Study of Mechanism of Quenching & Calculate the Cooling Rate of Quenching Oils by Quenching Instrument

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Abstract - *In this project the proposal concept is to check the cooling rate of quenching oil. At metal heat treatment processes, quenching oil are applied in order to achieve specific material quality. Desirable selection of quenching oil decreases the risk of stresses, cracking and distortion of workpiece. Quenching oil is exposed to high temperatures in the presence of metals and air which has an adverse impact on the working life of oil. The cooling properties of a quenching oil varies with the used time, so it is important that quenching cooling rates be analyzed with respect to used time. The cooling curve test is a most significant method of examining the entire quenching path of the quenching oil. Initial test of this concept was to performed experiment and studied the quenching effect i.e. temperature drop and other aspects should be studied. . It used to examine the condition of an oil to ensure that the quenching characteristics are the same as fresh oil and whether corrective action is required to be taken.*

Key Words*: *Quenching Process, Cooling rate Effects on Steels, Continuous Cooling Transformation (CCT) Diagrams & Time-Temperature-Transformation (TTT) Diagram, Heat Treatment, Metallurgy of steels, etc.

1. INTRODUCTION

In the heat treatment of metals, metals are heated and cooled in a series of specific operations so that it never allowed the metal to reach the molten state. The purpose of heat treating is to make a metal more efficient & durable by changing & restoring its mechanical properties. In the heat treatment of metals, Quenching is one of the most important process. It improved the surface hardness of metals but improper selection a quenchant (oil) or a drift in its cooling characteristics during its life time may cause large, unexpected costs due to products not meeting specifications. For example, the costs for straightening, rework & even rejection. Every year, lots of money is lost as a result of mechanical property variations due to un-expected problems in the quenching process. The smart quench (cooling characteristic tester) is an international quality assurance tester for evaluating quenching media cooling performance and quenching systems. This instrument is allowed suppliers (of quenching oil) to safeguard the quenching performance of their quenching oils before shipment, and have allowed heat treaters to check them while in use. Increased awareness of the importance of quenching came as a result of the introduction of new ISO and ASTM standards for testing cooling during the decade 1990 to 2000.

1.1 Mechanism of Quenching

When a hot component (test probe) comes in contact with a liquid quenchant (oil), there are normally three stages of quenching. The three stages of quenching are given below:

1.1.1 Film Boiling

The vapour stage is obtained when the hot surface of the heated test probe comes in contact with the liquid quenchant (oil). It becomes surrounded with a blanket or layers of vapour. In this stage, heat transfer is slow. It occurs most significantly by the radiation through the vapour blanket. Some other conduction also occurs through the vapour phase.

Figure-1: Vapour Blanket [1]

This blanket is very stable & its removal can only be enhanced by speed improving additives. This stage is accountable for many of the surface spots encountered in quenching. High pressure sprays & stronger agitation eliminate this stage. If it is allowed to persist undesirable micro sized constituents can form.

1.1.2 Nucleate Boiling

As the test probe cools, the vapor blanket collapses at this stage and nucleate boiling happened. Heat transfer is fastest during this stage with heat transfer coefficients most of the times obtained over two orders of magnitude higher than during film boiling, largely due to the heat of vaporization. The boiling point of the quenching oil determines the conclusion of this stage. The ideal quenchant (oil) is one that exhibits little or no vapor stage, a rapid nucleated boiling stage and a slow rate during convective cooling.

Figure-2: Nucleate Boiling [1]

The high cooling rates are obtained. It resulted into increase of high hardness because of quenching (cooling rate) faster than critical transformation rate and then cooling at a slower rate as the metal continues to cool. This allows stress equalization i.e. reducing distortion & cracking in the workpiece.

1.1.3 Convective Heat Transfer

The last stage of quenching is the convection stage. This occurs when the test probe has reached a point below that of the oil's boiling temperature.

Figure-3: Convective Heat Transfer [1]

Heat is removed by convection. It is controlled by the oil's specific heat, thermal conductivity. It is also controlled by the temperature differential between the component's temperature and that of the oil. The convection stage is usually the slowest of the all above three stages.

1.2 ASTM Methods for Testing of Quenching Oils

There are numerous standard specific physical properties characterization procedures that are used for testing of Quenching oils. The objective is to provide testing procedures based on physical properties that are used. Here, we used ASTM method D6200 which is based on Cooling Characteristics. Hence, we arranged the setup of Quenching instrument like IVF smart quench instrument. ASTM methods are tabulated below based on properties of quenching oil.

