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دراسة خصائص المنفوثات باستخدام تقنية رقمنة الصور

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ملخص البحث

يتناول هذا البحث تقديم تقنية عملية جديدة يمكن بواسطتها رصد وتحليل خصائص المنفوثات، إلى جانب دراسة التكوينات الدوامية الناتجة من تداخل منفوث مع تيار متعارض.وتعتمد هذه التقنية على ما يعرف بـــ "رقمنة الصور" وذلك بالتقاط مجموعة متتابعة من الصور باستخدام كاميرا رقمية سريعة ثم رقمنتها من خلال برنامج على الحاسب الآلي، بمعنى تحويل كل لون إلى رقم يمثل درجته، ويتكرر الرقم بتكرار درجة اللون في الصورة، وهو ما يمثل تركيز المنفوث عند نقطة معينة. وقد أتاحت هذه التقنية استنتاج صور جانبية متوسطة وملونة. وقد أمكن التوصل إلى أن، "رقمنة الصور" هى تقنية بسيطة وسهلة ورخيصة ويمكن الاعتماد عليها فى دراسة خصائص المنفوثات فى تيار متعارض و دراسات أخرى، وأن المفهوم الجديد للصور المتوسطة يقدم صورا منطقية وأفضل من الطرق السابقة.كذلك أمكن باستخدام التقنية الجديدة دراسة خصائص المنفوثات مثل توزيع نسبة التركيز، مسار المنفوثات، حدود المنفوثات، والدوامات الناشئة على جدر المنفوثات وهو ما يساعد فى شرح عملية التداخل بين المنفوث والتيار المتعارض.

Abstract

Struetural features resulting from the interaction of a turbulent jet issuing transversely into a uniform stream are deseribed with the help of flow visualization. Jets to erossflow velocity ratios have been investigated with primary goal of introducing a new experimental technique to study characteristies of jets in crossflow. The technique introduced in this study ealled image digitizing technique. It is based on capturing series of images using a high speed digital camera then processing the obtained images. Accordingly, a new definition for the average image has been introduced and applied. The obtained conclusions are; Image digitizing technique, provided and used in this study, is a reliable and inexpensive technique. The new method of averaging is more deseriptive for jet characteristics. Jet characteristics, e.g. eoncentration distribution, jet eenterline, jet boundaries, .. etc, can be studied using image digitizing technique. Roll-up shear layer vortiees are obtained, which can help in explaining their role in the entrainment mechanism.

Nomenclature

C	mean radial concentration
C_o	concentration at the jet exit
CVPs	counter-rotating vortex pairs
d_j	jet diameter, *mm*.
JICF	jet in erossflow
PLIF	planar laser induced floreseent
S	arc length along the jet centerline, *mm*
STOVL	short take-off and/or vertical landing
V_R	velocity ratio

1. Introduction

Jet characteristics can be defined as concentration distribution, velocity distribution, jet trajectory, defining jet boundaries, and coherent structures issued with the flow,... etc. These characteristics play important roles in understanding numerous of technical problems such as exhaust of the smoke stakes, fuel injection, ehemical reactions, and short take-off and/or vertical landing, STOVL.

A jet of fluid entering into a flow of the same or some other kind of fluid moving at an angle to the jet's axis is known by jet in crossflow, JICF. The obtained flow field contains different types of coherent structures, so it is very complex, and unsteady. Veloeity ratio is a very important parameter.

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which can be defined for unheated flows as the ratio between jet velocity to crossflow velocity, Roth (1988). Accordingly, the flow field can be divided into two sections near-field, $0 \leq S \leq 4d_J V_R$, and far-field $S > 4d_J V_R$.

Simulating this flow field in a laboratory requires special devices to measure and analyze these characteristics. Velocity at specific locations can be measured by using hot wire anemometer, or laser Doppler velocimeter. Meanwhile concentration distributions at different cross-sections can be investigated individually using planar-laser induced fluorescent, PLIF technique. Instantaneous concentration images can be used to study mixing in fast turbulent flows.

Roth (1988) mentioned that, perhaps the earliest attempt to analyze the characteristics of a JICF can be referred to Chang Lu, who was interested in the discharge of effluent from a pipe into a stream. She uses potential flow theory with the concept of bound vortex filaments to draw the shape of the separation boundary between a perpendicular cylindrical jet and a crossflow fluid.

