International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Improving Mixtures of Natural and Synthetic Rubber with Carbon Black

Sanaa A. Hafad
Energy and Renewable Energy Technology Center-Baghdad-Iraq
Email address: 100285 @ unotechnology.edu.iq

***Abstract*—** *The current study includes improving the properties of natural and synthetic rubbers in five percentages (100% natural rubber, 80% natural rubber + 20% synthetic rubber, 60% natural rubber + 40% synthetic rubber and 40% natural rubber + 60% synthetic rubber, 20% natural rubber) +805 synthetic rubber, 100% synthetic rubber) as it was strengthened by mixing them with carbon black in different proportions (10, 20, 30, 40 and 50%) of carbon black powder, where they were mixed with open kneading for 20 minutes for each mixture and was done Standard samples for the following tests: Tensile and hardness, and A change in mechanical properties has been observed due to the type of polymers mixture that is characterized by its ability to have regular structural composition, especially synthetic rubber (SBR) with natural rubber, and the increase in tensile and shear resistances, which is considered evidence of extraction of the rest of the properties through these two resistances, in the presence of black carbon powder, which increased the evaluator of these resistors.*

I. INTRODUCTION

Natural rubber is considered to be a substance that has been studied very extensively. The mechanical and chemical properties have been studied very extensively, and the applications have been studied extensively. The availability of a review of investigations by other researchers is the basis of this study. Previous research focused on studying all aspects of natural rubber, as many researched additives, including fillers such as carbon black powder. Many researchers also went into a study in measuring mechanical properties, insulating and chemical properties, and the effects of different sunlight. [1]

H. S. Ahmad, H. I, Azura A. Rashid [2] in this research, recycled materials such as gloves made of synthetic rubber with natural rubber epoxide were used, where they were mixed for different time periods, changing according to the requirements of the mixture, the material and the application. Remarkably, with the attraction of the elastic and recycled materials, here the mechanical properties were studied and the final shape was observed by a scanning optical microscope where the imaging topographic microscopic examinations of the homogeneous mixture were shown in different proportions. Recycled materials such as gloves made of synthetic rubber with natural rubber epoxide were used, where they were mixed for different time periods, changing according to the requirements of the mixture, the material and the application. Remarkably, with the attraction of the elastic and recycled materials, here the mechanical properties were studied and the final shape was observed by a scanning optical microscope where the imaging topographic microscopic examinations of the homogeneous mixture were shown in different proportions.

W. Ariyawiriyanana, J. Nuinua, K. Sae-heng, S. Kawaharab [3] in this research, DPNR rubber was used as thin film products as the proteins were removed from the natural rubber by incubating the natural rubber with 0.1% urea by weight. I specialized in the study. He also studied the mechanical properties, especially tensile strength, where satisfactory results appeared. The tests that were worked on are the solubility of protein and how pressure and temperature affect it. In this research, DPNR rubber was used as thin film products as the proteins were removed from the natural rubber by incubating the natural rubber with 0.1% urea by weight. I specialized in the study. He also studied the mechanical properties, especially tensile strength, where satisfactory results appeared. The tests that were worked.

S.Z. Salleha, M.Z. Ahmada, H. Ismaila [4] The effect of ambient temperature and the controlling pressure on the environment both dissolve the protein in the rubber, which changes the rubber's structure. I studied and completed a lot of research on the type of elastomeric polymers used, the amount of humoral ratios and their effect on the tensile properties. The results obtained evaluated the effect of reinforcement after comparing it with the rubber materials before mixing, as it was found to be less tensile strength due to the high mixing speed, and the effect of review and treatment changes with the addition of recycled materials. These materials were supported with hundreds of them (silica and carbon black) and both changed according to its basic properties. As the physical properties of silica and carbon black were evidenced by the density and specific weight of the remarkable change of mechanical properties according to the type of material to which it was added and the rates of addition.

