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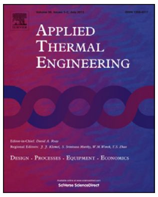

Review on two-phase flow distribution in parallel channels with macro and micro hydraulic diameters: Main results, analyses, trends

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HIGHLIGHTS

- The state of the art on two-phase flow distribution in parallel channels.
- Experimental, numerical and theoretical works of several researchers are analyzed.
- Numerical simulations are a good alternative to predict the phase distribution.
- It was verified that the mist flow pattern induced the best level of distribution.

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ABSTRACT

Two-phase flows in parallel channels are found in various industrial applications employing heat exchangers, boilers and condensers, cooling systems, etc. Two-phase flow distribution in headers with multi-parallel channels has been studied over the past decade. Uneven phase distribution causes a reduction in both the thermal and fluid-dynamic performance and in many cases the failure of the device. The phase separation in these devices with several channels connected to a header is complicated. Thus, to date, there is no general way to predict the distribution of two-phase mixtures. The design of headers, in most cases, is still based on an empirical approach, due to the great number of variables which act together, that is, geometrical parameters, operating conditions and fluid properties. This paper aims to address the fundamental questions related to the main influences on two-phase flow distribution in devices with multi-parallel channels. This review summarizes the experimental, numerical and theoretical work carried out by various investigators over a period of several years, including works in micro (0.8 mm $< d_h \leq$ 2.0 mm) and macrochannels (2.0 mm $< d_h <$ 30.0 mm). The investigation allowed us to identify the main geometrical and operating conditions which influence the two-phase flow distribution in parallel channels. A tentative assessment of the role of these parameters is also carried out.

The header and the feeding tube positions were found to be the main factors influencing the mass flow rate distribution among parallel channels. An analysis of the action of the main forces (inertial and gravitational) in each case, due to the geometrical parameters, operating conditions and fluid properties, was essential to determine the two-phase flow distribution among the channels. It was verified that the mist flow pattern induced the best level of distribution among the parallel channels, independently of the header position and flow direction.

The existing models and correlations developed for two-phase flow distributions are still preliminaries, and do not reflect the real complexity of two-phase flow inside the header. Further developments are needed to make these tools enough mature to predict the two-phase flows in such complex geometries. Modifying the geometry by inserting specific devices into the header or the feeding tube is one promising approach to improve the two-phase flow distribution in parallel channels.

1. Introduction

Many devices based on two-phase flow or single-phase flow commonly use multiple parallel channels for various purposes, for example, to intensify the heat transfer in heat exchangers and

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the mass transfer in absorbers, or simply to improve the transport and distribution of the fluid. In the case of heat exchangers and mass absorbers the surface area increases with the number of channels, improving the heat and mass transfer, while the inlet and outlet collectors facilitate the fluid distribution in multiple channels and provide connections to external ducts. Some examples, such as boilers, heat exchangers, and cooling systems, include thermal cycles and the use of such components improves the compactness and the heat transfer and mass performances. Heat exchangers are normally found, for example, in mobile air-conditioning applications.

In parallel channels, flow distribution is generally assured by means of headers. Fig. 1 shows a typical header with parallel channels. This arrangement includes inlet and outlet tubes, an inlet header, a set of parallel tubes, where the heat transfer, chemical reaction or absorption process takes place, and an outlet header where the whole flow is regrouped.

The effectiveness of these heat exchangers is dependent on the uniformity of the mass flow rate distribution through parallels channels. However, uneven distributions generally occur, reducing the effectiveness of the system. Such situations of maldistribution are particularly unfavorable for two-phase flows due to the possible uneven phase split at each junction of the dividing header.

In two-phase flow, maldistribution of the mass flow rate can significantly reduce the effectiveness of heat exchangers. While some cases of uneven distribution have little effect on heat exchanger performance, others result in significant loss of the effectiveness and may lead to mechanical failure of the devices, hydraulic instabilities, etc. In heat exchanger-reactor, for example, the non-uniform distribution of the reactants among different channels or individual microreactors can result in substantial temperature deviations, resulting in thermal runaway, which could arise from an exothermic reaction (Rebrov et al. [1]).

