

Chapter 15

Dynamic Instabilities and Their Control in Flow Boiling in Microchannels



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Abstract The progress in manufacturing techniques in last few decades has accelerated the application of micro-structured devices in a range of industrial sectors such as healthcare, pharmaceuticals, electronics, environment, chemical processing and energy. Many of these applications stem from the advantages of high surface area to volume ratio, small diffusion paths and ability to operate safely at high temperatures and pressures in micro-devices. The applications of these devices in the energy sector often involve convective heat transfer, condensation, evaporation and boiling in microchannels. Extensive experimental studies on flow boiling in microchannels in the last twenty five years suggest the boiling at the microscale to be significantly different from that in the large channels and the critical heat flux above which the boiling heat transfer becomes ineffective and catastrophic is scale-dependent. The studies also indicate that several dynamic instabilities occur during two-phase boiling in microchannels and these can be different from those that occur in large channels. Therefore, it is imperative to understand the mechanisms of boiling stabilities in microchannels and develop techniques to control them to design efficient and safe micro-structured devices. The boiling instabilities in microchannels can be categorized in two groups- one, those caused by interaction between upstream compressibility and bubble generation and second, those caused by parallel channel instability. This chapter reviews the current status of the understanding of these instabilities and the techniques to avoid or minimize them.

Keywords Microchannel · Boiling · Instability

15.1 Introduction

In recent years, there has been a growing trend towards developing miniature devices such as micro-electro-mechanical systems (MEMS), lab-on-a-chip devices, micro heat exchangers and chemical micro-processing systems for applications in a range of

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industries. In the energy sector, perhaps the most important contribution of the miniaturized systems has been in the development of microchannel-based heat exchanging systems.

In the electronics industry, the number of transistors per square inch has been doubling every 12–18 months for past few decades, as observed by Gordon Moore, co-founder of Intel (Moore 1965). With an increase in the number of transistors per square inch, the requirement of the heat removal rate also increases accordingly. With air-based cooling, heat fluxes up to 1 MW/m^2 can be removed (Tullius et al. 2011). For the removal of higher heat fluxes, liquid (Tuckerman and Pease 1981) or gas-liquid (Bar-Cohen 1995) based cooling systems has been employed. Therefore, the semiconductor industry has been one of the major drivers of the research and development in the area of heat transfer in micro-structured systems.

One of the major requirements in the aerospace industry is the development of compact systems which can deliver maximum performance per unit mass. Therefore, the micro heat exchangers are best suited for applications in aircrafts and space vehicles. The offshore industry also has a similar requirement of compact heat exchangers. One such example of compact heat exchangers is the printed circuit heat exchanger (PCHE) of Heatric division of Megitt Aerospace which has been deployed in the offshore, onshore and floating applications in the oil and gas industry for past 30 years.

The rate of heat transfer is directly proportional to the surface area. A reduction in the channel dimension results in an increase in surface area to volume ratio. As a result, the microchannel-based systems can provide large surface area per unit volume when compared with conventional heat exchangers. Scale up of such system can be achieved by ‘numbering-up’ the microchannels. For example, numbering up in PCHEs is achieved by etching a number of microchannels on metallic plates. A number of plates are then diffusion-bonded together to make the compact heat exchangers. A reduction in the channel dimension results in smaller heat diffusion length scale (of the order of channel radius, R) and consequently, the transverse temperature gradients ($\frac{\partial T}{\partial r}$) are large. Moreover, the microchannel systems are safer to operate than the conventional systems. As a result, they are considered to be the best-suited to perform exothermic reactions. Microchannels often have square, rectangular, semi-circular and triangular cross-sections which is rarely the case in large diameter channels.

The channel dimension in such systems is often of the order of few hundred microns to few millimeters. The expressions and correlations developed for single-phase flow in conventional systems can be used for these small diameter channels also with a careful consideration of the effect of surface roughness. However, such is not the case for adiabatic two-phase flow or boiling.

