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RESEARCH PAPER

Experimental Investigation of the Effects of Ring Turbulators on Heat Transfer in Two-Phase Flow

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Abstract

Studies that have been conducted in the field of Fluid Mechanics have shown that two-phase flows are preferred more over single-phase flows as their heat transfer coefficient is higher. In this study, it was aimed to experimentally investigate the effects of a ring-shaped series as a pipe part towards eliminating negative situations in two-phase flow systems. In the experimental study, the test setup consists of a two-phase flow system with forced convection boiling inside a straight horizontal pipe with an internal diameter of 17.6 mm and an external diameter of 25 mm. A heat transfer surface configuration was used during the experiments. In the system, the effects of the part consisting of series of rings as an in-pipe heat transfer improvement element on the flow instabilities were investigated. By selecting the fluid input variable flow rate as a parameter, the effects created by series of rings were examined in constant operational pressure, constant input temperature, constant thermal power and exit limiter conditions. Additionally, the wall temperatures of the pipes and pressure-flow rate changes were examined. According to the results of the experimental study, it was observed that the temperature limits of the "burn-out" forming in the surface-increased test pipe were highly reduced in comparison to the empty pipe. It was determined that, with this, damages to be incurred on the pipe walls were reduced. Moreover, it was observed that, at a certain mass flow rate, as the thermal power increased, the pressure drops also increased. Between the two different pipes that were used, the pipe with the high-pressure drop was the surface-increased pipe. This study aims to examine the experimental effects of ring turbulators as pipe elements in addition to the previously studied turbulator types for eliminating the negative effects in two-phase flow systems. As a result of the experiments, it was observed that the pressure drop increased with the increase of the thermal power at a certain mass flow. Previously used heat transfer when compared with the test results with surface elements, in the two different pipes used, the pipe with a high drop in the pressure was the Pipe-2.

Keywords Two-phase flow · Instability · Oscillation · Heat transfer improvement · Ring turbulator

1 Introduction

Due to the constant reduction of the energy reserves in the world, a number of studies have been carried out to meet the needs of finding alternative energy resources. Some of these studies are those conducted to improve heat transfer. As the heat transfer coefficient of two-phase flows is higher than that of single-phase flows, studies in this field have increased towards meeting the need that increases in time in applications that require high heat flux and industrial activities.

In two-phase systems, there are two types of instability situations as static and dynamic instabilities (Lahey 1980). Flow excursion (Ledinegg) instabilities, flow regime relaxation instabilities, geysering or chugging instabilities and instabilities originating from the terrain that may be formed in offshore oil-well lines may be given examples of static instabilities, while examples of dynamic instabilities include density-wave oscillations, pressure drop oscillations, instabilities related to the flow regime and acoustic instabilities. Amongst these types of instability, the most significant and prevalently studied ones are Ledinegg's instabilities and density-wave instabilities. Although the focal point will be on boiling systems, it should be kept in mind that similar instabilities will also form in condensation systems. While

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the cause of these instabilities may be a sufficient interaction between the inertia of the flow and the compressibility of the two-phase fluid and multiple feedbacks between flow and/or pressure drop and density change in the channel where boiling happens, it may also be just feedback (Yeşilyurt 2015). In this experimental study, by placing ring turbulators inside a horizontal empty pipe, the effects of the part on two-phase flow instabilities were investigated. The experiments were conducted towards investigating the types of oscillations, their forms of emergence and variables affecting instabilities.

In their experimental studies, Stenning and Veziroğlu (1965) determined three types of dynamic instability situations by using the R-11 fluid, and it was stated that the first type of instability named as "density change type instability" occurred as a result of the different movements of fluid waves with high and low density along the channel that was heated.

Kakaç (1994) numerically investigated density change type oscillations with a mathematical model according to two non-linear, functional integral/differential equations, and they used the mathematical data they obtained to explain some physical mechanisms that are the main cause of the formation of density change type oscillations.

Kakaç and Cao (1999) conducted experiments inside a horizontal boiling pipe by using the R-11 working fluid. They stated that pressure drop type oscillations and thermal oscillations were formed. They observed that the amplitudes and periods of the oscillations increased by the increase in the thermal power and input subcooling.

In the study, they conducted on a horizontal pipe regarding horizontal water boiling wave flow oscillations, Karagoz et al. (2008) determined that, in comparison to other dynamic oscillation types, density change type oscillations had lower amplitudes and higher frequencies.

By using four different horizontal flattened copper pipes at the heights of 2 and 3 mm, Quibén and Thome (2007) determined two-phase pressure drop data for boiling flow, and they observed that heat flux did not have a significant effect on two-phase friction pressure drop values. The circular pipe model used for equivalent diameter by Moreno Quibén and Thome was compared to the experimental data obtained for the flattened pipe model, and it was concluded that this model applied for determining the pressure drop values in the flattened pipe was impractical.

