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A Study on Gas-Liquid Contact in a Perforated Plate-Type SO_2 Absorber at Flooding Conditions

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Abstract

Gas-liquid contact tests above a perforated-plate were conducted with air and water at flooding gas-flow conditions in order to study two-phase flow characteristics in a limestone-gypsum SO_2 absorber. Gas layers were in the form of air pockets and confined to the limited areas around each duct pipe, while the remaining tray area were in the wet condition. The liquid above the tray was always in the flooded and even fluidized conditions at gas flows over the range studied, although vigorous bubbly or churn-turbulent two-phase regime was only observed in the immediate vicinity of the gas hole exit at low gas loads. The froth zone was extremely active to provide intimate contact between gas and liquid so that the necessary mass transfer operation can take place, which is the primary purpose of high-performance SO_2 absorbers. However. the absorber ΔP was 250 mmH_2O for the initial water level at 150 mm, which is an important issue to be resolved for economical operation of the SO_2 absorber. It was seen in the liquid level- and gas flow-transient tests that changes in the absorber liquid inventory were much more pronounced for intimate gas-liquid contact than changes in the gas flow. Based on the 4- and 8-duct pipe test results, grouping the duct pipes near the center of the test tray seemed to promote better recirculation of liquid from the gas-liquid contact zone back to the reaction tank so that the absorbed SO_2 can be neutralized.

Key words : absorber, flooding, perforated plate, limestone-gypsum, L/G ratio

1. INTRODUCTION

SO_2 is a typical air pollutant produced in the process of combustion of fossil fuels and is generally known to cause acid rain that is damaging forests and soil around the world. More stringent boiler emission standards have already been enforced in Korea to reduce SO_2 emission to the atmosphere (Ministry of Environment, 1991): Less than 540 ppm SO_2 in the 1.0% S fuel zone, 270 ppm SO_2 in the 0.5% S fuel zone, and 180 ppm SO_2 in the 0.3% S fuel zone for oil-fired industrial boilers and 250 ppm SO_2 for coal-fired industrial boilers; and less than 150 ppm SO_2 for the existing coal- or oil-fired power boilers and 120 ppm SO_2 for new coal- or oil-fired power boilers. Most of the industrial and power boilers are thus required to install FGD's (Flue Gas Desulfurization), unless lower sulfur fuels are used to meet the new emission standards.

The wet limestone-gypsum process SO_2 absorbers are usually classified into spray towers, tray towers, or bubbling reactors, depending on the internal gas-liquid contact mechanism. The liquid-to-gas contact ratio, generally known as the 'L/G Ratio', is one of the important SO_2 absorber design criteria. For counter-flow spray or tray tower absorbers, the L/G Ratio is generally designed at 10~20 Liters/Nm^3 with gas flowing upward and liquid flowing downward (Bobcock & Wilcox, 1995, Steinmuller, 1995; Hitachi, 1988). Clear understanding of the gas-liquid contact mechanism is a pre-requisite for assurance of the high SO_2 removal efficiency in the absorber as well as successful design of the absorber internals.

The spray tower absorber with countercurrent gas-liquid contact has been dominating the FGD market since its first appearance in early 1970's. The tray tower absorber belongs to a family of the spray tower absorber, which is equipped with a perforated plate (or sieve tray) to maintain a certain amount of liquid inventory above the tray and enhance gas-liquid contact more significantly than in the spray tower absorber. The L/G ratios for the tray tower absorber are usually in the neighborhood of 20 Liters/Nm^3. In the bubbling reactor absorber, flue gases laden with SO_2 are introduced directly into a liquid pool through a number of sparger pipes that are immersed into the liquid to create vigorous bubbly two-phase contact regime (Chiyoda Corp., 1994). Though the L/G ratio is not applicable, more efficient gas-liquid contact can be achieved in the bubbling reactor absorbers. However, one of the major disadvantages in the bubbling reactor absorber is that absorber pressure losses will also increase much more than in the spray or tray tower absorbers.

For betterment of the existing spray or tray tower absorbers, it is often required to treat more flue gas volume without major absorber modification due to change in the environmental regulations. One of the possible solutions is modification to a high-velocity tray tower absorber that enables desulfurization of more flue gas in the same time scale as in the conventional low-velocity absorber. The term 'high-velocity' absorber means a tray tower absorber that operates at the flooding gas velocities with no or little fallback of the liquid through gas holes. On the contrary, the 'low-velocity' absorber allows significant liquid fallback because gas velocities are lower than the flooding conditions. In the high-velocity absorber, more liquid inventory is needed to allow enough contact time between the gas and the liquid. However, more liquid inventory will result in overall pressure loss increase in the tray. Balancing the two conflicting design conditions-lower pressure loss and longer gas-liquid contact is the key for successful design of a high-velocity absorber.

