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Simulation of heat losses and temperature of blast furnaces tuyeres

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Abstract. The calculation technique of heat losses and temperature, adapted to blast furnaces tuyeres is described. Using a linear excel program the effect of gas-thermal coating and insulation lining on thermal state of the blast tuyere was studied. Problems of the blast tuyeres hardening and reducing heat losses through their surface are relevant, but finding ways of the blast tuyeres hardening and reducing heat losses through their surface by simulation of the thermal state of blast furnaces tuyeres are carried out. Key words: blast tuyere, blast furnace, tuyere nose, air passage, internal nozzle, gas-thermal coating, insulation lining.

1 Introduction

Blast tuyere is a key constructional element of blast furnace, determining its running efficiency. For this reason the furnace downtime leads to considerable reduction of iron smelting and increasing coke consumption. Besides, blast tuyeres account for 30% of all heat losses in furnance. So the problems of the blast tuyeres` hardening and reducing heat losses through their surface are relevant. While under normal condition of blast-furnace operation through a tuyere nose, external and internal nozzles of tuyeres flow 18, 36 and 46% respectively [1].

At the present time the given problems are solved by different ways: applying gas-flame sprayed coatings on an external surface of tuyere and lining-up by firebrick from the direction of air passage [2], applying heat-resisting backfill on an external surface of tuyere [3, 4] and others.

For further thinking on the ways of the blast tuyeres` hardening and reducing heat losses through their surface, simulation of thermal state of blast furnaces tuyeres is useful [5-7].

Let us use a calculation procedure of heat losses through blast tuyere [8]. In work the steady heat conduction formulae for flat and cylindrical wall were used [9, 10].

2 Research technique and results

Heat transfer through tuyeres surface is:

$$Q = Q_n + Q_r + Q_d = Q_n + Q_{rn} + Q_{rt} + Q_v + Q_{rv} = K_n^* \cdot (t_g - t_v) \cdot H_n + K_{rn}^*(t_g - t_v) \cdot (H_{rn} - h_{rt}) + K_{rt} \cdot (t_g - t_v) \cdot S_{rt} + K_v^* \cdot (t_d - t_v) \cdot H_v + K_{rv}^* \cdot (t_d - t_v) \cdot (H_{rv} - h_{rt})$$

where Q_n, Q_r, Q_d is the heat transfer through external nozzle, tuyere nose (from outside and cross-cut end) and from side of air passage respectively, W;

Q_{rn}, Q_{rt}, Q_v, Q_{rv} is the heat transfer through external surface of tuyere nose, butt end of tuyere nose, internal nozzle and tuyere nose from side of air passage respectively, W;

K_n^*, K_{rn}^*, K_v^*, K_{rv}^* is the testing heat-transfer rate through external nozzle, external surface of tuyere nose, internal nozzle of tuyere and tuyere nose from the side of air passage respectively, W/(m·K);

K_{rt} is the heat-transfer rate through butt end of tuyere nose, W/(m2·K);

t_g, t_d is tuyere temperature in iron receiver and hot blast temperature respectively, °C;

t_v is water temperature in tuyere, °C;

H_n, H_v, H_{rn}, H_{rv} is the length of external nozzle, internal nozzle, nose outside tuyere and tuyere nose from the side of air passage respectively (fig.1), m;

h_{rt} is the thickness of cross-cut end of tuyere nose (fig.1), m;

S_{rt} is the area of butt end of tuyere nose, m^2.

$$\frac{K_n^*}{2 \cdot \pi} = \frac{1}{\frac{1}{\alpha_{gn} \cdot R_n^*} + \sum_{i=1}^{m} \frac{1}{\lambda_i} \cdot \ln \frac{R_{nj}}{R_{nj+1}} + \frac{1}{\lambda_{Cu}} \cdot \ln \frac{R_n}{R_n - h_n} + \frac{1}{\alpha_v \cdot (R_n - h_n)}}$$

where α_{gn} is coefficient of heat-exchange to external nozzle from gas forge, W/(m2·K);

$$R_í^* = R_í + \sum_{i=1}^{m} h_i \ , ì$$

$$R_{í1} = R_í^* \ , ì$$

$$R_{í_j} = R_í^* - \sum_{i=1}^{j-1} h_i \ , ì$$

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$$R_{f_{j+1}} = R_f^* - \sum_{i=1}^{j} h_i \,, \grave{\imath}$$

$$j = 1, \ldots m$$

R_n is the midradius of external nozzle from the side of furnace, m;

