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École doctorale "Sciences pour l'ingénieur : Mécanique, Physique, Micro et Nanoélectronique", Université d'Aix-Marseille

Graduate Program on Mechanical Engineering, POSMEC – UFSC

CONVECTIVE BOILING OF R-134A IN PARALLEL MICROCHANNELS AND DISTRIBUTION ANALYSIS OF AIR-WATER TWO PHASE FLOW IN AN DISTRIBUTOR COUPLED TO MICROCHANNELS

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Overview:

- Part A - Convective Boiling in microchannels
  - ✓ Introduction: Motivations and Objectives
  - ✓ Brief Literature review
  - ✓ Materials and Methods
  - ✓ Analysis of experimental results
  - ✓ Conclusions

- Part B - Two-phase flow distribution
  - ✓ Introduction: Motivations and Objectives
  - ✓ Brief Literature review
  - ✓ Materials and Methods
  - ✓ Analysis of experimental results
  - ✓ Conclusions

PARTE A

CONVECTIVE BOILING OF R-134A IN PARALLEL MICROCHANNELS

Part A: Introduction

Motivations:

- ✓ The increasing development of practical engineering applications to micro-system components;
- ✓ Development of new technologies and devices for energy conversion and heat transfer;
- ✓ The recent emergence of new applications demanding high heat flux dissipation;
- ✓ The necessity improving energy efficiency and material savings;
- ✓ Interest in various industrial applications such as commercial refrigeration, automotive air conditioning, cooling of electronic components, among others.

Motivations:

Advantages of using heat exchangers with two-phase flow in micro-channels:

- ✓ Dissipates large amounts of heat flux;
- ✓ Keep a more uniform temperature distribution on its surface due to almost constant temperature of the fluid in two phase systems;
- ✓ Provides a higher heat transfer coefficients with lower mass flow rates when compared with single-phase systems;
- ✓ Reduced size, improved efficiency and a little amount of fluid, which is beneficial for cost and system security.

Part A: Introduction

Objectives:

- ✓ To achieve the domain and understanding of the physical mechanisms involved in flow boiling in microchannels in attempts to increase the effectiveness of the systems that use them;
- ✓ To verify the influence of input parameters on the flow boiling heat transfer coefficient;
- ✓ To analyze the applicability of the models and correlations proposed in the literature for the flow boiling in microchannels, concerning: heat transfer coefficient and pressure drop;
- ✓ To verify the behavior and the influence of input parameters on ONB in microchannels;

✓Part A: Brief Literature review

Macro-to-microscale transition in evaporation:

Kew e Cornwell (1997):

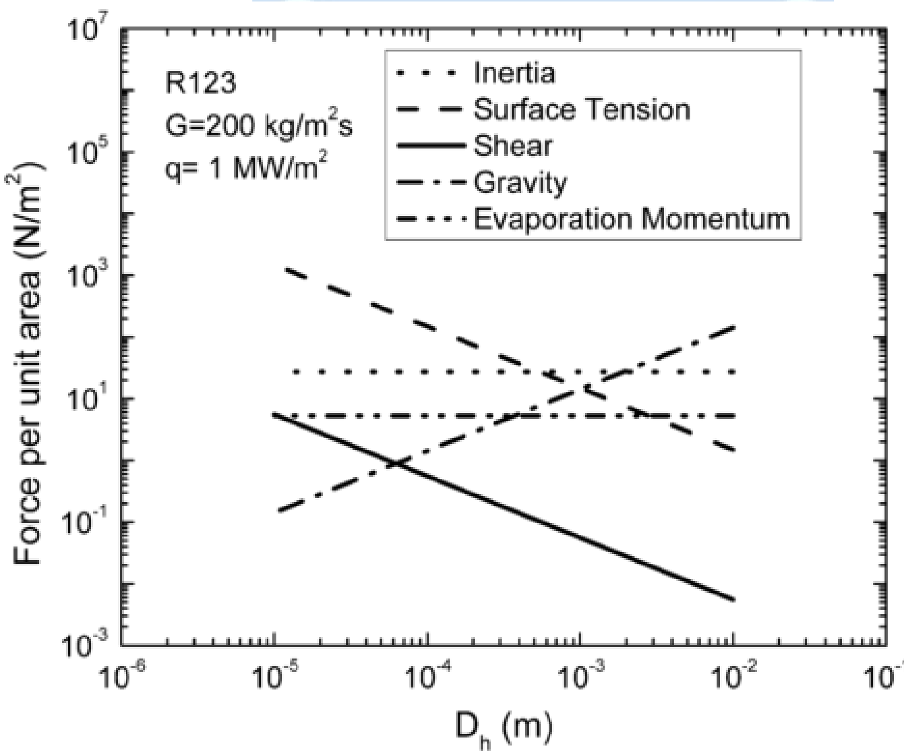
$$Co = \left[\frac{\sigma}{g(\rho_l - \rho_v)d_h^2}\right]^{0,5}$$

