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EXPERIMENTAL STUDY OF TWO-PHASE FLOW AROUND HYDROFOIL IN OPEN CHANNEL

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ABSTRACT

The purpose of this paper is to study the two-phase flow around hydrofoil. Experimental studies have been conducted in a channel with air-water flow for different angles of hydrofoil with different air and water discharges. The paper describes experiments carried out in the channel with the rectangular test section of 100 x 30 x 800 mm. The maximum inlet velocity at the test section for air is 1.115 m/s and for water is 0.022 m/s. These experiments have been aimed to visualize the two phase flow phenomena as well as to studies effect of pressure difference through channel with hydrofoil. All sets of flow data in this study were obtained using pressure transducer and visualization by video camera and recorded at multiple angles of attack (0^o,15^o and 25^o) and different Water discharge (l/min) (20, 25, 35 and 45) and different air discharge (l/min) (10, 20, 30 and 40). When (α=0°) the flow is parallel to the hydrofoil surface and there is no vortex shedding behind the hydrofoil. When (α=15°) the flow separates from the upper-surface and the separation point moves towards the leading edge of the hydrofoil as the air water discharges increases. When the angle of hydrofoil (α=25°), the flow separates near the leading edge of the upper surface and large eddies are shed from both the upper and lower surfaces. For constant water discharge, the pressure difference increased with increased air discharge with the same angle of hydrofoil

KEYWORD :- Two-Phase; Hydrofoil; Channel; pressure drop

دراسة عملية للجريان ثنائي الطور حول جنيح في قناة مفتوحة

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جامعة بابل/ كلية الهندسة/ قسم الهندسة الميكانيكية

الخلاصة :

الغرض من البحث هو دراسة الجريان ثنائي الطور حول جناح. تم إجراء دراسة عملية و بناء منظومة للجريان ثنائي الطور باستخدام قناة شفافة وتم وضع الجنح داخل القناة. وتم إجراء الاختبارات لعدة زوايا ميلان للجنح و لعدة معدلات جريان للماء والهواء. تم وصف التجارب المختبرية باستخدام نموذج اختبار بأبعاد (100 x 30 x 800) ملم و باستخدام أقصى سرعة جريان للهواء بمعدل 1.115 م/ثا و سرعة ماء 0.022 م/ثا. النتائج العملية تم أخذها عند عدة زوايا هجوم (α = 0°, 15° and 25°) و باستخدامعدلات جريان مختلفة للماء (20, 25, 35 and 45) لتر/دقيقة و للهواء (10, 20, 30 and 40) لتر/ دقيقة. يهدف الجزء العملي لدراسة الجريان ثنائي الطور على جنح و دراسة ظاهرة الجريان الثنائي التي تحصل عند الجريان و دراسة الاختلاف بالضغط عند مدخل و مخرج القناة بوجود الجناح و باستخدام التصوير الفديوي و كذلك حساب الضغط عند مدخل و مخرج القناة. تم الحصول على نتائج عملية و هي بزيادة

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زاوية الهجوم فان الجريان سوف ينفصل في النهاية الامامية لسطح الريشة المواجهة له مع تولد و دوامات كبيرة تنفصل من السطح العلوي و السفلي للريشة. كذلك لوحظ انه عند ثبوت كمية الماء يزداد الضغط مع زيادة كمية الهواء المجهزة عند ثبوت زاوية الهجوم .

INTRODUCTION :-

Two-phase flow over hydrofoil is found in many engineering applications, such as hydraulic constructions, aeronautics, aerospace, power systems and turbomachinery. In the case of hydraulic machinery, modern design requirements lead to more compact machines with higher rotation speeds and higher cavitation risk. The cavitation in flowing liquids may be occur if phase transition to vaporization or condensation driven by pressure change without any heating. It can be interpret as the rupture of the liquid continuum due to excessive stresses. Cubaud et al. (2006) investigated experimentally two-phase flows in microchannels with surface modifications. They investigated the shape of static and moving bubbles in microchannels with square cross-sections for different contact angles .Water and air were mixed on-chip in a cross-shaped mixing chamber. These experiments highlight the importance of wall properties for two-phase flows in microfluidic devices. Tomomi Uchiyama and Tomohiro Degawa (2007), this study was concerned with the two-dimensional simulation for an air-water bubbly flow around a hydrofoil. The liquid vorticity field was discrerize by vortex elements, and the behavior of vortex element and the bubble motion were simultaneously computed by the Lagrangian approach. The effect of bubble motion on the liquid flow was taking into account through the change in the strength of vortex element. It was confirm that the simulated distributions of air volume fraction and pressure agree well with the trend of the measurement and that the effect of angle of attack on the flow was favorably analyze. These results demonstrate that the vortex method was applicable to the bubbly flow analysis around a hydrofoil. Dular et al. (2008) performed Experimental measurements and simulations of the flow over a hydrofoil in a closed circuit cavitation channel. Ellenrieder and Pothos (2008), Used Particle image velocimetry to examine the flow behind a two-dimensional heaving hydrofoil of NACA 0012 cross section, operating with heave amplitude to chord ratio of 0.215 at Strouhal numbers between 0.174 and 0.781 and a Reynolds number of 2,700. The measurements show that for Strouhal numbers larger than 0.434, the wake becomes deflected such that the average velocity profile was asymmetric about the mean heave position of the hydrofoil. Scott David Kelly and Hailong Xiong (2010), presented a model for the self-propulsion of a free deforming hydrofoil in a planar ideal fluid. They were begin with the equations of motion for a deforming foil interacting with a pre-existing system of point vortices and demonstrate that these equations possess a Hamiltonian structure. Majid (2011), reported simulations of gas-liquid two-phase flow in microchannels periodically patterned with grooves and ridges. A constant effective body force was applied on both fluids to simulate a pressure-driven creeping flow, and a diffuse-interface model was used to compute the interfacial evolution and the contact line motion. A map of flow regimes was constructed for a set of geometric and flow parameters starting from a prescribed initial configuration. Some of the regimes are new, while others have been observed before in straight tubes and pipes. S. J. ZHU et al. (2009) present the production and entrainment of bubbles in ship wakes was not completely understood despite the fact that it has many practical applications. This work presents numerical results on the effect of a hydrofoil on a population of bubbles as they pass over it, and the resulting distribution of bubbles downstream for a range of angles of attack and Reynolds numbers. Direct numerical simulation (DNS) was use with a Lagrangian particle tracking method, which was more suited for fundamental investigations of the bubbly flow. It was see that the effect of the angle of attack on the downstream bubble distribution was small at low Reynolds number but the effect increases at higher Reynolds number. Our data also shows that the effect of angle of attack on downstream bubble distribution was more significant for $\alpha = 20°$ rather than for $\alpha \leq 10°$ **.** The main objective of this research is to investigate the experimental study of two-phase flow gas – liquid around hydrofoil in open channel with various angles for hydrofoil and various gas-liquid flow rates. All experiments investigated the flow by visualization in video camera and study effect of pressure difference in channel with change angle of attack **.**