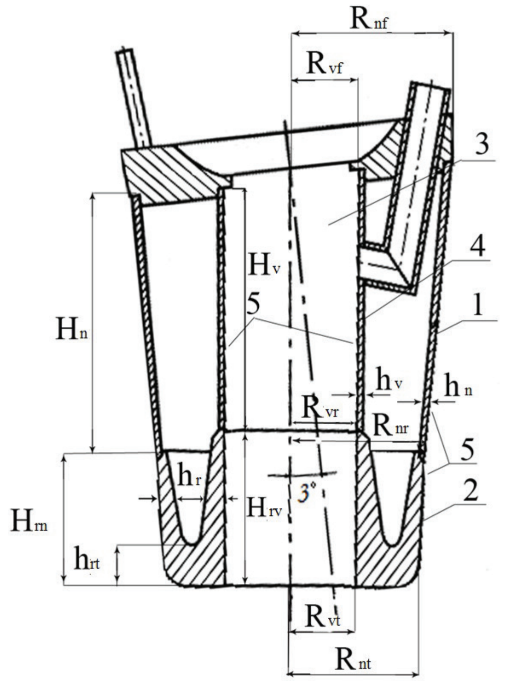

Fig. 1. Longitudinal section of blast tuyere:1- external nozzle, 2- tuyere nose,3- air passage, 4- internal nozzle, 5- covering

$$R_n = \frac{R_{nr} + R_{nf}}{2}$$

R_{nr}, R_{nf} is the radius of external nozzle from the side of furnace against tuyere nose and flange respectively (fig.1), m;

h_n, h_i is the thickness of external nozzle and i- coating material respectively (fig.1), m;

λ_{Cu}, λ_i is the heat conduction coefficient of cuprum M1 and i-coating material respectively W/(m·K);

m is the allotment of covering materials (layers);

α_v is the coefficient of heat-transfer from tuyere wall to water, W/(m^2·K).

$$= \frac{\frac{K_{rn}^*}{2 \cdot \pi}}{\frac{1}{\alpha_{gr} \cdot R_{rn}^*} + \sum_{i=1}^{m} \frac{1}{\lambda_i} \cdot \ln \frac{R_{rnj}}{R_{rnj+1}} + \frac{1}{\lambda_{Cu}} \cdot \ln \frac{R_{rn}}{R_{rn} - h_r} + \frac{1}{\alpha_v \cdot (R_{rn} - h_r)}}$$

where α_{gr} is the coefficient of heat-transfer of tuyere nose from gas forge W/(m^2·K);

$$R_{rn}^* = R_{rn} + \sum_{i=1}^{m} h_i$$

$$R_{rn1} = R_{rn}^*$$

$$R_{rnj} = R_{rn}^* - \sum_{i=1}^{j-1} h_i$$

$$R_{rnj+1} = R_{rn}^* - \sum_{i=1}^{j} h_i$$

$$j = 1, \ldots m$$

R_{rn} is the midradius of tuyere nose from the side of furnace, m;

$$R_{rn} = \frac{R_{nr} + R_{nt}}{2}$$

R_{nt} is the radius of tuyere nose against tuyere`s cross-cut end (fig.1), m;

h_r is the average thickness of tuyere nose without butt end thickness considering, m.

$$K_{rt} = \frac{1}{\frac{1}{\alpha_{gr}} + \sum_{i=1}^{m} \frac{h_i}{\lambda_i} + \frac{h_{rt}}{\lambda_{Cu}} + \frac{1}{\alpha_v}}$$

where h_{rt} is the thickness of cross-cut end of tuyere nose, m.

