

## Applications of nanofluids in geothermal: A review

Mohammad Hossein Ahmadi<sup>1\*</sup>, Mahdi Ramezanizadeh<sup>2</sup>, Mohammad Alhuyi Nazari<sup>2</sup>, Giulio Lorenzini<sup>3</sup>, Ravinder Kumar<sup>4</sup>, Ravindra Jilte<sup>4</sup>

<sup>1</sup> Faculty of Mechanical of engineering, Shahrood University of Technology, Shahrood, Iran

<sup>2</sup> Aerospace Engineering Department, Shahid Sattari Aeronautical University of Science and Technology, Tehran, Iran

<sup>3</sup> Università degli Studi di Parma, Dipartimento di Ingegneria e Architettura, Parma 43124, Italy

<sup>4</sup> Department of Mechanical Engineering, Lovely Professional University, Phagwara-144411 Punjab, India

Corresponding Authors Email: [mohammadhosein.ahmadi@gmail.com](mailto:mohammadhosein.ahmadi@gmail.com)

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### ABSTRACT

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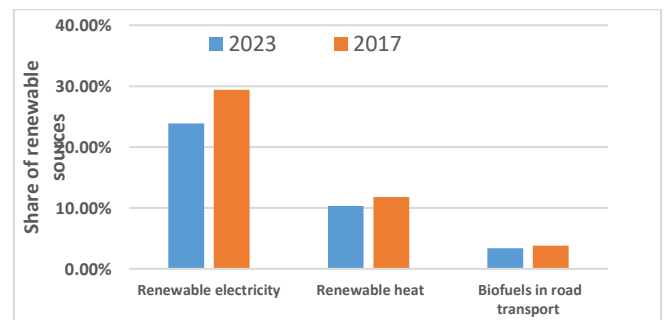
Geothermal energy is one of the most suitable sources of energy since it is possible to use it continuously for generating power and providing heat. Firstly, recent trends in geothermal energy are discussed and compared with other types of renewable energies. According to the results of this section, geothermal energy is an attractive choice for future power generation due to its low carbon dioxide emission and levelized cost of electricity in comparison with other renewable energy sources. Afterwards, applications of nanofluid in geothermal-based energy systems are reviewed and their important results are represented. On the basis of literature review, using nanofluids can result in augment in geothermal systems. The enhancement is dependent on several factors including the type of nanofluid, concentration and system specification. According to the results of a study, the effect of using nanofluid on heat transfer rate became more significant at higher flow rates. In addition, using nanofluids can reduce the size of heat exchangers used in geothermal-based system. The main effects of employing nanofluids is increase in convective heat transfer and pressure loss.

## 1. INTRODUCTION

The primary energy supply of the world has increasing trend because of industrial development and population growth [1-2]. Total primary energy supply increased by approximately 2.5 times between 1971 and 2016 [3]. Another important aspect which must be considered in energy sector is environmental issues [4-5]. Based on International Energy Agency report, energy related carbon dioxide emission had 1.4% growth in 2017. Clean energy sources including solar, geothermal, wind and hydropower gained importance in recent decades because of fossil fuels' environmental problems and the possibility of their exhaustion in near future [6-7]. Renewable energies are employed for various applications such as heating [8-10], cooling [11], electricity generation [12-13], and desalination [14]. According to International Energy (IEA) report [15], the share of renewable energies in various sectors will increase as shown in Figure 1. As it is illustrated, it is expected to have increase in global renewable energy demand.

Geothermal energy is one of the most attractive renewable sources due to its low environmental issues and affordable cost of generated electricity and provided heat by using this source of energy [17]. Since the stored thermal energy must be extracted for using geothermal, heat transfer augment has significant importance. By improving the heat transfer, the overall efficiency of the system can be improved. Studies have shown that nanofluids are appropriate choices for improving heat transfer [18-20]. Nanofluids are applicable in numerous heat transfer mediums such as heat pipes, heat

exchangers and etc. [21-24].



