International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 5528-5533

Applications of Nano-Fluid in Nuclear Power Plants within a Future Vision

Malek Khalaf Albzeirat [1,*], Muhammad Iqbal Hussain[1], Rosmaini Ahmad[1], Falah Mustafa Al-Saraireh[2], Alaa Salahuddin[1] and Nazih Bin-Abdun[3]

[1]*School of Manufacturing Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.*
[2]*Department of Mechanical Engineering, Mutah University, Mutah, Alkarak, Jordan.*

[3]*School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.*

Abstract

This study aims at providing an overview of the application of nano-fluid in nuclear reactors, and the statement of practical meeting points between the basic processes in the nuclear reactors and the field of the use of nano-particles in these processes. The conclusion derived from this study suggests a wide scope for scientific research in the field of the use of nano-particles of different types in the cooling processes of the heart of the reactor and in the heat exchange in the process of electricity production or improving the exploitation of hot water in other areas.

Keywords: Nuclear Reactor, Nano-fluid, Nuclear safety and security.

INTRODUCTION

Nuclear energy is one of the most important sources of electricity production in the world at present, and improving the production processes of these plants is very important for reducing the risks and increasing the efficiency of the production of electricity in these stations [1-2]. Within the nuclear reactors, the water system represents one of the most important areas of improvement either internally or externally. The internal water system acts as a coolant and a neutron moderator and the external is related to the amount of the electrical energy and other uses of heat generated by the reactor [3-4]. As for the process of improvement and development, it can take several forms, including designs, tools and materials. In the field of heat exchange, research uses nano-fluids which assist in enhancing heat transfer via various important applications, such as thermal control in power generation, microelectronics, heating, cooling, and chemical processes [5]. Therefore, this study aims at presenting a vision for the possibility of using nano-fluids in nuclear reactors and identifying aspects that are effective in this area.

NUCLEAR POWER AS A SOURCE OF ELECTRICITY

The annual reports and statistical information available on the amount of electricity production depending on the source of energy can be put in Table 1.

Table 1. Main Sources of Electricity Generation (International Energy Agency)

NO	Type of Energy	Percentage of Amount
1	Fossil Fuel	65%
2	Hydroelectric	16%
3	Nuclear	11 %
4	Biofules and Waste	3%
5	Renewable Energy and	4%
6	Other Sources	1%

Due to the recent rising prices of fossil fuels and limited resources as well as global conflicts, the industrial growth, the population growth, and the environmental challenges of the provision of electricity represent a challenge faced by many countries. Therefore, countries are seeking alternative solutions for the production of electricity through the use of modern technologies, including the construction of modern non-fossil fuel power plants. Among these solutions are:

1. Tidal Power Plants: These stations depend on the movement of tidal to move the turbines to generate electricity and are considered the most environmentally friendly stations. However, they are limited under unique environmental conditions. Hence, it is difficult to rely on generating large amounts of energy [6].
2. Wave Power Plants: In this type of the power plant, electricity is generated by the movement of the ocean waves [7]. However, this type is very limited to be used because predicting the movement of the waves is difficult and it requires constant monitoring and control techniques. In addition, the amount of energy is limited and useless to supply residential communities and is away from the electrical distribution networks.
3. Solar Power Plants: this station is one of the major renewable energy sources; this type of stations depends on the solar heat as the main source of electricity generation through different types of solar cells [8]. In addition, this type of stations is safe and a natural source of energy and does not cause any chemical environmental damage.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 5528-5533

4. Wind Power Plants: This type of stations is one of the major renewable energy sources; it depends on the wind as the main source and engine of the turbines to generate electricity [9]. This station is safe and a natural source of energy and does not cause any chemical environmental damage. Recently, there has been a rapid growth in global recommendations and guidance for increasing dependence on these types of stations as an electric power source and an interest to improve the technology used in terms of the efficiency of solar cells and their availability in the markets.
5. Hydroelectric Power Plants: Hydroelectricity is produced by harnessing the gravitational force of flowing water [10]. Compared to fossil fuel-powered energy plants, hydroelectric power plants emit lesser amounts of greenhouse gases. However, the cost of building these stations is very high compared to the amount of energy that can be obtained from the station.
6. Geothermal Energy Power Plants: This is a very powerful and an efficient way to extract a renewable energy from the earth through natural processes [11].
7. Biomass Energy Power Plants: This station is one of the renewable energy sources, which refers to living and recently a dead biological material that can be used as fuel in power plants [12].
8. Nuclear power plants: By using uranium as fuel to generate a high amount of electricity, nuclear energy sources have a higher density than fossil fuels and release massive amounts of energy. Consequently, nuclear power plants require low quantities of fuel, but they produce enormous amounts of power [4].

