MZM -16 Oil Cooling Capacity Investigations Based on Solving Inverse Problem

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Abstract:- Heat flux densities and heat transfer coefficients on the basis of solving inverse problem of Tikhonov method have been investigated. It is established that the less diameter of cylindrical sample the higher heat flux density during nucleate boiling and higher heat transfer coefficient. During nucleate boiling and convection one can use average values of heat transfer coefficients. It is established that Kondratjev numbers including average heat transfer coefficients during nucleate boiling are changing very slowly with the changing diameter of samples. Using this regularities one can propose express method of calculations. A new technology of quenching steel parts in oils is proposed.

Key-Words:- Heat flux densities, Heat transfer coefficients, Kondratjev numbers, Express method of calculations, New technology.

1 Introduction

Even till the middle of the last century inverse problems were considered incorrectly posed (ill-posed) and incorrectly describing the natural phenomena, from both mathematical and physical point of view. Despite of it, inverse problems were posed and solved. Inverse problems do not meet the principles of correctness, which were formulated by Hadamard in the beginning of the last century [1]. Due to works of N.A.Tikhonov and his school the attitude of mathematicians towards this problem changed. N.A.Tikhonov theoretically proved the opportunity of posing problems that are incorrect according to Hadamard and practical ways of their solving.

N.A.Tikhonov also created a new direction in methods of their solving, regularizing algorithms, which allowed to solve inverse problems that could not be solved by any other method. The first works were devoted to problems that are solvable analytically, that is, mainly, to linear heat conduction problems. For many problems theorems of existence and uniqueness of the solution were proved, algorithms of search for the regularization parameter α were suggested, the convergence of various regularizing algorithms was proved [2 -7].

Since thermal processes during quenching are very complicated, more prominent mathematicians and thermal scientists are involved to solve these complicated problems [8 – 13].

Table 1 Thermal conductivity of supercooled austenite versus temperature

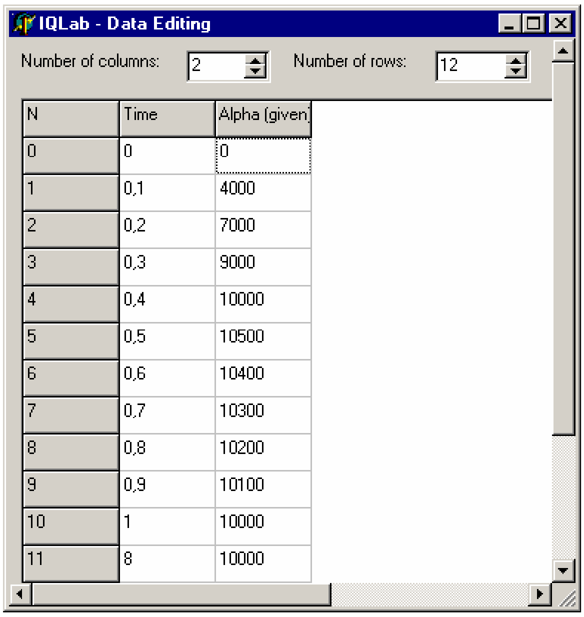
T, ºC	100	200	300	500	600	700	800
λ, $\frac{W}{mK}$	17.5	18	19.6	23	24.8	26.3	27.8
$\bar{\lambda}$, $\frac{W}{mK}$	17.5	17.7	18.55	20.2	21.1	21.9	22.6

Table 2 Thermal diffusivity a of supercooled austenite versus temperature

T, ºC	100	200	300	500	600	700	800
$a \cdot 10^6$, $\frac{m^2}{S}$	4.55	4.6	4.70	5.3	5.6	5.8	6.2
$\bar{a} \cdot 10^6$, $\frac{m^2}{S}$	4.55	4.6	4.63	4.9	5.1	5.2	5.4

2 IQLab Software for Solving Inverse Problem

For determination of cooling properties of a quenchant, the experiments are carried out which lie in cooling probes of a simple shape (cylinder, plate, sphere) with thermocouples inserted inside. Here sizes of samples are selected so that the problem of heat conductivity be unidimensional. The data are preliminary processed and then the inverse problem is solved. As a result of the solution of the inverse problem the program produces a temperature field and heat flux density. Upon the finish of solving the inverse problem, the program also calculates heat transfer coefficients, Biot number Bi, the generalized Biot number Bi_V, Kondratjev number Kn for both boiling and convection. Results are presented as functions versus time in usual and logarithmic coordinates, versus surface temperature and other characteristics, in charts and in the text form. The temperature field may be viewed on CCT diagram, which can simplify the quenching condition design.



