MultiScience - XXX. microCAD International Multidisciplinary Scientific Conference
University of Miskolc, Hungary, 21-22 April 2016, ISBN 978-963-358-113-1

POSSIBILITY OF USE BIO OILS AS QUENCHANT

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INTRODUCTION

Quenching is one of the most effective way to improve the properties of different component made from ferrous alloy. In case of enhancement of strength, hardness, wear resistance by transformation hardening and also increasing of toughness by quenching and tempering on high temperature the most critical subprocess is probably the fast cooling from austenitizing temperature (quenching). When the cooling is realized by immersion the heat flux density is changing as the function of temperature difference between the hot surface and the liquid. [1]

Table 1.
Nomenclature

Unit symbol	Description (Dimension symbol)
T_k	the initial temperature of cooling liquid (°C)
CR_{max}	maximum cooling rate (°C/s)
$T(CR_{max})$	the temperature when cooling rate reach its maximum
T_{vp}	first transition temperature, (°C) transition temperature between vapour blanket and nucleate boiling stage
T_{cp}	second transition temperature, (°C) transition temperature between nucleate boiling and convective stage
HTC(T)	heat transfer coefficient, (W/m^2K)

The cooling rate does not depend on temperature linearly through characteristic of heat transfer process that cause additional stresses in workpiece. To minimize the thermal and structural stress and avoid the dissociation of austenite the quenchant should cool the specimen faster in the region of higher temperatures – typically in interval of the pearlitic transformation – and slower above M_s for decreasing the temperature gradient in the volume. In respect that the heat transfer occurs at the boundary layer, therefore the chemical and physical properties (such as chemical composition, thermo-physical properties, the surface quality of solid media, relative agitation rate, surface tension of liquid, viscosity, etc.) of cooling media at the opposite side of boundary has a significant effect on the heat transfer [2]. In other aspect if we knew the effect of parameters we could vary their behaviour in a given interval, we could extend their usability in certain cases and we could detect the start of quenchant‘s degradation. Besides the knowing of heat removal characteristics is basically important to do the right selection of quenchant.
Mineral oils are one of widely-used liquids to realize the rapid cooling in case of quenching of medium- and high-alloyed steels. The most important advantages of these are

DOI: 10.26649/musci.2016.082

- medium cooling rate, therefore the internal stress gets moderate thereby the risk of deformation or cracks gets low
- less corrosive media,
- the boiling takes place in a more or less wide interval of temperature and this can be changed by the composition.
- the operating temperature can be higher than M_s

But some disadvantages exist in point of applicability such as

- produce Leidenfrost-effect so the cooling rate can be really low at the start of quenching
- flame is generated above theirs flashpoint, and above fire point the oil starts burn continuously
- hazardous for environment and health
- not regeneratory

Vegetable oils – as all kind of oils and fats – are triglycerides with a distribution of saturated, monounsaturated and polyunsaturated fatty acids. These carboxylic acids contain typically a large amount of carbon atoms. In case of vegetable oils the main acids are

- palmitic acid, stearic acid (saturated ones) and
- oleic, linoleic, linolenic acids (monounsaturated and polyunsaturated ones).

Unfortunately the vegetable oils have a few of same disadvantages of mineral oils (flash point and fire point is low or lower than mineral oil), but probably the greatest one is the low resistance against oxidation. The presence of unsaturated fatty acids in molecular structure plays a significant role in the interaction of oil with oxygen.
The resistance against oxidization of raw vegetable oils is poorer than mineral oils. When the double bonds in unsaturated fatty acids are ruptured the molecule becomes active, and reacts with the oxygen. L.C.F. Canale et al. showed the relationship between the unsaturated fatty acid concentration and the changing of viscosity during oxidization. The viscosity of soy-bean oil in that the ratio of unsaturated acids is quite high increased more than twofold, the increasing in case of petroleum-based oil was only +2.1% [3]. But the reasons why these could be a potentially alternative quenching media instead of mineral ones are

- the Leidenfrost-effect is missing in case of many type of these,
- regeneratory, and
- eco-friendly.

