Effects of Gas Injection Condition on Mixing Efficiency in the Ladle Refining Process

S.-M. Pan, J.-D. Chiang, and W.-S. Hwang

The aim of this research was to investigate the effects of injection condition on the mixing efficiency of the gas injection treatment of the ladle refining process in steelmaking. A water modeling approach was employed. A NaCl solution was injected into the vessel and the electric conductivity value of the water solution was measured to represent the concentration of the additive. The results of this investigation reveal that up to a certain level, mixing efficiency is improved as the gas flow rate increases. Off-center injection is better than centerline injection. However, the injection lance should not be too close to the wall. Also, mixing efficiency is improved when the submerged depth of the immersion lance increases. The immersion hood has a optimal size as far as mixing efficiency is concerned. A larger or smaller hood would reduce its efficiency. The submerged depth of the immersion hood should be kept to a minimum to improve mixing efficiency.

Keywords

gas injection treatment, ladle refining process, mixing efficiency, steelmaking process, water modeling

1. Introduction

TO IMPROVE steel quality and simplify operating procedures, the steelmaking process is divided into two stages (Ref 1): primary steelmaking in a furnace to produce raw steel and secondary steelmaking in a ladle with various refining treatments. In recent years, gas injection by blowing argon gas through an injection lance has been widely utilized in the refining ladle for the purposes of desulfurization, degassing, minor composition adjustment, temperature homogenization, and inclusion removal (Ref 2). A schematic diagram of a gas-injected ladle is shown in Fig. 1. As the gas bubbles are introduced through the injection lance into the ladle, they rise through the molten steel and cause the molten steel to flow. Because of the melt flow, the additives (either desulfurization agents or alloying elements) can be mixed more effectively with the molten steel. Also, degassing and temperature homogenization can be achieved more readily.

However, the treatment also causes several problems, including reoxidation of the molten steel, slag entrapment, and nitrogen pick-up. To improve the treatment, a slag and atmosphere control (SAC) process which places an immersion hood in the ladle was suggested (Ref 3). A schematic representation of the SAC process is shown in Fig. 2. When an immersion hood is used, undoubtedly there will be good slag and atmosphere control inside the hood; hence, the main concern is the effect of the immersion hood on the turbulent mixing and agitation in the gas-injected ladle. To evaluate the feasibility of the SAC process along with the gas injection treatment and, subsequently, to optimize the operating conditions and to design the immersion hood, the interactive flow phenomena of molten steel and gas bubbles under various operating conditions with and without the addition of the immersion hood must be understood.

In the literature a number of investigations have been conducted with mathematical and/or water models to understand the characteristics of fluid flow, heat transfer, and mass transfer phenomena in gas-stirred vessels (Ref 4-8). However, very few studies have been for gas injection treatment in the steel ladles. The main differences between gas injection and gas stirring are the size and number of gas bubbles in the ladle. In a gas-stirred ladle, many small bubbles are introduced into the vessel through a porous plug from the bottom of the ladle. As the small bubbles float to the top, they cause the molten steel to flow and mix. In gas injection treatment, gas bubbles are introduced through a submerged lance. The gas bubbles are much fewer and much larger than those in a gas-stirred ladle. The mixing

