# INFLUENCE OF RERADIATION ON THE METAL TEMPERATURE OF FINNED TUBES

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The influence of reradiation of heat on the rise in metal temperature of finned tubes is examined.

Let us number the bodies taking part in radiant heat exchange in a system consisting of a torch and tubes connected by a fin, as shown in Fig. 1.

The set of irradiation coefficients $\varphi_{ik}$, where i is the number of the radiating and k the number of the irradiated body, forms a system of equations

$$\left.\begin{aligned}\varphi_{11}+\varphi_{12}+\varphi_{13}+\varphi_{14}&=1,\\ \varphi_{21}+\varphi_{22}+\varphi_{23}+\varphi_{24}&=1,\\ \varphi_{31}+\varphi_{32}+\varphi_{33}+\varphi_{34}&=1,\\ \varphi_{41}+\varphi_{42}+\varphi_{43}+\varphi_{44}&=1.\end{aligned}\right\} \quad (1)$$

Let us use the recommendations elucidated in [1] to solve the system. Hence, if one of the irradiation coefficients is determined directly, then the rest are calculated in an elementary manner.

Let us select the coefficient of irradiation from the tube (more exactly from an arc of the tube) onto the torch $\varphi_{13}$ as such a directly determined coefficient. This can be done by finding the local irradiation coefficients at points of the arc by a method from [2] and integrating them numerically. Then

$$\varphi_{13}=\frac{1}{\psi_1}\int_0^{\psi_1}\varphi(\psi)\,d\psi=\frac{1}{\psi_1}J,$$

where $J=\int_0^{\psi_1}\varphi(\psi)\,d\psi$; $\varphi(\psi)$ is a function describing the irradiation field of the tube. The solution of the system (1) yields the value of all sixteen irradiation coefficients:

$$\varphi_{23}=\varphi_{13}=\frac{1}{\psi_1}J,$$

$$\varphi_{32}=\varphi_{31}=\frac{1}{2}\frac{d}{S}J,$$

TABLE 1. Values of the Coefficients of the Increase in Irradiation as a Function of the Relative Spacing between Tubes

| $S/d$ | $a$ | | | | | |
|---|---|---|---|---|---|---|
| | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 |
| 1,1 | 1,142 | 1,119 | 1,096 | 1,071 | 1,047 | 1,023 |
| 1,7 | 1,116 | 1,061 | 1,047 | 1,057 | 1,038 | 1,019 |

TABLE 2. Rise in the Spreading Coefficient Taking account of Reradiation

| $a$ | $\Phi^{*}_{\text{tube}}\Delta\mu^{*}_{\pi/2}\frac{1-a}{a}$ | Rise in the spreading coefficient, % |
|---|---|---|
| 0,7 | 0,06 | 11 |
| 0,6 | 0,12 | 17 |
| 0,5 | 0,18 | 24 |

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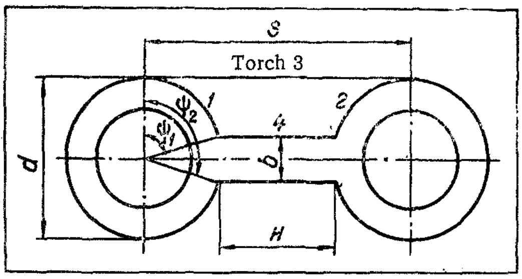

Fig. 1. System of bodies taking part in heat exchange.

$$\varphi_{34}=1-\frac{d}{S}J,$$

$$\varphi_{43}=\frac{1-d/SJ}{1-d/S\sin\psi_1},$$

$$\varphi_{42}=\varphi_{41}=\frac{1}{2}\left(1-\frac{1-d/SJ}{1-d/S\sin\psi_1}\right),$$

$$\varphi_{24}=\varphi_{14}=\frac{J-\sin\psi_1}{\psi_1},$$

$$\varphi_{21}=\varphi_{12}=1-\frac{2J-\sin\psi_1}{\psi_1},$$

$$\varphi_{11}=\varphi_{22}=\varphi_{33}=\varphi_{44}=0.$$

Values of the irradiation coefficients $\varphi_{34}$, $\varphi_{31}$, $\varphi_{41}$, $\varphi_{12}$ and $\varphi_{14}$ as a function of the relative spacing between the tubes S/d and the relative thickness of the fin b/d are represented in Fig. 2.*

For S/d < 1.5 the irradiation of the arc from the torch is higher than the irradiation of the fin. As the relative spacing increases, these quantities converge and for S/d > 1.5 $\varphi_{34} > \varphi_{31}$. Let us note for comparison that the irradiation of the metal wall in [3] exceeds the irradiation of the tube for S/d > 2.5.

