THESIS

A COMPARISON OF COMMERCIAL COOLING MEDIA FOR HARDENING STEEL

BY

R. D. KEAN, A. L. MC CLELLAN

1917

THESIS

Steel - Tempering of

Tillie. Cooling media for hardening steel

Mechanical engineering

THESIS

Preface.

In this thesis we have endeavored to check previous investigations and comparisons of cooling media for hardening steel, adding some interesting data in comparing the heat absorbing power of cooling media, at different temperatures, for our particular test piece.

The work was done by practical tests under conditions which were analogous to those in modern shops.

In our theoretical work we used the following books and articles as references.

Factors in Hardening Tool Steel, by John A. Matthews and Howard J. Stagg, Jr.

Handbook for Mechanical Engineers, by Kent.

Journal of the Iron and Steel Institute, 1908, II p.208. An article by Benedicks.

Willie on Heat Treatment of Steel in The Proceedings of A.S.T.M., p.28, Vol. XV.

Part I

Description of apparatus and method of running the test.

Part II

Resulting curves and their analysis.

Part III

Comparison of absorbing power of cooling media at various temperatures, with illustrative curve.

DESCRIPTIVE APPARATUS AND METHOD OF RUNNING THE TEST.

The test piece was turned from a piece of cold rolled steel to the dimensions given on the drawing. The piece was then bored for the thermal couple, the hole tapped and a piece of three-quarter inch pipe, twelve inches long, screwed into the hole. This pipe acted as a handle and as a conduit for the thermal couple leads. It also admitted withdrawing the couple for inspection, if necessary.

All thermal couples used, were couples made from iron and constantan wire.

The source of heat was a gas furnace used in connection with a lead bath, which was kept at a temperature of 1200°F.

Five gallons of each medium was used in each test.

The following method was used throughout the test.

The test piece was immersed in the lead bath together with another thermopyle. When the couple inside the test piece read 1200°F., and the couple in the lead pot read 1200°F., the test piece was removed and quenched to 700°F. in the quenching medium under consideration. At the start the medium was maintained at room temperature. The time that it took the test piece to fall from a temperature of 1200°F. to 700°F. was noted with the aid of a stop watch.

The cooling of the test piece in the medium naturally raised the temperature of the medium. The test piece was then replaced in the lead, heated to 1200°F., quenched in the medium at this known higher temperature and the time again taken with the stop watch. These operations were continued until the quenching media had attained such a temperature that excessive smoking or boiling prevented its further use.

During the above operations care was taken that the test piece was immersed the same amount each time both in the lead bath and in the cooling media. The test piece during all the quenching rested on the bottom of the container of the medium and the medium was not stirred except when taking its temperature just before immersing the test piece.

RESULTING CURVES AND THEIR ANALYSIS.

In plotting the following curves, the results obtained by our experiments, time in seconds, for a fall from 1200°F. to 700°F., were plotted against the temperature of the quenching medium.

An analysis of the curves is interesting. The M.A.C. well water, Fig. II, has a fairly constant quenching rate up to 120°F. At 150°F. the slope of the curve is quite marked. Excessive boiling prohibits further use of the medium over 180°F.

A saturated salt solution (NaCl) gives a quicker rate of cooling than water and a fairly constant rate up to 125°F. From 125°F. to 190°F. where excessive boiling occurred, the slope is very decided.

The soda solution, Fig. IV, $NaHCO_3$ 7 H_2O, has an extremely quick rate of quenching and has the peculiar characteristic that it cools much faster at moderate temperature (85°-110°) than at either lower or higher temperatures. Foaming and boiling was excessive at 120°F. This medium would probably cause cracking of steel where the pieces were of considerable size, but for small pieces where extreme hardness was desired, should prove satisfactory.

The speed of cooling is much greater than even the salt (NaCl) solution.

Kerosene oil, Fig. V., at low temperatures has a quick cooling rate, for an oil, but decreases at a nearly uniform rate throughout its useful range. At 250°F. and above unpleasant gasses are given off and the use of this oil should be confined to temperatures below 250°F. A temperature above 400°F. was reached before the oil caught fire.

"Renown" engine oil, Fig. VI., is a fairly thick oil similar to gas engine cylinder oil. Its slope is less than kerosene oil but is much slower. Where the piece required 100 seconds to cool in this oil at 70°F. it cooled in 70 seconds in the kerosene. The rate of cooling was nearly constant up to 360°F. but smoking was excessive above 300°F. and this medium should not be used on this account above that temperature.

