FLOW MEASUREMENTS IN RECTANGULAR BASINS

R.IASENZA and S.BABARUTSI

Department of Civil Engineering and Applied Mechanics, McGill University
817 Sherbrooke St. W., Montreal, Canada H3A 2K6
Tel: 514-398-8731, Fax: 514-398-7361, e-mail: Babarutsi@Agreng.lan.mcgill.ca

ABSTRACT

The hydraulic behavior and mixing processes in rectangular basins are studied experimentally in a laboratory scale model. The laboratory basin was modeled after a full scale aerated lagoon operating in Saint-Julie, Canada. Two sets of experiments were conducted: one without artificial aeration and the other using a large bubble diffuser. For both sets, two-dimensional mean and root mean square velocities were measured using a hot-film anemometer. Further, a flow visualization technique was used as a qualitative approach.

The results show that the hydraulic behavior of non-aerated rectangular basins is very complex, due to the formation of flow patterns such as stagnant zones and recirculation. The location and size of these flow patterns are determined using the measured velocity flow field and the flow visualization. Mixing in these basins is highly non-uniform, since flow is clearly segregated into high-velocity and low-velocity areas. The exchange between these areas is very low, affecting the distribution of solids and contaminants.

When large bubble aeration is introduced, mixing becomes more uniform, as the size of stagnant zones and the extent of recirculation decreases. For the tests studied, aeration increases mixing predominantly in the lateral direction. Also, aerator position and flowrate are identified as important parameters which influence mixing.

The understanding of mixing and transport mechanisms in rectangular basins is important, because such basins are often used in applications which require settling or mixing of solids and contaminants.

Keywords: Rectangular Basins, Mixing, Velocity Field, Turbulence, Measurements, Hot-Film Anemometry, Artificial Aeration, Flow Visualization, Hydraulics.

INTRODUCTION

Rectangular basins are used as means of mixing or settling of various solids and contaminants in many applications including aerated lagoons, stabilization ponds and activated sludge processes. Therefore, it is important to understand the mixing and transport processes which take place within such basins. The hydraulic behavior of rectangular basins is very complex, largely due to the formation of flow patterns such as recirculation, stagnant zones and channeling .These flow patterns determine the mixing and transport processes, and ultimately, the distribution of solids throughout the basin. That is, stagnant zones and regions of low velocity will be dominated by molecular diffusion, resulting in slow mixing. Regions with high velocities such as channeled and recirculating flows will be dominated by turbulent diffusion, resulting in strong mixing (Fischer, 1979; Thirumurthi, 1969).

In the past, reactor models have been used to study the hydraulic behavior of basins (Mangelson and Watters, 1972; Ferrara and Harleman, 1981; Marecos do Monte and Mara, 1987). However, these models are not able to accurately simulate the mixing and transport processes, since they are based on ideal flow conditions. Hydraulic behavior can best be characterized by obtaining the velocity of each element within the basin. A more practical approach is to measure velocity at different points in the basin, in order to acquire a detailed picture of the velocity field. These measurements can be used to locate flow patterns and can provide detailed information about the mixing processes, and thus, the distribution of solids and different pollutants throughout the basin.

In this study, a hot-film anemometer is used to measure the two-dimensional velocity field in aerated and non-aerated rectangular basins. The results are analyzed to identify the formation of flow patterns, and further, to study the hydraulic behavior and mixing and transport processes. These measurements will also be used to verify and test a mathematical model developed for rectangular basins to simulate numerically their hydraulic behavior and mixing processes.

EXPERIMENTAL SETUP

The experiments were conducted in the laboratory on a scaled rectangular basin, with the intent of simulating a full-scale aerated lagoon operating in Saint-Julie, Canada. The lab-scale basin was designed geometrically similar to the full-scale aerated lagoon by using a length to width ratio of 2, and a depth to width ratio of 0.1. Also, the aerator size and flowrate were scaled accordingly. The basin, shown in Figure 1, was 60 cm by 120 cm, and had a maximum possible depth of 12 cm. A constant flow pump supplied the water feed to the basin via a 4 mm diameter inlet pipe. The aeration system consisted of a large bubble diffuser connected to an air compressor which supplied a constant air flowrate. The exit weir was constructed of plexiglass, and its position and width could be varied.

