STRUCTURE OF AN ADIABATIC TWO-PHASE TWISTED FLOW IN VARIOUS CHANNELS

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ABSTRACT

Results of visual research of regimes of adiabatic two-phase (air-to-water) flows in various channels with a length-continued twisting (coil tubes, annular channels with spiral wire coiling including tapes having slanting ribs on the surface) are presented at pressure P=0.1…0.3 MPa. At visual research slug, wave, annular, disperse and cord regimes of two-phase flow have been revealed. Two-phase flow regimes and their boundaries in coil tubes, tubes with twisted tape and annular channels can bear significant differences despite similitude of channels. Dependences for calculation of boundary lines of annular and disperse flows are gained. Maps of two-phase flow regimes in such channels are drawn. The main feature of structure of two-phase flow in tubes with twisted tape insert is that the liquid phase part always moves in a form of a stream (a cord) across the central part of a tape which is not an active heat transfer surface. Installation of ribs on a tape under an angle to its axle prevents cord flows on a tape surface.

INTRODUCTION

Two-phase steam-and-fluid flows are presented in variety of production units (flash chambers, condensers, distillers etc.) Despite of a great deal of researches conducted within the given issue, for the present, there is no reliable method of estimation for gas-liquid flow due to two-phase flow complexity, and, in particular, irregular shape of interface between the phases. The main research objective of two-phase flow is flow regime (structure) determination, as well as dynamic parameters of each of the phases which is the most significant for an accurate estimation of liquid resistance and heat loss at boiling and condensing. At this point, classification has been made for the major regimes and numerous maps of regimes of a two-phase flow in straight-line channels are known [1].

There is a keen interest in the structure of two-phase twisted flows. Flows twist in high steam volume can contribute in increase of acritical heat transfer area at boiling on account of liquid phase separation on the surface. Obviously, two-phase twisted flows regimes differ from flows in direct tube. The centrifugal pull produced by centrifugal motion discards to the wall droplets and more massive fluid inclusions from gas stream housed in the centre of a channel. Generally, there are comparatively few works dedicated to the research of two-phase twisted flows regimes.

STRUCTURAL FEATURES OF TWO-PHASE FLOWS IN COIL TUBES

Investigation of two-phase air-to-water stream with downflow in coil tubes is presented in the article [2] in which existence domain of flow slug regime is determined including boundary steam quality ($X>0,8$) whereby transformation from slug regime to annular-dispersed takes place. According to investigation results of boiling cryogenic flux structure in coiling tube [3], flow regimes were subdivided in 3 groups implemented on coil tube length: stratified, stratified flow regime with Leidenfrost effect and disperse regimes. The structure of flow in vertical coil channel essentially depends on the ratio of centrifugal and gravitational forces. In the area of low mass velocities there is a certain similitude between the flow in coil tube and in horizontal or low-inclined direct tube [4]. Secondary flows facilitate more balanced liquid distribution on the perimeter due to dripping on tube wall.

Some parts of the data upon two-phase flow structure have been gained while studying the location of critical heat flux in coiled channels [1]. At low mass velocities and high pressure (more than 16 MPa) as a consequence of gravitation effects, major part of a liquid phase flows across the lower channel line whereas critical heat flux occurs adjacent to the upper line. At high pressure and high mass velocities due to centrifugal forces domination, the liquid is forced to external line of the channel bend and critical heat flux occurs on the internal side line [5]. At low pressures secondary flows cause prevailing impact under which the liquid travels to the internal line of coil tube bend, as a result, critical flux occurs on the external side line. Similar liquid migration to the internal part of a channel was observed while spending visualization research of air-to-water flows in coil tubes [6, 7].

Visual research results of flow regimes (and their boundaries) of adiabatic air-to-water flow (P=0.1…0.3 MPa) in coil tubes (D_e/d=5.19…19.7; d=9.5…12.7 mm) are presented herein [8] at $Re_{mix}<70000$ and more recent research [9] in more high range of regime parameters ($Re_{mix}<180000$, $Re_0=0\div12000$) At visual research of air-to-water structure in coil tubes slug, wave, annular, disperse and cord regimes have been revealed. Some of the flow regimes in coil channels are shown in fig.1

