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(54) AN IMPROVED LANCE FOR LD STEELMAKING

VERBESSERTE LANZE FÜR DIE LD-STAHLHERSTELLUNG

LANCE AMELIOREE POUR LA PRODUCTION D'ACIER SELON LE PROCEDE LD

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Description

FIELD OF APPLICATION:

[0001] The present invention generally relates to an improved lance for LD steelmaking. In particular the invention relates to a multi-hole lance design with a central separately-controllable subsonic nozzle for varying the generation of liquid metal droplets according to the process requirement.

BACKGROUND OF THE INVENTION:

[0002] Steel is produced through many processes such as basic oxygen furnace (BOF) process, electric arc furnace (EAF) process, Kaldo process, etc. Of these, the basic oxygen furnace (BOF) or LD steelmaking process is widely used in the world presently due to the effectiveness of the process and the quality of the steel produced. LD steelmaking process is a purification process of liquid pig iron that contains, along with very high percentage of iron, carbon, phosphorus, magnesium, manganese, aluminium, etc as principal impurities. These impurities are removed by oxidation reactions using gaseous oxygen as the oxidizer. The oxygen gas is introduced into the LD vessel by means of multiple supersonic jets through a water-cooled lance with a copper head. Further, argon gas is introduced through tuyres at the bottom of the vessel to stir the liquid metal thoroughly. This process of blowing oxygen gas from the top through the lance and injecting argon through the bottom is called combined blowing process.

[0003] The refining process within the LD vessel can be summarized in the following way. Liquid pig iron is charged into the vessel along with metal scraps. These metal scraps can easily be melted because most of the reactions taking place in the LD vessel are exothermic reactions and the whole LD steelmaking process is an auto-generation process, i.e. it requires no external supply of heat. Lime (CaO), as a flux, is also added according to the required basicity ratio defined as the gravimetric ratio of lime to silica (CaO/SiO_2) and the blowing of oxygen gas onto the liquid metal is started. The impurities are oxidized and the oxides, other than the oxides of carbon, form the liquid slag that floats on top of the liquid metal. Carbon is oxidised as carbon mono-oxide (CO) gas that passes through the liquid slag. Due to this, the slag layer swells in volume and forms what in general, called as "slag foam". The slag foam comprises of liquid slag, gases evolving from the liquid metal and the liquid metal droplets thrown into the vessel due to the impact of the oxygen jets on the liquid metal surface. The foam thus formed, occupies a large volume of the vessel completely covering the lance head and partly the lance itself. The foam creates a large interfacial area between the liquid metal and the slag and thereby promotes interfacial reactions such as dephosphorization.

[0004] Since the LD steelmaking process is highly dynamic and the conditions inside the vessel continuously change during the oxygen blowing period, the control of the oxygen lance is imperative. So, the oxygen lance is operated at different lance heights to control the intensity of impingements of the supersonic jets. The lance height is defined as the distance of the lance tip at any instance to the flat liquid metal surface before the start of the blow. At the start of the blow, the prime interest of the steelmaker is to form the liquid slag quickly and dissolve the charged lime completely. It is felt that hard blow or lesser lance height will be disadvantagesous because the oxidation of the carbon is not preferred in this stage. So, the lance is operated at a higher height, say for example, the initial lance height is 2.2 m.

[0005] During the initial period, the slag starts forming with the required chemical and physical properties. Now, it is necessary to create a foamy slag by producing more CO gas by oxidizing carbon since only the foamy slag can increase the interfacial area between the slag and metal and thereby promoting the important reaction of dephosphorization. So, the lance height is reduced to give a hard blow. The reduced height can be around 1.5 m. At this stage, the creation of metal droplets is also of great importance as far as the dephosphorization reaction is concerned. Mostly, the lance is operated in this shorter height for most of the blow to promote the oxidation of carbon.

[0006] During the last stages of the blow, the carbon percentage in the steel is very low and the generation of CO gas is reduced to a great extent. The slag is no longer foamy because of the absence of the generation of CO gas and it is understood that a thick liquid slag layer is formed on top of the metal surface. The hard blow and the creation of liquid metal droplets in this stage are not preferred due to similar reasons mentioned in the earlier stages of the blow. So, the lance height is increased again to the initial lance height to give a softer blow.

[0007] From the above discussions, it is clear that the physical requirements of the lance changes completely during the blow into the LD vessel. At some stages of the blow, droplet generation is of prime importance and at some other stages, the liquid metal droplet generation can be disadvantageous and detrimental to the operation of LD vessel. It is clear that the lance plays a much greater role than the simple supplier of oxygen gas into the vessel. Proper design of the lance and control during the blow can greatly improve the efficiency of the steelmaking process and enhance the quality of steel produced thereby.

[0008] The lance is made up of copper and has a detachable head where the nozzles are fixed. The oxygen is blown into the vessel with supersonic velocities in the range of Mach number 2.0-2.4 through the nozzles. The number of supersonic nozzles in the lance is decided based on the size of the vessel, mass of the charge and the other operating conditions. A typical lance can have 6 supersonic nozzles with an angle of inclination from the vertical axis of 17.5° to minimize jet coalescehce. The nozzles are designed to produce the supersonic jets with the exit Mach number of 2.2. All the nozzles have a single supply of oxygen at the pressure of 13.5 bar. The employed lance is water-cooled to protect it from the hot temperature within the LD vessels.

[0009] A need was felt to improve the dephosphorization within the LD vessel. As already stated, the lance design and control during the blow will have a substantial effect on the steel making process and on improving the quality of steel produced.

[0010] FR 1,346,214 discloses a lance for blowing oxygen for use in steel refining comprising a plurality of gas conduits.

SUMMARY OF THE INVENTION:

[0011] One object of the present invention is to improve the liquid metal droplet generation to increase the slag-metal interfacial area for improving the dephosphorization within the LD vessel. Since dephosphorization is essentially an interfacial reaction between the slag and metal, increasing the metal droplets would enhance the dephopshorization efficiency. In the present invention therefore, an effort has been made to improve the droplet generation in LD vessel. The metal droplets formation is essentially the function of the lance. Thus, in order to improve the generation of metal droplets, the function of the oxygen jets have to be considered carefully under steelmaking conditions or very close to such conditions.

[0012] It has been found that the provision of a central hole in the oxygen lance creates a lot of metal droplets and causes spitting. Spitting is disadvantageous because it might cause the blockage of the vessel mouth and further reduce the life of the lance and the vessel lining. So, though the central hole can produce a lot of droplets, it has disadvantages also.

[0013] Apart from improving the droplet generation, the central hole has a further advantage that was hitherto unknown in steel industry. The effect of high density slag foam on the supersonic jet characteristics in the LD vessel was considered. It has been found that the slag foam absorbs all the momentum supplied by the oxygen jets and the jets lose the momentum completely to the slag. Thus the existing knowledge on the supersonic oxygen jet characteristics within the LD vessel can be considered to be wrong. Although the droplet generation studies done using hydrodynamic models of LD vessels will not reveal the true mechanisms of droplet production within the LD vessel, they provide the basis for improved understanding of the droplet formation. Since the peripheral jets are exposed to the slag foam, they are expected to lose all the momentum to the slag layer through the jet-slag foam interface. Because the gas jets do not have sufficient momentum when they reach the molten metal surface, they cannot produce metal droplets as needed.

[0014] However, as the present reasoning suggests, the central jet will be covered by very little or no slag foam as compared to the peripheral jets. The reasons for this is that the peripheral jets will cover the central jet and make a protective cover to the central jet from the high density slag foam. Further, there is a positive pressure due to the presence of the central jet and this will also push away the little entrainments of slag foam into the space amongst the peripheral jets. This means that the central jet will not lose its momentum to the slag layer and will reach the metal surface with concentrated momentum, i.e. with very high velocity that will tear the metal surface to produce the much needed metal droplets for improving the dephosphorization.

[0015] Thus, it is clear that having a central jet will be advantageous in augmenting the metal droplet production that can improve the rate of dephosphorization.

[0016] As explained earlier, when the foamy slag is absent during the initial and final stages of the blow, the central jet would cause enormous spitting, i.e., ejection of liquid metal through the vessel mouth. So, it is not advisable to have a very strong blow through the central hole during all the phases of the LD steelmaking process. Spitting or strong metal droplets generation during the initial and final phases of the blow will damage the lance since there is no protection from the slag foam. It is expected that the presence of the slag foam slows down the metal droplets and protects the lance and vessel refractory from the impact of the metal droplets. It is clear from the above arguments that having a strong blow through the central hole is disadvantageous during these two stages of the blow.

