Performance Evaluation Of Africa Elemi, Melon And Africa Locust Bean Oil As Potential Quenchants For Medium Carbon Steel

C. S. Ibeh, J. Audu, C. O. Okpanachi, Y. L. Abdulganiyu, I. S. Ogbonnaya

Abstract: A qualitative and comparative study was carried out on some locally sourced oils (melon oil, Africa elemi oil and Africa locust bean oil) to evaluate suitability as substitute quenching media to mineral-based oil. The cooling ability of the oils *was* investigated using AISI 1034 medium carbon steel. The effect of heat transfer coefficient on quench severity, mechanical properties of the quenched specimens were investigated in the course of the study. Results showed that the peak rate of heat extraction of melon oil, Africa locust bean and Africa elemi oil were higher than that of mineral oil. Higher heat transfer coefficient of 1463, 1023 W/m^2k were obtained for melon oil and Africa locust bean*;* Africa elemi and SAE 40 oil have heat transfer coefficient of 982 and 469 W/m^2k respectively. The selected oils can be used as quenchants for medium carbon steel, since the oils exhibits better cooling properties and mechanical properties than mineral-based oil.

Keywords: Africa locust bean oil, Africa elemi oil, Heat Transfer, Quench severity

1. Introduction

In heat treatment industries, quench hardening is of paramount important in heat process as it alters, improves mechanical and microstructural properties of the components quenched. It is carried out from a higher (majorly above the austenitised temperature) temperature, hold for definite time at same temperature then to a lower temperature with the use of cooling medium. Such cooling may be continuous or not continuous depending on the type of microstructure required. The use of water, mineral has been the commonly used quenching medium in heat treatment industries [1]. Though quenching with the use of water plays a significant role in heat treatment as it provide higher, improved hardness, hard or higher proportion of martensite [2], it do have a major setback (higher degree of cracking). However, mineral oil quenchants are used when lower rate of cooling and consistent cooling of alloy steels is desired. However, it exhibits quite a number of disadvantages which include: 1) Poorly biodegradable 2) Toxicity 3) highly flammable [3]. It has therefore, become a continual interest to establish a possible substitute to water and mineral oil as base-stock for industrial heat treatment. Nothwistanding, heat treatment with oil does not show these disadvantages as with water quenchants but could not as water quenching medium provide extensive cooling rate, extensive enough to adequately harden steel components. Considering the disadvantages of water and mineral/petroleum oil quenching in steel heat treatment, and the continuous search for appropriate quenching medium that will not only to provide required severity for hardening but will also at the end of heat treatment could also provide desired quench properties, some locally sourced edible vegetable oils (melon oil, Africa locust bean and Africa elemi oil) are being investigated as an alternative to conventional quenchants in comparison to water and petroleum based-oil (SAE 40 oil).

- *C. S. Ibeh, J. Audu, C. O. Okpanachi, Y. L. Abdulganiyu, I. Ogbonnaya*
- *Scientific Equipment Development Institute, Minna, Nigeria.* stanleybyhisgrace@yahoo.com

Africa elemi, popularly known in Nigeria ''Atili'' in Hausa, ''Ube'' in igbo language [4]. The fruits are found sparingly in western parts of Nigeria but chiefly in many parts of north and eastern state of the country [5]. Africa elemi oil is known for its lubricating properties [6]. It exhibits high flash and better oxidative stability [7] but no information regarding the use of this oil for heat treatment (quenching). The melon seed (*Citrullus colocynthsis l.)* belong under the family of *Cucurbitaceae*, locally referred as egusi [8]. It is not regular in size, shape and 3.9 – 4.9g in weight. It's a major soup ingredient, soup thickener in most West Africa countries [9]. Melon oil has been experimentally proven to show high heat transfer coefficient, it was confirm suitable for the use as cutting fluid coolant since it shows good cooling ability and high rate of heat extraction [10]. Africa locust bean belong to the family of *Mimosaceae,* it is locally known as ''dawa-dawa'' in Hausa language, ''Ogiri'' in Igbo language and ''Iru'' in Yoruba language in Nigeria. African locust bean are majorly used in Nigeria and West Africa rural resident for the treatment of different diseases [11]. The ability to produce a desired amount of it is widely applaud by the Hausa in the northern part of the country Nigeria for the treatment diseases like malaria, diabetes mellitus and pains [12]. It has not been maximally utilized for commercial production in spite of its richness in oil though similar oil content with that of soybean (about 18-20%) used for commercial production [13]. No record of Africa locust bean oil been used in heat treatment (quenching). The study is aimed investigating the suitability of the oils (melon oil, Africa locust bean and Africa elemi) as substitute for quenching medium carbon steel.