The lard oil used, Fig. VII., had been in use for some time in the M.A.C. forge shops. This oil is particularly interesting in that throughout the entire range of temperature used, the rate of cooling was constant. The rate was slower than any of the other oils, being about 102 seconds for all temperatures. Even at the extreme temperature of 420°F.

the rate of cooling varied but little. 300°F. is about the practical limit for this oil as above that a gas is liberated which is very annoying.

Of the extremely heavy, viscous oils it might be well to say that those of the steam cylinder oil type are unsuitable as cooling media.' Heavy steam engine cylinder oil under test was unable to carry the heat away from the test piece rapidly enough and the resulting highly heated gasses which were liberated caught fire. There is a possibility however that this type of oil if used at a temperature somewhat above room temperature might then be used, but we believe that the viscosity is too great for a good cooling medium.

COMPARISON OF ABSORBING POWER OF COOLING MEDIA AT VARIOUS TEMPERATURES WITH ILLUSTRATIVE CURVE.

In determining the heat flow per sq. in. of surface from the test piece, we referred to Kent's Handbook for the specific heat of steel. Observations by Dr. I. P. Obenhoffer, quoted in the handbook, gave an average of .135 as the specific heat between the points 700°F. and 1200°F.

The weight of the test piece (without handle) was 2310 grams.

Therefore the total heat given up in cooling from 1200°F. to 700°F. equals

(1200-700)x2310 x .135 equals 156000 calories.

The sq. in. of surface of the test piece (without handle) equals the circumference times the length plus the area of each end.

Equals $(2\pi r \times 4\ 1/3) + 2\pi r^2$

Equals $(\pi \times 2\ 9/16 \times 4\ 1/3) + \frac{\pi d^2}{2}$ equals 43.5 sq. in.

Therefore the number of calories given off per sq. in. of surface equals $\frac{156000}{43.5}$ equals 3600 cal.

In plotting the accompanying curve, the calories absorbed per sq. in. of steel surface per second are plotted against the temperature of the quenching bath degree F.

This gives a series of curves which, after one knows how many calories per second ought to be taken away for a given hardness, should be valuable. As an example, suppose we have the quenching mediums at hand that are listed on the curve and they are at various temperatures because of recent use. Suppose that we have a piece to be hardened and for the degree of hardness desired 45 calories per second should be taken away. A glance then at the curve shows that "Renown" engine oil and lard oil are too slow, while a soda solution is altogether too fast. The choice lies between well water, salt water and kerosene oil. Salt water and well water, if cool, are too fast and the point at which they carry away 45 calories per second is at a temperature which is almost prohibitive. Therefore, if we have kerosene oil at any temperature between 60°F. and 180°F. it will answer the purpose.

A point which has been proven a great number of times but which is nevertheless interesting to note, is the fact of the tendency of the test piece to become round after repeated heatings and coolings. In all the test piece was quenched some 60 times. Upon examination, after these tests, the diameter of the test piece at the center was found to be 1/8 in.

larger. The diameter of the piece at the ends was 5/16 in. less than originally.

The hole in the piece where the thermal couple was inserted had closed up so that the thermal couple could not be withdrawn, although the hole was much too large originally.

Fig I

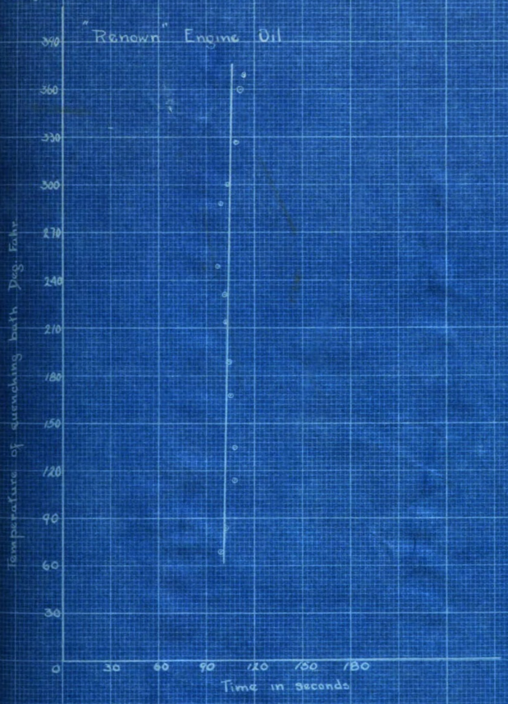
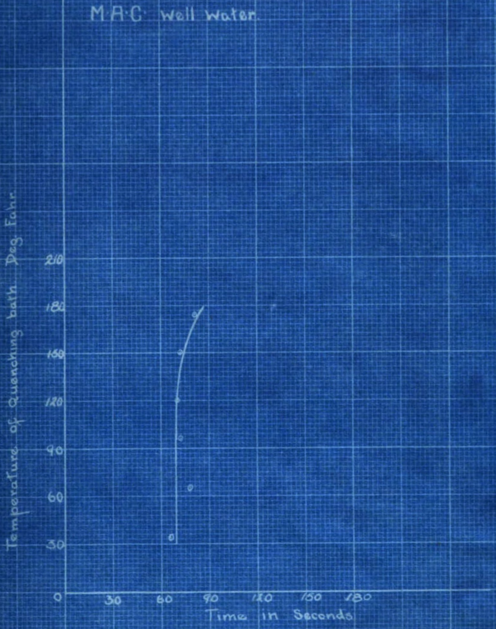