[0017] If the supersonic nozzle is operated at a lesser presssure ratio than the design pressure ratio or in other words if the nozzle is underblown to reduce the flow rate to avoid spitting during the initial stage, shocks or strong discontinuities in pressure, velocity, temperature and density of the gas can occur within the diverging section of the nozzle itself. Such shocks formed at the diverging section can severely effect the performance of the supersonic nozzle and will reduce the life of the nozzle considerably. Moreover, under steelmaking conditions, such a shock formed inside with diverging section of the nozzle, can suck the high temperature slag foam and metal droplets into the nozzle and severe erosion and failure of the lance can occur. It is clear that it is not possible to have a great degree of control of flow rates, as needed in the different phases of the LD steelmaking process, through the supersonic nozzle.

[0018] Because of the above mentioned considerations, in the present invention it has been found to have a subsonic nozzle, i.e., nozzle with only a converging section, through which it is easy to control the flow rate and a wide range of flow rates can also be achieved by changing the supply pressure. Furthermore, the problem of shock formation is not there with a nozzle providing subsonic velocities. The explanations also make clear that it is not possible to control the flow rate through the central hole alone if all the nozzles have the same gas supply line. As explained earlier, the droplet generation needs to be augmented only during the middle duration of the blow and a lot of droplet generation during the initial and final stages of the blow is not preferred. For such a lance operation, a control of the flow rate through the central hole is required and as said above, it is not possible with the same oxygen gas supply for all the nozzles. So, in the present invention a separate and controllable gas supply has been provided for the central hole. All the other six peripheral supersonic nozzles can share the high-pressure gas supply.

[0019] Thus the present invention provides an improved lance for LD steelmaking comprising:

> a plurality of peripheral supersonic nozzles arranged surrounding a central axis of the lance, the peripheral nozzles being provided with a single inlet high pressure gas supply line (2); and
> a central converging subsonic nozzle provided with a separate low pressure gas supply line (1);
> wherein the central subsonic nozzle is adapted for controlling gas flow rate therethrough for varying the generation of liquid metal droplets during blow according to an LD steelmaking process requirement; and
> wherein the gas supply line (2) for the plurality of peripheral supersonic nozzles and the gas supply line (1) for the central subsonic nozzle are provided with two separate control valves with actuators for controlling the flow rate therethrough.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

[0020] The invention will now be described referring to the figures of the drawing where

Figure 1	shows the schematic arrangement of a 6-hole lance design.
Figure 2	shows a typical geometric arrangement of a supersonic nozzle.
Figure 3	shows a schematic sketch of an LD vessel.
Figure 4	shows a schematic sketch of the 7 hole lance with separate air supply line used in the hydrodynamic model experiments
Figures 5(a) and (b)	are photographs showing extent of droplet generation in the case of an existing 6 nozzle lance and a 7 hole lance of the present invention
Figure 6	shows a schematic representation of the droplet generation mechanism
Figure 7	shows the droplet generation rates with 7-hole lance with different flow ratios
Figure 8	shows the computational model and the mesh used for numerical simulation.
Figure 9	gives a closer look of the nozzles
Figure 10	shows the velocity contours for 7-hole lance with angle of inclination of 17.5° with the presence of vessel walls and metal surface
Figure 11	shows the temperature contours with shock at the nozzles with 17.5° angle.
Figure 12	shows velocity contours showing the impact position on the metal surface
Figure 13	shows velocity contours at different axial locations (a) X = 0.5 m (b) X = 1.0 m (c) X -1.5 m and (d) X = 2.0 m.
Figure 14	shows schematic diagram of the domain with boundary conditions used for the high density ambient simualtion
Figure 15	shows mixture density contours near the nozzle exit at an instant of time.
Figure 16	shows momentum flux rates profiles at different axial locations(a) Nozzle exit;(b) 0.5 m;(c) 1.5 m and (d) 2.5 m

Figure 17 shows schematic representation of a 7-hole lance design

[0021] Since it has been found that the central hole will augment the droplet generation, the droplet generation mechanisms were studied through hydrodynamic model experiments on a 1:6 scale down model with the central hole as shown in the schematic sketch of figure 3. A 1:6 reduced scale model of the LD vessel made with plexiglas is used. The reduced scale models of the existing and the proposed lance designs were made in order to study the advantageous of the central hole in augmenting droplet generation.

[0022] The top part of the vessel is made of stainless steel where the cylindrical and the vessel bottom portions are made of plexiglas to have required transparency for visualization of the experiments. The lance is made up of copper with the facility of putting different design of lance tips for investigation.

[0023] The scaled down lance was designed having six peripheral nozzles with a central nozzle as shown in Figure 4. There are two separate air lines, line 1 is connected to all the six outer peripheral nozzles whereas line 2 is connected to the central nozzle. The flow rate through the central hole was controlled separately by means of a set of pressure regulator and air flow rotameter connected in series whereas the flow rate through the six peripheral nozzles was controlled through another set of pressure regulator and air flow rotameter. The inclination of the peripheral nozzles to the central axis were investigated at 17.5° (as existing in practice) and 22° as well, by using two different lance tips 3.

[0024] The droplet generation mechanisms were investigated when all the 7-holes were in operation and comparisons were made with only the six peripheral nozzles in operation. In Figures 5(a) and 5(b), the intensity of droplet generation is shown for the cases of the blow through only the peripheral nozzles and the blowing through all the 7-holes respectively. It can be seen visually that the extent of droplet generation is much higher with the central hole in operation in conjunction with the peripheral nozzles than that of only with the peripheral nozzles.

[0025] It was observed during the experiments that there is a critical flow rate after which onset of the droplet generation starts. The mechanism for the accelerated rate of droplet generation, due to the presence of the central jet, is explained schematically in Figure 6. The center jet impacts the liquid metal vertically and creates the central strong depression of the liquid surface. The depression thus formed is wavy in nature and provides "lips out of the central water paddle" as shown schematically in Figure 6. The water lips thus formed around the paddle are then torn apart by the side jets and yield an improved droplet production. These side jets also were thought to prevent the slag foam to enter the centre space amongst the peripheral jets in the actual vessel and therefore ensure that the central jet with its high momentum reaches the metal bath surface and permits the droplet production similar to the one schematically sketched in Figure 6.

[0026] The quantification of the droplet generation was studied in order to understand the optimum flow rate to be given through the central nozzle to maximize the droplet generation rate. The droplet generation rate is measured by putting a collecting pan having dimension 400 x 100 x 50 mm^3 and the measurements were carried out for the existing 6-nozzle lance and the new 7-hole lance with a central nozzle. The dimension of the pan was decided to measure the effective droplet generation surrounding a single nozzle of the 6 peripheral nozzles. The rate of droplet generation is expressed in terms of the rate of mass of droplets collected (g/sec) on the pan.

[0027] The rate of droplet generation is studied for various flow rates through the central nozzle for selecting the optimum flow rate through the central nozzle to maximize the droplet generation. A flow rate ratio, X is defined as the ratio flow rates through the central hole to that of one of the peripheral nozzles.

$$X = \frac{\text{Flow through the central nozzle}}{\text{Flow through one of the peripheral nozzle}} \times 100$$

[0028] The rate of droplet generation plotted against the flow rate ratio is shown in Figure 7. The flow rate through the central nozzle was varied from a flow rate ratio of as low as 25 % to as high as 125 %.

[0029] The optimum flow rate through the central nozzle is obtained by maintaining the balance between an improved droplet generation and control of splashing and spitting due to bath spilling out of the mouth of the vessel. It was quite apparent that as the flow rate through the center hole was increased progressively, the rate of droplet generation was enhanced. Figure 7 shows that for a flow rate ratio, X of 1 (100%) given through the central nozzle, the droplet generation almost doubles and reaches a maximum value. Beyond this flow rate, there was vigorous splashing and spitting out of the mouth of the LD vessel water model which is detrimental to the operation of the LD vessel. Thus, from the hydrodynamic model experiments, the optimum flow rate ratio, X through the central hole is decided that maximizes the droplet generation rate but without spitting and splashing out of the vessel.

[0030] Numerical simulations were performed using the commercial computational fluid dynamic software, FLUENT to study the characteristics of the jets coming out of the 7-hole lance as explained earlier with 6-peripheral holes and 1-central hole. The angle of inclination of the peripheral jets were chosen to be 17.5° as the initial value and it is the same as that in existing 6-hole lance designs. A centre subsonic nozzle was added to carry out the jet flow predictions for the reasons discussed earlier.

[0031] To reduce the computational time of the numerical simulations for the new lance design, only half of the total flow domain was simulated by splitting the whole domain using the vertical mid-plane of the vessel. So, two complete supersonic jets and two half supersonic jets were numerically simulated. The central subsonic jet was also simulated as a half jet. The dimensions of the supersonic nozzles Figure (2) were kept as the old dimensions, i.e. inlet dia 32.7 mm, throat dia 25.7 mm and exit dia 37.3 mm.

[0032] Since the optimum flow ratio obtained from hydrodynamic model experiments was unity, the subsonic nozzle has been designed with a larger exit diameter (54 mm) as compared to that of the peripheral supersonic nozzle (37.3 mm). This is needed to push the same mass flow rate through the central subsonic nozzle and one of the supersonic nozzle.