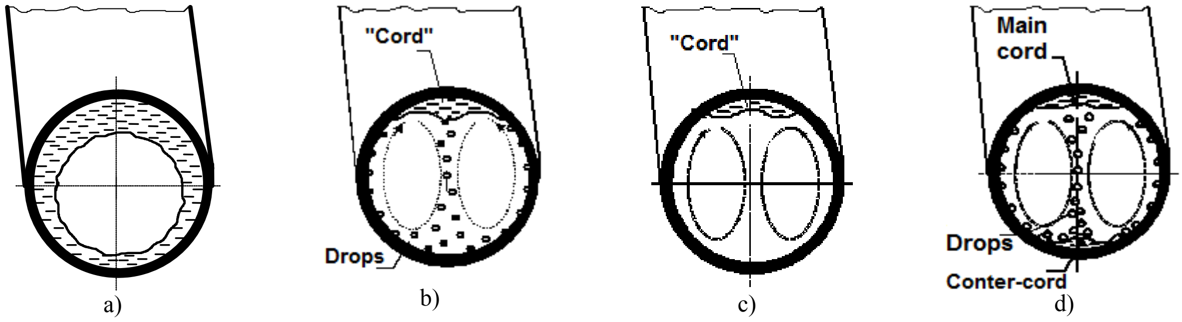


Fig. 1. Pictures of flow regimes of gas-liquid flow in cross-sectional view of coil channel:
a) annular regime; b) disperse regime; c) cord regime ($Re_{mix}>45000$); d) dual-cord regime

At small values of gas content X, gas bubbles movement is observed adjacent to the wall similar to slug regime flow in horizontal tubes: at relatively low velocities the bubbles, in the same manner as in horizontal tubes are located in upstream part of a channel section whereas at velocity increase they are shifted closer to internal line of a channel bend due to centrifugal force increase which considerably higher than gravity acceleration [8, 9].

Increase of volumetric steam quality derives all bubbles fusion and regime similar to wave flow in horizontal tubes is observed. In this case, gas travels in upstream part of a channel section and liquid is in the lower part with evident waves on its surface. With further increase of steam till mass values $X<X_{Ann}$ nearly in all Re_0 range annular regime is observed. In that case liquid stream in a cross section is in the shape of irregular circle; central part is occupied with gas (Fig. 1, a). On the surface of a liquid layer waves are observed which range is decreasing at flow velocity rise. When regimes boundaries are located under the annular flow regime all the regimes are also understood under annular flow regime at which “dry spots” are absent on the wall (for instance, slug regime).

At increasing of gas content up to $X>X_{Ann}$ annular integral liquid film dissolves and disperse regime starts. At this time some part of liquid is not pressed to the external channel periphery, but travels in a form of a “cord” (stream) in internal line of a coil tube bend, similar to the presented in Fig. 1, b. Fluid drops travel across vortex pair streamline: under the influence of centrifugal force and gas dynamic impact they break down from a “cord” and enter the flow core (where they accelerate) and then gravitate on the external side oa a channel bend where from they expelled along the wall to the internal bend line of a channel from the external and over again merge with a “cord” (detailed description of drops travel in coil tubes is presented in the articles as well [7]).

At $X>X_d$ cord regime is observed – all liquid travels in the form of a separate “cord” across the internal arch of a coil tube bend which is similar to presented in Fig. 1, c. The shape of a “cord” in a cross section can vary depending on regime parameters [9].

The observed liquid displacement to the internal arch of coil tube mentioned in the articles [1, 6, 7] is provided by the following principals. Firstly, vortex pairs taking place in coil channel “tighten” the liquid from the wall into a stream (a "cord") to the internal channel line. Secondly, gas traveling with considerably higher velocity impacts on a liquid surface by pressurizing.

In case of steam quality decrease till $X<X_d$ (disperse regime) a "cord" goes wider and thicker, waves range on its surface rises which result in their breakdown as it was mentioned above. At Reynolds number less than some boundary value ($\mathrm{Re}_{\mathrm{mix}}<\mathrm{Re}_{\mathrm{d}}$) disperse regime is not presented and at steam quality increase up to $X>X_{\mathrm{Ann}}$ transition is accomplished straightly from annular flow regime to "cord" form which is in the shape of half moon in this case.

When flow velocity increases (at $\mathrm{Re}_{\mathrm{mix}}>80000$) under the influence of growing centrifugal force in disperse regime the considerable part of fluid is pressed to the external line and being kept there (Fig. 1, d). Thus dual cord regime can be observed: one "cord" (main) travels across the internal line, the other one "rear cord" – across the external line.