Table-1: ASTM Methods for Testing of Quenching Oils

Sr. No.	Test Based on	ASTM Method
1	Viscosity	D445
2	Flash Point	D92
3	Water Content	D95
4	Neutralization Number	D974
5	Saponification Number	D484
6	Precipitation Number	D91
7	Sludge Content	D91
8	Cooling Characteristics	D6200

2.1 Components used in experiment

1. Muffle Furnace
2. Test Probe (AISI 304) with in-built thermo-couple
3. Thermometer
4. Temperature Indicator
5. Oil (MT650)
6. Beaker
7. Heating Mantle

Figure-4: Experiment Overview

2.2 Procedure of Experiment

1. Connect the furnace to the main power supply.
2. Turn on the furnace by means of the switch on it.
3. Probe preparation can be done by cleaning the probe surface with emery paper before each test.
4. Heat the probe in muffle furnace for 855 °C
5. The sample oil container (beaker) must be clean and dry. Take 400 ml oil (MT650) in beaker.
6. Preheat the oil for 120 °Cby using heating mantle.

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7. Rapidly immersing the probe in oil and immediately record the temperature reading up to 200°C by recording device (we used mobile).
8. Put all readings i.e. time (sec.) and temperature (°C) in observation table.
9. Plot the graph with time (sec.) on X axis verses temperature (°C) on Y axis.
10. Calculate the cooling rate for every interval of time by using formula as followed.

$$\text{Cooling rate} = \frac{\text{Difference between any two successive temperatures(°C)}}{\text{Time Interval (sec)}}$$

11. Put all values of cooling rates in observation table.
12. Plot the calculated values of cooling rate on same graph with all values of cooling rate on secondary X axis.
13. Find the maximum cooling rate and study time when it obtained.
14. Observe the graph carefully and study the stages of cooling of quenching processes.
15. In order to ensure reliable and consistently reproducible results, and to ensure correct operation of the test probe over a longer period of use, it must be carefully cleaned after each test.
16. After use in quenching oils, clean the probe in white spirit and dry it with a clean cloth.

2.3 Observation Table, Calculations & Graph

We performed experiment as stated in the procedure and recorded Temperature reading for every 5 seconds. All this reading putted in the following table. Here, readings of first 90 seconds are shown in observation table because after 90 seconds, cooling rate is changed very negligibly, but we plotted all readings of cooling rate (with respect to time from 0 second to 345 seconds) in CCT diagram (Refer Figure-5).

Table-2: Observation Table

Time (sec)	Temperature (°C)	Cooling Rate (°C/sec)
0	719	1.2
5	713	9.6
10	665	**9.8 (Max.)**
15	616	6.6
20	583	5
25	558	6.2
30	527	4
35	507	3.8
40	488	3
45	473	2.8
50	459	2.6
55	446	2.8
60	432	2.2
65	421	2.6
70	408	1.8
75	399	2
80	389	2.2
85	378	1.8
90	369	2

Calculations:

The Cooling Rate is given by

$$\text{Cooling rate} = \frac{\text{Difference between any two successive temperatures(°C)}}{\text{Time Interval (sec)}}$$

We take third successive two readings i.e. 665 °C& 616 °C, because there is maximum temperature difference. Hence, it gives maximum cooling rate.

Time interval = 5 sec.

$$\text{Cooling rate} = \frac{665 - 616}{5}$$

$$\textbf{Cooling rate} = \mathbf{9.80\ °C/sec}$$

Similarly, we calculated Cooling rate of all successive temperatures and put in table of observation. We had obtained maximum cooling rate of the quenching process is 9.80°C/sec. Then, we plotted readings in graph as shown below.