[0033] To accommodate the bigger central nozzle, the lance pipe diameter had to be increased by 100 mm compared to the existing lance dimensions. The volume flow rate through the central subsonic nozzle was kept almost the same as that of one of the peripheral supersonic jets. This means that mass flow rate through one of the supersonic nozzles in the periphery when compared to the central subsonic nozzle is different. This is due to the fact that because of the supersonic flow in the outer nozzles, the nozzle exit temperature falls down to 150 K. Due to this, the density of the gas at the exit of the supersonic nozzles becomes much higher, given that the pressure is almost uniform everywhere in the vessel. For the subsonic central jet, such low temperatures at the nozzle exit do not reach.

[0034] Since it is intended to vary the flow through the central subsonic nozzle during the blow, the ratio of flow rate through the subsonic nozzle to that through one supersonic nozzle is kept as a variable. To keep the numerical efforts small, it was decided to study the flow induced by the jets for only two volume flow rate ratios. These were chosen to be 1.0 and 0.5. The results of the simulations are given below for volume flow rate ratio of 1.0.

[0035] In Figures 8 and 9, the computational model and the mesh used for the numerical simulation of the 7-hole lance design suggested above are shown. More than 1.3 million grid nodes were used in the simulations of the jet flows. The simulations were performed with standard k-ε model. 12 processors of a one tera-flops Linux cluster were used for simulation and it took around 72-80 to complete one flow simulation. It is well-known that k-ε turbulence model predicts the flow features of the multiple jets with some deviations from the real flow but the deviations are not large. However, it is easy to get reasonable solutions quickly with k-ε model with short computational time. For this reason, this model was used.

[0036] In Figure 10, the velocity contours in the symmetry plane, for the case of 7-hole lance are shown in the presence of vessel walls and metal surface, for the peripheral hozzles' angle of inclination of 17.5°. In the numerical simulation, the metal surface was assumed to be a stress free horizontal layer. It is seen from Figure 10 that the jets follow their geometrical path closely and the interaction between them is small. It can be seen from Figure 10 that the jets interact only in the middle elevations.

[0037] There is only little interaction of the jets closer to the metal surface. This is due to the central stagnation zone at the metal surface. The higher stagnation pressure in this region pushes the jets away and reduces the coalescence.

[0038] In Figure 11, the shocks formed at the nozzle tips of the 7-hole lance design are shown by the temperature contours. It can be seen that there are smaller shocks at the subsonic nozzle outlet also. This is because of differences in temperature between the ambient and the nozzle outlet and the smaller differences in pressure. This can be reduced by increasing the angle of the convergent section of the nozzle. For the present simulations, the angle is kept at 10°.

[0039] In Figure 12, the velocity contours are plotted at the symmetry plane to show the impact positions of the jets on the metal surface. The geometrical projections of the jets are also shown on the liquid metal surface by dark circles. It can be seen that the jets almost follow the geometrical path and the coalescence is minimal due to the presence of the central jet and the bottom stagnation region. In Figure 12, the velocity contours are shown only for the velocity magnitudes less than 150 m/s. It can be observed that the supersonic jets and the central subsonic jet reach the liquid metal bath with almost the same velocity magnitudes although the exit velocities at the respective nozzles were different.

[0040] Since the subsonic nozzle exit diameter is hither (54 mm) than the supersonic nozzle exit diameter (37.3 mm), the velocities closer to the metal bath are matched.

[0041] In Figure 13, the velocity contours are plotted at different axial distances from the nozzle tip for the 7-hole lance. It can be seen from Figure 13 that up to the axial distance of 1 m, the interactions between the jets are minimal. At 1.5 m distance, there is considerable interaction amongst the jets. But the bottom stagnation region pushes the jets away and the coalescence is reduced at 2 m. The streaks shown in Figure 13 (d) are due to the presence of the central jet.

[0042] The gas in the central jet has to pass through the surrounding supersonic jets since it cannot pass through the metal surface (in the simulation). This kind of flow feature may not happen in the actual vessel because in the simulation, the metal surface is assumed to be a stress free flat wall. In LD vessel, the impact of the central jet will create a depression, which will change the flow characteristics completely.

[0043] In order to explain the effect of slag foam on the jet characteristics the single jet results are discussed here. The likely range of ambient density (foam/emulsion) values are possible in the LD vessel has been calculated by assuming uniform decarburization rate throughout the blow. It turn is out that the average slag volume fraction in the foam inside the vessel will be in the range of 12-15%. This would result in an average ambient density range of 360-450 Kg/m^3.

[0044] The numerical domain and the boundary conditions used are shown in Figure 14. The vessel diameter required for a single axisymmetric nozzle has been calculated by using 1/6 of the original vessel cross-sectional area (because out of 6 nozzles, only one is being simulated). Furthermore, the liquid metal surface has been assumed to be a shear free flat wall. The lance height (distance between nozzle tip to the liquid metal surface) is taken to be 3.5 m, in order to study the behaviour of the jet over a long axial distance. The actual lance height in the vessel varies from 1.5-2.2 m.

[0045] The simulations have been carried out using a 2D axisymmetric unsready RANS with volume of fluid (VOF) multiphase model to track the interface between the phases. No differentiation has been made between oxygen and carbon mono-oxide gas. Hence only one gas phase has been considered. The Realizable k-ε turbulence model is used to close the system of equations. PISO algorithmhas been used for pressure - velocity coupling. Second order upwind discretization scheme has been used for all the flow variables except temperature for which power law scheme is used. The average slag volume fraction (15%), computed from the steady decarburisation rate, is patched in the vessel domain as an initial guess. During the computation, the slag is free to move throughout the domain depending on the local flow conditions unlike the earlier simulation. The surface tension forces have also not been included in this simulation when entering into a still ambient, the gas jet with high velocity invokes flow in the ambient also.

[0046] Due to the momentum transferred to the ambient, the ambient fluid adjacent to the jet boundary starts moving in the predominant flow direction of the jet fluid. So, the ambient fluid in the neighboring locations moves towards the jet because of this flow induced by the jet. Slag along with the ambient gas rushes towards the jet boundary owing to the flow induced by the jet. Here, slag accumulates and the volume fraction/local density increases. The momentum transferred from the jet imposes movement to the slag and slowly, the slag covers the high-speed jet core. The slag foam density contours near the nozzle tip are plotted in Figure 15 in order to show the slag accumulation at the nozzle tip and its movement along the jet.

[0047] The resultant momemtum flux rate (ρV) at different axial locations is shown in Figure 16 at a particular instant of time. It is worth noting that the maximum momentum flux rate does not occur at the axis of the jet but away from it in the radial direction as shown in Figure 16. The high speed core of the jet continuously pumps momentum to the jet shear layer, both convectively and diffusively. The velocity at the axis is still the maximum at any axial location.

[0048] So the diffusive transport of axial momentum in the radial direction ( ) will be towards the shear layer from the jet axis. Since the jet is spreading, the radial velocity, v will be towards the shear layer within the jet so the net convective transport of momentum in the radial direction (ρuv) is also towards the shear layer

[0049] Since the density of the shear layer fluid (slag + gas) is very high compared to the jet gas, the shear layer can store higher momentum fluxes without increasing the velocity enormously just like storage of thermal energy in a reservoir with higher specific heat/thermal capacitance without appreciable temperature differences. Moreover, the gravity is aiding the slag layer to gain momentum, i.e. the slag layer moves in the direction of the gravitational acceleration.

[0050] The momentum transferred from the high speed jet core to the high density shear layer will be in addition to the momentum imparted by the gravitational acceleration. From the momentum flux rates Plots shown in Figure 16, the momentum flux rate at the high density shear layer is minimum 2 orders of magnitude higher than the high speed jet core. It is clear from the above discussions that the high density slag-gas foam present in the LD vessel poses some interesting flow features of the supersonic gas jets. The understanding of the depressions created during the blow might be changed completely.

[0051] It is important to note that the multiple supersonic jets inside the LD steel vessel will also be subjected to such characteristics as shown above due to the presence of high density slag foam. It is clear from the above discussions that the peripheral supersonic jets will lose all their momentum to the slag layer adjacent to them. The slag layers will move towards the liquid metal pool with very high momentum and create complicated depression profiles. But due to the presence of the central jet in the new 7-hole design, the pressure inside the space amongst the supersonic jets will prevent the entrainment into this region.

[0052] So, the central jet will not see or see minimally the slag foam and unlike the supersonic jets, it will not lose its momentum completely to the slag foam. So the central jet will reach the liquid metal surface with very high velocities as compared to the supersonic jets and is expected to produce more droplets. This kind of droplet production is not possible with the 6-hole design since all the 6 supersonic jets will completely lose their momentum to the slag layer that moves relatively slowly. It is clear from the above discussions that the 7 hole design is more efficient than the 6-hole conventional design.

