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SUPERHEATER TUBE FLAT WALL STATIONARY TEMPERATURE FIELD

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Abstract. The BKZ-220-100-9 steam generator platen superheater tube flat wall stationary temperature fields analysis have been made. The six steel grades, using in boiler fabrication, namely, St. 10, St. 20, 12H1MF, 15HM, 1H18N9T and 12H18N12T, have been used. The temperature curves calculation has been made by using outer and inner surface heat-transfer coefficients nine different combinations.

1 Problem physical model

The present paper takes the BKZ-220-100-9 steam generator platen superheater tube element as an investigation object. The investigation object wall is flushed with the following operation mediums such as flue gases with the temperature of 1374.15 K on the outer surface and steam with the temperature of 619.15 K on the inner surface [1, 2]. It follows that the steam heating process occurs in tubes using the heat released by flue gases by means of a heat-transfer through the cylindrical wall. The heat is transferred through the wall by means of the heat conductivity process and from the inner surface to the steam by convection. The steels heat conductivity coefficients are known [3, 4] and have constant values (Table 1). The object calculation geometrical characteristics and heat-transfer coefficients are known also [1, 2] and are the constant values (Table 1). The investigation object stationary temperature distributions analysis for a six steel grades at the various outer and the inner surfaces heat-transfer coefficients combinations are the present paper problem. The one-dimensional stationary heat conductivity equation with the third type boundary conditions is used for a task set solving.

2 Problem mathematical model

The flat wall stationary temperature field is determined by a mathematical model follows as:

$$\frac{d^2T(x)}{dx^2}=0,\ \ L_1<x<L_2,$$

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$$\lambda \frac{dT(x=L_1)}{dx} = \alpha_{m1}\left(T(x=L_1) - T_{m1}\right),$$
$$\lambda \frac{dT(x=L_2)}{dx} = \alpha_{m2}\left(T_{m2} - T(x=L_2)\right). \quad (1)$$

λ is the steel heat conductivity coefficient, measured by Wt per m per K. α_{m1}, α_{m2} are heat-transfer coefficients on the inner and outer surface, respectively, measured by Wt per square meter per K. T_{m1}, T_{m2} are medium temperatures on the outer and the inner surface, respectively, measured in K. $T(x=L_1)$, $T(x=L_2)$ are temperatures on the left and the right boundaries, measured in K.

The (1) equation analytical solution is obtained in compliance with [5, 6] and looks like so:

$$T(x) = T_{m1} + \frac{\left(T_{m2} - T_{m1}\right)}{\delta + \frac{\lambda}{\alpha_1} + \frac{\lambda}{\alpha_2}} \cdot \left(x + \frac{\lambda}{\alpha_1}\right). \quad (2)$$

δ is the wall thickness, measured in m.

This expression is as follows in a dimensionless form:

$$\Theta_{station}(\mathrm{X}) = \frac{\mathrm{Bi}_2\left(\mathrm{Bi}_1 \cdot \mathrm{X} + 1\right)}{\mathrm{Bi}_1 + \mathrm{Bi}_2 + \mathrm{Bi}_1 \cdot \mathrm{Bi}_2}, \quad (3)$$

$\Theta_{station}$ (X) = $(T(x)-T_{m1})/\ (T_{m2}-T_{m1})$ is the dimensionless temperature. X = x/δ is a dimensionless thickness. $\mathrm{Bi}_1 = \alpha_1 \cdot \delta / \lambda$; $\mathrm{Bi}_2 = \alpha_2 \cdot \delta / \lambda$ are the Biot numbers.

The obtained solution check are made by its substitution from an initial equation and corresponding boundary conditions (1). This equation dimensions check are made also. The made check results have confirmed the computed solution accuracy.

3 Results and discussion

The nine heat-transfer coefficients variations on the outer and the inner surfaces are used in the paper. α_{zh1} and α_{zh2} are reduced by 100, 10 4 and 2 times, respectively, from the first alternative to the forth alternative comparing with the seventh alternative. A_{zh2} is reduced by 10 times in the fifth alternative, but is increased by 10, 20 and 30 times, respectively, from the seventh to the ninth alternatives comparing with the calculation value [1, 2]. The made calculations results are showed below.

Table 1. Heat-transfer coefficients, Wt/(m^2·K) and heat conductivity coefficients, Wt/(m·K).