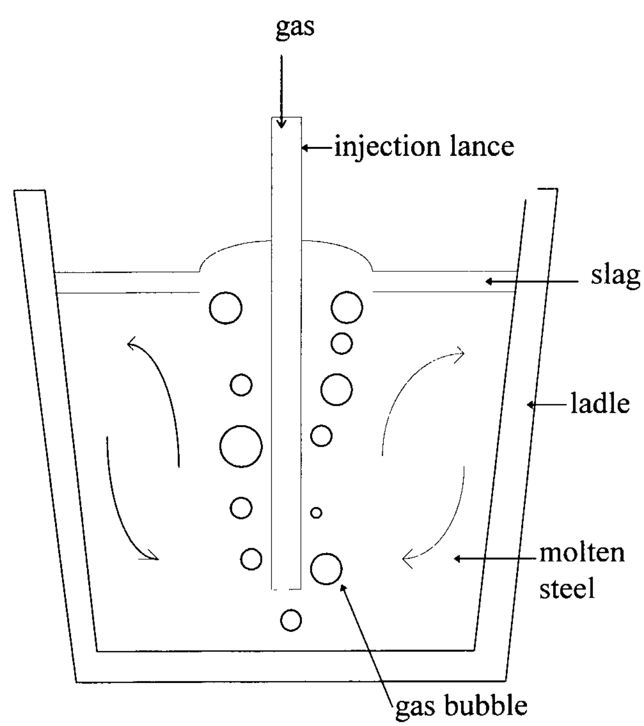

Fig. 1 Schematic diagram of a gas-injected ladle

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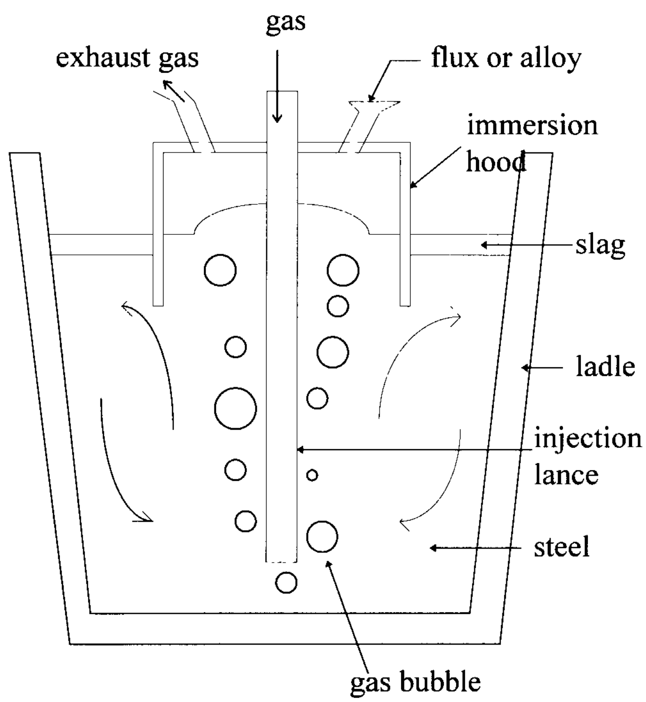

Fig. 2 Schematic representation of the SAC process

characteristics are therefore rather different in these two treatments.

The purpose of the present study was to investigate the effects of gas injection conditions on the mixing efficiency in the ladle with the water modeling technique. The effect of the introduction of an immersion hood (SAC process) on the mixing efficiency was evaluated. The various designs and operating conditions of the immersion hood were also considered.

2. Water Modeling Technique

The water modeling technique uses a transparent vessel to represent the ladle and water to simulate the molten steel. Nitrogen gas is used instead of argon gas and NaCl solution is added in the water as the tracer. The added solution changes the electric conductivity of the water, so the electric conductivity value of the water can represent the concentration of the additive. In this study, mixing time was the primary quantity to be measured to evaluate the efficiency of mixing. A certain amount of NaCl solution was injected into the system at one place and the time was set to be zero. The conductivity values of the water in various locations were then monitored. The mixing time was defined as the time required for the conductivity values at the various locations to reach a uniform value.

Other than mixing time, the flow field of the liquid is very important. In this study, plastic particles of polyethylene were added in the system. The polyethylene particles then flowed with the water when nitrogen gas was injected into the system. As steady flow was observed, pictures were taken. The pathlines of the plastic particles were very useful to demonstrate the flow pattern of the liquid. The flow directions and the velocity values can also be measured from the pictures.