**Figure 1.** Future of renewable energy sources in various sectors [16]

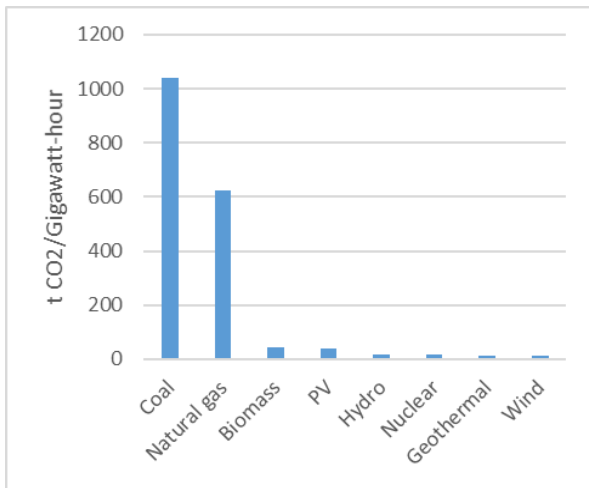
Heat transfer enhancement by employing nanofluids is mainly attributed to its higher thermal conductivity in comparison with conventional fluids [25-27]. Increase in the thermal conductivity of these fluids is due to dispersion of solid nanostructures which have higher thermal conductivity compared with liquids [28]. Various materials such as metal-oxide, metal and carbonic structures can be used as nanostructures to prepare nanofluids [29-32]. The properties of nanofluids are highly dependent on the type of solid phase, synthesis procedure, temperature and other factors [33-35]. Nanofluids are broadly utilized in various renewable energy systems such as PV/T, solar collectors and solar ponds [36-37]. The results of studies have revealed that applying

nanofluids in the mentioned renewable energy systems results in improved performance and efficiency.

In addition to solar energy applications of nanofluids, these types of fluids are applicable in geothermal-based energy systems [38]. Due to their improved thermal specifications, it is expected to achieve higher efficiency by using nanofluids. In this study, applications of nanofluids in geothermal energy systems are reviewed. The important findings of the reviewed studies are represented and discussed. Finally, some suggestions are offered for future researches based on the results of the literature review.

## 2. GEOTHERMAL ENERGY OVERVIEW

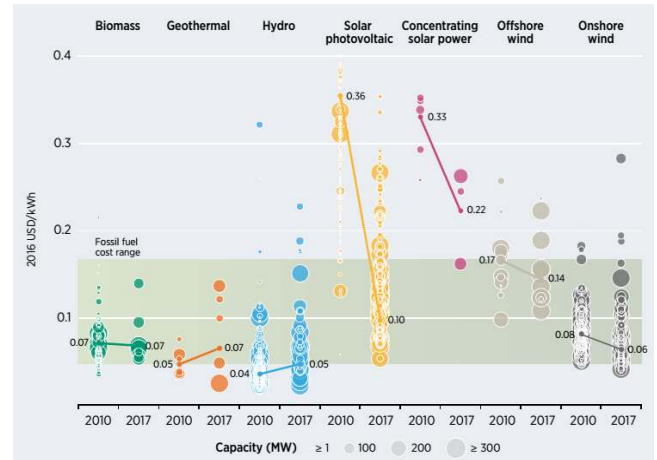
Geothermal energy exists in rock and trapped liquid or vapor which can be applied for heating and generating electricity [39-40]. Generally, geothermal resources with temperature higher than 100 °C are required for electricity generation; while there is a wide range for temperatures appropriate for heating [39]. Electricity generation by using geothermal energy have some advantages compared with fossil fuels plant, solar PV modules and hydropower, since it has lower carbon dioxide emission. Comparison between life cycle emission of various energy resources for electricity generation is represented in Figure 2. In addition to lower carbon dioxide emission, it is possible to generate electricity with lower levelized cost compared with other renewable resources as shown in Figure 3.