2. Materials and Methods

2.1 Materials

A 0.34%C medium carbon steel was used in this study. The edible vegetable oils (melon oil, Africa locust bean and Africa elemi seed oil) are majorly oils, obtainable in the country.

2.2 Methods

2.2.1 Sample Preparation
Melon seeds and Africa elemi seeds were purchased in a local market of Bukuru, Jos-south local government of Plateau state. Africa locust bean seeds were harvested within the premises of Scientific Equipment Development Institute, Minna (Kadna), Niger state. The seeds (melon) oil were locally produced by sun drying the seeds for 8-10 days, it was then fried under an intense heat for 15 minutes and was grinded. Half a litre of hot water was poured into the grinded powdered seeds and was stirred until oils float on the top of the grinded product. These oils were removed locally with the use of a bowl. Samples of Africa elemi were washed and sundried for the purpose of removing dirt and afterwards transferred into a bowl. Warm water of about 60°C – 70 °C was poured into it and covered with the lid which was allowed to stay for 10-15 minutes. Thereafter, the seeds were removed from the water and dehusked, separating the hard seeds from the mesocarp (soft fleshy part). Samples of Africa locust bean were boiled for 10 hours for easy removal of the testa. At the end of dehusking, the cotyledon was made to sun dried for three days. The dried samples were grounded into a powdered form. A litre of water was pour and was stired thoroughly to remove the oil.

2.2.2 Oil Extraction
The oil samples were poured in to an extraction chamber of soxhlet extractor. At the end of extraction, the hexane-liquid was then transferred into a round bottom flask and fixed to a rotary evaporator which was then used in separating the mixtures. The final oils was then stored for further investigation.

2.2.3 Cooling Rate Experimental Detail
The cylindrical probe of 0.34 %C steels of 12.5mm diameter x 60mm long fitted with a type K thermocouple. The thermocouple was inserted in a hole of diameter 3mm diameter drilled from the top surface of the probe and care was observed to ensure a rigid condition. Five standard tensile test steel specimens of 5mm diameter by 20mm long, also five standards impart test steel specimens of 10mm square by 55mm long were machined from the same steel rod. All the test specimens were heated in a muffle electric furnace at 25 ºC/sec of heating rate to a temperature of 850°C±3 °C and allow to soak at that temperature for 15minutes. The heated specimens were manually and was speedily transferred (under 2 s) into 1000ml of the quenching media. The temperature-cooling time curve was established using SD card datalogger digital thermometer Model MTM-380SD.

2.2.4 Mechanical Properties

2.2.4.1 Hardness Test
Rockwell Hardness test of ‘C’ scale (HC) method was used to determine of the hardness of the steel specimens quenched. Hardness impressions were taken at five (5) different points on each quenched steel specimens by an indenter Rockwell hardness testing machine (Model: 6187.5B) under applied load of 187.5kg and remain for about 8 seconds with the use of ‘C’ scale (HC). Hardness values recorded at various points were automatically read from the digital counter and the average value was taken respectively.

2.2.4.2 Tensile Strength Test
The tensile strength was determined from the load-extension (stress-strain) curves. The tensile strength of the quenched steel specimens were carried out on a 20KN Hounsfield Tensiometer and connected to a data logger. Percentage elongation and reduction, ultimate tensile strength, yield strength was calculated based on the stress-strain curve, in accordance with ASTM standard tests [14].

2.2.4.3 Impact Test
The impact test was carried out on an Izod impact testing machine to measure the toughness of the quenched specimens. The notched (45°) specimen is broken under impact loading in an impact test. The maximum capacity of the Izod impact machine used is 120FT. An average impact test of five steel specimens was calculated [15].

3. Results

3.0.1 Steel Composition
The chemical composition of steel used in the study is summarised in Table 1.

Table 1. *Chemical composition (wt %) steel use*

Elements %	C	Mn	Ni	Cr	V	Si	P	Fe
Composition	0.34	0.72	0.01	0.01	0.006	0.21	0.004	98.66

The steels composition meet the minimum carbon content required for it to be materially affected by heat treatment, since it has 34% carbon which is higher than 25 % [16].

