МЕТАЛУРГІЯ СТАЛІ

УДК 669.187.243

© Kharlashin P.S.[1], Voloshin V.S.[2], Asseel Mohammed Kadhim[3], Havalic Y.B.[4]

RESEARCH ON RELATION OF HEAT AND OTHER FACTORS THAT INFLUENCE THE GAS SUSPENSION FLOW IN THE GUNITE LANCE OF THE 160T CONVERTER

The position of a blast tube for supply of gas-powdered mixture and oxygen in the lance with different levels of the outflow. Using such constructive solution gas suspension is heated from the wall of the lance's body by means of convective heat flow, delivered by the wall to the carrier gas. there is no danger in its heat-up through the separating wall of the line because the temperature t_w of the wall of the lance's body, but increasing of the temperature O_2 is recommended. In order not to let the line of the oxygen blast tube in the moment of the 90° turn of the gas-powdered flow wear out. The results of numerical calculations of the equilibrium two-phase flow in the gunite lance with the extraction of the gunite mass at different levels along its length are shown that with such a constructive solution pressure, velocity and density change in leaps and bounds. Also shown that if the body becomes heat exchanger, the energy potential of the gas-dispersed flow significantly changes. It is recommended to perform the pipe of the lance stepped in order to reduce the loss of the compressed gas suspension flow.

Keywords *gunite lance, energy potential, gas suspension flow.*

Харлашин П.С., Волошин В.С., Ассиил Мохаммед Кадхим, Хавалиц Ю.В. Исследование соотношений между теплом и другими факторами, влияющими на течение газовзвеси в торкрет фурме 160-тонного конвертера. *В работе рассмотрен элемент газоохлаждаемой торкрет-фурмы, из которого видно, как расположены сопла для подачи газопорошковой смеси и кислорода в фурме с различными уровнями расхода. При таком конструктивном решении газовзвесь нагревается от стенки корпуса фурмы за счет конвективного теплового потока, передаваемого стенкой несущему газу. За счет термического сопротивления температура t_{12} газовзвеси будет всегда ниже, чем температура t_w стенки корпуса фурмы, но повышение температуры O_2 желательно. Чтобы не допустить износ трубки кислородного сопла в момент поворота газопорошкового потока на 90°, следует предусмотреть установку керамических вставок. Представлены результаты численных расчетов двухфазного равновесного течения в торкрет-фурме с выводом части торкрет- массы на разных уровнях по ее длине. Показано, что при таком конструктивном решении давление, скорость, плотность газовзвеси изменяются скачкообразно. Показано, что если корпус фурмы становится теплообменником, то энергетический потенциал газодисперсного потока существенно возрастает. Рекомендовано, для уменьшения потерь потенциала сжатого потока газовзвеси трубу ствола фурмы выполнять ступенчатой.*

Ключевые слова: *фурма, энергетический потенциал, течение газовзвеси.*

Харлашин П.С., Волошин В.С., Асіїл Мохаммед Кадхім, Хавалиць Ю.В. Дослідження співвідношень між теплом та іншими факторами, що впливають на

---

[1] *Dr. tech. of sciences, Prof., Priazovskyi State Technical University, Mariupol, azov@online.ua*
[2] *Dr. tech. of sciences, Prof., Priazovskyi State Technical University, Mariupol, azov@online.ua*
[3] *Ph.D. candidate, Priazovskyi State Technical University, Mariupol, azov@online.ua*
[4] *Ph.D. candidate, Priazovskyi State Technical University, Mariupol, azov@online.ua*

течію газосуспензії у торкрет-фурмі 160-т конвертера. *В роботі розглянуто елемент газоохолоджуємой торкрет-фурми, з якого видно, як розташовані сопла для подачи газосуспензії та кисню в фурмі з різними рівнями витрат. При такому конструктивному рішенні газосуспензія нагрівається від стінки корпусу фурми за рахунок конвективного тепловову потоку, що передається стінкою газу носію. За рахунок термічного супротиву температура t_{12} газосуспензії завжди буде нижче, ніж температура t_w стінки корпусу фурми, однак підвищення температури O_2 бажане. Щоб не допустити зношення трубки кисневого сопла у момент повороту потоку газосуспензії на 90°, слід передбачити установку керамічних вставок. Представлені результати численних розрахунків двохфазной рівноважної течії у торкрет-фурмі з виводом частини торкрет- маси на різних рівнях по її довжині. Показано, що при такому конструктивному рішенні тиск, швидкість, щільність газосуспензії змінюються стрибкообразно. Показано, що якщо корпус фурми стає тепловим обмінником, то енергетичний потенціал газо-дисперсної течії значно зростає. Тому, щоб зменшити втрати у течії газосуспензії, рекомендується зробити трубу фурми ступінчастою.*

