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THEORETICAL AND PRACTICAL ASPECTS OF PNEUMATIC POWDER INJECTION INTO LIQUID ALLOYS WITH A NON-SUBMERGED LANCE

TEORIA I PRAKTYKA WDMUCHIWANIA PROSZKÓW DO CIEKŁEGO METALU LANCĄ NIEZANURZONĄ

The method of powder injection into molten metal has been widely known since tens of years and successfully utilized in various metallurgical processes. The most common is a solution with injection lance submerged under the liquid alloy surface, because it is easier apart from some of disadvantages of this approach. In this paper the authors' complex experiments on the pneumatic injection process with non-submerged lance have been presented. The new approach on jet cone angle importance and its influence on the efficiency of the injection process has been shown. The issue of the effective jet radius that was proposed by former scientists as well as computer modelling and injection experiments recorded with high speed camera have been presented. The final comparison of the typical injection lance and developed by authors new lance with flange was presented, too. The benefits of use of a new one for the treatment of small liquid alloy volume (e.g. inoculation or alloys addition introduction) have been pointed.

Keywords: Powder Injection, Injection Lance, Pneumatic Conveying, Cast Iron Treatment, High Speed Camera

Technologia wdmuchiwania proszków do ciekłego metalu jest znana od kilkudziesięciu lat i z powodzeniem stosowana w różnorodnych procesach metalurgicznych i odlewniczych. Zdecydowanie najczęściej stosowane jest rozwiązanie z użyciem lancy zanurzonej pod lustro obrabianego stopu, jako łatwiejsze choć nie pozbawione wielu istotnych wad. W pracy zaprezentowano zakończone kompleksowe badania autorów nad procesem wdmuchiwania proszków bez zanurzania lancy w kąpieli. Przedstawiono nowe spojrzenie na tzw. „kąt stożka rozejścia strumienia" i jego wpływ na skuteczność procesu, przeanalizowano zagadnienie tzw. „skutecznego promienia strumienia" proponowanego przez wcześniejszych badaczy oraz opisano wyniki badań symulacyjnych oraz eksperymentów wdmuchiwania, zarejestrowanych z użyciem kamery do szybkich zdjęć. Podjęto się także ostatecznego porównania rozwiązań lancy zwykłej i opracowanej przez autorów tzw. „lancy kołnierzowej" wskazując na zalety tej drugiej, jako narzędzia do obróbki niewielkich objętości ciekłych stopów np. w procesach wprowadzania żelazostopów czy też modyfikacji.

1. Introduction

The most important factor of the production of any goods is apart from final price their quality. To ensure it is always at the same high level a lot of quality tools and methods have been developed as was mentioned among the others in [1,2]. But the quality tools are only a way of production management and still the most important in so-called heavy industry are materials, their properties [3-7] and the processing methods [8-11]. One of the methods of liquid alloy processing is pneumatic powder injection which is often the best way to fast and uniform distribution of various additions. Additionally the method could be used to utilize the industrial wastes as it was analyzed in [12]. The most important advantage of this technique is high efficiency of the process i.e. high yield of alloy addition being introduced. But as usually there are some disadvantages or limits of the method and it is especially a matter of powder injection with non-submerged lance. In such case the problem of proper gas-solid particles jet penetration into liquid appears so the dynamics of the jet must be well analyzed and estimated. That is why many authors have made research on the character of diphase jet motion what has resulted in many measuring method as it was mentioned in [13-16]. The authors of the paper have started their own experiments on the character of the jet released by the injection lance in the case of non-submerged lance. They have developed a mathematical model of the jet pointing the importance of so-called effective jet radius which decides of the jet's ability to penetrate liquid as well as have verified the slip coefficient of solid particles against the gaseous phase. Additionally, using the same high-class equipment the powder injection experiments have been carried out to finally prove the advantages of invented new lance with flange.

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2. Research methodology

The experiments were a part of a complex and thorough experimental plan based on many previously published author's researches [17-20]. The main aim of this approach was to verify the numerical model developed in earlier experimental stage and presented in [21]. The final results of the mathematical considerations presented there was the formula developed under conditions proposed by Waghulde in [22] and applied to the problem of powder injection with non-submerged lance:

$$r_s = 0,45\sqrt{zd_l\frac{w_{gl}}{w_{go}}} \tag{1}$$

where: r_s – effective jet radius, z – distance from the injection lance outlet, d_l – lance inner diameter, w_{gl} – gas velocity on the lance outlet, w_{go} – gas velocity in the jet centre (axis).