Many of researcher investigated the cooling performance of vegetable oils and compared with mineral oils [4]. The results show than bio-oils can cool faster than miner ones, but the cooling behaviour is strongly depend on chemical composition. From the point of view of molecular composition and the saturated/unsaturated ratio of vegetable oils the climate where the raw material of oils grown has a great effect. Vegetable oils from tropical climates are typically highly saturated than from northern climates [5]. Therefore it is necessary to investigate the cooling performance of oils produced at our climate.

EXPERIMENTAL WORK

The primary goal of our experimental work was to obtain the cooling characteristic of vegetable oils as base of the further investigation of quenching capabilities. We focused on determination of these behaviours at higher temperature, between 100°C..200°C interval. We applied one of the well-known measuring methods to record the cooling curves and we did further analysis based on these T-t data pairs.
We used four kind of commercially available vegetable oils as quenchant: sunflower, soybean, corn and rice oils. In favour of comparing the obtained results with a mineral oil, we applied a high-temperature quenching oil (Petrofer Marquench 4500). The vegetable oil samples were heated up to 100, 120, 140, 160, 180, 200°C, the mineral oil to 160°C. (This temperature is in the recommended operating temperature range of this oil.)

Equipment

We determined the thermo-physical properties using a standardized (ISO9950:1995) measurement method based on register of cooling curves. The most important part of system is a specimen has the following properties and dimensions:

- Geometry: cylindrical, 12.5mm diameter, 400m height
- Material: Ni-based alloy (Inconell 600)
- Thermocouple: K-type, 30mm from the lower surface in the centreline

The main steps of measurement are: heating the specimen up to approximately 850°C then cooling it in a pre-conditioned quenchant. In this case the pre-condition means only heating the cooling liquid to the desired temperature (T_k). During cooling the data acquisition was occurred with 10Hz sample rate [6]. For advanced analysis we used SQintegra to obtain thermo-kinetic parameters (such as CR_{max}, T_{vp}, T_{cp}). We used the software's in-built inverse algorithm (see Figure 1) to determine the heat transfer coefficient function (HTC(T)).

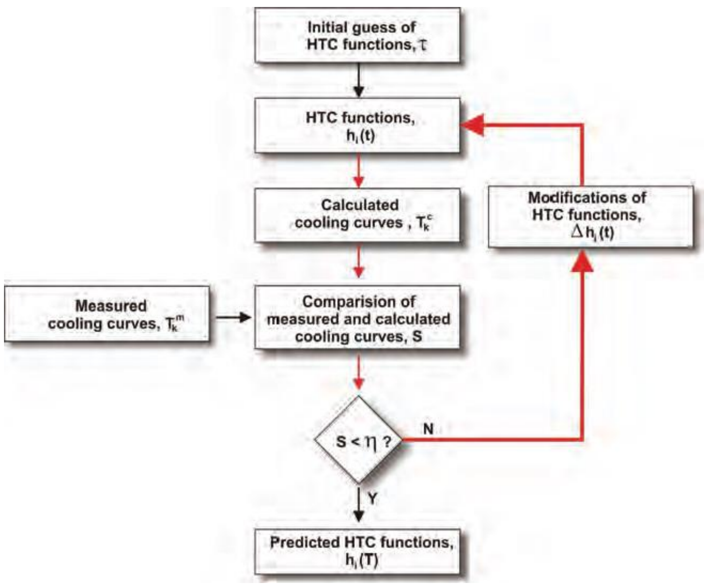

Figure 1. The iterative procedure for the determination of thermal boundary conditions [7]

RESULT AND DISCUSSION

In this chapter we discuss about the results by two aspects. Once we analyse the influence of T_k on thermo-kinetic parameters and the cooling performance (HTC function). Then we compare the cooling behaviour and quenching performace of vegetable oils with it of the mineral oil. The evolution of cooling rate as function of temperature could give a first impression of behaviour of cooling media (see Figure 1).

