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HEAT TRANSFER IN TURBULENT FLOW ON A HORIZONTAL TUBE FALLING FILM EVAPORATOR. A THEORETICAL .APPROACH•	QUÁ TRÌNH TRUYỀN NHIỆT Ở CHẾ ĐỘ DÒNG CHẢY RỐI TRONG THIẾT BỊ BỐC HƠI MÀNG RƠI KIỂU ỐNG NẰM NGANG: MỘT PHƯƠNG PHÁP TIẾP CẬN LÝ THUYẾT
SUMMARY	TÓM TẮT
A simplified theoretical approach for the prediction of evaporation (no-nucleate boiling) heat transfer coefficient in a horizontal tube falling film is proposed. The correlation is derived from an analysis of the thermal boundary layer under the assumption of turbulent flow regime and taking into account the thermal developing region. A diagram to evaluate h(J.c2fp2gk3 " as a function of Re and Pr is proposed.	Trong bài báo này, chúng tôi đưa ra (đề xuất) một phương pháp tiếp cận lý thuyết đơn giản để tiên đoán hệ số truyền nhiệt bay hơi (không sôi sủi bọt) trong một màng rơi ống nằm ngang. Sự tương quan được rút ra từ phân tích lớp biên nhiệt trong chế độ dòng chảy rối và có tính đến các khu vực đang hình thành nhiệt. Chúng tôi cũng đề xuất một sơ đồ để đánh giá…..theo Re và Pr.
A regresaion analyais of the numerical computations allows us to provide a dimension.lesa formula 1i (J.c2/p2gk3 1 3 = 0.046 Re0• 11P,.0-47 valid in the ranges Re • 150Q-5000 and Pr = 1-5.	Phân tích hồi quy của các tính toán số cho phép chúng ta đưa ra một biểu thức không đơn vị (J.c2/p2gk3 1 3 = 0.046 RE0 • 11P , 0,0-47 có thể áp dụng được trong khoảng Re • 150Q - 5000 và Pr = 1-5 .
SYMBOLS	CÁC KÍ HIỆU
I -acceleration of gravity, m/a2	g- gia tốc trọng trường, m/s^2
hx -Jocal beat transfer coefficient, KJ/m2 °C	h$_x$-hệ số truyền nhiệt cục bộ , KJ/m^2 °C
h -average beat transfer coefficient, K.J/m °C	$\bar{h}$ - hệ số truyền nhiệt trung bình, K.J / m ° C
k -thermal conductivity of liquid K.l/m °C	k- độ dẫn nhiệt của chất lỏng K.l / m ° C
n -numerical constant inDeisaler Eq. (4)	n- hằng số tính toán trong phương trình Deisaler (4)
Nu -NW118lt number	Nu – Số Nusselt
Pr -Prandtl number	Pr- Số Prandtl
Prt -turbulent Prandtl number	Prt - Số Prandtl xáo trộn
R -tube radius, m	R- bán kính ống , m
Re -Reynolds number	Re-Số Reynolds
T - local temperature of the	T - nhiệt độ cục bộ của chất lỏng, °

liquid, °C
Taat -saturation temperature of the liquid, °C
T.., -wall temperature, °C
u -velocity component of the liquid in x direction,m/s v -velocity component of the liquid in y directio m/s x - tangential coordinate, m
X -numerical constant in von Karman Eq. (5)
y -radial coordinate, m

Greek symbols
a - of the liquid, m2/s

r - mass flowrate per axial unit length flowing over one side of the tube,
kgfsm
o -film thickness of the liquid, m
fH -eddy diffusivity for beat transfer, m2/s ,..
fM -eddy diffusivity for momentum tmnsfer, m2/s
p -absolute viscosity of the liquid, kg/m s
11 -kinematic viscosity of the liquid, m2/s
p -density of the liquid, kg/m3

INTRODUCTION

The horizontal tube evaporator (HTE) is characterized by a falling film of the vaporizing solution that flows over the outside of the tube, while the hot fluid (generally condensing steam) flows inside the tube bundle. There is the opposite situation in the falling film long tube evaporator (LTV) where the film of cold fluid flows downward, cocurrently with the vapour, along the inside of the vertical tube, and the condensation takes place on the outside.

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During the last few years, indUJtrial interest in HTE has been increuing due to ita higher heat transfer coefficient compared with the conventional evaporators.