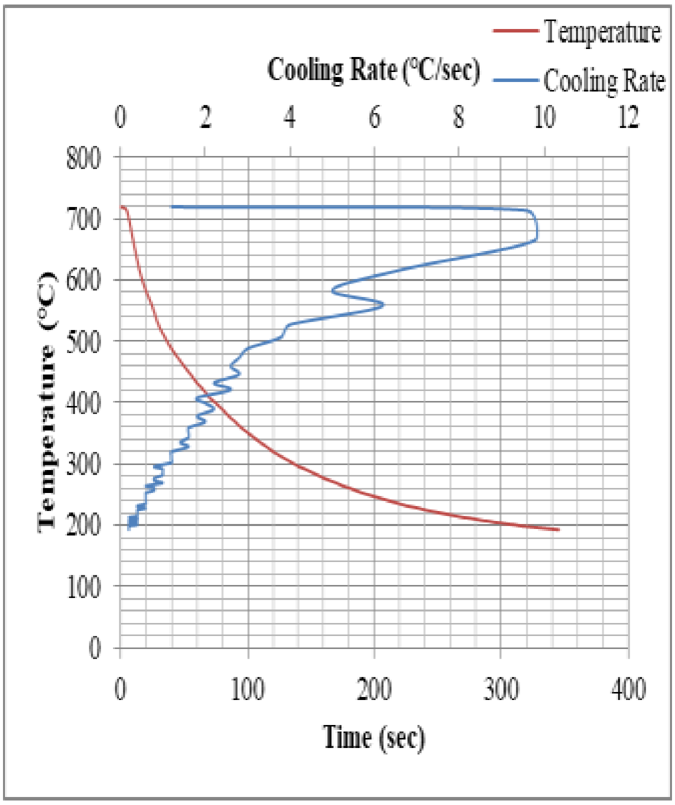

Figure-5: CCT diagram of Conducted Experiment

We compared above graph (obtained by our experiment) with the typical cooling curves and cooling-rate curves shown below.

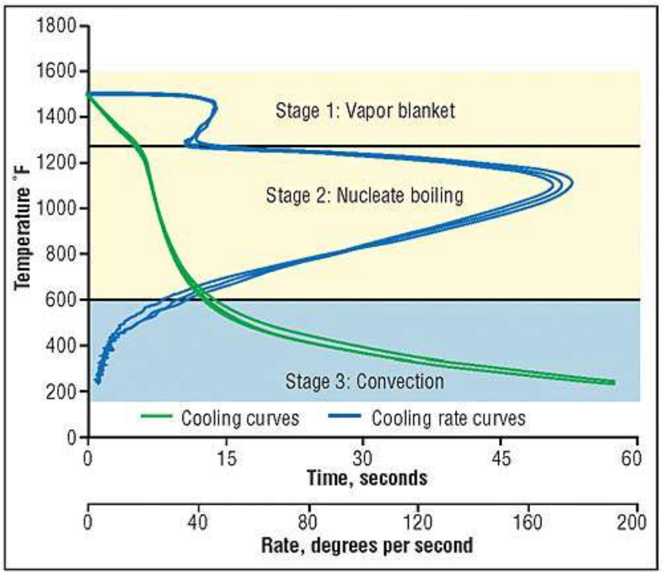

Figure-6: Typical cooling curves and cooling-rate curves for new oils [Image credit: Vac Aero International Inc.]

We find that stage 1 (vapour Blanket) wasn't obtained in our experiment because temperature wasn't reached to 855°Cor more.

3. CONCLUSIONS

A review of quenching oil cooling mechanism had provided. We used quenching oil testing system which utilized a type 304 stainless steel probe. The use of this equipment and probe system was used to characterize the quenching behavior (cooling rate path) of commercial quench oil MT650.

Here, the temperature of test probe reached to 725°C instead of desirable temperature 855°C, because of fault of furnace. Hence, the vapour blanket stage not obtained in our experiment and eventually actual maximum cooling rate hadn't obtained. If we compare the cooling rate of same oil obtained by IVF smart quench instrument, there is difference of 65°C. IVF smart quench instrument given cooling rate is equal to 75°C/sec and our experiment given is equal to approximately 10°C/sec. This difference occurred due to various factors but the most significant factors are given below:

1) The vapour blanket stage wasn't obtained in our experiment.
2) We used tset probe of different material (AISI 304) & dimensions than IVF smart quench test probe material (Alloys 600) & dimensions, it is very expensive to manufacture test probe as IVF Smart Quench Instrument.

So we can use this instrument to examine the condition (cooling rate) of an oil to ensure that the quenching characteristics are the same as fresh oil. These studies showed the importance of cooling curve analysis as part of a quality assurance in any heat treating plant. In addition, these results show that cooling curve analysis is an integral part of a quench oil recycling or recovery process. It would yield more durable & resulted into lower production cost. It reduced environmental impact.

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