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INFLUENCE OF AL_2O_3 NANO ADDITIVES ON THE VISCOSITY AND THERMAL CONDUCTIVITY OF DOUBLE DISTILLED WATER

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ABSTRACT

The nano fluid consist of Al_2O_3 nanoparticles was dissolved by double distilled water (DDW) in three concentrations, 0.5% wt, 1%wt, and 1.5%wt of nanomaterials. The effect of adding nano materials on the viscosity and thermal conductivity was calculated experimentally at room temperature. Some mathematical models were used to calculate the viscosity and the thermal conductivity and compare it with the experimental work. The results showed that viscosity and thermal conductivity increased with increasing concentration of Al_2O_3 nanoparticles, and there is a great convergence between the theoretical and measured viscosity and thermal conductivity. The SEM images showed that there is homogeneity in the distribution of the nano fluid at 1%wt., and some agglomerations were detected at a concentration 1.5%. The EDS spectrum showed that the percentage of aluminum increased gradually with increasing the Al_2O_3 concentration. The X-Ray diffraction indicated slight increase in the intensity of diffraction with increasing the Al_2O_3 concentration.

KEYWORDS: Nano fluid, Alumina Nanoparticles, thermal conductivity, viscosity.

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1. INTRODUCTION

The cement industry is considered one of the strategic industries in the countries of the world because of its economic importance in developing countries and achieving economic and urban development for countries. This important industry, which began to appear in the late eighteenth century, has developed in terms of production methods, including the wet and dry method, as well as in terms of the variety of equipment and machines involved in production. Among the important equipment in cement factories are boilers and heat exchangers, which almost no factory is devoid of because of their importance in the continuation of the production process of cement factories. This equipment (boilers and heat exchangers) suffers from many technical problems that affect operations and cause high financial losses. (Sallal, A.S et al., 2020).

Teng et al., (2010) studied the thermal properties of liquids such as thermal conductivity, viscosity, density and specific heat capacity. In the past two centuries, scientists have been trying to find mathematical formulas that express thermal conductivity and viscosity in order to save time and avoid repeating practical experiments in the laboratory. At the forefront of these scientists is the scientist Maxwell in 1873, followed by the two scientists Hamilton and Crosser in 1962, who devised mathematical equations to calculate thermal conductivity. Also they used mathematical models to estimate the thermal properties of nanofluids based on statistical nanomechanics. It is possible to calculate the thermal properties of nanofluids by both classical mechanics and statistical mechanics theories. It is worth noting that the classical mechanics theories do not take into account the microstructure of the material, so they were not accurate in describing the thermal properties, while statistical mechanics can calculate these properties based on the molecular movements of the material, as well as according to the chemical interactions between nanoparticles and the base fluid.

The mathematical models equations that were derived by means of classical thermomechanical theories are empirical equations and can only be applied locally and they lack insight into the microstructure of the nanomaterial, therefore statistical mechanics can be adopted to calculate the thermal properties of matter based on the interactions between molecules in the same system of molecules (Avsec et al 2007)

Prasher et al., (2005), investigated the enhancement the thermal conductivity of nanofluids reasoned through the Brownian of the nanoparticles motion.

Patel et al., (2008) used the Maxwell mathematical model for determining the thermal conductivity of nano fluids consist of water/carbon nanotube CNTs. Due to the high effects of thermal conductivity of CNTs and the dispersion in water and oil the high improvement in thermal conductivity was used. They used water and oil as the based fluids. The model was determined to predications of the trends investigated in the experimental data nanofluid combinations of CNT Nano fluids with changeable concentrations.