Instantaneous radial profiles of the concentration in a turbulent jet were measured using a PLIF technique by Dahm & Dimotakis (1987). The obtained mean radial concentration, C, was normalized with the concentration value at the jet exit, C_o, then the obtained profiles have been compared with other experimental results. The most significant feature of the instantaneous radial extent of the jet, are of two types. The first one is the "two-level" type, in which the mixed concentrations in a large region near the jet axis are within a narrow range. While the mixed fluid concentrations across the remainder of the jet are within a lower range values. The second type is the "top-hat", in where the mixed fluid composition across the entire jet are within a narrow range of concentrations relative to what the mean profile might suggest.

Species concentration measurements are an essential element to study chemically reacting systems, e.g. flames, or other combustion flows. Doweling & Dimotakis (1990) investigated the turbulent concentration field formed when the nozzle gas from a round free turbulent jet mixes with gas entrained from a quiescent reservoir, using a laser-Rayliegh scattering technique. Smith (1996) and Smith & Mungal (1998) studied mixing of a round jet to a uniform crossflow in the near-field. A range of jet-to-crossflow velocity ratios has been applied. They used PLIF technique to acquire quantitative two-dimensional images of the scalar concentration field. Based on Smith investigation, Hasselbrink (1999) studied the centerline concentration along the jet trajectory for velocity ratios 10 and 21 in the far-field. Also, jet trajectory has been defined and traced as the locii of maximum concentration values in the jet direction.

Meanwhile, the injection of a liquid fuel into a gas eventually results in the formation of droplets, Gosh & Hunt (1998) focused in their study on the interaction between an external crossflow and the spray jet. This interaction over a longer distance, and the trajectory of large droplets was found to depend largely on the ratio of the crossflow speed to the jet velocity. They have developed analytical models for many practical ranges of the velocity ratio; this enables spray drift to be calculated.

Numerical models have been introduced to simulate a jet flushing into a crossflow. Sykes et al (1986) represented numerical solutions of the fully three-dimensional flow of a round turbulent jet emitted normal to uniform free stream. Comparisons between available laboratory data and different numerical grid resolutions are used to demonstrate the quality of the simulation. Needham et al (1988) treated the behaviour of a jet exhausting into a fluid of similar density, which is flowing at an angle to the jet axis. The mathematical problem that arises from a highly idealized model of flows was presented. The fluid is assumed to be inviscid and incompressible, with the same density throughout. In addition, the following motivations for this approach have been provided. The first characteristic feature of the real flow is that the jet path is deflected towards the direction of the ambient flow. The second is a counter-rotating vortex pairs, CVPs, aligned with the jet, dominate the distribution field of the deflected jet at a large distance from the orifice. The later characteristic feature is the highly turbulent nature of the flow.

Studying coherent structure dynamics, which govern the evolution and interaction of turbulent shear flows, with background turbulence, is promising not only for understanding turbulence phenomena such as heat transfer Goldstein & Behbahani (1982), entrainment and mixing Kida et al (1991) and Shelly et al (1993), chemical reactions and combustion, Virk et al (1995), drag and aerodynamic noise generation, but also for valuable modeling of turbulence, Lifschetz et al (1996). Efforts have been exerted towards understanding the reasons of shedding these coherent structures, also their merging and cancellation, which known by 'the interaction of two vortex rings'. Some of these efforts have been done by, Perry & Steiner (1987), Saffman (1990), Lim, C. K. (1996), Garten (1997), and Eiff & Keffer (1997).

From previous studies eoncerned with jet characteristics, and others presented by Taylor (1993) it has been found that, although very complicated and expensive techniques have been applied they couldn't study both near- and far-field at the same time. In addition, the idea of averaging used in previous studies based on obtaining a numerous number of images for the same section, and selects one of them as a representative image. Therefore the aim of this work is, to develop an inexpensive experimental technique able to study jet characteristics at both fields at the same time. In addition it should be reliable and easy to use, and able to generate an average image to represent group of images instead of selecting one of them.

