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TEMPERATURE ANALYSIS OF A FLAT SOLAR COLLECTOR USING ALUMINUM NANOFLUIDS

In this work, the thermal characteristics of a flat solar collector were performed using a nanofluid of aluminum oxide- water. The purpose of this article is to develop a hydrodynamic model using the CFD program. The main direction of the study is that the model is confirmed by the results of the experiment conducted in this study. The model is modeled in the temperate climate of Kazakhstan. The idea of the scientific research was that with the help of the ANSYS FLUENT 19.0 CFD (Computational Fluid Dynamics) package, to calculate the presence of nanoparticles in the working fluid of a flat solar collector increases the pressure drop in a flat solar collector, but also an increase in thermal characteristics is achieved. It has been experimentally established that the optimal volume fraction of nanoparticles, which is 0.5% aluminum oxide, provides the greatest thermal efficiency of a flat solar collector. A new design of a flat solar collector has been developed, in which thermal insulation occurs in a heat-insulating transparent double-glazed window. The data on the temperature of the flat solar collector were determined using the commercial software package CFD (Computational Fluid Dynamics) ANSYS FLUENT 19.0. Numerical analysis of temperature data confirmed the accuracy of the results obtained as a result of experimental analysis. The practical significance of the results of this work suggests that the presence of nanoparticles on the upper glass of the collector increases thermal efficiency, efficiency and service life.
Key words: Flat solar collector, aluminum oxide nanoparticles, thermal model, thermal efficiency.

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Алюминий нано сұйықтықтарын қолдана отырып, жалпақ күн коллекторының температурасын талдау

Бұл жұмыста жалпақ күн коллекторының жылу сипаттамалары алюминий оксиді-судың наножидкости көмегімен жасалды. Бұл мақаланың мақсаты CFD бағдарламасын қолдана отырып гидродинамикалық модель жасау болып табылады. Зерттеудің негізгі бағыты-модель осы зерттеуде жүргізілген эксперимент нәтижелерімен расталады. Модель Қазақстанның қоңыржай климатында үлгіленген. Ғылыми зерттеудің идеясы ANSYS FLUENT 19.0 CFD пакетін (есептеу гидродинамикасы) қолдана отырып, жазық күн коллекторының жұмыс сұйықтығында нанобөлшектердің болуын есептеу жазық күн коллекторындағы қысымның төмендеуін арттырады, сонымен қатар жылу өнімділігін арттырады. 0,5% алюминий оксидін құрайтын нанобөлшектердің оңтайлы көлемдік үлесі жазық күн коллекторының ең жоғары жылу тиімділігін қамтамасыз ететіндігі тәжірибе жүзінде анықталды. Тегіс күн коллекторының жаңа дизайны жасалды, онда жылу оқшаулағыш мөлдір екі қабатты терезеде жылу оқшаулау жүреді. Жазық күн коллекторының температурасы туралы деректер ANSYS FLUENT 19.0 коммерциялық CFD (есептеу гидродинамикасы) бағдарламалық пакетін пайда-

лану арқылы анықталды. Температура деректерін сандық талдау эксперименттік талдау нәтижесінде алынған нәтижелердің дәлдігін растады. Бұл жұмыс нәтижелерінің практикалық мәні коллектордың жоғарғы әйнегінде нанобөлшектердің болуы жылу тиімділігін, тиімділігі мен қызмет ету мерзімін арттырады.
Түйін сөздер: Жазық күн коллекторы, алюминий оксидінің нанобөлшектері, жылу моделі, жылу тиімділігі.

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Анализ температуры плоского солнечного коллектора с использованием алюминиевых нано-жидкостей

В этой работе тепловые характеристики плоского солнечного коллектора были выполнены с использованием наножидкости оксида алюминия-воды. Целью данной статьи является разработка гидродинамической модели с использованием программы CFD. Основным направлением исследования является то, что модель подтверждается результатами эксперимента, проведенного в данном исследовании. Модель смоделирована в условиях умеренного климата Казахстана. Идеей научного исследования было то, что с помощью пакета CFD (Вычислительная гидродинамика) ANSYS FLUENT 19.0, рассчитать присутствие наночастиц в рабочей жидкости плоского солнечного коллектора увеличивает перепад давления в плоском солнечном коллекторе, но также достигается повышение тепловых характеристик. Экспериментально установлено, что оптимальная объемная доля наночастиц, составляющая 0,5% оксида алюминия, обеспечивает наибольшую тепловую эффективность плоского солнечного коллектора. Разработана новая конструкция плоского солнечного коллектора, в котором теплоизоляция происходит в теплоизоляционном прозрачном стеклопакете. Данные о температуре плоского солнечного коллектора были определены с использованием коммерческого программного пакета CFD (Вычислительная гидродинамика) ANSYS FLUENT 19.0. Численный анализ температурных данных подтвердил точность результатов, полученных в результате экспериментального анализа. Практическим значением итогов данной работы говорит о том, что присутствие наночастиц на верхнем стекле коллектора увеличивает тепловую эффективность, КПД и срок службы.
Ключевые слова: Плоский солнечный коллектор, наночастицы оксида алюминия, тепловая модель, тепловая эффективность.