For determination of annular regime boundary the following ratios have been obtained:
for horizontal coil tube when $2000<\mathrm{Re}_{\mathrm{mix}}<30000$

$$X_{Ann} = 4 \cdot 10^{-3} Re_{mix}^{0,5}, \tag{1}$$

for horizontal coil tube at $30000<\mathrm{Re}_{\mathrm{mix}}180000$ and vertical at $2000<\mathrm{Re}_{\mathrm{mix}}180000$

$$X_{Ann} = 0{,}96 - 0{,}9999^{Re_{mix}}, \tag{2}$$

For determination of boundary of transformation from disperse regime to flow regime in a form of a "cord" in coil tubes dependency relation has been suggested

$$X_d = \left(0{,}99 + 8 \cdot Re_{mix}^{-18{,}9 \cdot 10^{-6} Re_{mix}}\right) \left[\frac{d}{D_e}\right]^{(10^{-4} Re_{mix})^{-2{,}4}}, \tag{3}$$

As it was mentioned above, disperse flow regime exists only at Reynolds number of mixture which exceed some value of Re_{d} which is estimated with consideration of dependency on relative coiling rate:

$$Re_d = 5220 \cdot (D_e/d)^{0,3}, \tag{4}$$

Thus, we can speak about the fact when $\mathrm{Re}_{\mathrm{mix}}>30000$, regimes boundaries are mainly determined by stream travel velocity and coiling and gravitational forces have weak affect.

All the considered and summarized dependences for regime boundaries determination haven't been obtained in an evident view as $\mathrm{Re}_{\mathrm{mix}}$ value is a function of mass steam quality X. For more evident presentation of flow regimes boundaries, summarized dependences which were obtained in a view of $X=f(\mathrm{Re}_{\mathrm{mix}})$, have been converted depending on $X=f(\mathrm{Re}_0)$ (Fig. 2).

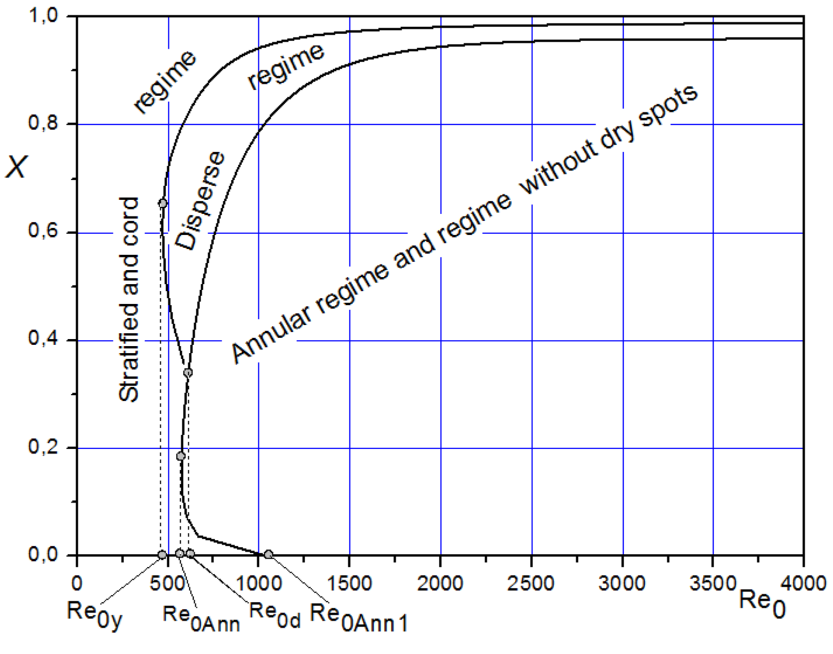


Fig. 2 Generalized picture of $X=f(\mathrm{Re}_{\mathrm{mix}})$ flow regime map in coil channel with $D_e/d=13{,}8$

Re_0 value is not conditional on gas capacity as $(\rho W)_{cm}$ complex is determined only by mass flow and channel sectional area. Conducted research of flow regimes of adiabatic water-to-air stream represents a steam water flow in the condition of heat transfer, thus, at the inlet of evaporator (steam generator) when X=0, Re_0 value is similar to Reynolds number. Following that, flow regimes map presented in the fig. 2 is more practical for usage while forecasting of actual vaporation process development.

On the presented map (Fig. 3) some boundary values of Reynolds numbers are indicated. Re_{0y}, value at which drops carry over occurs from the surface of a fluid "cord" and Re_{0d} value relevant to X_d and X_{Ann} boundaries crossing can be determined at the first approaching with the following dependences:

$$Re_{oy} = 50 + 280 \cdot \lg(D_e/d), \tag{5}$$

$$Re_{od} = 380 \cdot (D_e/d)^{0.08}, \tag{6}$$

Re_{0Ann} value also indicated on the map is compliant with the minimal value of Reynolds number at which the annular regime exists. When $Re_0 < Re_{0Ann}$ due to low travel velocities, there is always a rupture in fluid film and regimes close to wave and stratified are observed in horizontal tubes. As an outcome of experiment shows, $Re_{0Ann} \approx$ (approximately equals to) 500÷600.