2. Experimental Rig

An arrangement of the experimental test rig is shown in Fig. (1). A Plexiglass 1′ × 1′ square cross section of 2′ length mounted in a sub-sonic wind tunnel is used as a test section to study the concentration variation at different cross sections in both near- and far-field. The test seetion is painted with a black color to avoid external light reflection. Jet is mounted at the center of the test section, and is fitted with a heat exchanger to reduee temperature of the paraffin smoke produced from a smoke generator to the ambient temperature. In addition, a sheet of light with 0.25 mm in width is produced from a lighting system aligned to the center of the jet, and images are captured using a high-speed camera. Pressure and temperature of the smoke have been measured by digital micro-manometer, and digital non-contact thermometer, respectively. Meanwhile a digital illumenance meter has been used to check test section darkness. Jet diameter used in this study is 4 mm, jet velocities are 2, and 3 m/s, and crossflow velocity is fixed at 1m/s.

3. Image Digitizing Technique

Computer graphics is one of the most exciting and rapidly growing fields in computer science. Furthermore, pictures are a valuable means for effective eommunieations. Using computers to communieate with pictures is revolutionizing the way eomputers are being used in all areas.

An image may be directly processed on the monitor, in case of real-time control, or saved into a file for later use. These saved images become useful when they are available to be manipulated by another application. To make it able to occur, it is necessary to put the image data into a standard form that other applications can be interpreted and used, in this study PCX format is used. Hearn & Baker (1986) have been mentioned that, there are two categories for images: raster format and vector format, which sometimes called random scan.

Digitized images are useful for looking at man systems or objects that cannot be seen directly. Examples include TV scans from spacecraft, views from the eye of an individual robot, and images obtained by a digital camera. Once a picture has been digitized and saved into a file, additional processing techniques can be applied to improve the contrast, enhance color separation, remove unwanted visual information, improve focus, and rearrange picture parts, Negroponte (1995).

El-Khayat (2002) noted that, digitizing images depend on convert image into a group of digits; each digit represents a unique color degree. This digit will be repeated in the digital file, whenever, its corresponding color degree exists. In this study a mono-color digital camera has been used, the camera outputs are files with PCX format. So, a color palette with 16 different color has been used to reproduce gray images using pseudo-color image technique, and their equivalent numbers. Each color in the new palette has 16 different degrees, this means the total number of colors can be presented is 256 color.

4. Developed Image Digitizing Software

A special program has been designed and implemented, named FLUIDLAB package, to digitize and analyze the camera outputs; PCX files. The instantaneous mono-color eaptured side-view images for a JICF reflects jet concentration as a variation of color. A mono-color palette with 256-color degree, varies from fully darkness to fully whiteness, has been used to represent the captured images. The fully darkness concentration has its lower value. On contrary, fully whiteness reflects the maximum value concentration that can be reached. In general, color variation may points to temperature gradient or concentration as in the current study. The main concept for the FLUIDLAB package is to sense the variation of image color degrees. Convert each degree to a unique number. Then, a series of processing procedures can be implemented.

FLUIDLAB package consists of six functions (e.g. re-coloring, image averaging; trace jet trajectory, .. etc) each one may performs one task or more. These tasks have been determined according to the research goals. Considerations of minimizing processing time and efficient memory management have been taken.

One of the important functions inherited in the FLUIDLAB package is producing mean image. The process can be described as follows: to obtain one mean image a 15 sequential images should be digitized, therefore 15 arrays for the same run condition will be obtained. By averaging the obtained arrays, only one array will be produced, this array will be re-drawn using a special function inherited also in the FLUIDLAB package.