Choi et al. [2] studied the two-phase flow distribution in evaporators with parallel channels. They showed that maldistribution caused a 30% reduction in the performance of the evaporator. Wu and Webb [3] conducted tests in an evaporator with a horizontal header and an upward tube configuration. The capacity of the evaporator had an estimated 8% reduction due to refrigerant maldistribution. Lalot et al. [4] investigated fluid maldistribution in an electrically-heated heat exchanger. They developed a numerical model to determine the effectiveness of the heat exchanger and noted a 7% reduction in the calculated heat exchanger performance due to maldistribution in the counter-current flow heat exchangers and condensers. For a cross-flow heat exchanger this reduction may reach more than 25%. Stott et al. [5] used a tube evaporator with tube feeding the two-phase flow at four locations along the inlet header. Measurements of the superheat at the outlet of the tubes were used to quantify the maldistribution. The reduction in capacity due to maldistribution in the evaporator was estimated to be 13% under dry conditions and 19% under wet-coil conditions. Pettersen et al. [6] modeled the effect of two-phase flow maldistribution using R134a in a multiport tube evaporator, with an inlet vapor quality of $x = 0.8$. A reduction in capacity of 30% was calculated compared to a uniform two-phase flow distribution. Rao et al. [7,8] evaluated the thermal performance of falling film plate condensers with flow maldistribution from the feeding tube to the channel. The heat transfer coefficient was considered as a function of mass flow rate inside the channels. They evidenced a heat transfer coefficient reduction due to maldistribution among the parallel channels.

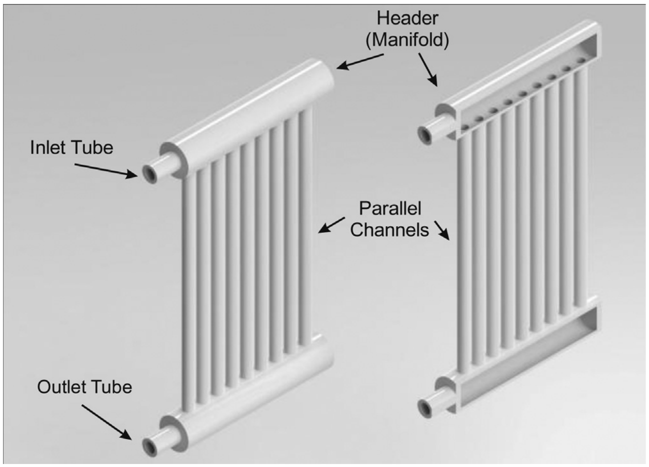

Fig. 1. Typical device with header, feeding tube and parallel channels.

Marchitto et al. [9] commented that uneven two-phase flow distribution may occur inside each channel, owing to the asymmetrical parallel and diagonal flow, and inside the header, owing to the separation of the two-phase mixture in the header–tube junctions. Depending on the two-phase flow regime in the header, the gas and liquid can be distributed unequally in the tubes.

In evaporators a proper distribution is necessary to avoid dryout. This may lead to deficient heat transfer and high temperatures. In condensers, an uneven distribution of the liquid may create regions of less heat transfer due to high liquid loading. Thus, the reduction in capacity due to a maldistribution of the two-phase mass flow rate is more detrimental in evaporators, because the heat transfer coefficient can be decreased in tubes that receive a lower quantity of liquid.

In a heat exchanger in which some channels have single-phase vapor flow, for example, the heat transfer coefficient is lower and the temperature difference between the refrigerant (vapor) and the secondary fluid (air) is reduced as the refrigerant superheats. Therefore, an uneven two-phase flow distribution in these heat exchangers will produce a non-uniform wall temperature, leading to a non-uniform air outlet temperature. This concern is important in applications associated with human comfort, e.g., in automotive air-conditioning, where variations in the air temperature can cause discomfort to the occupants of the vehicle.

Due to the complexity of the two-phase flow structure and diversity of potential situations, there is no quantitative method to predict the distribution of the two-phase flow in headers with parallel channels. The design and optimization of these devices is extremely difficult due to the complexity associated with attempts to control and optimize these components. Therefore, an understanding and prediction of the two-phase distribution in parallel channels is of great importance to avoid such drawbacks.

Several authors have investigated two-phase flow distribution in T-junctions (Azzi et al. [10], He et al. [11]). However, phase separation in headers is so complex that the results and knowledge related to T-junctions cannot be directly applied to multi-channel systems, mainly due to geometrical and operational differences. Nevertheless, in some cases there are header regions where the two-phase flow distributions are similar to those found in T-junctions, for example, in headers that share the same section of the feeding tube (Lee [12], Vist and Pettersen [13]).

In this paper, a review of two-phase flow distribution in headers with parallel channels is presented, covering both macro and micro-channel investigations. For this purpose a total of 66 papers are reviewed including studies on isothermal two-phase flow and two-phase flow with phase change. At least two reviews on the maldistribution of two-phase flow are available. Guglielmini [14] carried out a review of experimental and theoretical studies on