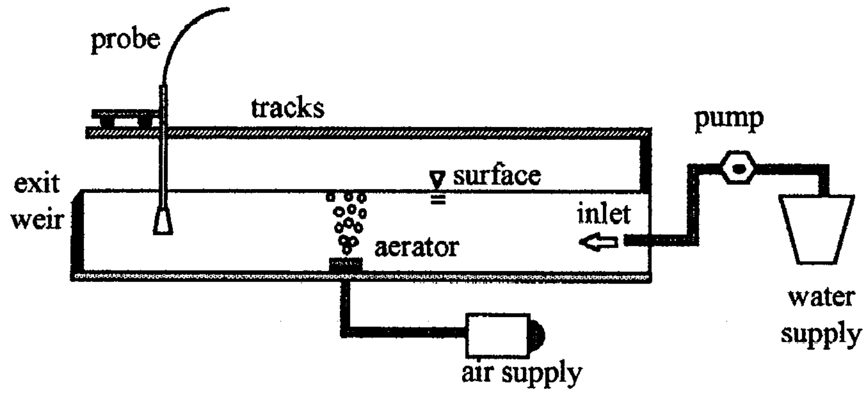

Figure 1: Side view of laboratory basin

The hot-film anemometer used in this study is the Dantec Streamline system equipped with a single wire hot-film probe. Two-dimensional velocity measurements were obtained by rotating the probe 90 deg. As shown in Figure 1, the basin was equipped with tracks which supported the measurement equipment, and allowed easy access to different sections of the basin area.

A large number of tests were conducted using different geometries and flow conditions. Only three of these tests are presented in this paper. The conditions of these tests are shown in Table 1, and the geometries are shown in Figures 2 and 3.

Test no.	length/ width	depth/ width	Inlet flowrate (ml/min)	hydraulic residence time (min)	aerator flowrate (ml/min)
E-1	2	0.1	500	86.4	0
F-1	2	0.1	450	96	0
F-2	2	0.1	450	96	165

Table 1: Parameters and conditions of the three tests: E-1, F-1 and F-2.

First, flow visualization was conducted for each test to obtain a qualitative picture of the hydraulic behavior and mixing processes. Digitized images at different time intervals were obtained by video recording the movement of an injected mass of tracer. The results are presented in Figure 2 for test E-1 and Figure 3 for test F-1 and F-2. The geometry of each test is included with the first video image. Second, hot-film measurements of both U and V velocity components, and the root mean square (rms) of each component were acquired at four cross-sections: x = 15, 45, 75 and 105 cm. Graphs of both the mean velocity (U,V) and the associated rms values (U_{rms}, V_{rms}) are plotted versus y-axis position in Figures 2 and 3. Both velocity and rms components are normalized with respect to the basin average velocity $\overline{U}$, which is defined as Q/A, where Q is the inlet flowrate and A is the basin cross-sectional area. The y-axis position is normalized by the basin width.

FLOW PATTERNS AND MIXING

The test E-1 shown in Figure 2 has the inlet pipe oriented at 25 deg from the right side wall. The flow images reveal a highly channeled flow, with a stream of tracer remaining close to the right side wall for the first 30 sec. After approximately 50 sec, a large fraction of the tracer recirculates back towards the inlet, forming a large stagnant zone in the middle of the basin at 135 sec. The level of mixing in this basin is non-uniform. The majority of the tracer is confined to the strong recirculating channel, and is only mixed within this area.