Gas-liquid contact above the tray is generally dependent upon the tray geometry, the liquid inventory, the gas flow, and the liquid flow. Several different two-phase flow regimes are anticipated to occur especially at the flooding gas flow conditions. As gas flow or gas velocity increases for constant liquid flow, flooding of the liquid above the tray will commence soon, which is usually termed as 'onset of flooding'. Liquid penetration through gas holes in the tray will begin to decrease and further increase in gas velocity will result in zero penetration and then complete flow reversal, giving rise to cocurrent flow of gas and liquid (Bankoff and Lee, 1983). Additional liquid flow passage will be required at the zero penetration condition. Cross-flow is one possible way to enable liquid recirculation over the tray to the reaction tank at the bottom of the absorber. At the same time, vigorous bubbling or churn-turbulent two-phase flow regime will be developed in the liquid above the tray, followed by breakup of the bulk liquid into many small liquid drops that will be fluidized with increasing gas velocity (Mayinger, 1981). Cross-flow of the liquid to the peripheral tray area will enhance mixing of gas and liquid in the churn-turbulent regime. However, gas-liquid contact will be less efficient in the fluidization regime than in the churn-turbulent regime due to gas flow channeling through the space between disintegrated liquid drops.

In the present paper, intimate gas-liquid contacting is studied with air and water in a scale–down plastic SO_2 absorber model with a proprietary perforated–plate. Gas velocity exiting gas holes in the perforated plate will be controlled sufficiently high until flooding or even fluidization of liquid drops occurs in the test model. The main purpose of the present study is to understand two–phase flow regimes between gas and liquid in a limestone–gypsum process SO_2 absorber and to develop a hydrodynamic information basis for designing a new industrial and power boiler SO_2 absorbers with the present air–water test results.

2. GAS-LIQUID CONTACT TESTS AT FLOODING GAS-FLOW CONDITIONS

2. 1 Plastic Scale Model

A series of gas–liquid contact tests were conducted in a plastic scale model to investigate two–phase flow characteristics above a proprietary perforated plate at flooding gas flow conditions using air and water. Fig. 1 shows a schematic description of the experimental apparatus used for the present tests. A cylindrical plastic scale model (2 m diameter × 2.34 m height) with a square test tray (1.3 m × 1.3 m, 18.8% open area) was constructed with clear acrylic plastic for visual observation of the two–phase flow from outside. A 75 horsepower motor–driven air blower was chosen to supply maximum air–flow of $350\,m^3/min$ at $500\,mm\ H_2O$.

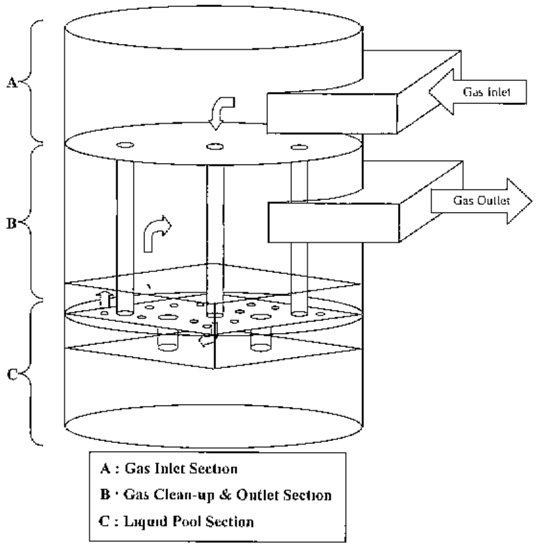


Fig. 1. Schematics of the experimental apparatus.

As shown in Fig. 1, the whole test model is subdivided into three sections: The gas inlet and distribution section at the top, the gas cleanup and outlet section in the middle, and the liquid pool section at the bottom. Gas flows from the inlet duct to the upper plenum, to the duct pipes, to the gas layer beneath the tray, to the gas hole in the tray, to the froth zone in the middle plenum, and then finally to the outlet duct. High–velocity gas flow pushes water which initially flooded a lower part of the duct pipe below the test tray to make large air pockets (or termed as gas layers hereafter) around each duct pipe, whose sizes are dependent upon the gas velocity and flow conditions. Area outside the thus formed gas layer may be in ‘wet’ condition, unless the nearest gas layers are large enough to meet and coalesce one another. The water displaced by the gas layer will rise above the tray through gas holes in the wet area or through riser pipes immersed in the liquid pool, which is one of the important design criteria.

There are sixteen (16) duct pipes for the gas flowing downwards and nine (9) riser pipes for the liquid flowing upwards. Rectangular weirs are attached to four sides of the test tray and cross–flow is expected to occur above the plate over the weir to the liquid pool. In addition to the weir, rectangular divider plates (1,500 mm L × 700 mm H) are installed 50 mm apart from the weir to collect all the liquid drops hitting the divider plate.

2. 2 Test Conditions

For the given geometry of gas–liquid contacting, the initial liquid inventory level, the gas flow rate, and the gas hole area ratio are three important test parameters for two–phase flow characteristics above the test tray. The test conditions are:

- Initial Liquid Level: 50 mm, 100 mm, and 150 mm
- Gas Flow Rate: 25%, 50%, 75%, and 100% (w.r.t.