"Renown" Engine Oil
390
360
330
300
270
240
210
180
150
120
90
60
30
0
30
60
90
120
150
180
Temperature of quenching bath Deg. Fahr.
Time in seconds

Fig II


M.A.C. Well Water.
Temperature of Quenching bath Deg. Fahr.
210
180
150
120
90
60
30
0
30
60
90
120
150
180
Time in Seconds

III

Saturated Salt Solution

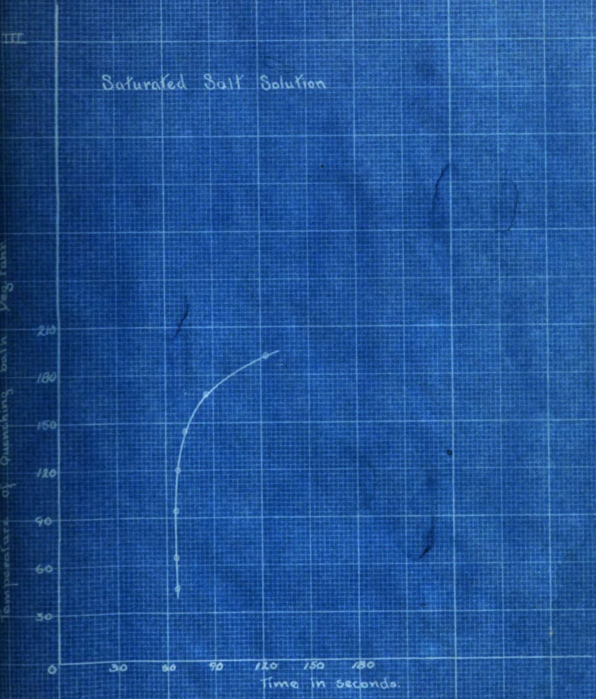
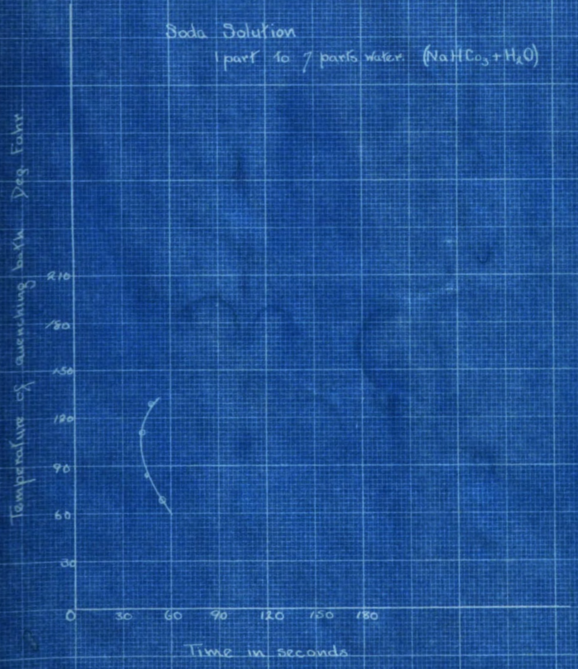


Fig IV.