In gas-liquid or liquid-liquid systems, the interfacial area density or interfacial area per unit volume also becomes large in microchannels. As a result, the rates of interfacial heat and mass transfer are enhanced in microchannels. With a decrease in channel size, the relative importance of surface tension, which is a surface force, increases when compared with the body forces such as gravity. As the velocity and

length scales are small, the flow is generally laminar in microchannels over a large range of gas and liquid flow rates. As a result, the flow regimes during adiabatic two-phase flow and boiling in microchannels are significantly different than those occur in conventional large channel systems.

Flow boiling is susceptible to thermal and hydrodynamic instabilities which may cause oscillations in flow rate, pressure and temperature of constant and increasing amplitudes (Boure et al. 1973). These oscillations are generally undesirable as they disturb the control systems, may result in boiling crisis or can even cause mechanical damage. It is therefore imperative to develop a comprehensive understanding of the origin of flow boiling instability in microchannels and the measures that can mitigate or eliminate the instabilities.

In this chapter, the instabilities that occur during flow boiling in microchannels and the measures that can be taken to tackle them are discussed.

15.2 Fundamentals

Boiling refers to the change of liquid phase to the gas phase caused by heat transfer. This occurs when the liquid temperature exceeds the saturation temperature (or boiling point) at the system pressure.

Various physical effects such as surface tension, change in momentum during evaporation, viscous and inertial effects are important during flow boiling. To compare the relative effect of different physical phenomena, several non-dimensional parameters are defined and are relevant to flow boiling in microchannels.

1. **Bond or Eötvös number:** Bond or Eötvös number is defined as the ratio of buoyancy force to surface tension force.

$$Bo = \frac{(\rho_l - \rho_v)gL^2}{\sigma}$$

where ρ_l and ρ_v are densities of liquid and gas phases, respectively, g is the acceleration due to gravity, L is the characteristic length and σ is the surface tension. The value of Bond number decreases with a decrease in the channel size. For a channel of size 1 mm, the value of Bond number is about 0.14 for two-phase flow of water i.e. for a millimeter-size channel, the buoyancy and surface tension forces are comparable and surface forces start dominating as the channel size is further reduced.

2. **Weber number:** Weber number is the ratio of inertial and surface tension forces. Baldassari et al. (2013) suggested that the difference between the average liquid velocity and vapour velocity should be used as the velocity scale.

$$We = \frac{\rho_l(u_l - u_v)^2L}{\sigma}$$

3. **Reynolds number:** Reynolds number is the ratio of inertial and viscous forces.

$$Re = \frac{GL}{\mu_l}$$

where G is the mass flow rate and μ_l is the dynamic viscosity of the liquid. For two-phase flow systems, different Reynolds numbers can be defined.

$$Re_L = \frac{G(1-x)L}{\mu_l} \text{ for the liquid flow only}$$

$$Re_G = \frac{GxL}{\mu_l} \text{ for the vapour flow only}$$

$$Re_{TP} = \frac{Gd}{\mu_{tp}} \text{ where } \mu_{tp} \text{ is the weighted average of the liquid and vapour phase viscosities and } x \text{ is the vapour quality.}$$

4. **Capillary number:** Capillary number is the ratio of viscous and surface tension forces.

$$Ca = \frac{\mu_l U}{\sigma}$$

5. **Boiling number:** Boiling number represents the ratio of evaporation mass flux to the total mass flux.

$$Bl = \frac{q''/h_{lv}}{G}$$

where q'' is the wall heat flux and h_{lv} is the latent heat of vaporization.

6. **Jakob number:** Jakob number is the ratio of sensible heat to the latent heat absorbed/released during liquid-vapour phase change.

$$Ja = \frac{c_p(T_s - T_{Sat})}{h_{lv}}$$

Based on the occurrence of external flow, boiling can be characterized in two categories- pool and convective. Pool boiling refers to the boiling caused by natural convection only e.g. boiling of liquid in an electric kettle. Convective boiling refers to the boiling over a surface during fluid flow caused by the external flow e.g. boiler tubes in power plants.