[0053] One embodiment of the present invention with a 7-hole design is schematically shown in Figure 17. It shows 6 peripheral supersonic jets with a central jet. The central jet is to be controlled separately with a separate gas supply line whereas the peripheral supersonic jets will have a single inlet gas supply line. The gas supply line for the 6 peripheral supersonic jets and the gas supply line for the central subsonic jets are provided with two separate control valves with actuators. The central jet can be put into operation during different stages of the blow and the flow rate can also be varied according to process requirement since it is a subsonic nozzle.

[0054] The flow rate through the central subsonic nozzle is kept as a variable. In the numerical and experimental simulations, the ratio of the volume flow rate through the central subsonic nozzle and that of one of the supersonic nozzles is kept as a variable. The maximum value of this ratio is kept as 1 in numerical simulation. The dimensions of the central nozzle are calculated by keeping this in mind. The outlet diameter of the subsonic nozzle is 54 mm and that of the supersonic nozzle is 37.3 mm (existing value).

[0055] The angle of inclination of the peripheral jets is kept at 17.5% (the existing value). In order to see the performance of a 7-hole lance with modified angle for the peripheral jets, a study was carried out for a jet arrangement with the 22° angle for the inclination of the side jets.

Further, the angle of inclination of the peripheral supersonic nozzles can be equal or alternately varying. The alternately varying angle of inclination can have a distinct advantage. As shown earlier, the covering of slag foam on the jet surface results in lower velocity of the gas jet and the slag layer covering the jet reaches the liquid metal surface with high momentum. This impact of slag layer onto the liquid metal will create a lot of slag droplets into the liquid metal and create interfacial area for slag-metal reactions. By keeping the alternately varying angle of inclination, the surface area of the jet that is covered with slag layer can be increased and more slag can reach the liquid metal with high momentum. This is expected to improve the interfacial reactions such as dephosphorization.

[0056] Through the numerical and experimental simulations and also by considering different dynamics inside the LD steelmaking vessel, the following 7-hole lance design was arrived at in a preferred embodiment. This design is much superior to the existing designs and can perform better in steelmaking conditions.

6 peripheral supersonic nozzles with a single gas supply line.

A central bigger subsonic nozzle with a separate gas supply.

The central nozzle can be put into operation during different stages of the blow as required and the flow rate can also be varied easily without paying the penalty of nozzle life.

The angle of inclination of the peripheral jets is kept at 17.5°. This angle can be increased in the further modifications.

[0057] The advantageous features of the present invention provides better on/off control of the central nozzle during the blow because of the separate gas supply line. This will give a strong control of the spitting of metal droplets off the vessel.

[0058] The bigger subsonic nozzle at the centre of the lance head is useful to control the flow rate of oxygen through the central nozzle. This would mean more flexibility and control over the process.

[0059] The system provides increased metal droplet generation. Since the central jet is protected from the slag foam by the peripheral jets, this would reach the metal bath with high velocities and promote increased droplet generation.

[0060] The system provides improved effectiveness in dephosphorization. Improveed metal droplet generation will promote the interfacial reactions particularly dephosphorization.

[0061] The present invention has been described with reference to certain embodiments which are only illustrative and not intended to be limiting. Changes in details and forms may be made by one skilled in the art without departing from the scope and intent of the invention. It has been shown that the objective of improving dephosphorization in LD steelmaking process is achieved by increasing the generation of liquid metal droplets. In other processing industries, where there may be other objectives, which may also be achieved by increasing liquid droplet generation, the system of the present invention can be used.

Claims

1. An improved lance for LD steelmaking comprising:

a plurality of peripheral supersonic nozzles arranged surrounding a central axis of the lance, the peripheral nozzles being provided with a single inlet high pressure gas supply line (2); and
a central converging subsonic nozzle provided with a separate low pressure gas supply line (1);
wherein the central subsonic nozzle is adapted for controlling gas flow rate therethrough for varying the generation of liquid metal droplets during blow according to an LD steelmaking process requirement; and
wherein the gas supply line (2) for the plurality of peripheral supersonic nozzles and the gas supply line (1) for the central subsonic nozzle are provided with two separate control valves with actuators for controlling the flow rate therethrough.

2. The lance as claimed in claim 1, wherein the lance comprises six peripheral supersonic nozzles and one central subsonic nozzle.

3. The lance as claimed in claim 1 or claim 2, wherein the central subsonic nozzle is provided with only a converging section for easily controlling flow rate therethrough.

4. The lance as claimed in any one of the preceding claims, wherein the central subsonic nozzle has a larger exit diameter than that of said peripheral supersonic nozzle.

5. The lance as claimed in any one of the preceding claims, wherein the peripheral supersonic nozzles can have equal or alternately varying angles of inclination from the vertical axis of the lance.

Patentansprüche

1. Verbesserte Lanze für LD-Stahlherstellung, umfassend:

   eine Vielzahl von peripheren Überschalldüsen, angeordnet zum Umgeben einer zentralen Achse der Lanze, wobei die peripheren Düsen mit einer einzelnen Einlass-Hochdruck-Gaszuführungsleitung (2) versehen sind; und
   eine zentrale konvergierende Unterschalldüse, versehen mit einer separaten Niederdruck-Gaszuführungsleitung (1);
   wobei die zentrale Unterschalldüse zum Steuern der Gasflussrate dadurch angepasst ist zum Variieren der Erzeugung von flüssigen Metalltröpfchen während des Blasens gemäß einer LD-Stahlherstellungsprozess-Anforderung; und
   wobei die Gaszuführungsleitung (2) für die Vielzahl von peripheren Überschalldüsen und die Gaszuführungsleitung (1) für die zentrale Unterschalldüse mit zwei separaten Steuerventilen mit Stellgliedern zum Steuern der Flussrate dadurch versehen sind.

2. Lanze nach Anspruch 1, wobei die Lanze sechs periphere Überschalldüsen und eine zentrale Unterschalldüse umfasst.

3. Lanze nach Anspruch 1 oder Anspruch 2, wobei die zentrale Unterschalldüse mit nur einem konvergierenden Abschnitt zum einfachen Steuern der Flussrate dadurch versehen ist.

4. Lanze nach einem der vorstehenden Ansprüche, wobei die zentrale Unterschalldüse einen größeren Austrittsdurchmesser als der der peripheren Überschalldüse aufweist.

5. Lanze nach einem der vorstehenden Ansprüche, wobei die peripheren Überschalldüsen gleiche oder alternativ variierende Neigungswinkel zu der vertikalen Achse der Lanze haben können.

Revendications

1. Lance améliorée pour l'élaboration de l'acier selon le procédé LD, comprenant :

   une pluralité de buses supersoniques périphériques disposées autour d'un axe central de la lance, ces buses périphériques étant pourvues d'une seule conduite d'alimentation en gaz haute pression d'entrée (2) ; et
   une buse subsonique convergente centrale pourvue d'une conduite d'alimentation en gaz basse pression séparée (1) ;
   dans laquelle la buse subsonique centrale est adaptée de façon à régler le débit de gaz à travers elle pour varier la production de gouttelettes de métal liquide pendant le soufflage selon une exigence du processus LD d'élaboration de l'acier ; et
   dans laquelle la conduite d'alimentation en gaz (2) pour la pluralité de buses supersoniques périphériques et la conduite d'alimentation en gaz (1) pour la buse subsonique centrale sont pourvues de deux vannes de réglage séparées avec des actionneurs pour régler le débit à travers elles.

2. Lance selon la revendication 1, cette lance comprenant six buses supersoniques périphériques et une buse subsonique centrale.

3. Lance selon la revendication 1 ou la revendication 2, dans laquelle la buse subsonique centrale est pourvue

seulement d'une section convergente pour régler facilement le débit à travers elle.

4. Lance selon l'une quelconque des revendications précédentes, dans laquelle la buse subsonique centrale a un diamètre de sortie plus grand que celui de ladite buse supersonique périphérique.

5. Lance selon l'une quelconque des revendications précédentes, dans laquelle les buses supersoniques périphériques peuvent avoir des angles d'inclinaison égaux ou variables alternativement par rapport à l'axe vertical de la lance.

