consumption, efficiency in heat transfer and the reduction of CO2 emissions. A GSHP is composed of three important elements: the space to be conditioned, the Heat Pump (HP) and the Geothermal Heat Exchanger (GHE). The latter uses the subsoil as an energy source, which through the use of pipes buried under the subsoil (horizontal or vertical) and through the HP, can move the fluid to transfer heat into the space to be conditioned as a source (heating in winter) or heat sink (cooling in summer). The GHE is a process of high-energy efficiency because the soil temperature remains stable throughout the year. Over the last decade, research has been carried out to enhance heat transfer in heat pipes using traditional working fluids or developing new pipe materials. The aim of this review is to summarize recent research on the study of heat transfer using nanotechnology in the Geothermal Heat Exchangers pipes (GHEP). This work analyzes the development of new fluids (nanofluids) and new materials (nanoparticles and nanocomposites) which enhance heat transfer efficiency of heat pipes. As a result, the present review may generate a perspective for future research regarding the use of nanotechnology to reduce the costs involved in the Geothermal Heat Exchangers design by means heat transfer optimization.

1. INTRODUCTION

Ground-coupled heat pumps are energy efficient and environmentally friendly systems for heating and cooling buildings but are expensive to install. The ground heat exchanger (GHE) is the most expensive component of the system. This is particularly true for vertical GHEs installed in boreholes that tend to be more expensive than horizontal installations in trenches (Gosselin et al., 2017).

For the Ground Source Heat Pump Systems (GSHPS), typically used high-density polyethylene (HDPE) pipes in the GHE which the pipes are thermal insulators due to its low thermal conductivity. This is a factor affecting the heat transfer between the ground and the space to be conditioned. The first solutions to solve this problem was the use of thermally enhanced grout to improve thermal conductivity. In Allan and Kavanaugh (1999) use thermally enhanced grout and with their results reduced the borehole thermal resistance, which it involved minimize the length and the number of boreholes of GHE and save the cost to install.

In the last years, the researchers strive to develop technologies related to the improvement the heat transfer increasing the thermal conductivity of soil, changing the properties of pipe material, using different fluids and changing the geometrical configurations pipes, all these used in the GHE. A new area of research to solve these problems grows rapidly, called Nanotechnology.

Nanotechnology is considered now one of the most recommended choices to heat transfer enhancement of thermal systems. From the last few decades, this technology has been used in various fields such as electronics, communication, and computing technologies, principally to solve high cooling techniques. At present, the use of nanotechnology is explored in different energy sectors: solar, fuel cells, hydrogen, nuclear, photovoltaic, wind and geothermic.

In this paper, a literature review worldwide is presented, in order to know the solutions that have been implemented to improve to extracted/rejected of heat in the ground by mean of the ground heat exchangers applied to ground source heat pumps systems. The works reviewed including theoretical, experimental, and reviews works, related to the use of nanotechnology (nanofluids and nanomaterials). The literature is reviewed and summarized carefully, in the end in a table, a panoramic overview is given about the role of nanotechnology in improving the heat transfer of ground heat exchangers.

2. LITERATURE REVIEW

The research was conducted by selecting and analyzing available published literature to analyzes the development of new fluids (nanofluids - is a suspension composed for a fluid normally an oil or water and nanoparticles) and new materials (nanoparticles and nanocomposites) which enhance heat transfer efficiency of heat pipes.

In nanotechnology, a particle is defined as a small object that behaves as a whole unit with respect to its transport and properties. Nanoparticles are particles between 1 and 100 nanometers (nm) in size with a surrounding interfacial layer. The interfacial layer is an integral part of nanoscale matter, fundamentally affecting all of its properties. The interfacial layer typically consists of ions, inorganic and organic molecules.

Nomenclature

Ag	silver		
Al_2O_3	aluminum oxide	FSPCM	form–stable phase change materials
Au	Gold	GNP	graphene nanoplatelets
Cu	copper	GHE	ground heat exchanger
CuO	copper oxide	GSHP	ground source heat pump
DWCNT	double-walled carbon nanotube	HDPE	high density polyethylene
EG	ethylene glycol	HTC	heat transfer coefficient
EO	engine oil	HTF	heat transfer fluid
Fe_2O_3	iron oxide	HP	heat pipe
MgO	magnesium oxide	MA	myristic acid
MWCNT	multi-walled carbon nanotubes	MEPCM	micro–encapsulated phase change material
		NG	nano–graphite
SiO_2	silicon dioxide	NSGA-II	non-dominated sorting genetic algorithm
TiC	titanium carbide	PA	palmitic acid
TiO_2	titanium dioxide	PCM	phase change material
ZnO	zinc oxide	Rb	borehole thermal resistance
		SEM	scanning electronic microscope
Acronyms		SST	shear stress transport
		SWCNT	single-walled carbon nanotube
BHE	borehole heat exchanger	TE	thermally enhanced
BHTC	boiling heat transfer coefficient	THW	transient hot-wire technique
CCHP	combined cooling, heating, and power	TPS	transient plane source technique
CNT	carbon nano tube composite		
FESEM	field emission scanning electron microscope		

The following summarizes important aspects and/or conclusion drawn by some research related theoretical, experimental, and reviews, principally in applications of geometrical modifications, use of nanofluids as a heat carrier fluid, and the modification of pipe material (using HDPE pipes to extracted/rejected the heat in the ground).

Ahmadi et al. (2018) present a reviewed different experimental and theoretical studies on the thermal conductivity of nanofluids with the aim of showing the influential parameters affecting thermal conductivity. In this paper, the authors discuss an investigation done on thermal conductivity of CuO-EO nanofluid was done by Aberoumand et al. (2017), where results showed an increase of 49% in thermal conductivity of nanofluid with 1% concentration compared with the base fluid. The concentrations of nanoparticles reported by the authors were 0.2%, 0.5% and 1% wt. Another issue addressed in the present paper was the effect of the size of nanoparticles. Sharifpur et al. (2017) found that the increase in particle size caused a reduction in thermal conductivity ratio of the Al_2O_3-glycerol nanofluid. A similar study was done by Esfe and Saedodin (2015), where they examined the effects of particle size as well as the concentration of nanoparticles on MgO-water nanofluid thermal conductivity. The results showed an enhancement in thermal conductivity with a decrease in nanoparticles size. Thermal conductivity of nanofluids is affected by the shape of nanoparticles. Alawi et al. (2018) investigated different materials, e.g., Al_2O_3-water, CuO-water, ZnO-water, and SiO_2-water. Their thermal conductivity values were measured. Another issue which has not been addressed enough is related to the effect of magnetic fields and their strength on thermal conductivity. Ebrahimi and Saghravani (2017) proved that the presence of a magnetic field led to an improvement in thermal conductivity of the nanofluids of CuO/water and $Fe3O4$/water.