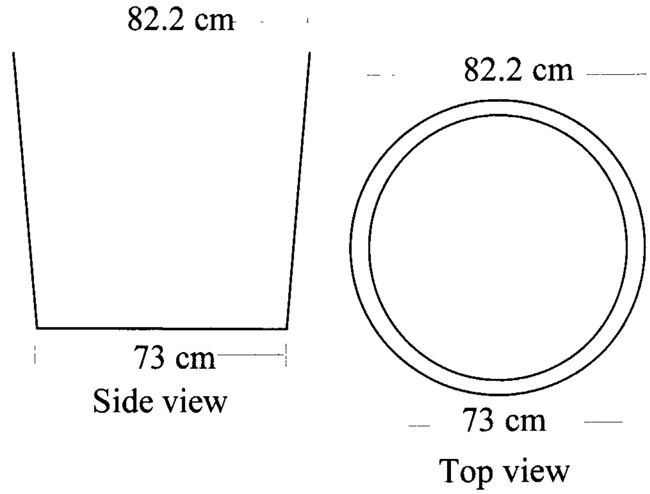

Fig. 3 Schematic diagram of the plexiglass vessel

2.1 *Experimental Setup*

A transparent vessel made of plexiglass was fabricated to simulate the ladle. The vessel was one-fourth the scale of a 150 ton steel ladle. The bottom diameter was 73 cm, the top diameter was 82.2 cm, and the height was 83.7 cm. A schematic diagram of the plexiglass vessel is shown in Fig. 3. The injection lance was also made of plexiglass. It was 100 cm long. The outer diameter was 2.8 cm and the inner diameter was 1.8 cm. There were three types of injection lances. The first type had one opening at the bottom of the lance, diameter 0.2 cm. The second type had two openings on the side of the lance. The two openings were 180° apart from each other and allowed the gas to be injected horizontally. The third type had three openings on the side of the lance, 120° apart from one another, which also allowed the gas to be injected horizontally. The immersion hood was also made of plexiglass. The height of the hood was 47 cm. Three hoods were fabricated with diameters of 24, 34, and 44 cm, respectively.

Four electric conductivity sensors were used in this study, inserted in four different locations of the vessel. One of them, however, was placed at the position where NaCl solution was injected. The electric currents received were then transferred to voltage values through a resistor and recorded by a computer. The whole experimental setup is shown in Fig. 4.

2.2 *Experimental Procedures*

Before the experiment, the conductivity cells were cleaned and calibrated, then inserted in the designated positions of the ladle. The positions of the inserted conductivity cells are shown in Fig. 5. The ladle was then filled with water to the height of 70 cm, which corresponds to the molten steel height in a 150 ton ladle. The immersion hood was then put in the system if required. The injection lance was submerged into the water through the immersion hood and the gas tank was turned on. Everything was adjusted to its predefined condition. The system was run for a period of time. When the system was observed to have reached the steady state, 15 ml of NaCl solution was injected into the ladle. At the same time the measurement cells and the recording system were switched on. When the

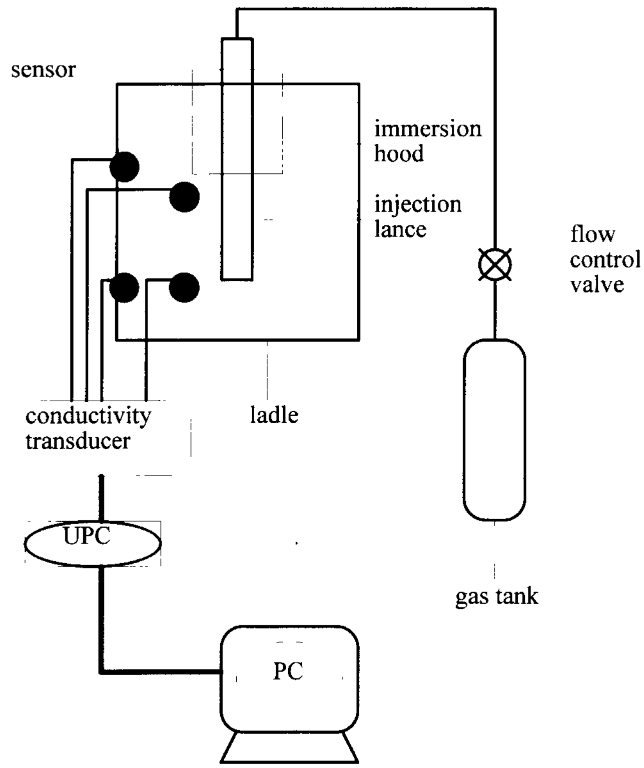

Fig. 4 Schematic representation of the experimental apparatus

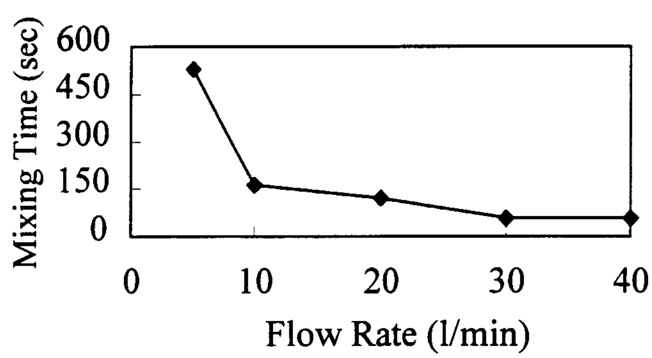

Fig. 6 Plot of mixing time vs. gas flow rate

voltage values received reached a uniform value, the recording system was turned off.

When the conductivity measurements was done, the plastic particles were added in the ladle and the flow pattern was photographed.