Temperature curves	1	2	3	4	5	**6**	7	8	9
α_{m1},	34.84	348.4	871	1742	3484	3484	3484	3484	3484
α_{m2}	11.03	110.3	275.8	551.5	11.03	110.3	1103	2206	3309
λ(St.10)	39.53	39.41	39.20	38.89	47.04	45.93	38.31	33.96	31.51
λ(St.20)	37.60	37.51	37.36	37.13	43.13	42.27	36.72	33.78	32.17
λ(12X1MF)	36.74	36.66	36.54	36.36	40.45	39.93	36.02	33.49	31.90
λ(St.15XM)	35.44	35.36	35.23	35.03	39.43	38.86	34.66	32.00	30.40
λ(St.12X18H12T)	23.52	23.59	23.71	23.87	20.64	21.20	24.14	25.44	26.12
λ(St.1X18H9T)	23.41	23.49	23.62	23.81	20.46	21.01	24.11	25.69	26.59

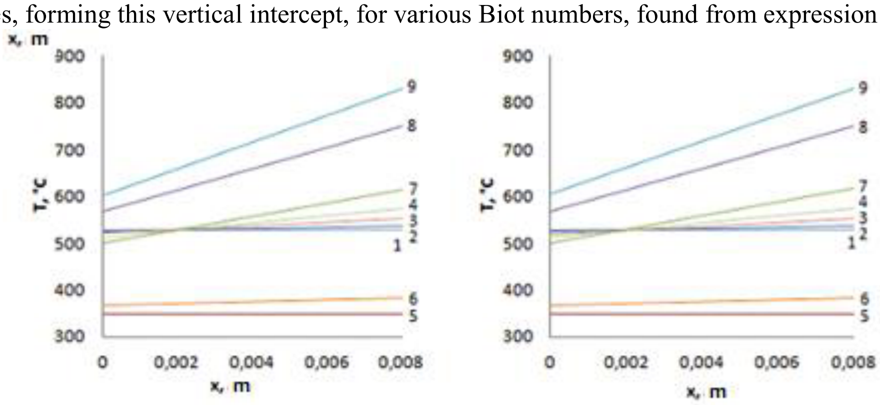
Table 2. Temperature differences and temperature drops, K.

steel grade		1	2	3	4	5	**6**	7	8	9
St.10	*А*	181.2	178.5	174.1	167.1	2.4	22.7	154.5	222.1	257.0
	Б	1.3	12.6	30.9	59.9	1.4	13.8	112.4	182.2	830.4
	В	572.5	563.9	549.9	528.0	751.2	718.5	488.1	350.7	270.6
St.20	*А*	181.2	178.4	173.8	166.5	2.4	22.7	153.5	221.8	258.6
	Б	1.3	13.3	32.4	62.5	1.5	15.0	116.5	183.0	830.4
	В	572.4	563.4	548.8	526.0	751.1	717.3	484.9	350.2	272.3
12X1MF	*А*	181.2	178.3	173.6	166.2	2.4	22.7	153.1	221.3	258.0
	Б	1.4	13.6	33.1	63.7	1.6	15.8	118.4	184.3	830.4
	В	572.4	563.2	548.3	525.1	751.0	716.5	483.5	349.5	271.6
15XM	*А*	181.2	178.2	173.3	165.7	2.4	22.7	152.1	218.8	254.2
	Б	1.4	14.0	34.3	65.9	1.7	16.3	122.3	190.6	830.4
	В	572.4	562.8	547.4	523.4	750.9	716.1	480.5	345.6	267.7
12X18H12T	*А*	181.0	176.5	169.6	159.2	2.4	22.3	142.1	205.4	242.0
	Б	2.1	20.9	49.8	92.9	3.2	29.3	164.1	225.1	830.4
	В	571.8	557.6	535.6	502.9	749.4	703.5	448.8	324.5	254.8
1X18H9T	*А*	181.0	176.5	169.5	159.1	2.4	22.3	142.1	206.0	243.4
	Б	2.2	20.9	50.0	93.2	3.2	29.5	164.2	223.6	830.4
	В	571.8	557.5	535.5	502.7	749.4	703.2	448.7	325.4	256.3

а is the temperature difference on the inner surface ($\Delta T_{wm1} = T(x = 0) - T_{wm1}$), K; *б* is temperature drop in the cylindrical wall ($\delta T = T(x = L) - T(x = 0)$), K; *в* is temperature difference on the outer surface ($\Delta T_{wm2} = T_{wm2} - T(x = L)$), K.

Analyzing the flat and cylindrical walls temperature curves showed in figure 1, as you can see the obtained results correspond to the physical meaning. The high temperatures are on the outer surface, but on the inner surface temperatures are below. The temperature curves from the first to the ninth alternatives are the same qualitatively, but there is their quantitative distinction.