The plots of U-velocity shown in Figure 2b clearly illustrate the flow patterns identified in the images. The cross-section at x=15 cm shows the high velocity inlet stream and the relatively stagnant area left of the inlet. The cross-sections at x = 45 cm and 75 cm indicate high U-velocities near the right and left side walls of the basin. In these regions, the V-velocity is low, suggesting that strong mixing occurs in the longitudinal direction. Since the hot-film probe is not able to detect the flow direction, the flow images are studied to obtain this information. The direction of flow near the right side wall is in the positive x-direction, and the fluid near the left side wall is moving in the negative x-direction. Velocities in the middle of the basin are much lower, confirming the existence of a stagnant area. The size of the stagnant area can be determined from the flow field. Figure 2b shows the width of the stagnant area is approximately half of the basin width, and half of the basin length. The exchange rate between this stagnant area and the high velocity areas is very low, resulting in poor mixing conditions. The plots at x = 105 cm show higher V-velocity, since at this cross-section, the fluid separates and recirculates back towards the inlet. Therefore, lateral mixing in this area is quite strong.

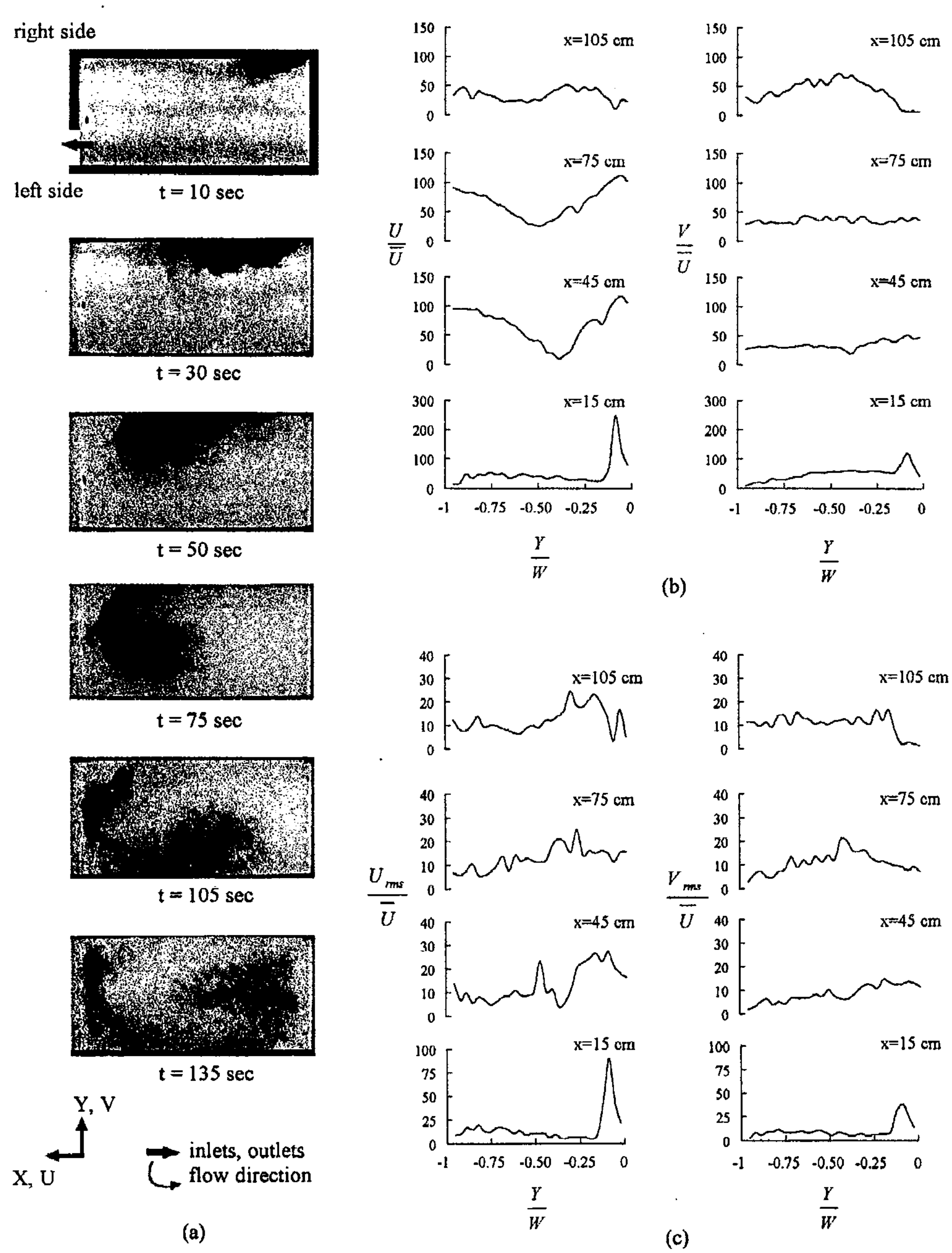

Figure 2: Test E-1, inlet oriented at 25 deg from right wall
(a) Flow visualization images with geometry of test outlined in first frame
(b) Mean velocity measurements (c) rms measurements