Similar articles reviewed by the authors were on hybrid nanofluids thermal conductivity. Das (2017) and Jana et al. (2007) found enhanced characteristics of thermal conductivity in comparison with the traditional nanofluids. Similarly, the thermal conductivity of SiO_2-water and SiO_2/EG was measured by Amiri et al. (2016) and compared with SiO_2–Cu-water and SiO_2–Cu-EG. The result obtained indicated that the small amount of SiO_2 nanoparticles added led to less than 2% enhancement in thermal conductivity of fluid; on the other hand, an improvement in thermal conductivity of water and EG was seen after deposition of Cu nanoparticles on the SiO_2. Ahmadi et al. (2018) identified different parameters which affect the thermal conductivity of nanofluids. Among the more important are temperature, the concentration of solid phase, size of nanostructures and their shape. It was concluded that nanofluids with more appropriate properties could be obtained using hybrid nanofluids.

Ahmadi et al. (2018) discuss and compare the use of geothermal with other types of renewable energies, they research and present the important results of different applications of nanofluid in geothermal-based energy systems. The authors mentioned that the Heat transfer processes play a key role in the efficiency of geothermal energy systems based on Wang et al. (2018) and that in work Bobbo et al. (2016) mentioned applying nanofluids as heat transfer fluids is an attractive idea to achieve higher efficiencies and the using nanofluids can reduce the size of systems, for example, can be used to in reduction in borehole thermal resistance. Addition they mentioned the research of Jamshidi et al. (2018) were reported the numerical development of the performance of geothermal heat exchanger and the effects of utilizing nanofluids in extracted heat.

The authors concluded that the heat transfer enhancement using nanofluids is dependent on several factors including the type of nanofluid, concentration and system specification, addition, using nanofluids can reduce the size of heat exchangers and boreholes sizes used in geothermal-based system.

Alirezaie et al. (2018) investigated the thermal performance and economic efficiency of nanofluids. Three questions were tried to be answered: have nanofluids met the expectations of heat transfer researchers?, would nanofluids increase efficiency and reduce costs? and will nanofluids acquire a share of the fluid market of heat transfer in the near future?

The authors reviewed several articles about thermal conductivity, where they found differences between thermal conductivity in solid particles and thermal conductivity in of the heat transfer fluid. Other articles (Xuan and Li, 2000; Wang et al., 2009; Li et al., 2008; Huang et al., 2009) related to acidity of base fluids were also addressed by the authors. Another topic addressed was the heat transfer coefficient, where it was found in an investigation done by Shanbedi (2012) that nanofluids increase thermal efficiency by 17% and pressure drop by 14.5%.

For the experimental data, the relative thermal conductivity and relative viscosity of MWCNT-water, DWCNT-water, Ag-water, and MgO-water published in different articles were compared. MWCNT-water nanofluid showed higher relative thermal conductivity (0.2 vol. %) and relative viscosity than the other nanofluids. The authors stated that some factors have an influence on the thermal conductivity of nanofluids, e.g., method of nanofluid production (single-stage and two stages), type of surfactants used, sonication rate, the device of characteristic measurement, nanoparticle size, and their shape.

Alirezaie et al. (2018) presented a study to evaluate different nanofluids (Ag, MgO, MWCNT and, DWCNT) comparing the price, the efficiencies and the benefices to improve the heat transfer. The economic analysis of these nanofluids indicated that it has economic justification except in high-tech devices with critical applications.

The authors used the Mouromtseff criterion to evaluate the performance of nanofluids with turbulent flow. This criterion uses four characteristics in its performance and efficiency in turbulent flow conditions: density, thermal conductivity, specific heat capacity, and viscosity.

For the experiment setup, the following materials were used by the authors: a double-pipe heat exchanger, digital pressure gauge, digital flow-meter, four temperature sensors, nanofluid tank, hot water tank, a cold water tank and three pumps for fluid flow, data logger and connections. Data is recorded by data loggers and processed with a computer.

After the literature review on feasibility of the use of nanofluids, the following conclusions were done by the authors: The efficiency-price index showed that nanofluid of magnesium oxide is the most economical. The thermal efficiency of carbon nanofluids was found to be slightly better than oxide nanofluids, even though its price is several times the price of oxide nanofluids. The total efficiency of the nanofluids is often in the range of 10-40%, while their increase in the heat transfer coefficient is usually not exceeded by 50%. As a final conclusion, it was said that the use of nanofluids as a heat transfer is not profitable. In the same way, it was stated that in many equipment and industries, the use of nanofluids as a heat transfer fluid is not profitable and it can only be used in high-technology industries with high-profit.

Ambreen and Kim (2018) present a review of different research done in the development of heat transfer and pressure drop correlations for nanofluids. It is known that nanofluids preparation require special attention in order to avoid mistakes and that a combination of metals, metal oxides and carbides are used for their preparation. According to the authors, fouling in the machines can be produced by nanoparticles aggregation in poorly prepared nanofluids. Other researchers (Das et al., 2008) stated that high particle concentrations are required to prevent particle sedimentation; however, this will lead to an increase in the cost.

Another important aspect the authors considered, together with the heat transfer enhancement of nanofluids, is the pressure drop. For this reason, correlations for friction factor estimation of nanofluids have been done using the general expression of the Nusselt number and friction factor equations.

The Nusselt number is the ratio of convective to conductive heat transfer across a boundary. The convection and conduction heat flows are parallel to each other and to the surface normal of the boundary surface, and are all perpendicular to the mean fluid flow in the simple case.

The authors concluded that few studies proposed models for heat transfer and pressure drop estimation of the nanofluids in the smooth tube, a tube with inserts, counter flow heat exchangers, heat sink and, few other constructions. They found that different factors such as thermal conductivity, gravity, inter-phase frictional force, sedimentation, dispersion, ballistic phonon advection, non-uniform shear rate, nanoparticle migration induced by viscosity gradient and layering at the solid-liquid interface, including nanoparticle morphology (size, shape), the material base fluid properties and pH value, temperature, additives, particle clustering and most importantly particle concentration, have an influence on the thermal efficiency of the nanofluids and the pressure drop characteristics.

Diglio et al. (2018) conducted a preliminary evaluation of the potential of nanofluids as heat carrier by using a very simple mathematical model was carried out with the aim of telling which nanoparticle gives the best performance in borehole heat exchanger. The authors presented a numerical study on how nanofluids can replace ethylene glycol-water mixture as heat carrier in a BHE, and then, evaluation of nanofluids with low nanoparticles volumetric concentration (0.1%–1%) was done with a numerical model, based on energy and momentum balances.