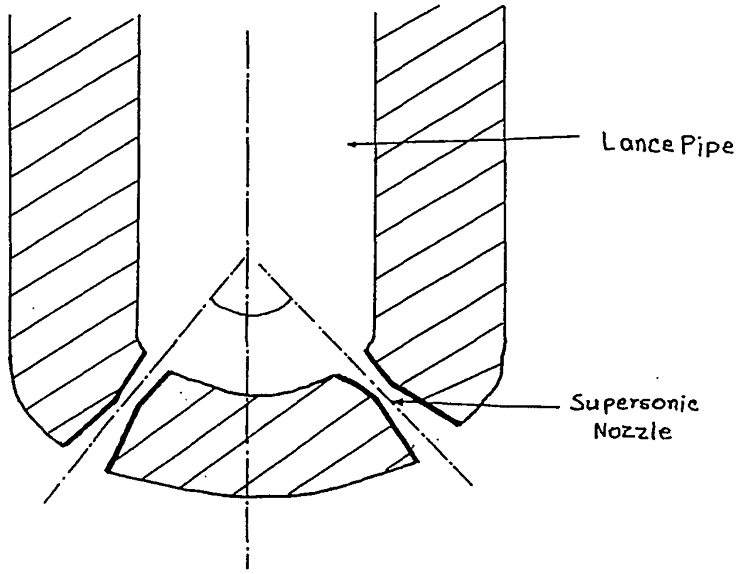


Fig. 1

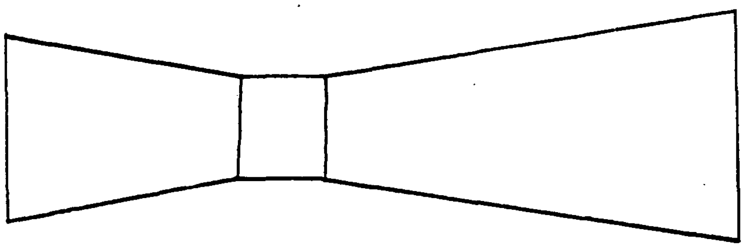


Fig. 2

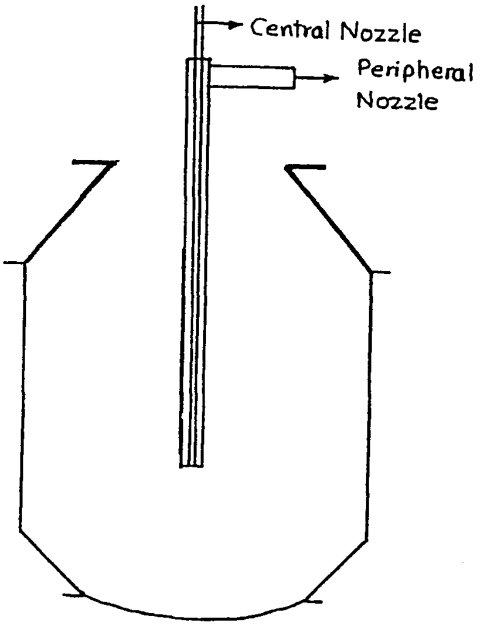


Fig. 3

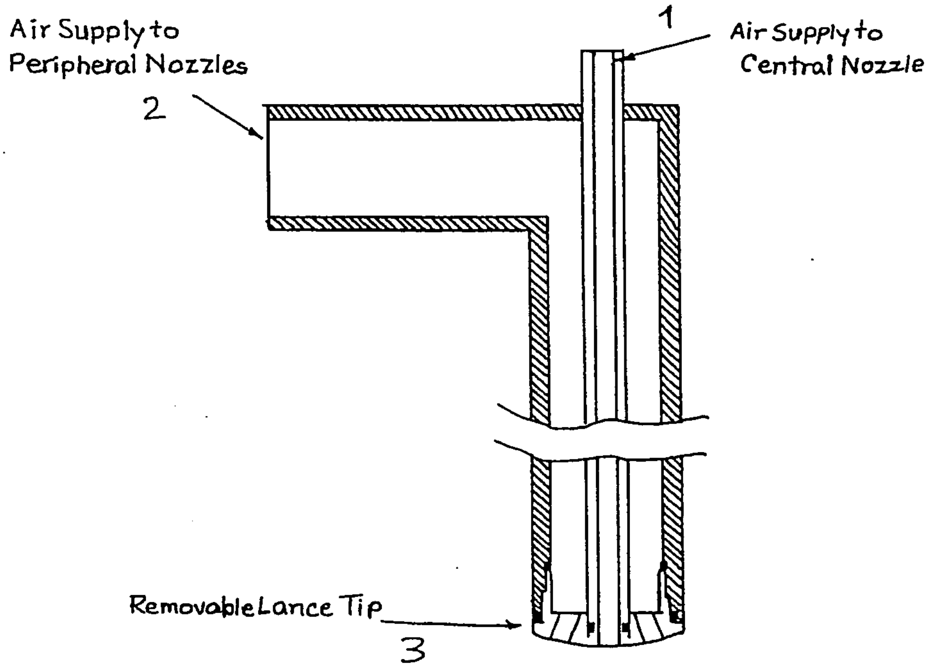

Air Supply to
Peripheral Nozzles
2
1
Air Supply to
Central Nozzle
Removable Lance Tip
3

Fig. 4

Fig. 5(a)

Fig. 5(b)