As demonstrated in Table 1, two thirds of world electricity production is based on fossil fuel, followed by hydroelectric plants 16.0%, nuclear plants 10.6%, biofuels and waste 2.2%, and geothermal, solar, whereas wind and other sources make up the remaining percentage with 4.9%. The statistical review of the world energy refers to the nuclear power plants as the third source for the electricity in the world. The establishment of electrical stations is based on several factors according to the perspective of each country as follows.

1. Environmental factors such as global warming, which is a challenge faced by the world in the future because of high levels of carbon dioxide in the atmosphere, and fossil fuels are a major cause of this problem.
2. Economic factors represented by the inability to absorb the high prices of fossil fuels.
3. Industrial factors are the ever-increasing need for energy.
4. Demographic factors are characterized by the rapid population growth and change in the behavioral patterns associated with this growth, which requires more consumption of electricity.

At present, the nuclear energy is one of the most important solutions that can be used to avoid problems of electricity production in the future. The move towards the nuclear energy is a strategic solution for countries suffering from the scarcity of fossil fuels. It is clear that the peaceful applications of nuclear energy has the potential to increase the worldwide energy and water security through non-electric applications, such as seawater desalination [13], hydrogen production [13], district heating [14], and various industrial applications [15]. In the middle of the last century, nuclear technology was the exclusive preserve of the United States and Russia, but the use of nuclear technology quickly spread to 32 countries. France is the world's leading producer of electricity through nuclear power plants. The map illustrated in Figure 1 shows the geographical distribution of countries using the nuclear energy in the production of electricity.

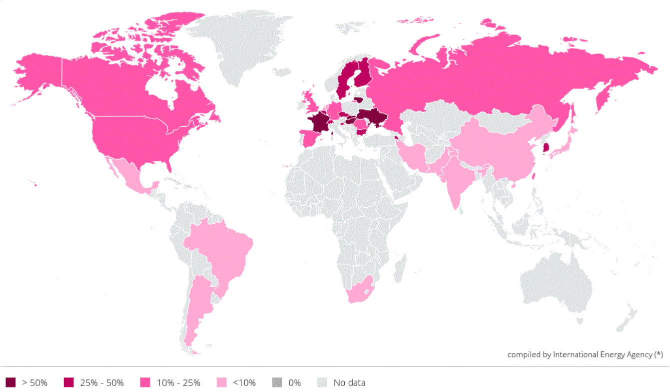

Figure 1. Geographical Distribution of the Use of Nuclear Energy to Produce Electricity

Different uses of the nuclear energy require the continuation of research and development of nuclear technology and how to use and employ it in other areas. In general, nuclear technology development and improvement need additional research to address the increased safety requirements and improve the economic conditions. To achieve the goal of the development and improvement, a need arises to focus on the components of the process of manufacturing electricity and additional outputs that can be recycled and used in other production processes. Except for the reactor itself, a nuclear power station, like plants that burn coal, oil and natural gas, produces electricity by boiling water into steam.

TYPES OF NUCLEAR POWER PLANTS

Nuclear reactors uses water as a coolant and a neutron moderator and it is classified in terms of the type of water used.

1. Light Water Reactor (LWR): It is a kind of thermal nuclear reactors that uses ordinary water H_2O passing through the heart of the nuclear reactor to generate electricity. This type of reactor includes three types, namely Boiling Water Reactor (BWR) [16], Pressurized Water reactors (PWR) [17], and

Supercritical Water Reactor [18]. Light water is available at a lower cost and is widely used in nuclear power plants [19]. This type of reactor uses enriched uranium [20], where the enriched uranium is a type of uranium in which the percent composition of uranium-235 has been increased through the process of isotope separation. Natural uranium is 99.284% ^{238}U isotope, with ^{235}U only constituting about 0.711% of its mass [21].