S.Salina Sarkawi*, A K. Che Aziz, R. A.Rahim, R. Abdul Ghani, A. N. Kamaruddin [5] in the present study, reinforcement of natural rubber with silica appeared to be highly compatible. Where he evaluated the natural rubber (ENR) reinforced with silica compound, the physical and mechanical properties of silica were tested. Also, the increase in stiffening ratios changes the studied properties values compared to standard mixtures because they have a ripening time.

Mr. Colin S Ruggles Revertex [6] in this paper, the specifications of the rubber propulsion part of the standard mixture performance development system used in the manufacture of this part were studied. Natural rubbers and some types of synthetic rubbers used different proportions of

Sanaa A. Hafad, "Improving Mixtures of Natural and Synthetic Rubber with Carbon Black," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 4, pp. 248-252, 2020.

silica as a reinforcing agent used in the standard mixture for this product, as the results of manufactured mixtures High due to the presence of silica and carbon black, as well as the ability to tear, compressibility, reflux, abrasion and other tests used.

E. M. Ginting, N. Bukit, E Frida [7] Carbon black and bentonite powder are added to the natural rubber in different proportions ranging between 10, 20 and 30. The samples were prepared by an open mixer for a period of 6 minutes where the mechanical properties were also studied, which showed that the mechanical properties changed with the presence of such additions. Including coefficients of tensile elongation, elasticity, and shear due to displacement and stress indicate a response to the rubbery part.

E M Ginting, N. Bukit, E Frida [8] the variable rubber mixtures of different rubber blends with a mixture (SBR) filled with silica and carbon black containing a wide range of different mixtures were measured. The behavior of tensile strength, stiffness, flexibility, wear and fatigue showed clear behavior under variable transitional conditions. An improved formula was proposed that includes multiple mixtures filled with a mixture of black carbon and silica to obtain a suitable formulation for development as it gave good results in tire applications, eliminating skidding, rolling, stress and environmental damage in an accurate manner. used in the standard mixture for this product, as the results of manufactured mixtures High due to the presence of silica and carbon black, as well as the ability to tear, compressibility, reflux, abrasion and other tests used.

Carbon black and bentonite powder are added to the natural rubber in different proportions ranging between 10, 20 and 30. The samples were prepared by an open mixer for a period of 6 minutes where the mechanical properties were also studied, which showed that the mechanical properties changed with the presence of such additions. Including coefficients of tensile elongation, elasticity, and shear due to displacement and stress indicate a response to the rubbery part.

Variable rubber mixtures of different rubber blends with a mixture (SBR) filled with silica and carbon black containing a wide range of different mixtures were measured. The behavior of tensile strength, stiffness, flexibility, wear and fatigue showed clear behavior under variable transitional conditions. An improved formula was proposed that includes multiple mixtures filled with a mixture of black carbon and silica to obtain a suitable formulation for development as it gave good results in tire applications, eliminating skidding, rolling, stress and environmental damage in an accurate manner.

E. Farida, N. Bukit, E. M. Ginting, B. F. Bukit [9] In this paper, the effect of the thermal properties of carbon black filler formation (CB) on natural rubber as a compound and functional performance was determined. The results of the mixtures with carbon black were shown in proportions which gave high-efficiency homogeneity as shown by the variable thermal results, as shown in the drawing. Graphically, there is no significant difference between composite with filler and without filler. Thermal scanning shows, adding carbon black increases the natural rubber formation of the compound's heat delta compared to no CB.

M. Masłowski, J. Miedzianowska, Kr. Strzelec [10] The current work examines agricultural residues in the form of cereal straw as a support material and how to use it and enter as a reinforcing material as it mixes with natural rubber to produce a composite material. With different materials, including black carbon, silica and chalk. The properties of the rubber and straw reinforced overlays resulted in an increase in torque, which showed a high mechanical arrangement as indirectly indicating a high degree of crosslinking and stiffness of the compounds. The mixing process, temperature, mixing speed and mixing time are all factors that affect the type of product and the rubber compound, which in turn is reflected in the resulting mechanical properties. The current work examines agricultural residues in the form of cereal straw as a support material and how to use it and enter as a reinforcing material as it mixes with natural rubber to produce a composite material. With different materials, including black carbon, silica and chalk. The properties of the rubber and straw reinforced overlays resulted in an increase in torque, which showed a high mechanical arrangement as indirectly indicating a high degree of crosslinking and stiffness of the compounds. The mixing process, temperature, mixing speed and mixing time are all factors that affect the type of product and the rubber compound, which in turn is reflected in the resulting mechanical properties.

