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# EXPERIMENTAL MEASUREMENT OF OIL SPILL SPREADING IN A WAWE TANK USING DIGITAL IMAGE PROCESSING

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## ABSTRACT

In this work, an experimental study of spreading of crude oil is carried out in a wave tank. The tests are performed by spilling different volumes and types of crude oil on the water surface. An experimental measurement technique was developed based on digital processing of video images. The acquisition and processing of such images is carried out by using a video camera and inexpensive microcomputer hardware and software. Processing is carried out by first performing a digital image filter, then edge detection is performed on the filtered image data. The final result is a file that contains the coordinates of a polygon that encloses the observed slick for each time step. Different types of filters are actually used in order to adequately separate the color intensities corresponding to each of the elements in the image. Postprocessing of the vectorized images provides accurate measurements of the slick edgc, thus obtaining a complete geometric representation, which is significantly different from simplified considerations of radially symmetric spreading. The spreading of the oil slick was recorded for each of the tests. Results of the experimental study are presented for each spreading regime, and analyzed in terms of the wave parameters such as period and wave height.

*Keywords*: Experimental measurement, oil spill spreading,digital image processing

## MEDICIÓN EXPERIMENTAL DE LA DISPERSIÓN DEL DERRAME DE CRUDO EN UN TANQUE DE OLEAJE USANDO PROCESAMIENTO DIGITAL DE IMÁGENES

## RESUMEN

En este trabajo, un estudio experimental de la dispersión de crudo es realizada en un tanque de oleaje. La pruebas son realizadas derramando de diferentes volúmenes y tipos de crudos sobre la superficie del agua. Una técnica de medición experimental fue desarrollada basada en el procesamiento de imágenes de vídeo. La adquisición y procesamiento de las imágenes son realizadas usando una cámara de vídeo y un computador y programas de bajo costo. El procesamiento es realizado en primer lugar por un filtro digital de imagen, entonces la detección es realizada sobre la imagen filtrada. El resultado final es un archivo que contiene las coordenadas del polígono que encierra el derrame observado en cada paso de tiempo. Diferentes tipos de filtro son utilizados con el propósito de separar las intensidades del color correspondientes a cada uno de los elementos en la imagen. El postprocesamiento de las imágenes vectorizadas provee la medida del derrame, obteniendo así una representación geométrica completa, la cual es significativamente diferente de la consideración simplificada de la dispersión de simetría radial. La dispersión del derrame de crudo fue capturada para cada prueba. Los resultados del estudio experimental son presentados y analizados para cada régimen en términos de los parámetros de oleaje, como lo son el periodo y la amplitud de la ola.

*Palabras clave*: Medida experimental, dispersión del derrame de crudo, procesamiento digital de imágenes.

## INTRODUCTION

Thc development of offshore oil production and transportation facilities has justifiably been accompanied by concern for thc possibility of oil spills and the associated potcntial for adverse impacts upon coastlines and coastal watcrs.

Therefore it is necessary to know the mechanism of crude oil spreading on the water surface, in order to reduce its environmental impact by means of adequate contingency plans. This is the reason to carry out oil spreading tests in the laboratory and to develop a technique for measuring the oil spreading by means of digital image processing.

The object under study for this experimental research work, is the unsteady motion of a crude oil spill in a laboratory tank.

## SPREADING OF OIL

The tendency of the oil to spread in the surface of water is the results of balance of four physical forces: gravity, surface tension, inertia and viscous. In terms of these forces, we expect gravity and surface tension to increase the spread while inertia and viscous forces retard it. According to (FAY 1969) the history of the spread then passes through three phases:

i. the beginning phase in which only gravity and inertia forces are important,

ii. an intermediate phase in which gravity and viscous forces domínate and

iii. a final phase in which surface tension is balanced by viscous forces.

The equations corresponding to the Fay spread theory are:

Gravity-Inertia

$$l = K_1 \left( \Delta g V t^2 \right)^{1/4} \tag{1}$$

Gravity-Viscous

$$l = K_2 \left( \Delta g V^2 t^{3/2} / v_w^{1/2} \right)^{1/6} \tag{2}$$

Surface Tension-Viscous

$$l = K_3 \left( \sigma^2 t^3 / \rho_w^2 v_w \right)^{1/4} \tag{3}$$

where $\Delta = 1 - \rho_0/\rho_w$, is the ratio of density difference between water ($\rho_w$) and oil ($\rho_0$) to density of water, $g$ is the gravitational acceleration, $V$ is the volume of oil, $l$ is the diameter of oil slick, $t$ is the time, $V_w$ is the kinematic viscosity of the water, $\sigma$ is the spreading coefficient, and $K_1 = 1.14$, $K_2 = 1.45$, $K_3 = 1.0$ are experimental spread constant.