2. Heavy Water Reactor (HWR): This is a kind of thermal nuclear reactors that uses heavy water D_2O where it is made from deuterium instead of hydrogen + normal oxygen [22]. This type of reactor uses natural uranium [23].

The stations are classified as follows.

1. BWR:- Figure 2 shows the main parts of BWR and all main processes from 1 to 7.
2. PWR:- Figure 3 shows the main parts of PWR and all main processes from 1 to 2.

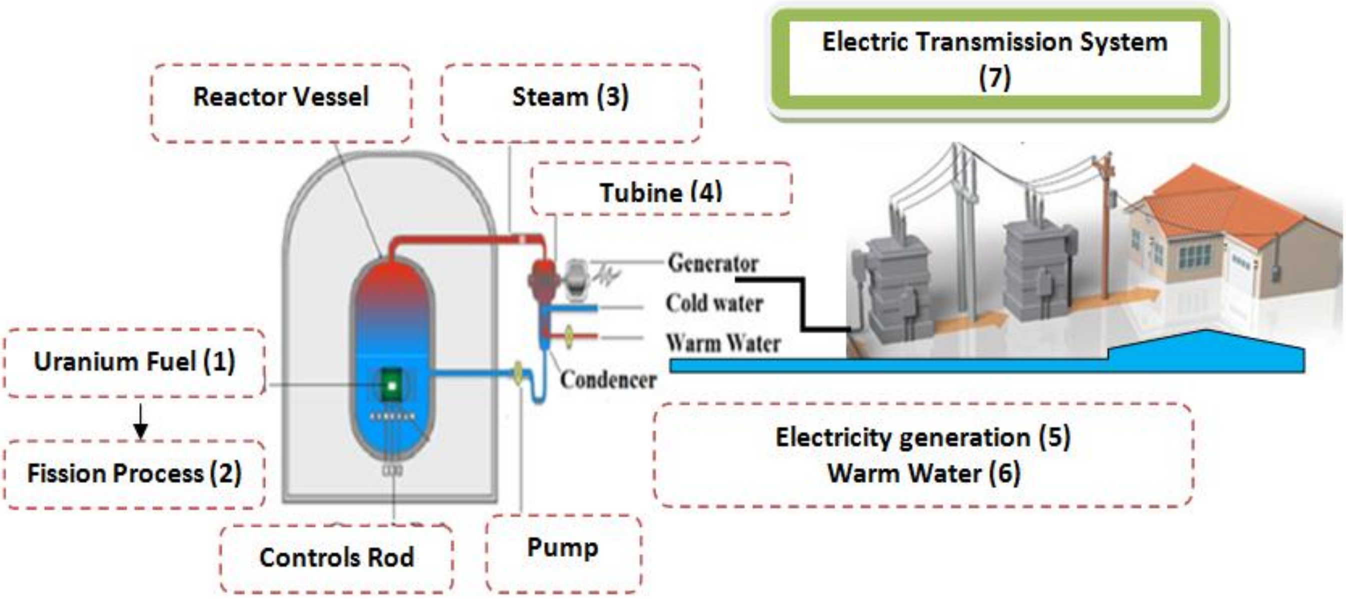

Figure 2. The Boling Water Reactor

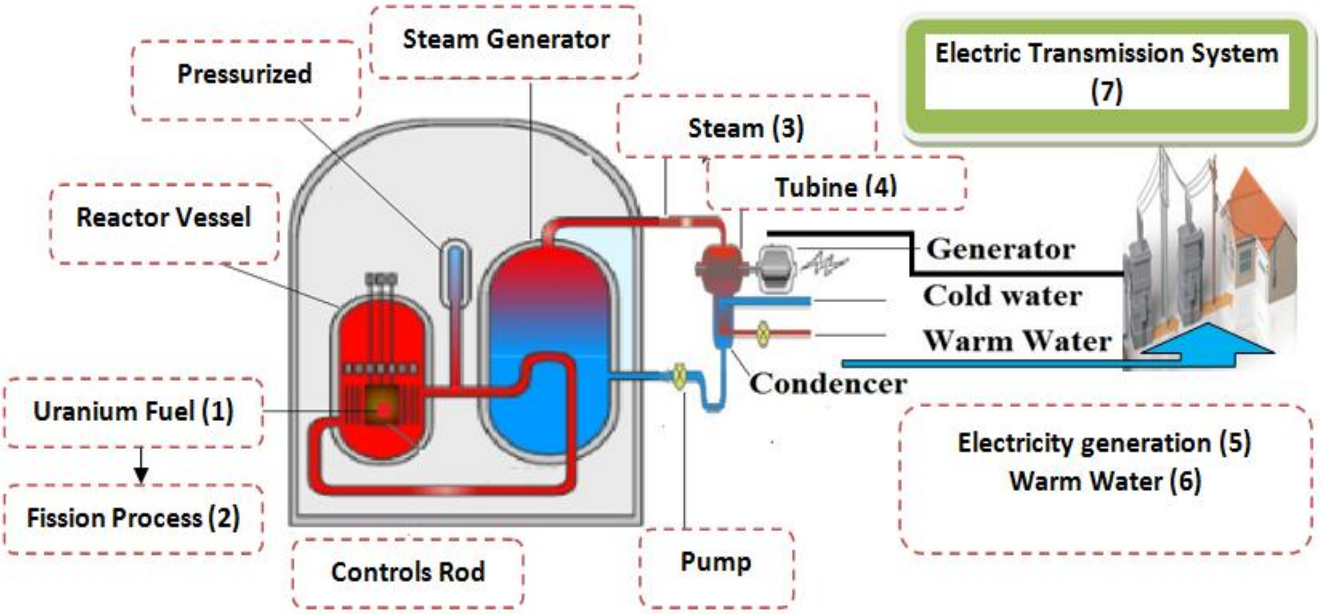

Figure 3. The Pressurized Water Reactor

EXPECTED RISKS IN NUCLEAR POWER PLANTS

Like other stations, nuclear reactors can be exposed to a range of risks that can be summarized as follows.

1. Natural disasters such as earthquakes and floods.
2. Terrorism and the control of non-competent bodies.
3. Human errors in the management and control of the nuclear reactor.

Historically, interest in nuclear power has begun after World War II, countries around the world began to develop nuclear reactors to meet civil energy needs for economic and strategic considerations. Reactor core is one of the most important parts of the nuclear reactor and it containing the nuclear fuel components where the nuclear reactions take place and the heat is generated. In the core of the nuclear reactor, the heat from fission or splitting of uranium atoms is used to produce steam. This steam is used to power a turbine to generate electricity. While nuclear reactions produce huge amounts of energy and emit few greenhouse gases, nuclear power has been a source of controversies among governments, experts and the public. One of the main reasons people are fearful of nuclear power is the possibility of accidents. This fear is generally fueled by three high-profile nuclear accidents:

1. Three Mile Island on March 28, 1979 [24].
2. Chernobyl on April 26, 1986 [25-26].
3. Fukushima Daiichi March 11, 2011. [26].

Official reports refer to three key risks, all related to the cooling process, which included:

1. Leakage of cooling fluid.
2. Error in cooling system.
3. Radiation leakage.

These key risks can be addressed by:

1. Strengthening the role of geological research before building a nuclear reactor.
2. Strengthening the security research in the region before building a nuclear reactor.
3. Strengthening qualifications, capabilities and expertise before starting nuclear reactors.
4. Strengthening the security capabilities surrounding the nuclear reactors.
5. Ensuring the availability of disaster management and disaster management plans.
6. Ensuring the rapid solutions to deal with any emergency within the nuclear reactor.
7. Increase interest in studying the internal environment surrounding the nuclear reactor.
8. Conducting studies on integration: management science related to human resources / nuclear engineering / safety science / lean manufacturing practices.
9. Develop long-term time plans to deal with changing factors and conditions.
10. Permanent control by identify and analyse different hazards that can occur during operations.
11. Put the conditions which guarantee existence multiple safety systems to protect the public in the event of an accident such as emergency core cooling systems.
12. Develop a rapid intervention team for emergency evacuation situations.