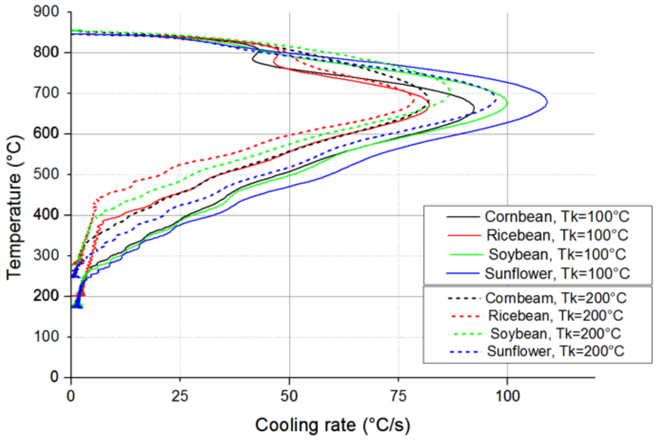

Figure 1
Cooling rate of bio-oils as function of temparature in case of different T_k

The CR-T curves of oils are different, and these difference remain at higher T_k. As can see, sunflower oil cools the fastest, and the rice the slowest. The different of CR_{max} of these is approximately 30°C/s. If the T_k is 200°C the CR_{max} values are decreased quite uniformly in case of sunflower, soybean and corn oil, but the rate of decreasing is very small in case of rice oil. Comparing the bio-oils with PM4500 it can be mentioned only rice oil cools slower the specimen the others produce quite the same CR_{max} value or higher in case of sunflower oil (see Figure 2).

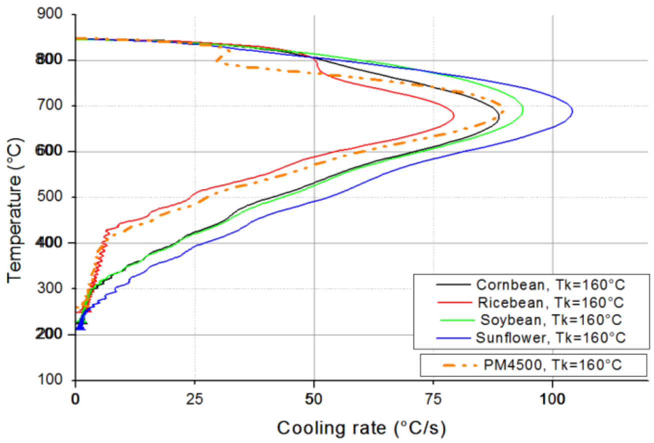

Figure 2.
Compare of cooling rate of bio-oils and mineral oil as function of temparature (T_k=160 °C)

The main difference between curves is the curvature in range 770..830°C. The cooling performance of PM4500 gets slower in this temperature range than it of vegetable oils. These phenomenon is associated with the evolution of heat transfer modes during immersion cooling. As known, a forming vapour blanket with low heat conduction slow down the heat transfer. The presence and the influence of it can be analysed only in details by the evolution of transition temperatures.