HTE can find application in the vapour compreuion or multiple effect processes for the concentJation of solutions with non volatile components. Particular interest for HTE bas been expressed in the desalination field, where the horizontal tube multiple effect process appears to be very promising. In fact, it is possible to anange a large number of effects in a vertical pattern, removing the problems arising from the large number of pumps, one for each effect, typical of the conventional horizontal arrange- ment of LTV evaporators. Other fields of application are the refrigeration systems and, more recently, the Ocean Thermal Energy Convenion (OTEC) power plants. The main problem in the design of the HTE is the computa- tion of the beat t:ransfer coefficient, due to the limita of the theoretical analysis whose agreement with experimental data has been verified at Reynolds numbers lower than tboae of indUJtrial interest.

The paper of Solan and Zfati [1) shows the solution for the film thickness and heat transfer rate obtained by a Karman-Poblhausen analysis and by a local similarity technique. The laminar theory proposed is in good agreement with the experiments up to Re = 600. An

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analysis substantially similar to that of Solan and Zfati for the laminar falling film flow and heat transfer characteristics is presented by Rogers [2]. One of the main dif.ferences is a simplification of the diffetential equation that allows him to provide a closed-form analyti<;alsolution at the sacrifice of some accuracy.

The theoretical analysis of Moalem and Sideman [3] is based on the integration of dimensionless continuity, momentum and energy equations in a laminar flow regime. The film side and the overall heat-transfer coeffi- cient are evaluated and compared with limited available experimental data. The conclusions of the authors are that the lamin.S theory yields coefficients which are some 50% of those derived from expenmental measurements.

Lorenz and Yung [4] have developed a semi-empirical model of combined boiling and evaporation of liquid films on horizontal tube using the correla- tions proposed by Chun and Seban (5) for vertical tubes and the experi- mental data of Fletcher et al. [7,8] and Liu [9]. Similarly Owens [6] has proposed laminar and turbulent relations obtained by the use of the Chun and Seban [5] formula to correlate the experimental data of Fletcher [7,8], 'Liu [9] and Parken and Fletcher [10]. Although the same dimensionless formula and the data of the same experimenters are utilized, the two papers provide correlations that are not in agreement as far as the dependence from the Reynolds number is concerned (see

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Fig. 3).
Experimental data and related empirical correlations have been proposed by Slesarenk.o [11], Berezin et al. [12], and Putilin and Podberezney (13]. Also in these cases a wide range can be noted as far as the dependence of the heat transfer coefficient from Reynolds and Prandtl numbers is con- cerned. In our opinion, the scattering of the experimental data of various authors, amplified by the presence of the nucleate boiling phenomenon, makes every empirical approach unreliable and probably can explain the disagreement among these kinds of heat transfer correlations.

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In this paper a simplified theoretical approach for the prediction of evaporation (no-nucleate boiling) heat transfer coefficient in a horizontal tube falling film is proposed.

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The correlation is derived from an analysis of the thermal boundary layer under the assumption of turbulent flow regime as in the Dukler [14] approach for vertical long tube falling film, but differently from his work, the thermal developing region is taken into account, due to the short run of the vaporizing liquid on the tube. The turbulent model is at variance with the method recently proposed by Parken and Fletcher [15] based on the 888Umption of laminar and steady flow. This hypothesis cannot be accepted due to the high values of the Reynolds number (300(}-5000)

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investigated. As a matter of fact the experimental values of the local coefficient found by the authors are systematically in excess with reference to their theoretical predictions. This fact supports the assumption of turbulent now regime.	[redacted]
A schematic sketch of falling film flow on a horizontal tube is shown in Fig.1. Fia. 1. Horizontal tube fallint lilm. A. ssuming that the pressure gradient is negligible and that the local rectangular coordinates may be used, due to the small thickness of film, the continuity, momentum and energy equations for turbulent fiow are:	[redacted]
where the second order and the viscous dissipation terms have been neglected.	[redacted]
At. in the paper of Lorenz and Yung [4] we consider the tube "unwrapped" to form a vertical surface, neglecting the component v of the local velocity. This implies a constant thickness of the film along x and a fully developed turbulent velocity profile. At. a consequence the system (Eq. (1)) is reduced to	[redacted]