3. Results and Discussion

The design and operating conditions under consideration in this study included gas flow rate, submerged depth of the immersion hood, size of the immersion hood, submerged location of the injection lance, submerged depth of the injection lance, and type of the injection lance. Mixing time was the primary quantity to be measured. Also, the flow pattern was photographed by taking pictures of the pathlines of the plastic particles in the water model. As the effect of one individual design or operating condition on the mixing efficiency was investigated, that condition was varied while the other designs and operating conditions were fixed at certain reference values. The reference designs and operating conditions were 30 L/min for the gas flow rate, 17 cm for the submerged depth of the immersion hood, 44 cm for the diameter of the immersion hood, center for the injection lance to be submerged, 65 cm for the submerged depth of the injection lance, and one opening for vertical injection of the injection lance. The results of the investigations are discussed in the following sections.

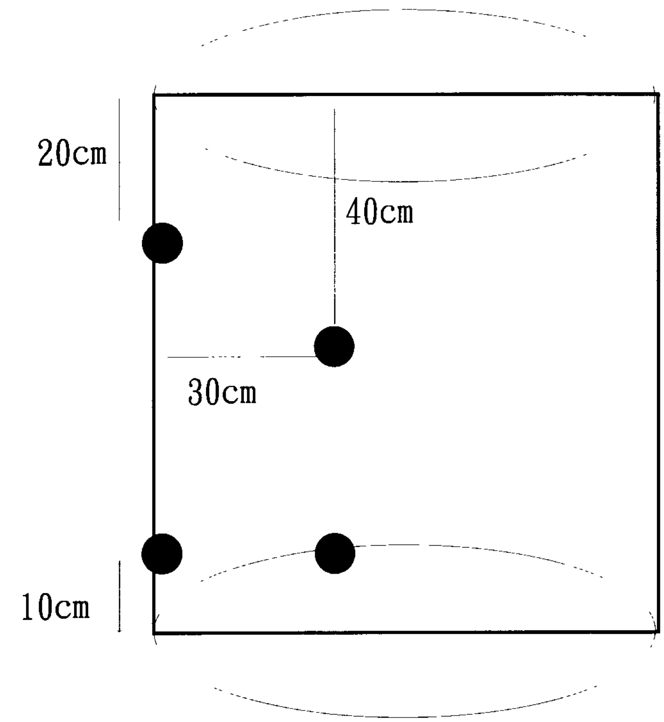

Fig. 5 Schematic representation of the conductivity cell positions

3.1 *Effect of Gas Flow Rate*

Five gas flow rates were used to find the effect of gas flow rate on the mixing efficiency: 5, 10, 20, 30, and 40 L/min. The results shown in Fig. 6 demonstrate that a larger flow rate reduced mixing time. However, as flow rate reached 30 L/min, mixing time showed no improvement if the gas flow rate was further increased. This is in good agreement with the study of Kim and Fruehan (Ref 9), although they used an oil/water system to measure mixing time. The flow pattern was photographed with a gas flow rate of 30 L/min, as shown in Fig. 7. Flow turbulence was very much limited to the inside of the immersion hood; the areas outside the immersion hood were rather stagnant.

3.2 *Effect of the Submerged Depth of the Immersion Hood*

Four submerged depths were investigated: 7, 17, 27, and 37 cm. It is obvious from Fig. 8 that the deeper the hood was sub-

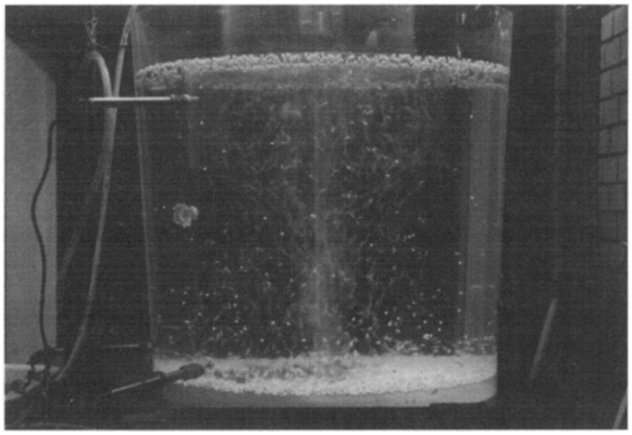

Fig. 7 Picture of the flow pattern of plastic particles with gas flow rate of 30 L/min

