Analysis of Pollutant Dispersion in Channel Flow in Interaction with Mobile Solid Using Visualization Techniques

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Abstract: - At present, a very important aspect that is present in the rivers and / or channels that transport superficial water is the dispersion that the chemical compounds can have in the superficial water flow. In general, the analysis of the dispersion of a pollutant in the field studies are the costs, for this reason the development of techniques for the analysis of the dispersion of a contaminant in the surface water flow in an open channel through the processing of digital images can also reduce the costs of this type of analysis, have various applications ranging from specific studies to the validation of numerical models. Analysis of the dispersion of the contaminant can afford the fate that the compounds in the water may have. Therefore, this work develops a method of analyzing the behavior of a tracer through its concentration without having to involve processes of mathematical modeling, where the dispersion of a contaminant in the water flow of an open channel through a mobile solid, using digital image processing. This work concluded that the effects of the dispersion on a tracer intensified the interposition of a solid with the movement in its path up to 93.3%, promoting the disorder in its molecules and the process of mixing with the medium.

Key-Words: - Dispersion, channel flow, turbulence, pollutant, visualization, fluid mechanics

1 Introduction

Field studies to analyze the dispersion of a contaminant in surface water can be difficult to control and costly, however, the analysis of the dispersion of a contaminant can determine the fate that compounds can have in water. In this sense, a problem that is present in Mexico and the world, are the constant episodes of constant spills in rivers and / or channels due to various human activities (consequences of accidents, bad management practices, exceptional weather events, or a combination of these factors), and not determining the dispersion of a pollutant in a river system and / or doing it in an inappropriate manner, can have negative impacts on water quality and aquatic biota, as well as problems in the effectiveness of water management plans remediation.

In this work, the analysis of the dispersion of a contaminant in the water flow in an open channel is proposed using image editing techniques to study dispersion problems. For the study, images of a pollutant plume in the water flow that represents the dispersion phenomenon of the pollutant that allow its use to adequately represent the dispersion process are analyzed. The image processing technique is used to solve a wide variety of problems (not necessarily related), which commonly require methods capable of enhancing and extracting the information contained in the images for interpretation and analysis by humans [1].

The problems related to episodes of spills of constant in rivers and / or channels by diverse human activities, requires of studies and information to determine properly the dispersion of a contaminant in a fluvial system, in addition to problems in the effectiveness of remediation plans. However, often to determine the dispersion of a contaminant in a surface flow requires expensive field studies. That is why this thesis develops a technique to analyze the dispersion of a contaminant in the water flow of an open channel through a mobile solid, using digital image processing using *ImageTool* software.

Developing a disruptive technology to analyze the dispersion of a pollutant using the *ImageTool* software, will allow for an additional technique to analyze this type of case, with the option of reducing the costs that are required to analyze this type of case. In addition, the technique developed will provide the basis for the development of analysis and obtaining knowledge, for future research related to the dispersion of pollutants and the analysis of images.

2 Transport phenomena

Transport phenomena study the transfer of quantity of movement, energy and matter. In this sense, chemical compounds need to be analyzed through transport phenomena, due to the fate they may have in the environment, for example the aquatic environment, as well as the reactions to which they may be subjected. In this way, there are three important transport processes that are: advection, diffusion and dispersion.

The transport of these quantities has strong analogies, both physical and mathematical, in such a way that the mathematical analysis used is practically the same.

2.1 Advection

It is a process of transporting substances in solution or suspension from one point to another through a medium, which is usually water or air. Water flows in a river due to the force of gravity and is delayed due to internal friction (viscosity) and friction corresponding to the contact between the moving water and the sediment over which it flows. If a substance is carried in moving water, it is transported in the same direction and at the same speed as the water [2].

2.2 Molecular diffusion

It is the mixture of dissolved chemicals due to the random displacement of the molecules in the fluid. This displacement is also known as "Brownian motion". Even if the water appears to be completely at rest, the molecules of the compound move from regions of high concentration to regions of low concentration. This movement is caused by kinetic energies of molecular, vibrational, rotational and translational movement. In essence, molecular diffusion corresponds to an increase in entropy [2].