The graphic explanation of the critical jet radius r_s is presented on the Fig. 1. The gas or gas-solid jet released by the injection lance is spreading so the jet cone angle increases. In some area the gas velocity finally reaches value of 0 but earlier the jet has no ability to penetrate the liquid. The r_s value describes the jet area which is still quite stable and uniform and possess high enough velocity to distribute inside liquid volume. The boundary condition was estimated as:

$$w_{gr_s} = 0,1w_{go} \tag{2}$$

where: w_{grs} – gas velocity for the effective jet radius r_s.

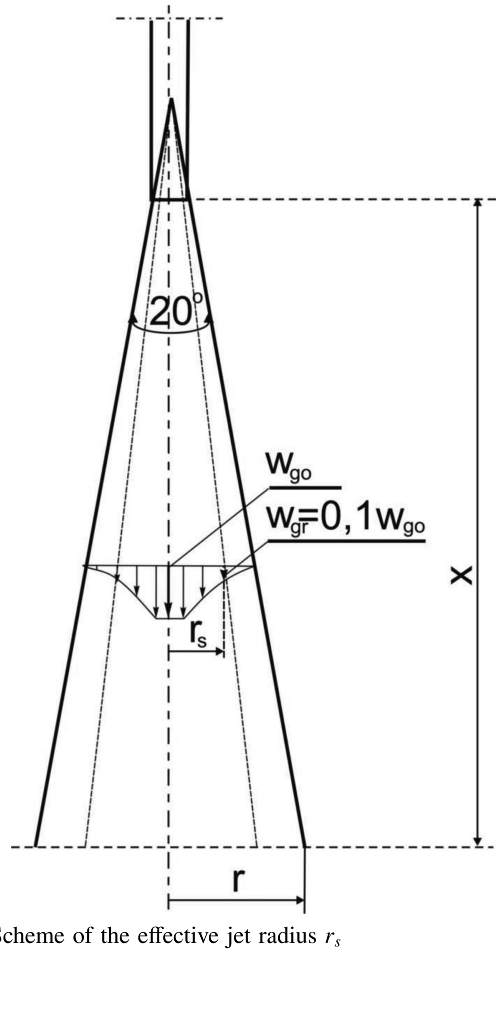

Fig. 1. Scheme of the effective jet radius r_s

After the jet radius analysis the jet cone angle was analyzed with use of data captured by high speed camera and thorough image analysis with use of Tema Motion Lite dedicated software was performed. The research stand was similar to this presented in [21] and in Fig. 2. The results of the experiments have been presented in chapter 3.

Then the powdered ferroalloy FeSi75 injections into liquid cast iron were carried out. The high speed camera was pointed exactly on the bath surface to observe the moment when jet attacks the surface to penetrate it deeply. Some typical results were presented further in the paper.

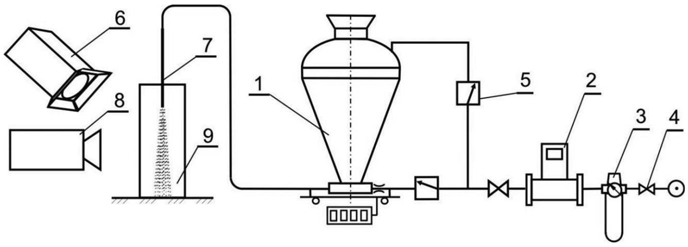

Fig. 2. The research set-up for two-phase jet recording: 1- pneumatic feeder, 2- gas flow meter, 3- pressure reducer, 4- shut-off valve, 5- gas pressure inside feeder reducer, 6- halogen lamp, 7- injection lance, 8- high speed camera, 9- powder receiver [21]

3. Results analysis

The mathematical model was validated during the experiments in which the real gas velocity was measured with use of anemometer moving the probe along the axis (z distance from lance outlet) and along the radius (perpendicularly to the jet axis). Fig. 3 presents the gas velocity w_g as a function of r_s for the 1m long lance of 0,008m inner diameter for the various z values. The analysis of the formula (1) regarding to the data from Fig. 3 has shown good correlation between the model and experimental data.

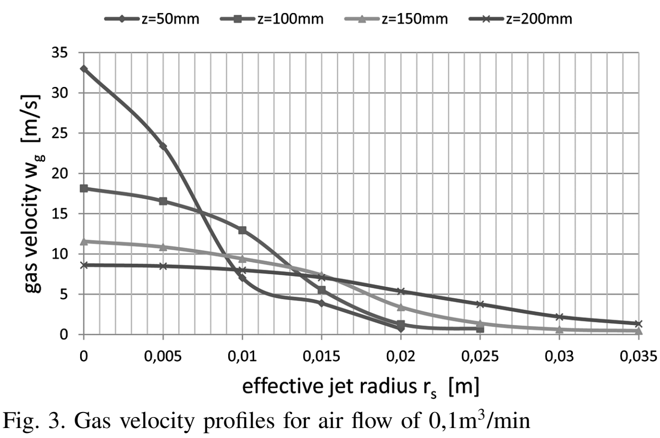

Fig. 3. Gas velocity profiles for air flow of 0,1m^3/min

The curves shape analysis has shown that the jet has spread in line with the formula (1). Moreover, the analysis of the images and graphs of FeSi grains displacement made possible to estimate the jet cone angle as it was shown in Fig. 4.