Jiang et al., (2012) studied the thermal conductivity using Hamilton and Crosser theoretical models to improve the of nano fluids by allowing for the graded of nano layer. The authors propose an interaction effect of ordinary hemispherical nanoparticles with Brownian motion. The model resolves the relationship between thermal conductivity enhancement and nanolayer thickness, nanoparticle size, and the interaction of neighboring nanoparticles, temperature and volume fraction. on the other hand, the theoretical results under the effects of thermal conductivity of nano fluids were in good convergence with that of experimental results. Hezaveh et al., (2011) and Tugolukov et al., (2020) indicated a great interest in nanofluids thermal properties such as thermal conductivity of at low volume fractions of nanoparticles. Hence, in the last years many experimental studies investigate the thermal conductivity and viscosity of nanofluids have been disscused due to high thermal conductivity compred with their base fluids. Elif et al., (2019) reported that the thermal conductivity of nanofluids increases reasonably with increasing nanoparticle size concentration results on equivalent thermal conductivity of nanofluids from a different group of authors. Chaharborj., (2018) showed that the transformer oil thermal conductivity can be increased by over than 22% with a volume fraction of 4% Al_2O_3NPs also, the aluminum nitride nanoparticles at volumetric fraction of 0.5%, the thermal conductivity enhanced by 8%. Florence et al., (2022) conducted the experimental work of TiO_2 nanoparticles dispersed in 3-7% of water lead to greater thermal conductivity than water with a volumetric fractions from 0.2% to 2.0%. Loya et al., (2022) presented the simultaneous control of both chemical surfactant and pH to enhance the thermal conductivity of CuNPs / water nano fluids for experimental applications. They wrote that the maximum thermal conductivity improved by 10.7% at a weight fraction of 0.10%. The equivalent thermal conductivity of Al_2O_3 / water nano fluids at low volume fraction from (0.01-0.3) % at 21 °C was measured by Lee et al. They observed a best improvement was 1.5% at a 0.3% volume fraction.

In this paper the viscosity and thermal conductivity of Al_2O_3/ DDW will be studied. The nano fluid will be prepared as weight fraction with (0.5%, 1 % and 1.5%) of Al_2O_3. The FESEM images and EDS spectrum will be investigated. The theoritical models of viscosity and thermal conductivity will be used to compared with experimental data results.

2. THEORITICAL MODELS

2.1. Thermal Conductivity Models

Zhu et al., (2022) used several mathematical models suggested by previous scientists such as Maxwell in 1873 and Hamilton and Crosser 1962. Maxwell was the first to analyze the thermal conductivity of colloidal solutions. In 1873, he created a mathematical model known as Maxwell's equations. Mathematical models applicable to nanofluids assume spherical particles, uniform, lightweight and randomly distributed in the base fluid. The effective thermal conductivity K_{nf} can be obtained from:

$$K_{nf} = K_f + 3\varphi \frac{K_p - K_f}{2K_f + K_p} K_f \tag{1}$$

Where;

K_{nf} is the thermal consuctivity of colloidal, K_f; is the thermal conductivity of base fluid,

φ; is the weight fraction of the nano particles and $K_{p;}$ is the thermal conductivity of nanoparticles.

(Zhu et al 2022) also studied the Hamilton model to calculate the thermal conductivity of nanofluids. Tun-Ping Teng et al used eq. 2. to calculate the thermal conductivity in terms of volume fraction for nanomaterials and thermal conductivity for the base fluid, in addition to the constant n. [13]

$$K_{nf} = K_f \frac{K_p + (n-1)K_f - (n-1)(K_p - K_f)\varphi}{K_p + (n-1)K_f + (K_f - K_p)\varphi} \tag{2}$$

Parameter n >5 for semispherical nanoparticles.

Fadaei et al studied two theories such as parallel mixture theory (1978) as indicated in equation (3) and Velikanova et al udes the series mixture theory (1993) as shown in the equation (4) to obtain the viscosity of fluids mixed with suspended particles of micro or nano size according to the weight ratio of the particle and its thermal conductivity. The modern wasp model was used by some author (Fadaei et al. 2022 and Velikanova et al. 2018).

$$K_{nf} = (1-\varphi)K_f + \varphi K_P \tag{3}$$

$$K_{nf} = K_f + \frac{(K_p - K_f)\varphi K_f}{K_p - (K_P - K_f)\varphi} \tag{4}$$

$$K_{nf} = K_f \left(\frac{K_p + 2K_f - 2\varphi(K_f - K_p)}{K_p + 2K_f + \varphi(K_f - K_p)} \right) \tag{5}$$

2.2. Viscosity Models

The Enstein model is one of the simplified model that is used to calculate the viscosity of nanofluids based on the viscosity of the base fluid and the volumetric ratio of nanomaterials as shown in eq. 6 (Hezaveh et al. 2011).

$$\mu_{nf} = (1+2.5\varphi)\mu_f \quad (6)$$

There are other models may be used to calculate the viscosity such as Batchelor , Brinkmann and Wang which represented as Eqs. 7, 8, and 9 respectively.

$$\mu_{nf} = (1+2.5\varphi+6.5\varphi^2)\mu_f \quad (7)$$

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \quad (8)$$

$$\mu_{nf} = (1+7.5\varphi+123\varphi^2)\mu_f \quad (9)$$

3. EXPERIMENTAL WORK

3.1. Materials Used

The nanoparticles Al_2O_3 99.0% type Alpha with diameter (40nm) provided by Sky spring nanomaterials Inc. The physical properties are listed in the Table 1.