EXPERIMENTAL APPROACH AND PROCEDURE :-

The experiments are conducted in a two-phase flow loop, the schematic diagram of which is shown in figure (1). The channel is built as a closed-loop horizontal plane air-water with put hydrofoil inside it.. The main parts of this rig contained from main tank capacity 1 m^3, compressor, pump and pressure sensor as shown in figures below. The test section was mounted on a blind panel on the bottom of the rectangular section (100 × 30 × 900 mm) allowing optical access through three large Perspex windows located on lateral and top sides of the test section. The hydrofoil was used made from stainless steel and coated with a very thin layer of black paint. with 100 mm chord and 18 mm span length. The detailed of a hydrofoil shown in figure (3) and located inside at section at 15 cm in length from entrance and 3 cm in height and at middle of width. The hydrofoil attack angle is set as 5^o, 15^o and 25^o for all experiments. A rotameter was used to control the gas volume flow rate that enters test section. It has a volume flow rate range of (6-50) l/min . As like as in gas flow meter, a variable area meter was used to control the liquid volume flow rate that enters test section. It has a volume flow rate range of (10-80) l/min. The pressure transducer sensors are used to record the pressure field with a range of (0-1) bar. These pressure transducer sensors are located in honeycombs at entrance and end of channel. The pressure sensors with a distance of 15.7 cm between them are measured with an accuracy of 0.1%. The sensors are connection with interface and the processor which is represented by a program on the personal computer. The interface system consists of two parts which are the data logger and the transformer which is contains in a white plastic box. The data logger has three connections two of them are connects to the outside of the box one connects to the sensors and the other connects to the personal computer, the third connection connects to the transformer, its work is receive the signals as a voltage from the sensors and transmit it into the transformer and then re-received these signals after converting it to ampere signals in the transformer. A Sony digital video camera recorder of DCR-SR68E model of capacity 80 GB with lens of Carl Zeiss Vario-Tessar of 60 x optical, 2000 x digital was used to visualize the flow structures. The visualized data are analyzed by using a AVS video convertor software version 8.1. A typical sequence snapshots recorded by the camera using a recording rate of 30 f/s. For more accuracy in the experimental work calibration of the rig measuring devices are worked. The flows of both gas and liquid are regulated respectively by the combination of valves and by-passages before they are measured by gas phase flow meter and liquid phase flow meter. The gas phase and the liquid phase are mixed in mixing device before they enter test section. When the two-phase mixture flows out of the test section, the liquid phase and the gas phase are separated in liquid storage tank. Experiments were carried out to show the effect of different operation conditions on pressure difference a cross test section and to visualization of flow around hydrofoil. Such conditions are water discharge, air discharge and different value of angle of hydrofoil in test section.

RESULTS AND DISCUSSION :-

The results from experimental work are presented in this paper for three different angles of attack (α = 0°, 15° and 25°), different Water discharge (l/min) (20, 25, 35 and 45) and different air discharge (l/min) (10, 20, 30 and 40) have been studied.

Angle of attack at α = 0°

Figure (6) present the Visualizations of a hydrofoil in gas-liquid flow through channel at α = 0° for (20, 25, 35 and 45) l/min water discharge and different air discharge (10, 20, 30 and 40) l/min respectively. The large bubbles released from the upper surface of the hydrofoil. For all three cases, bubbles flow along the hydrofoil surface, as the fluid flow is parallel to the surface. They flow almost straight into the wake of the hydrofoil and stability at the end of channel. As the air discharge increases, the vortices on both side of the hydrofoil are stretched further downstream but no vortex, shedding is observed at this angle of attack. The size of bubble increase when air discharge increased for all water discharges.

Angle of attack at α = 15°

Figure (7), shows the Visualizations of a hydrofoil in gas-liquid flow through channel at α = 15° for (20, 25, 35 and 45) l/min water discharge and different air discharge (10, 20, 30 and 40) l/min respectively. The large bubbles released from the upper surface of the hydrofoil. As the air discharge increases, the separation point moves towards the leading edge. When water discharge increase with increased air discharge, flow becomes unsteady and vortices developed from upper and lower surfaces and the bubble transformed to cloud flow.

Angle of attack at α = 25°

Figure (8), shows the Visualizations of a hydrofoil in gas-liquid flow through channel at α = 25° for (20, 25, 35 and 45) l/min water discharge and different air discharge (10, 20, 30 and 40) l/min respectively. The flow separation from the upper surface is confirmed in all three cases. The bubbles released near the leading edge from the upper surface are entrained into the reverse flow region above the trailing edge of the hydrofoil. When water discharge increase with increased air discharge, flow becomes unsteady, vortices developed from upper, and lower surfaces and the most bubble transformed to cloud flow and strong vortex shedding from both upper and lower surfaces are observed.