3.0.2 Cooling Curve Analysis
Quenching abilities for the oils was experimented and recorded with the cooling curve in accordance to ASTM D6200 conducted at an un-agitated state. Figure 1 shows the cooling curve values obtained after quenching in the selected vegetable oils.

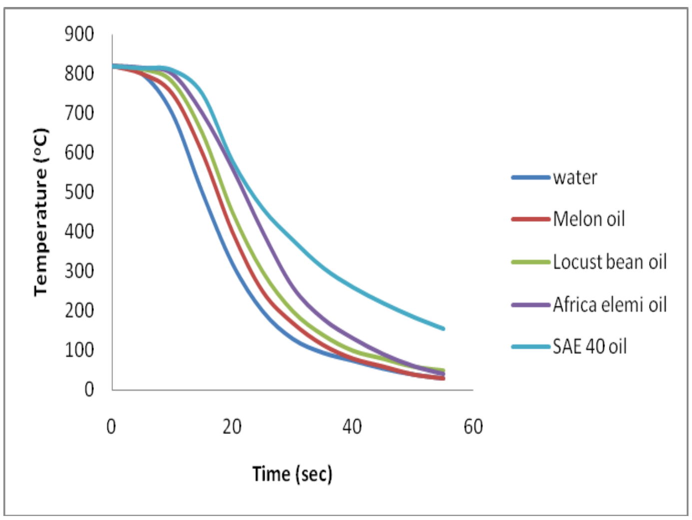

Figure 1: *Cooling curve for various quenching media*

Figure 1 shows the cooling gradients of the oils. It indicates various important cooling stages in quenching which are film boiling, bubble boiling and convection phase for all the oils used. The film-boiling phase existed at a short time of 8 seconds in all the quenchants with the exception of SAE 40 oil. The curve shows that the oils do not show same film-bubble boiling behaviour as possess by SAE 40 oil.

3.0.3 Cooling Rate Analysis

Figure 2 indicate the cooling rates curves of the quenchants used. They were obtained from the gradients of figure 1 above.

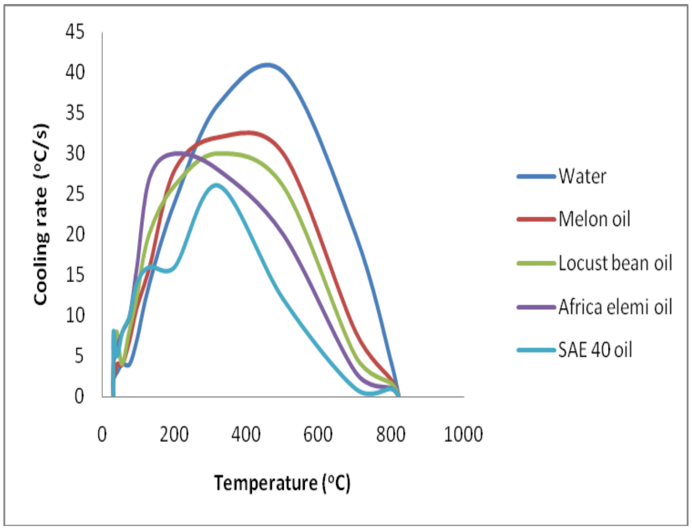

Figure 2: *Cooling rate of the quenching media*

Cooling rates of the quenching media were significantly different from each other, and it's in two major parts namely peak cooling rate and minimum cooling rate. Maximum cooling rate take place at the nucleate cooling part (Figure 2). In the selected oils, water and melon oil the maximum cooling rate were 40 and 32 $^oC/s$ with corresponding temperature of 410 and 390 ^oC respectively, while Africa elemi and Africa locust bean oil had same peak cooling rate of 30 $^oC/s$ at different corresponding temperature of 200 and 320 ^oC respectively. Minimum rate of cooling for water, melon, Africa locust bean, Africa elemi oil and SAE 40 oil is 2, 2, 4, 8 $^oC/s$ at corresponding temperature of 30, 50, 65, 75 and 90^oC. The period of occurrence of the peak cooling rate for melon, Africa locust bean and Africa elemi oil was 20, 25 and 35 seconds respectively from the start of quenching, while water and SAE 40 oil was 15 and 35 seconds. The cooling rate is higher in melon oil than other oils used. A higher cooling rate is found with the use of water quenchnats than all quenching media used. Cooling rates were found to be in this order:

Water > melon oil > Africa locust bean oil > Africa elemi oil > SAE 40 oil.