Ключові слова: *фурма, енергетичний потенціал, течія газосуспензії.*

Description of the problem. During implementing of the high technology in the metallurgy must reducing the expenses on energy and resources. Also must to increase lining life in the oxygen converters during steel production. We used during experimental-industrial analysis of lining slagging, gas-cooled gas-powder lance. nitrogen is warmed during movement in the stem. It is also proved that if gas suspension is warmed, it is more efficient to use gas-cooled lance with the body as a heat exchanger. in the new technical solution earlier lost warmth can be used for gas suspension warm-up in the lance and increase of its energy potential during gas-dust flowage in the converter's void space. Besides, at present technologies are developed and in accordance with these new technologies before lining shotcreting junk is put in the empty converter, and coal - on top of it. Coal penetrates into formless junk, firing and space burning occurs from the shotcrete flame's warmth. Usage of part of the earlier lost warmth of the flame for junk warm-up enhances heat balance of the following melting. Alos there was developed a mathematic model of gas suspension flow in the lance for blow of liquid-alloy considering velocity non-equilibrium of the phases, besides there were taken into account particle collision with the walls, non-standard heat supply to the flow through channel's walls, heat-up of the gas and particles in the lance. It should be noticed that double-speed and dual-temperature model of the gas suspension flow must be used for coarse powder.

Analysis of the last researches and publications. At trial approbation slag lining used gas-cooled gas-powder lance, while driving in the trunk of heated nitrogen. If you heat the gas suspension, it is advisable to use a gas-cooled lance body which acts as a heat exchanger. The relevance of the technical solution is obvious - previously lost by heat can be used to heat the gas suspension in the lance and increase its energy potential at the end of the gas-dust flow into the cavity of the converter. In addition, the technology currently being developed, in which the lining before gunning into an empty converter scrap poured and poured it on top of the coal. Coal enters into a shapeless mass of scrap from the heat of the flame sprayed is its ignition and combustion volume. The use of the previously lost heat torch to heat the scrap improves the thermal balance of the next heat. A mathematical model of the flow of the gas suspension in the lance for blowing the melt with the velocity nonequilibrium phase, which takes into account particle collisions with the walls, unsteady heat supply to flow through the channel walls, heating gas and particles in the lance. Note that the two-speed and two-temperature model of the flow of the gas suspension should be used for coarse powder.

The objective of the article. The aim is to show the way heat supply from the heated wall of the shotcrete lance with changeable gas suspension outflow, also to show how influences of mass powder concentration (μ), outflow change m_{12} on different levels, pressure p, mixture velocity w_{12} along the length l of the lance, also density ρ_{12}, volume ratio ε_2 of the solid phase in the transverse section of the lance.

Basic material. The number experiment was executed relating to the shotcrete lance of the 160t converter from one of plant in Mariupol, the calculations were performed using following basic data: inner hydraulic diameter of the tube of the shotcrete lance D = 98 mm, the length of the lance in the area of high temperature l = 12 m, outflow of the carrier gas (N_2) is V = 480 m³/h, powder outflow was changed within the range m_2 = 200-800 kg/min, where mass concentration corresponded μ = 40-80 kg/kg [1]. It was given that particles' heat capacity c_2 = 800 kJ/(kg.K), equivalent diameter of particles and their density δ_2 = 0,05 mm, ρ_2 = 1900 kg/m³, a number of blast tubes on the same level n = 2, quantity of levels z_1 = 3, inner diameter of the blast tube D_0 = 39 mm, distance to the upper level of the blast tubes l_1 = 1,5 m, equivalent undulation of the lance's tube Δ = 0,06 mm, Mehaelidis coefficient of the losses K = 0,06, coefficient of the lance's finish part. The temperature of the wall of water-cooled lance's body was t_w=30°C the temperature of the dust-gas flow in input t_1 = 27°C. The quantity of checkout nodes N_1 = 600. In this work heat exchange between high-temperature gas of the converter's cavity and outer wall of the lance's body wasn't calculated, and it only was calculated equal t_w = 30-700°C.