Another spreading theory is that of (MACKAY et al 1980) in which one starts with the Fay Gravity-Viscous and Surface tension-Viscous formulation to obtain a thick and thin slick equation. (GARCÍA et al 1996) have recently proposed a correction to the Mackay spreading theory, by determining expressions for Mackay's constants, which are shown to be variables which depend on oil and water characteristics.

## EXPERIMENTAL SETUP

The experiments were carried out by (FLORES 1996) at the Instituto de Mecánica de Fluidos. For this purpose, a coastal modeling tank (Figure 1) was adapted. The size of the concrete tank is 18x27x0.5 m. It is equipped with a system for pumping, recirculation and draining, as well as structures for wave control and dissipation. The wave generator is of the vertical paddle type with a total length of 9.04 m. A reduction gear allows speed control. Parallel wave guides were placed at the ends of the generator. On the bottom of the test platform a grid of square cells of 0.5x0.5 m was drawn. The water depth was 0.25 m. A cylinder with 0.1 m diameter and 0.6 m height was used to spill the crude oil on the tank. The spill was initially located at the center ofthe grid.

### 1.- Data acquisition:

In the experimental setup, wave transducers of capacitive type and a wave linearizing equipment were used. The latter linearizes the transducer signal which is then sent to a data acquisition system connected to a personal computer which performs data analysis to obtain the wave parameters.

### 2.- Instrumentation:

Technological innovations enable us to use image processing techniques on a video sequence of the studied phenomenon. The use of mixed techniques (data acquisition and control combined with image digitizing) is currently a must in a hydraulics laboratory, thus they are used in the present work.

The image processing technique is widely used, due to its versatility. It is readily applicable to unsteady flow problems. Image processing has been used by (FLORES & SOLANA 1996) for determination of currents induced by waves.

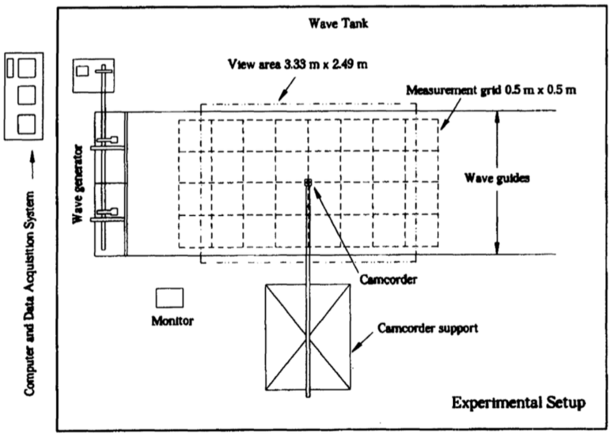


***Figure I.*** *Experimental setup*

## DIGITAL IMAGE PROCESSING

The technique consists of taking an analog magnetic file (video tape) from a conventional video camera and converting it to a digital file by means of the appropriate hardware. The image is then directly processed inside the computer. The camera thus becomes the measuring instrument (sensor) and the digitizing board in the computer becomes the data acquisition system. The digital file is processed next by means of graphics computational techniques which are mainly known as vectorization.

### 1.- Image capture setup:

The equipment consists basically of an optical bench which performs video taping of the experiment, an outlining and lighting setup, and the image digitizing board. Lighting was accomplished by means of an array of fluorescent lamps which provided uniform distribution of light over the free surface.

The optical bench is composed by a conventional video camera, which is placed vertically over the platform at 5 m height. The image digitizing system is a microcomputer video capture board with 2 Megabytes of memory and real-time acquisition to disk. The capture speed is 30 frames/second when operated by the commercíal capture software. Data processing was performed by means of a Pentium PC. The resolution of the captured video frames is 320x240 pixels, corresponding to 0.01m/pixel resolution of the observed experiment. From each digitized and filtered image an irregular polygon which represents the slick edge was obtained by vectorization.