The process of phase change in a liquid pool begins with the formation of vapour embryo and is named as nucleation. Nucleation can be of two types: homogeneous and heterogeneous. Homogeneous nucleation refers to the formation of the vapour embryo in the superheated liquid pool. Solid surfaces or surfaces of the foreign bodies present in the liquid pool has a number of small cavities which can act as nuclei for vapour formation. This is known as heterogeneous nucleation.

Figure 15.1 shows a typical pool boiling curve. When the temperature of the bulk liquid is less than the boiling point, the phenomenon is known as subcooled boiling whereas saturated boiling occurs when the bulk liquid temperature is equal to the boiling point.

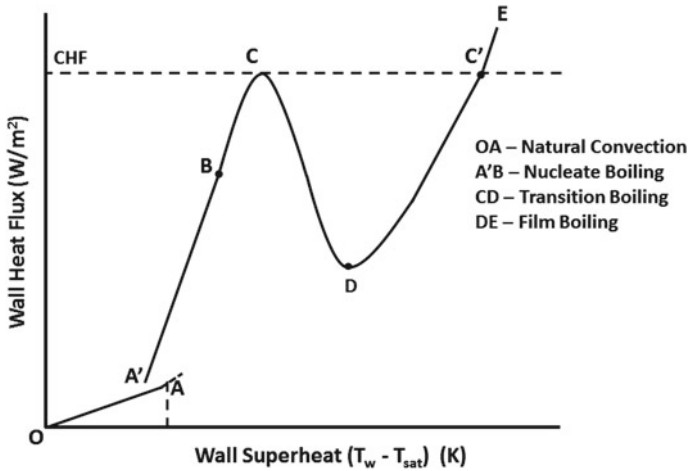


Fig. 15.1 Pool boiling curve (adapted from Collier and Thome 1996)

When the water in a pan is heated, temperature gradients are set up in the liquid pool and natural convection currents are set up causing the movement of hot liquid from the bottom to top and that of the relatively colder liquid from top to bottom. The hot liquid moving to the interface may evaporate depending upon its degree of superheat.

When the wall superheat is sufficient to cause vapour nucleation at the heated surface, the onset of nucleate boiling (ONB) is said to occur. In some cases, the ONB may occur when the liquid superheat is more than that required to support fully-developed nucleate boiling. One such example is water boiling at sub-atmospheric pressure. This results in a sharp drop in the temperature of the surface.

During the nucleate boiling, vapour bubbles start forming at the nucleation sites. The number of nucleation sites grow with an increase in the wall heat flux. As the wall heat flux increases further, bubbles coalesce and vapour patches are formed at the surface. Finally, when the wall heat flux becomes equal to the critical heat flux (CHF), the solid surface is completely covered with the vapour blanket. The vapour blanket acts as an insulator and the heat flux decreases in the transition boiling regime (region CD). In the film boiling region (DE), a stable and continuous vapour film covers the solid surface completely.

The convection or flow boiling is generally described by an example of flow in a vertical, uniformly heated tube at low wall heat flux having upward flow as shown in Fig. 15.2. As the subcooled liquid moves along the tube, its temperature increases. The wall temperature would be higher than the fluid temperature. When the wall temperature is sufficiently high to sustain nucleation at the wall, bubbles start to nucleate on the channel wall though the bulk (or mixing cup) temperature of the fluid is less than the saturation temperature. This is known as subcooled nucleated boiling.