Table 1. Physical and Thermal Properties Of Al_2O_3NPs.

Purity	surface area m^2/g	shape and color	Density g/cm^3	Thermal conductivity W/m.k	Heat capacity J/kg.K
99.99%	> 20	white spherical	3.950	40	765

3.2. Methodology

The nano colloidal was prepared by dissolve 0.5, 1, and 1.5 g of Al_2O_3 in 100 ml of distills water. in order to overcome the Van der Waals links between Nanoparticles improved their dispersion and stability the magnetic stirrer and ultrasonic mixer were used for two hours to prepared the weight fraction of Al_2O_3 / water 0.5%, 1 % and 1.5% as shown in the Fig. 1 and Fig. 2 respectively.

Fig. 1. magnetic stirrer

Fig. 2. ultrasonic mixer

3.3. Thermal Conductivity Measurements

The KD2 device of American origin, Decagon Devices, Inc., Pullman, WA, USA, is used to measure the thermal conductivity of various types of liquids, polymers, and solids at a certain temperature, Fig. 3. According to the operating instructions, the examination conditions must be taken into account, which is to make a model that is identical to the standard models, in addition to taking into account that the sample would be fixed by Laboratory holder to warent does not vibrate during the examination to ensure the validity of the thermal conductivity reading .

3.4. Viscosity Measurements

The nano fluids viscosity was measured using viscometer type FUNGILAB provided from Brookfield Labs. of Engineering, Inc., Middleboro MA/USA. The viscometer guides the rotor immersed in the nanofluid. As the spindle rotates; the friction of the viscosity of the solution next to the spindle is determined by the calibrated spring deflection. The viscometer gives the temperature range for this experiment. The viscometer has a model chamber and is carefully monitored with a temperature sensor for viscosity measurement as shown Fig. 4. The viscosity measurements were done for nano colloidal for (0.5 % wt., 1 % wt., and 1.5%wt.).

Fig. 3. Thermal Conductivity Device

Fig. 4. FUNGILAB Viscometer

3.5. SEM and EDS Tests

The FESEM works by dropping a bundle of electrons onto the sample to be examined, and therefore the sample must be prepared in advance to make it electrically conductive by coating it with a thin layer of gold. The sample is placed in a vacuum chamber and a high energy electrons are released to the surface of the sample. When the electron comes into contact with surface of the sample leading to release a group of electrons that can be detected by specific detectors and sends a special signals to the amplifier device to display it as a picture.

4. RESULTS AND DISCUSSION

4.1. Viscosity Results

This test was carried out on alumina nanoparticles dissolved in distilled water by weight (0.5%, 1% and 1.5%). The viscosity test results indicate that it increased with increasing concentration of alumina nanoparticles. The improvemet factor ranging between (2.2 to 2.5) times compared with DDW as shown in Fig. 5. This increase is attributed to the Van der Waals forces among the Al_2O_3 nanoparticles and their tendency to increase viscosity with increasing concentration due to the increase in the bonding forces between them. Fig. 6 represents a comparison between the theoretical models Einstein, Batchelor, Brinkmann and Wang with experimental work results of viscosity values of the Al_2O_3 nano solutions. The results indicate that there is a great convergence between the theoretical and experimental results, and that the highest error percentage reach to 14% according to the Wang mathematical model at 1.5% wt. while the lowest error percentage occurs is 1.25% according to the Einstein model at 0.5%wt.

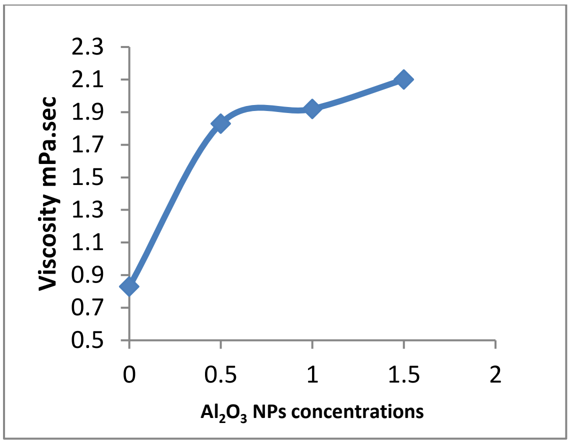

Fig. 5. Viscosity with different concentration of Al_2O_3 NPs.

