An Experimental Study of the Temperature Distribution In a Horizontal Refrigerant 12 Evaporator Fitted with Twisted Tapes

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AN EXPERIMENTAL STUDY OF THE TEMPERATURE DISTRIBUTION IN A HORIZONTAL REFRIGERANT 12 EVAPORATOR FITTED WITH TWISTED TAPES

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1. INTRODUCTION

Augmentation of heat transfer rates has been one of the principal aims of heat equipment designers. Considerable investigations /1,2,3/ were carried out in the past to maximise heat transfer rates, and are still continuing in this direction /4,5/. One of the techniques adopted to meet this objective consists of inserting objects, called generally 'turbulence promoters', inside fluid flow passages, and it has been reported by many investigators /6,7,8/ that such a technique yields heat transfer coefficients several times higher than those obtainable in a plain tube. It was also observed that the use of turbulence promoters always increased the pressure losses in the system.

A review of literature indicates that the majority of work done in the area of heat transfer augmentation pertains to nonboiling systems. Literature on swirl flow boiling, and more so on refrigerants, is scanty. Studies of temperature variations are also generally missing, while the heat transfer and pressure drop behaviour have been extensively reported. The temperature is the parameter which is of prime concern in a refrigerant evaporator and its behaviour is expected to represent the heat transfer mechanism also. Hence its study appears to be an important step in understanding its performance. This paper briefly reports the results of such an investigation done in a horizontal refrigerant 12 stainless steel evaporator.

2. EXPERIMENTAL FACILITY

The experimental facility consisted of test section - a round stainless steel tube, 10mm in internal diameter, 12.94mm in outer diameter and 2.1 meters long. It was heated by passing regulated alternating current through the wall of the tube. Any desired vapour quality at the test section inlet was obtained with the help of a preheater located ahead of the test section. Wall temperatures of the test evaporator tube were measured at the top, side and bottom points of the tube with the help of thirty copper-constantan thermocouples spot welded at the outer surface at a regular distance of 200mm. The refrigerant temperatures and pressures at the test section inlet and outlet were also measured.

Four stainless steel twisted tapes were used as the swirl generators (turbulence promoters) which were snugly fitted inside the tube. The data were collected and analyzed in the following range of operating parameters:

(i)	Heat flux, q	8, 10.7 and 13.6, kw/m^2
(ii)	Refrigerant mass velocity, G	7.0 (10^5) to 14.0 (10^5) (five values), $kg/hr\text{-}m^2$

(iii) Twist ratio*, y, of the tapes — 3.76, 5.58, 7.37, 10.15

(iv) Vapor quality, x — 0.30 to 0.75

(v) Test section pressure, p — 138 to 166, kPa

3. RESULTS AND DISCUSSIONS

Earlier studies on two-phase flow boiling in a horizontal tube reported a considerable fluctuation in wall temperatures /9,10/. This suggests that the two-phase boiling flow is highly unstabilized phenomenon with large flow fluctuation. In the present work, in which a twisted tape was used to create swirl in the flow, it was considered desirable to investigate the effect of introducing the tapes on tube-wall temperatures and to find whether the tape has any effect on stabilizing the flow.

Variation of inside wall temperatures-general trends. Figures 1,2,3 and 4 show few typical curves of the axial variation of top, side and bottom wall temperatures with length. Each of the figures has been drawn for the all four twist ratios and the pain flow as well, at a constant heat flux and mass velocity and nearly same range of vapor quality. Figures 1 and 2 show the wall temperatures for the same heat flux of 10700 w/m^2 and refrigerant mass velocity of $8.5x10^5$ $kg/hr-m^2$, but in different vapor quality ranges of 0.288 to 0.501 and 0.530 to 0.744 respectively. Similarly, Figures 3 and 4 have been drawn for another heat flux of 13600 w/m^2, but at the same mass velocity of $8.5x10^5$ $kg/hr-m^2$ and in different ranges of vapor quality. A general observation in all these four figures is that the three ktemperature lines for the top, side and bottom of the tube cross one another not only in plain flow but also in swirl flow. Further, no regular pattern of variation in either of top, side or bottom wall temperatures is visible suggesting that in the entire range of boiling, the swirl flow phenomenon is as unstabilized as the plain flow boiling.

