A STUDY IN FLOW CHARACTERISTICS OF LIQUID FALLING FILM IN SPIRAL TUBES

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ABSTRACT

A study has been done on experimental investigation of the flow characteristic of water falling film in spiral tubes. The ratio of the surface film velocity to average film velocity (u_s/u_F) is less than 1 for low angle of inclination (4-8 ^{o}) where as it increases as the angle of inclination increases reaching a value of about u_s/u_F = 1.2 . This small value of the velocity ratio is due to the liquid film rotation in coil which causes some deletion.

The film thickness (δ) experimental data correlated well by the following equation:

$$\delta = 0.0048\ Re_F^{0.7064}\ \sin^{-1/3}\theta \qquad (\text{ with } R^2 = 0.959\ )$$

KEYWORDS

Coils, spiral tubes, falling film, hydrodynamic

NOMENCLATURE

a	Constant parameter	**-**
b	Constant parameter	**-**
d	Tube diameter	**L**
D	Coil diameter	**L**
H	Pitch between two turns of coil	**L**
L	Tube length	**L**
Nu_F	Nusselt number based on film thickness ($= \delta(g\rho^2 \sin\theta/\mu^2)^{1/3}$)	**-**
Q_L	Liquid flow rate	**L^3T^{-1}**
Re_F	Reynolds number of film ($=u_F\delta\rho/\mu$)	**-**
t	Time	**T**
u_F	average film velocity ($=\Gamma/\delta\rho$)	**LT^{-1}**
u_s	Surface film velocity	**LT^{-1}**
V_L	Liquid volume holdup in coil	**L^3**
V_T	Total liquid volume filling the coil	**L^3**
μ	Liquid viscosity	**$ML^{-1}T^{-1}$**
δ	film thickness	**L**
ε_L	Liquid holdup	**-**
θ	angle of inclination with the horizontal	**-**
ρ	Liquid density	**ML^{-3}**
Γ	liquid loading per tube perimeter ($=\rho Q_L/\pi d$)	**$ML^{-1}T^{-1}$**

INTRODUCTION

Falling film refers to thin liquid layer flowing under the influence of gravity over inclined or vertical surface. The kind of flow is greatly complicated due to the disturbing of its free surface (unbounded by a solid wall) by various forces. Such forces are gravity and surface tension. They are responsible for the waviness of the free surface. In spiral tubes, additional centrifugal force influences film thickness, surface profile, velocity profile and wave types. Secondary flow develops due to the curvature of the tube. Curved configurations of circular tubes, such as helical or spiral coils are frequently used in heat exchangers, gas liquid contactors & chemical reactors. They have many features; compactness ; high rates of momentum, heat and mass transfer; wide range of contact time; less wetting conditions.[1-6]

Despite varying applications of coils or spiral tubes, literature on the liquid falling film is rather scanty. Literature review suggested that the analysis of the flow characteristics of liquid falling film in spiral tubes is carried out by using the following dimensionless groups equation of the following form.[1,2,4]

$$Nu_F = a\, Re_F^{\,b} \qquad \ldots\ldots\ldots\ldots (1)$$

where $Nu_F = \delta(g\rho^2 \sin\theta/\mu^2)^{1/3}$(Nusselt number based on film thickness), $Re_F = u_F\delta\rho/\mu$ (Reynolds number of film),$u_F = \Gamma/\delta\rho$(average film velocity), δ=film thickness, θ=angle of inclination with the horizontal, Γ=liquid loading per tube perimeter ($\rho Q_L/\pi\, d$).

The purpose of the present study is to investigate experimentally the effect of coil parameters (curvature or coil diameter (D), pitch between two turns (H) or the angle of inclination θ), tube diameter (d) and liquid flowrate (Q_L) on the falling film hydrodynamics.

EXPERIMENTAL WORK

The schematic diagram of the experimental setup is shown in Figure (1). Detailed dimensions of the coils used in the experiments are given in Table (1).

Experiments have been conducted to measure liquid holdup (ε_L) and the surface film velocity (u_s) at different water flowrates (Q_L) and different coil parameters (curvature or coil diameter (D), pitch between two turns (H) or the angle of inclination θ (Table (2)), & tube diameter (d),with constant tube length (L) of 3 meters.