212 m^3/min)
- Gas Hole Area Ratio: 12.0% and 15.5%
- Weir Height: 250 mm, 350 mm, and 450 mm

2. 3 Gas Flow Calibration

Gas flow from the air blower was directed into the cylindrical test tray section through a rectangular gas duct (390 mm H × 1,000 mm W), in which the maximum gas velocity was designed to reach 9.4 m/s (or 220 m^3/min). A perforated plate with 30% open area was installed inside the gas duct to calibrate the gas flow rate and a pair of 1-to-5 inclined U-tube manometers were connected before and behind the perforated plate. The intention is that instead of measuring volumetric gas flow rates directly with a hot-wire anemometer, pressure loss over the plate is measured with the inclined manometers and simply correlated to gas flow rates. The rectangular cross-section of the gas duct after the perforated plate was subdivided into 20 (4 rows × 5 columns) hypothetical rectangular sections of the same area. Five measuring and guiding taps were attached to the bottom surface of the gas duct. Gas velocity at the center of each section was measured with a pitot tube to calculate area-averaged gas velocity and then gas flow rate.

Fig. 2 is the thus produced gas flow calibration curve for the present test range. A regression equation is then obtained as follows:

$$\log Q = 0.5623 \log(\Delta P) + 1.3616 \, (R^2 = 0.9977) \quad (1)$$

Therefore, once ΔP is known, one can easily calculate the gas flow rate and gas velocity with Eq. (1).

2. 4 Test Results and Discussion

2. 4. 1 Dry Tray Test

First, dry tray tests were performed only with air to study pressure losses over the dry tray as a reference for 12% and 15.5% open areas and 50~100% gas loads. Initial water levels were always controlled at 200 mm below the test tray to make the tray 'dry'. For 12% open area tray ΔP was measured 18 mm H_2O at 43% load and 63 mm H_2O at 100% load, whereas for 15.5% open area ΔP was measured 27 mm H_2O at 50% load and 56 mm H_2O at 104% load. The ΔP increasing slope was much larger for 12% open area than for 15.5% open area, which is one reason to choose the 15.5% open area for the present test. It is important to maintain ΔP as low as possible for economic operation of a full-scale absorber.

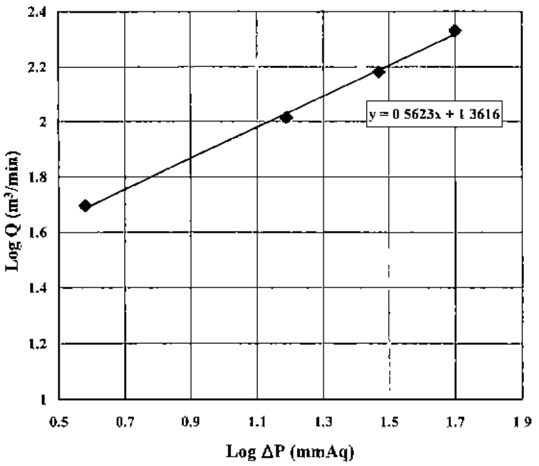


Fig. 2. Gas flow calibration curve.

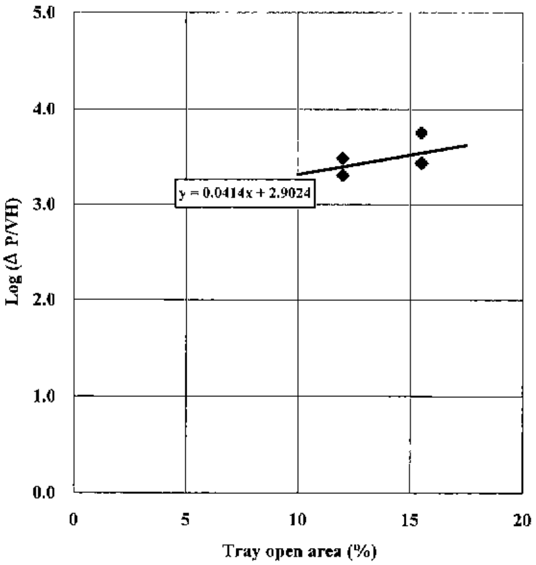


Fig. 3. Dimensionless pressure loss over the dry test tray.

Fig. 3 shows the effect of gas hole area ratios on the dimensionless pressure loss over the dry tray. Both pressure loss (ΔP) and gas velocity head (VH) were calculated in mmH_2O to form a dimensionless pressure loss variable, (ΔP/VH). Then pressure loss over the tray can be obtained from the following equation:

$$\mathrm{Log}(\Delta P/VH) = 0.0414\gamma + 2.9024 \qquad (2)$$

$$\text{Where } VH = \rho_g * V_g^2/2/g_0\,(mmH_2O);$$
$$g_0 = 9.807\,kg/m/s^2/mmH_2O \qquad (3)$$

A linear dependency of the dimensionless pressure loss on tray open area ratio is assumed especially below 20% open area range as already predicted by Maroti (DynaFlow Systems, 1997).

2. 4. 2 Wet Tray Test: Steady State

One of the key purposes of the steady state test is to observe the operation of the test tray design at steady state. After the test model was filled with water to the desired initial water level above the tray, making the tray 'wet', a series of parametric testing were performed at steady state air-flow conditions with respect to weir height, air flow rate, initial water level, and percent open area. Gas-liquid contact was visually observed and recorded with a video camera, while the inlet-outlet pressure losses were measured with U-tube manometers and ΔP gauges. Extensive use of video photography allowed documentation of the observed phenomena, even in cases for which no measurements are possible, such as the extent of gas layer formation beneath the tray. The observations made regarding some key aspects of the test model operation are listed below.