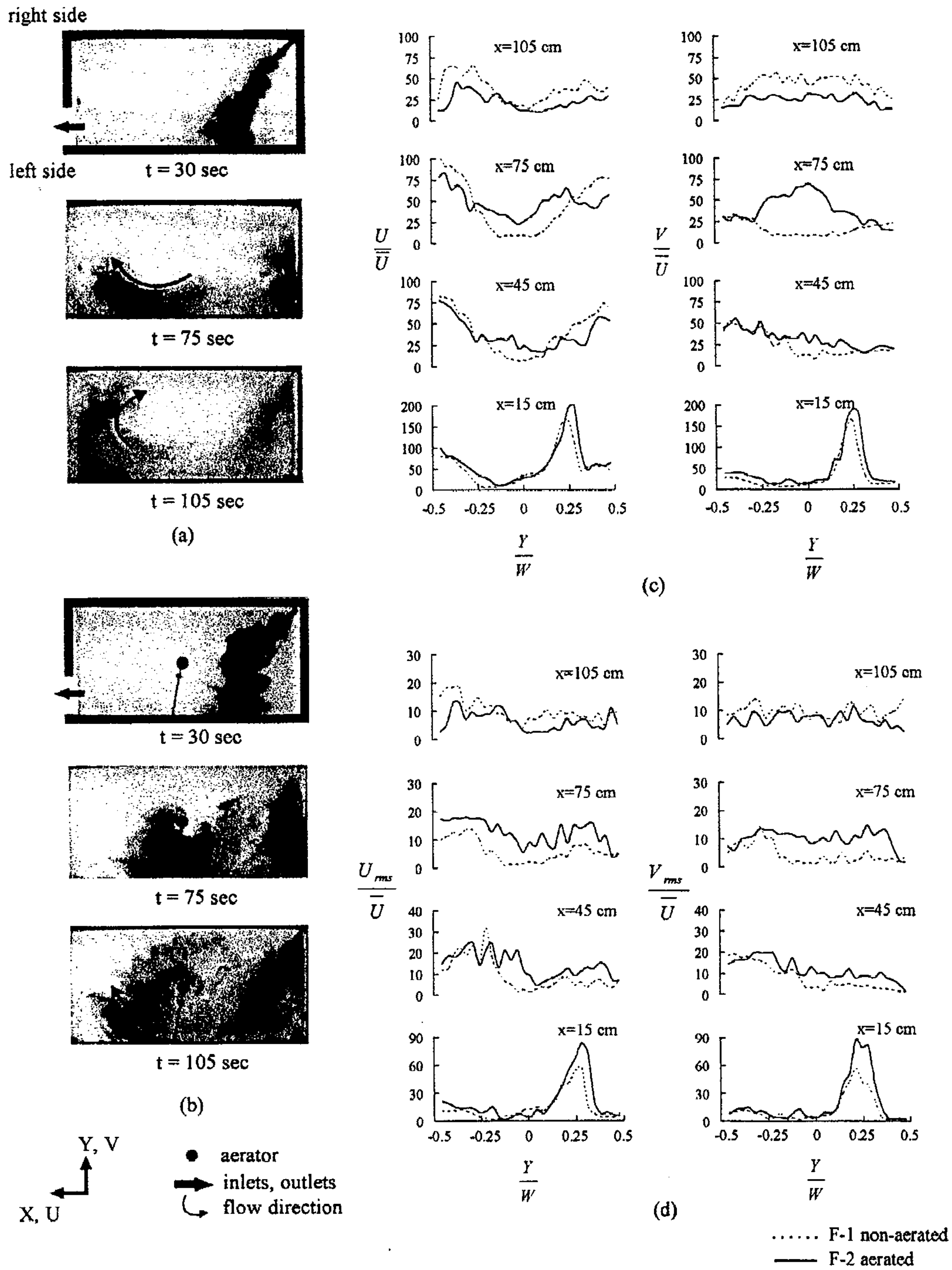

Figure 3: Comparison of Test F-1 and F-2, inlet oriented at 45 deg from right wall
(a)Flow visualization images for F-1 with geometry outlined in first frame
(b)Flow visualization images for F-2 with geometry outlined in first frame
(c) Mean velocity measurements (d) rms measurements

The rms plots shown in Figure 2c reveal a highly turbulent zone along the right wall, confirming strong mixing in that region. The turbulence is due to the shear that develops between the high velocity area and the stagnant central region. This is confirmed by the peak in rms near the shear boundary at Y/W= -0.25. The rest of the basin exhibits relatively low turbulence values, suggesting low intensity mixing.

EFFECT OF AERATION

The aerated and non-aerated tests F-1 and F-2, both with an inlet oriented at 45 deg, are shown in Figure 3. The flow images for test F-1, shown in Figure 3a, illustrate a well defined inlet stream which separates on the left wall after 30 sec, and then proceeds to form two recirculation zones near each end of the basin. The majority of the tracer is dispersed into the larger, slower moving zone near the outlet of the basin, which results in a large poorly mixed stagnant zone clearly visible after 75 sec. This flow pattern is similar to test E-1, suggesting that the change of inlet angle had no notable effect on mixing. The flow images for test F-2, shown in Figure 3b, with an aerator located in the center of the basin, illustrate significant changes in hydraulic behavior. An increase in the level of mixing is apparent, and the size of the stagnant zone is smaller than in test F-1. Also, the recirculation pattern is disrupted, as the tracer is pulled into the region surrounding the aerator.

