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COMPARATIVE REVIEW OF HEAT TREATMENT QUENCHANTS IN MANUFACTURING PROCESS

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ABSTRACT
Water usually causes distortion corrosion and cracking of component due to its high quenching severity, SAE oil on the other hand has low quenching severity, has high cost, its non biodegradable and excessive fume generation during the quenching operations. The focus of this work is to review from past literature the suitability of edible and non edible vegetable oils abundantly available in Nigeria as effective alternatives to the conventional media, water and SAE oil. Particular emphasis will be on the traditional selection and use of different vegetable and animal oils for steel hardening applications and the cooling time-temperature behavior of these fluids to characterize their quenching performance Harnessing Vegetable oil quenchants will give rise to investments and employments in the cultivation and processing of these edible and non edible seed oils thereby lending support towards achieving sustainable development through environmental protection.

Keywords: *Vegetable oil, quenchants, biodegradable, hardenability, austenite, SAE oil.*

INTRODUCTION
Heat treatment combines heating and cooling of metals and alloys to obtain desired properties. The processes of heat treatment includes Annealing, normalizing, hardening and tempering which are the most important heat treatments, They are often used to change the microstructure and mechanical

properties of engineering materials especially steels. Annealing is a method of heat treatment frequently applied in order to soften steel materials; it is used where elongations and appreciable level of tensile strength are required in engineering materials [Kempester,1984 and Raymond,1985]. In normalizing, the material is heated to the austenitic temperature range and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlite matrix, which results into strength and hardness higher than in as received condition. It can also used to remove undesirable free carbide present in the as-received sample [Fernandes,2008]. Steels are usually hardened and tempered to improve their mechanical properties, particularly their strength and wear resistance. In hardening, the steel or its alloy is heated to a temperature high enough to promote the formation of austenite, held at that temperature until the desired amount of carbon has been dissolved and then quench in oil or water at a suitable rate. Also, in the harden condition, the steel should have 100% martensite to attain maximum yield strength, but it is very brittle too and thus, as quenched steels are used for very few engineering applications. When tempering, the properties of quenched steel could be modified to decrease hardness and increase ductility and impact strength gradually.

Hardening is a heat treatment process carried to increase hardness of steel by heating it above critical point and then allowing it to cool down by immersing in a quenching medium such as water or oil. By quenching in appropriate medium the mechanical properties of steel can be improved[Sreeja,2016] To achieve proper strength and toughness, it is necessary to convert Austenite to Martensite, which is then tempered to form the proper tempered Martensite microstructure. To achieve this conversion of Austenite to Martensite, a rapid quench rate is required. This quench rate must be fast enough to avoid the formation of upper transformation products like Bainite and Pearlite, and convert all Austenite to Martensite. In practice, when a steel component is quenched, the surface cools much more rapidly than the center. This means that the surface could cool at the critical cooling rate and be fully hardened, but the center cools more slowly and forms a soft Pearlitic or Bainitic microstructure[Scot, 2012]

The commonly used quenching media are water, SAE oil, brine, and synthetic solutions. Water though abundant and low cost has the drawback of inducing crack or dimensional changes on the quenched component due to its high cooling rate and oil has the problem of not inducing enough hardness. Water quenching is a rapid cooling, where water as a quenching medium extracts heat much faster. While oil as a medium will extract heat much slower, hence rate of cooling will be slower than water. Each of these have advantages and disadvantages. Water cooling typically will give you higher hardness but more stressed component. Oil cooling will generate lesser stress and moderate hardness.

Polymer quenchants though can provide severity between those of water and oil but has the problem of varying concentration during the quenching process and it is also more expensive. Brine produces more quenching severity than water; but it also has a problem of corrosive attack on the components and the equipment used for the quenching operation. Therefore a need for the development of a quenching medium with good economics like water, environmentally friendly and having less severity of quench and yet producing appreciable hardening characteristics. Hence this research has studied the suitability of using various non-edible seed oils as alternative quenching media for hardening process in low and medium steels, with and without agitation effects. Quenching oil and heat treatment fluids are designed for rapid or controlled cooling of steel or other metals as part of a hardening, tempering or other heat-treating process. Quenching oil serves two primary functions. It facilitates hardening of steel by controlling heat transfer during quenching, and it enhances wetting of steel during quenching to minimize the formation of undesirable thermal and transformational gradients which may lead to increased distortion and cracking.