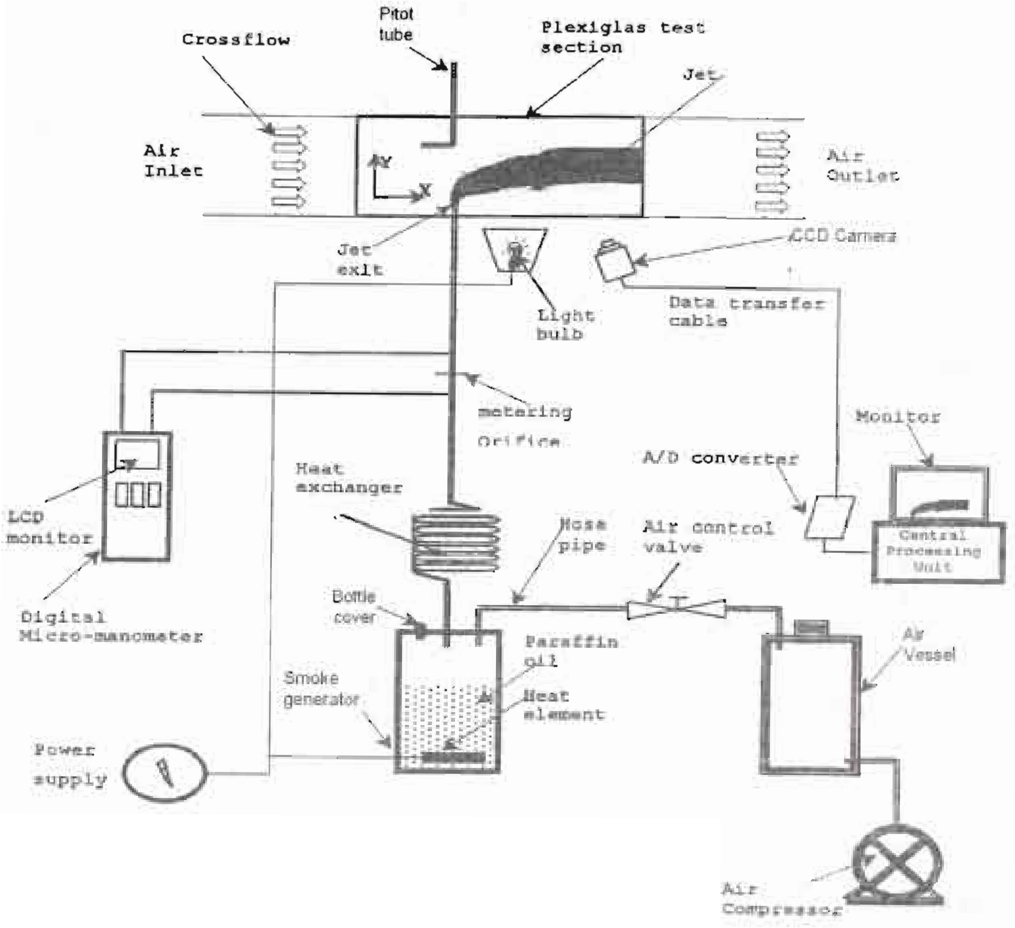

Fig. (1): Schematic of the experimental rig arrangement

5. Results

Figure (2) shows three samples of 15 sequential images, with time intervals 6 seconds, taken for d_o=4mm, and V_R=2, and their mean image. The obtained image is used to give the details of the jet characteristics. As a result of the re-coloring process, color variation in each image reflects the concentration distribution for each case. This makes an easy visual comparison between images. The color representation is based on a color palette contains 256 color, to represent the concentration distribution, in near- and far-field at the same time. The determination of the jet trajectory was a primary objective for many of the experimental and theoretical studies. In this study, the determination of the jet trajectory, called jet centerline is defined to be the locii of points of maximum concentration in the direction of the jet within the flow symmetry, as recommended by Smith (1996), Smith & Mungal (1998), and Hasselbrink (1999).

Concentration profiles through the jet for velocity ratios 2:1 and 3:1 and d_J=4mm, are presented at several locations as shown in Fig. (3). The ensemble-averaged profiles are included on each instantaneous profile shown in these figures. A smooth shape of these profiles characterizes the average, which is "top hat" when sliced perpendicular to the jet direction. The instantaneous profiles are marked by sharp vertical rises in concentration resulting in small plateaus of high concentration fluid.