Kakaç and Cao (2009) investigated convective two-phase flow instabilities in vertical and horizontal pipe boiling systems. They determined the pressure drop characteristics in stable-state systems with numerical solution equations derived from the drift-flux model. The numerical solutions were determined with the help of an open-ended difference schema, and the numerical solution data were validated with experimental findings. The amplitudes and periods of the oscillations were inversely proportional to the mass flow rate at the initial negative slope point, and the stable-state characteristics determined with the drift-flux model and oscillations were compatible with the experimental results.

Venkatesan et al. (2010) examined the effects of diameter on two-phase pressure drop data in a narrow pipe by using air and water and circular pipes with internal diameters of 0.6, 1.2, 1.7, 2.6 and 3.4 mm. More different and variable forms of flow were observed with smaller pipe diameters. Pressure drop was measured and compared to different existing models such as the homogenous model and the Lockhart-Martinelli model, but it was observed that the existing models were not sufficient in determination of pressure drop for all observed flow regimes. The effect of the flow stratification in the annular regime on the decreasing surface tension was found to be significant. It was observed that the flow regime-based modification approach of the liquid–gas interaction parameter was a highly important method for determining pressure drop in narrow pipes.

In their study, on a flat straight pipe evaporator regarding two-phase flow instabilities, Liang et al. (2010) measured the relationship between pressure drop and mass flow rate with constant heat flux and evaporation pressure. It was determined that density-wave oscillations were observed in almost all mass flow rates, they had low amplitudes, and their periods varied between 1 and 3. The limit initial data of pressure drop type oscillations and thermal oscillations were experimentally obtained, and the test results and limit values of three types of oscillation were determined with a mathematical model. The initial experiment conditions of pressure drop oscillations and thermal oscillations were obtained based on experimental results. Additionally, initial empirical correlations were obtained with the homogenous phase model. The results of their study not only allow a better understanding of two-phase flow instability mechanisms in a cooling system but also may be used for design against serious oscillation problems that may be encountered by a cooling system.

Marchitto et al. (2011) investigated the effects of in-header flow direction on two-phase flow distribution within parallel vertical channels. The objective of their experiments was to understand the main mechanisms of the flow distribution in a two-stage horizontal header to optimize the design of advanced distributors in a compact heat exchanger and flow distribution. In the experiment, it was observed that the phase/mass distribution in the parallel vertical channel was dependent on the effects of the channel/distributor geometry and input conditions.

Omeroglu et al. (2013) examined two-phase flow instabilities in a horizontal pipe system with forced convection boiling of tube inserts consisting of bended stripes and springs. The experiments were conducted by using 7.5 bar system pressure and 24 kw thermal power for 3 dıfferent ınput temperatures to investigate the effects of input subcooling of output restrıctor conditions. Consequently, usage of tube inserts narrowed the unstable zone where oscillations were observed, and oscillation limits were broadened as the effective diameter increased. In addition to these results, it was observed that, as the steps of the inserts in the pipe got smaller, the system became more stable.

In their experimental and theoretical study, Guo et al. (2014) investigated two-phase flow characteristics and density change and pressure drop during heat transfer inside a pipe. It was determined that pressure drop was directly proportional to the increase in thermal power and higher in the long heat transfer line than the short heat transfer line. The increase in pressure drop occurred at a smaller slope angle, and it was observed that steam quality was lower.

In their experimental study, Yeşilyurt. (2015) examined the effects of parts consisting of different spring steps with conical winding as heat transfer improving tube inserts under the conditions of a constant input temperature, constant thermal power and exit limiter in forced convection boiling two-phase flow system in a horizontal straight pipe. As a result, with the increase in minimum point thermal power, the characteristic curve was shifted to the right, and in addition to this, it was observed that, at a certain mass flow rate, pressure drop increased in direct proportion to thermal power. The systems with the minimum and maximum pressure drop were determined for four different experiments conducted in the two-phase zone.

Boiling two-phase flow in small channels exists in various applications in power and process industries (Madhavi et al. 2016). Heat transfer, boiling flow regimes and flow instabilities are some of the important issues related to pressure drop and two-phase flow in dried-out channels. The focus of the study is on boiling pressure drop in two-phase flow in tubes of 19-mm diameter. These tubes are typically used in steam generators. There is a relatively limited experimental database on 19-mm ID tubes. For this reason, in the study, the experimental setup was designed for flow boiling operation in a way that different flow regimes (drying of subcooled water from its pre-heating) would be formed in a steam generator tube in a 19-mm ID tube. The reported results cover a reasonable set of thermal and mass flow conditions as 9–27 kW/m^2 and 2.9–5.9 kg/m^2 s. In the study, existing correlations were assessed against experimental data in terms of pressure drop in a single vertical channel during boiling of water close to atmospheric pressure. A special characteristic of these experiments is the measurement of time-dependent pressures from four points along the channel. Stable-state pressure drop is estimated, and definition of boiling flow regimes is made with temporary characteristics using time series analysis. Experimental data and corresponding results were compared to reported correlations. It was observed that the results were useful for understanding the important access of source of flow in small channels.