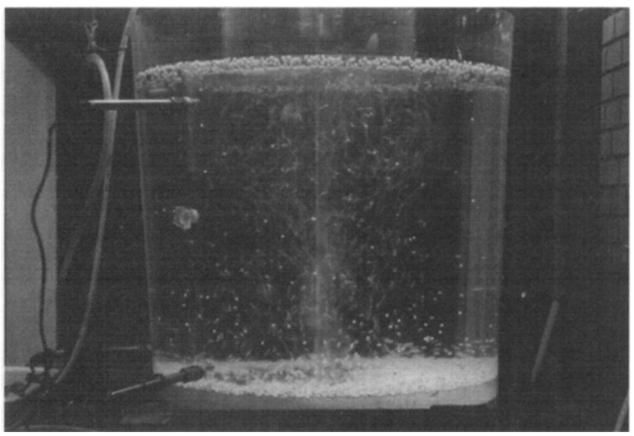

Fig. 9 Picture of the flow pattern of plastic particles with gas flow rate of 30 L/min and submerged hood depth of 27 cm

merged, the longer the mixing time. Figure 9 shows the flow pattern when the submerged depth was 27 cm. The only differences between Fig. 7 and 9 are the submerged depth and the dead zone outside the immersion hood, which is larger for the deeper hood. This explains why deeper immersion hood resulted in longer mixing time and therefore worse mixing. However, one must remember that the introduction of the immersion hood is to protect the slag broken surface. In order to achieve this goal, all the floating gas bubbles have to be confined in the hood. Since the gas flotation forms a plumlike area, the submerged depth of the immersion hood must be deep enough not to let the bubbles float outside the hood.

3.3 *Effect of the Size of the Immersion Hood*

Three hood diameters were investigated: 24, 34, and 44 cm. From Fig. 10, it can be seen that as the hood diameter was increased from 24 to 34 cm, the mixing time decreased. However, as the hood was further enlarged, mixing time increased. This implies that the immersion hood should not be larger than is necessary to confine the floating gas bubbles.

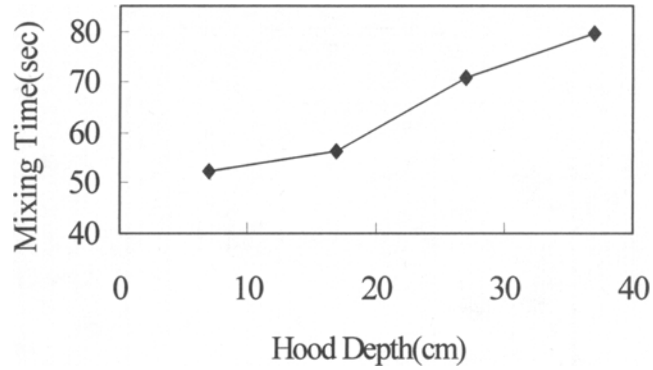

Fig. 8 Plot of mixing time vs. hood depth

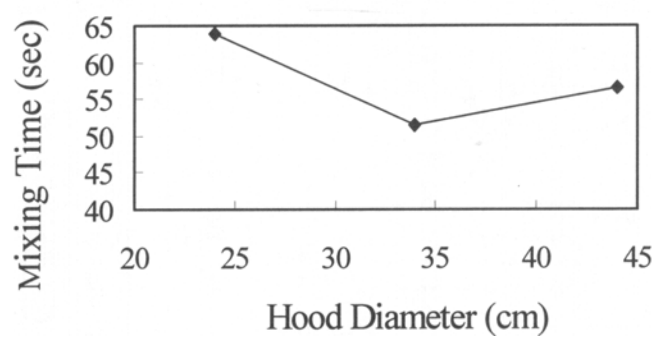

Fig. 10 Plot of mixing time vs. hood diameter

3.4 *Effect of the Submerged Position of the Immersion Hood*

It is natural to submerge the injection lance into the ladle at the central point of the ladle. However, it has been learned from gas stirring treatment (where a porous plug is used to introduce the gas into the ladle to enhance mixing) that it is often better for the gas to be introduced at the off-center position to improve mixing. It is therefore desirable to see if the same phenomenon occurs in the gas injection treatment. Besides the centered injection, two other injection positions were investigated in this study, one 13 cm off center and the other 26 cm off center. The radius of the top surface was around 41 cm. Figure 11 shows that mixing time was reduced as the injection lance was submerged into the ladle at the position of 13 cm off center. However, when the injection lance was positioned 26 cm off center, mixing time increased. This phenomenon can be explained by the fact that slightly off-center injection induces better circulation in the ladle. However, positioning the ladle too much off center results in dead zone formation in the other half of the ladle.