Effect of Time Evolution of Pressure

Figures (9, 10 and 11) represent effect of time evolution of pressure obtained by experiment for water discharge Qw=20 l/min, air discharge Qa=10 l/min and various angle of hydrofoil α=0, 15 and 25^{o} respectively. It is shows the pressures fluctuate as a function of time. The pressure sensor at the inlet to the test section after honeycombs is recorded pressure with time. It should also be noted that the pressure recording fluctuate with time due to two-phase effect. At the end of test section, the pressure sensor recorded the pressure with time and pressure increased-decreased with time due to the same reason mentioned above. Figures (12, 13 and 14) represent effect of time evolution of pressure obtained by experiment for various water discharge Qw=20, 25 and 45 l/min respectively and air discharge Qa=20, 10 and 30 l/min respectively with constant angle of hydrofoil $\alpha=15^o$. It is shows the pressures fluctuate as a function of time. When the air discharges increase the pressure fluctuations increase too due to high inertia force in two-phase flow. Also, noted that when increase water discharges the pressure fluctuation increase too with time due to the same reason mentioned above .

Effect of Pressure Difference

It is already noticed that the mean pressure difference has a significant influence on hydrofoil. Therefore, it is expected that the flow instability will also depend upon the pressure difference. Figures (15, 16, 17 and 18) represent effect of time evolution of pressure obtained by experiment for water discharges Qw=20, 25, 35 and 45 l/min respectively, various air discharges Qa=10,20, 30 and 40 l/min and various angle of hydrofoil $\alpha=0^o$, 15^o and 25^o respectively. For constant water discharge, the pressure difference increased with increased air discharge with the same angle of hydrofoil. When angle of hydrofoil increase the vortices developed from upper, and lower surfaces increased too, so that the pressure difference increase with increase angles. Figures (19, 20 and 21) represent effect of time evolution of pressure obtained by experiment for various water discharges Qw=20, 25, 35 and 45 l/min respectively, various air discharges Qa=10,20, 30 and 40 l/min and various angle of hydrofoil $\alpha=0^o$, 15^o and 25^o respectively. It is noted that for the pressure difference increased with air discharges increase. In addition, the pressure gradient plays an important role to trigger the entrance air-water discharge, and the interaction between the water and air causes the cavity periodical shedding of the cloud flow. The angles of hydrofoil play an important role to satisfy the bubbly flow. When increase angles the pressure difference increase too, so that, most bubble transformed to cloud flow and strong vortex shedding from both upper and lower surfaces are observed.

CONCLUSIONS :-

In this study, experiments were conducted to measure pressures in a air-water two-phase flow around hydrofoil in open channel. Visualization is study of flow around the hydrofoil in channel using air-water two-phase flow as a working fluid. The conclusions are summarized as follows:

1. When the angle of hydrofoil $\alpha = 0°$, the flow is parallel to the hydrofoil surface and there is no vortex shedding behind the hydrofoil.
2. When the angle of hydrofoil $\alpha = 15°$, the flow separates from the upper-surface and the separation point moves towards the leading edge of the hydrofoil as the air water discharges increases.
3. When the angle of hydrofoil $\alpha = 25°$, the flow separates near the leading edge of the upper surface and large eddies are shed from both the upper and lower surfaces.
4. Periodical shedding of cloud flow was observed when high air discharge and high water discharge. The visualization by a video camera revealed that a flow

separation and circulating flow. Flow patterns will be observed bubble flow and cloud flow.

5. For constant water discharge, the pressure difference increased with increased air discharge with the same angle of hydrofoil.
6. The angles of hydrofoil play an important role to satisfy the bubbly flow.

1-Water Tank
2-Water pump
3-Valve
4-Water Flow meter
5-compressor
6- Air Flow meter
7-Valve
8-Pressure sensor
9-Hydrofoil
10-Tese section
11-Data logger
12-personal computer