If the body of the shotcrete lance is gas-cooled, i.e. it works as a heat exchange, than intensive heat transfer occurs from high-temperature flare of the converter's cavity to gas-disperse flow through separating wall of the lance with given temperature t_w.

Mathematic model: the equation system for gas-disperse flow in one-velocity and one-temperature we can write in this form:

- Motion equation

$$\frac{d}{dx}(G_{12}w_{12}) = -\frac{dp}{dx} - F_w + \rho_{12}g - \chi w_{12}\,; \tag{1}$$

- Energy equation

$$\frac{d}{dx}(G_{12}c_{p_{12}}T) = w_{12}\frac{dp}{dx} + Q_w - \chi c_{p_{12}}T\,. \tag{2}$$

While mixture moving by the openings of the blast tubes in the channel $\chi \neq 0$:

$$\chi = n_i G_i / D. \tag{3}$$

In the equations (1) - (3) there are following markings of the parameters of equilibrium flow of the gas suspension (pseudo gas): G_{12} - given outflow, kg/(sm²); w_{12} - flow velocity, m/s; p – statistic pressure, Pa; F_w - frictional force of pseudo gas along the wall of the blast tube of the lance's body, N/m³; ρ_{12} - density, kg/m³; χ - intensity of decreasing mixture outflow along the length of the channel, kg/(cm³); $c_{p_{12}}$ - heat capacity, kJ/(kg.K); T – statistic temperature, K; Q_w - quantity of the heat, delivered by the convection from the wall to the gas suspension, Watt/m³; n_i - quantity of tube blasts on the i level; D – inner diameter of the shotcrete lance, m.

Heat exchange intensity of the carrier medium with channel's wall is defined with the equation

$$Q_w = \frac{4St}{D}\rho_{12}c_p w_{12}\frac{T_w - T_1}{D_e T_1} \approx T_{01}\,. \tag{4}$$

Where Stanton criterion *St=Nu/(RePr)* for high-velocity subsonic flow is calculated with Guhman formula

$$St = 0{,}0167/(Re_{12}Pr_{12})^{-0{,}18}(T_{01}/T_w)^{0{,}35}. \tag{5}$$

The calculation was made with the following conditions: the temperature, T_w of the tube's wall was given, and it stayed constant along the whole length *l* of the lance. Naturally, the temperature t_{12} along the length of non-water-cooled shotcrete lance's body grows along the length *l*.

The force F_w, that characterizes adhesion on the wall while gas suspension is in the tube, can be defined with Darcy-Weisbach formula [2].

$$F_w = \zeta_{12}\rho_{12}w_{12}^2/(2D) = \zeta_{12}Gw_{12}/(2D)\,; \qquad \zeta_{12} = \zeta_1 + \zeta_2\,. \tag{6}$$

The coefficient of hydraulic losses ζ_1, taking into the account gas adhesion on the channel's walls, can be calculated with Altshool formula

$$\zeta_1 = 0.11(\Delta/D + 0.68/\mathrm{Re}_{12})^{0.5}\,; \qquad \mathrm{Re}_{12} = Dw_{12}\rho_1/\eta\,, \tag{7}$$

where Δ – height of undulation bumps, m; D – diameter of a tube, m; ρ_1 – density of a carrier gas, kg/m³; η – coefficient of gas dynamic viscosity – carrier, Pa.s.

For calculation of the coefficient of hydraulic losses ζ_2, driven by disperse phase, the best results give Mehaelidis formula [5], in which the calculations are performed through Froude number

$$\zeta_2 = K\mu / \mathrm{Fr}_{12}^{0.5}, \qquad \text{where Froude number} \qquad \mathrm{Fr}_{12} = w_{12}^2 / (gD). \tag{8}$$

An empiric coefficient of the losses of Mehaelidis K depends on particles' material and wall's material. There were given results of experiment (≈600 p.) and were found values of the coefficient K for steel tubes, which depending on oiling ability of the material (glass, coals and others) changes in the limits K = 0,041 – 0,194. For a system "steel tube – coal powder" K = 0,058.

For solving equation system (3-5) border conditions are given: in input of the lance (x = 0) – outflow of both phases $G_{12} = G_1 + G_2$, the temperature T_{01}, in output (x = l) – counter pressure p.

