A THEORETICAL STUDY ABOUT MICRO HEAT EXCHANGERS

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Abstract. Applications in thermal and chemical process engineering may benefit from microstructure devices such as micro heat exchangers, micromixers, and microstructure reactors when high heat and/or mass transfer rates are mandatory and where small sizes of the devices are of advantage. The characteristics, advantages, and potentials of microstructure devices with regard to improved and novel chemical and thermal process control have been documented in various publications.

Keywords. Heat transfer, micro, heat exchangers

1. INTRODUCTION

Microstructure devices consist of different components with structural details in the range of a few microns. Thus they have specific advantages resulting from significantly miniaturised characteristic dimensions compared to conventional process engineering solutions. These advantages especially improve exchange properties so as heat exchange and material exchange.

Microstructure devices, in various designs, can be applied to many thermal and chemical operations in process engineering. The manufacturing process is outlined and cross flow and counter flow microchannel devices as well as devices with microcolumn structures in the fluid passages is presented. [2]

For applications in industry and in the laboratory, various micro heat exchangers have been developed for cross flow and counter flow operation. The multilamination principle allows designing the devices with scalable throughputs by keeping the heat transfer properties essentially constant. Moreover, this is a precondition for a fast scale-up of a process which has been developed in the laboratory and will be transferred to throughputs of technical relevance.

Devices for technical applications are characterized by thousands of uniform microchannels per flow passage and by specific heat transfer surfaces of up to 15,000 m^2/m^3.[1]

As a result of typical cross section of about 100 microns high, relevant heat and mass exchange are achieved more efficiently than in conventional equipment in order of magnitudes. The advantages in comparison with conventional equipment are:

- Outstanding heat exchange rates
- Improved material transfer
- Technical flow through in compact sizes
- Improved safety on production plants
- High pressure resistance

These properties enable exact process control of mass and heat exchange leading to purer products, better yields and low resource consumption. Furthermore, microstructure devices provide innovative processes, that were previously not possible in conventional solutions. [2]

2. TYPE OF MICRO HEAT EXCAHNGERS

2.1. Cross flow Microchannel Devices

Figure 1 shows a standardized microchannel reactor/heat exchanger of cross flow design having a cubical transfer volume of 1 cm^3. It has been fabricated for the laboratory and small-throughput applications in technical processes. With water, throughputs in the range of 700 kg/per hour and per passage have been applied at pressure drops of up to 6 bar. [1]

Fig. 1 Cross flow micro heat exchanger.

2.2. Counter flow Devices

Counter flow devices are mandatory for thermal applications where approximately the same thermal conditions have to be provided in every microchannel and where the temperature difference between the two fluids is to be kept low. In chemical applications, counter flow devices may have advantages when, for example, exothermic and endothermic processes will be combined [3].

Design. The designs of known counter flow micro heat exchangers always include contributions from a cross flow heat exchange. These regions are normally tried to be avoided, e.g., by keeping overlapping regions of inlets and outlets small and optimizing the flow distribution, or by a racked structure in order to reduce the influence of the overlapping regions, shown in figure 2. [1]

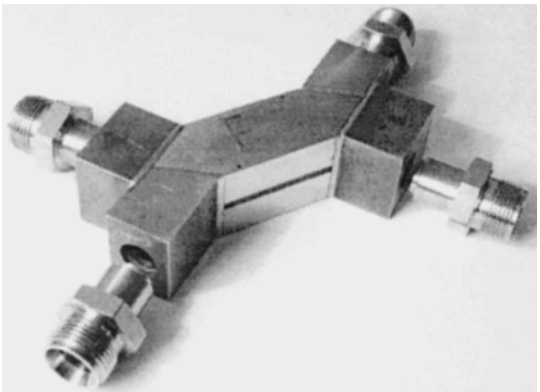

Fig. 2. Counter flow micro heat exchanger.

2.3. Devices with Enhanced Heat Transfer

The limiting factor of the overall heat transfer in microstructure devices is the heat transfer from the fluid to the wall or vice versa. With a simple comparison based on the comparison of thermal resistances, it can be found that with a wall thickness in the range of 100 μm, the thermal resistance of the separating wall makes only a minor contribution to the total thermal resistance, even if materials with low thermal conductivities are used.
Therefore, a strategy for further enhancement of the overall heat transfer coefficient should concentrate on the heat transfer between the fluid and the surface of the wall. One approach certainly is a reduction of the hydrodynamic diameters of the microchannels.

However, this may have disadvantages in technical applications where small particles may be present in the media and there would be the risk of blocking the channels. A possible solution could therefore be to use designs with wider openings but different internal microstructures. In order to achieve high heat transfer coefficients, flow regimes are necessary which differ from the laminar flow in microchannels. This can be achieved, for example, with structures consisting of microcolumns instead of microchannels, a design which has been used, e.g., for electronics cooling.