Liquid holdup (ε_L) was measured by sudden shutting of the inlet and outlet valves of the coil (V1& V2). The collected water in the tube (V_L) was measured by a graduated cylinder. Then the liquid holdup was calculated by the following relation:

$$\varepsilon_L = V_L/V_T \qquad \ldots\ldots\ldots\ldots (2)$$

where, V_T is total tube volume equal to $(\pi/4)d^2L$

Liquid film thickness (δ) was calculated from the data of liquid holdup assuming uniform thickness distribution as:

$$\delta = (d/2)\,(\,1 - \,(\,1 - \varepsilon_L\,)^{0.5}\,) \qquad \ldots\ldots\ldots\ldots (3)$$

Surface velocity (u_s) was measured by inserting a small foam particle (about 1 mm diameter) into the flow through a hole near the top entrance. The time required for the particle to travel the distance of the tube length (L=3 m) was measured. The time measurement was repeated many times & taking an average value.

$$u_s = L / t \qquad \ldots\ldots\ldots\ldots (4)$$

where as the average film velocity can be calculated from the following equation.[4]

$$u_F = Q_L / (\pi\, d\, \delta) \qquad \ldots\ldots\ldots\ldots (5)$$

RESULTS AND DISCUSSION

1- Surface Falling Film Velocity(u_s)

Figures (3) to (6) show the effect of film Reynolds number (Re_F) on the ratio of (u_s/u_F) at different coil parameters (curvature or coil diameter (D), pitch between two turns (H) or the angle of inclination θ), & tube diameter(d). The velocity ratio are fairly constant at a given angle of inclination. The value of u_s/u_F less than 1 for low angle of inclination (4-8 ^{o}) where as it increases as the angle of inclination increases reaching a value of about u_s/u_F = 1.2 . This is less than the value published in the literature[4]of u_s/u_F = 1.5 to 2 for circular tube vertical falling film.The reason of this deviation is because of the liquid film rotation in coil which causes some deletion.

2- Film Thickness (δ)

Figures (7) to (10) show the effect of film Reynolds number (Re_F) on the film thickness (δ) calculated by equation (3) at different coil parameters (curvature or coil diameter (D), pitch between two turns (H) or the angle of inclination θ), & tube diameter(d). Film thickness increases with increasing film Reynolds number (Re_F), where as it decreases with increasing the angle of inclination(θ).The trend of the results is in agreement with literature.[1,2,4].

The following equation correlate the experimental data very well:

$$\delta = 0.0048\, Re_F^{0.7064} \sin^{-1/3}\theta \quad \ldots\ldots (6)$$

with $R^2 = 0.959$

Figure (11) show that the experimental results of the film thickness (δ) are of good agreement with the predicted values obtained from the correlation of equation (6).

CONCLUSIONS

The following conclusions can be drawn from the present work:

1. The ratio of the surface film velocity to average film velocity (u_s/u_F) is less than 1 for low angle of inclination (4-8 ^{o}) where as it increases as the angle of inclination increases reaching a value of about $u_s/u_F = 1.2$. This small value of the velocity ratio is due to the liquid film rotation in coil which causes some deletion.
2. The film thickness (δ) experimental data correlated well by the following equation:

   $\delta = 0.0048\, Re_F^{0.7064} \sin^{-1/3}\theta$ (with $R^2 = 0.959$)

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Table (1) Detailed dimensions of the coils used.

Tube diameter (d)	10 , 20 mm
Coil diameter (D)	100 , 200 mm
Pitch (H)	30 , 60 , 90 mm
Tube length (L)	3 m

Table (2) Experimental angle of inclination cases.