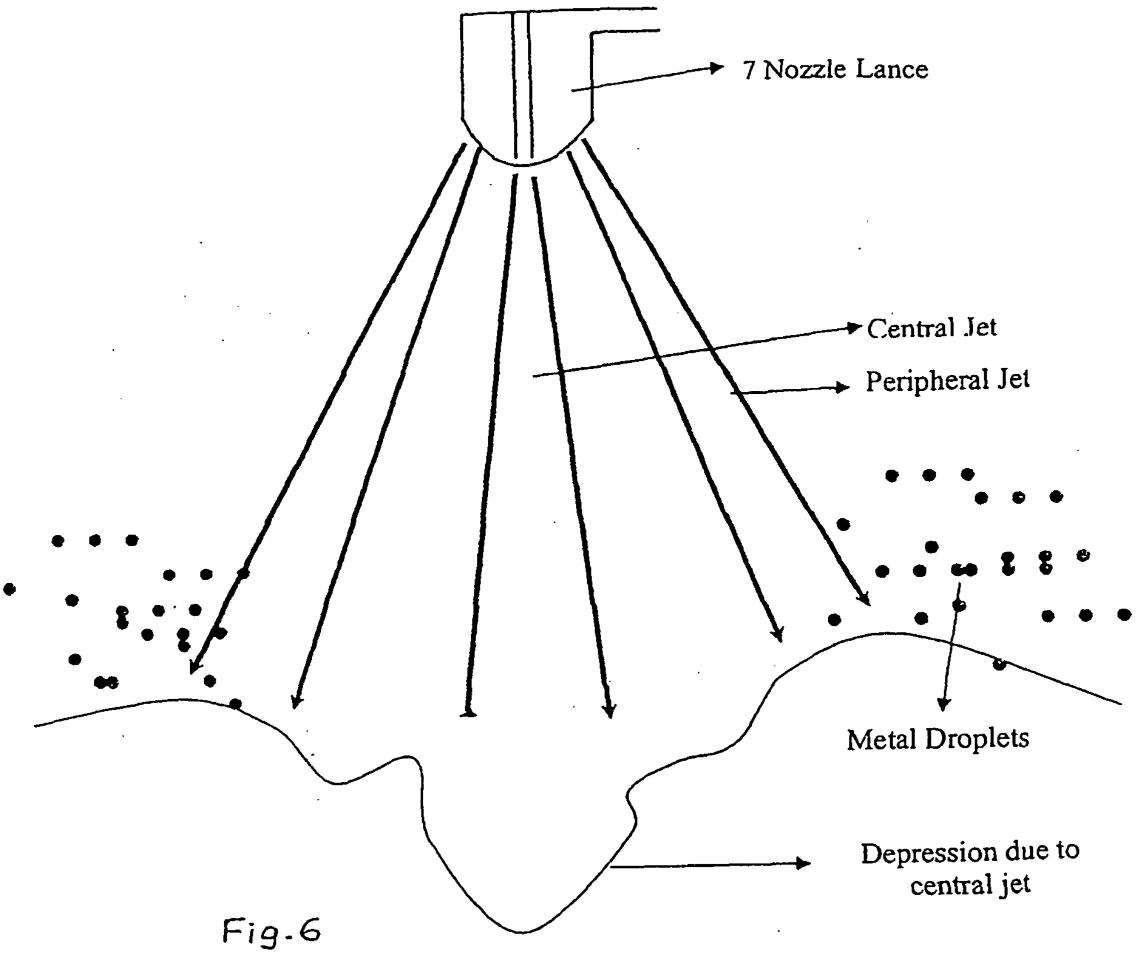

7 Nozzle Lance
Central Jet
Peripheral Jet
Metal Droplets
Depression due to central jet

Fig-6

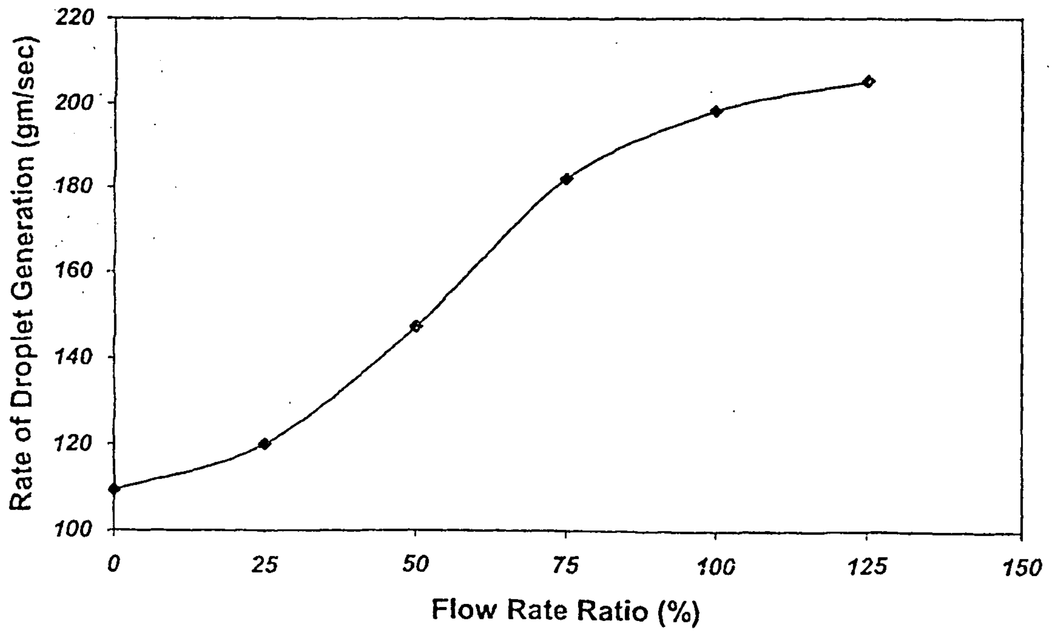

Rate of Droplet Generation (gm/sec)
220
200
180
160
140
120
100
0
25
50
75
100
125
150
Flow Rate Ratio (%)

Fig. 7

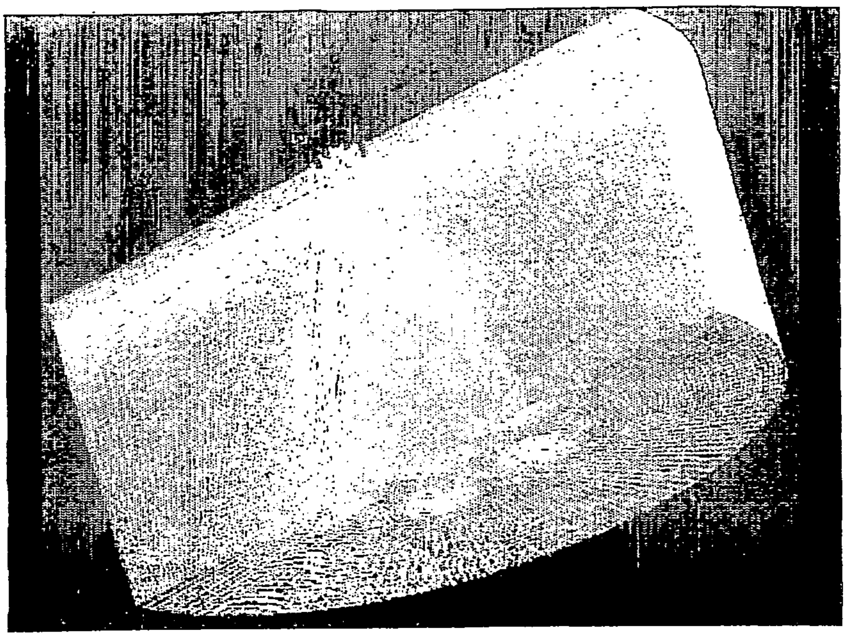
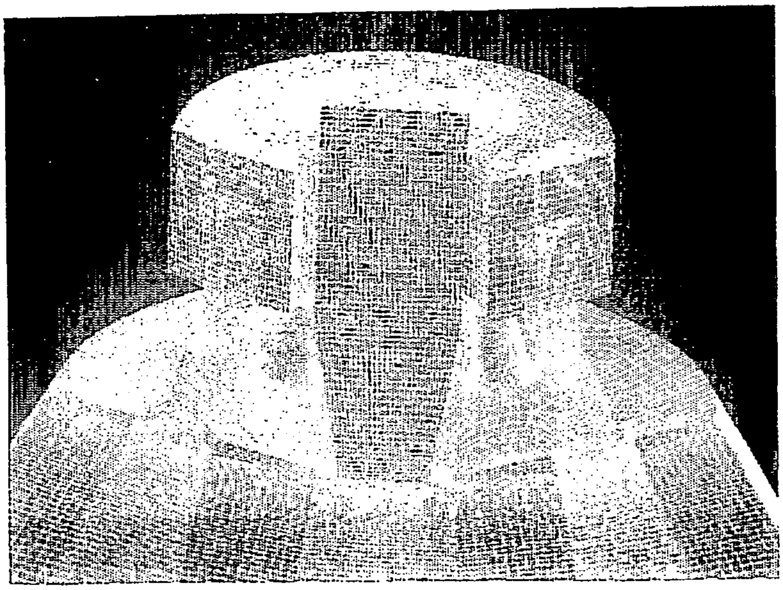
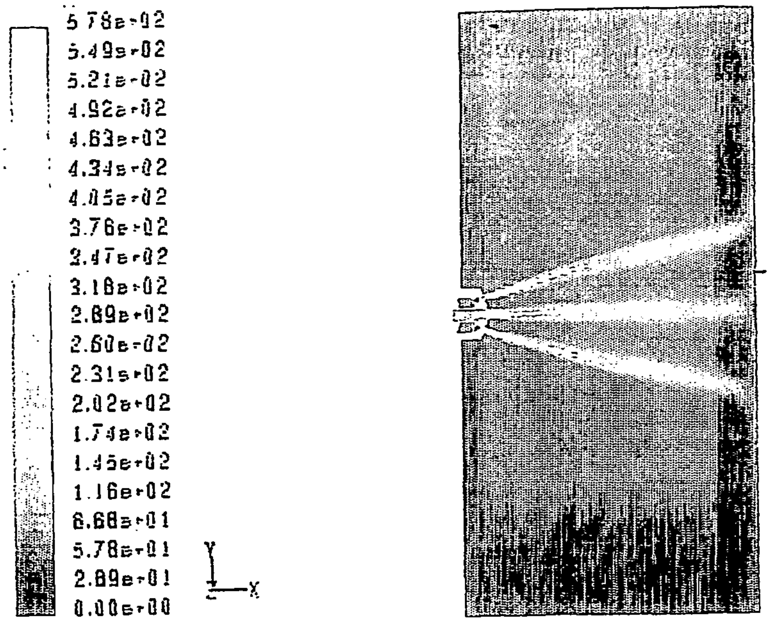


Fig. 8




5.78e+02
5.49e+02
5.21e+02
4.92e+02
4.63e+02
4.34e+02
4.05e+02
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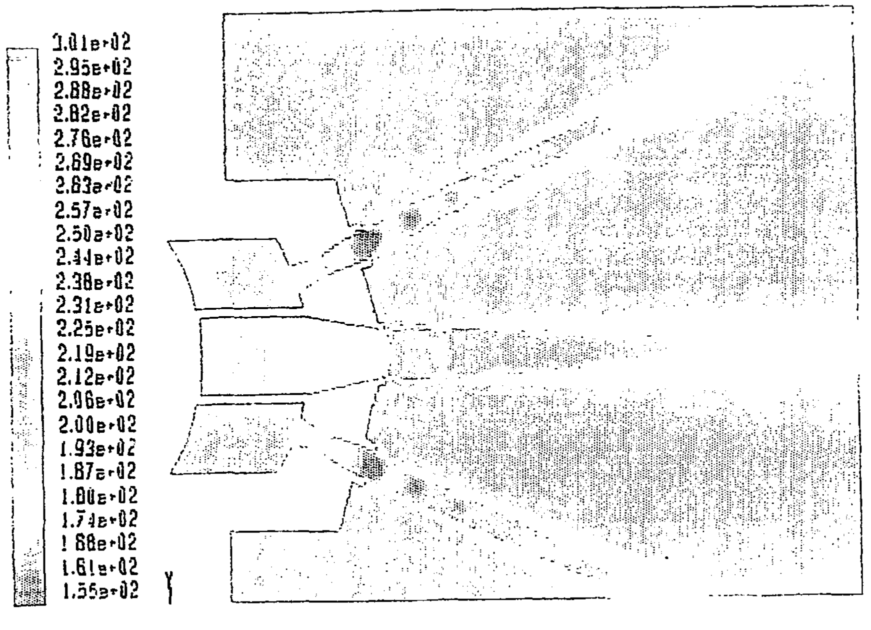
3.47e+02
3.18e+02
2.89e+02
2.60e+02
2.31e+02
2.02e+02
1.74e+02
1.45e+02
1.16e+02
8.68e+01
5.78e+01
2.89e+01
0.00e+00
Y
X