One of the most serious risks that can cause disasters within they nuclear reactors may occur due to a defect in the cooling system of the reactor; this defect may be caused by a previous risk. Therefore, the operational part of the cooling system within the reactor is one of the most important parts according to the following considerations:

1. Improving and developing the water system inside the reactor contributes to avoiding many accidents that may occur inside the reactor.
2. Improving the heat exchanger system can also have a significant impact on improving the production capacity of electricity.
3. It is possible to exploit the improvement of the thermal exchange system in the exploitation of heat in the heating systems of the population.

Avoid accidents at stations : The risk of a nuclear power plant accident can be avoided through :

- Setting diverse and redundant barriers and numerous safety systems in the power plant.
- Continuous attention in improvement the training and skills of the reactor operators.
- Improve the quality of permanent control.
- Continuous improvement of the radiation test systems and the actual activity of the reactor.
- Attention to maintenance program in aspects of modernization and continuous training of the maintenance team.
- Continuous knowledge exchange in the field of nuclear energy, especially in the field of the use of modern technology, such as nano-fluids applications in the process of cooling and thermal control.

NUCLEAR POWER PLANTS AND NANO-FLUIDS

It is clear that the point of convergence between nuclear reactor operations and nano-fluids in processes involves water movement. By reference to Figures 2 and 3, it is expected that the safety system around the core of the reactor will include nano-fluids to increase or decrease heat exchange efficiency through the control system is added to the control : The size, quantity and type of nano-particles in the heat exchanger. As a result, the safety system is configured to operate in conditions that include heat-up situations within the reactor. In addition, the exploitation of heat through heat exchangers increases the efficiency of heat transfer of cold water and converts it to hot water as well as maintains the heat for longer if water is used for heating in residential communities. Nano-particles that can be effective include the following substances Al_2O, SiO_2, TiO_2, AlO_3, CeO_2 and CuO [28-29].

CONCLUSION

The field of heat transfer applications in nuclear reactors will have a clear impact on improving the safety factors in nuclear reactors as well as raising the efficiency of production of electricity. In addition, it is clear that there is a wide scope for scientific research in the relationship between nuclear reactors and nano-fluid. The diversity of thermal properties of nano-particles in water will be reflected in cooling efficiency and electrical production. These findings can be exploited in water-cooled nuclear reactors to realize sizable power up rates in the core, thus achieving significant economic gains or improving the safety margins.

REFERENCES

[1] Pioro, I., & Duffey, R. (2015). Nuclear power as a basis for future electricity generation. *Journal of Nuclear Engineering and Radiation Science*, *1*(1), 011001.

[2] Malek, A. K., Muhammad, H. I., Rosmaini, A., Alaa, A. S., & Falah, A. M. (2017, September). Improvement of nuclear power plants within the perspective of applications of lean manufacturing practices. In *AIP Conference Proceedings*(Vol. 1885, No. 1, p. 020115). AIP Publishing.

[3] Attia, S. I. (2015). The influence of condenser cooling water temperature on the thermal efficiency of a nuclear power plant. *Annals of Nuclear Energy*, *80*, 371-378.

[4] Stacey, W. M. (2018). *Nuclear reactor physics*. John Wiley & Sons.

[5] Khattak, M. A., Mukhtar, A., & Afaq, S. K. (2016). Application of nano-fluids as coolant in heat exchangers: a review. *J. Adv. Rev. Sci. Res.*, *22*(1), 1-11.

[6] Zhang, L. X., Tang, S. J., Hao, Y., & Pang, M. Y. (2018). Integrated energy and economic evaluation of a case tidal power plant in China. *Journal of Cleaner Production*.

[7] Cantarellas, A. M., Remon, D., Garcia, J. M., & Rodriguez, P. (2017, October). Competitive control of wave power plants through price-signal optimum allocation of available resources. In *Energy Conversion Congress and Exposition (ECCE), 2017 IEEE* (pp. 5579-5586). IEEE.

[8] Liu, M., Tay, N. S., Bell, S., Belusko, M., Jacob, R., Will, G., ... & Bruno, F. (2016). Review on concentrating solar power plants and new developments in high temperature thermal energy storage technologies. *Renewable and Sustainable Energy Reviews*, *53*, 1411-1432.

[9] Le Gourieres, D. (2014). *Wind power plants: theory and design*. Elsevier.

[10] Pang, M., Zhang, L., Ulgiati, S., & Wang, C. (2015). Ecological impacts of small hydropower in China: Insights from an emergy analysis of a case plant. *Energy Policy*, *76*, 112-122.