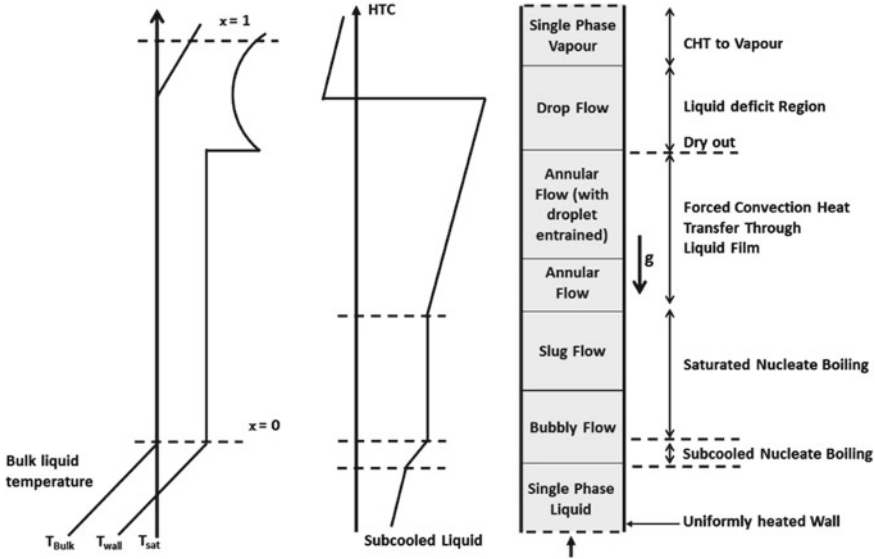


Fig. 15.2 Convective heat transfer in a vertically upward flow (adapted from Collier and Thome 1996)

The subcooled boiling region transitions to saturated nucleate boiling when the fluid bulk temperature becomes equal to the saturation temperature. Moving downstream in the saturated nucleate boiling region, a transition occurs in the heat transfer mechanism and the flow regime transitions to annular from bubbly/slug flow.

In the annular flow region, the heat is transferred from the wall in the liquid film by forced convection and evaporation occurs at the vapour-liquid interface. Thus, the heat transfer mechanism transitions from nucleate boiling to evaporation in the film region. The thickness of the liquid film decreases continuously along the downstream direction. Liquid dryout occurs on the wall when the film on the wall is completely evaporated. This results in sudden rise in wall temperature.

A typical variation of heat transfer coefficient at low wall heat flux is also shown in the figure. A rise in the wall heat flux would result in initiation of subcooled boiling at a shorter distance from the inlet, higher heat transfer coefficient in the nucleate boiling region and dryout on the wall at a lower quality. However, the heat transfer coefficient in the film evaporation region remains unchanged with an increase in wall heat flux.

At further high values of heat fluxes, the dryout may occur during the nucleate boiling well before the film evaporation could be initiated. This is similar to the phenomena that occurs in pool boiling when critical heat flux is reached and is named as departure from nucleate boiling (DNB). This results in transition to film boiling. For further details on the effect of heat flux, the readers are advised to refer to Chap. 4 of Collier and Thome (1996).

15.3 Boiling in Microchannels

The correlations developed for conventional large size channels have been found not to be able to predict the boiling heat transfer in microchannels. This can be attributed to several characteristic differences between the two cases. For example, the flow is often turbulent in conventional channels but laminar in microchannels. In the microchannels, the bubble nucleated on the wall are confined and can grow only in the axial direction.

Many advantages of the micro-structured devices stem from the high surface area to volume ratio when compared with the conventional channels. In the context of heat transfer, high surface area to volume ratio implies the availability of more heat transfer area per unit volume making the heat exchanging device compact. Another effect of high surface area to volume ratio is the dominance of surface forces such as surface tension in comparison with the body forces such as gravity and inertia. Flow boiling in capillary tubes is important in the applications which require small size and small weight for example electronics cooling, automotive air-conditioning, thermal management and fuel supply systems in aircrafts and spacecrafts.

The walls of microchannels are generally smooth when compared with the larger channels. Therefore, a high wall superheat is required to initiate nucleation in microchannels. In case of ultra-smooth microchannels, the onset of boiling might be a result of homogeneous nucleation.

During the convective flow boiling in large-size channels, nucleate boiling dominant regime is observed at low quality whereas the annular flow evaporation is dominant at moderate to high qualities. During nucleate boiling, heat flux is proportional to $q^{0.7}$ and independent of vapour quality. In the conventional channels, the flow accelerates rapidly resulting in considerable pressure drop in the channel. Pressure drop, mechanism of nucleation and bubble growth and evaporation in the annular flow regime are all affected by the reduction in channel size.