In nature, molecular diffusion occurs mainly through thin or laminar edge layers such as water-air, sediment-water or stagnant pore water interfaces. Thus, it can be said that it is generally not a very important process in the transport of dissolved substances in natural waters. In addition, it is an excessively slow phenomenon [2].

2.3 Turbulent diffusion

In addition to moving through molecular diffusion, a molecule of a chemical in surface water also moves due to turbulence or eddies in constant change and of different sizes depending on the flow regime. Random mixing caused by this type of turbulence is called turbulent diffusion. This mixing process is a micro-scale differential advective process. Mass transfer due to turbulent diffusion is several orders of magnitude greater than mass transfer due to molecular diffusion [2].

2.4 Dispersion

The interaction of turbulent diffusion with velocity gradients caused by shear forces in the body of water causes an even greater degree of mixing, known as dispersion. The transport of substances in streams and rivers is predominantly advective, but transport in lakes and estuaries is often controlled by dispersion [2].

3 Intrusive measurement systems

Flow measurements are used for numerous applications of hydraulic engineering in relation to water bodies, for example, the dispersion of pollutants in rivers and coastal areas, the problems associated with the behavior of watersheds (erosion, sedimentation, flooding and degradation of the environment), to mention a few [3]. In hydraulics, the allocation of speed in surface flows is useful to define spending; the influence of new elements and structures in the velocity components, such as weirs, outlet works, construction works in rivers [4].

Flow measurements are made by various techniques. Very often, a current meter or windlass (i.e., a mechanical device formed by propellers or rotating cup) was immersed in water to measure the flow rate in a section. For 30 years, acoustic and electromagnetic equipment have been used to measure the speed of water. In order to operate such equipment as the turnstiles should be immersed in water, which is not always practical: on the one hand, the sensors of the equipment are damaged (due to corrosion problems and / or embedding), and on the other, sometimes it is complicated (and even dangerous) to approach a flow to submerge an instrument [5] mentions that in September 2005 in Japan a worker fell into a river, while half a flood discharge.

4 Software for processing digital images

The ImageTool Software program was developed at the University of Texas for Microsoft Windows. "UTHSCSA *ImageTool*" (IT), is a free image processing and analysis program for Microsoft Windows 9x, Windows ME or Windows NT. It can acquire, visualize, edit, analyze, process, compress, save and print in grayscale and color images. It can read and write more than 22 common file formats, including BMP, PCX, TIF, GIF and JPEG. The image analysis functions include dimensions (distance, angle, perimeter, area) and gray scale measurements (point, line and histogram area with statistics). *ImageTool* supports standard image processing functions, such as contrast manipulation, sharpness, smoothing, edge detection, median filtering and spatial convolutions with convolution masks defined by the user. It has also been incorporated into the scripting capabilities that allow the user to record and play the repetitive tasks saved scripts to automate image analysis [6].

ImageTool was designed with an open architecture that provides extensibility through a variety of plug-ins (inserts). Support for the acquisition of images either using Adobe Photoshop plug-ins or scanners. Custom analysis and plug-in processing can be developed using the software development kit (SDK) provided (with source code). This approach makes it possible to solve almost any problem of data acquisition or analysis of it [6].

4.1 Analysis and classification of objects

UTHSCSA *ImageTool* provides automatic identification, analysis and / or classification of objects. This feature can be used for microscopy, histology, metallurgy, and many other fields. The process first involves segmenting the image into objects and background. ImageTool provides a manual and automatic algorithm for image segmentation. After segmentation, the image becomes a binary image. *ImageTool* proceeds to identify and count the number of all objects. Each object can be analyzed using any of the following measures: area, perimeter, compactness, roundness, elongation, which delimits the box area, centroids, gray centroid, main axis, length of the main axis, large slope of the axis, minor axis, minor axis length, minor axis slope, minimum gray level, maximum gray level, medium gray level, mean and gray level standard deviation. Objects can also be classified into different groups based on any of the measurements mentioned above. Each object can be classified by specifying a range of values for a specific measurement of the characteristic. This can be useful in the separation of objects with different morphological characteristics [7].

5 Image acquisition system

For the visualization and tracer registration tests for the present study, a Kodak high-speed camera was used, with the possibility of achieving up to 12,000 fps. The equipment used is shown in Figure 1.