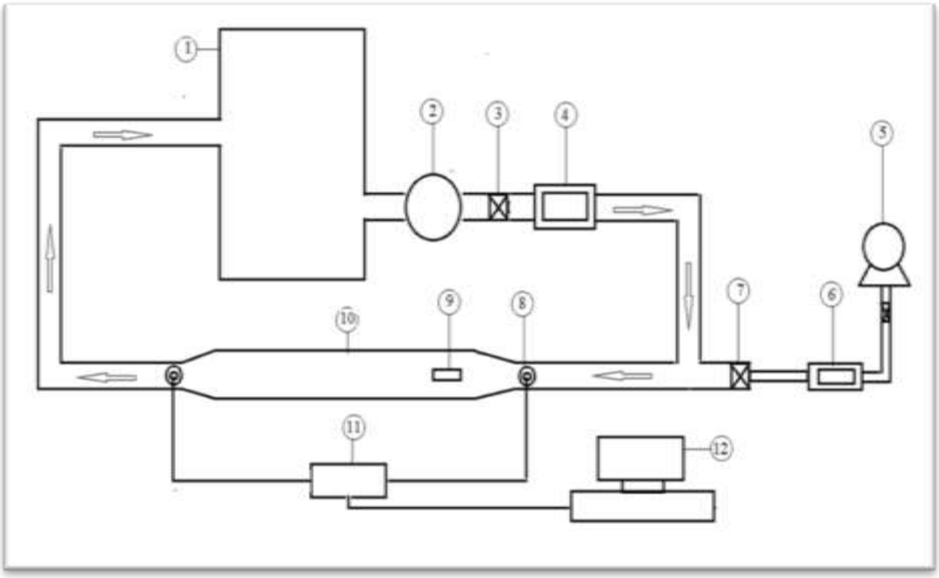


Figure (1) :The Experimental rig

Figure (2) picture of test section

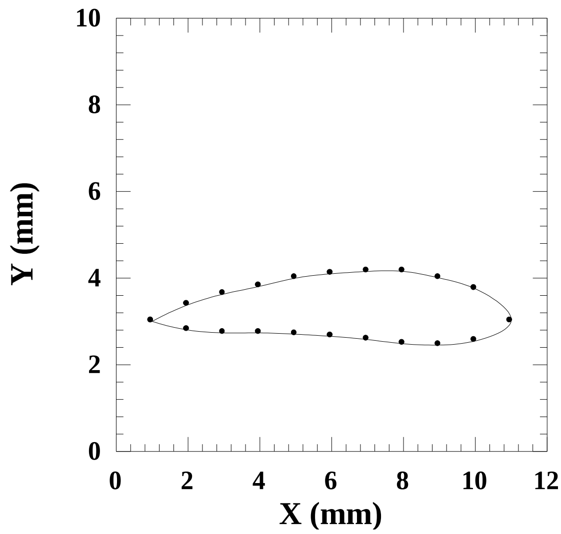
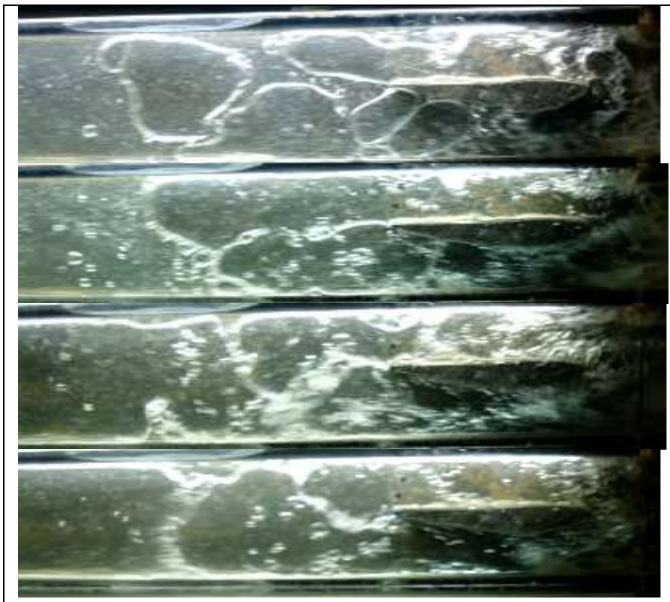