D (mm)	H (mm)	'tan θ	θ	'sin θ
100	30	0.15	8.5	0.1478
100	60	0.3	16.7	0.287
100	90	0.45	24.2	0.41
200	30	0.075	4.3	0.075
200	60	0.15	8.5	0.1478
200	90	0.225	12.7	0.22

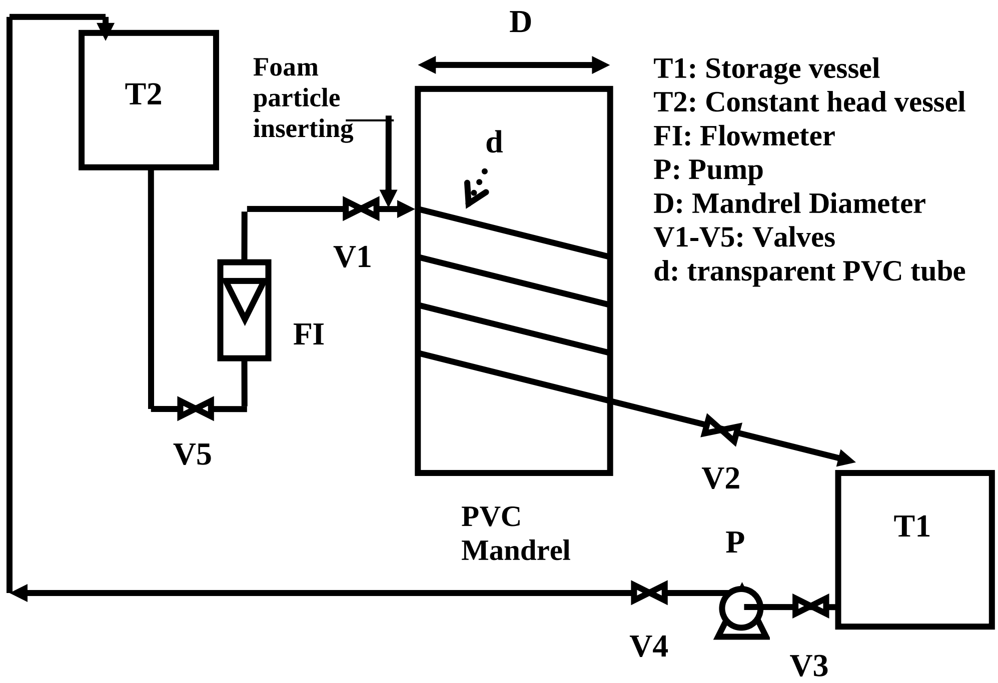

Figure (1) Experimental Setup

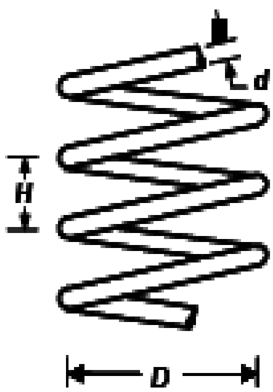

Figure (2) Geometry of the test section.