IQLab - Data Editing

Number of columns: 2 Number of rows: 12

N	Time	Alpha (given)
0	0	0
1	0,1	4000
2	0,2	7000
3	0,3	9000
4	0,4	10000
5	0,5	10500
6	0,6	10400
7	0,7	10300
8	0,8	10200
9	0,9	10100
10	1	10000
11	8	10000

Fig. 1. Input data edited in IQLab.

3 Results of Investigations

To investigate cooling capacity of MZM-16 oil cylindrical specimens of 20, 30 and 50 mm were used. The height of specimens H was H = 8D. The specimens were made of KH18N9T stainless steel. The thermal properties of stainless steel vs. temperature are shown in Table 1 and Table 2. The thermocouples were welded at the surface of specimens and at the core. Using IQLab software and experimental data, the heat flux densities and heat transfer coefficients for MZM-16 oil were calculated.

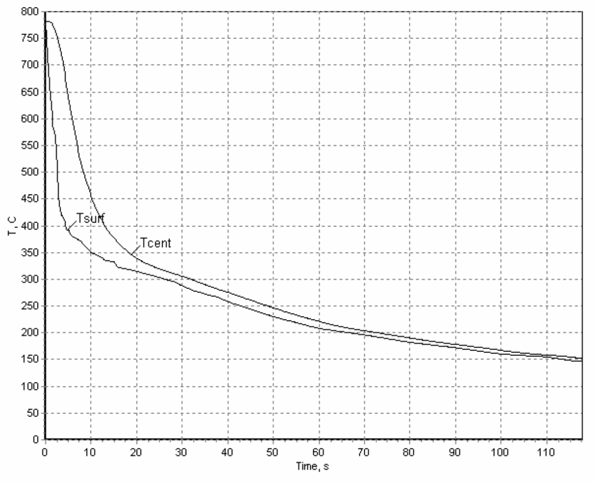


Fig. 2. Temperature at the surface and in the core versus time for MZM-16 oil at 61ºC, specimen: cylinder of 9.95 mm radius and 80 mm height.

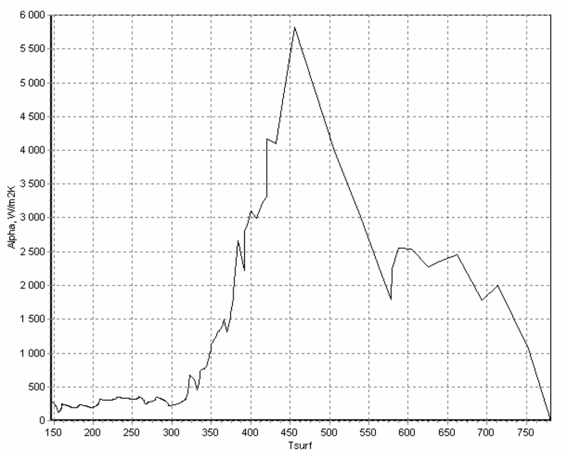


Fig. 3 Heat transfer coefficient versus surface temperature for MZM-16 oil at 61ºC, specimen: cylinder of 9.95 mm radius and 80 mm height.

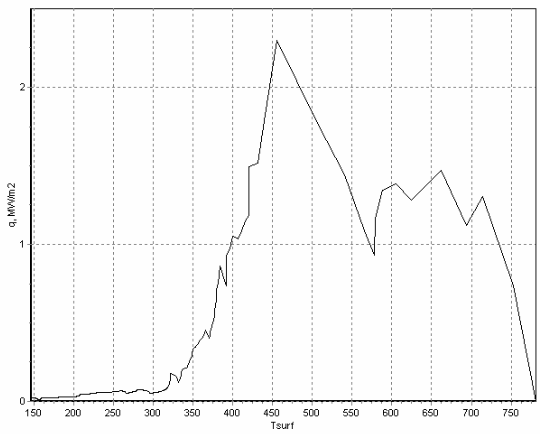


Fig. 4 Heat flux density versus surface temperature for MZM-16 oil at 61ºC.