From the experimental investigations on flow boiling in microchannels, two contrasting results have emerged. In one case, annular flow in which film evaporation is the boiling mechanism and the boiling is relatively steady is assumed to be the dominant mechanism. While several other researchers observed oscillations in the flow boiling which is often associated with nucleate boiling.

Agostini and Thome (2005) reviewed the experimental studies on boiling in microchannels. Several studies found the heat transfer coefficient to be dependent on heat flux and independent of or weakly dependent on the mass flux. Therefore, researchers believed nucleate boiling to be the dominant mechanism in flow boiling (Bao et al. 2000; Bertsch et al. 2008). However, it has been shown (Jacobi et al. 2002) that such heat transfer dependence can also occur during bubble train flow. So, there is no clear agreement between the researchers on the mechanism of flow boiling in microchannels.

15.4 Boiling Instabilities

Any system is considered to be stable if the system returns back to its original state when subjected to small disturbances or perturbations. The perturbations during the boiling can be caused by a number of factors such as nucleation, bubble generation or turbulence. The flow instabilities in the boiling systems is often classified in two categories: static and dynamic (Boure 1973; Das and Das 2016). Static instability occurs when the original steady state of the system shifts to a new steady state or shows periodic behaviour when subjected to a small disturbance i.e. the system moves to a different equilibrium state. The examples of static instabilities are Ledinegg or flow excursion instability, flow pattern transition, chugging or geysering whereas dynamic instabilities include acoustic and density wave oscillations, thermal oscillations, parallel channel instabilities etc. Boure (1973) suggest that inertia and other feedback effects such as between inertia and compressibility or those between pressure drop, flow rate and density change caused by evaporation (Kakac and Bon 2008) play an important role in the case of dynamic instability and there may be several feedback effects.

Amongst these, several instabilities have been reported to have occurred during boiling in microchannels. Liu et al. (2013) suggested that these instabilities can be classified in two modes: one, interaction between the bubble generation and upstream compressibility and two interactions between parallel channels.

Ledinegg Instability

A boiling system has several components such as pump, valves, and channels. These components can be divided into two categories: one those supplying the pressure head to drive the flow (pump) and the other those causing pressure loss (test section and valves). Figure 15.3 shows the characteristic curves for the two types of components. These curves are known as supply (pump) and demand (valve, test section) curves depending on the function of the component the curve represents. When the slope of the demand curve $\left(\frac{d(\Delta p)}{d\dot{m}}\right)_D$ becomes less than that of the supply curve $\left(\frac{d(\Delta p)}{d\dot{m}}\right)_S$, Ledinegg instability occurs. When the pressure head required to push the liquid through the system at a certain mass flow rate is more than the pressure head supplied by the pump, the flow rate decreases. Thus, the Ledinegg instability is characterized by a sudden decrease in the mass flow rate. Zhang et al. (2009) investigated Ledinegg instability in horizontal microchannels for water at sub-atmospheric pressures and for a refrigerant, HFE-7100.

Soft Inlet/Upstream Compressibility/Pressure Drop Instability

Upstream compressibility refers to the presence of the compressible volume upstream of the test section. The compressibility can be present in the form of an entrained air bubble, a flexible tube or even as the gas dissolved in the liquid. Qu and Mudawar (2003) observed pressure drop oscillations caused by the upstream compressible volume in microchannels. They showed that these pressure drop oscillations can be eliminated by adding stiffness to the upstream flow e.g. throttling the upstream flow.

