



Wetting kinetics, kinematics and heat transfer characteristics of pongamia pinnata vegetable oil for industrial heat treatment

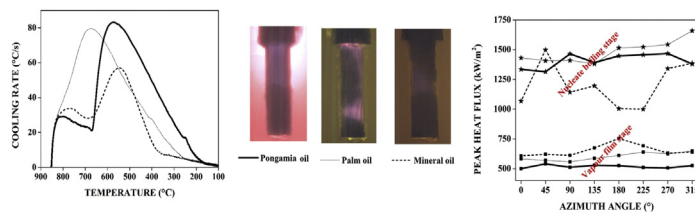
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HIGHLIGHTS

- Spreading kinetics was faster for pongamia oil than that for other quench oils.
- Pongamia oil showed vapour phase formation that was absent in other vegoils.
- Pongamia oil depicted uniform wetting front/cooling and higher hardening power.
- Pongamia oil was found to be more suitable for quench heat treatment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 2 September 2013

Accepted 8 January 2014

Available online 18 January 2014

Keywords:

Pongamia pinnata vegetable oil

Immersion quenching

Wetting

Cooling curve analyses

Spatially dependent heat flux transients

ABSTRACT

The suitability of pongamia pinnata vegetable oil as cooling medium for quench heat treatment was investigated. Wetting kinetics, kinematics and heat transfer characteristics of pongamia oil during immersion quenching of hot Inconel probe were determined and compared with palm and mineral oils. A comparison of the relaxation of contact angle indicated early attainment of equilibrium contact angle for pongamia oil droplet on Inconel substrate. The equilibrium contact angle value of pongamia oil was in between mineral and palm oils. However, the spreading kinetics was faster with pongamia oil. Pongamia oil showed the formation of a stable vapour film on the probe surface during quenching. This phenomenon was not observed in palm oil and other vegetable oils reported in literature. Pongamia pinnata oil exhibits uniform nature of wetting front, intermediate rewetting temperature and less variations in rewetting temperatures during quenching. The hardening power of pongamia oil was higher than palm and mineral oils and the cooling of the probe was more uniform during quenching in pongamia oil. The heat transfer characteristics of pongamia oil were found to be superior to palm and mineral oils after film/transition boiling. Pongamia oil showed lower heat transfer but more uniform cooling during film boiling.

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1. Introduction

Cooling conditions during quench heat treatment has a significant effect on final metallurgical and mechanical properties of components. In the case of steels, quenching process is done to

prevent ferrite or pearlite formation and to allow the formation of bainite or martensite. Upon quenching a hot metal in liquid fluid, cooling of metal occurs by three stages known as vapour blanket, nucleate boiling and convective cooling stages [1]. The important factors which influence the cooling condition during quench hardening depend on (i) workpiece characteristics (composition, mass, geometry, surface roughness and condition) (ii) quench characteristics (density, viscosity, specific heat, thermal conductivity, boiling temperature) (iii) quenching facility (bath temperature, agitation rate, flow direction) [2]. Redesigning of system or

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operational parameters for altering cooling conditions for quench heat treatment is difficult. Exchanging the suitable quench media is the better choice for heat treating engineers both from the technological and economical point of view [3]. Water, brine solution, polymer and mineral oil are some of the quench media used in heat treating industries. The Heat Treating Society of ASM International has proposed a research plan for three primary technology needs: (i) heat treating equipment and hardware materials (ii) processes and heat treated materials technology and (iii) energy and environment needs [4]. Among these, energy and the environment is one of the major areas.