(1) General Observations of Gas-Liquid Contact

The primary purpose of any SO_2 absorber is to provide intimate contact between gas and liquid so that the necessary mass transfer operations can take place. There are various types of SO_2 absorbers, including spray towers, counter-flow tray towers and cross-flow tray towers. When compared to other type of absorbers, the present test model has shown excellent gas-liquid contact characteristics in a flooded and even fluidized two-phase regime. Vigorous bubbly or churn-turbulent two-phase regime was only observed in the immediate vicinity of the gas hole exit at low gas loads. The rest of the two-phase zone, which is so called the froth zone, was always filled with liquid drops that were violently dancing up and down due to high gas velocity up-flow. The froth zone above the test tray is extremely active at nearly all the operating conditions. Even at low gas flow rates, the activity of the gas-liquid contact zone above the test tray can be easily enhanced by increasing the liquid inventory in the absorber. To the extent that overall pressure loss (inlet to outlet) provides a measure of the effectiveness of the gas-liquid contact, the test model geometry provides greater efficiency of gas-liquid contact at reduced loads than any type of absorber, with the possible exception of a Chiyoda JBR (Jet Bubbling Reactor).

① Liquid Recirculation

The second most important function of an SO_2 absorber is to provide recirculation of liquid from the gas-liquid contact zone back to the reaction tank so that the absorbed SO_2 can be neutralized. Normally, this recirculation rate is defined in terms of the liquid to gas flow ratio (L/G).

The liquid flow instrumentation selected for the present test, a paddle-type Signet flow meter, was capable of measuring velocities in the expected range of about 0.3～6.0 m/s. However, during the preliminary shakedown testing of the model it was discovered that no riser pipe flow measurement was possible. Although no reading was available, visual observation indicated that the velocity was probably far less than 0.3 m/s since the flow meter paddle was hardly seen rotating at all. In order to compensate for this drastic change in the expected liquid flow measurement range, all testing was conducted with eight of the nine riser pipes closed off by covering the bottom of each pipe with plastic sheeting secured with tape. Only the center riser pipe, which held the liquid flow instrument, was left open.

Riser pipe velocities for much of the testing were at or below the lower limit of the flow meter range, even with the riser flow artificially increased to what should have been nine times the expected value. The provision of the plastic sheeting at the bottom of the closed off riser pipes turned out to provide a good qualitative indication of the tendency toward flow up the riser pipe. The sheeting fit loosely enough that it would take on a concave shape when there was even the smallest tendencies for upflow near the bottom of the pipes. The visualization of flow tendencies allowed observation of those times when there was probably flow up the riser pipe, even when the quantitative measurement was not possible. Liquid flow visualization beads were also used to confirm periods of up-flow. The extreme low riser pipe velocities are believed to be an artifact of the gas layer formation tendencies as described below.

② Formation of Gas Layer

Based on qualitative observations as documented on videotapes, it was confirmed that complete gas layer formation is very rare and occurs only at high gas loads with moderate liquid levels on the tray More typically, gas layers are observed as air pockets that are confined to the area directly below and nearby each duct pipe. Because a consistent gas layer rarely forms across the tray, liquid recirculation is free to occur through the wet gas holes, reducing the need for and potential for riser pipe flow. Based on evaluation of several different duct pipe configurations, it is clear that the attainment of a consistent gas layer is not possible, and should be a controlling factor in the design of a full-scale absorber.

③ Froth Height

Froth height is an operating parameter that can be measured, yet the delineation of the height of the froth in any given situation is somewhat subjective. By consistently using the same observer to record froth heights on the data sheet, and by reviewing video of numerous tests as an independent check, the froth height data was reduced. In general, it was observed that, except at initial water levels approaching 0 mm above the tray or at extremely low gas flow rates, the froth is typically high enough to pass through the weir notch. Bottom of the V-shaped notch is 250 mm above the tray for the 350 mm weir height. In the majority of the tests the froth height is sufficient to pass well over the top of the weir. At high gas flow rates combined with initial liquid levels at or above 150 mm, the froth was frequently observed to clear even the divider plate (700 mm).

④ Carryunder Potential

Carryunder is the term used to describe the transport of gas bubbles which exist in the froth flowing over the weir completely through the downcomer and out into the tank. Downcomer is the rectangular liquid recirculation passage between the weir and the divider plate, whose depth is the same as that of the riser pipe (400 mm). The potential for carryunder was documented during the tests by measuring the extent of penetration of the bubbly layer down into the downcomer. It is apparent that the majority of the tests showed very low penetration depths of usually less than 100 mm, but that a group of tests had penetrations approaching or exceeding the downcomer depth. The data identified high weir heights (450 mm) and high initial liquid levels ($>$150 mm), in combination with high gas flow rates, to be the cause of these high penetration values. Since this combination can easily be avoided by operational guidelines, carryunder should not be a problem in the operation of the full-scale absorber.