$$= \frac{\frac{K_v^*}{2 \cdot \pi}}{\frac{1}{\alpha_d \cdot R_v^*} + \sum_{i=1}^{m} \frac{1}{\lambda_i} \cdot \ln \frac{R_{vj+1}}{R_{vj}} + \frac{1}{\lambda_{Cu}} \cdot \ln \frac{R_v + h_v}{R_v} + \frac{1}{\alpha_v \cdot (R_v + h_v)}}$$

where α_d is the coefficient of heat-transfer from hot blow to tuyere wall, W/(m^2·K);

$$R_v^* = R_v - \sum_{i=1}^{m} h_i$$

$$R_{v1} = R_v^*$$

$$R_{vj} = R_v^* + \sum_{i-1}^{j-1} h_i$$

$$R_{vj+1} = R_v^* + \sum_{i=1}^{j} h_i$$

$$j = 1, \ldots m$$

$$R_v = \frac{R_{vr} + R_{vf}}{2}$$

R_{vr}, R_{vf} is the radius of internal nozzle from the side of air passage against tuyere nose and flange respectively (fig.1), m;

h_v is the thickness of internal nozzle (fig.1), m.

$$= \frac{\frac{K_{rv}^*}{2 \cdot \pi}}{\frac{1}{\alpha_d \cdot R_{rv}^*} + \sum_{i=1}^{m} \frac{1}{\lambda_i} \cdot \ln \frac{R_{rnj+1}}{R_{rvj}} + \frac{1}{\lambda_{Cu}} \cdot \ln \frac{R_{rv} + h_r}{R_{rv}} + \frac{1}{\alpha_v \cdot (R_{rv} + h_r)}}$$

where,

$$R_{rv}^* = R_{rv} - \sum_{i=1}^{m} h_i$$

$$R_{rv1} = R_{rv}^*$$

$$R_{rvj} = R_{rv}^* + \sum_{i=1}^{j-1} h_i$$

$$R_{rvj+1} = R_{rv}^* + \sum_{i=1}^{j} h_i$$

$$j = 1, \dots m$$

$$R_{rv} = \frac{R_{vr} + R_{vt}}{2}$$

R_{vt} is the radius of air passage against cross-cut end of tuyere (fig.1), m.

$$S_{rt} = \pi \cdot (R_{nt}^2 - R_{vt}^2)$$

Methods of temperature calculation on different surfaces of blast tuyere with using steady heat conduction formulae through a cylindrical and flat multiple-layer wall is as follows [10]:

-For external nozzle:

Temperature on the surface of the first coating`s layer from the side of furnace is:

$$t_{g-1} = t_g - \frac{K_n^* \cdot (t_g - t_v)}{2\pi \cdot \alpha_{gn} \cdot R_n^*}$$

Temperature at the joint of j and j+1 coating`s layers or coating`s layer and external nozzle:

$$t_{j,j+1} = \\ = t_g - \frac{K_n^* \cdot (t_g - t_v)}{2\pi} \cdot \left(\frac{1}{\alpha_{gn} \cdot R_n^*} + \sum_{i=1}^{j} \frac{1}{\lambda_i} \cdot \ln \frac{R_{nj}}{R_{nj+1}} \right)$$

Temperature on the surface of external nozzle from the side of water is:

$$t_{n-v} = t_v + \frac{K_n^* \cdot (t_g - t_v)}{2\pi \cdot \alpha_v \cdot (R_n - h_n)}$$

- For tuyere nose from the furnaces side:

Temperature on the surface of the first coating`s layer from the side of furnace is:

$$t_{g-1} = t_g - \frac{K_{rn}^* \cdot (t_g - t_v)}{2\pi \cdot \alpha_{gn} \cdot R_{rn}^*}$$

Temperature at the joint of j and j+1 coating`s layers or coating`s layer and tuyere nose:

$$t_{j,j+1} = \\ = t_g - \frac{K_{rn}^* \cdot (t_g - t_v)}{2\pi} \cdot \left(\frac{1}{\alpha_{gr} \cdot R_{rn}^*} + \sum_{i=1}^{j} \frac{1}{\lambda_i} \cdot \ln \frac{R_{rnj}}{R_{rnj+1}} \right)$$