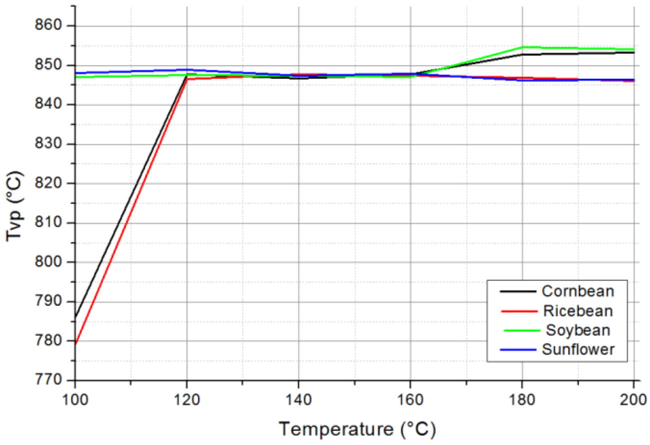

Figure 3.
The first transition temperature of bio-oils as function of T_k

This is an advantageous behaviour of vegetable oils because unwanted transformations can be avoided in a given quenching process. But the second transition temperature depends on the type of oil and T_k too. As is shown in Figure 4 the difference is not so great between the sunflower, corn and soybean oils, but the T_{cp} of rice oil is significantly higher than it of others. In point of M_s temperature of low-alloyed steels the higher T_{cp} is desirable and this can be reached by increasing the T_k or choose a right bio-oil type. In this case rice oil could be a better solution than the others.

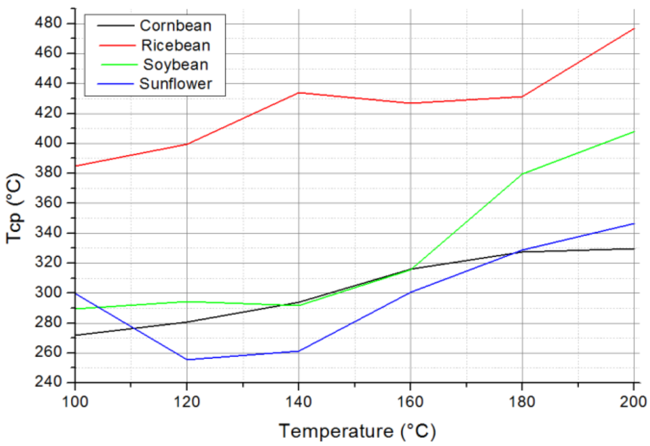

Figure 4.
The second transition temperature of bio-oils as function of Tk

Comparing the HTC(T) curves (see Figure 5) with the Cr-T curves in point of influence of oil-type and T_k similar observations can be remarked:

- the HTC values are differ in case of different oil: the greatest values belong to sunflower oil the lowest to rice oil
- when T_k is increased the maximum value of HTC will be higher

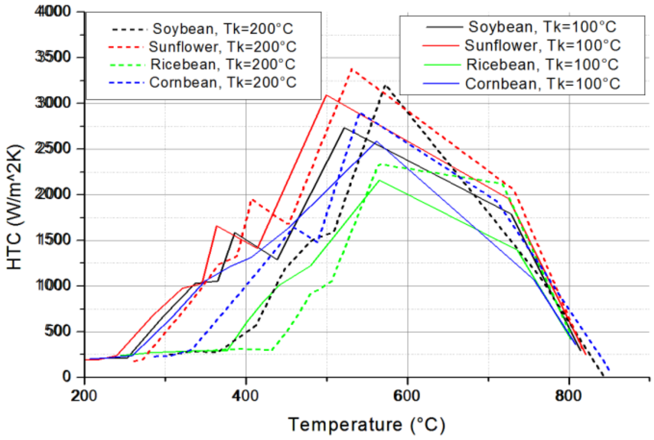

Figure 5.
Heat transfer coefficient of bio-oils as function of temparature in case of different T_k

Furthermore it can be seen that the slope of HTC(T) function is higher. That is significant when T<600°C. It is in accord with tendencies that can be noticed at T_{cp}-T_k curves, viz. the cooling is getting slower at lower temperature range (T<400°C). Considerable difference can be seen between bio-oils and mineral oil from the point of view of heat transfer coefficient at the same T_k temperature (see Figure 6). Practically every vegetable oil have higher HTC values besides the rice oil.