⑤ Carryover to Outlet Duct

Qualitative observations and video records revealed that the operating conditions which would produce the greatest potential for carryover of liquid to the outlet duct are combination of high gas flow and very low initial liquid level (0 or 50 mm). Under these conditions the liquid is easily sheared into very small droplets by the action of the gas passing through the gas holes. Some other test conditions may have appeared to result in high carryover rates based on comparison of the final water level with the initial level. However, in some cases these represented sloshing of froth into the outlet duct, especially during the tests at high froth conditions. This type of carryover would not occur in a full-scale absorber, where the distance between the

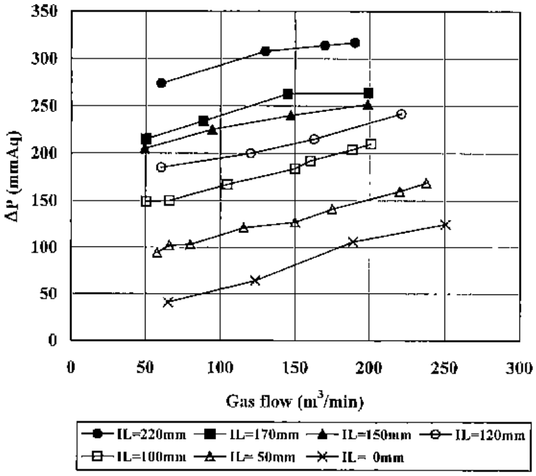


Fig. 4. Effects of the initial water level on DP.

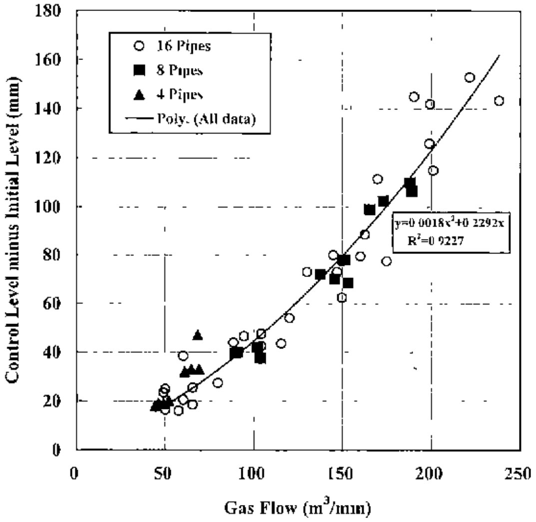


Fig. 5. Control level minus initial level.

tray and the bottom of the outlet duct is much greater than in the test model.

(2) Data Analysis

① Absorber ΔP

As expected, overall pressure loss, which is the differential pressure across the absorber inlet and outlet, is found to be a function of gas flow and water level. The relationship is illustrated on Fig. 4. At high gas loads absorber ΔP was still measured 100～300 mm H_2O, depending on the froth height between 300～700 mm. Taking into account the dry tray ΔP, the froth zone ΔP contributing most of the measured ΔP seemed to be lower than expected due to high void fraction in the two-phase zone.

Note that increasing water level by only 50 mm has an effect on pressure drop approximately equal to that represented by varying the gas flow over the entire test range. This means that the operator should be able to influence absorber performance significantly by changing the water level (or inventory). It also points up the importance of water level control to the absorber. Water level control is significantly more important in the present type of absorber than in any other type of absorber, with the possible exception of a Chiyoda JBR

② Control Level vs. Initial Level

For the purpose of this test, control level is defined as the water level in the external weir box after the absorber starts up with a known initial level of water in the idle condition. Both initial level and control level are expressed in millimeters of water above the tray. Due to the importance of water level control and the difficulty of measuring water level inside the absorber during operation, it is essential that a relationship be determined between control level and effective water level on the tray. Control level is a likely choice for a surrogate measurement.

After investigation of several other combinations, it was determined from analysis of the model test data that the parameter (control level minus initial level) could be correlated reasonably well with gas flow. The result is shown in Fig. 5. The ability to define a relationship for the test model geometry gives rise to expectations that a similar relationship can be found for any given full scale design.

③ Tray Percent Open Area

The test tray was constructed with 772 gas holes, representing an open area equal to 18.8% of the active area of the tray. Active area is defined as total tray cross-sectional area bounded by the weir, minus the

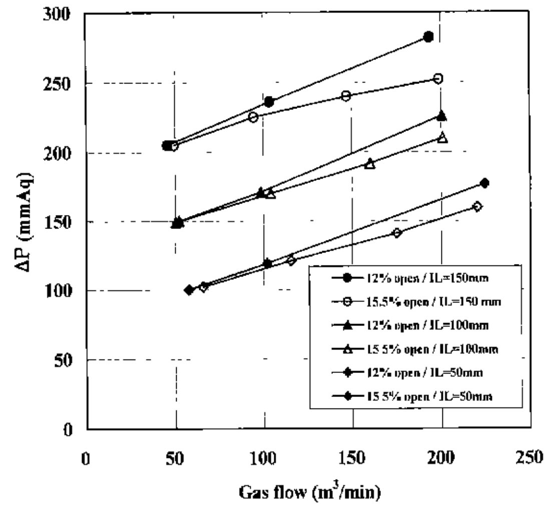


Fig. 6. Effects of the tray open area and the initial water level on D P.