3. MICROSTRUCTURE HEATERS AND EVAPORATORS

Controllable heating of fluids in process technology is normally done either by heat exchangers driven by heating fluids or by electrical heaters. However, available systems may have technical limits or disadvantages for the user. On the one hand, heat exchangers driven by heating fluids have an upper temperature limit depending on the fluid used. They are normally limited to operation temperatures of up to 350 C, and the initial expenditure for installation and operation of a thermooil circuit is high [3].

On the other hand, conventional electrical heating elements can be rather voluminous. Moreover, they may have a high temperature difference between the fluid and the surface of the heater, which may cause problems with fluids that are sensitive to overheating. Due to the low surface-to-volume ratio, the heating rates are lower than those realizable with microstructure devices. Hence, the combination of microchannel structures with electrical resistance heaters should lead to compact and efficient heater devices.

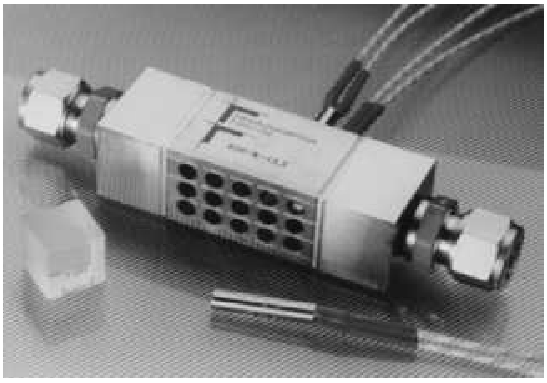

Fig. 3 Electrically heated microstructure device for gases and liquids.

For electrically heated microstructure devices, cartridge resistor heaters were chosen as heating elements. Between two stainless steel plates as top and bottom of the microstructure heat exchanger, different numbers of microstructured stainless steel foils and spacer blocks were arranged in alternating order and welded. The heater cartridges were inserted into holes of the spacer blocks. Then the micro heat exchanger was adapted to tube fittings as fluid connectors. Different microstructures with microchannel and microcolumn geometries have been investigated for their heating and evaporation properties.

Depending on the number and the power of the heater cartridges, the overall power of heater device has been in the range of several hundred watts up to several kilowatts. With the present heat exchanger device having 15 cartridges, a maximum electrical power of 15 kW can be reached. A photograph of the device is given in Figure 3. [1]

4. STATIC MICROMIXERS

Besides micro heat exchangers and reactors, the use of static micromixers may have distinct advantages in process engineering, because static micromixers provide for fast and complete mixing of the reactants. [1]

One of the working principles of such mixers is the separation of the fluids in numerous layers of substreams and a subsequent multilamination of these layers at the outlet of the mixer. Because of the small thickness of such a layer, typically in the range of 100 μm or less, the mixing efficiency by diffusion is high and mixing times are correspondingly low, shown in figure 4.

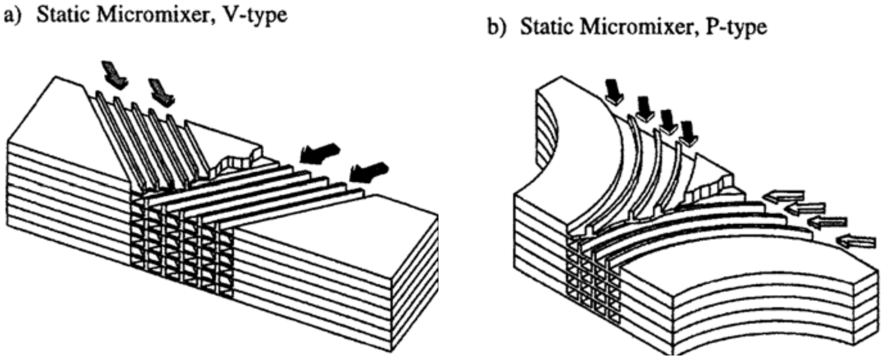

Fig. 4. Schematic designs of static micromixers:
(*a*) V-type; (b) P-type.

5. MICROSTRUCTURE REACTORS

Due to their outstanding heat and mass transfer capabilities, chemical process technology may benefit in different ways from microstructure devices. The main reasons are the possibility of precise control of the reaction conditions, especially temperature and residence times, which is a precondition to achieve high space-time yields. Another aspect is the inherent safety of the devices due to their small inventory of reaction mixture, their pressure resistance, leak tightness, and the flame-arresting capabilities of the microchannels. Besides the use of heat exchangers and reactors with adequate throughputs in production processes, smaller devices have been applied successfully as laboratory tools for the investigation of chemical reactions.

For noncatalyzed or homogeneously catalyzed reactions, devices similar to those mentioned in the previous chapters of this article can be utilized. However, many chemical reactions, especially in automotive, chemical production, and space and aviation industries are heterogeneously catalyzed and need microstructure reactors which are equipped with catalytic coatings. [1]

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