<u>*Calculations' results and their analysis:*</u> Using the method mentioned above, we show the influence of defining factors, including hardly predictable, with the example of the fuel and flame-proof powder's flow in the shotcrete lance of the 160t converter [3, 4].

Length of the lance l. gas suspension heats up intensely, its density ρ_{12} falls and solving the continuity equation $m_{12} = \rho_{12} w_{12} f = const$ makes it necessary to raise the pressure *p* along the whole length *l*. when the temperature *t* of the wall rises,

When density ρ_{12} of gas suspension lowers, its velocity w_{12} somewhat increases in the shotcrete lance and pressure p rises in front of blast tubes' blocks on different perspectives of the shotcrete lance (fig. 1).

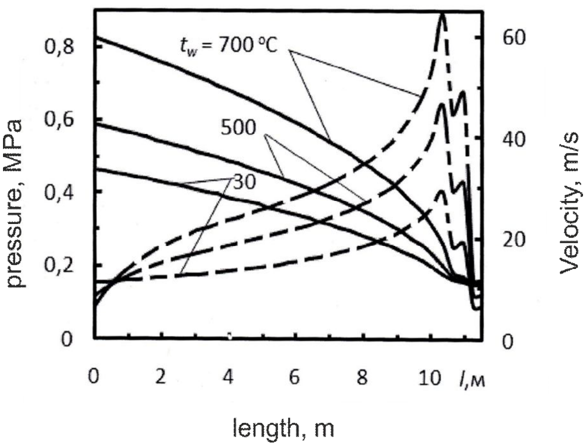

Fig. 1 – Influence of the temperature t_w of the tube's wall on the reticulation of the static pressure *p* (-) and velocity w_{12} (--) of the gas suspension along the length *l* of the shotcrete lance with 3 levels of the outflow

The most interesting processes for the lance with variable outflow occurs in the finish part of the lance, where gas suspension is withdrawn on several horizons. Unlike preceding pictures, let us look into details of the specifics in the flow along the length of the lance l = 8,5 – 12 m, which could not be presented on the preceding parts.

The (fig. 1) shows that gas suspension heat-up completely changes the gas-powder flow movement in the lance.

leads to considerable increase of so called heat resistance of the flow movement which calls for pressure raising *p* from 0,46 MPa to 0,82 MPa. Under these conditions.

On the one hand, this velocity increase is caused by the equation of the impact transformation, and, on the other hand, it corresponds with the continuity equation $m_{12} = \rho_{12} w_{12} f = const$.

The (fig. 2) also shows that velocity w_{12} increases when temperature t increases. For example, on the distance l = 9,5 m if the temperature t_w of the wall of lance's tube increases from 30°C to 700°C, than velocity w_{12} increases from 22 m/s to 45 m/s. These values t correspond with the temperature of the gas suspension t_{12} = 30°C and t_{12} = 697°C.

The results on the (fig. 2) show correct calculations with usage of mathematic model. For example, if the lance is made with several levels of withdrawal for gas suspension outflow, than parameters in the blast tube block with several horizons of the powder draw will not be subject to famous objective laws for a case with constant outflow m_{12}. For example, with temperature t = 700˚C gas suspension's velocity on the area from 8 m to 10,3 m gas-disperse mixture speeds up, and then velocity abruptly falls down to minimum – 64,4 m/s to 44,7 m/s, and in the second level, which is 61 mm behind the preceding one, velocity falls down from 48 m/s to 12,1 m/s and so on (fig. 2).

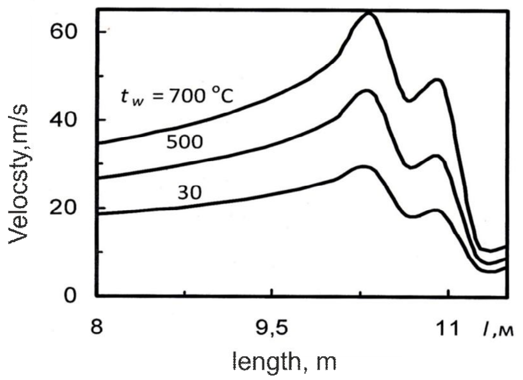

Fig. 2 – Velocity change w_{12} along the length l of the tube with variable outflow of the powder m_2 on 3 levels at different temperature t of the wall of t he shotcrete lance

Concentration of the shotcrete body μ. The (fig. 3) shows that with concentration μ increase pressure p before the lance grows at any temperature t. At the same time concentration μ increase pressure in the lance's input considerably grows. For example, when t increases from 30˚C to 700˚C pressure p increases from 0,59MPa to 0,9 MPa.