Fig. 1. Equipo de visualización de alta velocidad Kodak.

6 Laboratory facilities used

For the analysis of the dispersion of a pollutant in the water flow of an open channel around using digital image processing, it is known as the wave generator bank is one of the models that the laboratory of hydraulic works and equipment of the laboratory "ENZO LEVI" of the Mexican Institute of Water Technology (IMTA), located in the municipality of Jiutepec, Morelos, Mexico.

This model is used for the study of different phenomena related to water currents and their derivatives, through the operation of pumps and various systems. The figure 2 shows the measurements of the channel from a side view and figure 3 shows aerial view [8].

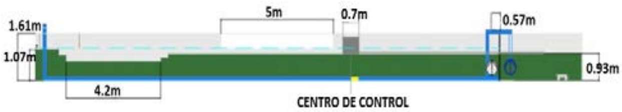


Fig. 2. Side view of laboratory facilities.

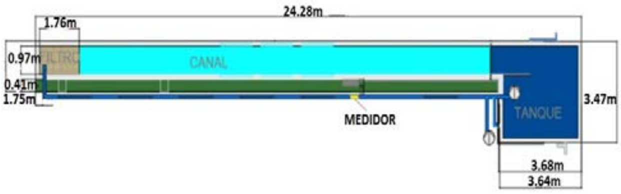


Fig. 3. Aerial view of laboratory facilities.

The model has two types of centrifugal and submersible pumps, and these supplies the channel with water, the centrifugal pump is located on one side of the channel and the submersible pump is located inside the tank.

Both pumps are connected to the same pipe system and can be operated at the same time or one at a time depending on the needs of the user, although for the tests only the centrifugal pump was used, since the submersible was removed, for purposes of maintenance use of the laboratory tanks, in figure 4 and figure 5 the channel pumps and flow measurement device are shown [8].

Fig. 4. Centrifugal and submersible pumps.

The meter used in the present study was a high-precision electromagnetic meter so that the flow quantity tests were controlled for each test. The criterion was to have the steady-state condition of flow in the open channel

Fig. 5. Electromagnetic meter.

The purpose of the mobile solid is to emulate aquatic vegetation and the dispersion processes that would naturally occur in some river or shallow waters, among other systems.

To simulate this phenomenon, methylene blue was used, with the aim of visualizing the dispersion of the tracer, and making a comparison when analyzing the phenomenon using the mobile solid and without it. Figure 6 shows the mobile solid used for the analysis.

The injection system has the purpose of continuous injection without pressure variations at the entrance of the dye to the liquid stream. For this, it was decided to install a container with an included drip system located in the hose of the same container. In Figure 7, the tracer injection system is shown.

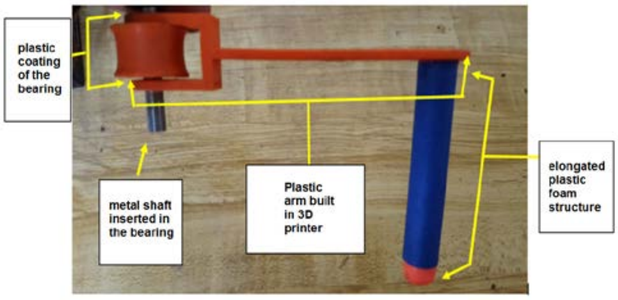


Fig. 6. Description of the components of the mobile solid

Being a gravity injection system, the container was placed 60 cm from the liquid by means of a metal structure 50 cm long, with a 30 cm arm, with an extension arm system of another 30 cm extra. To this arm was fixed the hose of the container, at the end of this hose was placed a needle with the purpose of a controlled injection and better administered.

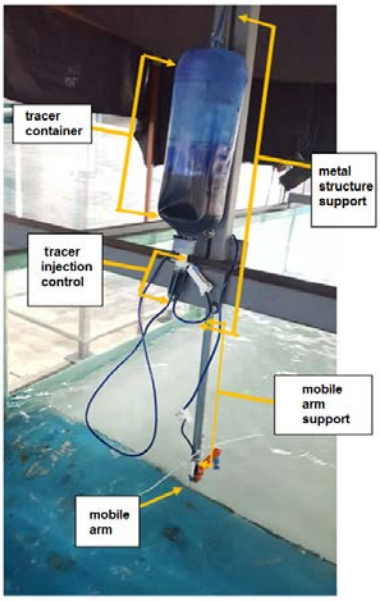


Fig. 7. The injection system.