The irradiation coefficients from the fin to the tube and from the tube to the tube are quantities of the same order which vary between 0.05 and 0.25. In other words, besides radiant heat from the torch, from 10-50% of the total quantity of heat radiated by the fin and the adjacent tube is incident on an arc of a tube. The coefficient of irradiation of the fin from its two adjacent tubes fluctuates between 0.1 and 0.2, i.e., the fraction of reradiated heat coming to the fin is somewhat lower than for the tubes.

The question of reverse radiation of the fin to the torch is not examined here under the valid assumption that the fin temperature is slight compared with the torch temperature.

Now, let us determine the tube irradiation $\Phi_{\text{tube}}$ and the fin irradiation $\Phi_{\text{fin}}$ taking account of reradiation and the emissivity $a$ of the bodies taking part in the heat exchange:

$$\Phi_{\text{tube}}=\varphi_{31}+(1-a_{\text{fin}})\varphi_{34}\varphi_{41}+(1-a_{\text{tube}})\varphi_{32}\varphi_{21},$$
$$\Phi_{\text{fin}}=\varphi_{34}+(1-a_{\text{tube}})\varphi_{31}\varphi_{14}+(1-a_{\text{tube}})\varphi_{32}\varphi_{24}$$

or, taking account of the solution presented above for the system (1)

$$\begin{gathered}\Phi_{\text{tube}}=[1+(1-a_{\text{tube}})\varphi_{12}]\varphi_{31}+(1-a_{\text{fin}})\varphi_{34}\varphi_{41},\\ \Phi_{\text{fin}}=\varphi_{34}+2(1-a_{\text{tube}})\varphi_{31}\varphi_{14}.\end{gathered}\tag{2}$$

It is interesting to establish how much the values of $\Phi_{\text{tube}}$ and $\Phi_{\text{fin}}$ exceed the quantities $\varphi_{31}$ and $\varphi_{34}$, respectively, which are usually taken in computations in which reradiation is neglected, as in [4-5], for example.

Let us call $\varkappa_{\text{tube}}=\Phi_{\text{tube}}/\varphi_{31}$ and $\varkappa_{\text{fin}}=\Phi_{\text{fin}}/\varphi_{34}$ the coefficients of an increase in irradiation. Then assuming $a_{\text{tube}}=a_{\text{fin}}=a_{\text{torch}}$, we obtain from (2)

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* It is interesting to note the qualitative agreement between the results and the data on irradiation coefficients presented in [3] for a torch–tube–metal wall system.

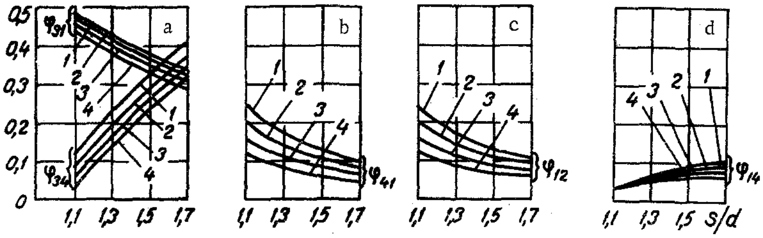

Fig. 2. Irradiation coefficients: 1) b/d = 0.1; 2) 0.2; 3) 0.3; 4) 0,4; a) from the torch to the tube and fin; b) from the fin to the tube; c) from the tube to the tube; d) from the tube to the fin.

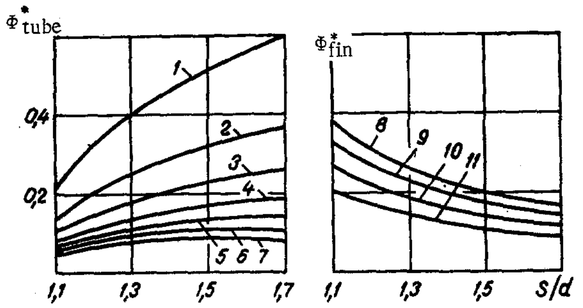

Fig. 3

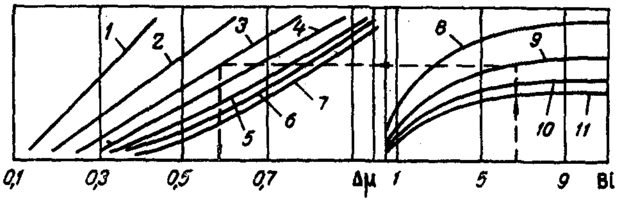

Fig. 4

Fig. 3. Values of the coefficients $\Phi^*_{\text{tube}}$ and $\Phi^*_{\text{fin}}$: 1) b/d = 0.10; 2) 0.15; 3) 0.20; 4) 0.25; 5) 0.30; 6) 0.35; 7) 0.40; 8) 0.10; 9) 0.20; 10) 0.30; 11) 0.40.