In their experimental and numerical study, Karagoz et al. (2017) attempted to increase the rate of heat transfer with a cylindrical turbulator creating a turbulent flow in an exchanger tube. The effects of blade geometry are also examined to investigate the heat transfer rate in experimental tubes. The experiments are carried out in different turbulator ranges (step 1, 2, 3 = 101–216–340 mm) and at varying turbulator angles (α 1, 2, 3 = 0°–45°–90°). The water flow rate in the tube is adjusted at three different ranges to converge towards the desired Reynolds numbers (Re 1, 2, 3 = 6000–11,000–17,000). The effects of the Nusselt number, Reynolds number and friction factor were separately examined. For all experiments, due to the tube inserts that are used, the increases in the Nu number are compared to each other and the straight tube in the relevant profiles. It was concluded that the tube inserts placed into the heat exchanger tube led to a significant increase in the Nu number and energy savings. Amongst different trial numbers, by using the mean value in various Re numbers, the highest Nusselt number was obtained as Sy1 = 101 mm. This way is 24% higher than that in the straight tube. This value for Sy2 = 216 mm and Sy3 = 340 mm was respectively 18.7% and 8.3%. This way, the friction factor according to the results was 0.30, 0.19 and 0.14. The presented study was simulated with the ANSYS Fluent 16 software to analyse flow behaviour and heat transfer properties.

In horizontal components, two-component gas–liquid two-phase slug flow occurs frequently in several industrial applications (Donga 2018). Flow and heat transfer properties are complicated due to intermittent flow structures. The purpose of the study is to show the importance of estimating the heat transfer properties of slug flow. Development of a semi-theoretical heat transfer correlation for two-component two-phase slug flow was based on the Reynolds and Chilton-Colburn analogies. First of all, a comprehensive literature review for the existing databases and an analysis of the heat transfer coefficient correlations for two-component two-phase slug flow was carried out. Afterwards, 500 experimental data and 8 heat transfer correlations were collected. The comparisons and correlations in the collected database showed that none of the correlations could satisfactorily estimate the entire database. The relationship between heat transfer and pressure drop was theoretically examined, and by using the semi-theoretical Reynolds and Chilton-Colburn analogies, experimental results were collected from 16 sources. The comparative analysis provided a broad test condition spectrum and an excellent estimation capacity with the newly developed correlation. The newly developed correlation showed that 91.5% of the data were estimated within a ± 30% error margin with the mean absolute value and 14.0% relative deviation. Additionally, generalization of the new correlation to other two-phase flow regimes was discussed. The newly developed semi-theoretical correlation will be useful to estimate heat transfer coefficients in two-component two-phase flow in horizontal pipes.

The two-phase (liquid and gas) flow distribution at the header of a single-plate heat exchanger was experimentally examined (Xin-Cheng et al. 2018). In the study, the small mass fractions of the liquid phase were considered in the liquification process of natural gas. Liquid and gas flow rates were measured by using optical methods such as PIV/PTV/LIF. The flow distribution of liquid and gas flows was quantified and discussed. The problem of attaching a porous deflector or modifying the input nozzle configuration was studied.

Yadav and Sahu (2019) investigated reports the effect of helical surface disc turbulators (HSDTs) on heat transfer and pressure-drop characteristics in double pipe heat exchanger (DPHE). HSDTs utilized in the annulus region. Tests were conducted by insertion of HSDTs with various operating parameters including three different diameter ratios (DR = do/Di = 0.42, 0.475 and 0.54), three different helix angles (ϕ = 20°, 30° and 40°) and varied range of Reynolds Number (3500–10,500). Results indicate that maximum enhancement was obtained for smallest diameter ratio (DR = 0.42) and helix angle (ϕ = 40°).

Khetib (2021) in this research, numerical study of the effect of curved turbulators on the exergy efficiency of solar collector (SC) with two-phase hybrid nanofluid (TPHN) addressed. The MWCNT-TiO2-water hybrid nanofluid was modelled as two-phase, and the Eulerian-Eulerian model used to model it. Based on the results, an increase in both Re and φ increases the exergy efficiency at both turbulator curvatures. Furthermore, with an increase in the lateral ratio of the curved turbulators, the exergy efficiency decreases.