The 1, 2, 3, 4 and 7 temperature curves vertical intercept is particularly useful. This flat wall intercept temperature is the same for all five temperature curves, in spite of the thermal physical properties distinction. At the same time this law may be observed for all six steel grades. This vertical intercept coordinates may be determined by using any two temperature curves, forming this vertical intercept, for various Biot numbers, found from expression (2).



a) b)

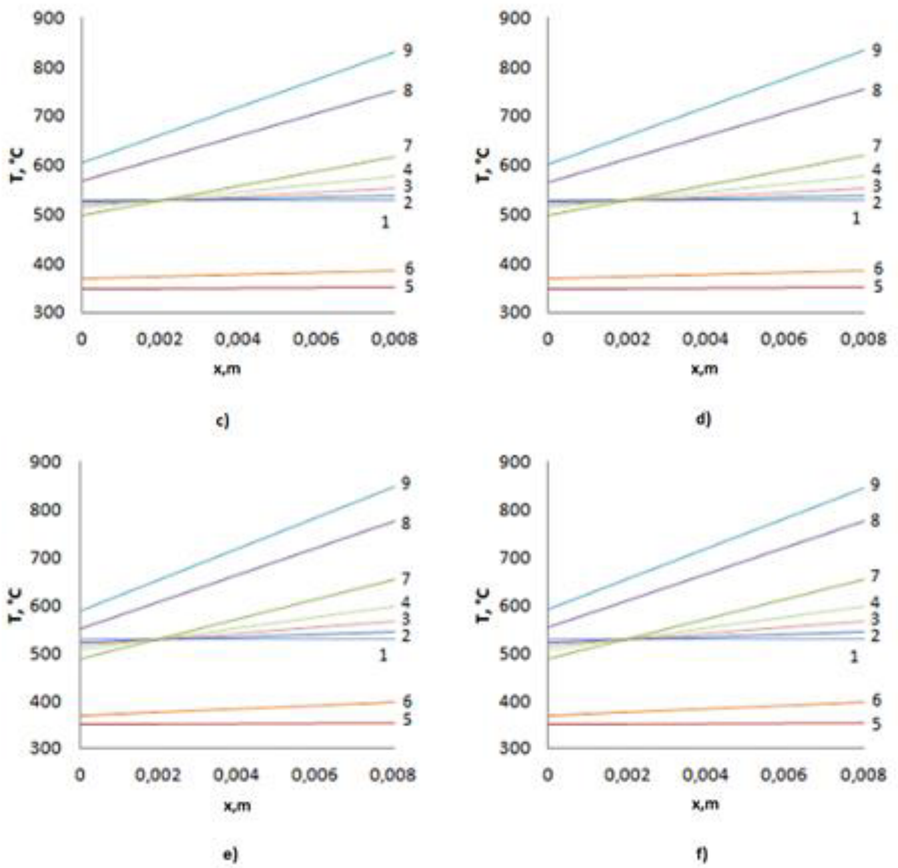


Fig. 1. Plane wall temperature distributions diagrams for steel, K: *a* – St.10; *b* – St. 20; *c* – 12Kh1MF; *d* – 15KhM; *e* – 12Kh18N12T; *f* – 1Kh18N9T.

These mathematical expressions are shown below:

$$x_{v.i.} = \frac{\left[\dfrac{1}{Bi_3 \cdot \left(1 + \dfrac{1}{Bi_4}\right) + 1}\right] - \left[\dfrac{1}{Bi_1 \cdot \left(1 + \dfrac{1}{Bi_2}\right) + 1}\right]}{\left[\dfrac{1}{1 + \dfrac{1}{Bi_1} + \dfrac{1}{Bi_2}}\right] - \left[\dfrac{1}{1 + \dfrac{1}{Bi_3} + \dfrac{1}{Bi_4}}\right]} \cdot \delta;$$

$$T_1(x_{v.i.}) = T_{m1} + \left(T_{m2} - T_{m1}\right) \cdot \frac{\dfrac{x_{v.i.}}{\delta} + \dfrac{1}{\mathrm{Bi}_1}}{1 + \dfrac{1}{\mathrm{Bi}_1} + \dfrac{1}{\mathrm{Bi}_2}};$$

$$T_2(x_{v.i.}) = T_{m1} + \left(T_{m2} - T_{m1}\right) \cdot \frac{\frac{x_{v.i.}}{\delta} + \frac{1}{\mathrm{Bi}_3}}{1 + \frac{1}{\mathrm{Bi}_3} + \frac{1}{\mathrm{Bi}_4}}.$$

$Bi_3 = \left(k\alpha_{m1}\delta\right)/\lambda_2$, $Bi_4 = \left(k\alpha_{m2}\delta\right)/\lambda_2$ are the Biot numbers. λ_1, λ_2 are the heat conductivity coefficients for 1 and 2 temperature curves, respectively, measured in Watt per meter per K. k is the proportional coefficient.