The cooling rate curve for melon, Africa locust bean and Africa elemi oil is similar to that obtained for water. The short blanket/vapour stage and higher cooling temperature of melon and false walnut oil affirmed that the oils as suitable base oil for martempering. The sudden drop in the cooling rate of SAE 40 oil can be associated to the instability of the quenching medium, which finally resulted in clogging building up around the quenched specimen and acting as temporal insulated layer, thereby reducing the heat transfer [17]. Table 2 show the summary of critical cooling parameters of the quenching media. The critical cooling parameters listed below are obtained from the cooling curve and the cooling rate curve in figure 2, as illustrated by kobasko [18].

Table 2. *Critical cooling parameter*

	Vegetable oil			Fast	Slow
Cooling Parameter	Melon oil	Africa Locust bean oil	Africa elemi oil	Water	SAE 40 oil
t A-B (s)	10	11	14	8	16
T A-B (^oC)	400	520	550	350	800
CR_{max}	32	30	30	40	26
T_{CRmax}	390	320	280	410	320
$CR_{700(^oC/s)}$	8	5	3	20	28
$CR_{300(^oC/s)}$	30	25	28	35	14
$CR_{200(^oC/s)}$	18	17	18	24	7
$t_{300^oC(s)}$	26	28	31	19	35

The cooling curves in Figure 2 and Table 2; Africa elemi oil and SAE 40 oil show longer film boiling to nucleate transition time of 14 and 16sec of corresponding temperature of 550 and 800 ^oC. Melon and Africa locust bean oils exhibits a shorter film boiling to nucleate transition time of 10 and 11 sec respectively at temperature of 400 and 520 ^oC. Water exhibit shorter film boiling to nucleate transition time than the quenching media used. The cooling profile suggests that the vegetable oils required no cooling rate accelerator. The rate of cooling, were much slower, most of all in the critical temperature martensite range (300 ^oC) compared to water evaluated which suggest that they are desirable for quench hardening of carbon steels [3]. However, the oils under study do not exhibit the same film - bubble boiling behaviour during quenching as indicated (figure 2). This is because of differences in high smoke points exhibited by the oils under atmospheric conditions. The steel temperature decreases below smoking point and cooling is predominately by convection. The results obtained in this work are consistent with the relatively fast cooling process reported for vegetable oils [3]. Cooling parameter IV (cooling rate at 700 ^oC) was obtained with the knowledge that its much desirable for maximising the rate of cooling while at same time minimise the temperature at positions of cooling to impede pearlite existence. Cooling rate at 200 and time at 200 ^oC were also obtain as much that it's related to susceptibility to steel cracking or distortion. It's recommendable to minimise the rate of cooling at this particular region to bring to its barest minimum its effect.

3.0.4 Heat Transfer Coefficient

The lump heat capacitance method was adopted to determine the time-heat transfer between the fluid and the body (heat transfer coefficient) with data obtained from the cooling curve. A considerable high heat transfer coefficient of 1463, 1023 and 1526 W/m^2K were obtained for melon oil, Africa locust bean oil and water while, Africa elemi oil and SAE 40 oil have heat transfer coefficient of 982 and 469 W/m^2K respectively. The apex in heat transfer coefficient of all quenching media used was much higher when compared to conventional mineral oil (SAE 40 oil) with heat transfer coefficient of 469 W/m^2k. The heat transfer coefficient in the oils used was found to be greatly influence on the viscosity of quench media. Higher heat transfer coefficient was found with melon and Africa locust bean oil having a lower viscosity oil of 161.302 cSt and 164.23 cSt respectively while Africa elemi oil exhibits a higher viscosity of 178.313 cSt with lower heat transfer coefficient.

3.0.5 Severity of Quench Media

Grossman H-factor method was determined to ascertain the quench severity of various quenching media used in this study (evaluates the rate of cooling of quenchants); it was calculated based on the experimental values obtained. Table 3 shows the summary of Grossman H-factor of the quenching media; SAE 40 and Africa elemi oil and Africa locust bean oil has a lower quench severity of 0.645, 2.462 and 2.623 m^{-1} respectively when compared to melon oil and water with higher quench severity of 3.568 and 3.982 m^{-1}

Table 3. *Heat Transfer Coefficient, Quench severity of quenchants*

Quenchants	Heat transfer coefficient (W/m^2K)	Quench severity (m^{-1})
Melon oil	1463	3.568
Africa elemi oil	982	2.462
Africa locust bean oil	1023	2.623
SAE 40 oil	469	0.645
Water	1526	3.982

From Table 3 above, quench severity of the quenching media are directly proportional to the heat transfer coefficient, the higher the heat transfer coefficient the higher the quench severity. The quench severity follows this order of decrease:

Water $\geq$ Melon oil >Africa locust bean oil $\geq$ Africa elemi oil > SAE 40 oil

The summary of mechanical properties of carbon steel quenched in various oils is represented in Table 4 below.