Huh et al. (2007) suggested that the pressure drop instability has a low frequency (~ 0.1 Hz). Liu et al. (2013) investigated the influence of upstream compressibility on the flow and heat transfer behaviour in microchannels by introducing inlet compressibility and measuring its effect on local heat transfer coefficient under sub-cooled and saturated boiling conditions. They introduced inlet compressibility by adding a buffer reservoir having a known gas volume upstream of the positive displacement pump. The condition of no upstream compressibility corresponded to zero gas volume in the buffer and was termed as hard inlet. They concluded that the inlet compressibility can affect the flow and heat transfer behaviour during flow boiling in microchannels. They found that the upstream compressibility causes the flow and heat transfer behaviour similar to that observed during nucleating boiling. They also showed that the hard inlet i.e. incompressible inlet condition causes convective heat transfer behaviour except at the low quality. This instability can be avoided by making sure the hard inlet condition e.g. by isolating the test section from the compressible volume by a throttle valve (Bergles and Kandlikar 2005). Kingston et al. (2018a) also observed the periodic oscillations in the pressure drop, mass flux, wall temperature and two-phase morphology and termed it pressure drop instability. They observed two peaks in pressure drop. The first, bigger peak occurred when the vapour generated in the channel increased and pushed the liquid upstream. This increased the flow resistance and was accompanied by a reduction in the mass flux. The second peak of smaller magnitude was accompanied by an increase in the mass flux caused by a decompression (or depressurization) of the upstream volume.

Rapid Bubble Growth Instability

Rapid bubble growth instability occurs in microchannels and is not so prominent during boiling in large systems (Kuo and Peles 2008). This is because the vapour bubbles generated are confined in the microchannels and significantly affect the hydrodynamics and thermal characteristics of the system. When a bubble nucleates on the channel wall, the pressure in the bubble is the saturation pressure at the local wall temperature. Growth of the nucleated bubble occurs in two stages: (1) free bubble growth when the bubble diameter is less than the channel diameter and (2) confined bubble growth when the volume of the bubble is larger than that of a sphere that can fit in the channel and therefore the bubble grows in the axial direction, upstream as well as downstream. Pressure fluctuations and flow reversal are observed in the confined bubble growth stage. Kuo and Peles (2008) suggested two mechanisms that cause rapid bubble growth instability.

(A) *Liquid Superheat*: The wall roughness in microchannels is typically of the order of 100 nm or less. Cavities on the wall caused by the roughness act as the bubble nucleation sites. Hsu (1962) showed as the size of available cavities become smaller, the liquid superheat required for the cavities to become active increases. When the cavities become active and the bubble nucleates, the bubble grows quickly resulting in an explosion-like vapour growth. This results in sharp increase in the pressure and fluid movement in the upstream and downstream directions. When the energy stored in the superheated liquid is released, the local temperature and pressure decreases

again and the higher pressure at the upstream pushes the liquid to move in the downstream direction. The entire cycle repeats when the liquid become superheated again. Li and Cheng (2004) suggested that the bubble nucleation in microchannels can be different from that in large channels because of the presence of sub-micron cavities having same size as that of a critical vapour bubble, presence of corners in microchannels having triangular, rectangular and trapezoidal cross-section and laminar flow.

(B) *Elevated Pressures*: In the liquid surrounding a rapidly growing bubble, the pressure can increase to very large values temporarily. While this local high pressure is confined to a very small region in large systems, a change in pressure surrounding a channel-size bubble in a microchannel causes a change in pressure field in the entire microchannel.

As the saturation pressure increases exponentially with temperature, the nucleated bubble in a microchannel would have a high vapour pressure resulting in the rapid growth of the bubble to the channel diameter. This momentum force generated by the evaporation of the bubble can sometimes be significantly larger than the dynamic pressure of the flow and the (manifold) pressure at the channel inlet. This would result in the growth of the bubble in the axial direction, upstream as well as downstream of the nucleation site. This would result in the flow reversal and has also been observed experimentally. Kingston et al. (2018a, b) studied rapid bubble growth instability during the onset of boiling and rapid bubble growth and pressure drop instabilities during the time-periodic boiling after the boiling incipience in a glass channel of 500 micron diameter subjected to a uniform heat flux.

Parallel Channel Instability

Scaling up of the microchannels can be achieved by numbering up the channels. This is generally achieved by cutting or etching a number of, typically of the order of 100 (Tuckerman and Pease 1981), parallel channels on a metal plate and bonding a number of plates together.

In parallel channel system, flow maldistribution is observed during flow boiling. The pressure drop across each channel is same in a parallel channel system. Each channel in the system has its own unique resistance depending on the two-phase flow conditions prevailing in the channel. As a result, each channel would have different flow rates. Different resistance to flow can be caused by the design of inlet header, difference in surface properties of the channels or non-uniform heating of the channel. The maldistribution can also be caused by the non-monotonic nature of the pressure drop-flow rate curve as shown in Fig. 15.3. Note that the total flow rate would be sum of the flow rates in each channel.