J. K. Oleiwi M. S. Hamza N.Almtteri [11] this research studies the preparation of different blends where the natural rubber (SMR20) and styrene-butadiene (1502) rubber were used with different loading ratios (pphr0, 25, 50, 75, 100) and each mixture was strengthened with carbon. Black with different load ratios (pphr20, 40, 60, 80). Many mechanical tests were carried out for the purpose of determining the properties of the prepared composite material while the elongation decreased at break for all mixtures. . The hardness and wear properties of all mixtures increase with increasing the level of synthetic rubber to natural and with the increase in carbon black. The physical-mechanical properties of the variable rubber mixtures of different rubber blends with a mixture (SBR) filled with silica and carbon black containing a wide range of different mixtures were measured. The behavior of tensile strength, stiffness, flexibility, wear and fatigue showed clear behavior under variable transitional conditions. An improved formula was proposed that includes multiple mixtures filled with a mixture of black carbon and silica to obtain a suitable formulation for development as it gave good results in tire applications, eliminating skidding, rolling, stress and environmental damage in an accurate manner. used in the standard mixture for this product, as the results of manufactured mixtures High due to the presence of silica and carbon black, as well as the ability to tear, compressibility, reflux, abrasion and other tests used.

A. A. Abdelsalam, S. Araby, S. H. El-Sabbagh [12] In this paper, carbon black has been used to natural rubber the main reinforcement material with a few small reinforcement materials such as clays, calcium carbonate and silicates where it was used in the reinforcement, to reduce the economic cost. Costs and improvement in mechanical properties. It was found

Sanaa A. Hafad, "Improving Mixtures of Natural and Synthetic Rubber with Carbon Black," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 4, pp. 248-252, 2020.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

that carbon black developed mechanical tensile strength values including mechanical wear due to friction.

This work aims to try to study the tensile strength and hardness with synthetic rubbers by cementing it with powder (carbon black) at different loading levels with styrene butadiene and natural rubber. NR separately and blending (SBR / NR) in different proportions. To improve: the blending and loading effect of NR with SBR. The work also aims to change the susceptibility of reinforced materials to change the susceptibility of mixtures to the mechanical properties studied in the current research.

II. EXPERIMENTAL

Materials:

Natural rubber:

Natural rubber is the first type of all plastics. It comes in several forms, including natural rubber in the form of epoxy rubber, protein-containing rubber, taste with polyethyl methcrylate and many other types, as the characteristics of NR are shown in the table 1. The natural rubber polymer consists of 100% cis-1,4 polyisoprene with a MRwR ranging from 1 to 2.5 x 10P6P. Natural rubbers have a uniform structural arrangement and crystallize at low temperatures or upon expansion. Crystallization at lower temperatures causes solidification, but it can be easily reversed by warming. Crystallization gives natural rubber high tensile strength, resistance to cutting, tearing and abrasion. Like other high polymers [13].

SBR:

The synthetic rubber of this type used in the current research is defined as a type of long and intertwined chains that possess different properties. These polymers are characterized by chemical stability, stability, resistance, and ability to expand due to twice its original length. Elastomers contain plastics that can be cross-linked, such as polybutadiene, polyisoprene, and ethylene propylene diene terpolymer. It also includes non-interlocking thermoplastics that are adapted for special purposes such as automobile bumpers and wire and cable coatings. These materials can be scraped off and reused.

TABLE 1. Types of rubber properties.