An adaptation of the model given by Beier et al. (2012) was done to assess the vertical distribution of temperature of heat carrier in the borehole. Different assumptions and simplifications were done for the model, e.g., variations of temperature with depth are taken into account, the model neglects heat conduction in the vertical direction within the pipe wall, the grout, and the ground. The assumptions of the model are:

- the variation of temperature of undisturbed ground with depth;
- the thermal resistance model adopted to evaluate the heat transfer between the circulating fluid and undisturbed ground.

- the borehole thermal resistance between the pipe and borehole wall; it includes the inner-pipe film resistance, pipe wall resistance, grout resistance and, any contact resistance;
- the ground thermal resistance, which determines the heat transfer from borehole wall to undisturbed ground;
- the thermal resistance that affects the heat transfer between the fluids in the two pipes.

The authors used Comsol Multiphysics to solve the numerical model proposed in the present work, where discretization of 100 nodes in depth was done. In general, a reduction in thermal resistance in the borehole was seen using nanofluids. The best thermal performance was seen with Cu, graphite, SiO_2, and Ag, respectively. On the other hand, Al_2O_3 and CuO proved to be the worst. In the case of Cu, the borehole thermal resistance (Rb) ranged from 0.219 to 0.218 m K W^{-1} increasing the volumetric concentration (ϕ) from 0.1% to 1%. Contrary to this, CuO showed Rb that varied from 0.226 to 0.225 m K W^{-1} increasing ϕ from 0.1% to 1%.

The conclusion of this work was done based on a comparison with conventional ethylene glycol/water mixture. The main results and conclusions were: a) Cu-based nanofluid is characterized by highest Rb reduction that ranges from about 3.5% to 3.8% varying ϕ from 0.1% to 1%, respectively. CuO-based nanofluid is the worst solution, with ΔRb that varies from about 0.020% to 0.20%, b) The lowest volumetric heat capacity reduction was seen in Cu and CuO based nanofluids, while graphite by highest one. For Cu based nanofluids it is within the range 0.2%–2%, while for CuO based nanofluids it varies between 0.4% and 4% and c) The highest convective heat transfer coefficient was seen in Ag-based nanofluid, followed by Cu-based nanofluid. A sensitivity analysis done by varying the main parameters of the model showed that the advantages deriving from the use of nanofluids as heat carrier depend by the operating and geometric conditions, and the reduction of BHE thermal resistance is strongly affected by pipe inner radius, which decreases with increasing the r_{ext} (External thermal resistance).

Sahu et al. (2018) prepared nanocomposites and hybrid nanocomposites based on high density polyethylene (HDPE) as matrix reinforced with an alternate and possible combination of 0D (Nano-Diamonds-(NDs), 1D (Multi-Walled Carbon Nanotubes-(MWCNTs) and 2D (Graphite nanoplatelets-(GNPs)). The aim of this study was to evaluate the nanomechanical behavior of HDPE by addition of nanofiller(s).

Based in Merah et al. (2006) says the mechanical properties of high density polyethylene like all polymers are very sensitive to service temperature. In general, all polymers at temperatures significantly below their glass transition temperatures (T_g) undergo brittle fracture, thus, the increase in mechanical properties results in the variation of material properties.

For their experiment, the different materials were used with some specifications:

- HDPE: Density > 0.940 g/cm^3, melting point of 125-135 °C.
- Nano-diamonds: Average particle size 4-6 nm, carbon purity >98%, specific surface areas 350 m2/g, density 3.18 g/cm3.
- Multi-Walled Carbon Nanotubes: Diameter 60-100 nm, length 5-15 mm, purity >95% and density 2.15 g/cm3.
- Graphite Nano-platelets: Average particle size 400-450 nm, purity >98%.

A quasistatic nanoindentation test was used to evaluate the following mechanical properties: hardness, plasticity, tensile modulus of pure HDPE and different HDPE based nanocomposites and hybrids. The tests were carried on under some parameters, e.g., peak force of 8000 mN, loading and unloading time of 10 sec and dwell time of 5 sec.

The dynamic nanoindentation allows a continuous measurement of modulus while running an experiment, which enables a continuous stiffness measurement. For this reason, the viscoelastic mechanical properties (e.g., storage modulus, loss modulus, loss factor, and creep behavior) were evaluated using dynamic nanoindentation. On the other hand, the mechanical properties obtained from quasi-static testing were calculated as described by Oliver and Pharr (1992).

The results and conclusions did after the tests showed that optimum properties were exhibited by hybrid nanocomposite 0.1 Graphite Nano Platelets/Nano Diamonds. Hardness, plasticity index and Young's modulus of Nano Diamonds based composite was superior in comparison to MWCNT and Graphite Nano-Platelets. The increase in storage modulus was attributed to produce the elastic behavior of samples. Regarding the creep strength, the highest was rate was exhibited by 0.1 Graphite Nano-Platelets/Nano Diamonds hybrids.

The authors came to the conclusion that higher surface properties were seen by the Nano-Diamonds and Graphite Nano-Platelets filled hybrid. For this reason, HDPE, Nano-Diamonds and Graphite Nano-Platelets could improve quasistatic and dynamic properties materials.

Daneshipour and Rafee (2017), show a numerical simulation for the application of the CuO-water and Al_2O_3-water nanofluids as the working fluids of a geothermal BHE. To show the validity of the simulations, the results were compared with available data in the literature. In this paper using the Reynolds Averaged Navier-Stokes (RANS) equations with SST k-ω turbulence model are numerically solved to model the flow and the physical properties of the nanofluids are obtained using the available correlations. The Fluent Software for simulations of the flow is used, the SIMPLEC algorithms that have been used for coupling between the pressure and velocity, by last the finite volume method on collocated cells has been used to discretize the Reynolds Averaged Navier-Stokes (RANS) equations.

In this work, they mention a few papers related to applications of the nanofluids in geothermal applications, for example: to study the influences of natural factors such as groundwater flow on heat pumps design, in the analytical method to obtain the temperature distribution along the heat exchanger, in the modeling and optimization of a novel combined cooling, heating, and power (CCHP) cycle driven by geothermal and solar energies using the CuO-water nanofluid. The results also show that the CuO-water nanofluid gives higher extracted heat than the alumina-water nanofluid but at the penalty of higher pressure losses and pumping powers (Daneshipour and Rafee, 2016).

Esfe et al. (2017) present the numerical solution to optimize MgO-water nanofluids in order to reduce the cost and increase the heat transfer coefficient. In this study, the optimization is performed by the non-dominated sorting genetic algorithm (NSGA-II) which has a significant capability of achieving optimal response.