Re_{0Ann1} value indicated on fig. 2 represents Reynolds number assumed by the authors at exceeding of which in a channel when minimal gas content occurs, dry spots are not observed any more – movement intensity is high enough and occurring gas bubbles are immediately carried over towards the stream centre. Re_{0Ann1} quantitation value has not been specified yet.

Consequently, on flow regimes map X=f(Re_0) (fig. 2) the five areas can be separated in which the process of mass gas content X increase (evaporation process outline) is performed by various means.

STRUCTURAL FEATURES OF TWO-PHASE FLOWS IN TUBES WITH TWISTED TAPES INSERT

The other method of coiling is represented by installation of twisted inserts in a channel (twisted tapes, feed worms), tangential stream admission, blade swirlers, internal spiral ribs, spiral knurls, wire rolls, etc. The most interest in the given direction is appealed by tubes with insert of twisted tape and feed worm swirlers. Tubes with twisted tapes insert can be considered as an particular case of coiling channels with relatively small tube coiling diameter D and large coiling pitch t. However, two-phase flow structure in such channels has some particular features.

In the paper [10] visual researches of adiabatic two-phase flow (air-to-water) regimes are presented in tubes with twisted tapes insert at p=0.1…0.25 MPa. Experimental section was presented by a glass tube in length of L=800 mm with internal diameter d=18 mm and inserted twisted tape with coiling ranges S/d=2.5…6. Half of a channel was filled with water pumped with a rubber bag to avoid flow irregularity in two halves of a channel and leakage from one half to another due to leakiness of tape adjacency. While visual research of structure of air-to-water flow in tubes with tape insert as well as in coil tubes, slug, wave, annular, disperse and cord regimes have been separated. At low velocities two-phase flows in tube with twisted tape are similar to flows in straight tubes.

At small values of gas content X, gas bubbles movement is observed in tube with tape adjacent to the wall similar to slug regime flow in horizontal tubes: at relatively low velocities the bubbles, as in horizontal tubes are located in upstream part of a channel section (fig. 3) As gas capacity increases, size of bubbles grows and they take elongated shape. Due to spiral motion gas accumulates under the tape and subsequently erupts to the upflow part of a channel in form of bubbles.

← flow direction

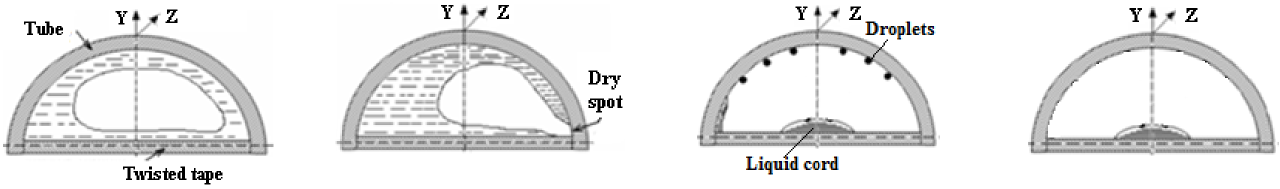
Fig. 3 The picture of slug flow regime in a channel with twisted tape

With increase of volumetric gas content in horizontal channel, fusion of all the bubbles takes place and regime close to wave flow in horizontal tubes is observed (fig. 4). In this case, gas moves in the upper part of a channel section whereas in the lower part liquid is observed with waves on its surface. As can be seen from the above, constant "transfusion" of fluid takes place from tape to the wall of a channel.

← flow direction

Fig. 4 The picture of wave flow regime in a channel with twisted tape insert

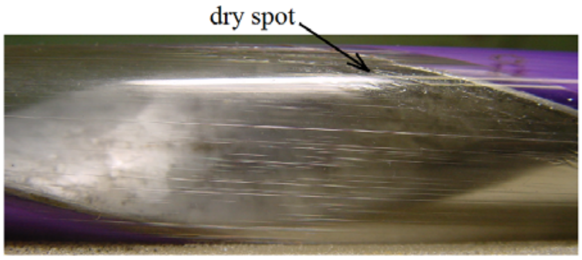
With subsequent increase of gas content up to mass values $X<X_{Ann}$ annular regime is observed. In this case, fluid stream has a shape of irregular ring in a cross section, the central part of which is occupied with gas (fig. 5, a) On the surface of a liquid layer waves are observed and their wave range is decreasing as flow velocity rises.