R types	Hardness	Tensile strength MPA	Elongation At room temp. %	Temp. Service co
NR	20-100	0.1-0.4	100-700	-55-80
SBR	40-100	0.1-0.35	100-700	-55-110

Black carbon:

Carbon black powder is considered as a filler in hot hardened polymeric materials and is used in the manufacture of tires and other industrial applications and is the result of incomplete burning processes for organic materials or petroleum derivatives. It has a high surface area where the granular size may reach 100 nanometers according to the nanoscale sizes. It is also characterized by high surface tensile strength as when mixed with very high bonding polymers, it provides high crosslinking and regular arrangement with rubber mixtures [15], such as the shape. (1).

Fig. 1. black carbon powder

Mechanical properties

Tensile test:

Tensile test using (maximum tensile strength and maximum shear strength) of the ASTM D412-98 rubbers were tested for (4) different samples at a temperature of 20 ° C, the applied strength was (1KN) with the speed of the traction device (20 mm / min). The tests are performed with a miniature computer controlled electronic universal tester as shown in fig (2) Model 1195 manufactured by (Instron). After longitudinal fixing of the specimen by the upper and lower jaws of the equipment, preparing as table 3, a tensile load is applied at max. At velocity rate (2mm/min), and by utilization of the connected graphic plotter, the relation of (P – Δl) is obtained. This relationship would be modified to relationship of (stress – strain) (σ – ε) to calculate the ultimate tensile strength (UTS) for the specimens.as equation 1 and 2[16]

$$\sigma = \frac{P}{A} \quad (1)$$

Where: P: load (N) A: cross sectional area

$$\varepsilon = \frac{\Delta l}{l} \quad (2)$$

Where: Δl: length change, l: original length

Fig. 2. Tensile instrument

Hardness test

In this work, hardness is measured using Shore A in accordance with ASTM D 2240. Where the models that are determined in the above specification are used, which facilitates the measurement process that such a tool is characterized by stitching a sensitive needle that gives places of application of a certain force on the used model, where the hardness measurements of the model appear, as it was found that the more carbon black added, the synthetic rubber increased more than the hardness of natural rubber and mixers of variable proportions as in figure 3 [17].

Sanaa A. Hafad, "Improving Mixtures of Natural and Synthetic Rubber with Carbon Black," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 4, pp. 248-252, 2020.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Fig. 3. Shore A instrument

III. RESULTS AND DISCUSSIONS

Tensile strength:

The tensile strength is measured by dividing the maximum stress by the strain. The maximum shear resistance of the five mixtures is also measured, as their results are shown in figure 4 and figure 5. The diagram show tensile strength and the percentage of addition of carbon black as a support material for the different compositions that increase with the increase in the reinforcement ratios with carbon black powder, and the maximum resistance value of carbon black can be 20 MPa, that this property is related to the amount of large cross-links when ripening, where the tensile value increases When cutting with increased bonds that occur upon ripening. Because of the dispersion of the reinforced material, which causes a highly resistant structural formation in combination with long polymeric chains. [19].