As we can see from Fig. 3 and Fig. 4 the film boiling is clearly observed. With the increase of oil temperature the first critical heat flux density increases and achieves its maximum at 100^{o}C (see Table 3). That is why it is very important to investigate cooling capacity of oil at 100^{o}C.

Table 3 The first critical heat flux density vs. temperature for oil MZM -16

T, ^{o}C	38	40	75	100	150	200
q_{cr1}, MW/m^2	2.8	3	3.3	3.4	3	2.5

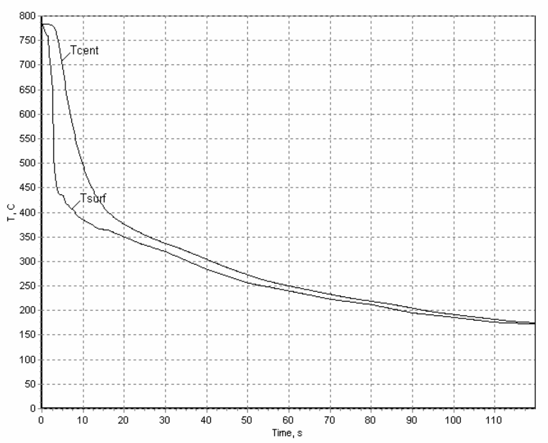


Fig. 5 Temperature at the surface and in the core versus time for MZM-16 oil at 100ºC, specimen: cylinder of 9.95 mm radius and 80 mm height.

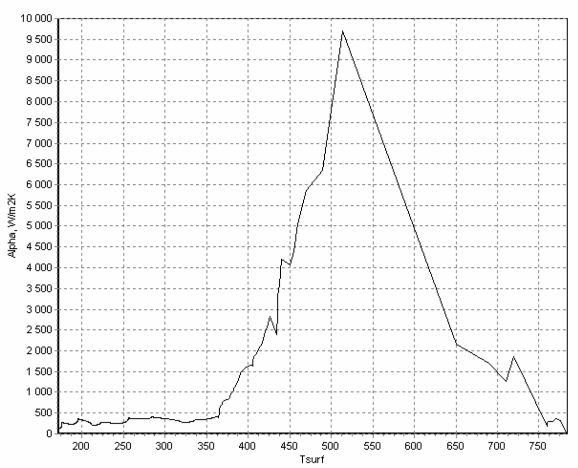


Fig. 6 Heat transfer coefficient versus surface temperature for MZM-16 oil at 100ºC, specimen: cylinder of 9.95 mm radius and 80 mm height.

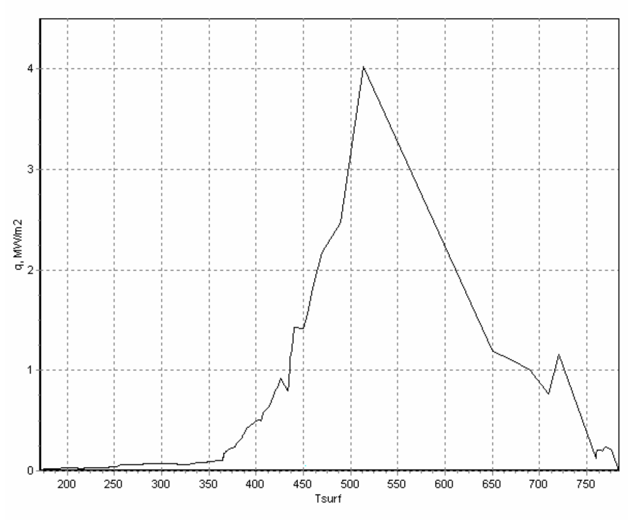


Fig. 7 Heat flux density versus surface temperature for MZM-16 oil at 100ºC..

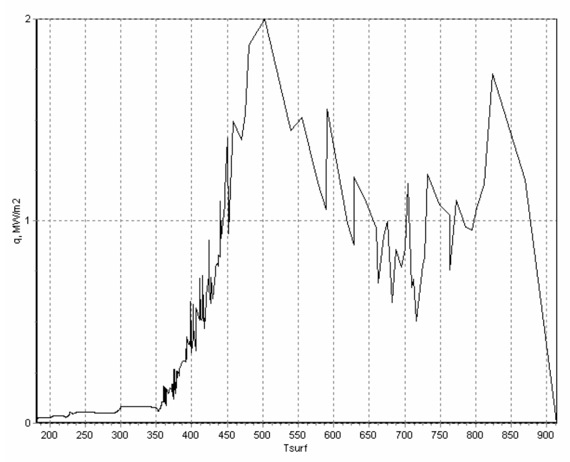


Fig. 8 Heat flux density versus surface temperature for MZM-16 oil at 170ºC..