## EXPERIMENTAL PROCEDURE

Previous to the experiment, the period is adjusted by means of the reducing gears. Adjustment of the wave height is accomplished by means of the horizontal displacement of the vertical paddle. The height is measured using the capacitive transducers and the paddle displacement is adjusted until the desired height is obtained. The testing procedure is as follows: the amount of crude oil to spill is measured, then the container is placed on the water surface, avoiding leaks below the cylinder with the help of buoyancy, the container is withdrawn next after waves are stabilized, thus allowing oil to flow freely on the water surface. At the end of the experiment the oil is swept from the surface by using a water jet.

Several tests were performed by varying the oil type, spilled volume, wave period and wave height. As an example, the tests performed for the Venezuelan Lagotreco oil type are presented. This oil type has the following properties:

density $\rho_0$= 0.80 g/cm$^3$ (23.5 ºAPI), spreading coefficient $\sigma$=22.2 dynes/cm. The results are presented for a spilled volume $V$=0.5 lt.

Table 1 the tests for this oil can be observed, where $H$ , $T$ and $d$ represent the wave height, the wave period and the water depth respectively.

A sequence of images for test Nº 06 is presented in *Figure II* The spreading and deformation of the slick under the wave action is observed, with its larger axis aligned with the direction ofwave propagation.

**Table 1.** Tests characteristics

| Test Nº | Wave Characteristic |
|---|---|
| 04 | Calm water |
| 06 | H=1.35 cm, T=0.8 sec, d=25.0 cm |
| 08 | H=1.01 cm, T=1.0 sec, d=25.0 cm |
| 09 | H=2.81 cm, T=1.0 sec, d=25.0 cm |
| 10 | H=2.23 cm, T=1.2 sec, d=25.0 cm |

## VECTORIZATION

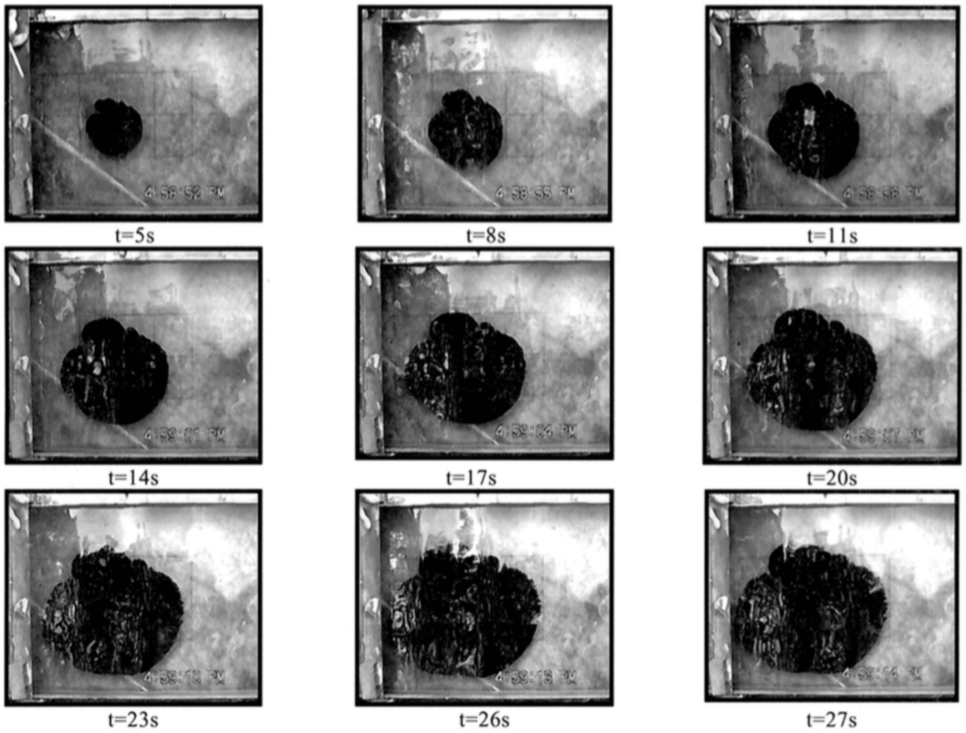
Vectorization is a procedure which converts the set of raw digital data (pixels) to a mathematical definition of the same image expressed as coordinates and/or curve properties. For the present case, the raw input consists of digitized video image files obtained from the experiment. After data processing, output is given in the form of a table of x,y coordinates for each time t, representing the points on the edge of the time varying oil slick.