Kingston et al. (2019) studied Ledinegg instability in a parallel microchannel system having two thermally isolated parallel channels of circular cross-section having diameters of 500 μ each and subjected to the same power. At very low powers, when only liquid phase exists in the two channels, the flow rates in the two channels was nearly equal. However, on increasing the power to a value sufficient to initiate boiling in one of the channels, the flow resistance of the channel with boiling increases and

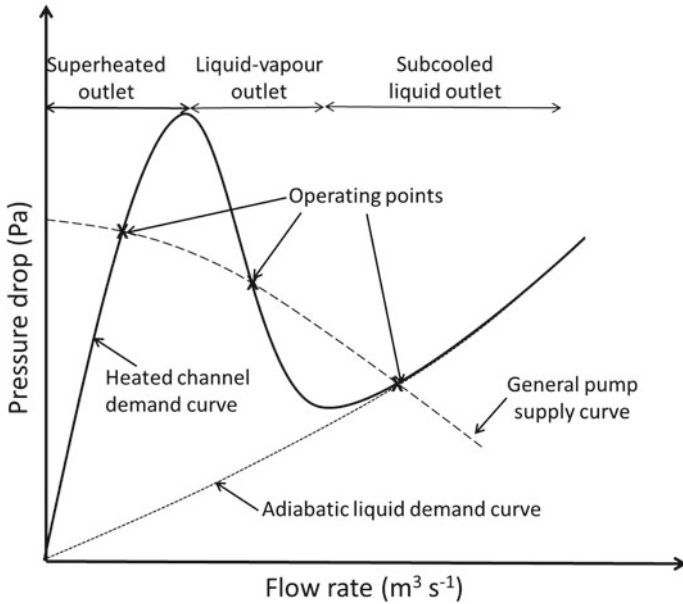


Fig. 15.3 Pressure drop versus flow rate curve for the supply and demand systems showing Ledinegg Instability (Adapted from Oevelen et al. 2017)

Ledinegg instability occurs. This causes low flow rate and high temperature in the channel with boiling. However, after the boiling initiates in the second channel, the maldistribution of the flow in the channels was reduced and the wall temperatures reduced significantly.

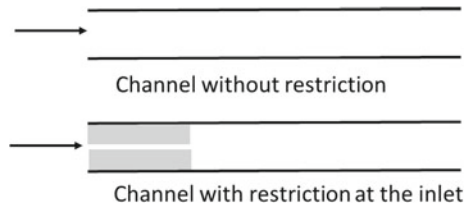
Oevelen et al. (2017) developed a model for the flow distribution in a system of heated parallel channels and integrated with a pump curve. They showed that for a constant pressure drop pump curve, the stability of the individual channels is independent of the other channels.

15.5 Measures to Control Instabilities

Several strategies have been proposed to suppress two-phase flow maldistributions and parallel channel instabilities. Some of these measures are described below:

- (A) **Inlet restrictions:** The instabilities can be eliminated by placing restrictors at the inlet as shown in Fig. 15.4. The restrictors increase the ratio of the pressure loss at the inlet to that in the microchannel. Koşar et al. (2006) showed experimentally that the introduction of orifices at the entrance of each channel in a test section having parallel channels reduced the instability significantly.

Fig. 15.4 Channel restriction to suppress boiling instabilities



(B) **Reentrant Cavities:** Reentrant cavities as shown in Fig. 15.5 can help to diminish the flow boiling instability. The rapid bubble growth instability is caused by high liquid superheat temperature caused by the very small cavities available for nucleation. The liquid superheat temperature can be reduced by providing structured surfaces in the form of reentrant cavities for the bubble nucleation. Kuo and Peles (2008) investigated boiling instability in microchannels with reentrant cavities, microchannels with interconnected reentrant cavities and plain wall microchannels. They observed a reduction in the liquid superheat and pressure at the initial stages of bubble nucleation. This helped in extending the stable boiling region and resulted in an increase in the critical heat flux (CHF).