Table 4. *Mechanical properties of quenched steel*

Mechanical Tests	Hardness (HC)	Tensile Test (Mpa)	Yeild Strength (Mpa)	Impact (J)	Percentage Elongation (%)	Percentage Reduction (%)
Melon oil	49.43	309	189	19.66	30.0	24.2
Africa elemi oil	46.29	461	309	22.15	22.5	21.2
Africa locust b. oil	48.93	492	363	29.15	33.3	23.6
SAE 40 oil	38.69	568	295	31.86	29.9	19.8
Water	51.69	455	249	6.78	41.1	16.9
As-Received	14.23	164	102	102.5	20.2	13.6

Carbon steel quenched in melon oil, Africa locust bean and Africa elemi oil show higher hardness values (49.43, 48.93 and 46.29HC) to that of mineral oil while steel quenched in water show higher hardness value (51.69HC) to all quecnhants used. This indicate that the oils can be used where cooling severity greater than mineral-based oil is required for hardening of medium carbon steel. Table 4, the tensile strength of melon seed oil and Africa elemi oil quenched steel samples increases slightly in the heat treatment while Africa locust bean and water quenched showed significant increase. However, the tensile strength of melon, Africa locust bean and Africa elemi oil quenched samples was higher than those quenched in SAE 40 oil. The as-received steel specimen produced the highest impact energy (102.5J), this was followed by SAE 40 oil of 31.86J, while water quenched specimens produced that least impact energy of 5.0J. For all the quenched specimens, there were tremendous decrease in the toughness in steel specimens, this indicates that though hardened material with higher hardness value, but at the expense of its toughness, hence where toughness is a major concern, the material should be oil tempered [19]. SAE 40 oil quenched specimen exhibited superior mechanical properties in relation to Izod/Impact. The elongation percentage of the steel specimen increases considerably with all oils in use but decreases with steel specimen quenched in water. However, the elongation tends to improve for the oils quenching compared with water quenching, as faster cooling rate has been reported to have a negative effect on elongation [20]. The as-received steel specimen exhibited ductile behaviour; the specimens quenched in various oils exhibited a brittle behaviour as indicated by the low value of percentage reduction in the course of strain measurement. It can be established that the oils can be used as a quenching medium for medium carbon steel since the mechanical properties of the specimen quenched with these quenchants shows significant improvement when compared with those of the as-received specimen.

Conclusions

The following conclusion can be drawn from the study;

(1) It can be established that melon, Africa locust bean and Africa elemi oil can be use as a quenching media for medium carbon steel, since the oils compete favourably with water and show better cooling, heat transfer and mechanical properties than mineral based-oil.
(2) The quench severity of the various quenchants used is greatly influenced by the viscosity of the oils. It increases with decrease in viscosity.
(3) Quench severity increases with increases in heat transfer coefficient. This implies that the oils exhibits better cooling ability, therefore can extract heat from the probe surface faster and more efficiently.
(4) On the bases on the heat parameters, melon oil and Africa locust bean oil may be used as high speed quenching oil while Africa elemi oil and SAE 40 oil can be used as low speed quenching media.

Acknowledgments
My profound gratitude goes to management of Scientific Equipment Development Institute, especially the Managing Director Dr. N. Ndalima for his support, encouragement and providing enabling environment in carrying out these researches. We are indeed grateful.

References
[1]. Agboola, J. B., Oladiran, A. K., Edeki, M., Adeyemi, M. B., and Afolabi, S.A.(2015). Performance Assessment of Selected Nigerian Vegetable Oils as Quenching Media during Heat Treatment of Medium Carbon Steel. Journal of Minerals and Materials Characterisation and Engineering, 3, 85-93.

[2]. Eshraghi, K. M., Soltani, M. A., Amini, K., Mirjalili, H. R., Rezaei, R., Haghir, T., and Zamani, M. R. (2009). Application of Polymeric Quenchants in Heat Treatment of Steels. International Journal of ISSI, Vol. 6, No. 1.pp. 34 - 38

[3]. Esther, C. S., Luiz, F .O. F., George, E. T., and Lauralice, C .F. C. (2013). Quenching and Heat Transfer Properties of Aged and Unaged Vegetable Oils. Journal of Petroleum Science Research (JPSR) Volume 2 Issue 1.