Variation of wall temperatures. A general study of the variation of wall temperatures in figures 1 through 4 indicates that both the heat flux and twist ratio, and also the vapor quality have considerable effect on wall temperatures. If, the trend of curves in figure 1, which has been drawn for a heat flux of 10700 w/m^2 and a mass velocity of 8.5 (10^5) $kg/hr-m^2$, is observed it is found that (i) temperature generally drops as the refrigerant gradually evaporates along the length of tube, (ii) wall temperatures at twist ratios y = 3.76 and 5.58 are lower than that at other twist ratios, and (iii) it is difficult to distinguish between the top, bottom and side wall temperature as to which one is generally the lowest among the three.

The uniformity of top, side and bottom temperatures in figures 1 and 2 show that annular flow pattern exists throughout the test-length in all cases. However, as the heat flux is increased, figure 3, the flow pattern in plain flow appears to be separated upto the test location number 5. The liquid film tends to rise and wet the top surface also when the twisted tape is inserted inside the tube causing swirl flow. This is evident in upper four sets of temperature distribution curves in figure 3. Figure 4 is drawn for the same heat flux and mass velocity as in figure 3 but at higher inlet vapor qualities. In plain flow, the flow is separated probably due to the reason that high heat flux and lower fraction of liquid mass flowing do not allow a liquid film to form on the total inside periphery of the tube which is required for annular flow. Insertion of twisted tape inside the tube again improves the tendency of the liquid film to rise and wet the entire periphery of the tube wall; this tendency is naturally increased when the twist ratio is decreased.

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*Defined as ratio of half of the pitch of the helix of the tape to the inside tube diameter.