The NSGA-II algorithm has been used to reduce the cost and increase the heat transfer coefficient. For this purpose, three variables including solid volume fraction (φ), the diameter of nanoparticles (Dp), and Reynolds number (Re) are intended as optimization variables (Esfe et al., 2017). At first, the heat transfer coefficient is obtained at various values of solid volume fractions, diameters of nanoparticles, and Reynolds numbers based on empirical data.

Considering the results, in order to reach the heat transfer coefficient of 280 W/m2K, the cost is equal to 355$ per liter in the first generation, and 218$ per liter in the last generation (total population of 50 members and repetition of 15 times) which is in the Pareto front. This result proves that the optimization has been able to reduce the cost up to 38%.

Ganvir et al., say "the heat transfer characteristics of current fluids are tremendously improved by suspending nano-sized solid particles with a diameter below 100 nm and are considered as prospective working fluids for the applications such as solar collectors, heat pipes, nuclear reactors, electronic cooling systems, automobile radiators, etc."

The reviews are centered in the current researches of nanofluid to increase on convective heat transfer rate, as well the studies of economy, thermal achievement rate, availability, and environmental impact, thermo-physical properties, effect of fluid temperature, inlet velocity, use of surfactant for better stability of nanofluids, particle size, and volume concentration effects.

The types of nanoparticles are summarized in tables thermal conductivity received most attention by the researchers. Suspension of small amounts of nanoparticles of oxides (Al_2O_3, CuO, TiO_2, Fe_2O_3, SiO_2, etc.), metals (Cu, Ag), carbon nanotubes (CNTs) in traditional base fluids (water, ethylene glycol, propylene glycol, engine oil, etc.) have resulted increase in thermal conductivity of mixture (Ganvir et al., 2017).

Gosselin et al. (2017) present a study comparing the performance different ground heat exchangers (GHE) configurations (single U-pipe, double U-pipe, and coaxial) each with standard HDPE pipes and thermally enhanced (TE) polymers pipes with inorganic nanomaterial fillers. The principal aim was to evaluate the economic benefits of TE pipes by comparing sizing calculations and 10-year hourly simulations of the configurations mentioned.

GLHEPro software was used for the calculations, using as input a synthetic thermal load profile, heating-dominated, medium office building located in the U.S. climate zone 5B enclosing Colorado. Results for the sizing calculations, energy consumption, and life cost analysis are presented was performed to compare the total costs (construction and operation) for the six GHE configurations using the full building loads.

The results show that the use of TE pipes instead of standard HDPE pipes allowed a reduction of the borehole thermal resistance between 22.3 and 24.4 % and a reduction of the total GHE length between 9.0 and 14.8 % and a reduction of the construction cost between 3.3 and 8.6 %. This study demonstrates that GHEs equipped with TE pipes can be a financially viable and environmentally beneficial solution, despite the current typical trade cost of TE pipes being almost two times higher than standard HDPE pipes.

For the authors, the future work on this topic will include the development of a tool to quickly and easily carry out sizing, performance and cost comparison analyses for a wide range of situations to present a more precise and realistic insight into the pros and cons of using TE pipes in the construction of GHE (Gosselin et al., 2017).

Gupta et al. (2017) researched the application of nanofluids in heat pipes due to its superior thermophysical properties. They summarize and provides the outcomes of experimental/theoretical studies of nanofluids as a working fluid in heat pipes, like metals (Cu, Ag, and Gold, etc.), metal oxides (Al_2O_3, CuO, MgO, ZnO, TiO_2, Fe_2O_3, and SiO_2, etc.) to obtain the enhanced thermal performance. In all revision includes thermal efficiency, thermal resistance, the effective thermal conductivity, surface temperature gradient, convective heat transfer coefficient at evaporator and condenser section.

In this paper, the authors reviewed different configurations of heat pipes depending were used in different size and shape depending upon the application requirement, integrating summaries and tables. The most popular types are Micro-grooved using nanofluids, and heat pipes type wick mesh, sintered wick, thermosiphon, oscillating/pulsating, etc. In conclusion, the heat transfer mechanisms depend upon, type of heat pipes, nanofluids characteristics, design and operating parameters of heat pipes, etc.

For Sarviya and Fuskele (2017) the nanofluids have become the aim of study for researchers since it is known that they increase thermal conductivity compared to the conventional fluids used for heat transfer. In this work, the authors showed various techniques and methods developed for measuring thermal conductivity. Different techniques are:

a) *Transient hot-wire (THW) technique:* Temperature and time response are measured after an abrupt electrical pulse is applied.
b) *Transient Plane Source (TPS) technique:* It is used to measure the thermal conductivity of nanofluid. As the THW method, it uses the Fourier law of heat conduction as a principle for estimating the thermal conductivity.

According to Sarviya and Fuskele (2016), many factors influence the thermal conductivity of nanofluids, such as particle volume fraction, particle size and particle shape. The solid volume content and the temperature also influence the thermal conductivity enhancement. They mentioned that the studies were done by Mare et al. (2015) on base fluids proved that conductivity decreases when there is an increase of surfactant, additionally that in Parametthanuwat et al. (2015) did research on silver nanofluids as a function of temperature to determine the thermal conductivity. It was found that the thermal conductivity increases independently on surfactant concentration

After the review of the recent developments in the field of nanofluids from thermal conductivity perspective, the authors concluded that the thermal conductivity of nanofluids depends on temperature, volume fractions, particle size, aspect ratio, weight concentration, surfactant concentration, and that the transient hotwire technique, is the most commonly used technique for measuring thermal conductivity.

Sui et al. (2017) presented this novel idea to utilizing nanofluids in geothermal energy applications. They investigated the potential of applying nanofluids as working fluids to extract more energy from reservoirs and to improve the exploitation of the geothermal resources, by increasing the returning fluid temperature.

In the document described that sensitivity analyses have been performed to demonstrate the importance of fluid viscosity and heat capacity in geothermal energy production, and nanofluids again have superior performance in heat transfer. They studied the potential to apply nanofluids as serve as working fluids in abandoned oil wells retrofitted into double pipe heat exchangers, by taking advantage of the reported significant heat transfer enhancement of the nanofluids.

They recommended the importance of the extensive knowledge on the thermophysical properties nanofluids, for example, the properties such as viscosity and specific heat capacity in the geothermal well-operation, in addition to the fluid circulation rate, this knowledge are of great importance for the performance and the cost-efficient production of geothermal energy.

Tang et al. (2017) presented the experimental results of the form-stable phase change materials (FSPCM). Due to the high thermal energy storage capacity and thermal conductivity, the FSPCM was manufactured by adding expanded graphite (EG) into stearyl alcohol (SAL) and high density polyethylene (HDPE) mixtures.