2 Material and Method

The experimental setup was establıshed to make studıes by creatıng two-phase flow and make examinations by forming pressure drop type oscillations, density change type oscillations and thermal oscillations. In the experiment, the effects of heat flux, flow rate and inserts in the form of rings in different steps on the two-phase stable and unstable flow characteristics in a horizontal pipe were examined. Figure 1 shows that the experimental setup consisted of three compartments as a fluid feeding compartment, a test compartment and a storage compartment. Figure 2 shows the schematic view of the experimental setup. Table 1 presents the materials constituting the experimental setup.

As seen in Fig. 2, the temperatures were measured with the help of 26 T-type thermoelement couples including 13 placed at the top peak point of the pipe and 13 placed at the bottom peak point of the pipe in equal intervals on the test pipe. As the test pipe was being heated with electricity, to eliminate electrical noise, the tips of the thermocouples were placed between mineral wool plates which were electrically insulating but had high thermal conductivity. To be able to read and assess the signals given by the thermoelements and pressure/flow transducers, an analogue/digital Advantech Data Reading Card and the VisiDAQ 3.1 software were used. Figure 3 schematically shows how the thermocouples were connected to the data reading card and the computer. The constantan end of the thermoelements was connected to the negative end, while their copper end was connected to the positive end of a channel on the card. The total error rate in the readings taken from this control card with the capacity of making a hundred samplings per second varied between ± 0.1 °C% and ± 0.5 °C% based on the selected gain value levels of the control card (Karagoz et al. 2017).

Fig. 1 Experimental setup

Determination of the oscillations occurring in the system was achieved by the method of Fast Fourier Transform which allows observation of an even observed in the time-space in the 1/time space, that is, the frequency space. The Fourier Transform of a function $f(t)$ defined in the entire space in a space w is expressed with Eq. (1).

$$F(w)\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} f(t)e^{-iwt}\mathrm{d}t \quad (1)$$

Fourier Transform is used in the analytical solutions of various mathematical operations. However, the measurement value obtained in scientific and technological applications is not a function but a numerical sequence with a certain number of elements. Therefore, such numerical data must be taken numerically in their transforms. Numerical Fourier Transform provides all properties of analytical transform.

Based on the definitions of Fourier Transform, the analytical solution is expressed with Eq. (2). The Fast Fourier

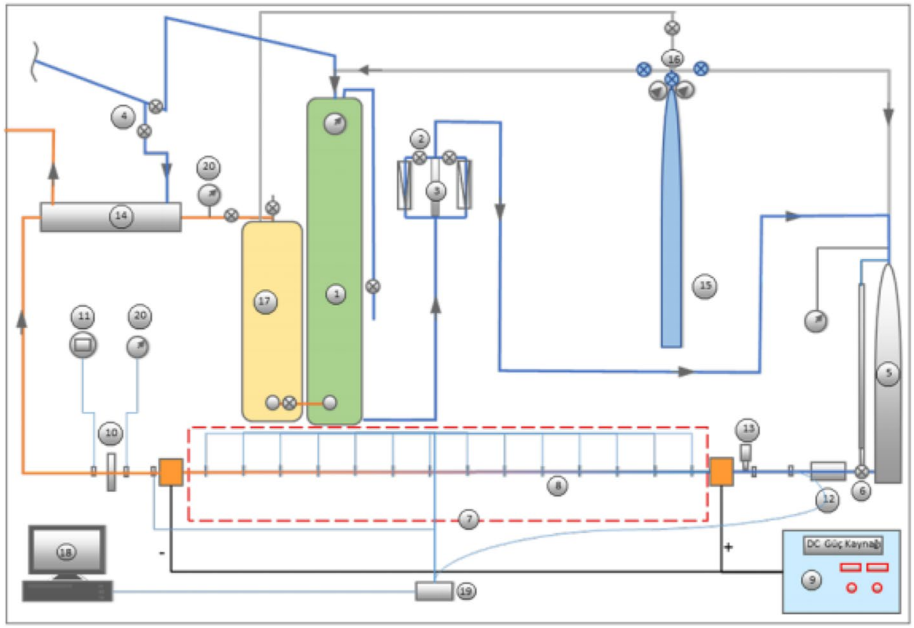


Fig. 2 Schematic view of the experimental setup (Yesilyurt 2015)

Table 1 Materials constituting the experimental setup

Fluid feeding compartment	Test compartment	Fluid output compartment
1. Main feeding tank	8. Test pipe	15. Nitrogen tank
2. Flow rate adjustment valve	9. DC power supply	16. Regulator
3. Flowmeter (two units)	10. Orifice	17. Fluid storage tank
4. Valve	11. Digital manometer	18. Computer
5. Balancer tank	12. Flow transducer	19. Data reading card
6. Fluid entry control valve	13. Pressure transducer	20. Dial manometer
7. Test chamber	14. Condenser	