This review is conducted to study from past literatures the possibility or replacing SAE engine oil and Tap water with Biodegradable quenchants such as palm oil shear butter cotton seed oil, palm kernel oil, neem seed oil and groundnut oils. Vegetable oils are natural products of plant origin consisting of ester mixtures derived from glycerol with chains of fatty acid containing about 14 to 20 carbon atoms with different degree of unsaturation (Souza, E.C et.al,2009) . Physicochemical properties of triglyceride and its applications depend upon fatty acid constituents in their molecule. However, the differences are due primarily to chain length, degree and position of unsaturation. No oil has any fixed combination of the different fatty acids present in it, but the proportions of these will vary with locality, soil, season, and other factors. This accounts for differences between the same species of oil from different places, or harvested at different times. It is also the reason why different vegetable oils exhibit different inherent properties or why one vegetable oil may be favoured for an application, such as quenching relative to another.(Totten, G.E,et.al 1993)

METHODOLOY

The implored in this research is the study of existing literature on related work from text books, journal and Post graduate thesis from recognized Universities. The following studies were carried out;

QUENCHANTS

Quenchants are a series of nonflammable, aqueous solutions containing special polymers and corrosion inhibitors for quenching ferrous and nonferrous metals. They can replace water, oil, or brine solutions and are the preferred quenching media for both low- and high-hardenability, plain carbon, and alloy steels.

BIODEGRADABLE QUENCHANTS

Biodegradability of any component is the ability to decay by microorganism [Mang,1993].A quenchant is classified as biodegradable if its percentage of degradation in a standard test exceeds a certain marked level. Vegetable oils exhibit better biodegradability than mineral oils and others.

EDIBLE AND NON-EDIBLE VEGITABLE OIL

Edible vegetable oil

(a) Rapseed oil **–** This is a family member of Brassica including mustard, rutabagas, kale. They seeds have oil content over 40%. In which oleic acid, linoleic acid are dominant fatty acid [Sauer,1983].

(b) Soybean oil **- —**Soybean has oil content in soybean seed ranges from 15% to 22% depending on environmental conditions during seeds maturity. The major fatty acids are oleic and linoleic [wikipedia.org,2014].

(c) Palm oil -Palm first received its botanical name from Jacquinin1763 as Elaeis guineensis . Palm oil is more saturated than soybean oil and rapeseed oil as its major fatty acids include palmitic, stearic, oleic, and linoleic acid [Corley,2003].

Non edible vegetable oils

(a) Castor oil **–** It's scientific name is Ricinus Communis L. It is non edible oil which is obtained from castor bean but technically is not a member of bean. Castor oil is a color less to very pale yellow liquid with mild or no odor or taste. Its boiling point is 313 °C and its density is 961 kg/m3. It is a triglyceride in which approximately 90 percent of fatty acid chains are ricinoleic acid [wikipedia.org 2014]

(b) Karanja oil - A thick yellow orange to brown oil is extracted from seed and scientific name is Millettia Pinnata. Its boiling point is 316 ºC and density is 924 Kg/m3.Oleic

acid is main fatty acid composition of karanja oil and it is about 52%. Linoleic Acid and palmitic acid present in karanja oil is 17% and 11% respectively [N.Panigrahi,2012].

(c) Jatropha Curcas L - Non edible Jatropha curcas is a succulent shrub from the Euphorbiaceae family. Jatropha is a perennial tree, which has a life span of 40-50 years and can bear fruits for 25 years [wikipedia.org 2014]

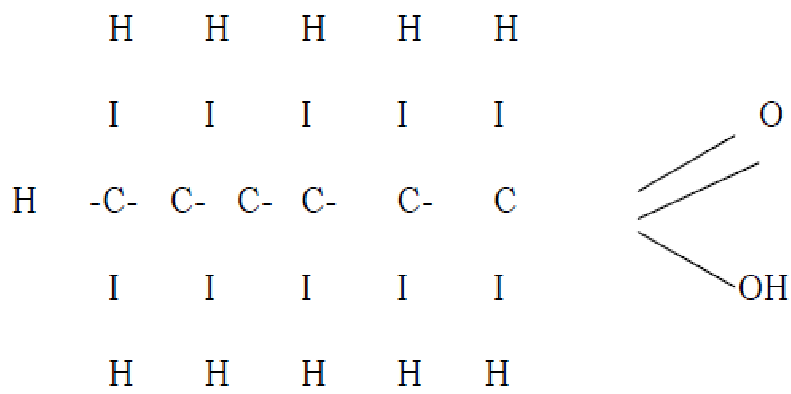
(d) Moringa oil **-** The characteristics of moringa seed oil can be highly desirable especially with the current trend of replacing polyunsaturated vegetable oils with those containing high amounts of monounsaturated acids. Moringa oil has 74% oleic acid content and thus possesses improved oxidation stability over many other natural oils [Brajendra 2009].