In the composites, HDPE was used to prevent SAL leakage, and EG was not only a supporting material just like HDPE but also a thermal conductivity promoter. The influences of EG on the thermal properties of the SAL/HDPE phase change materials were investigated with a series of measuring means (Tang et al., 2017).

The results were that the thermal conductivity of FSPCM with 3% EG increase up to 0.6698 W $(m K)^{-1}$ while thermal conductivity of FSPCM without EG was only 0.1966 W $(m K)^{-1}$. Finally, the thermal properties, chemical stability, and microstructure of the FSPCM were presented, and the addition of EG could provide a considerable thermal energy storage capacity and high thermal conductivity for latent heat storage.

Uddin et al. (2017) present a few theoretical/numerical studies of heat pipes applied rotate machines that convert electrical energy into mechanical energy or conversely. According to the authors, none of these studies presented involved the rotating heat pipe with nano-fluids. It was implemented the numerical models for the properties of nano-fluids that satisfy a wide range of experimental data, and study the effects of fluid mass to be inserted in the pipe, the rotation speed of the machine, the size and concentration of nanoparticles to know the performance of heat transfer.

Used a new methodology based on Particle Swarm Optimization (PSO) implemented in MATLAB code to solve the non-linear differential equations system (flow of nano-fluids inside the heat pipe) and the heat transfer equation. The computations have been carried out for the CuO-EG (ethylene glycol) nano-fluid under different conditions. The thermo-physical properties of pure CuO and pure EG at the reference temperature and the thermophysical properties of the CuO-EG nano-fluid are given are presented. The authors were found that the heat transfer through the heat pipe depends on various factors, the input nano-fluid mass, rotation speed of the heat pipe, nano-particle size and nanoparticle concentration.

Yang et al. (2017) explain in their paper that exist two different methods can be used for the preparation of nanofluids: one-step and two-step methods. According to the authors, the thermal conductivity and viscosity are important parameters to study the potential for heat transfer enhancement of flowing liquid. Viscosity is considered an important property when determining the so called flowing skin friction coefficient (Tamim, 2016). In the same way, this property will affect the temperature distribution, therefore, the heat transfer characteristics will vary (Dinarvand et al., 2016).

In this paper, they provide a classification on the experimental and theoretical results in order of the nanoparticle type synchronously to exhibit the influence factors on viscosity of nanofluids, to mention a few examples: Al_2O_3 nanofluids, CuO nanofluids, TiO_2 nanofluids, SiO_2 nanofluids. Below are some works related to viscosity:

- *Al_2O_3 nanofluids:* Information given by Murshed et al. (2008) and Prasher et al. (2006) showed that nanoparticles have a greater effect on the viscosity for water based nanofluids than PG based Al_2O_3 nanofluids. However, Kole and Dey (2010) stated that approximately 1.5 vol% Al_2O_3 nanoparticles could double the viscosity of car coolant. For this reason, it cannot be concluded that the effect on viscosity.
- *CuO nanofluids:* Research carried on by Namburu et al. (2007) showed measurements of the viscosity of CuO (29 nm) nanofluid with EG/Water as based fluid in the range of loading from 0 to 6.12% and temperature range from -35 to 50°C. The results suggest that an increase of viscosity is expected with an increase in particle loading, which will result in an enhancement in viscosity.
- *TiO_2 nanofluids:* Different results have been published on the viscosity of TiO_2 nanofluids. Silambarasan et al. (2012) and Fedele et al. (2015) showed the inverse behavior between the absolute viscosity and the temperature. Jarahnejad et al. (2015) did experiments on TiO_2 nanofluids, where it was found that the viscosity of such fluids did not increase after adding nanoparticles.
- *SiO_2 nanofluids:* Experiments on different types of water based nanofluids were carried on by Tavman and Turgut (2009). In general, the effective viscosity increases by increasing the particle loading. On the other hand, it decreases with increasing temperature. By adding 1.85 vol% SiO_2 nanoparticles, an increase of 90% in viscosity was measured.

To Yang et al. (2017) the thermal conductivity is regarded as the primary exploitable factor for the application of nanofluids. They present experimental and theoretical studies that affect the thermal conductivity for example particle type, loading, size, and shape, but also including environmental parameters such as base fluid, concentration, temperature and the standing time. Below are some works related to thermal conductivity:

- Effect of Temperature: According to Yang et al. (2017), the thermal conductivity of nanofluids is affected by temperature. Most results exhibit positive effects on thermal conductivity of nanofluids by increasing temperature; however, an increase of temperature does not always result in enhancement of thermal nanofluids. Qiao (2010) found an increase in thermal conductivity from 8.9% to 78.5% after raising the temperature from 20 to 60 °C. However, some researchers only found a slight effect on thermal conductivity after raising temperature, e.g., Singh et al. (2009), who found an increase on thermal conductivity ratio from 1.221 to 1.225 at 4% volume loading and from 1.04 to 1.042 at 1% volume loading after raising the temperature from 23 °C to 70 °C.
- Effect of Particle Size: According to Yang et al. (2017), particle size is another aspect controlling thermal conductivity of nanofluids. After measuring the thermal conductivity of Al_2O_3 water-based nanofluids in different particle size, Chon et al. (2005) found that the thermal conductivity enhancement of nanofluids containing 47 nm Al_2O_3 nanoparticles is around two times of those containing 150 nm.

In conclusion: the material type has a great effect in thermal conductivity of nanofluids since thermal conductivity of Graphene, CNTs, Au, Ag, etc. nanofluids are greatly higher than that of other type, such as TiO_2, SiC, SiO_2 nanofluids. However, it seems that material type has little effect on viscosity of nanofluids because no relationship can be concluded between different particle materials. Most results reveal that viscosity and thermal conductivity increase as an increase in particle loading (Yang et al., 2017).

Ferreira et al. (2016) show in detail the effect of carbon nanotube treatment on the mechanical property of polyethylene/carbon nanotube composite (HDPE-CNT). The CNTs were treated with HCl and then with H_2SO_4/HNO_3, which removed the amorphous carbon and residual metal catalysts of CNTs and these treatments damaged the graphitic structure (sp2C C) of CNT. The results demonstrated that the surface treatment of CNT with acid as described in this work did not decrease the mechanical properties of composites, even though an aromaticity loss of CNTs had been observed. With the used of it treatment the carbon nanotube dispersion can be improved.