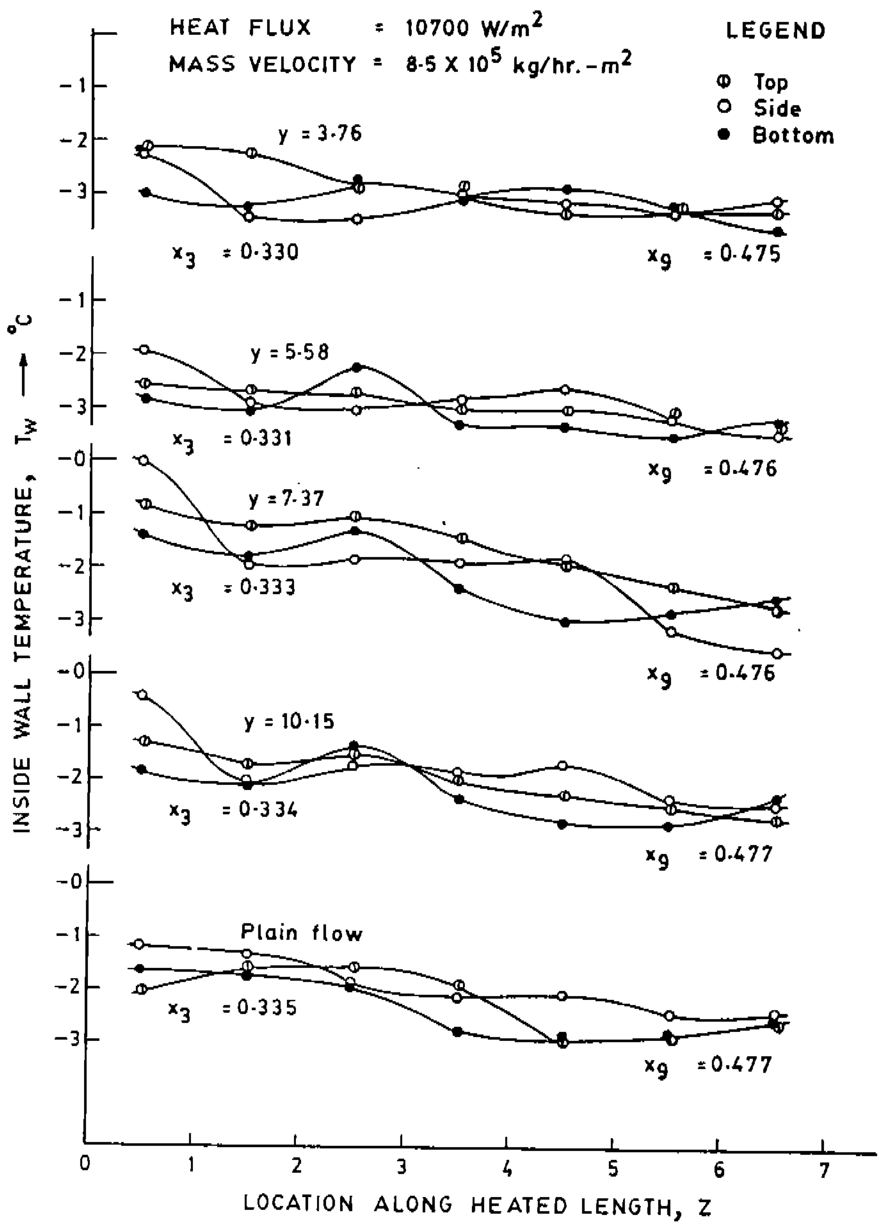

Fig. 1 Variation of top, side and bottom wall temperatures along the test section length.