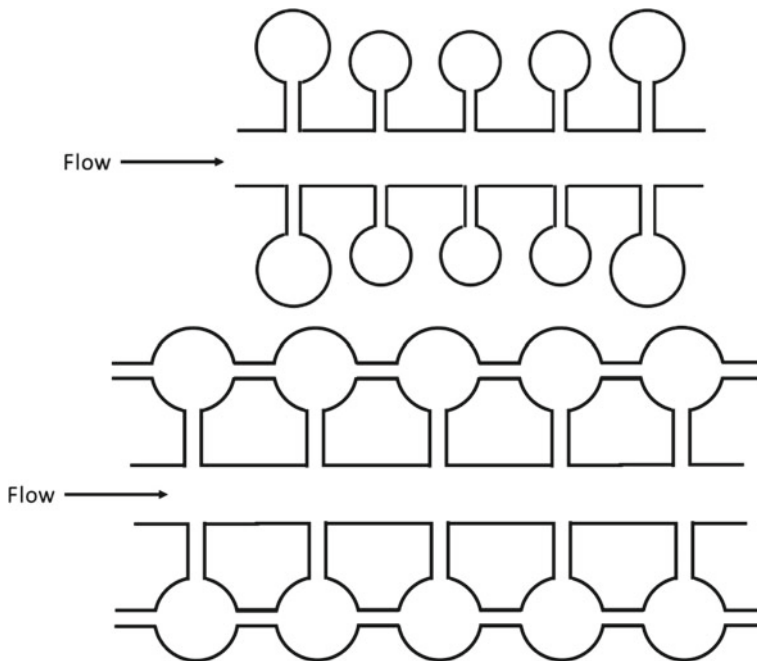


Fig. 15.5 Reentrant cavities and interconnected reentrant cavities

- (C) **Seed bubbles:** Xu et al. (2009) proposed to introduce seed bubbles for the reduction of the flow instabilities. The energy stored in the superheated liquid can be released through the seed bubbles. The seed bubbles introduced should be large enough so that they do not condense completely in the subcooled liquid before reaching the superheated liquid zone in the channel. While the introduction of seed bubbles at a low frequency (~ 10 Hz) causes only a reduction in the amplitude and period of oscillations, seed bubbles at high frequency (~ 100 Hz) are observed to eliminate the instability completely. The pressure drop across the system also remains unchanged on the introduction of seed bubbles unlike other methods of stabilizing flow boiling.
- (D) **Increased system pressure:** The Ledinegg instability occurs when the pump or supply system cannot act to balance the change caused by the perturbations in the mass flux. However, if the slope (magnitude) of the pump curve is greater than that of the demand curve, the system would remain stable. A constant displacement pump which deliver a fixed mass flow and therefore has infinite slope is suited to achieve this (Zhang et al. 2009).

Zhang et al. (2009) suggested that a high system pressure can help in the mitigation of static instabilities. In the electronics cooling applications, it is required to maintain low surface temperatures. Using water as coolant, this can be achieved when saturation temperature is low. Hence the system needs to be operated at low pressures. The instabilities that occur can thus be avoided using coolants having high reduced pressure.

Kuo and Peles (2009) showed that increasing the system pressure results in a decrease in the liquid to vapour density ratio and consequently results in a decrease in the instabilities.

15.6 Summary

Boiling in microchannels has received considerable attention over last few decades because of its application in a number of micro-structured devices and systems. Gas-liquid flows in general and boiling in particular are prone to instabilities. The boiling instabilities results in oscillations in flow, pressure and temperature and may result in critical heat flux condition causing failure of the system and sometimes even catastrophic accidents. In this chapter, the origin and mechanism responsible for the different types of instabilities in microchannels and measure that should be taken to overcome them has been discussed briefly. The basics of boiling has also been discussed so this chapter can serve as an introduction to the general reader without needing to go through the basics of boiling separately.

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