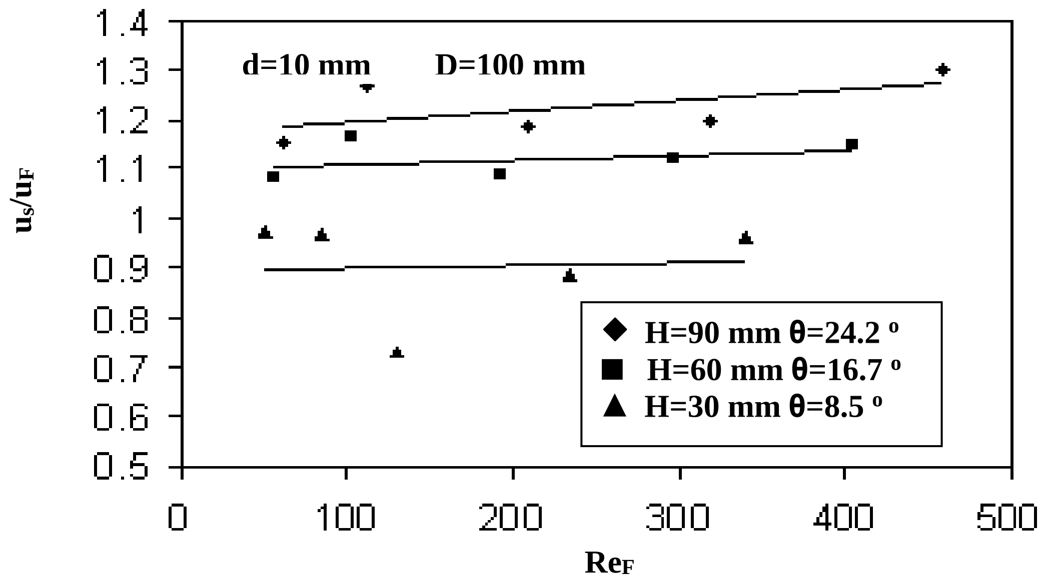

Figure (3) The variation of the ratio of the surface film velocity to average film velocity (u_s/u_F) at different angle of inclination θ, (d=10mm, D=100).

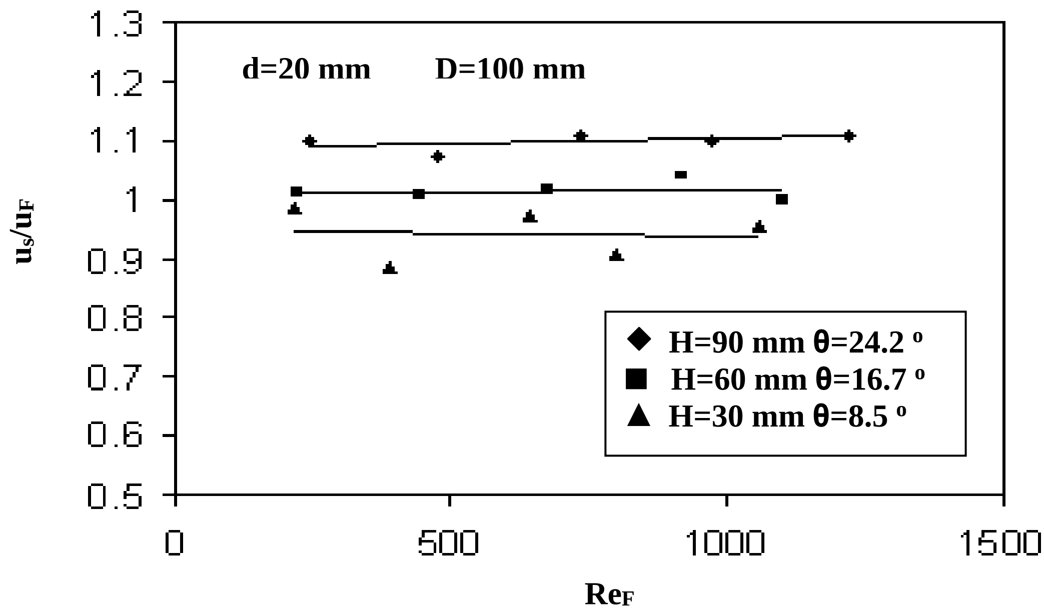

Figure (4) The variation of the ratio of the surface film velocity to average film velocity (u_s/u_F) at different angle of inclination θ,(d=20mm, D=100).