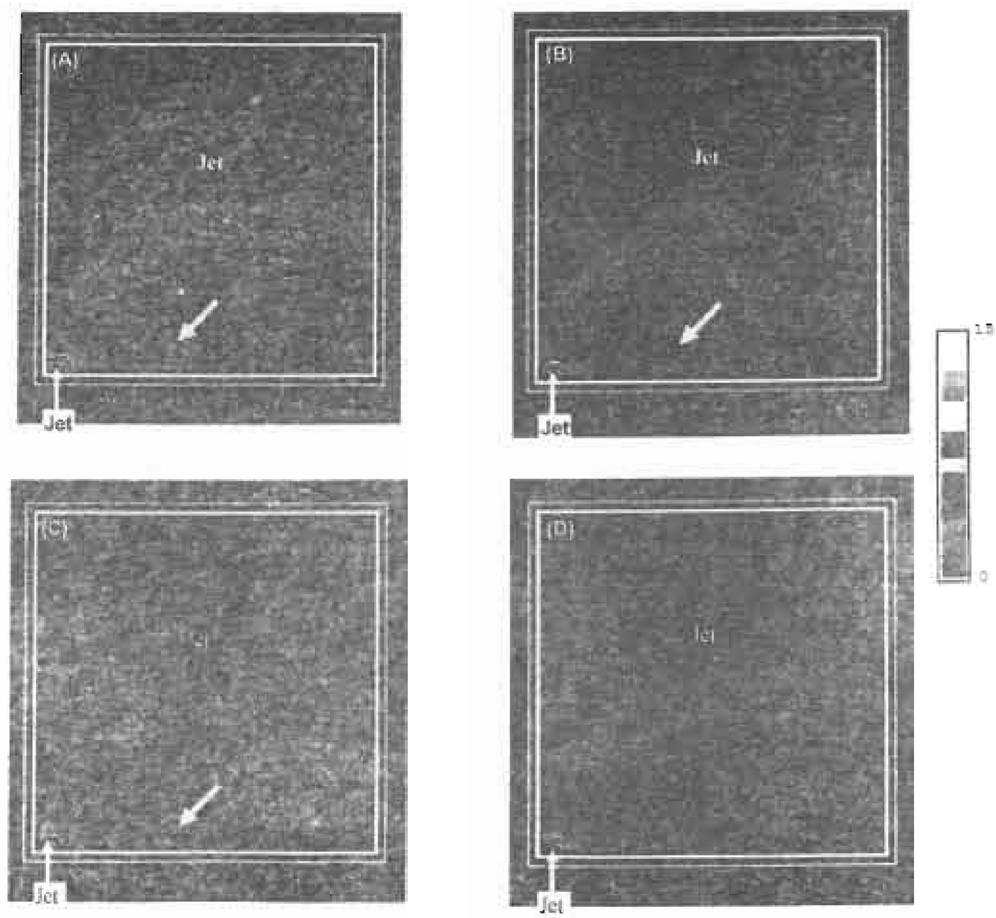

Fig.(2). Three instantaneous jet images (A), (B), and (C), and their mean image, (D). d_J=4mm. V_R=2. Yellow arrows point to the 'thin fingers' which form wake structure

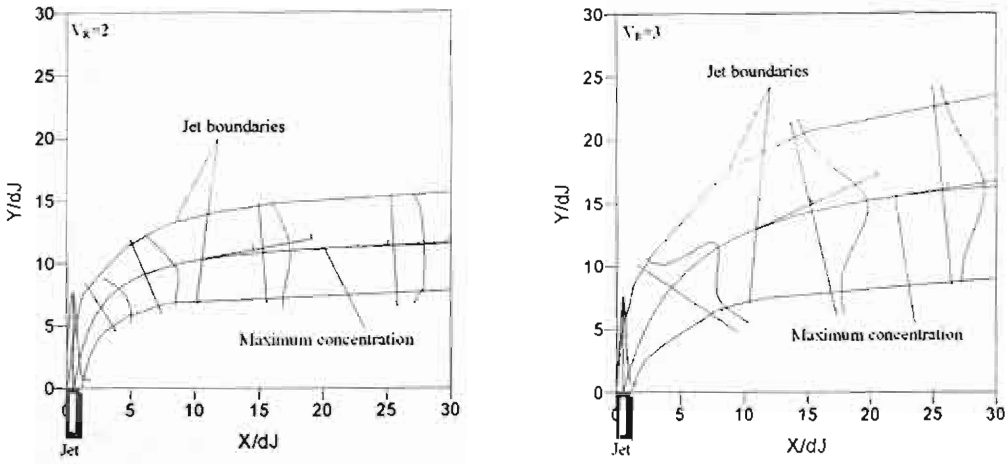

Fig.(3): Experimental jet boundaries, trajectories, and dimensionless mean concentration distributions. d_J=4mm, V_R=2, and 3