1 Introduction

All over the world, traditional energy sources and electricity are becoming increasingly scarce resources. Solar energy can be considered the most important renewable energy source due to its sustainability, favorable environment, and vital accessibility. Therefore, the use of solar energy to meet the growing energy needs is becoming more and more relevant. The water heating sector, industrial applications, and water desalination systems consume a significant amount of energy. In articles [1-3] solar energy was used to heat water, which can save this amount of energy easy to manufacture, install and operate, as well as the cheapest solar collectors with flat plates is considered [4]. In [5], several types of studies have been developed devoted to improving the thermal characteristics of cheap solar collectors with flat plates. In the article [6], solar collectors with flat plates of nanofluid were presented. While Maxwell was the first to present a theoretical basis for predicting the effective conductivity of a suspension. Nanofluid refers to a suspension mixture between a liquid and the smallest particles of metallic or non-metallic solids. Nanofluids are classified as a new class of liquids created by dispersing nanoscale particles in a coolant. The thermophysical properties of the nanofluid could be predicted theoretically [7]. On the one hand, the thermal conductivity of nanoparticles is high compared to the base fluid used in heat transfer applications, which leads to increased heat transfer. On the other hand, the high density of nanoparticles leads to an increase in the viscosity of nanofluids and an increase in the pressure drop and the required pumping power in forced conventional heat transfer systems [8]. The physical properties of the nanofluid are very different from the properties of the base liquid. Thermal conductivity, specific heat capacity, density, and viscosity change. The density of solids is higher than that of liquids, therefore, it is predicted that the density of the nanofluid will increase. Said et al. [4] conducted an experiment to study the effect of TiO2-water nanofluid as a working fluid on improving FPSC performance. The mass flow rates of the nanofluid varied from 0.5 to 1.5 kg/min, while the volume fraction of nanoparticles was 0.1% and 0.3%. Thermophysical properties and reduction of deposition of TiO2 nanofluid were achieved by adding polyethylene glycol (PEG 400) as a dispersant. The results showed that energy efficiency increased to 76.6%, and the highest obtained value of exergetic efficiency was 16.9%, assuming a volume fraction of 0.1% and a flow rate of 0.5 kg/min. They showed that for 0.1% and 0.3% of the volume fraction of the TiO2 nanofluid, the pumping power and pressure drop were equal to the base fluid. For more than one month, the water-based TiO2 nanofluid remained stable, the thermal conductivity is apparently affected by the volume fraction, since it increases by 6% at 0.3 vol.% TiO2. The solar collector in the case of using TiO2-H2O nanofluid has a higher exergy and energy efficiency than in the case of clean water. The use of nanofluids as an FPSC working fluid is one of the methods used to improve the thermal characteristics and performance of FPSC [9, 10]. Improving the thermal characteristics of FPSC by improving the thermal characteristics of the FPSC working fluid using nanofluids has been studied by many researchers in recent decades [7]. Dispersion of nanoparticles of highly conductive material in the base liquid increases the thermal conductivity of the liquid. High thermal conductivity and surface area of nanoparticles enhance thermal conductivity and convection in nanofluids [11,12]. Choi and Steven [6] presented the concept of increasing the thermal conductivity of nanofluids by adding nanoparticles. They reported that the addition of 1% by volume concentration of the nanoparticle can double the thermal conductivity of the liquid. Other researchers have confirmed the results of Choi and Steven [13-15]. The advent of unique technologies of the developing Solar Energy (SE), actual energy, faces economic and environmental problems. The main obstacle to the widespread use of SE is the low value of the average annual efficiency of known solar installations. In a sharply continental climate, they are exploited only in the warm season, about 6-7 months. Known combined systems, where additional conventional water heaters duplicate the operation of solar units, require additional costs for energy carriers. These disadvantages are not offered by the integrated system of SE use. In the article, the system was studied using the example of a cattle-breeding farm. The new system performs these functions; it recycles heat, organizes their movement and accumulation, and smooths out the uneven SE. The main components of the system are: Solar Power Plant (SPP), milk cooler, climate unit, Heat Pump (HP), the battery heat, automatic control system, and device heating and hot water. The main goal, i.e. lower cost of the energy produced and the elimination of the uneven SE, compared to the known SPP, is achieved through the flow of energy from the sources mentioned above [16].