3.5 *Effect of the Submerged Depth of the Injection Lance*

The injection lance was submerged into the ladle to eight different depths: 30, 35, 40, 45, 50, 55, 60, and 65 cm. The mixing times for the various depths are shown in Fig. 12. It shows that the deeper the lance was submerged, the shorter the mixing time. However, mixing time was only slightly shortened when the lance was submerged deeper than 45 cm. The injection

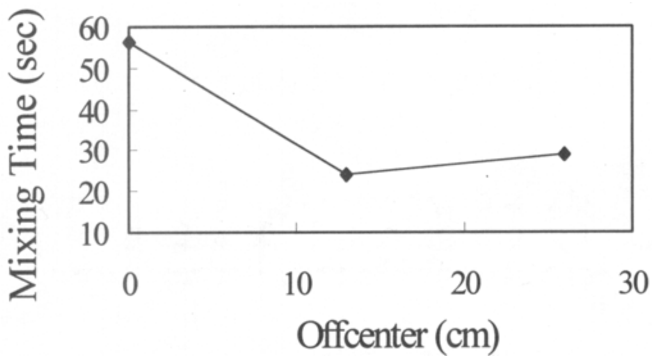

Fig. 11 Plot of mixing time vs. injection position

lance should be submerged to a depth where good mixing is obtained. However, it should not be deeper than is necessary, since deeper injection means higher impact on the refractory on the bottom of the ladle.

3.6 *Effect of the Type of Injection Lance*

The mixing times for the three types of lances, described above, are shown in Fig. 13. It shows that the one-opening type had the least mixing time and thus had the best mixing efficiency. The three-opening type was only slightly better than the two-opening type.

4. Conclusions

A water model was established in this study to investigate the effect of design and/or operating condition on the mixing efficiency of the gas injection treatment in the ladle refining process. The results can be summarized as follows:

- Mixing efficiency can be improved by increasing the flow rate of the injected gas. However, when the gas flow rate is over a critical value (30 mL/min in the water model), improvement of mixing efficiency becomes insignificant by further increasing the gas flow rate.
- Off-center injection is better than centerline injection. However, the injection lance should not be too close to the wall.
- Mixing efficiency is improved when the submerged depth of the immersion lance increases.
- The immersion hood has a optimal size as far as mixing efficiency is concerned. A larger or smaller hood reduces mixing efficiency.
- The submerged depth of the immersion hood should be kept to a minimum to improve mixing efficiency. However, the hood should be deep enough to confine all the floating gas inside the hood.

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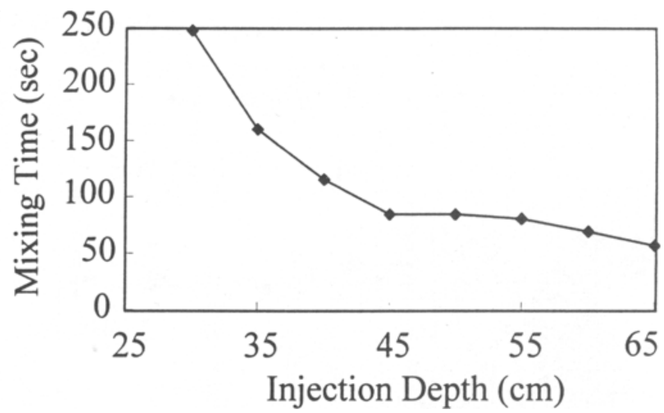

Fig. 12 Plot of mixing time vs. injection depth

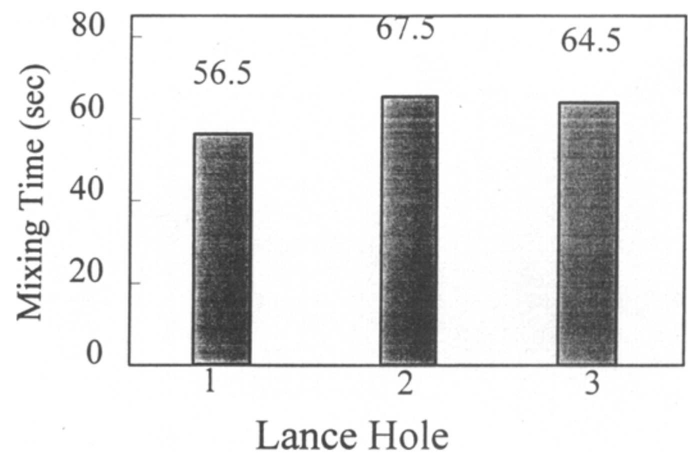

Fig. 13 Plot of mixing time vs. lance hole

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