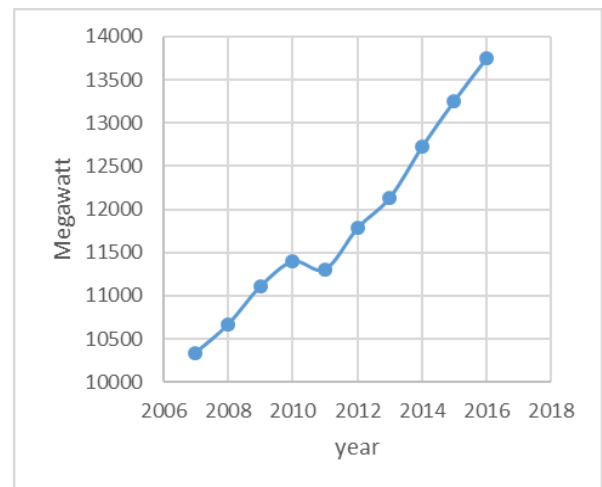
**Figure 2.** CO<sub>2</sub> emission of various energy resources for electricity generation [41]

Geothermal energy is more continuous compared with solar and wind which are intermittent. Due to this fact, electricity generation by using this renewable energy source is more reliable. According to the mentioned advantages, installation of geothermal-based power plants had growing trends in recent years. As shown in Figure 4, the cumulative capacity of geothermal power plants in the world has increased from 10.34 GW in 2007 to 14.30 in 2017. Among various countries, US has the highest share of installed geothermal power plants with 26.0%. Philippines and Indonesia had the 2nd and 3rd ranks with 13.5% and 13%, respectively [43]. It is expected to reach 1400 TWh electricity generation per year by using geothermal sources by 2050, which means 3.5% of global generated electricity

[44]. In addition to electricity generation, geothermal heat has ability to contribute 3.9% of final energy for heat by 2050, which means 1600 TWh thermal energy [44].



**Figure 3.** Global levelized cost of electricity for utility scale (©IRENA 2018) [42]



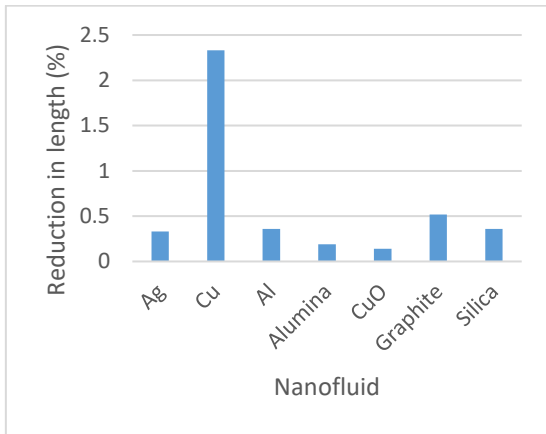
**Figure 4.** Cumulative installed geothermal power plants [43]

As it is discussed, geothermal sources have high potential for electricity generation and providing required heat for various purposes. Due to this fact, it is necessary to find ways and approaches for enhancement in geothermal-based energy systems. There are some researches focused on using nanofluids in these systems which are reviewed in following section.

## 3. APPLICATIONS OF NANOFUIDS IN GEOTHERMAL SYSTEMS

Heat transfer processes play key role in the efficiency of geothermal energy systems [45]. Enhancement in thermal performance of thermal devices applied in these systems leads to improved efficiency of the overall system. Applying nanofluids as heat transfer fluids is an attractive idea to achieve higher efficiencies [46]. In addition to improvement in heat transfer, using nanofluids can reduce the size of systems. Diglio et al. [47] investigated the effect of using nanofluid as heat carrier instead of conventional fluid, mixture of water and ethylene glycol, on a borehole heat exchanger. In this study, various nano particles such as

graphite, alumina, aluminium and etc were used in low concentrations. The volumetric concentrations of nanofluids were between 0.1% and 1%. It was observed that applying nanofluids can result in reduction in borehole thermal resistance. Since the type of nano structures influences on the thermophysical specifications [48], the results were dependent on the kind of nanofluids as shown in Figure 5. In addition, it was observed that using Ag nanofluids resulted in the highest convective heat transfer and pressure drop. By considering both heat transfer and pressure drop, it was concluded that using Cu-based nanofluids led to the most reduction in the length of borehole heat exchanger.