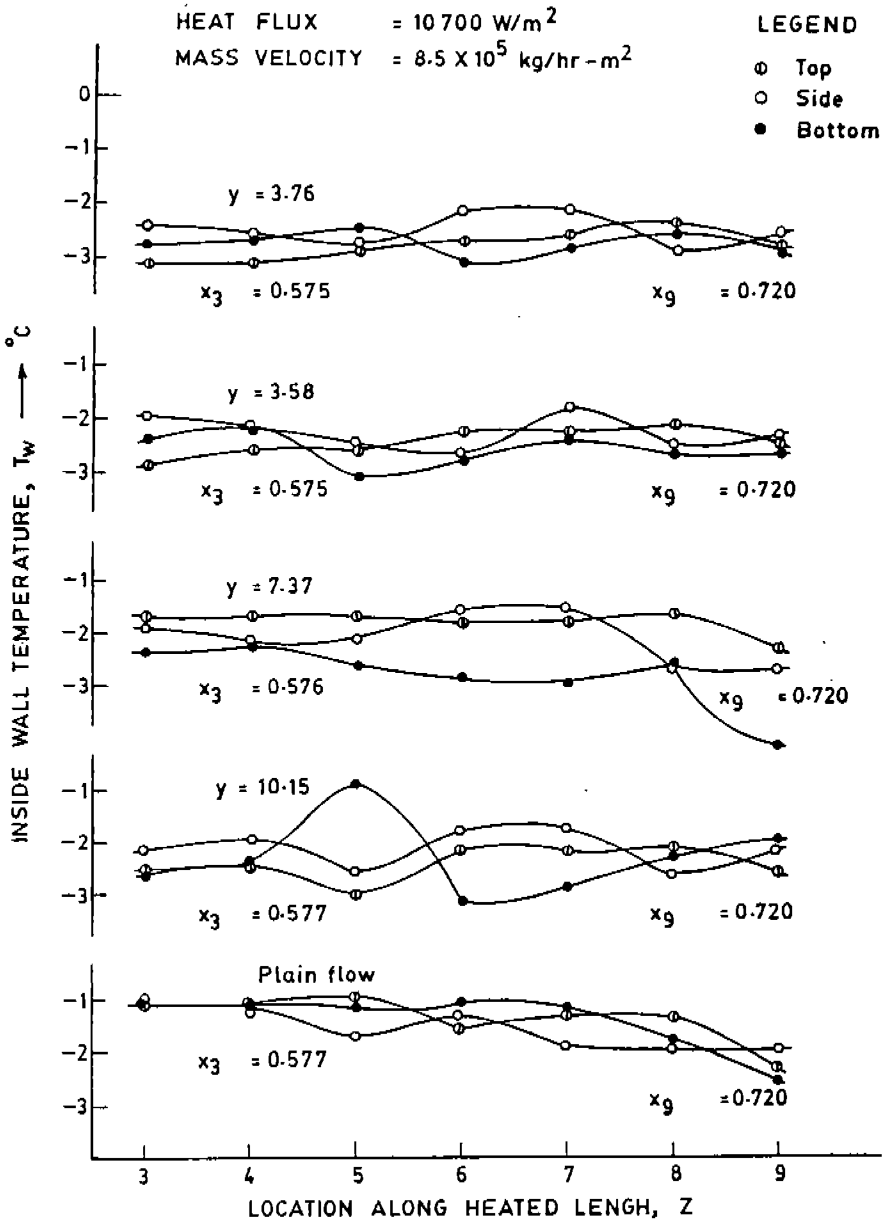

Fig. 2 Variation of top, side and bottom wall temperatures along the test section length.