Narei et al. (2016) presented the study of the effects of using Al_2O_3-water nanofluid as heat transfer fluid on reducing the bore length of a ground heat exchanger (GHE) in a vertical ground-source heat pump (GSHP) this is due to the high costs of vertical deep boreholes. Another of the reasons for the deep boreholes can be ascribed to the inherently poor thermal conductivity of conventional heat transfer fluids (HTFs) typically water or antifreeze/water mixture. For this reason, in this study used a nanofluid innovative type of HTFs engineered with dispersing solid nanoparticle in conventional HTFs. Is determinate that the effective thermal conductivity and the effective viscosity of the nanofluid play prominent roles in the convective heat transfer, this are optimized via using multi-objective Flower Pollination Algorithm (MOFPA).

The result of this study was to evaluate the impact of using optimized thermo-physical properties of nanofluid. The bore length computation and obtained that the use of Al_2O_3-water nanofluid instead of water as heat transfer liquid reduced less than 1.3% of the bore length. The other important result revealed that the use of tubes and grout reduces the bore length due to the thermal resistances produces for these.

Tang et al. (2016) conducted a series of studies for the purpose of improving the thermal conductivity of the form–stable phase change materials (FSPCM) using two types of nano–powders with high thermal conductivity (Nano–Al_2O_3 (NAO) and nano–graphite (NG)). The NG and NAO are added into the FSPCM to improve the thermal conductivity.

In this work, they modify the FSPCM, used myristic acid (MA) as a solid-liquid phase change material (PCM), and the high density polyethylene (HDPE) acted as supporting material to prevent the leakage of the melted MA, this is why that in recent years, developing micro–encapsulated phase change material (MEPCM) and form–stable phase change materials (FSPCM) is a popular solution to overcome the defect to store and release the latent thermal energy.

With the field emission scanning electron microscope (FESEM), showed that the MA was uniformly absorbed in the HDPE matrices and there was no leakage during the melting process when the mass fraction of the MA in the MA/HDPE composite was less than 70% and the thermal conductivity of the FSPCM can increase from 0.2038W $(m\ K)^{-1}$ to 0.3972W $(m\ K)^{-1}$ (NAO) and 0.4503 W$(m\ K)^{-1}$ (NG) at 30 °C when the mass fraction of nano–additives is 12%. And at 60 °C, the value can increase from 0.1918 W$(m\ K)^{-1}$ to 0.3471W$(m\ K)^{-1}$ (NAO) and 0.3923 W$(m\ K)^{-1}$ (NG).

Tang et al. (2016) presented in this work a variant of the previous work (they modify the FSPCM, used myristic acid MA-HDPE). In this work, the FSPCM consisting of palmitic acid (PA) and high density polyethylene (HDPE) was modified by graphene nanoplatelets (GNP). The materials of this experiment used for the FSPCM, was: PA ($C_{16}H_{32}O_2$, hexadecanoic acid, Chemically Pure) was used as a solid-liquid phase change material (PCM) for thermal energy storage, HDPE (melt flow index: 20 g/10 min, density: 0.953g/cm^3, Vicat softening temperature: 126 °C) was a supporting material to prevent the leakage of the melted PA, and he last, the GNP (Thickness:3–20 nm, Flake diameter: 5–10 μm, Specific surface area: 30 m^2/g, purity: 99.5%) was added for improving thermal conductivity and shape stabilized of the FSPCM.

The authors made a miscellaneous analysis of the different compositions for mention: FT-IR, XRD, microstructure, thermal energy store properties, thermal reliability, leakage and, thermal conductivity. And the end of the experiments the conclusion they found was with the scanning electronic microscope (SEM), shows that the PA is uniformly dispersed into the network structure of the HDPE and the PA-HDPE composite is attached to the broad surface of the GNP. The thermal conductivity of the FSPCM was measured by thermal conductivity meter and it increased to 0.8219W $(mK)^{-1}$ which is nearly 2.5 times as high as that of the pure FSPCM when the mass fraction of the GNP is 4%. In general, thanks to the high specific surface area and thermal conductivity of the GNP, the satisfied FSPCM with 4 wt% of the GNP has capacities of high thermal enthalpy and thermal conductivity, which guarantees the promising application in solar energy and building heating systems (Tang et al 2016).

Hussein (2015) showed an exhaustive review of the applications (include theoretical and experimental works) related with the use of nanotechnology in renewable energy systems: solar, hydrogen, wind, biomass, geothermal and tidal energies. All information was reviewed and summarized carefully in tables.

In his work, Hussein wrote: "this paper can be considered as an important bridge between nanotechnology and all available kinds of renewable energies". His review includes works for all renewable energies, with the use of nanofluids, nanomaterials, and nanoparticles.

For the case of Geothermal Energy, it is mentioned different applications with nanotechnology, for example, the use of nanofluids to cooling fluids inside the pipes exposed high temperatures, to cool sensors and electronic devices in drilling machines and ground heat exchanger depending on the temperature (low, medium or high), and district heating applications use networks of piped hot water to heat many buildings across entire communities. From the other side, nanofluids can be used as a working fluid to extract energy from the ground and processed it into a power plant system or produce large amounts of work energy.

Yang and Mai (2017) presented a review about a new interdisciplinary theory - nanothermodynamics, that is an extension of the classic thermodynamics' theory to the nanometer scale. It serves as a bridge between macroscopic and nanoscopic systems. The focus and emphasis are on the utilization of nanothermodynamics models to investigate the size-dependent thermal stability, magnetic properties, photoelectric behaviors, thermoelectric phenomena, mechanical properties, electrical properties, volume expansion coefficient, mass density, and energies of nanomaterials. The model developed predict macroscopic, mesoscopic and nanoscopic properties of materials.

Faizal et al. (2016) conducted a review technique of improving thermal properties of individual component that affect the heat exchanger between the heat carrier fluid and the ground, in this case, applied in geothermal energy piles. The review from literature is narrowed to geometrical modifications, application of nanofluids as heat carrier fluid, and modification of pipe material (the heat is extracted/rejected in the ground using HDPE pipes) and the concrete mix.

- To reduce the total pile thermal resistance, it's used geometrical optimization, is to say, different pipe configurations, reducing the number of pipes and their arrangement, improve the thermal behavior of GHE. Hamada et al. (2007) use different shapes and they report that the heat rejected for U-shaped and double-shaped pipes configurations was 53.81 W/m and 68.71 W/m respectively. In Li et al. (2006) using single and double U-shaped for application in boreholes with DN32 HDPE pipes and the results were that with the same flowrate with at inlet temperature of 35°C for heat rejection mode and 3°C for heat extracting mode the heat transfer of double U-pipes was about 50% and 45% respectively higher that of single U-pipe.
- To enhance the fluid conductive and convective heat transfer, the use of nanofluids can be used as the heat carrier fluid. Lotfi et al. (2012) studied the mix of multiwalled carbon nanotubes (MWCNT)/water (concentration of 0.015 wt%) given a higher heat transfer coefficient compared to water. Ghozatloo et al. (2014) use graphene in different concentrations 0.05, 0.075 and 0.1 wt%, this last, the viscosity and density were 0.997 cp and 1053.5 kg/m^3, increasing 11.97% and 5.79% compared to base fluid. The k increased by 12.6% at 25 °C.
- To increases thermal conductivity by modifying the pipe material increases the thermal conductivity using highly thermally conductive fillers can be mixed. Polymers with enhanced thermal conductivities generally find applications in circuit boards, heat exchangers, appliances and machinery. Versaprofiles, an HDPE pipe manufacturer for geothermal applications, developed an HDPE pipe for borehole heat exchangers, known as the GEOperforms, with a thermal conductivity 75% higher than the conventional HDPE pipe (Faizal et al., 2016).