Fig. 4. Rise in the spreading coefficient at the point $\pi/2$ of a finned tube ($\Delta\mu_{\pi/2}$): 1) b/d = 0.10; 2) 0.15; 3) 0.20; 4) 0.25; 5) 0.30; 6) 0.35; 7) 0.40; 8) $\beta = 1.2$; 9) 1.4; 10) 1.6; 11) 1.8.

$$\varkappa_{\text{tube}} = 1 + (1 - a_{\text{tube}})\left(\frac{\varphi_{34}\varphi_{41}}{\varphi_{31}} + \varphi_{21}\right),$$

$$\varkappa_{\text{fin}} = 1 + 2\,(1 - a_{\text{torch}})\,\frac{\varphi_{31}\varphi_{14}}{\varphi_{34}}.$$

Computations carried out have shown that the values of $\varkappa_{\text{tube}}$ depend slightly on S/d. This is seen from the values of $\varkappa_{\text{tube}}$ (Table 1): for a relative fin thickness of b/d = 0.2 and for S/d = 1.1 and S/d = 1.7 the relative differences between the magnitudes fluctuates between 0.5 and 5%.

Values of the coefficients of the increase in irradiation of a tube (arc) can be considered independent of the relative spacing between the tubes. The values of the coefficients of the increase in irradiation of the fin are characterized by a dependence on three parameters S/d, b/d, $a_{\text{torch}}$. It follows from the computations carried out that for an emissivity $a_{\text{torch}} > 0.7$ reradiation increases the quantity of incident heat by not more than 7%. Such an increase can be considered small, and taking it into account has very slight practical effect on the metal temperature of a finned tube.

For an emissivity $a_{\text{torch}} < 0.7$ the quantity of heat incident on a tube arc increases by 10-15% as compared with the incident radiant heat of the torch. For fins, particularly thin fins, this increase is still more significant.

Therefore, for an absorptivity of $a_{\text{torch}} \leq 0.7$ characteristic for combustion conditions of a gas or shale, say, the reradiation factor should be taken into account in the considered system of bodies.

Let us examine the temperature change at the fin vertex as a function of taking account of the reradiation factor.

If it is considered, as is assumed in [4, 5], that the heat distribution on the arc under the fin is uniform, then by taking account of (2) we obtain that the supplementary, i.e., that obtained because of reradiation, quantity of heat incident at each point of this arc is

$$q(\varphi) = \frac{1}{2}\cdot 2\,(1 - a_{\text{torch}})\,\varphi_{31}\varphi_{14}\,\frac{S}{r(\psi_2 - \psi_1)}\,q_{\text{incident}} = q_{\text{incident}}(1 - a_{\text{torch}})\,\Phi^*_{\text{tube}}, \tag{3}$$

where

$$\Phi^*_{\text{tube}} = \frac{J(J - \sin\psi_1)}{\psi_1(\psi_2 - \psi_1)}.$$

Let us determine the temperature at the $\pi/2$ point of the tube which originates from the calculated heat flux (3). This can be done by solving the Laplace equation with the boundary conditions

$$\lambda\left.\frac{\partial t}{\partial r}\right|_{r = r_{\text{outer}}} = q(\psi),$$

TABLE 3. Temperature Rise at the Fin Vertex Taking Account of the Reradiation Factor

| $a_{\text{torch}}$ | Excess temperature without reradiation taken into account, °C | Excess temperature with reradiation taken into account, °C | Temperature rise, % |
|---|---|---|---|
| 0,7 | 44,8 | 48,6 | 8,5 |
| 0,6 | | 50,5 | 13,0 |
| 0,5 | | 53,3 | 19,0 |

where $q(\psi) = 0$ for $\psi < \psi_1$ and $\psi > \psi_2$; $q(\psi) = q_{\text{incident}}\,(1 - a_{\text{torch}})\,\Phi^*_{\text{tube}}$ for $\psi_1 \leq \psi \leq \psi_2$,

$$\lambda \left.\frac{\partial t}{\partial r}\right|_{r=r_{\text{inner}}} = \alpha_2 t.$$

The method of solving the equation in this case is no different from that elucidated in [6].