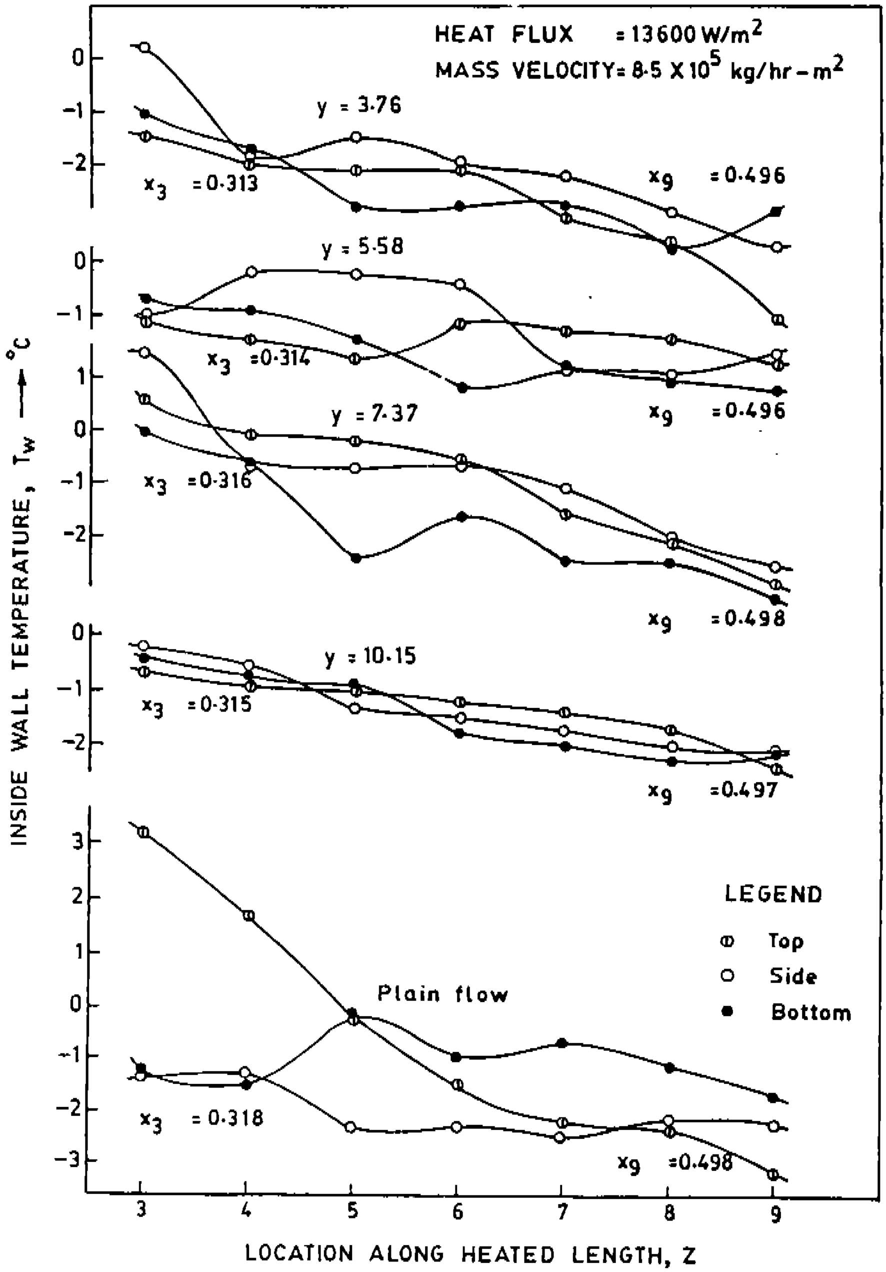

Fig. 3 Variation of top, side and bottom wall temperature along the test section length.