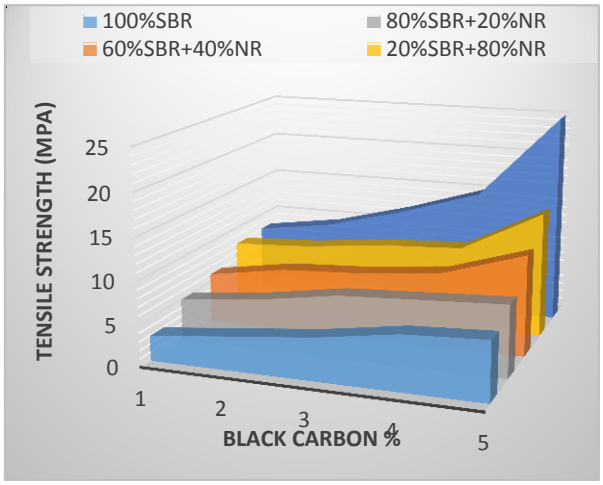

Fig. 4. Tensile strength and black carbon %

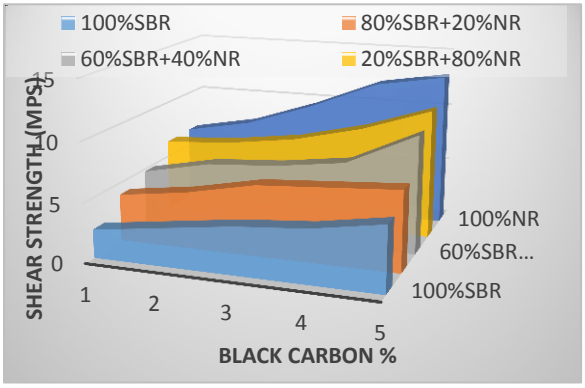

Fig. 5. Shear strength and black carbon %

Whereas the final shear strength values of the samples have 0.8 final tensile values, so the behavior of the sample increased with the addition of the carbon black percentage. Due to the tensile test that occurred with the horizontal plane of the parallel plane shear test [20-28]

Hardness results:

The values of hardness related to type of rubber and high value related to percentage of black carbon loading above 40 5with respect to rubber loading.as fig.(6)[21]and that because of the nature and structure of polymer of rubber and ability to cross bonding with each other (nutral rubber and SBR)from one side ,and the other side with black carbon[22, 28-39].

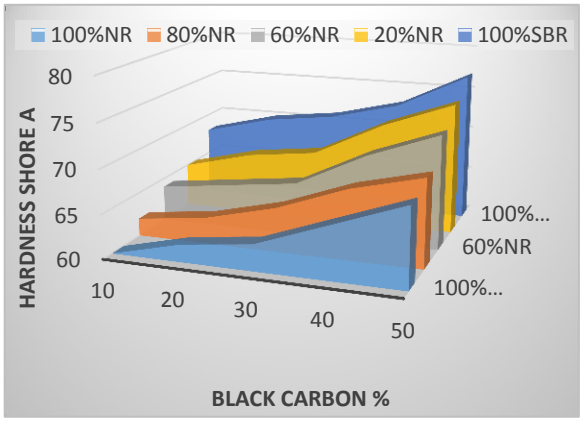

Fig. 6. Hardness shore A with black Carbone %

IV. CONCLUSSIONS

1. The mechanical value of mixed polymer increased with black Carbone percentage even 50%.
2. Tensile strength of natural rubber higher than mixed with SBR.
3. Hardness of SBR higher than NR.
4. The mixing two types of rubber give good properties and wide range of applications.

REFERENCES

[1] U. R. Chaudhuri "Fundamentals of Petroleum and Petrochemical Engineering." University of Calcutta Calcutta, India, 2011.

[2] H. S. Ahmad, H. I, Azura A. Rashid , Tensile Properties and Morphology of Epoxidized Natural Rubber/Recycled Acrylonitrile-Butadiene Rubber (ENR 50/NBRr) Blends, 5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015, Procedia Chemistry 19 (2016) 359 – 365.

[3] W. Ariyawiriyanana, J. Nuinua, K. Sae-heng , S. Kawaharab , The Mechanical Properties of Vulcanized Deproteinized Natural Rubber , Energy Procedia 34 (2013) 728 – 733 ,1876-6102 © 2013 The Authors. Published by Elsevier B.V.Selection and peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT) doi: 10.1016/j.egypro.2013.06.80610th Eco-Energy and Materials Science and Engineering (EMSES2012).

[4] S.Z. Salleha, M.Z. Ahmada, H. Ismaila ," Properties of Natural Rubber/Recycled Chloroprene Rubber Blend: Effects of Blend Ratio and Matrix, 5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate

Sanaa A. Hafad, "Improving Mixtures of Natural and Synthetic Rubber with Carbon Black," *International Research Journal of Advanced Engineering and Science*, Volume 5, Issue 4, pp. 248-252, 2020.

Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015 Procedia Chemistry 19 (2016) 346 – 350.
[5] S.Salina Sarkawi*, A K. Che Aziz, R. A.Rahim, R. Abdul Ghani, A. N. Kamaruddin, Properties of Epoxidized Natural Rubber Tread Compound: The Hybrid Reinforcing Effect of Silica and Silane System , Malaysian Rubber Board, RRIM Research Station Sg. Buloh, 4700 Selangor, Malaysia Polymers & Polymer Composites, 2016,Vol. 24, No. 9.
[6] Mr. Colin S Ruggles Revertex ,The Efficient Use of Environmentally-Friendly Natural Rubber Latex in Road Construction, - Past Present and the Future Seminar "Rubber in Transport", Breda, The Netherlands, 9-12-2004 Joint initiative of the BPRI and the VKRT.
[7] E M Ginting, N. Bukit, E Frida, Mechanical properties and mophology natural rubber blend with bentonit and carbon black, uly 2017 IOP Conference Series Materials Science and Engineering, 223(1):012003
[8] B. Mensah, B. Agyei-Tuffour, E. Nyankson, Y. D. Bensah, D. Dodoo-Arhin, J. K. Bediako, B. Onwona-Agyeman, and A. Yaya Preparation and Characterization of Rubber Blends for Industrial Tire Tread Fabrication, Volume 2018, 2473286.
[9] E. Farida, N. Bukit , E. M. Ginting, B. F. Bukit , The effect of carbon black composition in natural rubber compound, Case Studies in Thermal Engineering 16 (2019) 100566
[10] M. Masłowski, J. Miedzianowska, Kr. Strzelec, Natural Rubber Composites Filled with Crop Residues as an Alternative to Vulcanizates with Common Fillers, Journals Polymers Vol. 11, Issue 6, 3 June 2019,10.3390-11060972.
[11] J. K. Oleiwi M. S. Hamza N.Almtteri, studies of the effect of carbon black particles on the mechanical properties of sbr/nr blends used in passenger tire treads, conference: the second international scientific conference of the college of materials engineering 15 - 16 May 2013, 77-82.
[12] A. A. Abdelsalam, S. Araby, S. H. El-Sabbagh, Effect of carbon black loading on mechanical and rheological properties of natural rubber/styrene-butadiene rubber/nitrile butadiene rubber blends, May 6, 2019.
[13] R. D. Marinho and E. E. C. Monteiro, “Analysis of natural cis-and trans-polyisoprene mixtures by near-infrared spectrophotometry,”Polymer Testing, vol.19, no.6, pp.667–672, 2000.
[14] P. Sirisomboon, A. Kaewkuptong, and P. Williams, “Feasibilitystudy on the evaluation of the dry rubber content of field and concentrated latex of Para rubber by diffuse reflectance near infrared spectroscopy,” Journal of Near Infrared Spectroscopy,vol.21,no.2,pp.149–156,2013.
[15] P. Sirisomboon, M. Deeprommit, W. Suchaiboonsiri, and W.Lertsri, “Shortwave near infrared spectroscopy for determination of dry rubber content and total solids content of Pararubber (Hevea brasiliensis) latex,” Journal of Near Infrared Spectroscopy, vol.21, no.4, pp.269–279, 2013.
[16] A. K. Bhowmick, Rubber Products Manufacturing Technology, CRCPress, NewYork, NY, USA, 2014.
[17] A. R. Payne, “The dynamic properties of carbon black−loadednatural rubber vulcanizates. Part I,” Journal of Applied Polymer Science, 2016, vol. 6, pp. 57–63.
[18] O. H. Yeoh, “Characterization of elastic properties of carbon-black-filled rubber vulcanizates,” Rubber Chemistry and Technology, vol. 63, no. 5, pp. 792–805, 2010.
[19] M. Arroyo, M. A. L´opez-Manchado, and B. Herrero, “Organo-montmorillonite as substitute of carbon black in natural rubbercompounds,” Polymer, vol.44, no.8, pp.2447–2453, 2003.
[20] D. R. Paul, Polymer Blends, vol.1, Elsevier, 2012.
[21] M. H. Walters and D. N. Keyte, “Heterogeneous structure inblends of rubber polymers,” Rubber Chemistry and Technology, 2015, vol.38, no.1, pp.62–75.