The scientific novelty of this study is the development and study of a thermal model for a flat solar collector working with various nanofluids having different concentrations of nanoparticles. In this study, the developed CFD model is confirmed by experimental work.

2 Methods and Materials

Developed master control of solar thermal system is able to measure characteristics of thermal solar installation with chemical coating, which might be compared to similar features of traditional double circuit solar installation with thermosyphon circulation. Solar heat supply system with solar collector, covered with chemical etching has been constructed at the Institute of Information and Computer technologies in Almaty city, republic of Kazakhstan (latitude $45°24'5''n.l.$, longitude $9°14'58''E$). The installation has been developed without cable grooming, it is cheaper, than accessible solution and simpler in implementation to avoid the problems of communication with installation inside the building, far from a solar panel. The system anticipates installing of external heat exchanger, designed for modeling hot water consumption or dissipating the heat at temperature inside the tank exceeding the fixed value, set as a maximum threshold. Control system consists of external wireless solar power source unit with autonomous energy supply, which transfers the data on solar panel temperature (T1) to the inner control unit, which receives data and manages the system, controlling temperature values and states of two electric pumps.

Figure 2 shows the experimental installation, designed for specifying the temperature level of heated liquid and water in the reservoir, also for measuring the irradiation level on solar panels, which can be used for comparing the performances of double-circuit solar installation with thermosiphon circulation and solar installations with chemical coating.

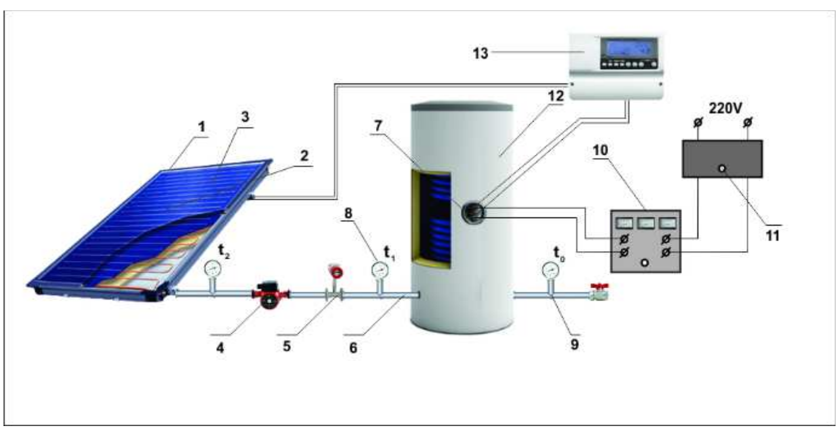


Figure 1: Experimental installation of solar heat supply system with controller. Where 1 – heat insulated body; 2 – translucent cover; 3 – tank-absorber; 4 – circulation pump; 5 – flowmeter; 6 – pipeline; 7 – THE; 8, 9 – thermometers for measuring water temperature at accumulator-tank inlet and outlet and external environment; 10 – set of electrical measuring instruments K 501; 11 – autotransformer; 12 – tank-accumulator; 13 – controller

Figures 2 a, b demonstrate the solar collector with chemical coating. It is made of hot-red glass with 1000×2000 mm^2 dimension, 4 mm thickness. Spiral- form copper tube with 10 mm

diameter, 4, 5 m length is soldered up to a back side of the absorbing copper sheet. A copper sheet of 1 mm thickness and 594×840 mm^2 size has coating, applied by means of chemical etching ($K_2S_2O_8 + NaOH + H_2O + Na_2S_2O_8$) with several microns thickness. Two-layered heating up is fulfilled with foil penofol and of 30 mm thickness foam plexus. Solar collector's reverse side is made of 2 mm thickness aluminum sheet.