Processing is performed in two steps. The first step is a digital image filtering, which operates in parallel on the data set, and the second step is a postprocessing procedure which detects the slick edge. Filtering is carried out by a master control program which controls the functions provided by video editing packages. The application of this filtering scheme to free surface flow measurement has been described by (ANDREATTA 1996).

### 1.- Processing sequence:

The filters which determine the color difference between the slick and the remaining of the image are applied first. The digital data are given in 24-bit Red- Green-Blue format, which uses 8 bits for each color intensity in the standard video basis. For this experiment a color variation was defined with good color separation between the slick and the remaining elements of a frame. The best definition for the present tests is given by the red channel.

A filter which obtains an image in 1-bit format from the image in 24-bit format is applied next. This is a black and white image where each pixel corresponds to 1 bit, with the black color for the crude oil slick and white for the remaining elements of the frame. Once the filtering for each frame is accomplished and 1-bit images are obtained with good definition, postprocessing is performed to determine the slick edge.


t=5s t=8s t=11s

t=14s t=17s t=20s

t=23s t=26s t=27s

***Figure II.*** *Image series from test Nº 06*

**2.- Filter for determination of the slick edge:**

As depicted in Figure III, the filter for determination of the slick edge is composed of the following steps:

*1st step: Color diffusion filter:* In the application of this filter, the colors from adjacent zones are averaged, thus obtaining a more homogeneous image at the smaller scale where changes are more important.

*2nd step: Color separation filter*: Colors are weighted combinations of the elements of a color basis. Separation of colors is aimed at determining the color component which defines the shape of the oil slick. After determination of this color, it is transformed to an equivalent gray scale in order to obtain a black and white image with different gray intensities.

*3rd step: Threshold Filter:* In this filter, all gray values above a certain reference value in the gray basis (0-255) are transformed to black (0) and all values below are transformed to white (255). This operation yields a 1-bit B/W image.

This procedure is carried out for each frame, and determination of the slick boundary is done in parallel for each video frame.

**3.- Test Nº 06:**

Vectorization of test Nº 06 is shown in *Figure IV* with a time interval $\Delta t = 3$ sec (numbers in the curves indicated time instant). In this figure it can be noticed that as the oil spill is spread, the initial perturbation tends to disappear and the slick takes a rounded shape. Unlike other tests, in this one the waves broke the oil- water interface tension and the crude oil suffered more spreading, with a fine slick appearing. The shape of the oil slick was adapting to the wave incidence downstream while the effective spreading speed was reduced upstream. This observation is related to the ratio of the spreading speed to the speed at the free surface due to the waves. Towards the end of the test, spreading does not stop since it has entered the surface tension-viscous regime and a fine slick appears which spreads in the diagonal direction. This test had a total time of 30 seconds. At 21 seconds, the oil spill reaches an equivalent radius of 0.82 m and a thickness of 0.0232 cm.