To carry out this experiment, auxiliary software was used to interpret the visual tests. The software used was *ImageTool*, this software requires a previous calibration because its main function is density calculation by means of gray scale.

The gray / dark ratio of the chromium is inversely proportional, with a lower gray scale, greater darkness in the color and therefore a higher density. A darker color represents a higher concentration.

The calibration process requires a set of samples with different concentrations scaled and therefore different colors. Said samples are agglomerated in a single photographic image, captured with the relevant conditions in light and background issues of the channel, figure 8.

Dilutions were made from the mother concentration using the following equation.

$$C_1 V_1 = C_2 V_2 \quad (1)$$

Where:

C_1 = Mother concentration (0.5 g / l).

V_1 = Volume taken from the mother concentration.

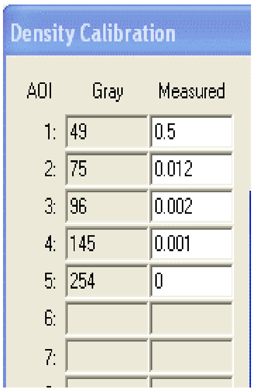
C_2 = unknown value.

V_2 = Volume of water for dilution

Fig. 8. Image used for calibration with the ImageTool software.

Using the *ImageTool* software, the gray level was related to the concentration of each sample, this relationship is shown in table 1.

Table 1. Gray level values with their respective concentration



Density Calibration

AOI	Gray	Measured
1:	49	0.5
2:	75	0.012
3:	96	0.002
4:	145	0.001
5:	254	0
6:		
7:		

The values obtained were adjusted by the *ImageTool* software with the most appropriate equation, as shown in figure 9.

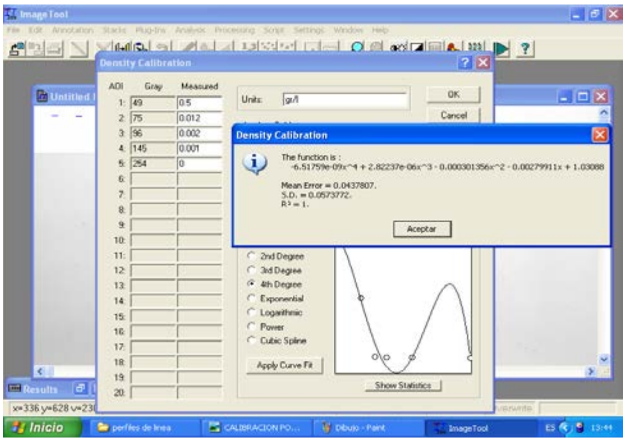


Fig. 9. Density calibration with the *ImageTool* software.

7 Experimental tests

The dispersion phenomenon is the action by which the flow mixes and dilutes a contaminating mass by the combined action of the distribution of velocity and turbulent diffusion. Thus, if a soluble material is discharged into an aquatic environment, it will be transported from the point of discharge by the movement of the water body and will be mixed longitudinally and perpendicularly to the flow direction by the effects of the turbulent flow movement. It is for this case, that a control area was established that was effective in all the tests, that control area was plotted and the tracer concentrations that were presented along it.

The tracer was released in the fluid and dispersed dragged longitudinally or in the direction of flow, by mixing and dilution processes thanks to the different speed profiles (high of 0.19 m/s and low of 0.11m/s).

In order to evaluate the dispersion effects of the tracer, two scenarios were proposed.

- Case A: The injection of a conservative type tracer into a hydraulic channel, where its behavior was merely influenced by the flow of the current.
- Case B: The injection of a conservative type tracer into a hydraulic channel through a solid with movement. The movement of this solid dominated by the channel current.

The tests were carried out considering, in both cases, two flow velocities with 0.11 m/s and 0.19 m/s. In addition, a control was made of factors that could affect the images directly, such as the case of light control and reflection: to avoid problems of brightness in the water, a shadow mesh was placed above the test area (Figure 10).
A good control of the lighting with lamps was used to distribute the light uniformly with what was always had the same conditions of light and controlled reflection for both scenarios.