(e) Mahua oil - Mahua seed contain 30-40 percent fatty oil called mahua oil. It is a slightly greenish yellow and derived from a tropical tree belonging to the family Sapotoceae. It has density of 945 kg/m3 and fire point is 250ºC.[Padhi,2010].

Structure and Rheological properties of vegetable oils

Vegetable oils are mainly triglycerides, which are glycerol molecules with three long chain fatty acids attached at hydroxyl group ester linkage [Fox,2007].

They are composed fundamentally of the elements carbon, hydrogen and oxygen. The fatty acids can be saturated or unsaturated. Unsaturated fatty acids have carbon-to-carbon double bonds. In saturated fatty acids all the carbon atoms are linked to two hydrogen atoms and there are not double bonds. The general formula of fatty oils is written as CnH2N-1COOH (Kirschenbauer, 1984)



Fatty oil (Unsaturated Molecules). Source: Kirshenbauer, 1984

REVIEW OF RELATED LITERATURES

(J. B. Agboola *et al*,2015) Conducted an experiment investigating six quenching media comprising of palm kernel oil, cotton seed oil, neem seed oil, palm oil, SAE40 engine oil and tap water were studied. The SAE40 engine oil and tap water served as control used for comparison in his study. His method involves Determination of Physicochemical Properties of the Oils and Mechanical Properties Determination.

The Table below is an extract from an experimental results by (J. B. Agboola *et al*,2015)

Quenched sample	Main structure	Average hardness (HRC)	Tensile strength (N/mm^2)	Percentage elongation (%)	Percentage reduction in area (%)	Izod impact value (J/m)
Palm kernel oil quenched	Predominantly martensite	40.85	300	0.1	3.5	10.0
Cotton seed oil quenched	Martensite and lower bainite	33.25	350	0.4	2.5	10.5
Neem seed oil quenched	Martensite and lower bainite	12.5	550	0.4	3.5	15
Palm oil quenched	Martensite and upper bainite	13.8	480	0.3	3	14
Water quenched quenched	Predominantly martensite	47.45	250	0.2	2	3.0
SAE40 engine oil quenched	Mixture of martensite and lower bainite	20.75	450	0.2	5	12.0
As-received	Pearlite and Ferrite	10.2	565	8.0	15	30.0

In his findings he concluded that palm kernel and cotton seed exhibited substantially fast cooling during the quenching period as reflected by their hardness values obtained which suggest that they would be suitable as alternative to petroleum based SAE40 engine oil for quenching low hardenability steels such as medium carbon steels without cracking or distortion. The most suitable among them according to (J. B. Agboola *et al*,2015) being palm kernel oil based on mechanical properties of its quenched steel sample as compared to others. He explained that based on the heat flow parameters, palm kernel oil can be used as fast quench medium while cotton seed oil and neem seed oil may be used as slow quench oil. And among the oils tested, palm oil exhibited the least quenching ability.

(S.A Salihu 2008) Conducted a research on an alternative quenchant to molten salt bath. Molten salt bath is used as a quenching media during austempering of steel and cast iron. (S.A Salihu 2008) explained that (ASM, 1991) and Higgins, 1998) highlighted that molten salt and lead have been the most popular quenchants used for austempering process. However, their substantial deficiencies with respect to environmental friendliness, high cost, non-availability and toxicity justify the search for alternative replacement media. (S.A Salihu 2008) research is to assess the potentials of using local vegetable oils (cottonseed, groundnut and shear butter oils) as quenchants for austempering heat treatment of steels and cast irons.

The result of(S.A Salihu 2008) research shows that, Hot shear butter and groundnut oils were able to cause formation of "bainite structure" at 250oC with medium carbon steel, ductile cast iron and low alloyed steel. , A complete bainite structure was obtained from austempered medium carbon steel in hot shear butter oil at 3hrs and 4hrs while at 4hrs, complete bainite structure was formed using groundnut oil as quenchant for ductile cast iron. The results of tensile strength, percent elongation, hardness and impact tests shows that the use of shear butter and groundnut oils as austempering quenching bath gave increase in tensile strength, ductility and impact toughness while the hardness values decreased marginally in the case of medium carbon steel and ductile cast iron. And The low impact and percentage elongation values obtained for austempered low alloyed steel and grey cast iron samples was due to the formation of martensite and retained austenite structure.

(J. B. Agboola *et al*,2015) Investigated Performance and assessment of vegetable oil and mineral oil blends during heat treatment of medium carbon steel.according to him Cooling effect of palm kernel oil and mineral oil (SAE 40) with their blends as quenching media for heat treatment of medium carbon steel was investigated. Palm kernel oil was blended with SAE 40 in the ratio of

1 : 3, 1 : 1 and 3 : 1. Medium carbon steel probe of diameter 12.5 mm and 60 mm height was used to determine the cooling intensities of the oils and their blends. Mechanical properties and microstructure of the quenched steel samples were determined. Quench severity of pure palm kernel oil was found to be greater than that of SAE 40. The blend consisting of 75% palm kernel oil and 25% mineral oil showed higher cooling power as compared to other blends. Samples quenched in 100% palm kernel oil showed higher hardness values than the blends whereas samples quenched in 100% mineral oil (SAE 40) showed the least hardness value.