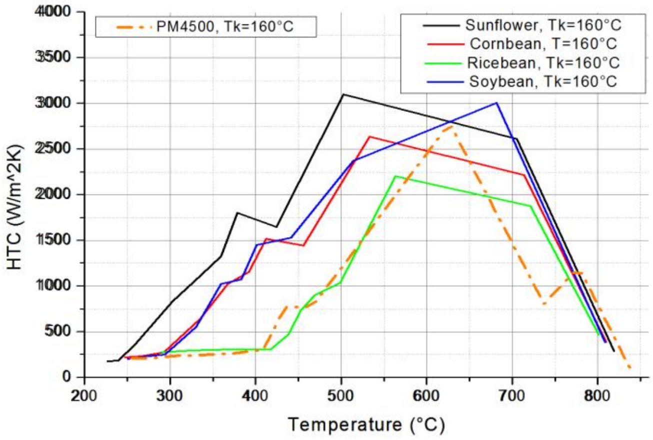

Figure 6.
Compare of heat transfer coefficient of bio-oils and mineral oil as function of temparature (T_k=160 °C)

Using the SQintegra Property Prediction module the Rockwell-C hardness can be calculated in case of cylindrical probe, if the following input parameters are given (after "→" sign our choices can be found):

- start temperature of quenching → 850°C
- T_k temperature → 160°C
- cylinder radius → 50mm
- HTC(T) function → all of investigated oils
- steel grade → 51CrV3

The calculated hardness profile are shown in Figure 7. The HRC values of different oils are quite similar, but the tendencies observed earlier are justified. The highest HRC in specimen can be reached by quenching it in sunflower oil, the lowest by using rice or mineral oil. The difference between the hardness values belong to each kind of oils are not neglectable.

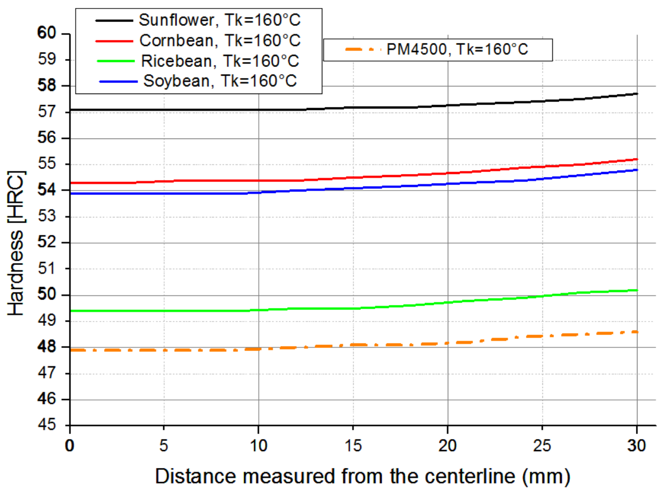

Figure 7.
The hardness distribution obtained along a radius of 51CrV3 cylindrical specimen after simulated quenching in bio oils (T_k=160 °C)

CONCLUSIONS AND REMARKS

In this paper we presented first a very general overview about the main topic of our research work. We determined our research question: is it real possible – based on characteristic data – to use the vegetable oils that are commercially available in our country as quenchant instead of mineral oil in a given condition? The results showed that bio-oils can be a real alternatives of mineral oils in a given case of course. The following main conclusions can be drawn when the initial bath temperature was in rage of temperature 100..200°C:

- practically can be not experienced the first stage during heat transfer because vapour blanket surrounding the surface of specimen did not form,
- the thermo-kinetic parameters of sunflower, soybean and corn oils are the same or better than the investigated mineral quenching oil that operates

generally in this temperature interval (based on data from literature and earlier presented measurement),
- in case of cylindrical specimen made of 51CrV3 with 30mm diameter vegetable oils have a better quenching performance than mineral oils when the initial bath temperature was 160°C.

To can determine general conclusions in this topic further investigations are necessary what may have the following goals:

- the effect of molecular composition on heat removal characteristics,
- the role of composition and initial bath temperature in change the cooling capability
- the effect of cooling cycles on oxidation,
- the possibilities to compensate the degradation of oil's cooling capability by oxidation, for example the role of agitation.

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