Lee e Mudawar (2009):

$$C_D\left(\frac{\pi {d_b}^2}{4}\right)\frac{1}{2}\rho_l U^2 \approx \pi d_b \sigma$$

$$d_{tran,lam} = \frac{160(\sigma\rho_l - 3\mu_l G)}{9G^2}$$

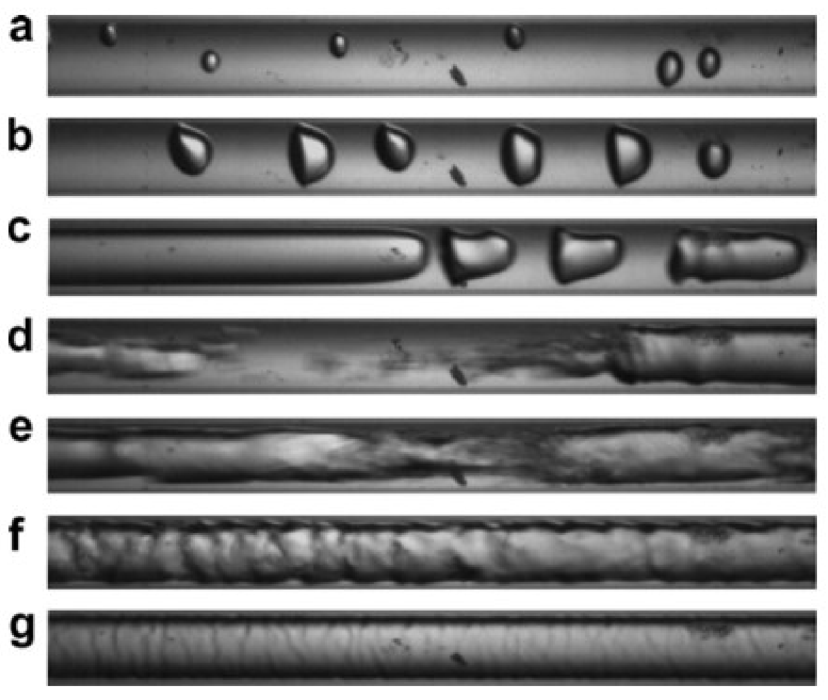
Kandlikar (2010):



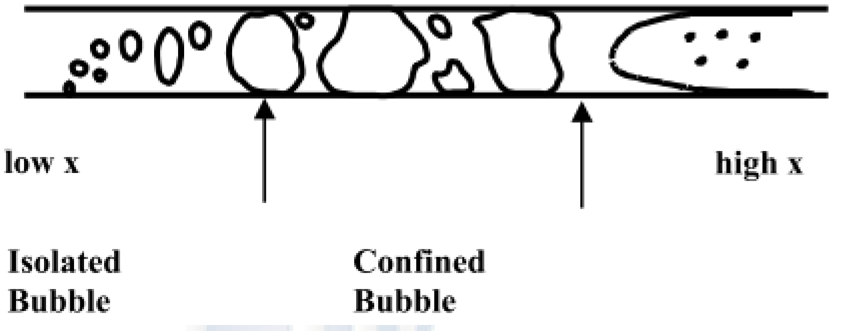
✓Part A: Brief Literature review

Flow Patterns in microchannels:

Revellin e Thome (2007)



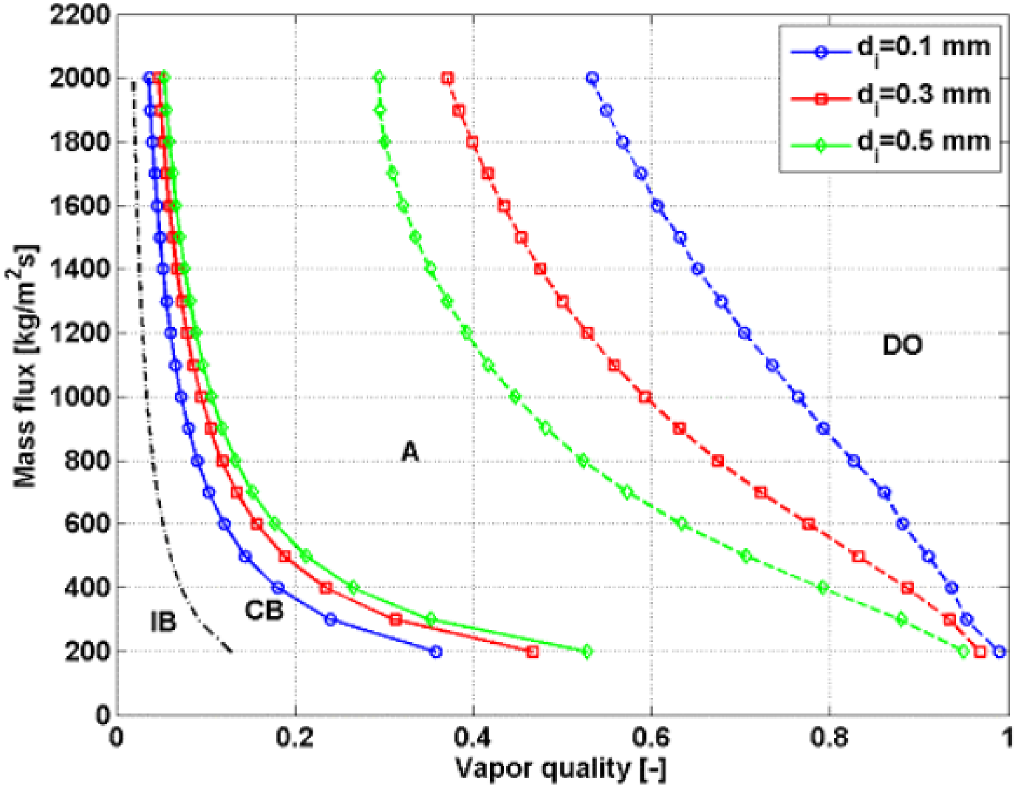
Cornwell e Kew (1993)