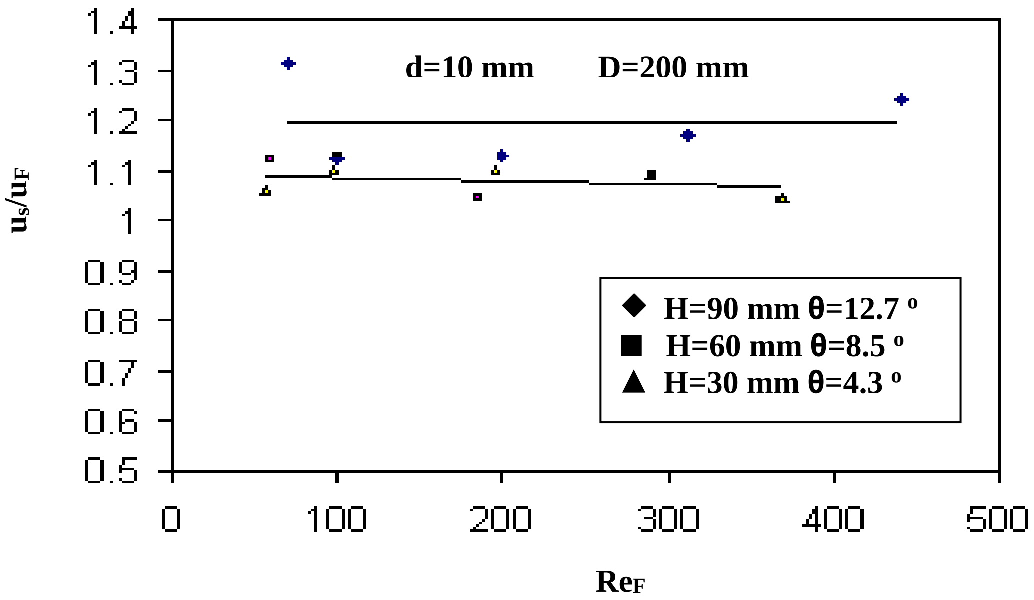

Figure (5) The variation of the ratio of the surface film velocity to average film velocity (u_s/u_F) at different angle of inclination θ,(d=10mm, D=200).

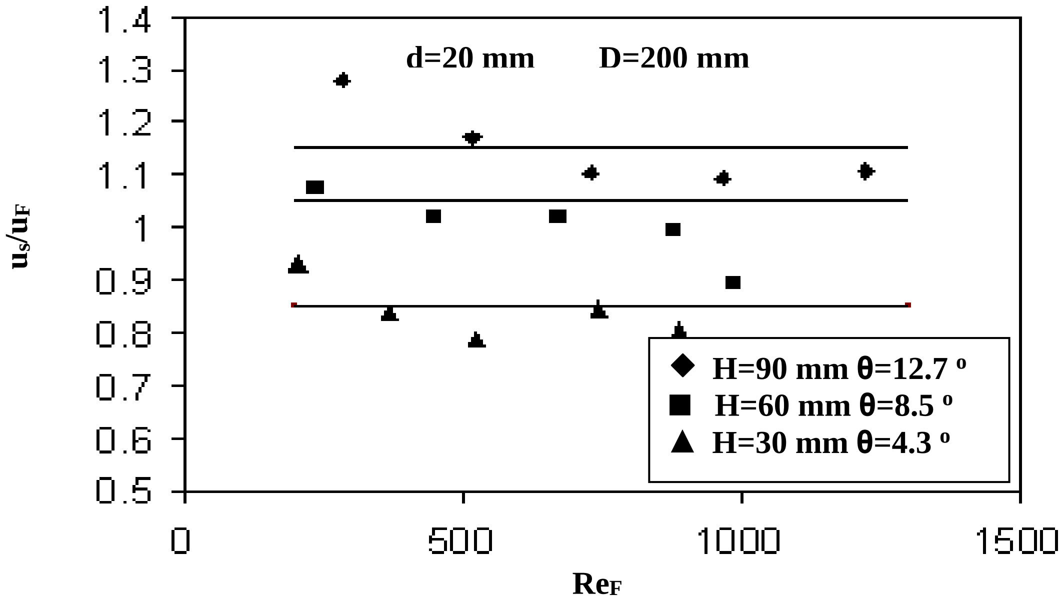

Figure (6) The variation of the ratio of the surface film velocity to average film velocity (u_s/u_F) at different angle of inclination θ,(d=20mm, D=200).