The experimental data that have been presented in Fig. (4) show that, when a turbulent jet spreads through a crossflow, the profiles of the mixture concentration in the cross sections of the jet are symmetrical in shape around the jet centerline. Also, it indicates a fast decay of the jet centerline, which means that fast mixing process has been occurred between the jet and the crossflow. In addition, the real data for concentration profiles, where concentration is normalized by concentration at the jet exit, is characterized by sharp gradients, and nearly can be considered as Gaussian shaped profiles. It can be classified as "top-hat" type, such as those illustrated by Dahm & Dimotakis (1987), as shown in Fig. (5).

Turner (1986) introduced an entrainment mechanism based on jet roll-up shear layer vortices. These vortices may occur as a result of jet and crossflow interaction. This creates a strong non-equilibrium turbulent field in the forward region of the jet. Also, the momentum of the crossflow affects their deformation. Fig. (6.A) presents the interaction between the jet and crossflow using recent technique used. Instabilities due to this interface are clearly shown on the jet boundaries. Figs. (6.B) to (6.D) introduce the mechanism presented by Turner (1986), where vortices have been affected, slightly, by the crossflow as shown in Fig. (6), then reach the pocket-like shape in Fig. (6.C), and the engulfing process has been reached in Fig. (6.D).

According to these results more characteristics can be obtained, such as concentration decay along the jet centerline, which is very important in mixing processes. Velocity profile, jet deformation, and wake structure can be investigated using image-digitizing technique.

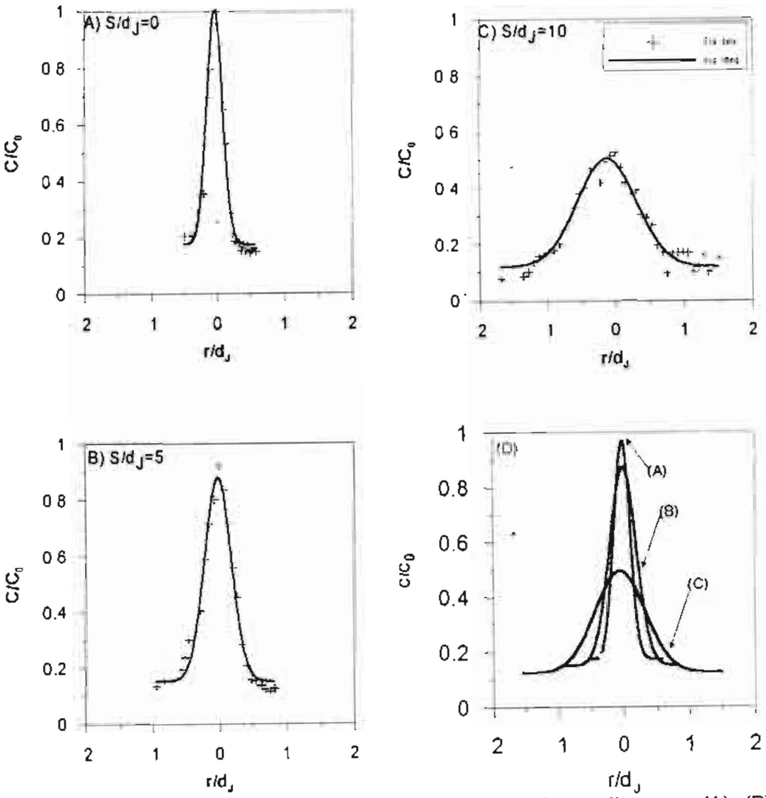

Fig.(4): Ensemble-averaged Concentration distribution at different distances (A), (B), (C), and a comparison between them in (D). d_J=4mm. V_R= 3