Fig. 10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2.95e+02
2.88e+02
2.82e+02
2.76e+02
2.69e+02
2.63e+02
2.57e+02
2.50e+02
2.44e+02
2.38e+02
2.31e+02
2.25e+02
2.19e+02
2.12e+02
2.06e+02
2.00e+02
1.93e+02
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1.74e+02
1.68e+02
1.61e+02
1.55e+02
Y

Fig. 11

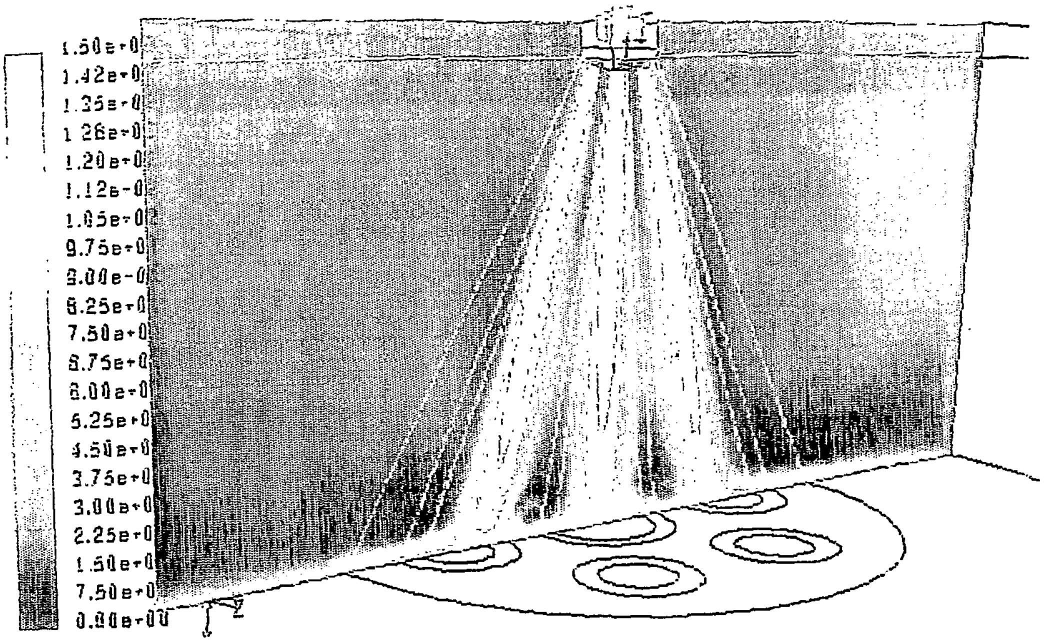
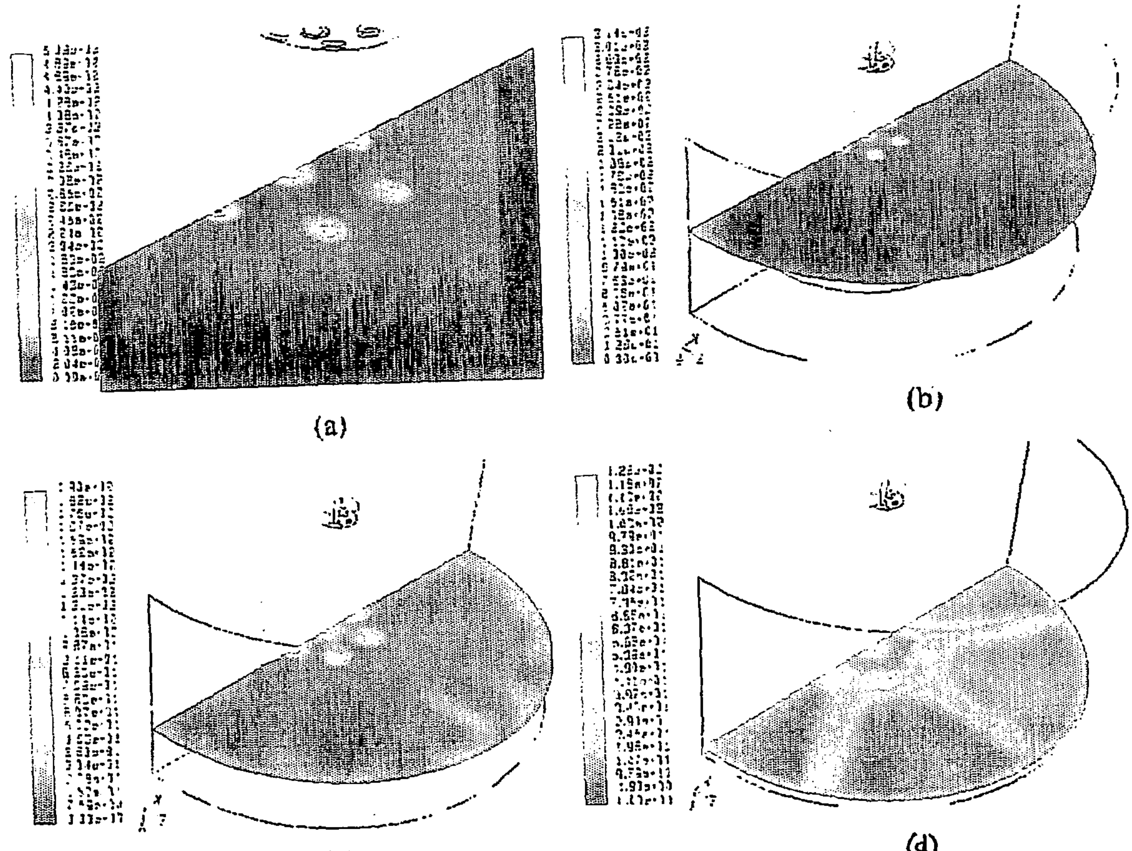


Fig. 12


(a)

(b)

(c)

(d)

Fig. 13

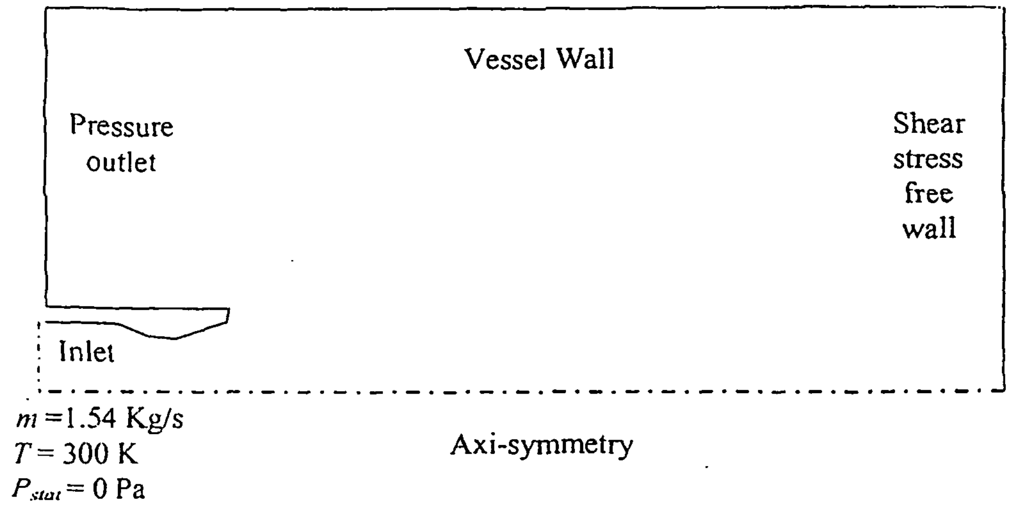

Vessel Wall
Pressure outlet
Shear stress free wall
Inlet
$\dot{m}$ =1.54 Kg/s
T = 300 K
P_{stat} = 0 Pa
Axi-symmetry

Fig. 14

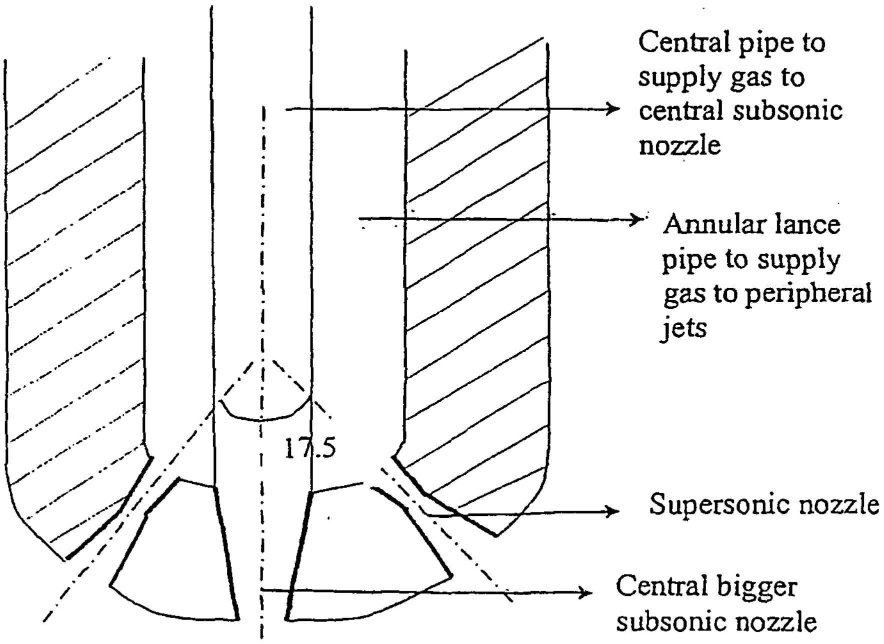

Central pipe to supply gas to central subsonic nozzle
Annular lance pipe to supply gas to peripheral jets
17.5
Supersonic nozzle
Central bigger subsonic nozzle