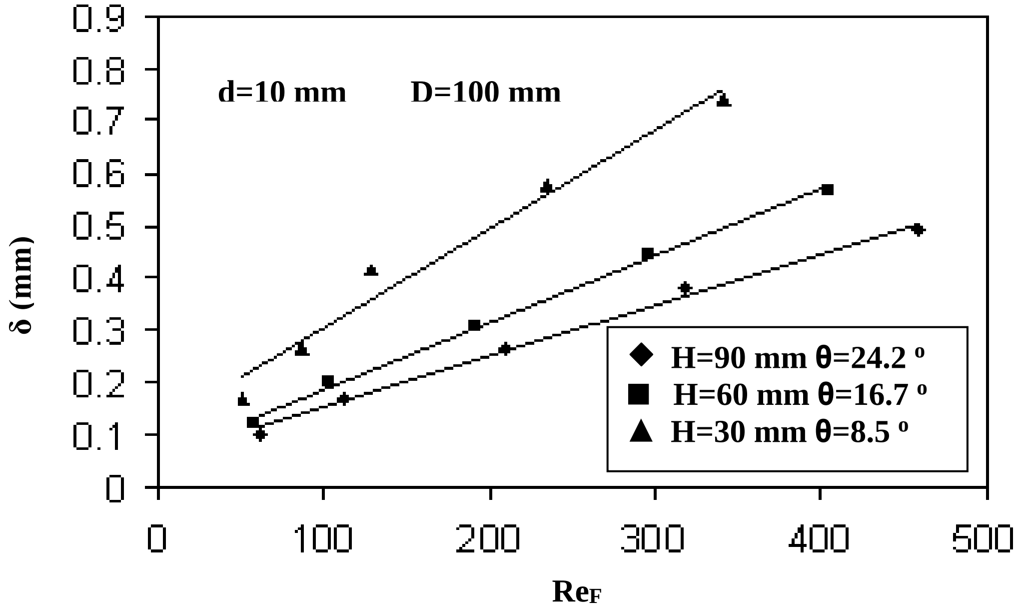

Figure (7) The variation of the film falling thickness (δ) at different angle of inclination θ,(d=10mm, D=100).

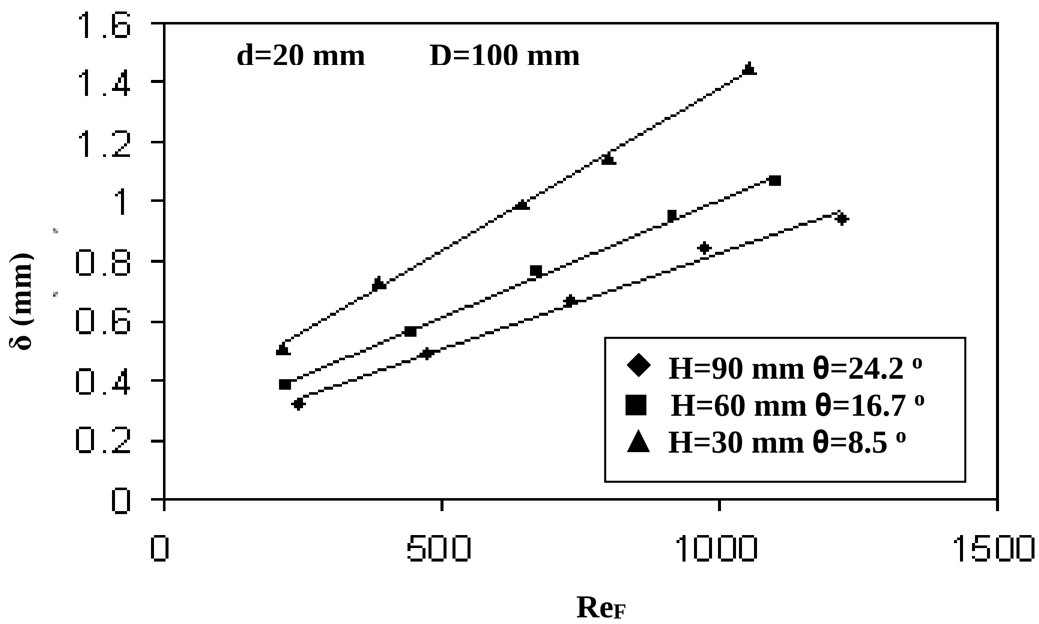

Figure (8) The variation of the film falling thickness (δ) at different angle of inclination θ,(d=20mm, D=100).