a) b) c) d)

Fig. 5 Pictures of two-phase flows in a cross section of a tube with twisted tape insert: a) annular regime; b) incomplete annular regime; c) disperse regime with a cord on a tape and the second cord on wall adjacent to the forward edge; d) cord regime

At high flow velocities (Re_{mix}>70000) both in horizontal and vertical tubes with twisted tape even with minor increase of fluid quantity, incomplete annular regime is observed (fig.5,b and fig.6) Dry strip is observed on the downstream by tape aft edge which is conditioned with U-shaped channel section with a tape and definite exhaustion in the given location. Hence, the major part of liquid is accumulated by forward tape edge on the downstream (fig.5, b). Due to irregular liquid distribution to the tube wall and flow of the major part of liquid component across the tape itself ruptures in annular film (dry spots) on tube wall at tape availability occurs with lower gas content than in a tube with no tape. It is also confirmed by the results of other researches [11] – installation of twisted tape in a tube leads to increase of dry spots quantity within two-phase flows at similar regime parameters which in fact, does not result in heat transfer decline at the expense of flow pattern change and intensification of mass-transfer in such channels.



← flow direction

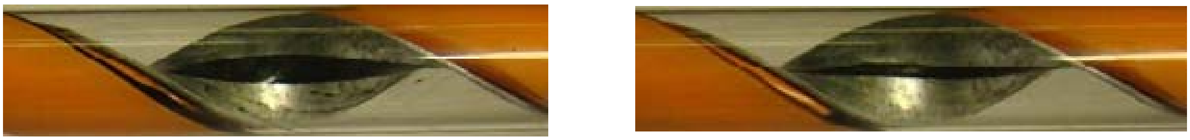
Fig. 6. The picture of incomplete annular flow regime

In case of increase of mass gas content till $X>X_{Ann}$ value, dry spots occur in a film and with subsequent rise of X, separate liquid streamlets and drops start moving across the walls. The regime similar to disperse regime in coil tubes is observed. When it happens, certain part of liquid is not pressed forward to tube wall but travels in a form of a cord across the central part of a tape. When steam quality decreases, a part of liquid can travel in a form of the second cord across the tube wall alongside of a tape forward edge. (fig. 5, c)

In contrast to the picture in coil channels, drops in tubes with twisted tapes mainly appear on film disruption on the tube wall, but not while their separation from a cord. Thus, in tubes with twisted tape insert there is no constant mass transfer between drops and a cord as it takes place in coil channels. It is stipulated by significant rise rate of radial acceleration on a channel radius with tape (on a tape acceleration is close to zero, whereas it can reach up to thousands of mps next to the wall), while the same rise rate is slight in coil tubes.

When $X>X_d$ all the liquid travels on a tape in a form of separate "cord" and cord regime can be observed (fig. 5, d) the same as shown in [8, 9] for coil tubes. Cord shape can be various (fig.7). Dual- cord regime can appear similar to presented on the fig. 6 (c), however, there are no drops but their occasional separation on a wall.

In the paper [10] annular and disperse regimes boundaries were determined on two-phase adiabatic flow in tubes with twisted tape insert. Therewith, under the annular flow regime all the regimes are regarded at which dry spots are absent on the walls and consideration of boundaries of which is particularly important while investigation of boiling crisis. It is mentioned, that annular regime boundaries in tubes with twisted tape insert are close at various positions, in addition, when $Re_{mix}<40000$ they are satisfactorily described with the dependency (2) for coil channels. When $Re_{mix}>40000$ annular regime boundary passes at less values of gas content than for coil tubes, which is conditioned by the presence of a dry spot in wide range X by aft tape edge of a downstream.



a) X=0,85

b) X=0,97

Fig. 7. Cord flows development in tube with twisted tape insert while change of gas content (liquid is colored in dark): G=7 g/s, p=0,13 MPa, S/d=3

Certain difference in annular and particularly disperse regimes is observed when $20000<Re_{mix}<100000$ – boundaries in a vertical channel pass at higher X values which is determined by more regular liquid distribution across the perimeter of a vertical channel section. When $Re_{mix}>100000$ there is minor difference between the boundaries, in other words, there is no impact of gravitational force. An evident impact of spin range in the considered scope has not been detected.