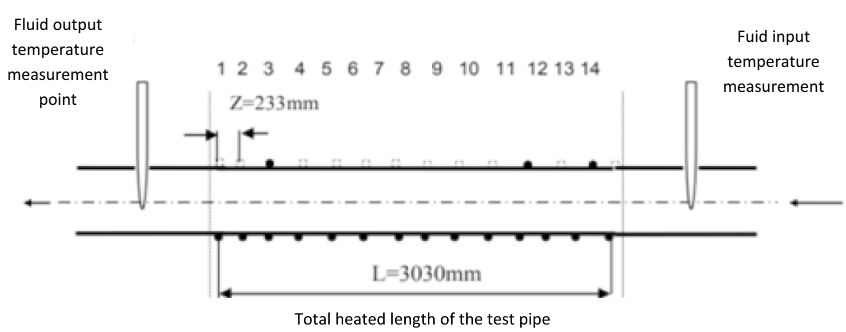


Fig. 3 Test pipe wall temperature measurement points (Karagoz et al. 2017)

$$\overline{Z} = \frac{\overline{z}}{L} = \frac{233 \ \text{mm}}{3030 \ \text{mm}} = 0.0769$$

Transform function in the Excel Analysis Toolkit was used in our calculations.

$$F_{\mathrm{L}} \frac{1}{N} \int_{k=0}^{N-1} f_k e^{-2\pi kl/N} \tag{2}$$

First of all, stable experiments where stable-state characteristics were determined were carried out, while secondly, unstable experiments where the dynamic instabilities of two-phase flow were determined were conducted. The experiments were conducted in 2 different types of pipe, at a constant fluid input temperature, constant thermal power and constant exit orifice diameter. Figure 4 shows the technical drawing of the heat transfer improvement elements. Figure 5 presents the photographs of the heat transfer improvement elements whose characteristics and heat transfer surfaces are given.

As shown in Fig. 3, heat transfer surfaces are characterized with the effective diameter calculated by using Eq. (3) below.

$$d_e\sqrt{\frac{4V}{\pi L}} \tag{3}$$

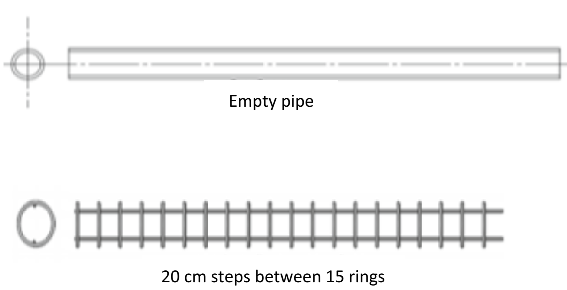
In the equation, V' is the net internal pipe volume, and L is the pipe length (Ejder 2013).

Figure 6 presents the connections and dimensions of the test pipe in the experiment system.

For pipe 1 and pipe 2, the following parameters were measured in the experiment system:

1. Test pipe surface temperature (13 bottoms, 13 tops, 26 measurements)
2. Test pipe entry and exit temperatures of the fluid
3. Test pipe entry and exit static pressure of the fluid
4. Flow rate at the input of the test pipe
5. Flow oscillations at the input of the test pipe
6. Pressure oscillations at the input of the test pipe
7. Pressure at the entry and exit of the orifice

For the purpose of finding the stable-state characteristics, the experiment was started with the empty type of pipe, and it was carried out at a constant exit orifice limit,



Pipe name	Characteristic of the pipe	$d_{e\ mm}$
Pipe-1	Empty pipe	17.60
Pipe-2	Element containing 15 rings with 20-cm steps at a wire diameter of .8 mm	17.34

Fig. 4 Technical drawing of heat transfer improvement elements

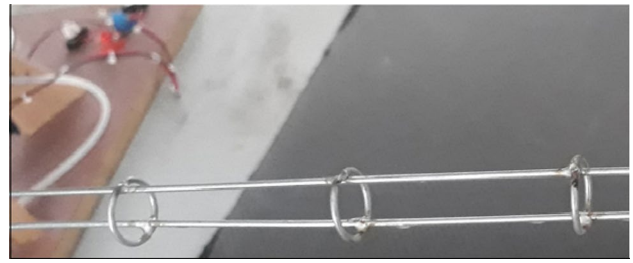


Fig. 5 Photograph of a heat transfer improvement element

$p_{sys} = 7.5$ bar, and Te = 15 °C fluid input temperature and $Q = 22$ kW thermal power.