Temperature on the surface of tuyere nose from the side of water is:

$$t_{rn-v} = t_v + \frac{K_{rn}^* \cdot (t_g - t_v)}{2\pi \cdot \alpha_v \cdot (R_{rn} - h_r)}$$

- For cross-cut end of tuyere nose from the furnaces side:

Temperature on the surface of the first coating`s layer from the side of furnace is:

$$t_{g-1} = t_g - \frac{K_{rt} \cdot (t_g - t_v)}{\alpha_{gr}}$$

Temperature at the joint of j and j+1 coating`s layers or coating`s layer and tuyere nose:

$$t_{j,j+1} = t_g - K_{rt} \cdot (t_g - t_v) \cdot \left(\frac{1}{\alpha_{gr}} + \sum_{i=1}^{j} \frac{h_i}{\lambda_i} \right)$$

Temperature on the surface of tuyere nose from the side of water is:

$$t_{rt-v} = t_v + \frac{K_{rt} \cdot (t_g - t_v)}{\alpha_v}$$

- For internal nozzle:

Temperature on the surface of the first coating`s layer from the side of air passage is:

$$t_{d-1} = t_d - \frac{K_v^* \cdot (t_d - t_v)}{2\pi \cdot \alpha_d \cdot R_v^*}$$

Temperature at the joint of j and j+1 coating`s layers or coating`s layer and internal nozzle:

$$t_{j,j+1} = \\ = t_d - \frac{K_v^* \cdot (t_d - t_v)}{2\pi} \cdot \left(\frac{1}{\alpha_d \cdot R_v^*} + \sum_{i=1}^{j} \frac{1}{\lambda_i} \cdot \ln \frac{R_{vj+1}}{R_{vj}} \right)$$

Temperature on the surface of internal nozzle from the side of water is:

$$t_{v-v} = t_v + \frac{K_v^* \cdot (t_d - t_v)}{2\pi \cdot \alpha_v \cdot (R_v + h_v)}$$

- For tuyere nose from the side of air passage:

Temperature on the surface of the first coating`s layer from the side of air passage is:

$$t_{d-1} = t_d - \frac{K_{rv}^* \cdot (t_d - t_v)}{2\pi \cdot \alpha_d \cdot R_{rv}^*}$$

Temperature at the joint of j and j+1 coating`s layers or coating`s layer and tuyere nose:

$$t_{j,j+1} = \\ = t_d - \frac{K_{rv}^* \cdot (t_d - t_v)}{2\pi} \cdot \left(\frac{1}{\alpha_d \cdot R_{rv}^*} + \sum_{i=1}^{j} \frac{1}{\lambda_i} \cdot \ln \frac{R_{rvj+1}}{R_{rvj}} \right)$$

Temperature on the surface of tuyere nose from the side of water is:

$$t_{rv-v} = t_v + \frac{K_{rv}^* \cdot (t_d - t_v)}{2\pi \cdot \alpha_v \cdot (R_{rv} + h_r)}$$

By the calculation methods of heat losses through tuyere surface and temperature a linear excel program has been developed. With this program it was calculated the heat losses of blast tuyere`s surface and temperature on tuyere`s details for conditions DP-5 OJSC “NLMK”. The values of heat-transfer coefficient had been calculated according to experimental data, were used [11].

We take t_g =16000 ºC; t_d =11500 ºC; t_v = 300 ºC; h_n = 7,0 mm; h_r = 16,0 mm; h_{rt} = 45,0 mm; h_v=5,0 mm; h_i= 1,5 mm; λ_{Cu} = 415,6562 W/(m·K); λ_i = 29,8891 W/(m·K); $\alpha_{gn} = \alpha_{gr}$ = 133,745 W/(m2·K); α_d = 465,2 W/(m^2·K); α_b = 5815 W/(m^2·K); R_{nr} = 154 mm; R_{nf} = 185 mm; R_{nt} =

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140 mm; R_{vr} = 72,5 mm; R_{vf} = 72,5 mm; R_{vt} = 72,5 mm; H_n = 305 mm; H_{rn} = 145 mm; H_{rv} = 167 mm; H_v = 283 mm.