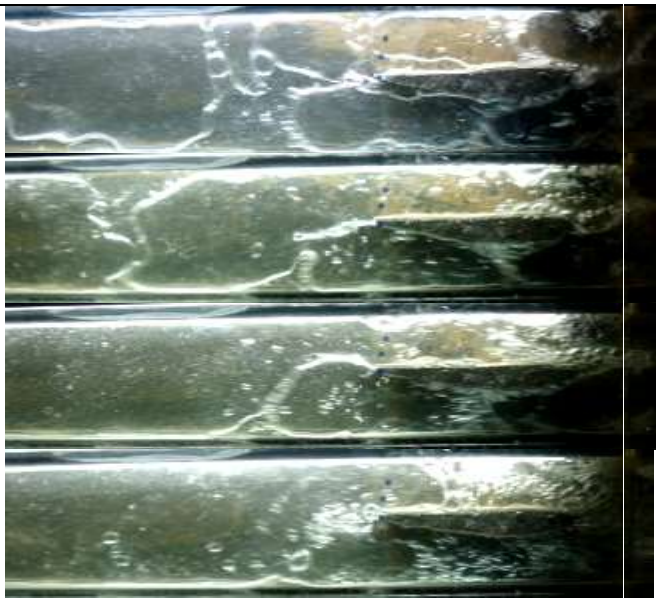
Figure (3) Dimensions of Hydrofoil

Figure (4) :The Pump and Flow meter

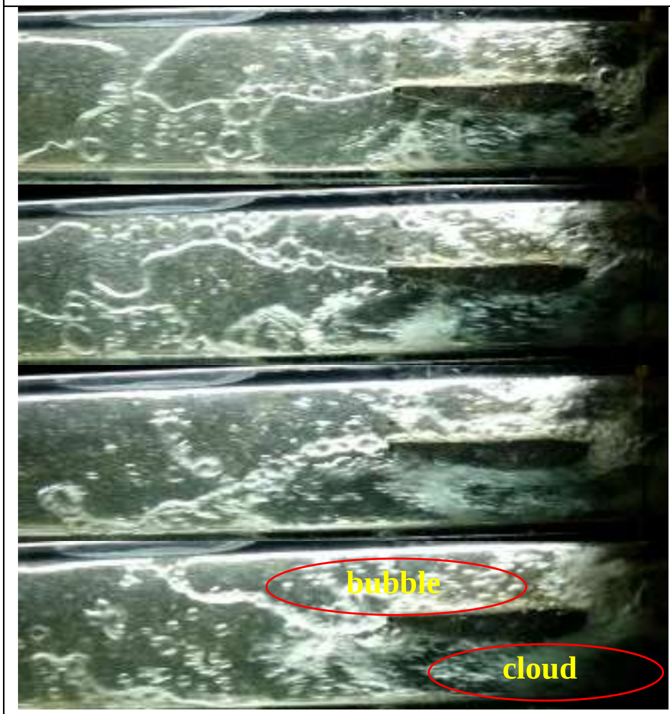
Figure (5) : The Pressure sensor



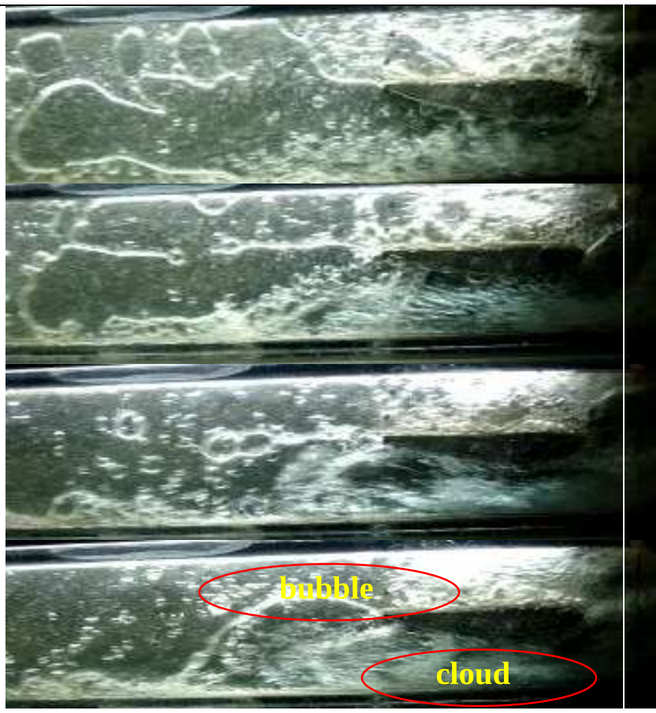
α=0 Qw=25 and Qa=10, 20, 30 and 40



α=0 Qw=20 and Qa=10, 20, 30 and 40

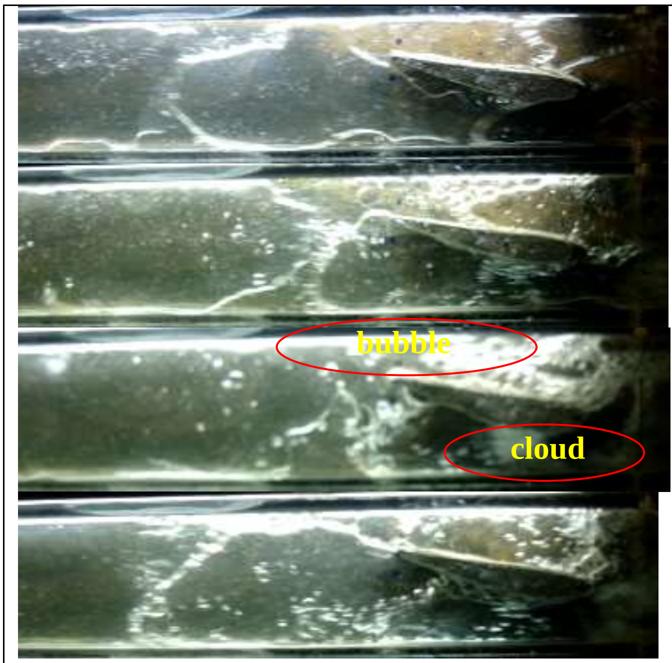


α=0 Qw=35 and Qa=10, 20, 30 and 40

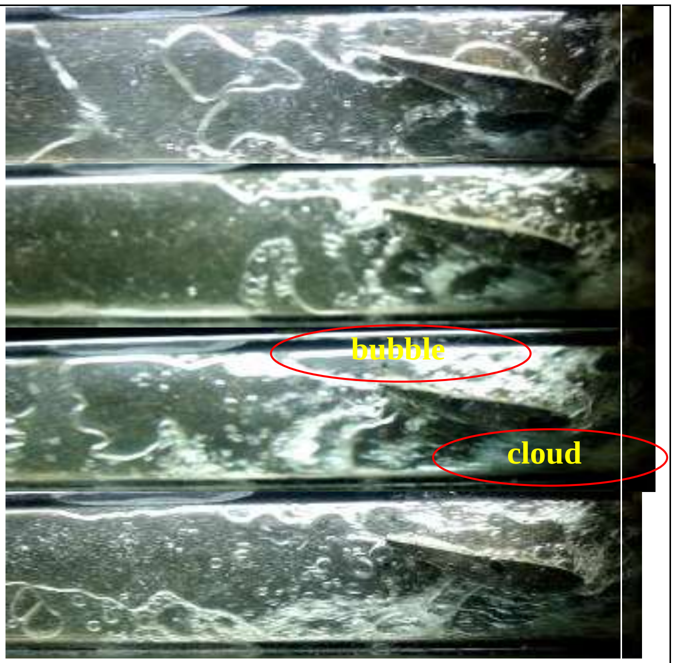


α=0 Q_w=45 and Q_a=10, 20, 30 and 40

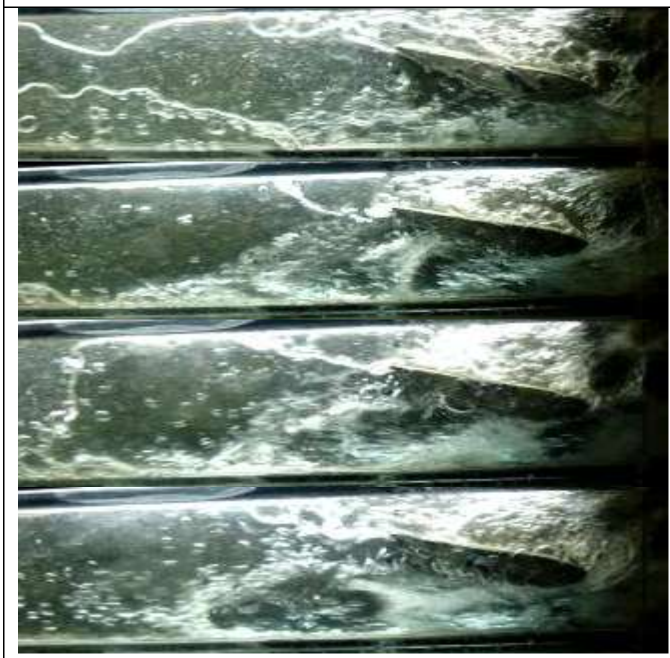
Figure 6 Visualizations of a two-dimensional hydrofoil in open channel