In the stable-state experiments conducted to determine the stable-state characteristics, these characteristics are shown with the help of plots created over the change in the pressure drop by the flow rate. The relationship between the balancing tank pressure and the pressure of the fluid after the orifice plate is the indicator of the pressure drop here. The experiments were started with the flow rate of $\dot{m} = 50$ g/s. The flow at high flow rates was a single-phase and liquid flow. To determine the characteristic curve, the flow rate was reduced in intervals of approximately 10–12 g/s. For the purpose of determining the characteristic of the steam flow as a whole, the flow rate was reduced to very low levels. In the experiments, the minimum flow rate was taken as 20 g/s, and in all experiments, lower flow rate values were not reached due to the possibility of burn-out. Whether or not the pipe reached the burn-out region was checked by observing the wall temperatures and the fluid output temperature.

3 Research Findings

In this section, using an empty pipe and a pipe with tube inserts consisting of ring turbulators and utilizing the results occurring in the experiments, stable-state characteristics, oscillation limits and PDO (pressure drop oscillations) were separately evaluated in terms of the surface configurations.

In order to determine the stable-state characteristics in the experimental setup, $\Delta p - \dot{m}$ (pressure drops in the test pipe corresponding to mass flow rate) plots and

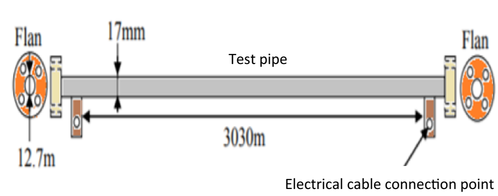


Fig. 6 Test pipe in the experiment system

stable-state characteristic curves in the shape of tipped "S" that is seen frequently in the literature in two-phase flow systems were drawn. The data created as a result of the experiments are shown with plots, and these present the pressure drop data calculated based on the difference between the balancing tank pressure corresponding to different mass flow rates for the two test pipes and the exit pressure of the test pipe. The single-phase liquid zone where the slopes of the curves were positive corresponds to high mass flow rate values. While the first bubbles were formed in the zone where the slopes turned negative, it is observed that two-phase flow started when the mass flow rate and pressure drop data decreased and reached the minimum point. Due to the numerical increase in the bubbles, the liquid and steam phases start to flow together. The density in the setting drops below that of the liquid phase, and this way, the pressure drops increase. It is observed that reducing the mass flow rate down to certain values led to the transition of the negatively sloped zones up to the saturated steam zone in the curves into a positive slope and the reduction of the pressure drop values.

Characteristic state curves were created for all test pipes that were used in the experimental setup. The experiments were conducted so that the fluid entry temperature was Te = 20 °C, and the thermal power was $Q = 21$ kW, and both were constant. The empty pipe without any surface-increase element was named as Pipe 1, while that containing a series of 15 rings with steps of 20 cm was named as Pipe 2. Characteristic state curves are given for all test pipes that were used in the system. It is seen that there were differences in the pressure drop values in the characteristic state curves given for the two different test pipes. The pressure drop value obtained from Pipe 2 containing a surface-increase element consisting of a series of rings with 20-cm steps was higher than the pressure drops value of Pipe 1.

The comparison of the pressure drops values resulted as Pipe 2 > Pipe 1. With the formation of stratification in the flow in the surface-increased pipe, there was an additional pressure drop caused by the steam phase besides the friction-related pressure drop, and the amount of increase in the pressure drop values corresponding to the reduced mass flow rate values was higher in comparison to the empty pipe. In the stable-state curves, the zones where the negative slope angle became steep were the zones where the instability of the system increased. In this case, it may be expected that there should be less negative zone slope in the stable-state curves belonging to the empty pipe in comparison to the curves of the pipe where the surface-increase element was used, and it appears that the plots obtained from the experimental results were compatible with this expectation.

The single-phase convection temperature values for Fig. 7 are shown in the empty pipe in which the surface increase element was not used. As seen in Fig. 8, the input temperature was 20 °C, the fluid input flow rate was $\dot{m} = 52$ g/s, and the thermal power was 21 kW.

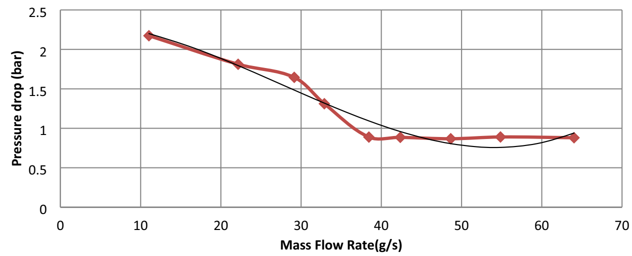


Fig. 7 Stable-state characteristic curve plot for Pipe 1

As seen in Figs. 9 and 10, in the single-phase zone, the bottom and top wall temperatures increased linearly along the pipe. There was no noticeable temperature difference between the bottom and top walls. Afterwards, as the liquid and steam phases flow in a mixed fashion, the top and bottom wall temperatures were also close. The most noticeable distinction was observed at low flow rates. If the system is examined, it may be seen that the bottom and top wall temperatures were approximately the same at the end of the equivalent pipe length. The reason for this situation was the turbulence provided by the ring element placed inside the pipe. This way, the liquid and steam phases flew complexly.