Fig. 10. Density calibration with the *ImageTool* software.

The tests in this work were carried out considering the flow as shallow, that is, the depth is negligible with respect to the width of the flow.

7.1 Test A

The results of test A are shown in the table 2 and figures 11 to 13:

Table 2. Results of case A measurements.

high speed (0.19 m/s)		low speed (0.11 m/s)	
Distance (m)	Concentration (gr/l)	Distance (m)	Concentration (gr/l)
0.120	0.291	0.12	0304
0.152	0.302	0.152	0.325
0.356	0.334	0.356	0.325
0.600	0.319	0.600	0.287
0.912	0.280	0.912	0.243
1.040	0.230	1.040	0.233
1.264	0.180	1.264	0.234
1.952	0.144	1.952	0.207

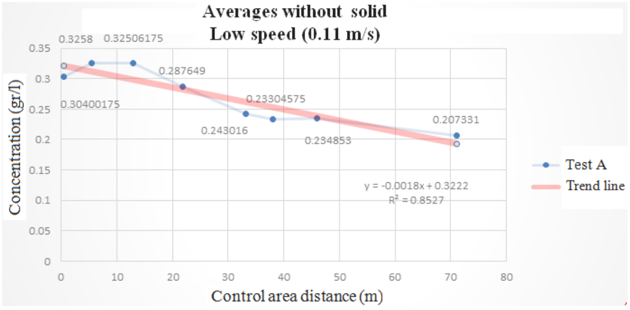


Fig. 11. Test A without solid mobile at low speed 0.11 m/s.

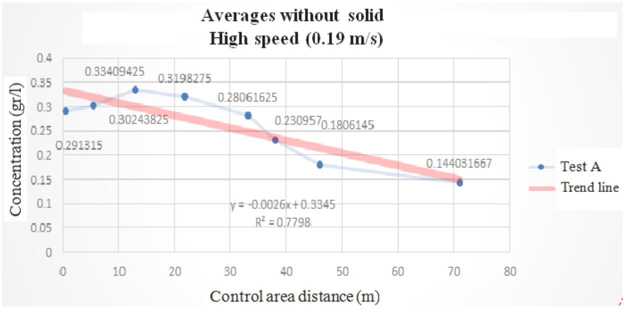


Fig. 12. Test A without solid mobile at high speed 0.19 m/s.

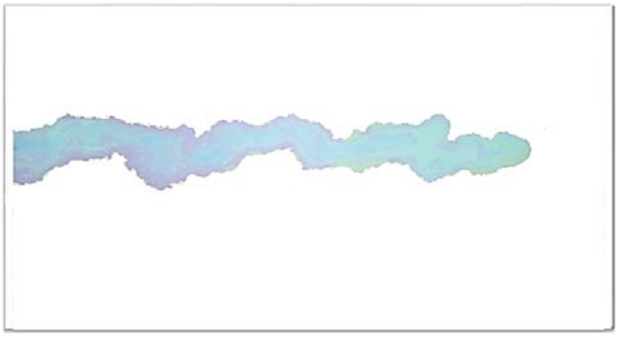


Fig. 13. Test with visualization technique for test A without mobile solid and speeds of 0.11 m/s and 0.19 m/s.

7.2 Test B

The results of test A are shown in the table 3 and figures 14 to 16:

Table 3. Results of case B measurements.

high speed (0.19 m/s)		low speed (0.11 m/s)	
Distance (m)	Concentration (gr/l)	Distance (m)	Concentration (gr/l)
0.120	0.331	0.12	0.222
0.152	0.332	0.152	0.254
0.356	0.299	0.356	0.258
0.600	0.256	0.600	0.224
0.912	0.151	0.912	0.123
1.040	0.059	1.040	0.093
1.264	0.051	1.264	0.090
1.952	0.033	1.952	0.091

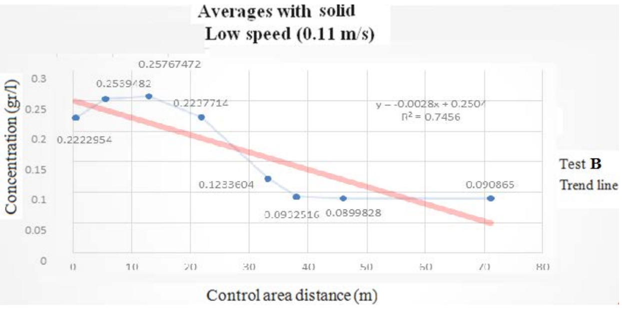


Fig. 14. Test B with solid mobile at low speed 0.11 m/s.