The difference of boundaries in vertical and horizontal channels lies within the limits of experimental uncertainty, hence, dependencies for evaluation for only minimal bounds according to X were determined (on horizontal position) when $Re_{mix}<170000$ [10]:

$$X_{Ann} = 0,76 - 0,98 \cdot 0,9991^{Re_{mix}}, \tag{7}$$

$$X_d = 0,96 - 0,59 \cdot 0,9996^{Re_{mix}}. \tag{8}$$

The given dependencies have asymptotic view and with Reynolds number increase approach the values $X_{Ann}=0.76$ и $X_d=0.96$ respectively that is, at lower values than in coil tubes which is conditioned determined by more regular liquid distribution across the perimeter of coil tubes section.

The map of regimes in view of $X=f(Re_0)$ in tubes with twisted tape insert (fig. 2) is also similar to the map for coil channels. Boundary Reynolds numbers can be determined on the map approximately: $Re_{0y}\approx550$; "triple" point $Re_{0d}\approx630$; $Re_{0Ann}\approx470$. Re_{ok1} value has not been determined quantitatively yet.

STRUCTURAL FEATURES OF TWO-PHASE FLOWS IN TUBES WITH TWISTED TAPES INSERT HAVING RIBS ON THE SURFACE

As it was mentioned above, one of the structural features of two-phase flows in tubes with twisted tape insert is that a part of liquid phase (or all the liquid at high gas content) always moves in a form of stream (a cord) across the central part of tape which does not present an active surface for heat transfer. At boiling this can lead to the increase of a channel length necessary for full flashing and earlier appearance of boiling crisis. For a heat and mass transfer enhancement in tubes with inserted twisted tape at one- and two-phase flows and, in particular, for prevention of cord flows on the tape the ribs can be installed on a tape surface at an angle to its axis. Under the influence of such ribs the part of heat-transfer agent moving along the tape will be displaced immediately to a heat transfer surface of channel into which the twisted tape is inserted [12, 13]. Some alternatives of such devices are shown on fig. 8. The device consists of the twisted tape *1* with ribs *2* discretely have been had on a tape at an angle to its axis in a direction or against a direction of tape twisting (fig. 8). Thus the flow part moving along the central part of a tape will be displaced accordingly either to a lobby or to back (on a flow direction) tape edge of a tape.

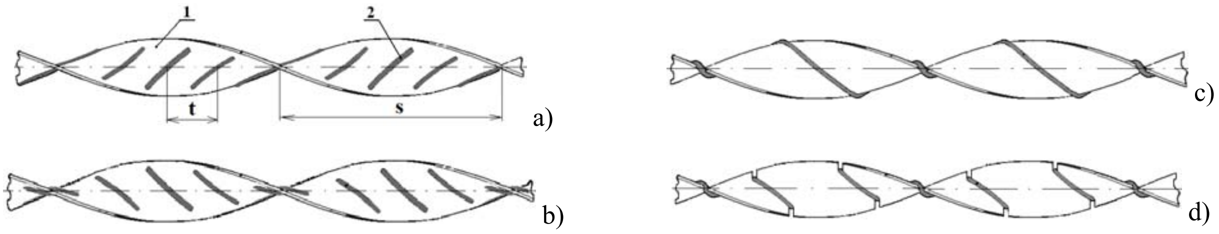
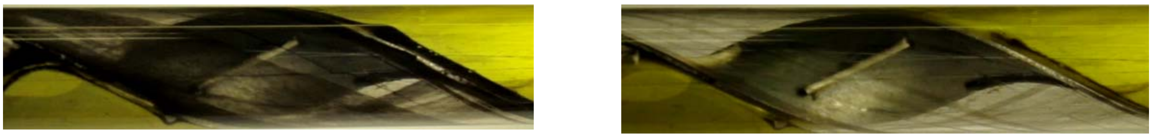


Fig. 8. Twisted tape with ribs on its surface at angle with its axle: a) ribs are arranged against the direction; b) ribs are arranged in the direction of spin; c) ribs in form of a wire coiled on a tape in the direction of its spin with ribs protrusion over side tips of a tape; d) ribs in form of a wire coiled on a tape in the direction of its spin whereas grooves are located on side tips of a tape in which ribs are sunk