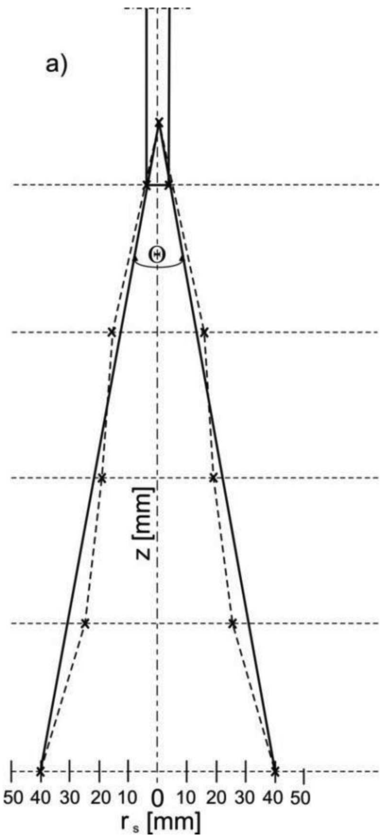

Fig. 4. The gas jet cone angle for the flow of $0{,}1m^3$/min

The authors' results have shown that the jet cone angle is much bigger for smaller jet velocity than it was mentioned by other scientists and what has been shown in Fig. 5 where the comparison between authors' and literature data [23] was presented.

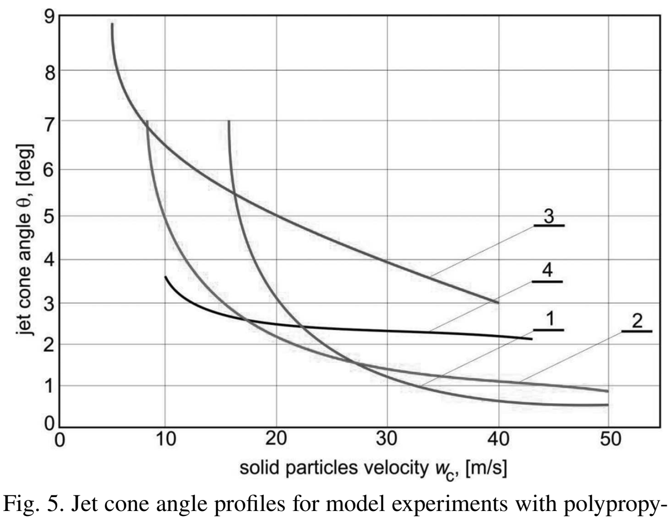

Fig. 5. Jet cone angle profiles for model experiments with polypropylene powder (1), FeSi powder (2), polystyrene powder (3) and polystyrene given by literature [23] (4)

The last part of the experiments was real pneumatic injection process again with assistance of high speed camera. The sample image for the good pneumatic parameters (ensure the jet penetration inside the liquid metal) is presented in Fig. 6. A pressure p_1 it is a pressure of carrier gas flowing through the mixing chamber at the bottom of pneumatic feeder, a pressure p_4 it is a pressure inside the feeder above the powdered material being pneumatically transported.

Fig. 6. Gas-ferroalloy particles penetration into liquid cast iron: left – simple steel lance for p_1 = 0,2MPa i p_4 = 0,08MPa, right – new lance with a flange p_1 = 0,2MPa i p_4 = 0,14MPa

4. Conclusions

The results presented in the paper have drawn to the following confusions:

– the diphase gas-solid particles jet character may be properly described by efficient jet radius which shows the borders of the uniform and stable jet flow. The particles inside the described area should have good dynamics to penetrate liquid,
– the gas and gas-solids jet profiles show good accuracy regarding to mathematical model being developed. The experiments proved the jet cone angle values for gas only flow given in the subject literature but for the diphase jet, the angles seem to be much higher for the lower gas velocity range. It is important from industrial applications point of view, because the jet conical shape with the angle as small as possible is sometimes critical for the powder injection process with use of non-submerge lance.
– the solid particles velocity is much lower than expected on the basis of previously reported experimental results. It seems that slip coefficient of solid phase against the gaseous one is much lower than literature data suggest. The result is that in injection conditions the gas velocity on the lance outlet should be higher to ensure that final solids velocity will be appropriate to penetrate the liquid.
– the technological parameters (mostly efficiency) of the injection process for the new lance with flange are more or less the same as for typical steel lance. The advantage of the new lance is lower temperature decrease and less carrier gas volume being introduced into liquid metal.

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