Peter Fernandes, and K. Narayan Prabhu conducted experiment to study the suitability of vegetable oils as bio quenchants for industrial heat treatment. The study involved the assessment of the severity of quenching and wetting behaviour of conventional and vegetable oil quench media. Quench severities of sunflower, coconut and palm oils were found to be greater than mineral oil. Among vegetable oils, highest heat transfer coefficients were obtained for sunflower oil and lowest heat transfer coefficients were obtained for castor oil. The results show that the thermal stability of palm oil is better than mineral oil. Palm oil is thus safer compared to mineral oil and its thermal stability is superior to mineral oil. Thus palm oil could be exploited as an effective bio quenchant for industrial heat treatment.[Peter F. (2008,]

Parodi et al.2004) have patented vegetable oil-based quenchant formulations based on rapeseed, hazelnut, sunflower, and soybean oils and the preferred quenchant temperature was 60^0C [1]These fluids contained additives such as octyl-butyl diphenyl amine, long-chain sulphonic acid salts, phenolic derivatives and benzotriazole derivatives including N,N-bis (2-ethylhexyl)-4-methyl-1H-benzotriazole-1-methyla- mine and N,N-bis-(2ethylhexyl)-5-methyl-1H-benzotriazole-1-methylamine. The advantages of these quenchant fluids include low environmental impact, high biodegradability, and “practically no toxicity.”[Peter, 2008]

Furthermore, these quenchants were reported not to form undesirable deposits or staining of the metal components being quenched and no additional parts-washing was required after quenching.

Honary did describe the generally excellent quenching properties of soybean oil; however, it was known that relatively poor oxidative stability should be expected [L.A.T. Honary, 2015]. Oxidative stability performance improvements of vegetable oils can be achieved by chemical or genetic modifications or by process improvements such as winterization and partial hydrogenation. Winterization (fractionation) may be performed to remove crystallized fats and improve the pour point of the base oil. The performance objective is to reduce the linolenic and linoleic ester content of the vegetable oil to increase the oxidative stability, making the resulting vegetable oil more suitable for use in industrial applications.

(Ashwini K Patil 2015) performed an experiment on heat treatment of steels using Castor oil is the quenching medium containing metal salts as quench accelerator (sodium nitrate and potassium nitrate). Medium carbon steels are heat treated using this quenching medium under various soaking temperatures. The heat treated specimens have been subjected to hardness, wear and impact tests to observe the influence of the quenching medium and accelerator on their mechanical properties. The results of these tests indicate that their values increase when quenched in castor oil having quench accelerator as compared to untreated condition. This establishes the fact that castor oil can be used effectively as a quenching medium with metal salts as quench accelerators. [B.Patil et al 2015]

Hassan et al conducted an experiment on the Hardening Characteristics of Plain Carbon Steel and Ductile Cast Iron Using Neem Oil as Quenchant, The experimental results shows that . Neem oil have a hardness value less than that of water but higher hardness value than that of SAE40 engine oil. Hence, Neem oil can be used where cooling severity less than water but greater than SAE 40 engine oil is required for hardening of plain carbon steel and ductile cast iron and that Neem oil can be used to improve the toughness of these samples since it has higher impact energy values than water which is the common quenching medium. [Hassan,et al 2011]

CONCLUSION

Extensive characterization of all the vegetable oils used has been carried out by various researchers and the correlation between physicochemical properties, fatty acid profile and their quenching characteristics were established. Viscosity Index (VI) of Palm kernel oil, neem seed oil, cotton seed oil and palm oil are higher than that of SAE40 which means that their viscosity is less sensitive to temperature variation than SAE40 engine oil. It is observed from reviewed literatures that vegetable oils perform well in manufacturing application such as heat treatment and are highly degradable, non toxic, good physical properties. The focus of this review is to study the effective alternative to conventional quenchants such as water and SAE oil. water due to its high heat removal has lead to set backs such as distortion/warping, crack formation and corrosion of component. SAE oil on the other hand though has quenching severity but is quite expensive to buy. Edible and Non-edible seed oils will create alternative usage for these edible plant there by opening up a huge investment and employment opportunities in their cultivation and processing. However, these oils are highly biodegradable which will support the federal government work towards achieving sustainable development through environmental protection.

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