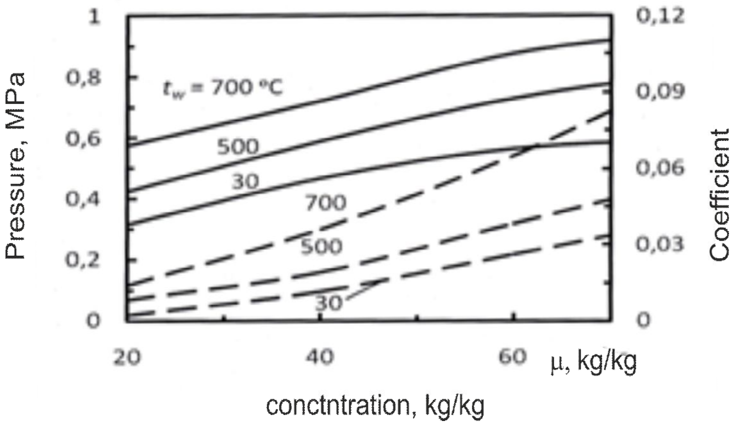

Fig. 3 – Influence of temperature t of the wall and concentration μ of powder on the change of pressure p (-) before the lance and volume concentration (--) before the blast tube block

As we see in the (fig. 3) volume ratio of the solid phase ε_2 increases if μ as well increases at any temperature of the wall t_w. leads to increase of the volume ratio of the solid phase ε_2. It is caused by the fact that $\varepsilon_2 = \left(1 + \frac{\psi}{\mu} \cdot \frac{\rho_2}{\rho_1}\right)^{-1}$ with μ increase and all other equal conditions, coefficient ε_2 only increases. It also results from the continuity equation $m_2 = \varepsilon_2 \rho_2 w_2 F = const$ as t with μ increase only decreases and ε_2 increases.

The velocity w_{12} of gas suspension with concentration decrease μ lowers at any temperature t_w of the wall of the lance's body (fig. 4). It is caused by resulting from the continuity equation $m_1 = \rho_{12} w_1 F = const$. density ρ_{12} increases from 39 kg/m³ to 90 kg/m³ under same conditions. As for density ρ_{12}, resulting from the pseudo gas condition $m_1 = \rho_1(1+\mu)$ – the more μ is, the higher value of ρ_{12} is. For example, at t = 500˚C with μ increase from 20 kg/kg to 80 kg/kg leads to increase of ρ_{12} from 40 kg/m³ to 90 kg/m³.

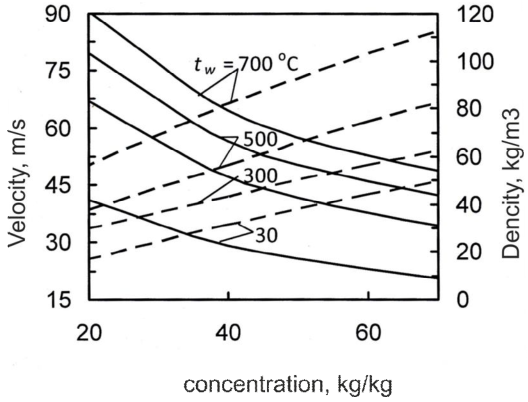

Fig. 4 – Influence of mass concentration μ of the powder on the velocity change w_{12} (-) of the gas suspension and its density ρ_{12} before the first level of the outflow m_{12} (l = 10,34 m) at different temperature t_w of the lance's wall

The temperature t_w of the lance's wall. Specialists take considerable interest in the influence δ on allocation of thermal-gas-dynamic parameters during gas suspension flow in the lance. The (fig. 5) shows that with δ increase velocity w_{12} increases as well. For example, when the tube's wall is heated up to 700˚C, 10 times δ increase, from 0,01 mm to 0,1 mm, velocity w_{12} double increases from 46 m/s to 91 m/s. It is caused by the fact that when δ increases, for example, 10 times, than mid-phase surface of the adhesion 100 times decreases.