[4]. Olawale, A. S. (2012). Solid-liquid extraction of oils of African elemi's (Canarium schweinfurthii's) fruit. Agric Eng Int: CIGR Journal Vol. 14, No. 2.

[5]. Ajiwe, V. I. E., Okereke, C.A., Ogbuagu, J. O, Ojukwu, U., and Onwukema, V. I. (1998). Characterisation and applications of oils extracted from Canarium schweinfurthii, Vitex doniana and Xylopia aethiopica fruit/seeds. Bioresources Technology, 64 (3): 249-252.

[6]. Gaminana., and Jimoh, O. (2011). Evaluation of Neem (Azadirachta Indica), Tiger Nut (Cyperus Esculentus) and False Walnut (Canarium Schweinfurthii) Oils As Metal Working Lubricants. MEngr Thesis, Department of Metallurgical and Materials Engineering, Faculty of Engineering Ahmadu Bello University, Zaria

[7]. Nehemiah, S. M., and Agnes, A. A. (2014). Production of activated carbon from Atili seed shells. Leonardo Electronic Journal of Practices and Technologies, ISSN 1583- 1078, pg 195-209

[8]. Solomon, G., Luqman, C. A., and Nor, M. A. (2010). Article on Investigating "Egusi" (Citrullus Colocynthis L.) Seed Oil as Potential Biodiesel Feedstock. energies, ISSN 1996-1073, 3, 607–618; doi:10.3390/en3040607

[9]. Fokou, B., Achu, M. B., and Chaungues, T. M. (2004). Preliminary nutritional evaluation of five species of egusi seeds in Cameroun. African Journal of Nutrition and Agricultural Development

[10]. Adekunle, A. K. A., and Mondiu, O. D. (2015). Performance Evaluation of Groundnut Oil and Melon Oil as Cutting Fluids in Machining Operation. Journal of Mechanical Engineering and Science.

[11]. Abbiw, D. K., 1990. Useful Plants of Ghana. Intermediate Technology Publications and the Royal Botanic Gardens, Kew. UK, pp: 337

[12]. C.I. Ezekwe, Anaya Chinenye Ada and P.C. Ugwu Okechukwu (2013). Effects of Methanol Extract of Parkia biglobosa Stem Bark on the Liver and Kidney Functions of Albino Rats. Global Journal of Biotechnology & Biochemistry. 8(2):40-50,DOI: 10.5829/idosi.gjbb.2013.8.2.1108

[13]. Rahman Akinoso and Akeem Olayemi Raji (2011). Optimization of oil extraction from locust bean using response surface methodology. Eur. J. Lipid Sci. Technol. 113, 245–252

[14]. ASTM E8. 2008, Standard Test Method for Tension Testing of Metallic Materials, American Society of Testing and Materials.

[15]. ASTM E23. 2008, Standard Test Method for Izod Bar Impact Testing of Metallic Materials, American Society of Testing and Materials.

[16]. Durowoju, M. O., Adebiyi, K. A., and Adekunle, A. S. (2013). Quench Severity of Bioquenchants on Medium Carbon Steel for Industrial Heat Treatment. ANNALS of Faculty Engineering Hunedoara, International Journal of Engineering. ISSN 1584-2673

[17]. Adeyemi, M. B., and Adedayo, S. M. (2009) Vegetable Oils as Quenchants for Hardening Medium Carbon Steel. Journal of Applied Science and Technology. Vol 14, pp. 1-2, 74-78.

[18]. Kobasko, N. I., Ester, C. S., Lauralice, C., Franceschini, C., and George, E. T. (2010). Vegetable Oil Quenchants: Calculation and Comparison of the Cooling Properties of a Series of Vegetable Oils. Journal of Mechanical Engineering-slovenia, 56, 131-142.

[19]. Hasan MF (2016). Analysis of Mechanical Behavior and Microstructural Characteristics Change of ASTM A-36 Steel Applying Various Heat Treatments. Journal of Material Sciences & Engineering 5:2.Retrieved from: http://dx.doi.org/10.4172/2169-0022.1000227

[20]. Odusote, J. K, Ajiboye, T. K., and Rabiu, A. B. (2012). Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil. Journal of Minerals and Materials Characterization & Engineering.11,859-862. Retrieved from: http://www.scriRP.org/journal/jmmce