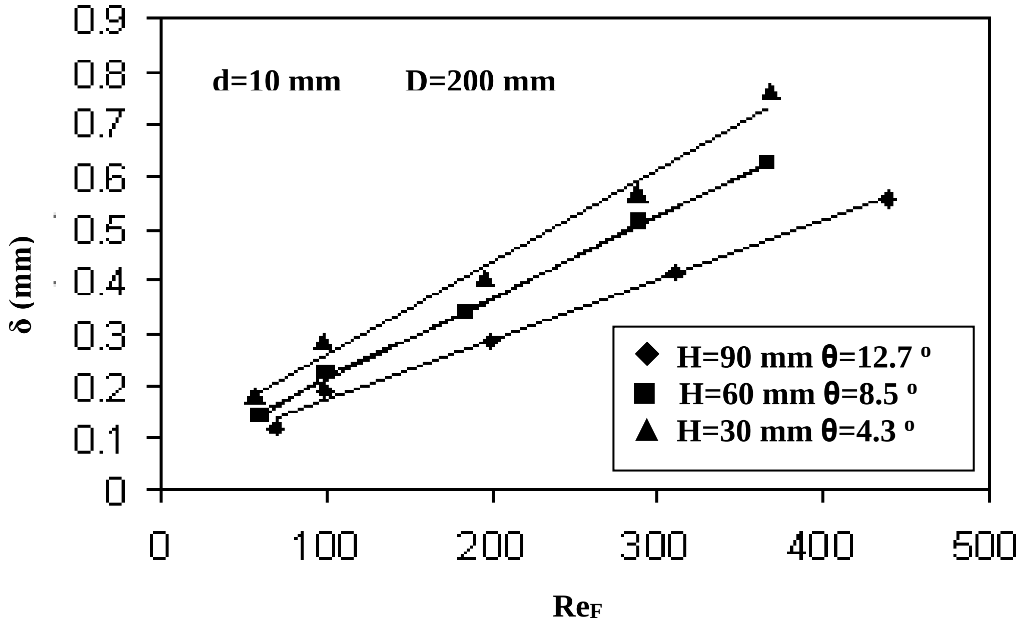

Figure (9) The variation of the film falling thickness (δ) at different angle of inclination θ,(d=10mm, D=200).

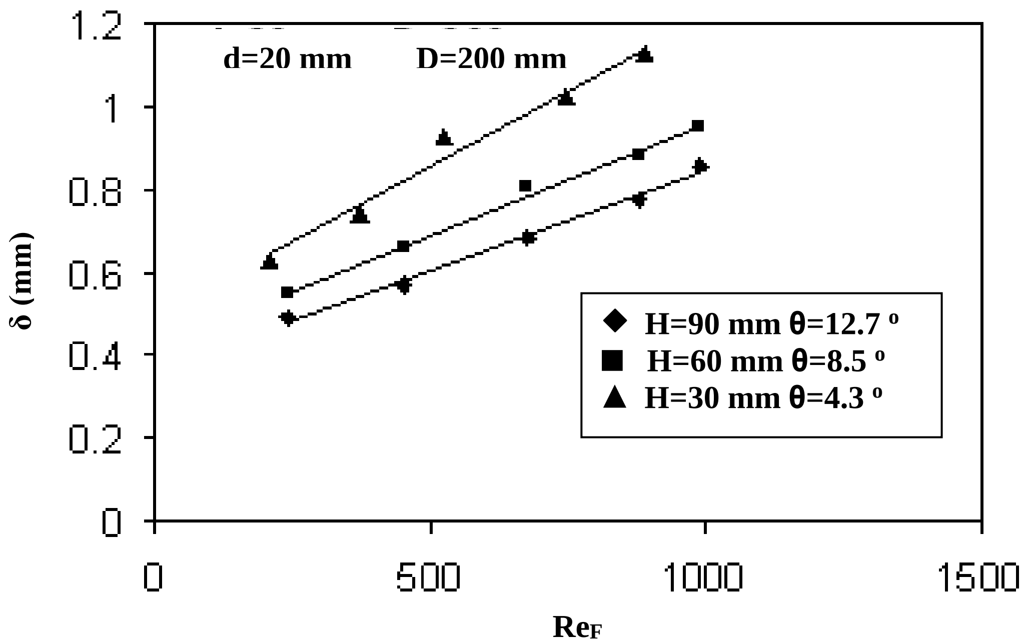

Figure (10) The variation of the film falling thickness (δ) at different angle of inclination θ,(d=20mm, D=200).