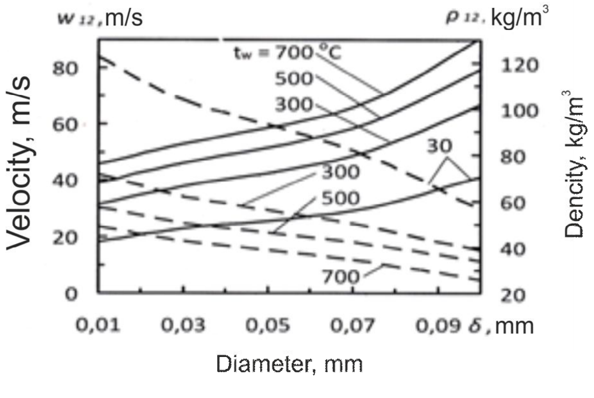

Fig. 5 – Velocity change w_{12} of the gas suspension and its density z depending on the diameter of the powder's particles at different temperature t of the wall of the shotcrete lance's body

With the same diameter of δ temperature increase leads to w_{12} increase. For example, when δ = 0,07 mm and temperature of the wall t increases from 30˚C to 700˚C the flow w_{12} speeds up from 30 m/s to 65 m/s, gas suspension density ρ_{12} decreases from 91 kg/m³ to 33 kg/m³. It results from pseudo gas formula $\rho_{12} = (p_1 / RT_1)(1+\mu)$ – the higher T_1 of the carrier gas is, the lower ρ_{12}.

It is seen in (fig. 6) that if concentration μ is controlled by the gas outflow V_n, the picture changes drastically. As in the regimes previously researched, gas suspension velocity w_{12} along the length of the lance l = 0 – 10 m increases at any value of μ. It follows from the impact inversion law, on one hand, and, on the other, – from the continuity equation $m_1 = \rho_{12} w_{12} f = \rho_1 (1+\mu) w_{12} f = const$, in accordance with which pressure P and density ρ_1 lowers on the length of the lance, and the flow only speed up.

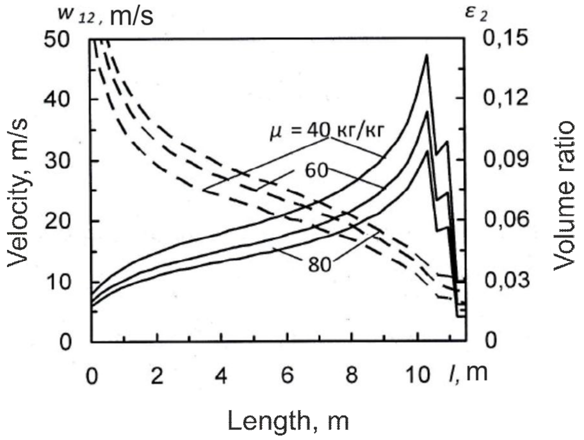

Fig. 6 – Influence of the powder concentration μ on allocation of the gas suspension velocity $w_{12\,v}$(-) and volume ratio ε_2 along the length l of the shotcrete lance with 3 levels of the outflow

<u>Verification of the results from numerical research.</u> In the lance, it is quite difficult to perform a physical experiment, situated in the converter's cavity. So if:

- Its required that density be lowers and pressure be higher for gas carrier heat up, to provide the same outflow of less dense gas through the tube of the constant flow (fig. 1, 3).
- Impact conversion law subsonic flow in the tube of constant section with carrier gas heats up, only speed up with $m_{12} = const$.
- Along the length l of the lance's tube, the velocity of the flow of gas suspension should lower (fig. 1, 2).
- the flow speeds up if the diameter δ of the powder increases (lowering of quantity of particles in gas suspension) (fig. 5).

laws of movement of gas-powder flows in the tubes, completely corresponds with received objective laws of gas disperse flow in the shotcrete lance. And the results of given research are representative.

Conclusions

1. Usage of algebraic and differential equations with Numerical researches on the gas suspension flow in the shotcrete lance allowed to get allocation of parameters of gas-disperse flow –pressure P, velocity w_{12}, density ρ_{12}, volume ratio of the solid phase ε_2, at any random section of the shotcrete lance considering several levels of shotcrete mass draw out.
2. Used equations of movement and energy are of high informational capacity – they help to consider threshold nature as of gas suspension flow as well as of heat exchange on several horizons of the lance with variable outflow.
3. than energy potential of gas-powder flow before the blast tube block of the shotcrete lance considerably grows, If the body of the shotcrete lance is heat exchanger, and aero-dynamic characteristics of the shotcrete flare improve.