The detailed results of visualization of two-phase adiabatic flows structure in tubes with twisted tape inserts having ribs are presented in paper [13]. The main conclusion that any devices shown in fig. 8 promote the absence of a cord flow on a twisted tape. But if ribs are on tape in a twisting direction (as shown in fig. 8, b-d) that liquid flow accumulation is observed on a tube wall near a front tape edge, as well as in a tube with simple twisted tape. However application of the twisted tape with ribs on its surface at an angle 45° to an tape axis against a twisting direction (fig. 8, a) has led to the best results on destruction of cord flow on a tape and to a stability improvement of a annular flow (without dry spots): the liquid cord on a tape also is absent, the accumulation of a liquid at a front tape edge is absent (fig. 9) and at an annular flow the liquid uniformly is arranged on a tube surface that promotes good stability of a continuous liquid film. It is caused by that under the influence of ribs the part of a flow runs from a tape to a front tape edge, shoves off the liquid from it and arranges liquid on a tube surface. Thus the dry spots appear in tubes with such devices at higher value *X*.



a) X=0,91 b) X=0,99

← flow direction

Fig. 9. The photo of two-phase flows at various value *X* in a transparent tube with twisted tape having ribs located against a twisting direction (the liquid is dark coloured, the half of channel is blocked): *G*=0.0145 kg/sec, *p*=0.15 MPa, *s*/*d*=3, *h*=1 mm, *t*=18 mm

STRUCTURAL FEATURES OF TWO-PHASE FLOWS IN ANNULAR CHANNELS WITH LENGTH-CONTINUED STREAM TWISTING

For the research of two-phase flows in annular channels the following working areas were used:
1) with relatively large annular space (5 mm) L=1200 mm, d_1=67 mm, d_2=77 mm with internal glass tube; spin was arranged by coiling on a central wire stem in a soft seal with external diameter equal to gauge of annular space, relational coiling pitch made T/d_{avg}=0.5, 0.75, 1; 2) with relatively narrow annular space (1 mm) – L=330 mm, d_1=16 mm, d_2=18 mm; central stems with coiled wire were used (T/d_{avg}=1.18, 2.94 and 5.88), with external transparent plastic tube.

Only vertical buoyant flow has been investigated. The given channels are similar to spiral coil tubes, but they have cross section of a coil which considerably differs from annular.

At vertical buoyant flow in annular channel with a relatively large annular space on low movement velocities regimes are also observed which are similar to straight horizontal and vertical flows: slug regime and stratified wave regime. In wave regime (fig. 10, a) gas moves in channel upside whereas in lower part – liquid on surface of which high-amplitude waves are observed. When moving velocity increases more regular distribution of fluid appears a cross the section (fig. 10, b) however, its basic weight travels in a lower part and along concave (external) surface. With subsequent increase of velocity, initially, concave wall is watered entirely (on the surface of central stem separate dry spots can be observed), following it buckled wall get watered and annular regime can be observed (fig, 10, c). As gas content increases annular film resolves, on the walls (particularly on concave) separate streamlets and drops are observed, however, basic portion of liquid still travels in the lower part of a coil (fig. 10, d). Drops in annular channel with spin basically occur as a result of stream dispersion but not their carrying over the cord surface, as liquid cord itself always moves here in the lower part of a coil, i.e. with a significant difference from flow picture in other spin channels.

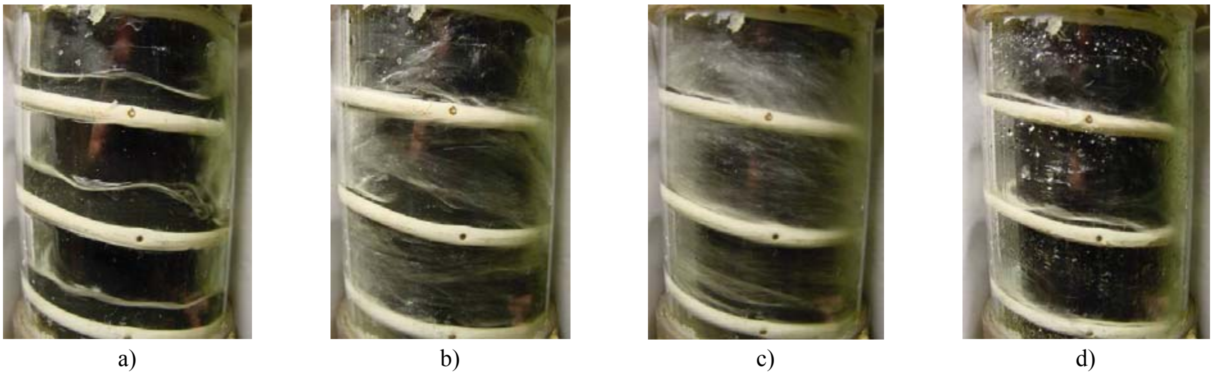

a) b) c) d)

Fig. 10. Pictures of two-phase flow regimes in annular spin channels at d_1=67 mm, d_2=77 mm and T/d_{avg}=0.5:
a) stratified wave regime; b) stratified wave regime at relatively high velocities; c) annular regime;
d) appearance of drops on the walls

According to visual research results, boundary of two-phase annular flow regime has been determined (with no dry spots on concave and buckled surfaces) in annular channel with relatively large annular space. Annular regime boundary takes place at lower gas content in annular channels than in coil tubes as in coil channels with cross section close to annular, the liquid is distributed more regularly across the channel section.