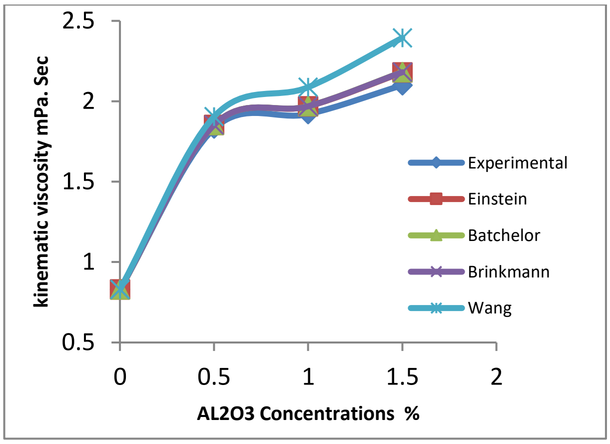

Fig. 6. Comparison between theoretical and Experimental Viscosity with different concentration of Al_2O_3 NPs.

4.2. Thermal Conductivity Results

The thermal conductivity of nano fluids depends on the type of nano fluid and the coating material on the outer surface of the tubes in the heat exchangers, the particle size of the nanomaterials used and the concentration of the nanomaterial in the coating layer. In low-carbon steels, the presence of water and oxygen leads to chemical corrosion on the outer walls of the tube in the heat exchanger, which leads to the formation of an insulating outer layer surrounding the tubes that prevents heat exchange between the internal and external fluid causing reduces the life of the tube and the efficiency of heat transfer through it. In this work, the presence of a layer of Al_2O_3 NPs on the walls of the tube prevents corrosion as well as increases thermal conductivity due to it has good thermal conductivity. Through the Fig. 7 that could see the thermal conductivity increases with increasing the concentration of the nanoparticles. Thermal conductivity increased with increasing concentration of Al2O3 nanoparticles with improving factor ranging from (1.19 – 1.38 times) compared with double distilled water. This closeness between nanomaterials leads to making them transfer heat continuously from the inside to the outside and vice versa. The maximum improvement percentage in thermal conductivity reach to 38% accrued at 1.5% wt. of Al_2O_3NPs.

Many authors study the theoretical models of thermal conductivity such as Maxwell model, Hamilton and Crosser model, Parallel Mixture model, Series Mixture model and Wasp model. Fig. 8 represent the comparisons among the experimental and theoretical models of thermal conductivity. The minimum difference percentage between theoretical and experimental results of thermal conductivity is 10% fall at 0.5%wt. for Parallel Mixture Theory. The maximum difference percentage was 40% accrued at 1.5%wt. of Al_2O_3NPs for same theory.

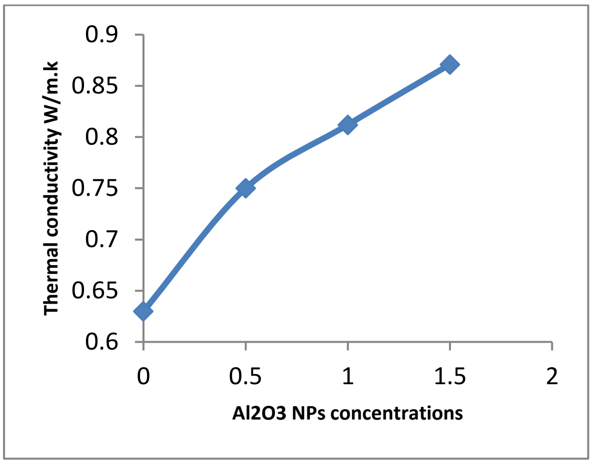

Fig. 7. Experimental Thermal Conductivity of different Concentration of Al_2O_3NPs/DDW.

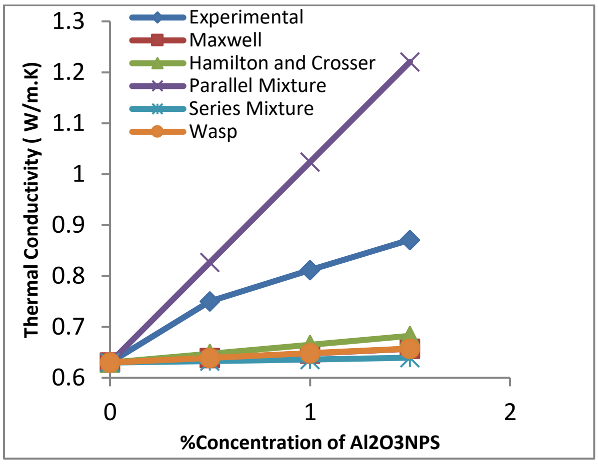

Fig. 8. Comparison between theoretical and Experimental thermal conductivity with different concentration of Al2O3 NPs.