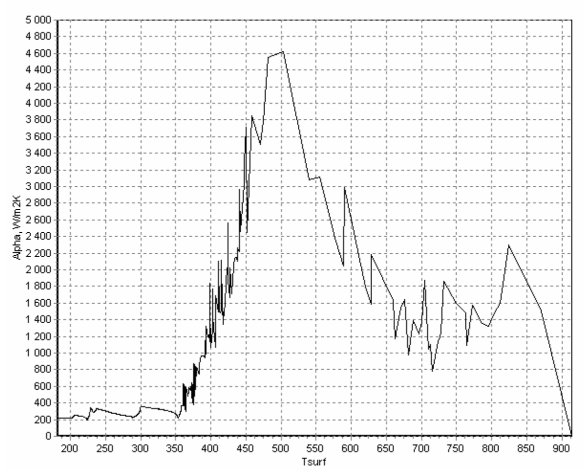


Fig. 9 Heat transfer coefficient versus surface temperature for MZM-16 oil at 170ºC

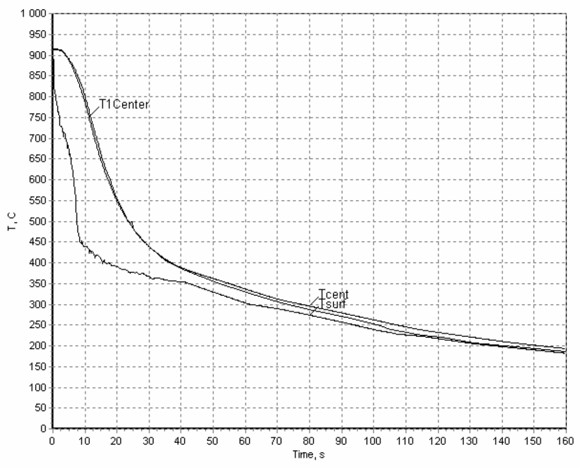


Fig. 10 Temperature at the surface and in the core versus time for MZM-16 oil at 170ºC.

4 Discussions

The achieved results can be used for designing new two-step quenching technology. At the first step steel parts are cooled in hot oil with optimal temperature and at the second step washing and intensive cooling within the martensite range is the same process. The cooling time at the first step is regulated by speed of conveyor. An equation for calculation speed of conveyor *W* is below:

$$W = \frac{L}{\tau} = \frac{aLKn}{(\Omega + b\ln\theta)K} \, ,$$

where L is length of conveyor; a is thermal diffusivity of steel; Kn is Kondratjev number; K is form factor.
Kondratjev numbers for oil depending on size of specimens are presented in Table 3.

Table 4 Kondratjev number *Kn* calculated on use experimental data achieved by different authors in different countries

Diameter of cylinder, mm	Malinkina, Lomakin [14]	Kobasko, Totten [15]	Authors	Average value
10-12.7	0.18	0.15	-	0.165
20-25	0.23	0.205	0.26	0.23
30	0.27	-	0.28	0.275
40	0.30	-	-	0.30
50	0.33	0.28	0.30	0.305
60	0.36	-	-	-
80	0.40			
100	0.43			
120	0.40			

The proposed technology allows to improve mechanical properties of steels.

5 Summary

1. On the basis of developed Software IQLab and fulfilled by author experiments cooling capacity of MZM-16 oil has been investigated.
2. Optimal temperature for MZM-16 oil is 100^{o}C.
3. Average heat transfer coefficients within nucleate boiling and convection can be used.
4. Kondratjev number *Kn* including average heat transfer coefficients at nucleate boiling differ very little with changing sizes of steel parts.
5. Express method of calculation the speed of conveyors is suggested.
6. The new method of quenching steel parts in hot oils is proposed.
7. Washing and intensive cooling within the martensite range at two step quenching should be the same process.

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