Both in coil channels [8, 9] and in annular spin channels the influence of coil range on annular regime boundary has not been determined yet. Such influence can be demonstrated by the following dependency of an asymptotic view which is similar to the dependency (2):

$$X_{Ann} = 0{,}82 - 0{,}9996^{Re_{mix}}, \tag{9}$$

The structure of two-phase flow in spin annular channels with relatively small annular space (1 mm) has some essential differences: firstly, liquid is distributed more regularly along the coil height and not accumulated in the lower part; secondly, almost all the liquid travels on a concave surface and even at minor gas content there are dry spots on a buckled surface; and thirdly, liquid drops fallen on a buckled surface are slow-moving which gives evidence of shifting under action of centrifugal force of velocity maximum towards the external wall.

This is indirectly verified by the research results on heat transfer in annular channel with annular space of 1 mm [14]. At boiling concave wall temperature changes slightly and high coefficient of heat transfer up to X<0.8…0.9 is observed on it, which is typical of bubble boiling process. On a buckled wall with rise of mass steam X quality, rapid increase of wall temperature is observed which shows the declension of heat transfer conditions. It is caused by liquid phase repulsion under the impact of centrifugal force towards concave surface and displacement of steam to the buckled wall. In this case, bubble boiling on a buckled can be observed only when X<0.1, and in some cases developed bubble boiling area is not presented and heat transfer crisis is observed even at liquid subcooling till saturated temperature.

Thus, in annular spin channels with small annular space the observation of a complete annular regime is improbable – we have observed only full wetting of concave (external) wall. The given fact gives one more evidence of impossibility of adoption of theories and calculated dependencies obtained for channels with relatively large dimensions for the channels with small dimensions.

Regimes boundaries on relatively narrow annular channels have not been determined as practically dry spots are always observed on a buckled (internal) surface.

SUMMARY

Structural features of two-phase flows in various channels with length-continued flow twisting are presented in the article. As visualization shows, the structure of two-phase flows and their boundary lines essentially depends on continued coiling means and cross section shape of a channel. The presented results are obtained for adiabatic (air-to-water) flows, which is connected with the complexity of such researches in conditions of heat transfer and phase transfers. In addition, researches have been conducted at relatively low pressures. Thus, the pictures of flow in real boiling conditions or condensing can differ significantly from the presented ones.

NOMENCLATURE

d – diameter of a channel;
D – coil diameter in a coiling tube;
d_e – equivalent hydraulic diameter of a channel;
D_e – effective diameter of coil tube, $D_e = D\left[1+(T/\pi D)^2\right]$;
d_{avg} – the average diameter of annular channel, $d_{avg}=(d_2+d_1)/2$;
d_1 – diameter of a buckled surface in annular channel;
d_2 – diameter of a concave surface in annular channel;
G – mass flow rate;
L – channel length;
P – pressure;
Re_{mix} – Reynolds number on homogenous mixture parameters, $\mathrm{Re}_{mix} = (\rho W)_{mix} d_e / \mu_{mix}$;
Re_o – Reynolds number on liquid circulation velocity, $\mathrm{Re}_o = (\rho W)_{mix} d_e / \mu'$;

S – bend pitch of a twisted tape through 180°, m;

T – twist pitch on 360° turn;

X – relative mass average flow rate gas content;

μ - dynamic-viscosity coefficient;

$\mu_{\text{см}}$ – mass density of homogenous mixture (according to Ibsen), $\mu_{mix} = 1/\left[\left(1-X\right)/\mu' + X/\mu''\right]$;

ρ - mass density;
$\rho_{\text{см}}$ - mass density of homogenous mixture, $\rho_{mix} = 1/\left[\left(1-X\right)/\rho' + X/\rho''\right]$

Index:
d – disperse regime;
Ann – annular regime;
mix – homogenous mixture;
$^{/}$ – liquid;
$^{//}$ – gas.

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