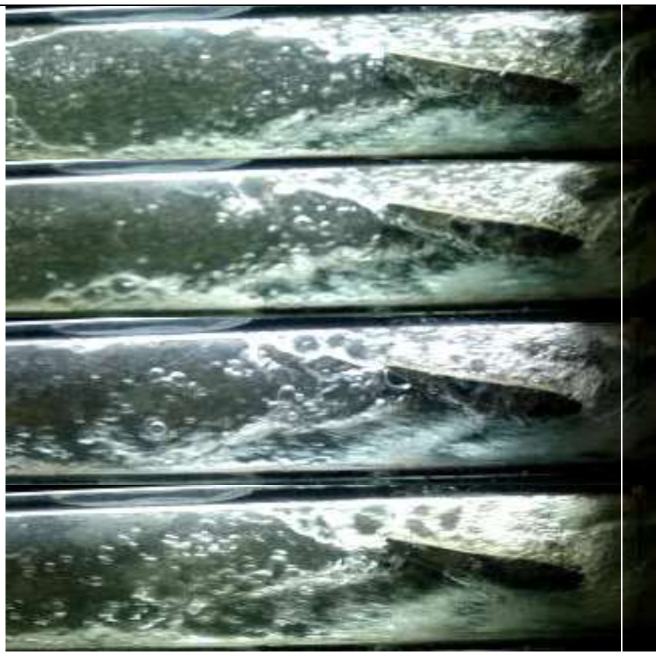
α=15 Qw=20 and Qa=10, 20, 30 and 40



α=15 Qw=25 and Qa=10, 20, 30 and 40



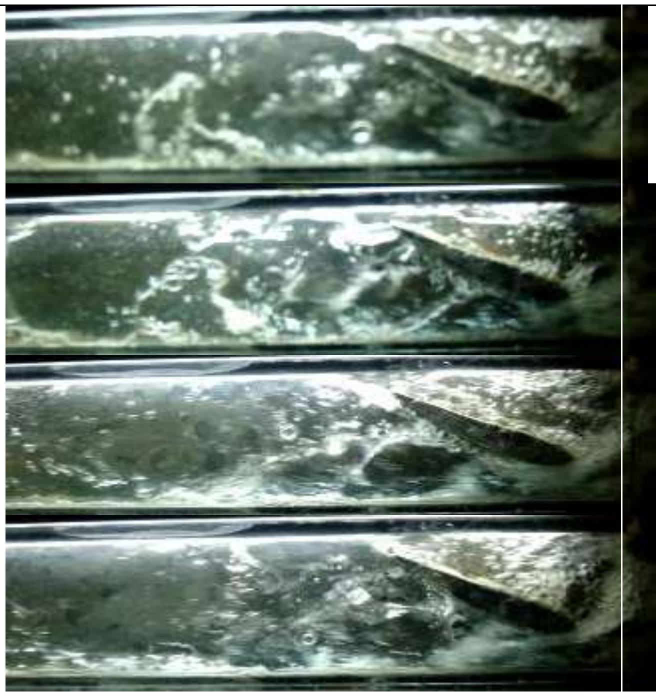
α=15 Qw=35 and Qa=10, 20, 30 and 40



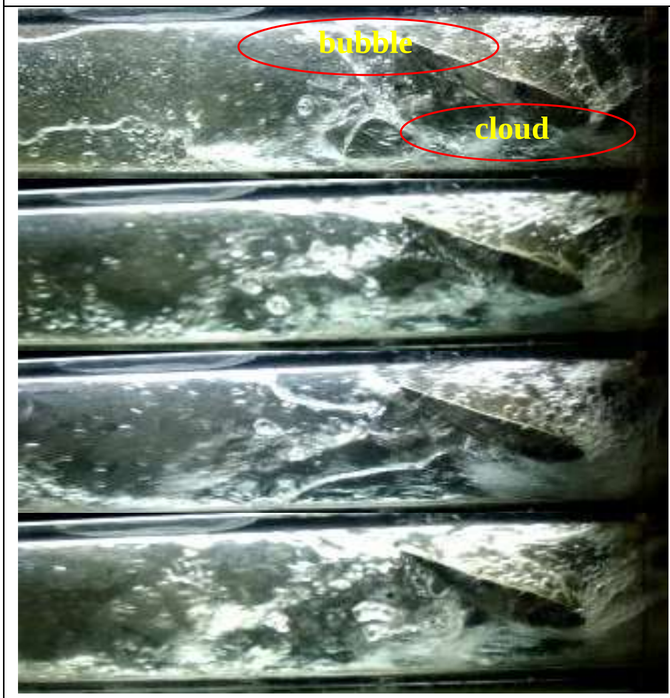
α=15 Qw=45 and Qa=10, 20, 30 and 40

Figure 7 Visualizations of a two-dimensional hydrofoil in open channel

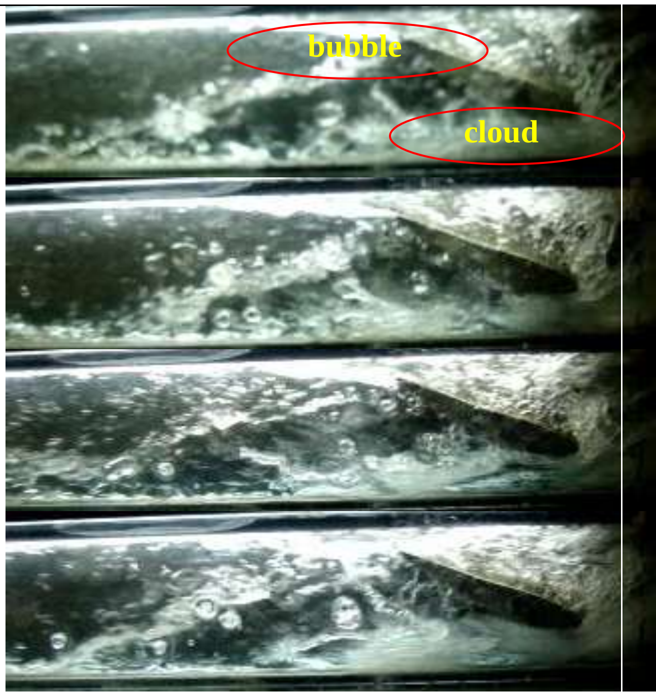
α=25 Qw=20 and Qa=10, 20, 30 and 40



α=25 Qw=25 and Qa=10, 20, 30 and 40



α=25 Qw=35 and Qa=10, 20, 30 and 40



α=25 Q_w=45 and Q_a=10, 20, 30 and 40

Figure 8 Visualizations of a two-dimensional hydrofoil in a open channel

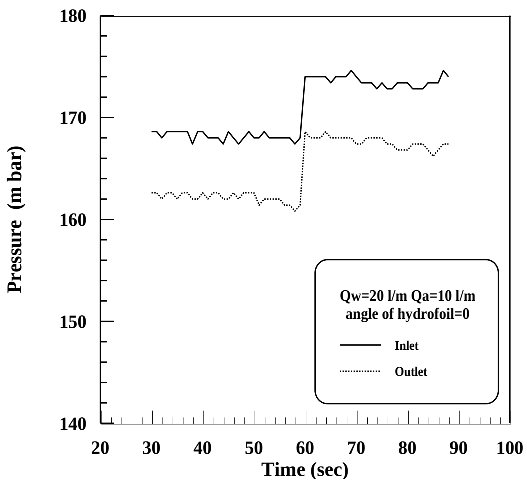


Figure (9) Effect of Time evolution of pressure obtained by experiment (Q_w=20, Q_a=10 and α=0°)