The cylindrical and flat walls vertical intercepts coordinates, determined according (3), are the following: $x_{v.i.} = 0{,}0019$ m, $T(x_{v.i.}) = 802{,}70$ K. For the vertical intercept forming laws determination make calculation, followed below.

Example

BKZ-220-100 steam generator platen superheater.

Steam temperature: $T_{m1} = 619.15$ K.

Flue gases temperature: $T_{m2} = 1374.15$ K.

Material: 1X18H9T steel.

Geometrical characteristics: $x = L_1 = 0$ m, $x = L_2 = 0.008$ m.

Heat-transfer coefficients: 1) $\alpha_{m11} = 348.4$ Wt/(m^2·K), $\alpha_{m21} = 110.3$ Wt/(m^2·K); 2) $\alpha_{m17} = 871$ Wt/(m^2·K), $\alpha_{m27} = 275.75$ Wt/(m^2·K); 3) $\alpha_{m18} = 3484$ Wt/(m^2·K), $\alpha_{m28} = 3309$ Wt/(m^2·K) (Table 1).

Heat conductivity coefficients: 1) $\lambda_1 = 23.49$ Wt/(m·K); 2) $\lambda_7 = 23.62$ Wt/(m·K); 3) $\lambda_8 = 26.59$ Wt/(m·K) [15, 16].

Now figure out the thermal flows ratios supplied to the outer surface and transferred from the inner surface of the cylindrical wall and heat-transfer coefficients and temperature differences ratios on the outer and the inner surfaces, respectively.

Solution

1) Now figure out the thermal flows densities supplied and transferred from the cylindrical wall (Table 2):

a) curve 1

$q_{s1} = \alpha_{m21} \cdot \Delta T_{m21} = 110.3 \cdot 557.5 = 61492.25$ Wt/m^2;

$q_{t1} = \alpha_{m11} \cdot \Delta T_{m11} = 348.4 \cdot 176.5 = 61492.60$ Wt/m^2;

b) curve 7

$q_{s7} = \alpha_{m27} \cdot \Delta T_{m27} = 275.75 \cdot 535.5 = 147664.13$ Wt/m^2;

$q_{t7} = \alpha_{m17} \cdot \Delta T_{m17} = 871 \cdot 169.5 = 147634.50$ Wt/m^2;

c) curve 8

$q_{s8} = \alpha_{m28} \cdot \Delta T_{m28} = 3309 \cdot 256.3 = 848096.70$ Wt/m^2;

$q_{t8} = \alpha_{m18} \cdot \Delta T_{m18} = 3484 \cdot 243.4 = 848005.60$ Wt/m^2.

2) Now figure out the thermal flows densities ratios supplied and transferred from the cylindrical wall:

$Q_{s7}/q_{s1} = 2.40$; $q_{t7}/q_{t1} = 2.40$; $q_{s8}/q_{s1} = 13.79$; $q_{t8}/q_{t1} = 13.79$.

3) Now figure out the heat-transfer coefficients ratios on the outer and the inner wall:

$\alpha_{m27}/\alpha_{m21} = 2.5$; $\alpha_{m17}/\alpha_{m11} = 2.5$; $\alpha_{m28}/\alpha_{m21} = 30$, $\alpha_{m18}/\alpha_{m11} = 10$.

4) Now figure out the temperature differences on the outer and the inner wall:

$\Delta T_{m27}/\Delta T_{m21} = 0.960$; $\Delta T_{m17}/\Delta T_{m11} = 0.960$; $\Delta T_{m28}/\Delta T_{m21} = 0.46$; $\Delta T_{m18}/\Delta T_{m11} = 1.38$.

The example demonstrates the temperature curves with the outer surface supplied heats and inner surface transferred heats equal ratios and platen superheater outer and inner surfaces temperature differences and heat-transfer coefficients equal ratios have vertical intercept.

Conclusions

There are temperature distributions vertical intercepts for steels discussed in the paper. It is possible if there are the outer surface supplied heats and inner surface transferred heats ratios equality and the superheater outer and inner surfaces temperature differences and heat-transfer coefficients ratios equality.

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