[11] DiPippo, R. (2012). *Geothermal power plants: principles, applications, case studies and environmental impact*. Butterworth-Heinemann.

[12] Afgan, N. H., & Carvalho, M. G. (2002). Multi-criteria assessment of new and renewable energy power plants.*Energy*, *27*(8), 739-755.

[13] Yan, X. L., & Hino, R. (Eds.). (2016). *Nuclear hydrogen production handbook*. CRC Press.

[14] Lake, A., Rezaie, B., & Beyerlein, S. (2017). Review of district heating and cooling systems for a sustainable future.*Renewable and Sustainable Energy Reviews*, *67*, 417-425.

[15] Murray, R., & Holbert, K. E. (2014). *Nuclear energy: an introduction to the concepts, systems, and applications of nuclear processes*. Elsevier.

[16] Bai, J., Bosch, R. W., Ritter, S., Schneider, C. W., Seifert, H. P., & Virtanen, S. (2018). Electrochemical and spectroscopic characterization of oxide films formed on Alloy 182 in simulated boiling water reactor environment: Effect of dissolved hydrogen. *Corrosion Science*.

[17] George, N. M., Terrani, K., Powers, J., Worrall, A., & Maldonado, I. (2015). Neutronic analysis of candidate accident-tolerant cladding concepts in pressurized water reactors. *Annals of Nuclear Energy*, *75*, 703-712.

[18] Al-Zareer, M., Dincer, I., & Rosen, M. A. (2017). Performance analysis of a supercritical water-cooled nuclear reactor integrated with a combined cycle, a Cu-Cl thermochemical cycle and a hydrogen compression system. *Applied energy*,*195*, 646-658.

[19] Lovering, J. R., Yip, A., & Nordhaus, T. (2016). Historical construction costs of global nuclear power reactors. *Energy Policy*, *91*, 371-382.

[20] 20.Jeong, E., Choe, J., Zhang, P., Shin, H. C., & Lee, D. (2018). New high-performance light water reactor core concept with mixed cycle length operation. *International Journal of Energy Research*, *42*(1), 53-67.

[21] Awan, I. Z., & Khan, A. Q. (2015). Uranium-The Element: Its Occurrence and Uses. *Journal of the*

Chemical Society of Pakistan, *37*(6).

[22] Budu, A. R., Pavel, G. L., & Moraru, D. E. (2017). Heat and mass transfer aspects in nuclear power generation. *Energy Procedia*, *112*, 571-578.

[23] Sinha, R. K., & Kakodkar, A. (2006). Design and development of the AHWR—the Indian thorium fuelled innovative nuclear reactor. *Nuclear Engineering and Design*, *236*(7-8), 683-700.

[24] Kemeny, J. G. (1979). Report of the President's commission on the accident at Three Mile Island. *The need for change: The Legacy of TMI*.

[25] Devell, L., Tovedal, H., Bergström, U., Appelgren, A., Chyssler, J., & Andersson, L. (1986). Initial observations of fallout from the reactor accident at Chernobyl. *Nature,321*(6067), 192-193.

[26] Hohenemser, C., Deicher, M., Ernst, A., Hofsäss, H., Lindner, G., & Recknagel, E. (1986). Chernobyl: an early report.Environment: *Science and Policy for Sustainable Development, 28*(5), 6-43.

[27] Headquarters, N. E. R. (2011). Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety-The Accident at TEPCO's Fukushima Nuclear Power Stations. *http://www. kantei. go. jp/foreign/kan/topics/201106/iaea_houkokusho_e. html*.

[28] Raja, M., Vijayan, R., Dineshkumar, P., & Venkatesan, M. (2016). Review on nanofluids characterization, heat transfer characteristics and applications. *Renewable and Sustainable Energy Reviews*, *64*, 163-173.

[29] Bin-Abdun, N. A., Razlan, Z. M., Hazry, D., Wan, K., Ibrahim, I., Kamarrudin, N. S., & Rani, M. F. H. (2017, September). Review on application CuO/distilled water & Al2O3/distilled water for enhancement heat transfer characteristics in cooling systems. In *AIP Conference Proceedings* (Vol. 1885, No. 1, p. 020085). AIP Publishing.