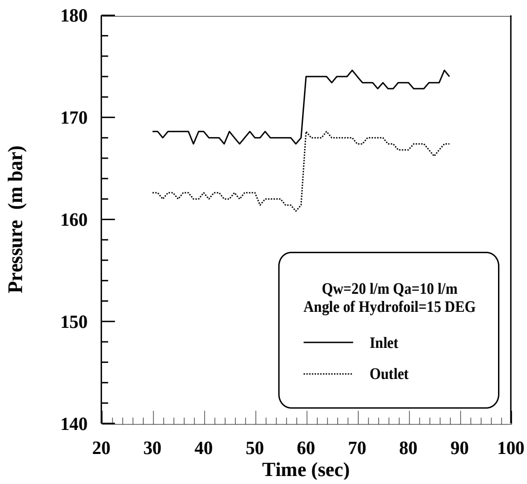


Figure (10) Effect of Time evolution of pressure obtained by experiment (Q_w=20, Q_a=10 and α=15°)

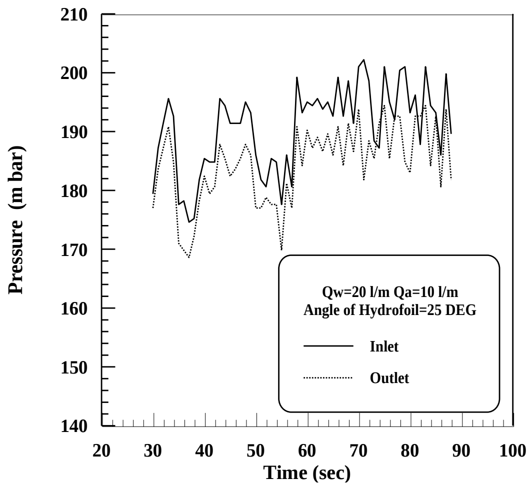


Figure (11) Effect of Time evolution of pressure obtained by experiment (Q_w=20, Q_a=10 and α=25°)

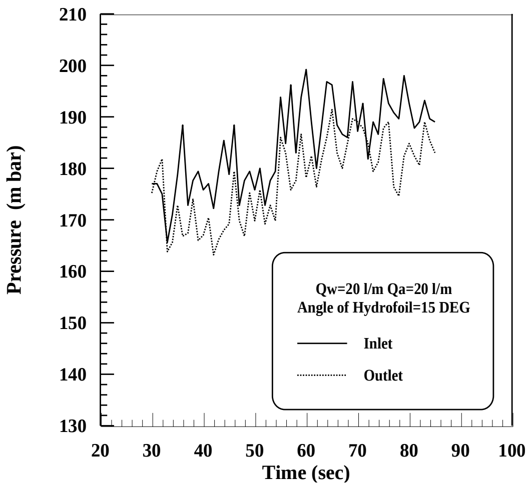


Figure (12) Effect of Time evolution of pressure obtained by experiment (Q_w=20, Q_a=20 and α=15°)

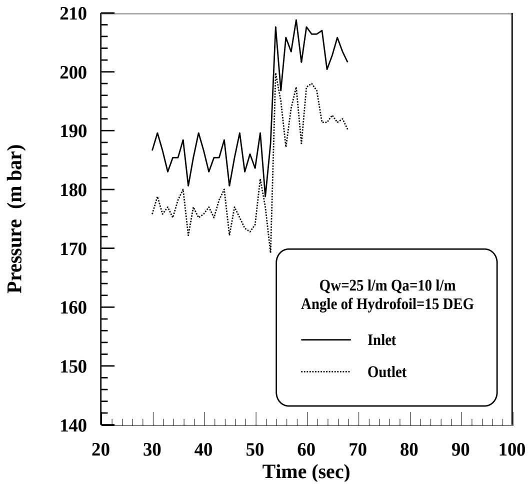


Figure (13) Effect of Time evolution of pressure obtained by experiment (Q_w=25, Q_a=10 and α=15°)

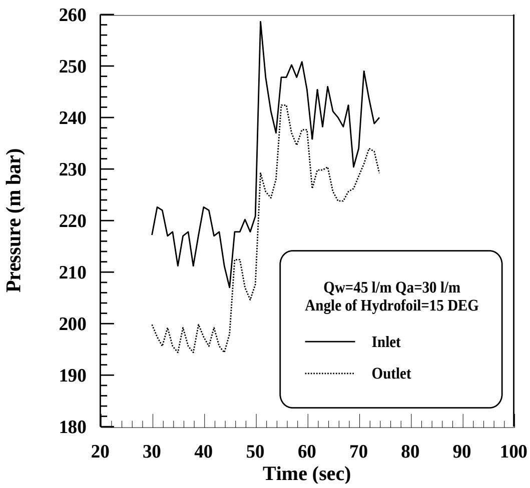


Figure (14) Effect of Time evolution of pressure obtained by experiment (Q_w=45, Q_a=30 and α=15°)

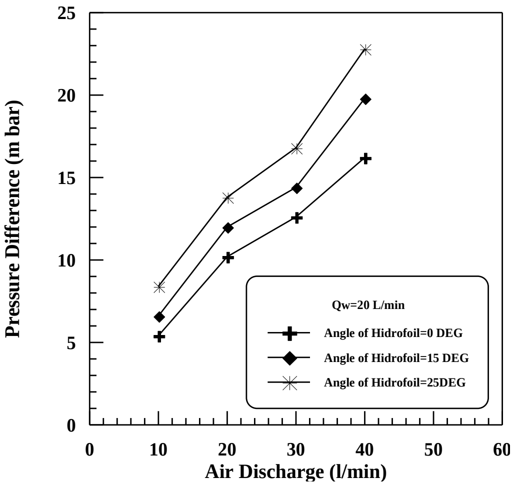


Figure (15) Effect of Air Discharge on Pressure Difference for Various Angles, Qw=20 l/min