Fig. 17

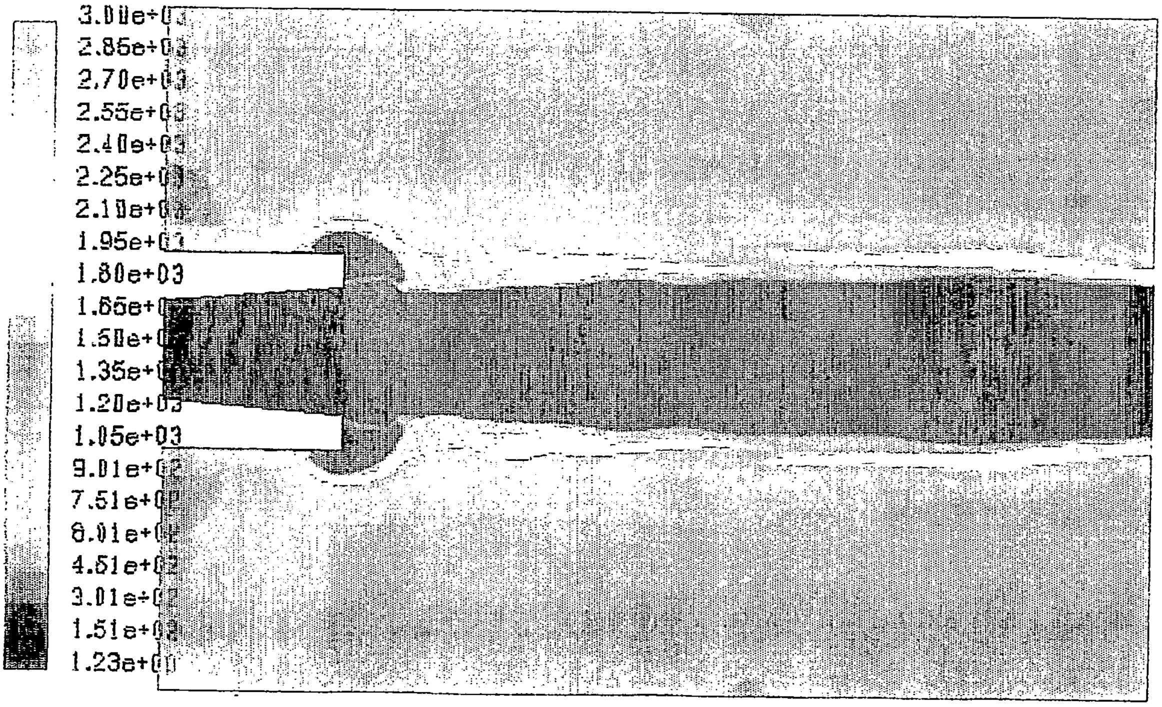

3.00e+03
2.85e+03
2.70e+03
2.55e+03
2.40e+03
2.25e+03
2.10e+03
1.95e+03
1.80e+03
1.65e+03
1.50e+03
1.35e+03
1.20e+03
1.05e+03
9.01e+02
7.51e+02
6.01e+02
4.51e+02
3.01e+02
1.51e+02
1.23e+00

Fig. 15

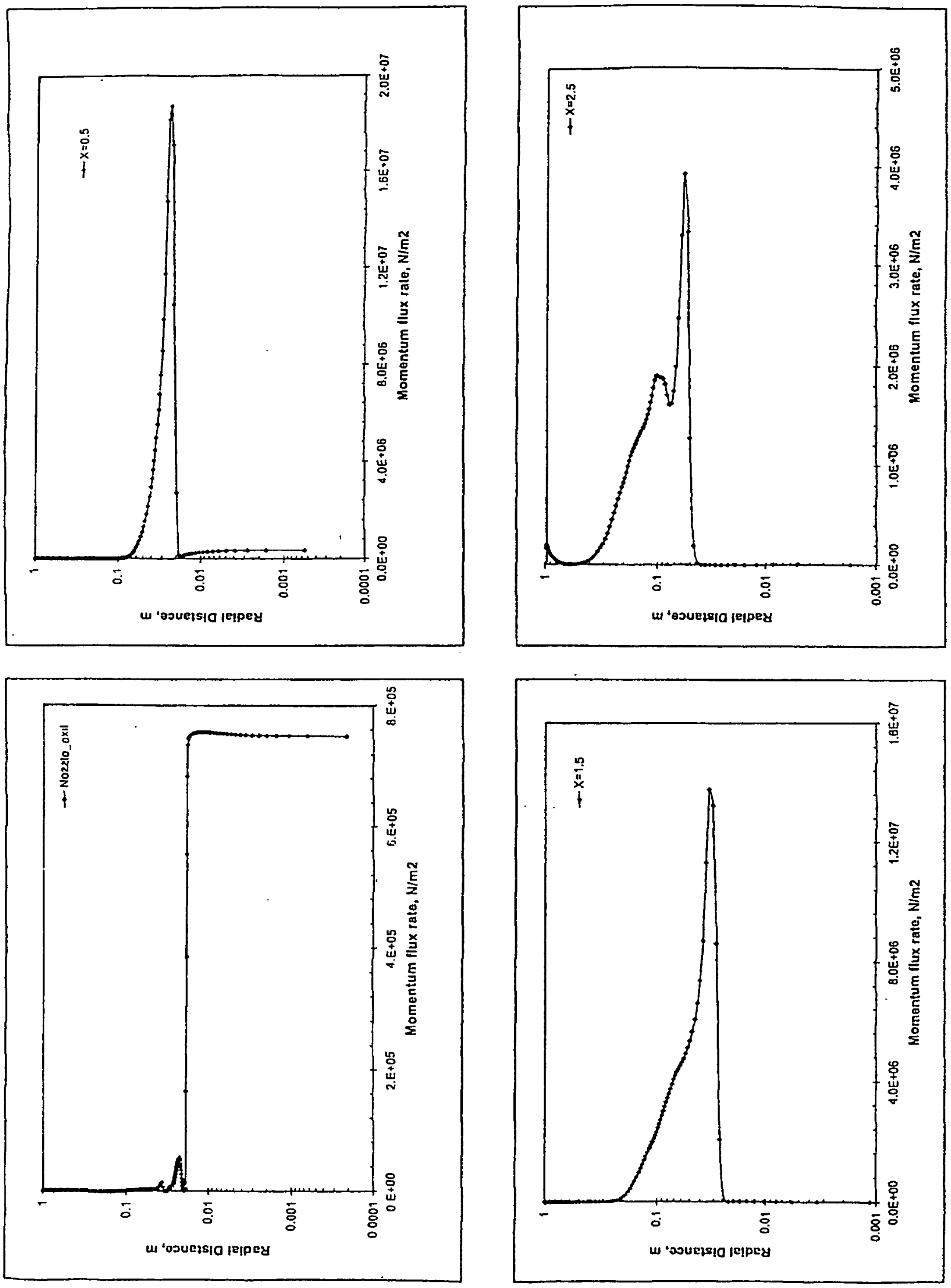

—X=0.5
Radial Distance, m
1
0.1
0.01
0.001
0.0001
Momentum flux rate, N/m2
0.0E+00
4.0E+06
8.0E+06
1.2E+07
1.6E+07
2.0E+07
—X=2.5
Radial Distance, m
1
0.1
0.01
0.001
Momentum flux rate, N/m2
0.0E+00
1.0E+06
2.0E+06
3.0E+06
4.0E+06
5.0E+06
—Nozzle_exit
Radial Distance, m
1
0.1
0.01
0.001
0.0001
Momentum flux rate, N/m2
0 E+00
2.E+05
4.E+05
6.E+05
8.E+05
—X=1.5
Radial Distance, m
1
0.1
0.01
0.001
Momentum flux rate, N/m2
0.0E+00
4.0E+06
8.0E+06
1.2E+07
1.6E+07

Fig. 16

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- FR 1346214 **[0010]**