Taking into account that the heat guard inside of air passage finds wide application [12, 13], it was a study on the thickness effects of insulation lining on heat losses through surface of air passage and it was obtained temperature distribution from water-cooled hole of tuyere to air passage (fig.2-3).

As a comparison, it was calculated heat losses through air passage with aluminum gas-thermal coating. Fig. 2 shows the presence of insulation lining has a significant effect on reduction of heat losses through air passage than application of aluminum coating. Creation of air gap between it and internal nozzle leads to additional reduction of heat losses. Besides, the more thickness of insulation lining, installed without gap in air passage, the less heat losses through air passage. If the insulation lining was installed with gap the thickness has little effect on heat losses through air passage.

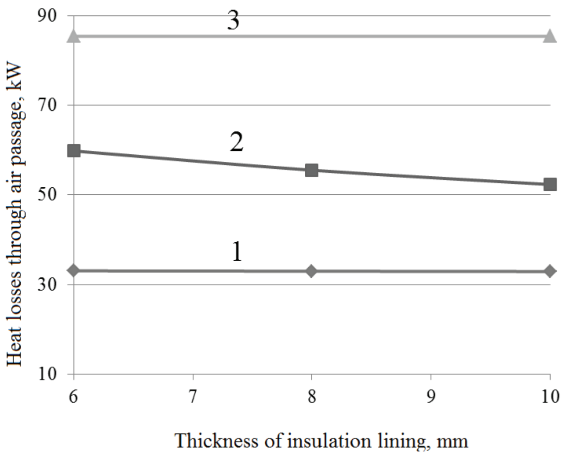

Fig. 2. Dependence of heat losses through air passage on thickness of insulation lining: 1– h_v=0,6 mm; 2– h_v=0 mm; 3– h_{Al} =1,5 mm; λ_{inl}.=3 W/(m·K), λ_v=0,0362 W/(m·K), λ_{Al} =29,8891 W/(m·K)

According to figure 3, it is observed the steep gradient of temperature between the insulation lining and internal nozzle in air gap via its low conductivity, so that the temperature of the insulation lining is higher and temperature of the internal nozzle is lower than in the absence of gap between them. In terms of lining`s life the heavy gradient of temperatures on its thickness in the absence of gap may cause of the appearance of high thermoelastic stresses, expediting its destruction [14, 15].

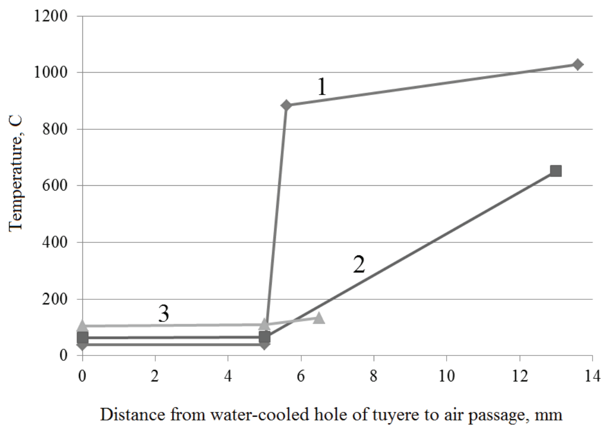

Fig. 3. Temperature distribution from water-cooled hole of tuyere to air passage: h_v =5 mm; 1– h_v=0,6 mm, h_{inl}=8 mm; 2– h_v=0 mm, h_{inl}=8 mm; 3– h_{Al} =1,5 mm; λ_{inl}=3 W/(m·K), λ_v=0,0362 W/(m·K), λ_{Al} =29,8891 W/(m·K)

3 Conclusion

The calculation technique of heat losses and temperature was adapted to blast furnaces tuyeres. Using a linear excel program the effect of gas-thermal coating and insulation lining on thermal state of the blast tuyere was studied.

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