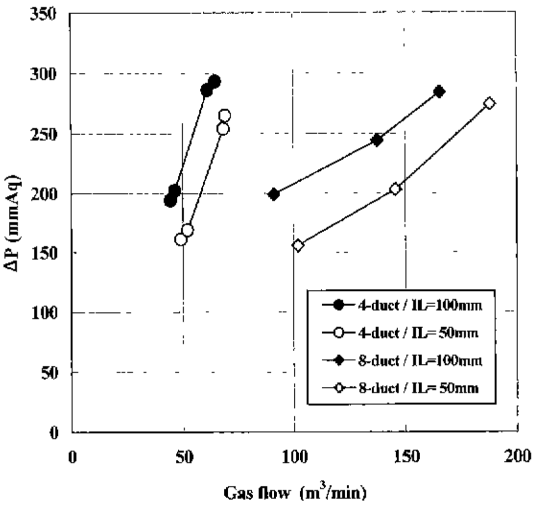


Fig. 7. Effects of the gas flow area and the initial water level on D P.

area taken up by the 16 riser pipes and the 9 duct pipes. The test plan originally called for test to be performed at three different open areas: 18.8%, 15.5%, and 12.0 %. However, preliminary tests indicated that no gas layer could be formed at the full 18.8% open area condition, so plans to test the 18.8% condition were abandoned. Most tests were conducted at the second highest open area of 15.5% by plugging 132 of the sieve tray holes with rubber stoppers, but one test series was conducted at 12% open area by plugging 140 additional test tray holes.

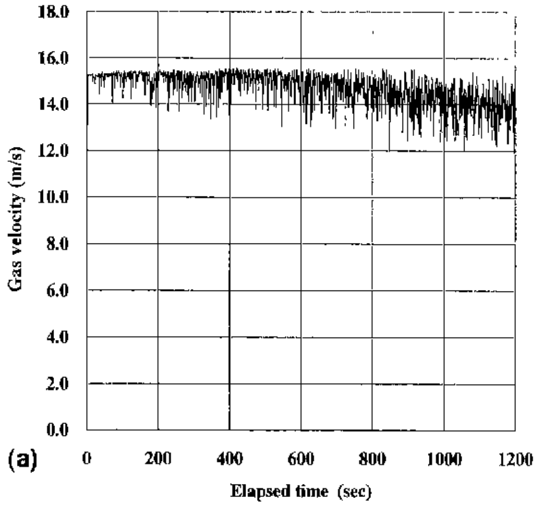
As shown in Fig. 6, the effect of the decreased open area on absorber ΔP is minimal at low gas flow rates. Conversely, at high gas flow rates the reduced open area creates a significant increase in ΔP at a point where additional ΔP is likely not needed for the absorber performance. It was expected that the use of the 12% open area condition would extend the range of gas flow rates at which a stable gas layer could be formed. However, this effect was minimal and, as noted previously, it was rarely possible to develop a complete gas layer during the model tests at less than full gas loads.

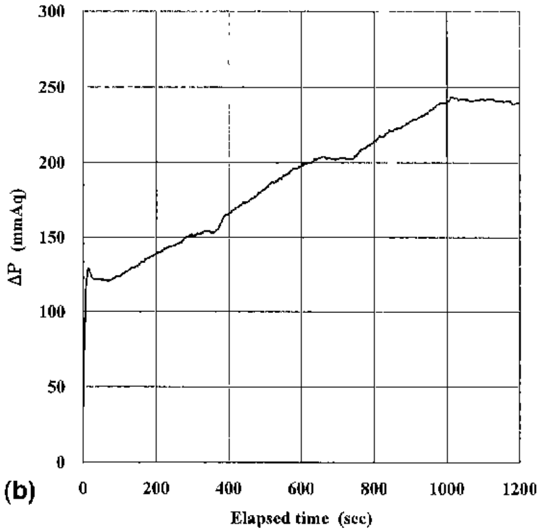
As previously illustrated on Fig. 4, the increase in water level has a much more dramatic effect on absorber ΔP than the increase in gas flow over the range studied. At most load conditions the effect of water level increases can also be expected to have a greater benefit to performance than the reduction in tray open area. Because a water level increase is easily reversible and a sieve tray design change is not, the 15.5% open area was maintained for the rest of the model test.

④ Configuration of Duct Pipes

During the model test it was necessary to close off some of the duct pipes in order to simulate various configurations of duct pipe arrangement. In doing so, gas velocities were increased up to four times the design value in the pipes that remained open. Except for the increased absorber ΔP caused by duct pipe pressure losses in this condition as shown in Fig. 7, any adverse effects of the higher duct pipe velocities were not observed. The gas layer in the vicinity of the high velocity discharge from the open duct pipes was much thicker than normal, then became thinner as it radiated out from the central portion of the tray.