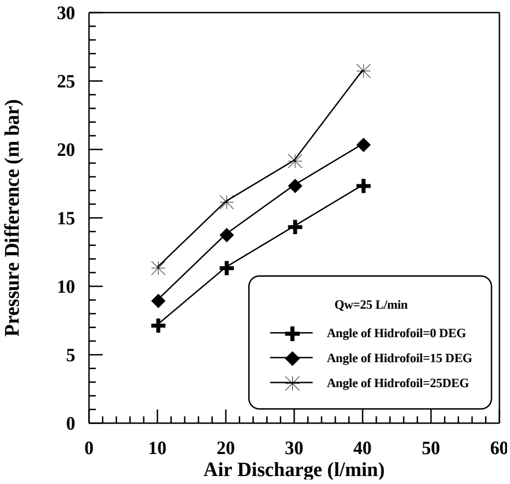


Figure (16) Effect of Air Discharge on Pressure Difference for Various Angles, Qw=25 l/min

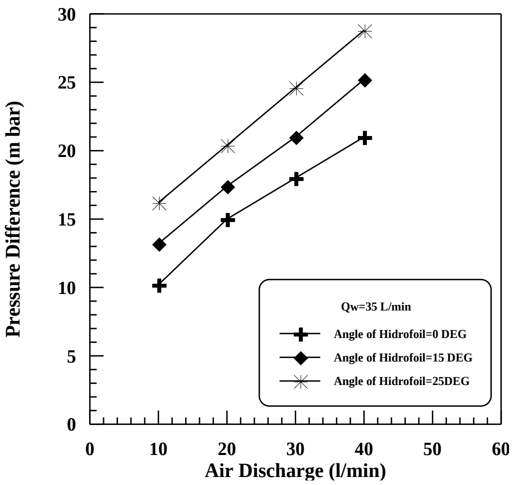


Figure (17) Effect of Air Discharge on Pressure Difference for Various Angles, Qw=35 l/min

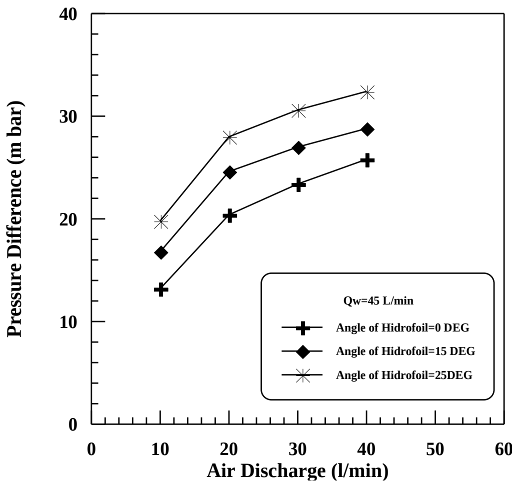


Figure (18) Effect of Air Discharge on Pressure Difference for Various Angles, Qw=45 l/min

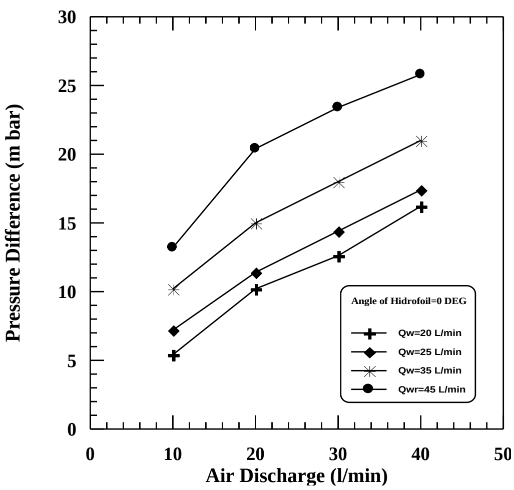


Figure (19) Effect of Air Discharge on Pressure Difference for different water discharge, α=0°

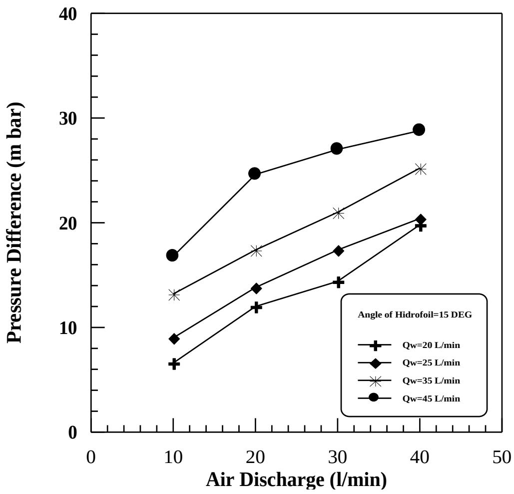


Figure (20) Effect of Air Discharge on Pressure Difference for different water discharge, α=25°

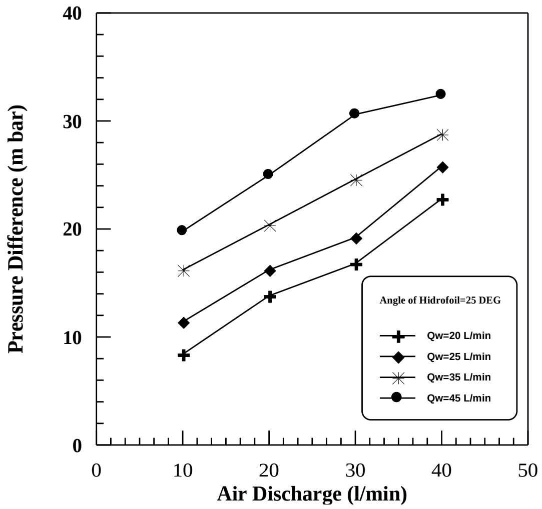


Figure (21) Effect of Air Discharge on Pressure Difference for different water discharge, α=25^{o}

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