According to the decreasing mass flow rate shown in Fig. 11, the bottom and top wall temperatures were much lower in comparison to the empty pipe. This is due to turbulence. Burn-in occurs at lower temperature values. Figure 12 shows the pressure drop in all pipes.

4 Conclusions and Discussion

With this experimental study, stable and unstable flow events were examined in a two-phase flow system consisting of two different horizontal pipes with forced convection. The effects of the surface-increase element used for heat transfer were investigated. Experiments were conducted with the empty pipe and a pipe equipped with equal rings with 20-cm intervals. By keeping the thermal power, exit orifice diameter, fluid entry temperature and input pressure constant during the experiment, the effects of two-phase flow instabilities were studied. The results of this study may be listed as follows:

In the experiment, the bottom and top wall temperatures increased linearly along the length of the pipe. There was a significant difference between the two wall temperatures. For all pipes, in this flow regime, the top wall temperatures were higher than the bottom wall temperatures.

In the experiment, pressure drop type oscillations were examined. The pressure drop data in the characteristic curves differed for the two types of pipe, and it was observed that

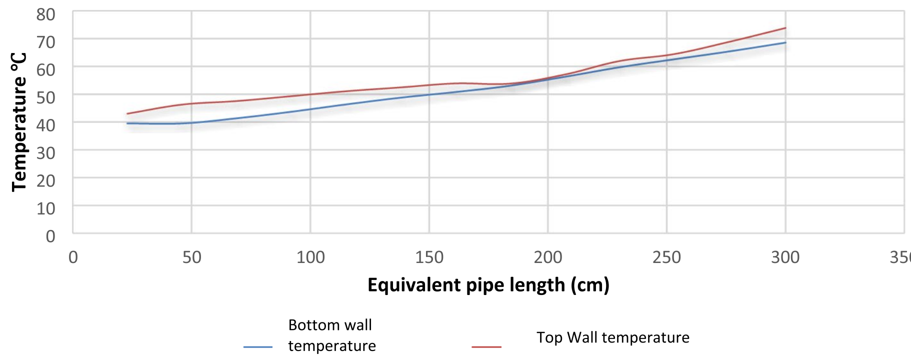


Fig. 8 Bottom and top wall temperatures for Pipe 1 at a mass flow rate of $\dot{m}$ = 52 g/s

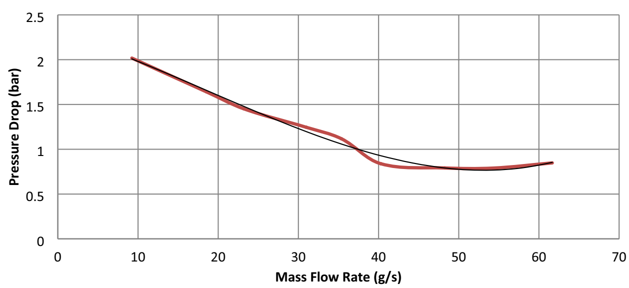


Fig. 9 Stable-state characteristic curve plot for Pipe 2

the pressure drops increased with the use of the surface-increase element.

In the experiments on the two different test pipes, how the Pressure Drop Type Oscillations (PDO) varied based on the mass flow rate was examined. By drawing input pressure–time and mass flow rate-time plots based on the data, the changes in the pressure drop oscillations by the mass flow rate for the test pipes that were used were examined. The pressure drops oscillations occurred in the negatively sloped region of the characteristic curve in both of the test pipes. With the oscillations occurring in the input

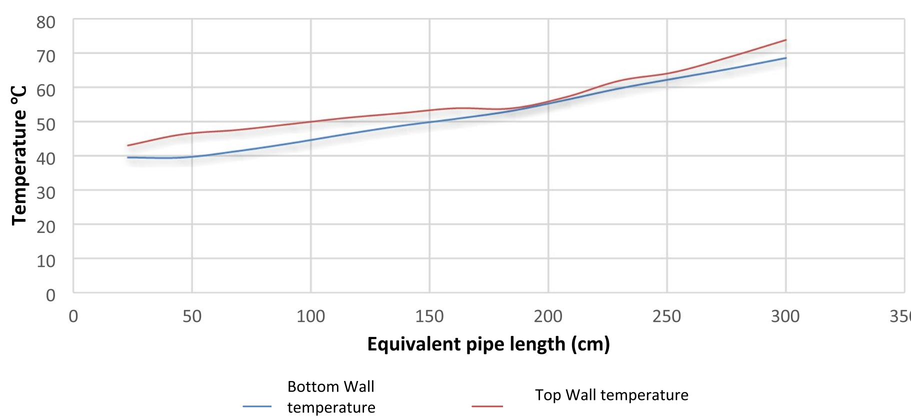


Fig. 10 Bottom and top wall temperatures for Pipe 2 at a mass flow rate of $\dot{m}$ = 50 g/s