4.3. SEM and EDS Results

From Figs. 9–14 show FESEM images and EDS results of colloidal Al_2O_3NPs samples with three concentrations (0.5%, 1% and 1.5%) and the granules were spherically shaped with an average grain diameter of 70 nm at a magnification of 20k. It is clear from the images that the. The EDS spectrum indicate the elements consist the Aluminum percent start from 17.5% at 0.5%wt of Al_2O_3 NPs at one coating layer. The Aluminum percent increase with increase coating layers and concentrations of nanoparticles.

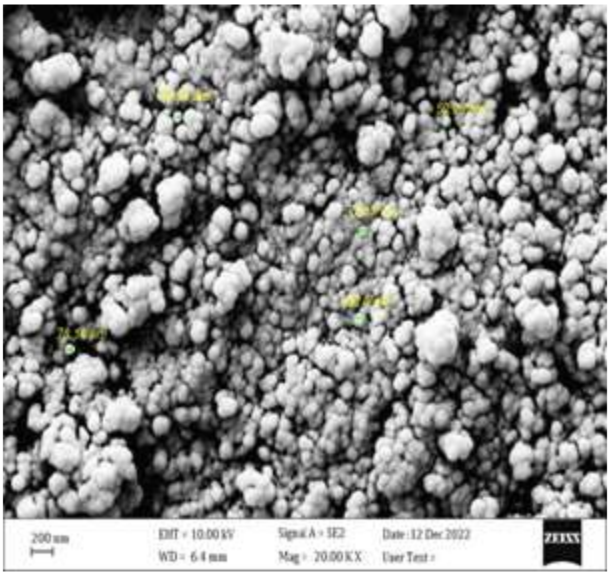

Fig. 9. FESEM Image of 0.5%wt. of Al_2O_3NPs.

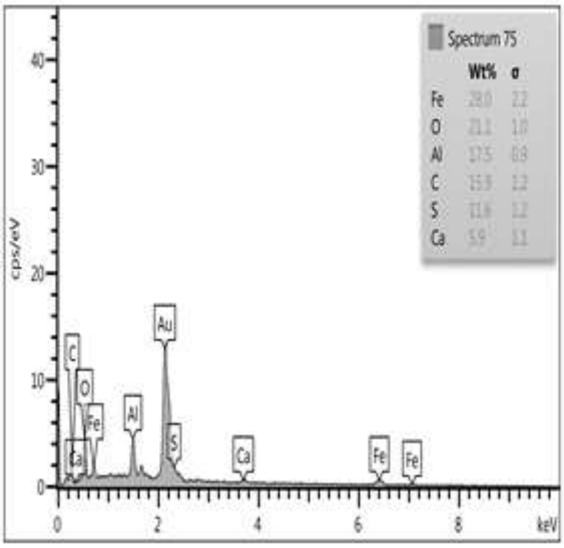

Fig. 10. EDS spectrum of 0.5%wt. Al_2O_3NPs.

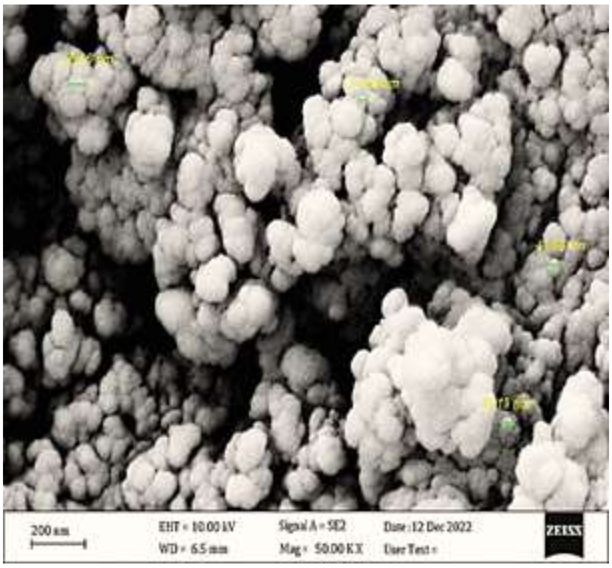

Fig. 11. FESEM Image of 1%wt. Al_2O_3NPs.