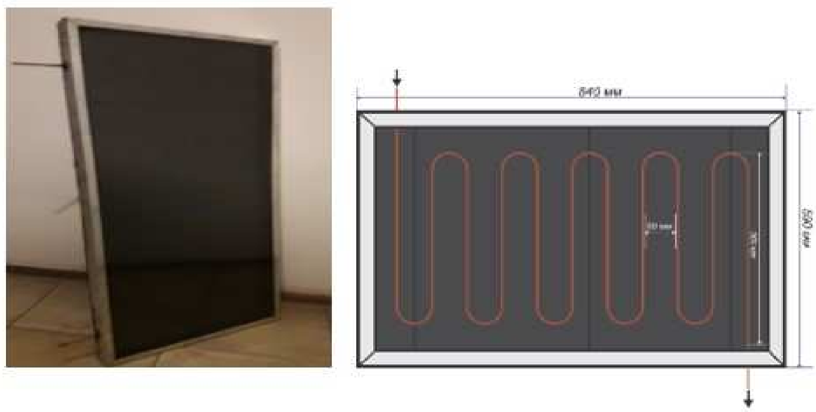


Figure 2: a) Solar collector with chemical coating; b) Solar collector's inner part with chemical coating

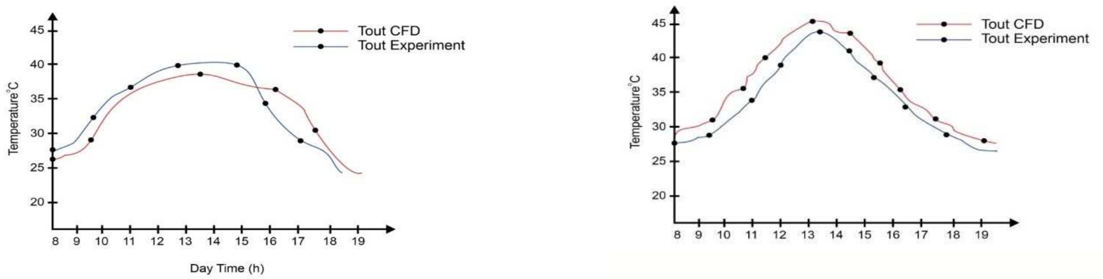
The fluid flow in a flat solar collector has a uniform velocity to the input cross-section. The uniform speed varies depending on the mass flow rate. To simulate a nanofluid, it is assumed that the nanofluid is single-phase. This means that changing the type of nanofluid and the volume fractions of nanoparticles changes the properties of the liquid. The upper half of the absorber of a flat solar collector is exposed to solar heat flux and heat loss. The two sides of a flat solar collector and the outer surface of the collector are an adiabatic process. If an adiabatic process occurs, a zero pressure gradient is used at the output boundary.

The experimental setup is shown in Figure 3.

Figure 3: Test bench of a two-circuit solar installation

3 Results

During the study of the CFD model and the experiment, graphs were constructed.



a) b)

Figure 4: Comparative results of CFD model and experiment

The outlet temperature decreases with increasing volume flow. This shows that a flat solar collector is used in a variety of applications, and can be easily controlled by the outlet temperature. A flat solar collector was investigated numerically for various volumetric flow rates of 5, 5.7 and 8 l/min for pure water.

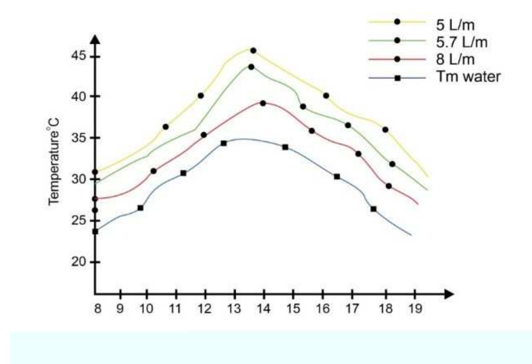


Figure 5: Temperature changes at the collector outlet for three volume flow rates under the same conditions

Figure 5 shows numerical temperature changes at the outlet of a flat solar collector for 3 volume flow rates under the same conditions. Numerical modeling was carried out for aluminum oxide nanofluids with different percentages of volume fractions. The temperature distribution of the working fluids, the pressure drop along the collectors and the thermal efficiency of the collector were evaluated for each working fluid and each percentage of the volume fraction of the nanoparticle.

Figure 6 shows the four temperature conditions at the inlet, 10°C, 30°C, 50°C, 70°C, were considered to obtain equivalent heat transfer coefficients of absorbent plates to predict the thermal characteristics of the collector.