**Figure 5.** Borehole length reduction for various nanofluids in 1% concentration [47]

In another study carried out by Deneshipour et al. [49], two nanofluids including  $Al_2O_3$ /water and CuO/water were used in geothermal borehole heat exchanger as circuit fluids. Numerical simulation by applying Reynolds Averaged Navier-Stokes was performed to analyze the effect of various factors. The turbulence model employed in the research was SST  $k-\omega$ . The volumetric concentration varied between 0% and 6% to evaluate the impact of concentration. Results of the study revealed that by using CuO/water nanofluid, higher heat extraction was achievable compared with  $Al_2O_3$ /water nanofluid; however, the pressure loss was higher in the case of using CuO/water nanofluid. Moreover, the results indicated higher local convective heat transfer coefficient by increment in the concentration of the nanofluids. Jamshidi et al. [50] numerically investigated the performance of geothermal heat exchanger and the effects of utilizing nanofluids in extracted heat. In their study,  $Al_2O_3$  nano particles were employed in volumetric concentrations between 0 and 0.5%. The obtained results showed that increase in the concentration resulted in improved heat flux. Moreover, the influence of size of nano particles on heat transfer was evaluated. The utilized heat exchanger in this study was finned conical helical type. It was concluded that using nano particles with lower dimensions resulted in improvement in Brownian motion; consequently, the heat transfer rate increased. According to the results of the research, employing the nano particles in 0.5% vol concentration could lead to approximately 18% increase in obtained energy from the earth.

The extracted heat from the earth in geothermal systems depends on numerous factors such as working fluid, its flow rate and well specification. In a study carried out by Sui et al. [51],  $Al_2O_3$ /water nanofluid was employed as working fluid

in a geothermal system. The thermophysical properties of the applied nanofluids, such as specific heat, dynamic viscosity and thermal conductivity, were calculated on the basis of the models proposed for them. In the first step, the effect of mass flow rate was investigated. The results showed that increase in flow rate led to lower temperature of returning flow and increment in extracted heat. In addition, the effect of adding nano particles to the working fluid was studied. According to the results, using nanofluid resulted in increased temperature of returning fluid. At low mass flow rate, the effect of using nanofluid on extracted heat was not significant, while increase in mass flow rate made it more sensible. For instance, in the case of  $15 \text{ kg/m}^3$ , the extracted heat by using water and nanofluid were 3050 kW and 3393 kW, respectively.

Although using nanofluids in heat exchangers of geothermal systems can improve the heat transfer and efficiency, there are some concerns about them. Sedimentation of nano particles can deteriorate heat transfer and performance of the systems. There are some suggestions to overcome these probable problems. According to a study conducted by Sun et al. [52], in the case of static fluid in shut-down condition, accumulation of nano particles appeared to exist close the bottom of borehole after long time (many hours) sedimentation. A numerical simulation was carried out to evaluate this phenomenon. Based on the results, relatively high velocity of the fluid can remove the accumulated particles which results in reliable performance of nanofluidic heat exchangers in geothermal systems.

#### 4. CONCLUSION

In the present article, a review study is carried out on the geothermal systems use nanofluids. In the first step, an overview of geothermal energy systems is provided. According to the literature review, geothermal energy is an appropriate alternative for fossil fuel power plants. Greenhouse gas emission of geothermal energy in generating electricity is much lower compared with fossil fuels. Moreover, the levelized cost of electricity generated by geothermal energy sources is very low which makes it more attractive for power production. In the next stage, the applications of nanofluids in geothermal energy systems are reviewed. According to the results, nanofluids are generally applied as heat transfer fluid in heat exchangers due to their ability in thermal enhancement. Using nanofluids in heat exchangers and boreholes can reduce the size of structures and improve the efficiency of the systems. The recommendation for future studies is focusing of finding various types of nanofluids, specially carbonic nano structures, to find more desirable fluids for heat transfer. Moreover, nanotechnology can be applied in geothermal structures due to their ability in enhancing the mechanical properties and heat transfer capacity.

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