Figures 3c and 3d show the U,V velocities and U_{rms},V_{rms} values respectively for tests F-1 and F-2. The dotted line denotes the test F-1 and the full line the test F-2. For test F-1, the first three cross-sections of the U-velocity plots outline the stagnant zone and clearly show the high velocity areas near the left and right side walls of the basin. The stagnant zone is centered between x=45 and x=75 cm, and its width is approximately one third the basin width. The rms values confirm that mixing is highest near the side walls, and that the stagnant zones show lower levels of fluid agitation. Test F-2 shows an increase in velocity and rms near the aerator (x=45 and 75 cm), especially the V-velocity at x=75 cm. This indicates strong lateral mixing at this cross-section of the basin. The velocity and rms profiles close to the inlet (x=15 cm) are not affected by the aerator, since the strong inlet flow dominates the flow field. An aerator placed directly in the inlet stream, or higher air flowrates would likely be needed to affect this region. At x=105 cm, both the velocity and rms profiles are more uniform when aeration is used; particularly the V-velocity. This shows that aeration has a larger effect in the lateral direction.

CONCLUSIONS

Hot-film anemometry is used to measure two-dimensional velocities in aerated and non-aerated rectangular basins. The results show that the mixing and transport processes are very complex. Basins without aeration are characterized by low velocity stagnant zones and regions with relatively high velocity and turbulence. The exchange processes between these two regions is very low, resulting in areas with poor mixing (stagnant zones) and areas with strong mixing. This non-uniform mixing affects the distribution of solids and contaminants. The aeration tends to produce more uniform mixing. It decreases the size of stagnant regions and increases mixing in the lateral direction of the basin. The location of the aerator and the air flowrate are important parameters which determine the effect of aeration.

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