Even though, water is naturally available inexpensive quenching medium and easily disposable without damage to the natural environment, it shows high cooling performance in all three stages of quenching. The high cooling severity of the water (Grossmann H factor $\approx 0.9\text{--}2.0 \text{ inch}^{-1}$) is restricted to quenching simple shapes and steels of comparatively low hardenability because of the occurrence of intolerable distortion, warpage and quenches cracks [5]. The most widely (about 85%) used quenching medium in heat treating industries is mineral oil. Mineral oil is a petroleum by-product, generally mixtures of chemical structures with a range of molecular weights. Generally the mineral oils are distilled from the C26 to C38 fraction of petroleum and composed of branched paraffins (C_nH_{2n+2}) and cycloparaffins (C_nH_{2n}) together with a small amount of aromatics (benzene ring and its derivatives). Within the individual molecule, there are some cycloparaffin rings, aromatic rings and the necessary paraffin and olefin side or connecting groups [6]. The cooling performance of the mineral oil is lower than the water and shows more uniform cooling and improved wetting characteristics. A variety of different quenching oils tend to show a prolonged vapour blanket stage, a short nucleate boiling stage with a much lower cooling rate, and finally a prolonged convective cooling stage with a very modest cooling rate. The slow cooling rate at the martensitic range results the distortion and cracking of component greatly reduced. A series of mineral oil quenchants under standard conditions show a wide variety of cooling rates [1,7]. However, oil quenching has a significant impact on the work environment. High risks involved due to fire hazard and production of fumes and vapours with use of mineral oil makes it harmful to the operating personnel and to the natural environment [5]. Repeated heating of mineral oil can cause the formation of polycyclic aromatic hydrocarbons (PAH) in the oil, resulting in a possible carcinogenic risk to workers either by inhalation of oil mist or by skin contact with oils [8]. The disposal of used mineral oils and their sludge are major problem in waste management and if it directly disposed to earth results water contamination and agricultural risks. Because of these several environmental liabilities, heat treating researchers are focused to development of alternative quenchant to mineral oil based quenchants. Use of aqueous polymer quenchants is increasing in heat treating industries for quenching of aluminium alloys and steels, as substitutes for both water and oil quenchants. The polymer quenchants are prepared by dissolving water soluble organic polymer in water by the solvation of polymer chains through hydrogen bonding interaction [1]. The properly prepared polymer quenchants have the advantages of easy handling, more stable and consistent cooling performance over a period of time. The polymer quenchants are non-flammable, non-toxic, harmless to the operating personnel, easily removed from parts after quenching and biodegradable. The cooling mechanism of polymer quenchant is different from water and mineral oil. Quenching of the component in polymer solution shows formation of polymer enriched film and pseudo-nucleate boiling process which results in uniform heat transfer and enhanced wetting during quenching [9]. By controlling the polymer concentration, temperature and agitation, wide range of cooling properties

of polymer quenchants are possible. However, continuous monitoring of the polymer quenchants is necessary because of its thermal degradation and contamination [1,10]. Vegetable oil quenchant is another environment friendly quenching media which are obtained from vegetable sources such as leaves, flowers, fruits or seeds of various plants by either mechanical processes (hot or cold pressing) or solvent extraction. The use of vegetable oils for hardening of steels is not new and heat treaters have used animal oils, vegetable oils and a mixture of both for quenching of steels in the early days [11]. The oxidation and hydrolytic stability of vegetable oils are poor and they are very expensive. Moreover, vegetable oils are available in narrow range of viscosities. Further, quenching of parts that were previously heated in salts or soaps of alkali metals in vegetable oils, precipitate to form sludge on quenched surfaces. Because of these disadvantages and the development of several inexpensive petroleum products, the use of vegetable oils almost entirely superseded [11,12]. With the present knowledge of science and engineering technology, the development of new processing techniques, anti-oxidants and equipment facility, the use of vegetable oil quenchants becomes popular which are biodegradable, environment friendly to replace the petroleum quenching oil. The cooling behaviour of vegetable oil is different from the conventional or accelerated quench oil. No stable film boiling phase is present on the surface of the sample for a significant time during quenching in vegetable oils. This is because of the vegetable oil does not boil under atmospheric conditions [13,14]. Totten et al. compared the performance of crude expelled and partially hydrogenated and winterized soybean oils with mineral oil. They concluded that vegetable oils have the potential to be used as quench media for industrial heat treating process and recommended for further research in this area [14]. Prabhu and co-workers investigated the wetting kinetics, interfacial heat transfer properties and quench severity of selected vegetable oils for heat treatment. The quench severity of sunflower, coconut and palm oils was higher compared to mineral oil. They observed that AISI 1040 steel specimens quenched in these vegetable oils consist a mixed microstructure of martensite and bainite, whereas ferrite and pearlite observed in the mineral oil quenched specimen and reported vegetable oils could be used as quench media for industrial heat treatment [15–17]. Some of the vegetable oils used for quenching purpose listed in literature are canola, soybean, rapeseed, sunflower, linseed, corn, cottonseed, gingelly, coconut, olive, palm, peanut, groundnut, castor, cashew nut shell, neem, crambe and tea seed. Most of them are edible oils and consumption of edible oil for industrial purpose may affect the food chain supply. Thus the development of non-edible vegetable oils for quench heat treatment is gaining importance.

An investigation was conducted in this study to assess the suitability of non-edible pongamia pinnata vegetable oil as cooling medium for quench heat treatment. The aim was to assess wetting kinetics, kinematics and hardening power of pongamia oil during immersion quenching of Inconel 600 probe and compare the results obtained with palm and conventional mineral oils.

2. Materials, methods and experiment description

Pongamia pinnata oil, palm oil and commercially available mineral oil were used as quench media. Pongamia pinnata oil was procured from Biofuel center, National Institute of Technology Karnataka, India. It was prepared from the seeds of pongamia plant using mechanical expeller. The oil collected from the mechanical expeller was filtered using muslin cloth and no further treatment was given to oil. The viscosities and thermal conductivities of the quenchants were measured using Brookfield LVDV-III U Rheometer and KD2 Pro thermal property analyser respectively. Flash and fire

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