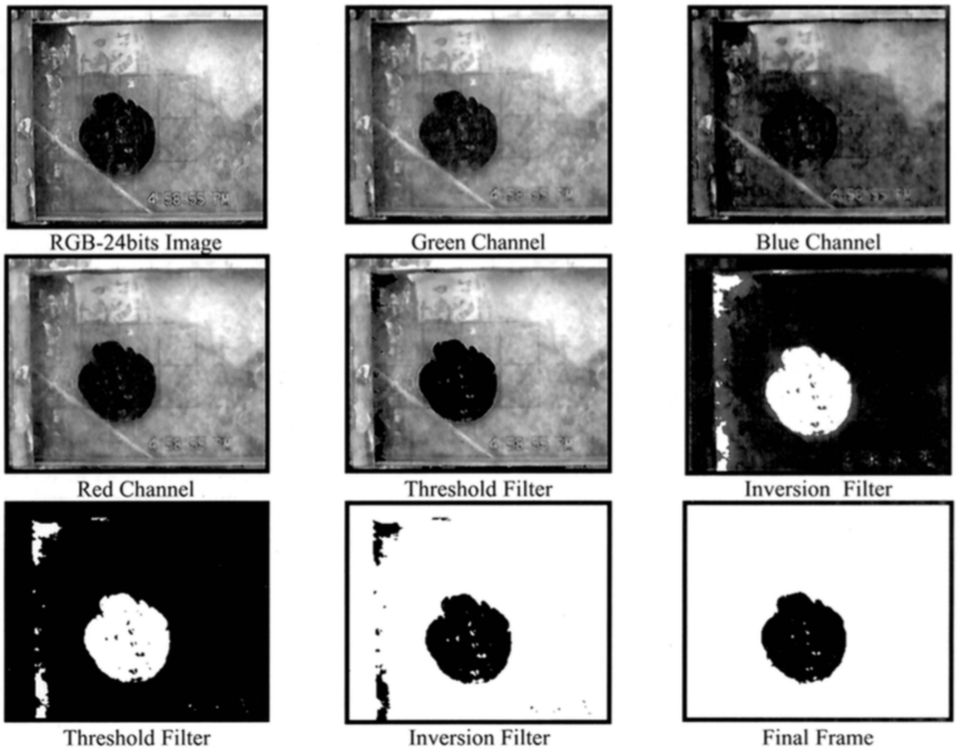

RGB-24bits Image
Green Channel
Blue Channel
Red Channel
Threshold Filter
Inversion Filter
Threshold Filter
Inversion Filter
Final Frame

***Figure III.*** *Filtering sequence for a video frame*

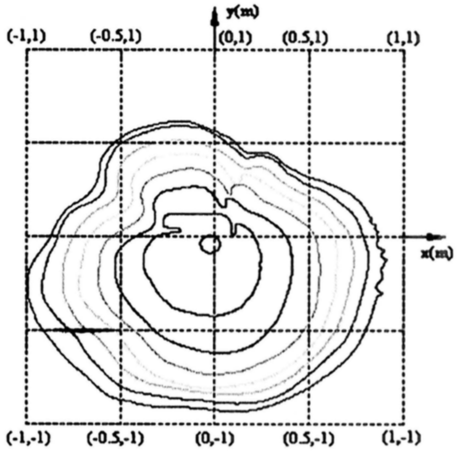


***Figure IV.*** *Digitalization test Nº 06, Δt=3 sec*

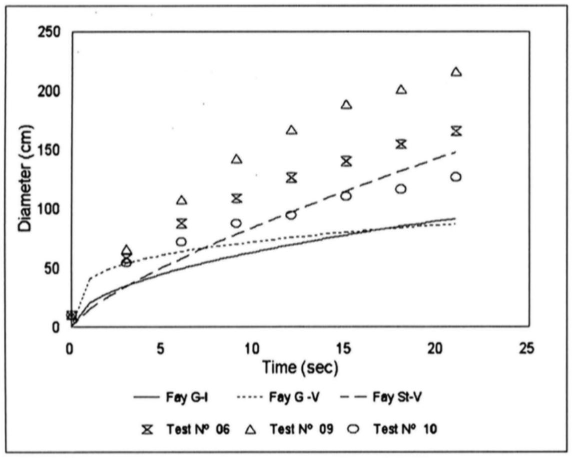


***Figure V.*** *Experimental results vs Fay spreading theory*

*Figure V* shows the comparison of the experimental results to those obtained by applying Fay's spreading formulae (where *G*-1= Gravitational-Inertial, *G-V*= Gravitational-Viscuos and *St-V*= Surface Tension- Viscuos). lt can be observed that due to the wave action the spreading regime is located in the viscous-surface tension zone. For the case of tests No 09 and 10 it is observed that they exceed the spreading given by the equations for Fay's surface tension-viscous regime. This is due to wave action, which produces breaking of the oil-water surface tension, thus increasing the spreading in the wave propagation direction.

## CONCLUSIONS AND RECOMMENDATIONS

The results from the oil spreading measurements obtained in this work confirm that when oil is spilled on the water surface, spreading under wave action is larger than that predicted by Fay's spreading theory. This is due to breaking of the oil-water interface tension under wave activity, since there is more perturbation and stirring than that considered for Fay's surface tension- viscous regime. It is important to notice that Fay's theory has been derived under the assumption of calm water, therefore spreading is expected to be larger under the effects of waves, marine currents and/

or wind. More reliable models of oil spreading need to be developed. This can be accomplished by performing tests for a large range of oil properties and water conditions.

In relation to the measurement procedure by means of image processing used in these experiments, it is noticeable that quality and precision of vectorization are primarily affected by the conditions around the experimental setup. Consequently, it is advisable to study how the surrounding lighting conditions affect the performance of vectorization in order to improve uniformity of light distribution on the experimental setup and to reduce reflection of light on the surface and under water. The success obtained in measuring oil spreading in a wave tank encourage to perform field tests using this technique and to compare them to laboratory tests.

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