Soda Solution
1 part to 7 parts water. $(NaHCO_3 + H_2O)$
Temperature of quenching bath Deg. Fahr.
210
180
150
120
90
60
30
0
30
60
90
120
150
180
Time in seconds

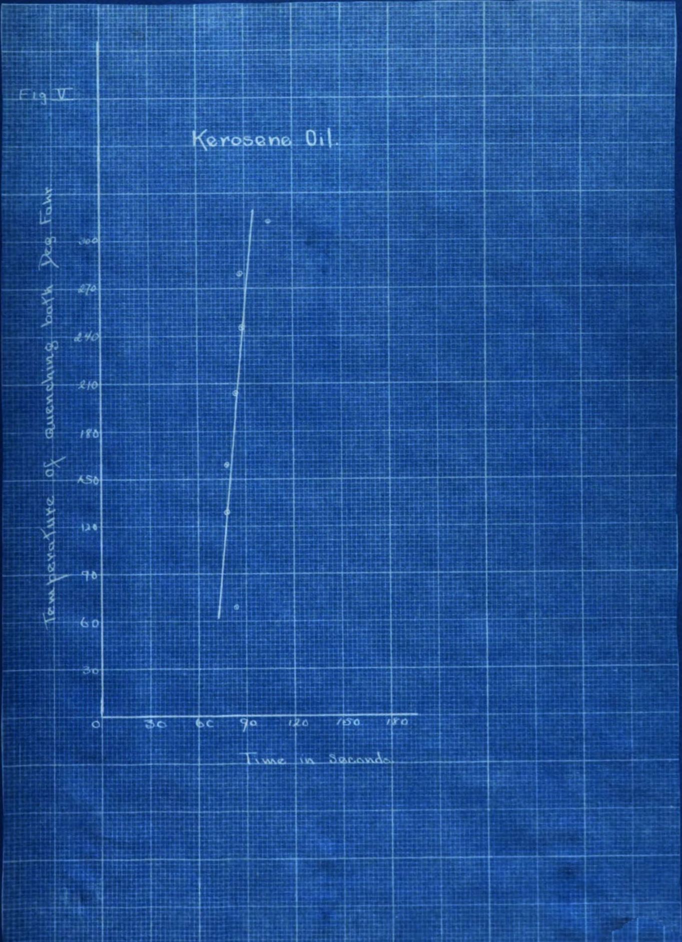


Fig V
Kerosene Oil.
Temperature of quenching bath Deg Fahr
300
270
240
210
180
150
120
90
60
30
0
30
60
90
120
150
180
Time in Seconds

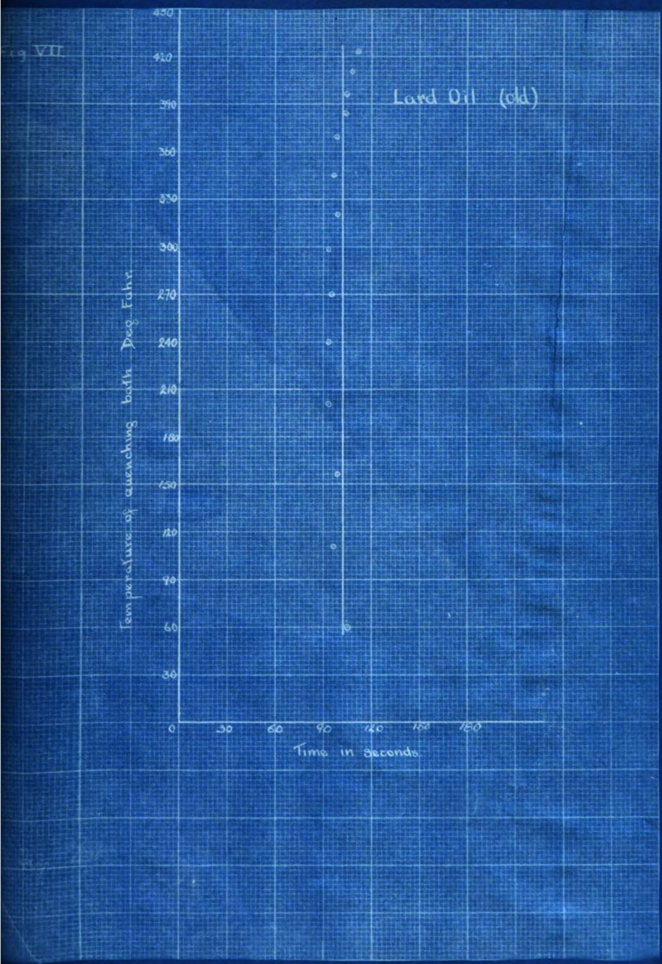
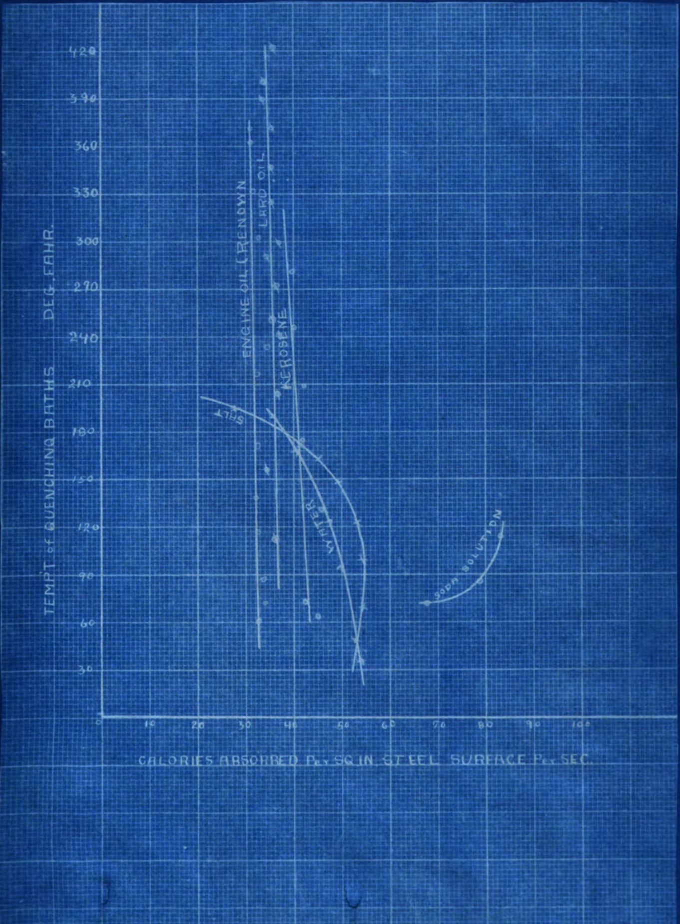
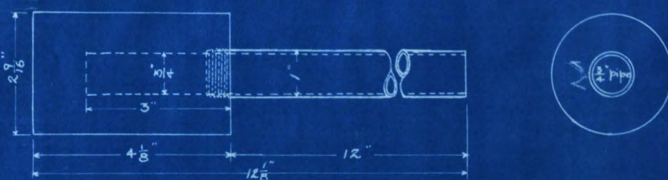