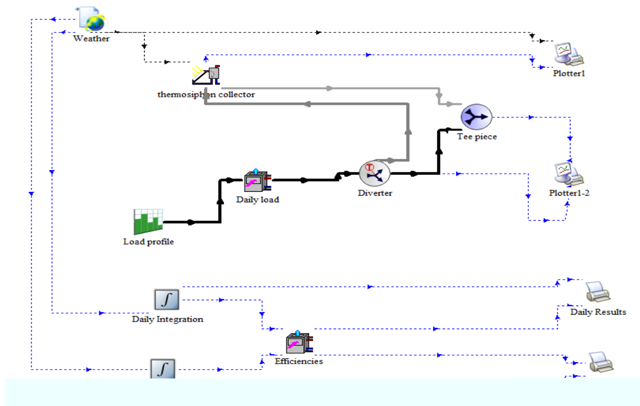


Figure 6: TRNSYS diagram of a simulated thermosiphon system of a solar collector

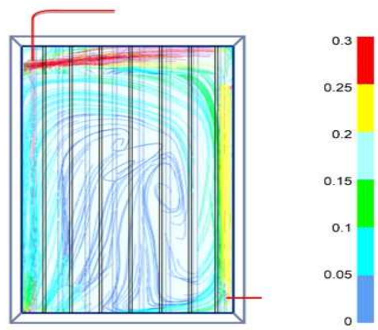


Figure 7: Temperature distribution over the absorber plate, riser pipes and collector collectors

Figure 7 shows the general behavior of the temperature of the working fluid together with the pipeline network of the absorber plate. As shown in the figure, the temperature of the liquid increases as it passes through the pipes of the risers.

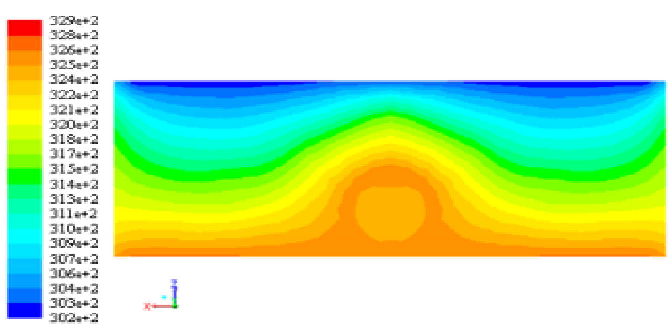


Figure 8: Contours of water temperature in a flat solar collector

Figure 8 shows the heat transfer from the absorber.to the riser with the help of convection mechanisms.

4 Discussion

The temperature characteristics of the new design of a flat solar collector presented in the article were created on the commercial software package CFD (Computational Fluid Dynamics) ANSYS FLUENT 19. 0. In comparison with previous works, analyses and conclusions, the efficiency of a flat solar collector with nanoparticles was 57.89% at a low temperature of 30 $°C$, while at a higher temperature the efficiency was 60.45%. The water temperature at the inlet of the flat solar collector was 68.56 $°C$, the consumption temperature was 31.44 $°C$, solar energy was 750.50 W/m^2. The water temperature at the outlet of the flat solar collector with nanoparticles was 75.76 $°C$, the air temperature was 31.44 $°C$ and the solar energy consumption was 750.50 W/m^2. On a clear day, the flow of solar energy reaching the Earth's surface at local noon is usually in the range of 700-1300 W/m^2, depending on latitude, longitude, altitude and time of year. In particular, for our region, Almaty, Republic of Kazakhstan, the solar energy flow is 750,50 W/m^2. Based on the results of the experimental work carried out, it can be concluded that the efficiency of a flat solar collector with nanoparticles increased by 6.5% compared to the solar collector in work [16].

5 Conclusion

In this paper, a numerical study has been developed to estimate the thermal conductivity of a flat solar collector with nanoparticles. For this purpose, CFD modeling was used, which was confirmed by comparison with previous experimental results. According to the results of the study, it was shown that nanoparticles in the working fluid slightly increases the thermal characteristics of the collector, especially in low temperature ranges, as well as an increase in the percentage of nanoparticles in nanofluids to 0.5% for aluminum oxide nanofluid. According to the thermal characteristics of aluminum oxide nanofluid, increases in pressure drop do not affect the increase in thermal characteristics of a flat solar collector. Prospects and opportunities for the implementation of the application of this development have a wide geographical location. The article [17] discusses the resources of the Republic of Kazakhstan based on solar energy. Estimates of solar systems when assessing solar energy resources on the territory of Kazakhstan are based on quantitative characteristics of direct solar radiation on a horizontal surface from which conversion from a horizontal plane to an inclined plane of any orientation can be performed. As a result, the statistical processing of the average values of direct, total exposure and duration of solar radiation was carried out, radiation was compiled, five zones were identified and a histogram was compiled characterizing the possibility of introducing solar installations in Kazakhstan.

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