In the work of Faisal et al. (2016) mentioned that Pasquier et al. (2009) tested the thermal performance of boreholes installed with the enhanced GEOperforms HDPE pipes and the experimental results from thermal response tests showed that the equivalent borehole thermal resistance of the well with GEOperforms pipe was 17% lower, as well as the simulation, it showed a reduction the borehole lengths by up to 10% of a conventional HDPE pipe.

Dorrian and Mumm (2011) patented a pipe with enhanced thermal conductivity for geothermal applications (GreenGeopipe), the thermal properties of HDPE material can be enhanced using different types of thermally conductive fillers: metallic oxide, non-oxides, and graphite for example. This last is one material that has shown promise in enhancing the thermal properties of HDPE material. Different studies showed the graphite is a good material applied to HDPE material: Ye et al. (2006), Krupa and Chodák (2001), Krupa et al. (2004).

Other works mentioned to the increase in the thermal properties of the concrete can also be enhanced by adding highly thermo-conductive materials to the concrete mix: Bentz et al. (2011), Xu and Chung (1999), Xu and Chung (2000), Fu and Chung (1999), Lie and Kodur (1996), Yun et al. (2013).

In conclusion, the purpose of Faizal et al. (2016) was to demonstrate in the literature on multidisciplinary methods to improve the thermal properties of elements in a geothermal energy pile. For the geometrical optimization, they found effects with the use of different pile diameters, concrete cover, number piles and configuration piles (simple-double-triple-multi U tubes). Also, the use of nanofluids have shown a lot of promise in enhancing heat transfer in heat exchanger and that highly thermally conductive material fillers can also be used to enhance the thermal conductivity of HDPE material.

Bassiouny et al. (2016) present a new idea to enhance the thermal conductivity of HDPE pipes typical, which are rust-resistant but with low thermal conductivity and are that used in many ground-source applications. This study based on a computational analysis presents a new manufacturing composite of HDPE with aluminum wires which are circumferentially and equally distributed in the pipe thickness.

Previously, Bassiouny et al. (2016) found that Kumlatas et al. (2003) investigated experimentally the effect of adding aluminum powder to an HDPE powder with different volumetric concentration, but the numerical model determined that the thermal conductivity of the composite was less than 10% by volume and Agrawal and Stapathy (2013) proposed a model using aluminum nitride-HDPE mix. The result shows that increasing the volume fraction of the A1N, increases the thermal conductivity.

In this study used the finite volume method, and developed a FORTRAN program to model the problem, comparing the pure HDPE and aluminum wire-HDPE. The results showed an enhancement in the equivalent thermal conductivity of the composite by almost 25% for the 2-mm aluminum wires, and 150% for the 3-mm wires depending on the number of wires, and finally that the outer surface temperature increases, increasing the number of the wires, this can be a result to save pipe's length required to reject the same amount of heat flow using HDPE typical.

Table 1 shows a matrix of the main features of the references discussed above sorted by the most recent. In the first and second column, the year and the name of paper are presented respectively, the third column presents the method used (nanofluids or nanomaterial), the fourth column presents the type of research (review, numerical or experimental), in column five indicates the application, and finally the principal results and/or conclusion is based is indicated.

Table 1. Summary of nanotechnology applications in HDPE, GSHP, GEX and heat transfer.

Year	Authors	Method	Type	Application	Results and remarks
2018	Ahmadi et al.	Thermal conductivity of nanofluids	Review	Several experimental and theoretical studies conducted on the thermal conductivity of nanofluids are represented and investigated	The increase in temperature and concentration of nanoparticles usually leads to the higher thermal conductivity of nanofluids.
2018	Ahmadi et al.	Nanofluids	Review	Study on the geothermal systems use nanofluids.	Nanofluids are generally applied as heat transfer fluid in heat exchangers due to their ability in thermal enhancement. The recommendation for future studies is focusing on finding various types of nanofluids, especially carbonic nanostructures to find more desirable fluids for heat transfer..
2018	Alirezaie et al.	Nanofluids	Experimental & Review	Experimental data of efficiency of different nanofluids (aqueous Ag, MgO, MWCNT and DWCNT) is reviewed and efficiency-price index is presented.	Economic analysis of heat transfers of nanofluids indicated that nanofluids don't have economic justification except in high-tech devices with critical applications.
2018	Ambreen and Kim	Nanofluids	Review	To review the research progress in the development of heat transfer and pressure drop correlations for nanofluids.	The review showed that the heat transfer and pressure drop characteristics of the nanofluids are sensitive to some factors such as nanoparticle morphology (size, shape) and material, and other factors.
2018	Diglio et al.	Nanofluids	Experimental & numerical	Reducing the BHE in a GSHP system using nanofluids to replace conventional ethylene glycol/water mixture as heat carrier	Copper-based nanofluid as het carrier has the highest borehole thermal resistance reduction, reaching 3.8%, compared to that of the base fluid, but also the second one highest pressure drop. It's a promising way to reduce the borehole thermal resistance of BHE-GSHP system.
2018	Sahu et al.	Nanomaterial	Experimental	To investigate the nanomechanical properties of HDPE based composites and hybrids using quasi-static and dynamic nanoindentation.	The local surface properties were evaluated using quasi-static and dynamic nanoindentation. Properties like hardness, Young's modulus, plasticity index, and dynamic modulus were reported.
2017	Daneshipour and Rafee	Nanofluids	Numerical	Applications of the CuO water and Al_2O_3 water nanofluids as the working fluids of a GBHE	Numerical simulation using Fluent 6.3.26 Software, finite volume method, and the SIMPLEC algorithms. The CuO-water nanofluid gives higher extracted heat than the alumina-water nanofluid and it has higher coefficients of convection heat transfer.
2017	Esfe et al.	Nanofluids	Numerical	Numerical solution to optimize MgO-water nanofluids in order to reduce the cost and increase the heat transfer coefficient	The NSGA-II algorithm has been used to reduce the cost and increase the heat transfer coefficient and the optimization has been able to reduce the costs up to 38%.
2017	Ganvir et al.	Nanofluids & Nanoparticles	Review	Current research in the nanoparticles/nanofluid studies	Summarized the nanofluids applications: automotive radiators, electronic cooling, space and defense, heat pipes, biomedical industry, etc.