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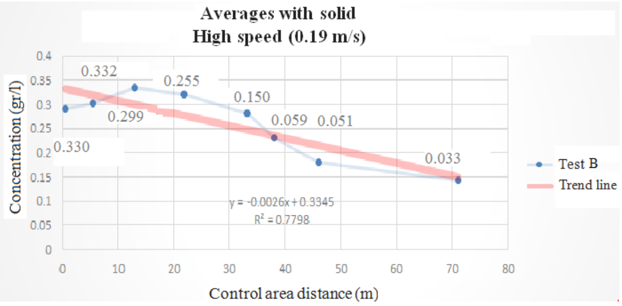

Fig. 15. Test B with solid mobile at high speed 0.19 m/s.

Fig. 16 Test with visualization technique for test B with mobile solid and speeds of 0.11 m/s and 0.19 m/s.

7.3 Comparison between tests

The dilution percentages with the different test characteristics of both scenarios (A and B) show below. These percentages were evaluated at the end of the control area, with the difference between the initial concentration in the tracer injection (0.5 g / l) and its concentration at the end of the length of the control area.

- Low speed without solid = 58%
- High speed without solid = 71.2%
- Low speed with solid = 81.8%
- High speed with solid = 93.3%

8 Conclusions

According to the theory a material diffuses through the flow, it is distributed in different regions that have different speeds, this because while some molecules follow a velocity profile others follow a different one; the disorder of the flow facilitates the dilution.

The solid interposed in the trajectory of the flow caused different flow lines with different speeds, the same ones that caused a bigger disorder in the molecules of the fluid and therefore a greater mixing. The addition of the lateral movement of this solid facilitated the effects of cross-mixing when in a common manner it is mixed is only provided by the effects of molecular diffusion.

There are a lot of applications of diffusion and dispersion processes considering the interaction of a flow with a mobile solid, including the case of flow with aquatic weeds. In the present case, we have the interaction of a flow with a regular solid whose characteristic is that it is mobile and the results show that there is greater dilution at high speed and in the case of mobile solid up to 93.3% dilution.

References:

[1] Pajares Martisanz, G., & M. de la Cruz Garcia, J. (2008). *Visión por Computador Imagenes Digitales y Aplicaciones*, Segunda Edición. México: Alfaomega Grupo Editor S. A. de C. V.

[2] Schnoor, J. L. (1996). *Modelización Ambiental: destino y transporte de contaminantes en el agua, aire y suelo*. Universidad de Michigan.

[3] Fujita, I., & Muste, M. y. (1998). *Large-Scale particle image velocimetry for flow analysis in hydraulic applications*. Journal of Hydraulic Research.

[4] Bieri, M., Jenzer, J., & Kantoush, S. y. (2009). *Large Scale Particle Image Velocimetry applications for complex free surface flows in river and dam engineering*. Paper present at 33rd Congress. Int. Assoc. of Hydraul. Eng. Res.

[5] Fujita, I., & Watanabe, H. y. (2007). *Development of a non-intrusive and efficient flow monitoring technique*. International Journal.

[6] UTHSCSA. (2002, Febrero 22). *UTHSCSA ImageTool*. Retrieved from http://compdent.uthscsa.edu/dig/itdesc.html#What

[7] HEALTH, U. (2017, Febrero 9). *UT HEALTH SAN ANTONIO SCHOOL OF DENTISTRY*. Retrieved from http://www.uthscsa.edu/academics/dental/departments/comprehensive-dentistry/imagetool/more

[8] IMTALAB. (2017). *INSTRUCTIVO DEL BANCO GENERADOR DE OLAS*. Jiutepec, Morelos: IMTALAB.