[22] M. Xanthos and S. Dagli, “Compatibilization of polymer blendsby reactive processing,” Polymer Engineering & Science, 2018,vol.3
[23] S. A. Hafad, Measured the mechanical properties of thermoplastic polymers using in healthy applications, International Journal of Computation and Applied Sciences IJOCAAS Vol. 9, Issue 1, August 202020 ISSN: 2399-4509.
[24] S. A. Hafad, Mechanical Properties of Concrete exposed to oil products, International Journal of Computation and Applied Sciences IJOCAAS Volume 8, Issue 3, June 2020, ISSN: 2399-4509.
[25] S. I. Ibrahim, Study the Non-Linear Properties of Rhodamine C Dye Dissolved in Different Solvents. Year: 2019, Volume: 6, Issue: 2, Page No: 446-451.
[26] A. H. Al-Waeli, Preparation of Nanofluids through Two-Step Method: Novel automation approach, Year: 2019, Volume: 6, Issue: 3, Page No: 461-465.
[27] M. J. Yousif, J. H. Yousif Humanoid Robot as Assistant Tutor for Autistic Children, Year: 2020, Volume: 8, Issue: 2, Page No: 8-13.
[28] A.Z. Salman, M.A. Fayad, and A.Q. Salam, Theoretical Investigation of Buoyancy-driven Cavity Flow by Using Finite Element, 2019. International Research Journal of Advanced Engineering and Science, 4(1), pp.66-70.
[29] M.A. Fayath, and S.T. Hamidi, Prediction of thermal characteristics for solar water heater. 2011. Anbar Journal of Engineering Sciences, 4(2), pp.18-32.
[30] M.A. Fayad, Investigating the influence of oxygenated fuel on particulate size distribution and NOX control in a common-rail diesel engine at rated EGR levels, 2020, Thermal Science and Engineering Progress, 19, p.100621.
[31] S.T. Hamidi, and M.A. Fayad, Theoretical study for aerodynamic performance of horizontal axis wind turbine. 2011, AL-TAQANI, 24(8), pp.E113-E124.
[32] M.A. Fayad, Effect of fuel injection strategy on combustion performance and NO x/smoke trade-off under a range of operating conditions for a heavy-duty DI diesel engine, 2019, SN Applied Sciences, 1(9), p.1088.
[33] M.A. Fayad, Analytical solution for predicting heat pipe performance. 2012, AL-TAQANI, 25(1), pp.E-82.
[34] M.A. Fayad, and B.R.AL-Ogaidi, Investigation the Morphological Characteristics of the Particulate Matter Emissions from the Oxygenated Fuels Combustion in Diesel Engines. 2019, Engineering and Technology Journal, 37(10A), pp.384-390.
[35] M.A. Fayad, A. Tsolakis, and F.J. Martos, Influence of alternative fuels on combustion and characteristics of particulate matter morphology in a compression ignition diesel engine, 2020, Renewable Energy, 149, pp.962-969..
[36] M.A. Fayad, Effect of renewable fuel and injection strategies on combustion characteristics and gaseous emissions in diesel engines, 2020, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 42(4), pp.460-470.
[37] M.A. Fayad, D. Fernandez-Rodriguez, J.M. Herreros, M. Lapuerta, and A. Tsolakis, , Interactions between after treatment systems architecture and combustion of oxygenated fuels for improved low temperature catalysts activity, 2018, Fuel, 229, pp.189-197.
[38] M.A. Fayad, J.M. Herreros, F.J. Martos, and A. Tsolakis, Role of alternative fuels on particulate matter (PM) characteristics and influence of the diesel oxidation catalyst, 2015, Environmental science & technology, 49(19), pp.11967-11973.
[39] M.A. Fayad, A. Tsolakis, D. Fernández-Rodríguez, J.M. Herreros, F.J. Martos, and M. Lapuerta, Manipulating modern diesel engine particulate emission characteristics through butanol fuel blending and fuel injection strategies for efficient diesel oxidation catalysts, 2017, Applied Energy, 190, pp.490-500.