One of the two test series conducted with eight duct pipes open resulted in a violent side-to-side surging of the froth above the tray. It was determined that this





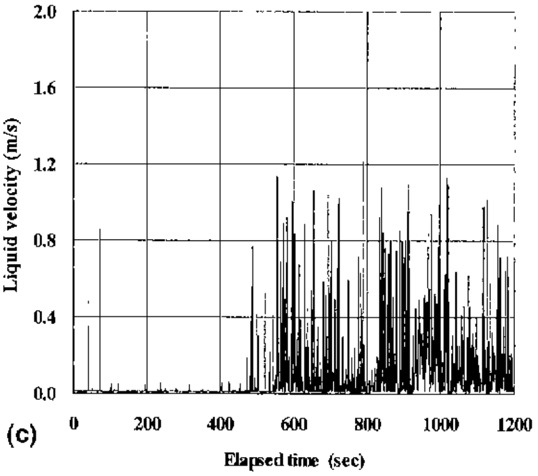


Fig. 8. (a) Duct pipe gas velocity change during the liquid level transient test. (b) D P change during the liquid level transient test. (c) Riser liquid velocity change during the liquid level transient test.

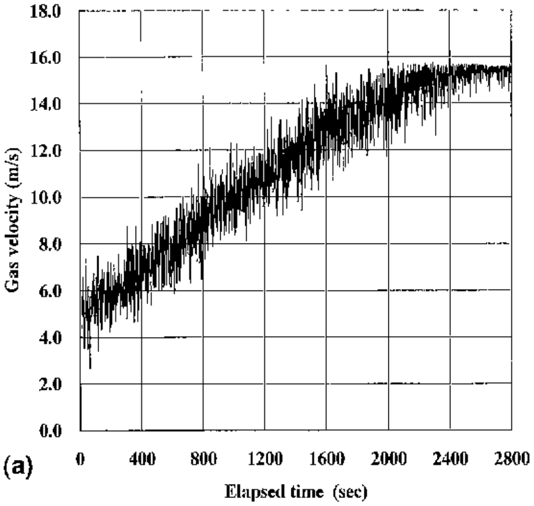
was due to the fact that the 8-pipe configuration pattern for that test was not symmetrical with respect to the centerline of the tray. The 8-pipe test series was repeated with a symmetrical pattern of duct pipes and the result was much more favorable.

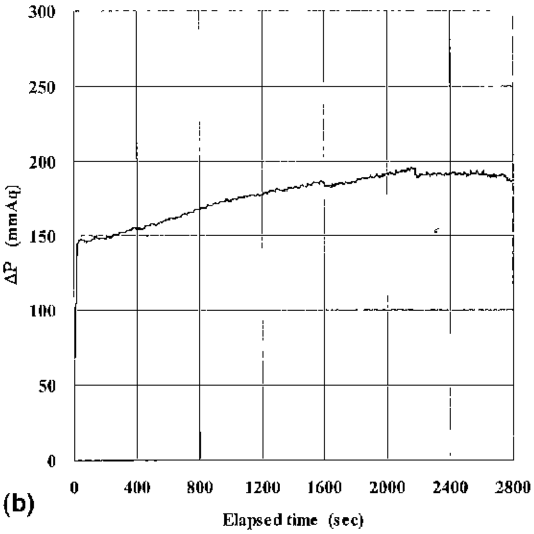
The symmetrical 8-pipe test used the four center duct pipes and the four corner duct pipes. One test series was also conducted with only the four center duct pipes open. Based on the riser pipe flows measured during these two test series, grouping the duct pipes near the center, around the center riser pipe, seems to promote better liquid flow. The highest values for the 8-pipe configuration are all from symmetrical test series which utilized the four center duct pipes and that the lowest values for the 8-pipe tests are all from the test series which utilized only two of the four center pipes. The tests of the 4-pipe and symmetrical 8-pipe configuration show that the riser velocity measured at an initial water level of 100 mm is significantly higher than any 16-pipe test conducted at that same water level.

Based on the results of these tests, it is recommended that duct pipes should be grouped together near the center of the tray, around the central riser pipe. With this type of duct pipe configuration, each gas layer may be integrated to form a single large one in the central area, while improving liquid recirculation flow significantly. Gas layer formation should be improved more by optimizing the number and configuration of riser pipes, in which the spreading gas layer will not encounter the resistance by the need to flow around the numerous riser pipes

2. 4. 3 Wet Tray Tests: Transient

Two different transient tests were conducted: Liquid





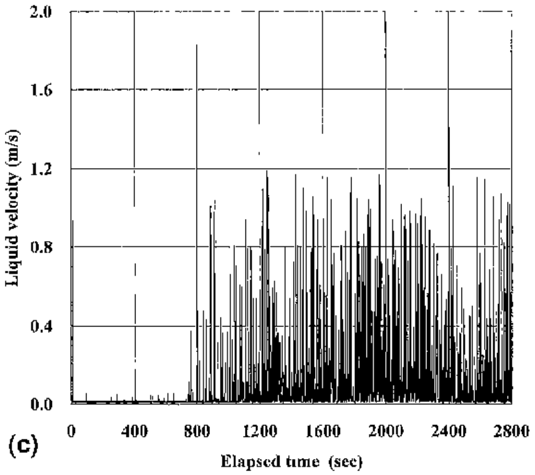


Fig. 9. (a) Duct pipe gas velocity change during the gas flow transient test. (b). D P change during the gas flow transient test. (c). Riser liquid velocity change during the gas flow transient test.

level transient and gas flow transient. In the former test, position of the air blower damper was fixed at 100 % load while additional liquid is continuously added from 0 mm to 150 mm level in the outside weir box. In the latter test, initial liquid level was fixed at 100 mm above the tray while gas flow is increased from 30% to 100% load to simulate the ramp rate of 1.5%/min.