Fig VII
Lard Oil (old)
Temperature of quenching bath Deg Fahr.
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
30
60
90
120
150
180
Time in seconds



TEMP'T of QUENCHING BATHS DEG. FAHR.
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
10
20
30
40
50
60
70
80
90
100
CALORIES ABSORBED Per SQ IN STEEL SURFACE Per SEC.
ENGINE OIL (RENOWN)
LARD OIL
KEROSENE
SALT
WATER
SODA SOLUTION



Test Piece Cold Rolled Steel

RENOWN ENINE OIL

TEMP MEDIUM	TIME of COOLING
69°F	1 MIN 39.6" SEC.
83°	1' 43.2"
113°	1' 47.4"
136°	1' 47.9"
168°	1' 46.0"
188°	1' 44.3"
214°	1' 42.8"
230°	1' 41.2"
250°	1' 37.4"
288°	1' 42.2"
300°	1' 45.6"
328°	1' 48.2"
360°	1' 49.3"
371°	1' 50.2"
385° BOILED	

SODIUM BICARBONATE

71°	52.5"
83°	45"
110°	43"
130°	47"
162° BOILED	

KEROSENE

TEMP. MEDIUM	TIME of COOLING
69° F	1 MIN 23.6" SEC
130°	1' 17.2"
170°	1' 24"
160°	1' 18.8"
205°	1' 23.2"
245°	1' 28.8"
280°	1' 27.1"
314°	1' 45.2"
420 BOILING	

SALT SOLUTION

44°	1' 7"
65	1' 5.2"
95	1' 5.4"
120	1' 6.8"
145	1' 11.8"
168	1' 25.4"
192	2' 3"
205 BOILED	

COLLEGE TAP WATER

TEMP. MEDIUM	TIME of COOLING
35° F	1 MIN 6.4 SEC
65°	1' 18"
95°	1' 11"
120°	1' 10"
150°	1' 13"
175°	1' 21"
200° Boiling	

LARD OIL

60°	1' 46"
110°	1' 35.8"
155°	1' 40.9"
200	1' 34.2"
240	1' 34.4"
270	1' 35.5"
298	1' 33.5"
320	1' 40"
345	1' 37.2"
370	1' 39.3"
385	1' 44."
395	1' 44."
410	1' 47.4"
425	1' 50"
440	1' 45"
450	1' 45.7"
470 BURNED	