Bibliography:

1. Sigaryov E.N. Numerical research of thermal-gas-dynamic peculiarities of the converter's lining shotcreting / E.N. Sigaryov, A.G. Chernyatevich, E.A. Chubina // High Institutes. Black metallurgy. – 2007. – №2. – P. 60-67. (Rus.)
2. Voloshin A.I. The mechanics of loose materials' pneumatic conveying / A.I. Voloshin, B.V. Ponomaryov. – Kyiv: Scientific thought. – 2001. – 521 p. (Rus.)

3. Development of lance's apparatus and technology of gas-powder slagging of the 160t converters' lining JSC «Arselor Mittal Kryvyi Rih» / E.N. Sigaryov [and others] // Metallurgic and metal mining industry. – 2010. – №7. – P. 134-137. (Rus.)
4. Theory and practice of flare shotcreting of the 160t oxygen converters' lining / P.S. Kharlashin, A.A. Larionov, A.K. Kharin, N.O. Chemeris // New refractory materials. – 2010. – №7. – P. 5-9. (Rus.)
5. Mehaelidis E.E. Particles movement in the gas flow. Middle velocity and pressure losses / E.E. Mehaelidis // Theoretical basis of engineer calculations. – 1988. – №1. – P. 276-288. (Rus.)

Reviewer: V.A. Maslov
Dr. tech. of sciences, Prof., Priazovskyi State Technical University

Received 26.11.2014

УДК 669.187.2

© Скребцов А.М.[1], Хлестов В.М.[2], Качиков А.С.[3], Секачев А.О.[4], Терзи В.В.[5]

СТРУКТУРА ЗАТВЕРДЕВШЕГО МЕТАЛЛА КАК НАСЛЕДСТВЕННОЕ СВОЙСТВО ХИМИЧЕСКОГО СОСТАВА ЖИДКОГО РАСПЛАВА

Обнаружено, что при плавке стали в электропечи действие компонентов расплава на наследственную структуру затвердевшего металла зависит от химического состава металла. Разработан показатель стабильности ферритной структуры стали с использованием электроотрицательности элементов.

Ключевые слова: *жидкая сталь, наследственная структура твердого, неравновесность структуры, феррит, перлит.*

Скребцов О.М., Хлестов В.М., Качіков О.С., Секачов О.О., Терзі В.В. Структура затвердiлого металу як спадкове властивість хімічного складу рідкого розплаву. *Виявлено, що при плавці сталі в електропечі дію компонентів розплаву на спадкову структуру затвердiлого металу залежить від хімічного складу металу. Розроблено показник стабільності ферритной структури сталі з використанням електронегативності елементів.*

Ключові слова: *рідка сталь, спадкова структура твердого, неравновесность структури, ферит, перліт.*

O.M. Skrebtsov, V.M. Khlestov, O.S. Kachikov, O.O. Sekachev, V.V. Terzi. The structure of the solidified metal as an inherited property of the chemical composition of the liquid melt. *It is found that when melting steel in an electric furnace to melt components acting upon the inherited structure of the solidified metal depends on its chemical composition. The experiments were performed in a 20 - ton electric arc furnace for smelting peritectic steel of the following composition: 0.17 - 0.25 C%; 0,90 - 1,4 Mn%; 0,30 -0,50 Si%; ≤ 0,030 S%; ≤ 0,040 P%; ≤ 0,30 Cr%; ≤ 0,30 Ni%; ≤ 0,60 Cu%; 0,07-0,13 V%. For metallographic studies all samples were subjected to standard metal annealing to eliminate the influence of microstructure on inherited sufficiently rapid cooling from the liquid state. From annealed samples prepared Micro-sections that etched in a 4% solution of nitric acid. With an increase from 100 to 500-fold sections were examined on an*

---

[1] *д-р техн. наук, профессор, ГВУЗ «Приазовский государственный технический университет», г. Мариуполь*
[2] *канд. техн. наук, доцент, ГВУЗ «Приазовский государственный технический университет», г. Мариуполь*
[3] *аспирант, ГВУЗ «Приазовский государственный технический университет», г. Мариуполь, aleksej.sergeevich@mail.ru*
[4] *аспирант, ГВУЗ «Приазовский государственный технический университет», г. Мариуполь*
[5] *ст. лаборант, ГВУЗ «Приазовский государственный технический университет», г. Мариуполь*