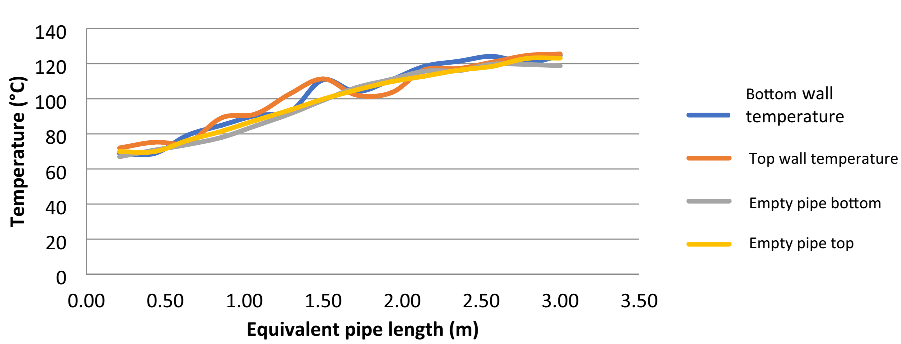


Fig. 11 Bottom and top wall temperatures for Pipe 1 and Pipe 2 at a mass flow rate of $\dot{m}$ = 50 g/s

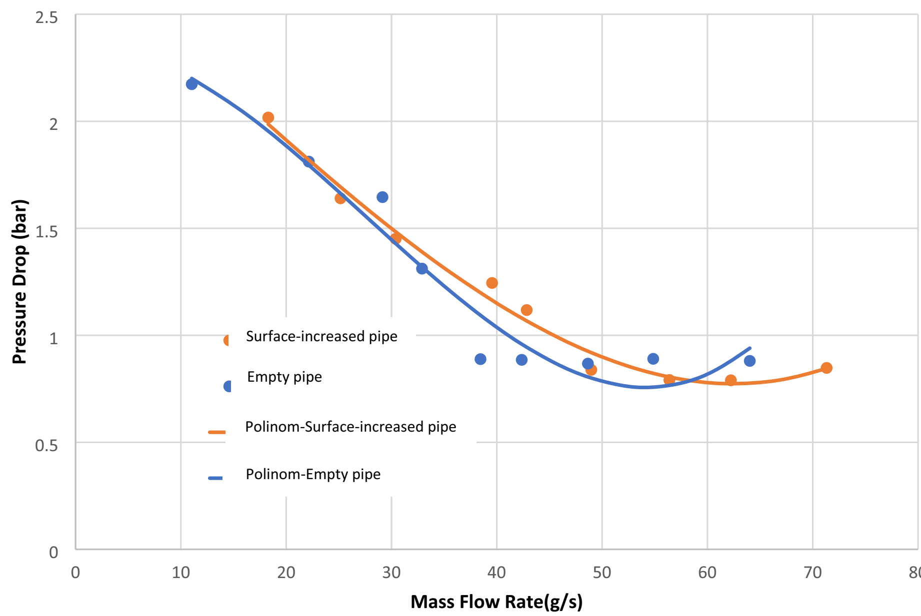


Fig. 12 Pressure drops for all pipes

pressure, it was observed that there were oscillations in the mass flow rate values.

The stability limits moved towards lower mass flow rate values with the decrease in the input temperature.

According to the experiment results, it was observed that the heat transfer characteristics of the surface-increased pipe were superior to those of the empty pipe.

This experimental work is carried out with horizontal tube forced convection boiling two-phase flow. In systems where ring arrays are used as in pipe surface enhancement element. Since it is an alternative study, it has been compared with previous studies and as a result, using a ring turbulator gives more stable results for each parameter appeared to be revealed. Interphase interaction of the results obtained from this study in two-phase flow systems considered to be important in providing.

Pressure drop in the negative slope region of the steady-state characteristic curve type oscillations caused large amplitude oscillations in inlet pressure and mass flow rate. Amplitudes are lower in pipes with an in-pipe surface increaser than in an empty pipe has been. In addition, as the amplitudes increase in pipe-2, the number of turns increases decreased and increased as the spring pitch increased.

For pressure drop oscillations, the amplitude and periods decrease as the mass flow rate decreases seen. In terms of pressure drop type oscillations, the increase in mass flow rate increases the inlet pressure. The amplitude and period of the oscillations also increased. Again, the largest amplitude and period when ordered by effective diameter values have been reached for Pipe 1.

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