2017	Gosselin et al.	Nanomaterial	Numerical	Different GHE configurations: single U-pipe, double U-pipe, and coaxial, each with standard HDPE and thermally enhanced (TE) pipes.	Comparison of the performance of different GHE configurations. They use GLHEPro to calculate the sizing, energy consumption, and cost analysis for each GHE configuration. The percentage reduction of the length, area, borehole thermal resistance, total GHE field, and construction costs obtained when using TE pipes instead of HDPE pipes are presented.
2017	Gupta et al.	Nanofluids	Review	Application of nanofluids in heat pipes	Outcomes of experimental/theoretical studies of nanofluids as a working fluid in heat pipes, like metals (Cu, Ag, and Gold, etc.), metal oxides (Al_2O_3, CuO, MgO, ZnO, TiO2, Fe_2O_3, and SiO_2, etc.).
2017	Sarviya and Fuskele	Nanofluids	Review	To lead to some directions for future research in nanofluids	Recent developments in the field of nanofluids from thermal conductivity perspective are presented.
2017	Sui et al.	Nanofluids	Numerical	A novel idea of utilizing nanofluids as working fluids to extract more energy from reservoirs and to improve exploitation of the geothermal resources.	The nanofluids properties such as viscosity and specific heat capacity in the geothermal well-operation are very important to geothermal applications, in this case, to improve the exploitations of the reservoirs
2017	Tang et al.	Nanomaterial	Experimental	Results experimental with FSPCM by adding expanded graphite (EG) into stearyl alcohol (SAL) and high density polyethylene (HDPE) mixtures	The focus of this work would be the effects of EG on the thermal conductivity and leakage rate in the SAL/HDPE/EG composites. The thermal conductivity of FSPCM with 3% EG increase up to 0.6698 W (m K)$^{-1}$ while thermal conductivity of FSPCM without EG was only 0.1966 W (m K)$^{-1}$.
2017	Uddin et al.	Nanofluid	Numerical	Heat transfer in rotating heat pipes	The heat transfer depends on various factors, the nano-fluid mass, nano-particle size and the concentration.
2017	Yang et al.	Nanofluids	Experimental & Theoretical	Viscosity and thermal conductivity of nanofluids.	The material type has a great effect in thermal conductivity of nanofluids. However, it seems that material type has little effect in viscosity of nanofluids because no relationship can be concluded between different particle materials. Most results reveal that viscosity and thermal conductivity increase as an increase in particle loading.
2016	Bassiouny et al.	A new idea/material	Numerical	HDPE pipes with aluminum wires used for ground source applications	The results showed an enhancement the thermal conductivity depending on the number of aluminum wires used in the HDPE. Increasing the number of wires increases the outer surface temperature, this can save the pipe's length of the heat exchanger.
2016	Faizal et al.	Nanofluids	Review	Improve the thermal properties of elements in Geothermal Piles. To enhance the thermal conductivity of HDPE pipes.	In the literature found: geometrical optimization with the use of different pile diameters, number piles and configuration piles (simple-double-triple-multi U tubes). With the use of nanofluids enhance heat transfer in HE and with highly thermally conductive material fillers to enhance the thermal conductivity of HDPE material.
2016	Ferreira et al.	Carbon nanotube	Experimental	Surface treatment, mechanical properties of HDPE/CNT	The results provide evidence that the sur-face treatment of CNT with acid as described did not decrease the mechanical properties of composites, even though an aromaticity loss of CNTs had been observed.
2016	Narei et al.	Nanofluids	Numerical	Effect of nanofluids on reducing the bore length of Vertical GSHP	Using Al2O3/water nanofluid instead of water as HTF reduced less than 1.3% of the bore length of a vertical GHE. However, the results of applying nanofluid are not satisfactory at all, as the grout had the most potential to decline the bore length.

2016	Tang et al.	Nano-grafite	Experimental	Enhancement FSPCM and MA-HDPE	In the modified FSPCM, the MA was used as a solid–liquid PCM, the HDPE acted as supporting material to prevent the leakage of the melted MA, and the NAO and NG were additives for thermal conductivity enhancement
2016	Tang et al.	Nanomaterial	Experimental	Enhancement FSPCM and PA-HDPE	The satisfied FSPCM with 4 wt% of the GNP has capacities of high thermal enthalpy and thermal conductivity. Promising application in solar energy and building heating systems.
2015	Hussein	Nanofluids	Review	The Review aims to introduce applications of nanotechnology in renewable energy	Geothermal energy has various applications. For example, district heating applications use networks of piped hot water to heat many buildings across entire communities. More than 72 countries have reported direct use of geothermal energy
2014	Yang and Mai	Nanomaterial/ Nanothermo-dynamics	Review & Numerical	An extension of the classic thermodynamics theory to nanometer scale	The model developed predict macroscopic, mesoscopic and nanoscopic properties of materials.

3. CONCLUSIONS

It was concluded that currently, the nanotechnology is a technological innovation that has grown in recent years in the energy sector (solar, fuel cells, hydrogen, nuclear, photovoltaic, wind) and the use of this technology currently is applied in various areas of Geothermal Energy.

Geothermal Heat Pump Systems (GSHPS) are known as energy-efficient air conditioning systems, however, installation costs are very higher, mainly the Ground Heat Exchanger (GHE), which is the most expensive component of all system, this means being the major obstacle to the widespread use of such systems.

This review aim was to demonstrate from the literature the different methods, types, applications, results and conclusions that have been made with the use of nanotechnology applied to GHEs of GSHPS to improve absorption/rejection heat from the ground and the space to be conditioned. Theoretical, numerical and experimental developments in the use of nanofluids and nanomaterials were presented applied to the GHE pipes to enhanced efficiency in the heat transfer in pipes.

Some works improve the thermal conductivity of pipes or exchanger and in some cases, reduce costs, such as the case of (Ahmadi et al., 2018), which using nanofluids, increases the thermal conductivity of exchanger and decreases the cost of product using magnesium oxide, while in other works, it's used nanomaterial like as (Faizal et al., 2016), they mention the development of an improvement in HDPE pipes, thus increasing the thermal conductivity by 75% and reduced the use of conventional pipes by 10%.

With the results obtained so far, the next step it's the exploration of generating a new material to increase the thermal conductivity of the geothermal heat exchanger pipes will continue.

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