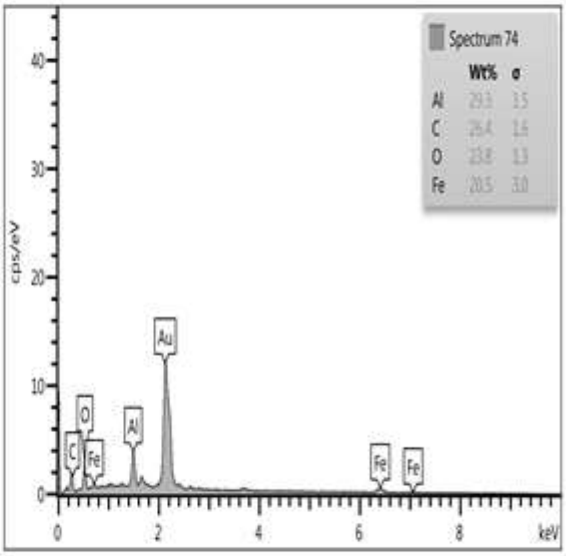

Fig. 12. EDS of 1%wt. Al_2O_3NPs.

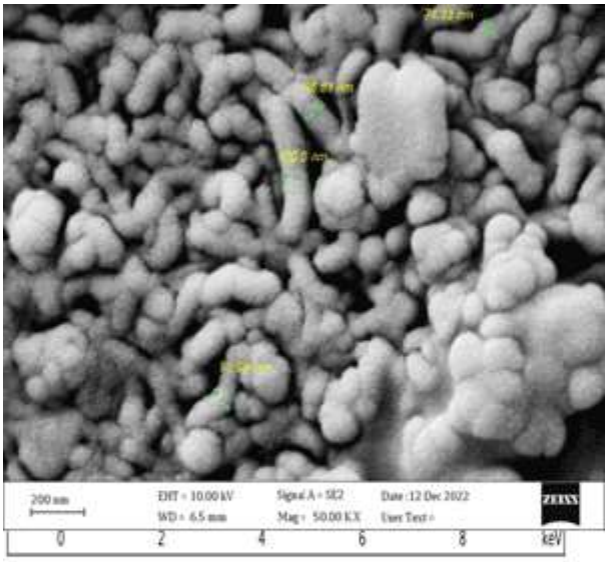

Fig. 13. FESEM Image of 1.5%wt. Al_2O_3NPs.

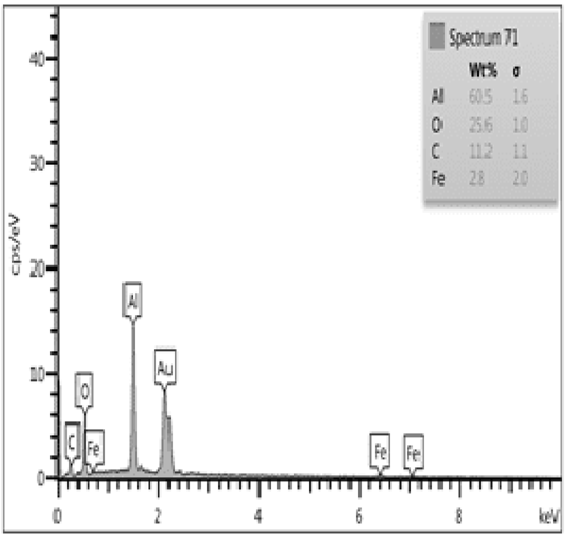

Fig. 14. EDS spectrum of 1.5%wt. Al_2O_3NPs.

5. CONCLUSIONS

From the above results, it can be concluded that the thermal conductivity increases near linearly with the increase in the weight fraction of Al_2O_3NPs. The viscosity increase with non-linear behavior with the increase in the concentration of Al_2O_3NPs. The results showed that viscosity was increase by improving factor ranging from (2.2 to 2.5 times) compared with double distilled water and thermal conductivity increased with increasing concentration of Al_2O_3 nanoparticles with improving factor ranging from (1.19 – 1.38 times) compared with double distilled water. The error percentage between theoretical and experimental work of viscosity and thermal conductivity measurements were (1.25% - 14%) and (10% -40%) respectively. The SEM images show the homogeneity of the nanomaterial distribution inside the nanofluid, especially at a concentration of 1%. The EDS results shows the rationality of increasing the weight fraction of aluminum by increasing the concentration of the nanomaterials. There are some aggrigation investigated in Al_2O_3 at 1.5% wt.

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