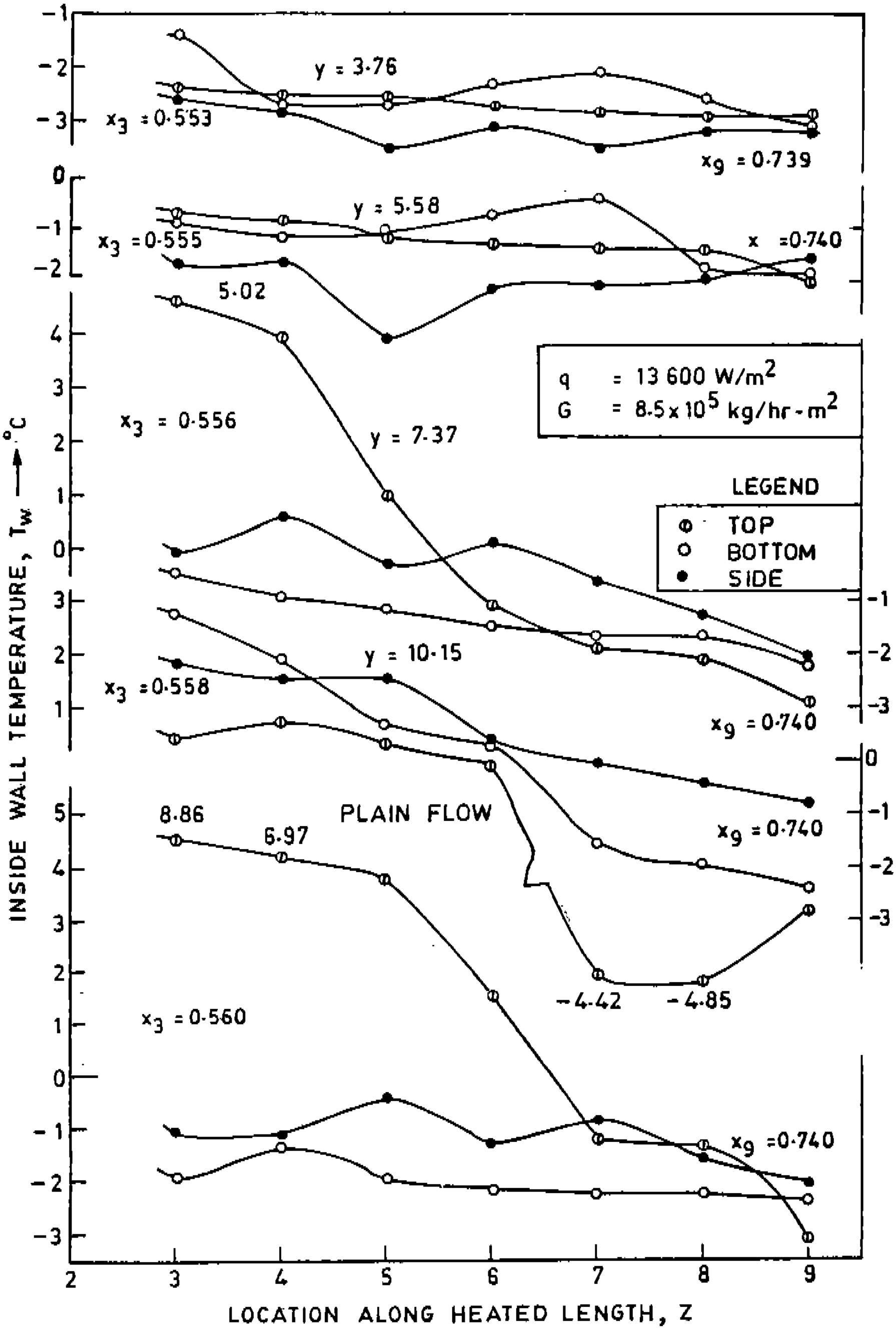

Fig. 4 Variation of top, side and bottom wall temperature along the test section length.

4. CONCLUSIONS

The following general inferences have been drawn from the pattern of wall temperatures observed in this investigation -

i) The tube top, side and bottom wall temperatures for the swirl and the palin flows vary in a random manner.

ii) The top, side and bottom wall temperature lines have been found to cross each other suggesting mostly an annular flow pattern and an instability of the liquid film inside the tube.

iii) The nature of the liquid film at the walls in swirl flow depends on the combination of heat flux, mass velocity, twist ratio and vapor quality values. Lower twist ratios, 3.76 and 5.58, were found to yield a better uniformity of top, side and bottom wall temperatures.

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SUMMARY

This paper describes the experiments measurements of swirl flow boiling inside a horizontal tube. The experimental data is presented and discussed.

The experimental facility consisted of a round stainless steel tube, 10 mm ID, twelve 94 mm OD and two 1 meter long. It was heated by passing alternating current through the wall tube. Four stainless steel twisted tapes were used as swirl generators. Wall temperatures were measured at the top, side and bottom points of the tube.

The following conclusions were drawn: (1) the tube top, side and bottom wall temperatures for the swirl and the non-swirl flow vary in a random manner, (2) the top, side and bottom wall temperature lines have been found to cross each other, suggesting mostly an annular flow pattern and an instability of the liquid film inside the tube and (3) the nature of the liquid film at the tube wall in swirl flow depends on the combination of heat flux, mass velocity, twist ratio and vapor quality values. Lower twist ratios were found to yield better uniformity of top, side and bottom wall temperatures.

RESUME

Le document décrit les données relevées lors des experiences concernant le flux bouillonnant à l'intèrieur d'un tube horizontal. Les données expérimentales sont présentées et discutées.

L'installation esperimentale était composée d'un tube en acier inoxidable, 10 mm ID, douze tubes de 12 mm OD et de deux tubes de un mètre de long. Celle ci était chauffée en faisant passer de courant alternatif à travers la paroi du tube. Quatre rubans d'acier inoxidable tordus étaient utilisés comme générateurs de remous. Les températures de la paroi ont été prises, au sommet, sur les côtés, et au fond du tube.

Les conclusions suivantes ont pu être tirees:

1. les temperatures au sommet, sur les côtés et au fond du tube pour un flux avec ou sans remous varient sans suivre aucune règle.

2. les repères de températures pris à differents niveaux (sommet, côtés et au fond) de la paroi s'avèrent se superposer, indiquant la plupart du temps un modèle de flux s'annulant et une instabilité du film liquide à l'intèrieur du tube.

3. la nature du film liquide sur le paroi du tube dans le cas de flux à remous dépend de la combinaissn de la chaleur, la viresse de la masse, le rapport de torsion et les valeurs qualitatives de vapeur. De faibles rapports de torsion s'avèrent produire une meilleure uniformité des temperatures de la paroi au sommet, sur les côtés et au fond.