Three major hydraulic operating parameters were automatically recorded with the electronic data acquisition system (DAS) during the gas flow- and water level-transient tests. The first of these parameters is the riser pipe velocity, which is an important measurement of liquid recirculation from the bottom section (or reaction tank of the absorber) to the middle section for intimate gas-liquid contacting. Most of the testing was performed with all riser pipes except one blocked to flow. The second hydraulic parameter measured was the overall pressure drop of the absorber. This measurement was made between the inlet and outlet plenums and is representative of the work required by the booster fan to overcome system resistance. The final parameter is the hot-wire gas velocity in the central duct pipe. This measurement was recorded with the exception for the reduced duct pipe configuration.

① Liquid Level Transient

Fig. 8 shows trends that are believed to be typical of the performance expected from the current absorber geometry. Absorber pressure drop starts to increases immediately, while riser pipe velocity starts to increase after a while at a fixed fan inlet damper position. It is seen again that changes in the liquid inventory can strongly affect absorber performance as discussed in the steady state tests

The test results for the 8-pipe configuration and the 4-pipe configuration showed somewhat different behavior from that observed for the base test cases with 16 duct pipes. The major difference is in the flow performance of the riser pipe. For the 8-pipe test riser flow appeared early in the data collection period and reduced over time as pressure drop increased. However, the flow in the riser pipe returned after a period of time. Upon further investigation, it was determined after reviewing the video tape that the riser pipe had reverse flow early in the test, transitioned to zero flow in the middle of the test and finally transitioned to up-flow at the end of the test. This recirculation mechanism was unexpected and is another indication of the operating flexibility. However, no riser pipe flow reversal was observed in the 4-pipe configuration tests.

② Gas Flow Transient

Fig. 9 shows the impact of gas flow increases on absorber pressure drop and riser flow. Both parameters are affected by increased gas flow. However the magnitude of the change is much less pronounced than the effect of increases in liquid level as seen in the liquid transient tests.

3. CONCLUSIONS

Gas-liquid contact tests above a perforated-plate were conducted with air and water at flooding gas-flow conditions in order to study two-phase flow characteristics in a proprietary SO_2 absorber. For the purpose of the test a scale model (2.0 m diameter × 2.34 m height) with a test tray (1.3 m × 1.3 m, 18.8% open area) was constructed with clear acrylic plastic to enable visual observation of two-phase characteristics from outside. The test tray was initially flooded with water and then gas flow was directed downward through vertical duct pipes connected to the tray to create a gas layer beneath the tray, resulting in gravity-dominated gas-liquid contact regime.

Several important hydrodynamic findings can be summarized as follows:

1. The present test model has shown excellent gas-liquid contact characteristics in a flooded and even fluidized two-phase regime, although vigorous bubbly or churn-turbulent two-phase regime was only observed in the immediate vicinity of the gas hole exit at low gas loads. The froth zone was always filled with liquid drops that were violently dancing up and down in the air due to high gas velocity up-flow. The froth zone above the test tray was extremely active to provide intimate contact between gas and liquid so that the necessary mass transfer operation can take place, which is the primary purpose of high-performance SO_2 absorbers.

2. Based on qualitative observations as documented on videotapes, it was confirmed that complete gas layer formation beneath the tray was very rare and occurred only at high gas loads with moderate liquid levels on the tray. Gas layers were in the form of air pockets confined to the limited areas around each duct pipe and the remaining tray area were in the wet condition

3. Riser pipe velocities for much of the testing were at or below the lower limit of the flow meter range. even with the riser flow artificially increased to what should have been nine times the expected value. Based on the 4- and 8-duct pipe test results, grouping the duct pipes near the center of the test tray seemed to promote better recirculation of liquid from the gas-liquid contact zone back to the reaction tank so that the absorbed SO_2 can be neutralized.

4. Absorber pressure loss is found to be a function of gas flow and water level, ranging from 200 mm H_2O at 25% load to 260 mm H_2O at 100% load for the 150 mm initial water level testing. Control of liquid inventory becomes significantly more important in the present test model than in any other type of absorbers, with the possible exception of a Chiyoda JBR. It is also confirmed in the liquid level- and gas flow-transient tests that changes in the absorber liquid inventory is much more pronounced for absorber performance than chan-

ges in gas flow.

5. Though a separate liquid flow passage is intended over the weir surrounding the test tray at flooding conditions, additional liquid recirculation was free to occur through the wet gas holes. At low gas loads with moderate liquid levels on the tray cross-flow occurred continuously over the weir. However, at high gas loads cross-flow were often interrupted, giving rise to intermittent flow over the weir.

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Nomeclature

Q = calculated gas flow rate, m^3/min
VH = gas velocity head, mmH_2O
V_{avg} = calculated gas velocity, m/s
V_g = gas velocity, m/s
ΔP = pressure loss, mmH_2O
γ = gas hole area ratio, -
ρ_g = gas density, kg/m^3

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