However, it is henceforth more convenient to operate not with the temperature directly, but with the so-called spreading coefficients $\mu = t/t^*$, where t is the true excess temperature of the tube metal at the given point, and $t^*$ is the excess temperature which would occur at an arbitrary point during uniform heating of the tube by the heat flux $q_0 = q_{\text{incident}}\,a_{\text{torch}}$ = idem, i.e.,

$$t^* = a_{\text{torch}}\,q_{\text{incident}}\left(\frac{r_{\text{outer}}\ln\beta}{\lambda} + \frac{\beta}{\alpha_2}\right).$$

Performing simple manipulations, we obtain that the supplementary quantity of heat which is a result of reradiation by thermal energy at the fin, will cause a temperature rise at the $\pi/2$ point of the tube equal to

$$\Delta t_{\pi/2} = q_0\,\frac{1 - a_{\text{torch}}}{a_{\text{torch}}}\,\Phi^*_{\text{tube}}\,\Delta\mu_{\pi/2}\,\beta\left(\frac{\delta}{\lambda}\cdot\frac{2}{\beta+1} + \frac{1}{\alpha_2}\right),$$

where in confirmity with the definition of the spreading coefficient $\Delta\mu_{\pi/2} = \Delta t_{\pi/2}/t^*$. (The values of $\Phi^*_{\text{tube}}$ and $\Delta\mu_{\pi/2}$ are presented in Figs. 3 and 4.)

The rise in the spreading coefficient taking account of reradiation is shown in Table 2.

Furthermore, considering the distribution of the reradiated heat over the fin to be uniform, we obtain that the supplementary quantity of heat is

$$\frac{d/SJ\,(J - \sin\psi_1)\,S q_{\text{incident}}(1 - a_{\text{torch}})}{\psi_1\,(S - d\sin\psi_1)} = q_{\text{incident}}(1 - a_{\text{torch}})\,\Phi^*_{\text{fin}},$$

where

$$\Phi^*_{\text{fin}} = \frac{J\,(J - \sin\psi_1)}{\psi_1\,(S/d - \sin\psi_1)}.$$

(The values of $\Phi^*_{\text{fin}}$ are presented in Fig. 3.)

Determining the temperature drop between the point $\pi/2$ of the tube and the vertex of the fin, as has been proposed in [5], we obtain, in our notation, that the increase of the mentioned drop due to reradiation is

$$\Delta t_{\text{в}} = q_0\,\frac{1 - a_{\text{torch}}}{a_{\text{torch}}}\,\Phi^*_{\text{fin}}\,\frac{H}{2\lambda}\left(\frac{H}{2b} + \frac{3b}{H}\right).$$

In conclusion, let us present results on a computation of the temperature at the fin vertex with reradiation taken and not taken into account for the following parameters: S = 48 mm; $d_{\text{outer}}$ = 32 mm; $\delta$ = 6 mm; b = 8 mm; $\alpha_2 = 10^4$ kcal/m$^2$·h·deg, $\lambda$ = 29 kcal/m$^2$·h·deg, $q_0 = a_{\text{torch}}\,q_{\text{incident}} = 10^5$ kcal/m$^2$·h (Table 3).

Considering a temperature rise more than 5% to be substantial, we should arrive at the deduction that for $a_{\text{torch}} \leq 0.7$ a computation of the temperature field of finned tubes must be carried out taking account of a single reradiation. Taking further account of reradiation is almost meaningless since it will not result in a noticeable temperature rise.

## NOTATION

| | |
|---|---|
| $\psi_1$ and $\psi_2$ | angles of fin and tube junction, rad; |
| $r_{\text{outer}}$ | outer tube radius, m; |
| $q(\psi)$ | heat flux distribution function in the tube; |
| $q_{\text{incident}}$ | specific incident heat flux, $\text{kcal/m}^2\cdot\text{h}$; |
| $\alpha_2$ | coefficient of heat exchange from the wall to the medium flowing in the tube, $\text{kcal/m}^2\cdot\text{h}\cdot\text{deg}$; |
| $\lambda$ | coefficient of heat conduction, $\text{kcal/m}\cdot\text{h}\cdot\text{deg}$; |
| $\delta$ | tube wall thickness, m; |
| H | total fin height, m; |
| b | fin thickness, m. |

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