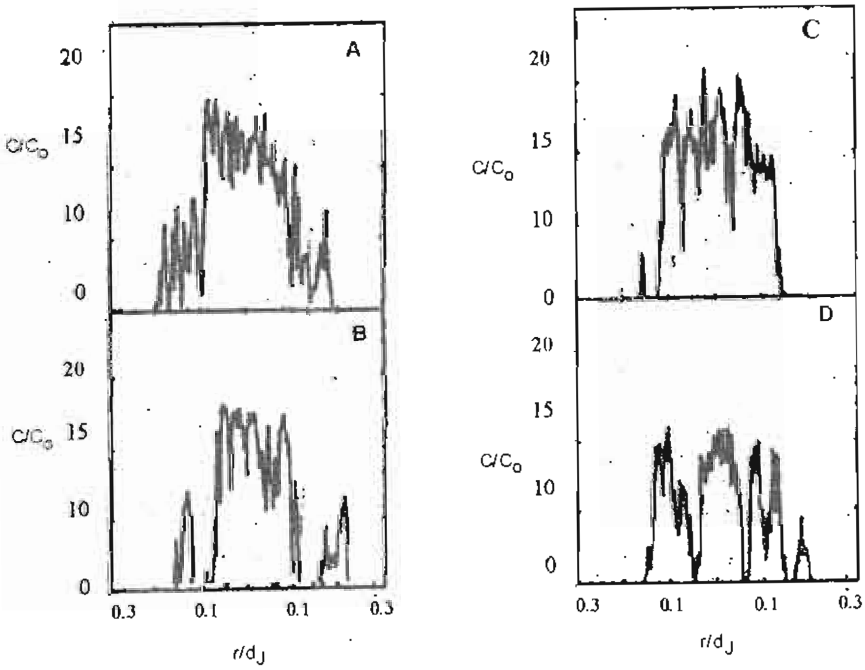

Fig.(5): Different concentration profiles, (a), and (b) "Two-Level" type, (c) and (d) "Top-Hat" After Dahm and Dimotakis (1987)

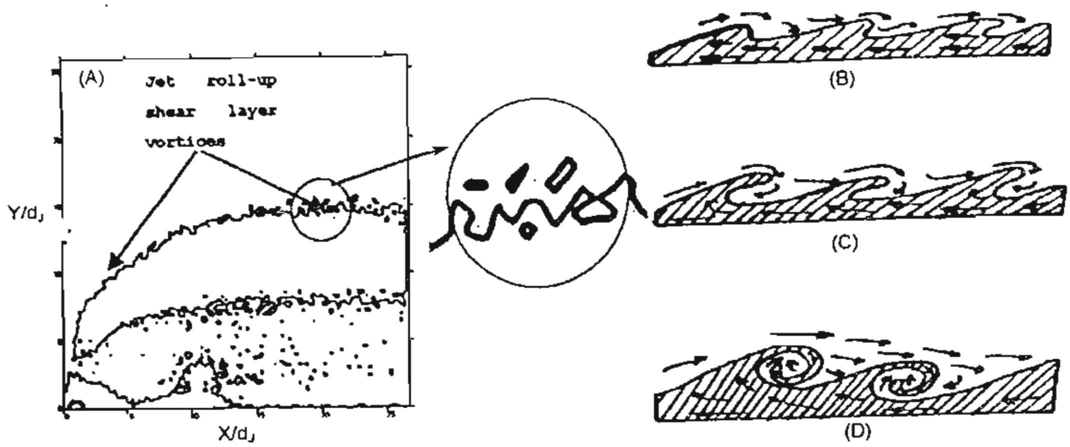

Fig.(6): The interface between crossflow and roll-up shear layer vortices, (A) obtained by the recent technique used, and (B), (C) and (D) suggestedby Turner (1986), d_J=4mm, V_R=2

6) Conclusion

Transverse jets at variant jet to crossflow velocity ratios have been investigated using a new experimental technique, named image digitizing technique with the primary goal of understanding the produced structure of JICF. The results of the present experimental study are sets of concentration images for a JICF, covers range of velocity ratios, 2:1 to 3:1 and for jet diameter, d_J= 4mm. Side-view images of the centerline section were processed using image digitizing technique. The obtained conclusions are;

- Image digitizing technique, provided and used in this study, is a reliable and inexpensive technique.
- The new method of averaging is more descriptive for jet characteristics.
- Jet characteristics, e.g. concentration distribution, jet centerline, jet boundaries, .. etc. can be studied using image digitizing teehnique.
- Roll-up sbear layer vortices are obtained, which can help in explaining their role in the entrainment mechanism.

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