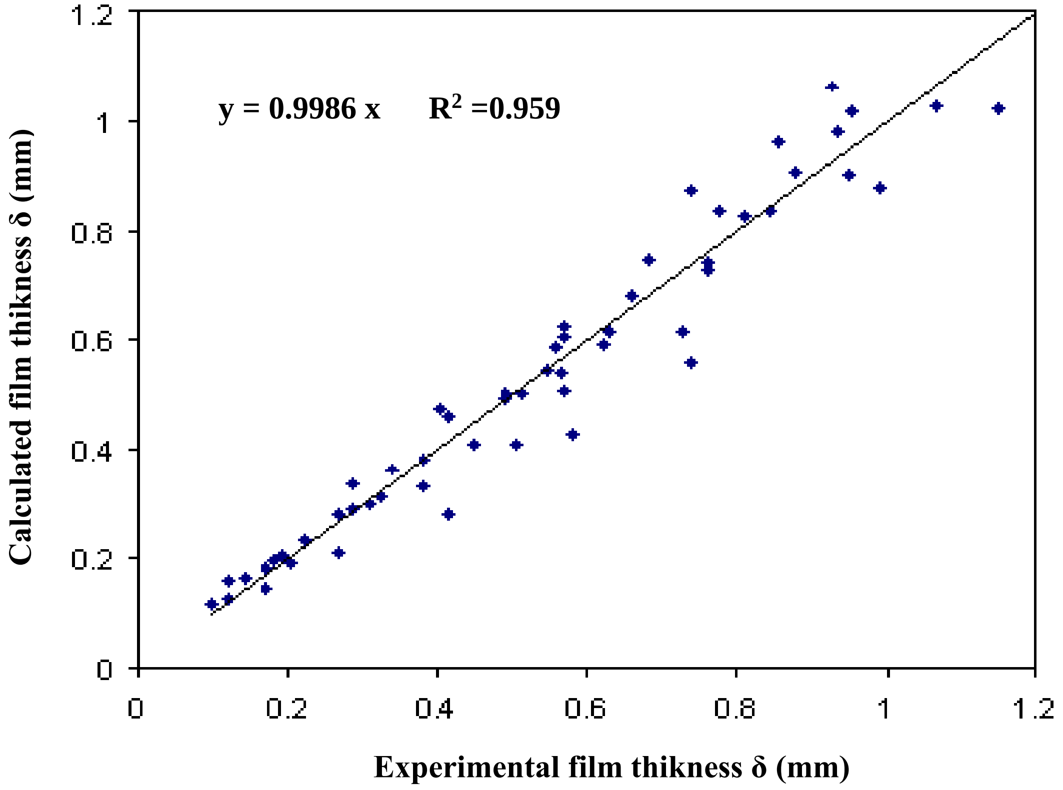

Figure (11) Comparison of the experimental results of the film thickness (δ) with the predicted values obtained from the correlation of equation (6).

دراسة طبيعة جريان الغشاء الساقط في الأنابيب اللولبية

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الخلاصة

تهدف الدراسة الحالية للتعرف تجريبيا على طبيعة جريان الغشاء الساقط في الأنابيب اللولبية. وقد وجد أن نسبة سرعة سطح الغشاء الساقط إلى متوسط سرعة الغشاء **(u_s/u_F)** هي اقل من 1 لزاوية ميلان θ (4-8 درجة) بينما تزداد هذه النسبة مع زيادة لزاوية ميلان لتصل إلى حوالي 1.2 . وهذه القيمة القليلة يمكن إرجاعها إلى دوران غشاء السائل الساقط في الأنبوب اللولبي والذي يسبب تأخير لسرعة سطح الغشاء.

وتم معالجة النتائج التجريبية لسمك الغشاء الساقط والتعبير عليها بصورة جيدة بالمعادلة التالية:

$$\delta = 0.0048\ Re_F^{0.7064} \sin^{-1/3}\theta \quad (R^2 = 0.959 \text{ لمعامل ارتباط})$$

الكلمات الدالة

ملف، انبوب حلزوني، الغشاء المتساقط، خواص هايدروديناميكية