✓Part A: Brief Literature review

Flow pattern map for microchannels:

Revellin e Thome (2007a)



(IB: isolated bubble regime; CB: coalescing bubble regime; A: annular flow regime; DO: dry out regime)

✓Part A: Brief Literature review

Pressure drop:

Homogeneous Model

$$Fe = \frac{j_v}{j_l} = \frac{\rho_l}{\rho_v}\frac{x_v}{(1-x_v)}\frac{(1-\alpha)}{\alpha}$$

$$\Delta p_{at,bif} = \frac{2 f_{bif} G^2 L}{d_h \rho_{bif}}$$

Separated flow models:

Mishima e Hibiki (1996)

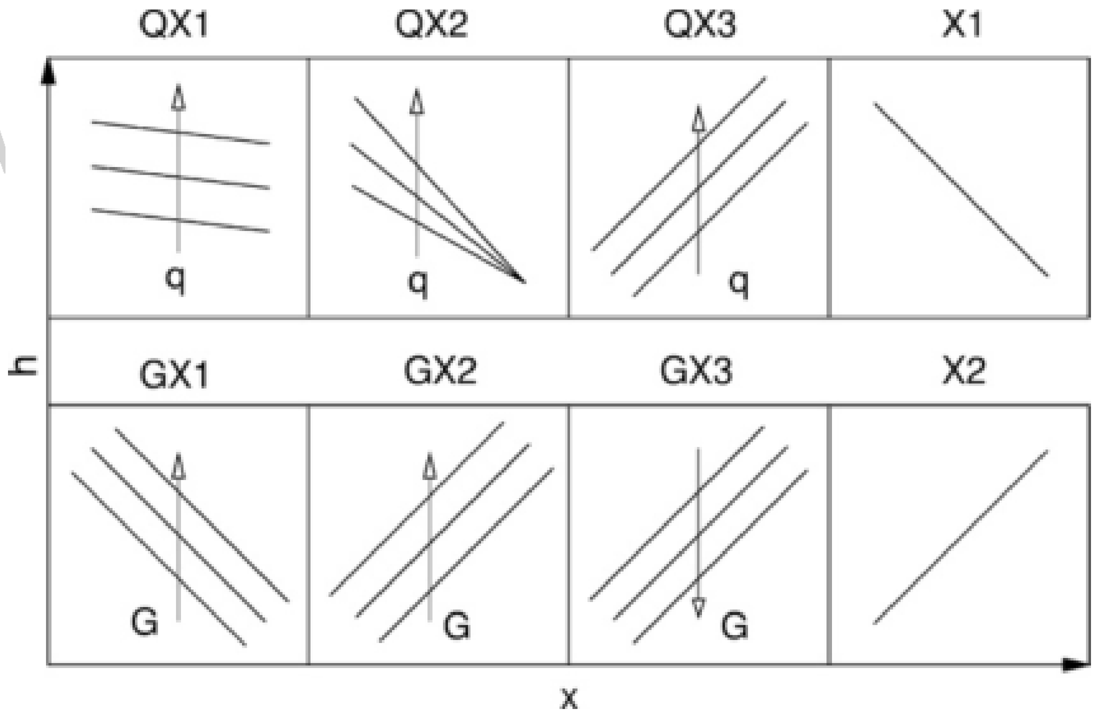
$$\Delta p_{at} = \frac{2G^2 L}{D_h x_v}\int_{x_{v,ent}}^{x_{v,sai}} f_l (1-x_v)^2 v_l \,\Phi_l^2 dx_v$$

$$\Phi_l^2 = 1 + \frac{C}{X} + \frac{C}{X^2} \qquad C = 21(1 - exp(-0{,}319 D_h)$$

✓Part A: Brief Literature review

Heat transfer in microchannels:

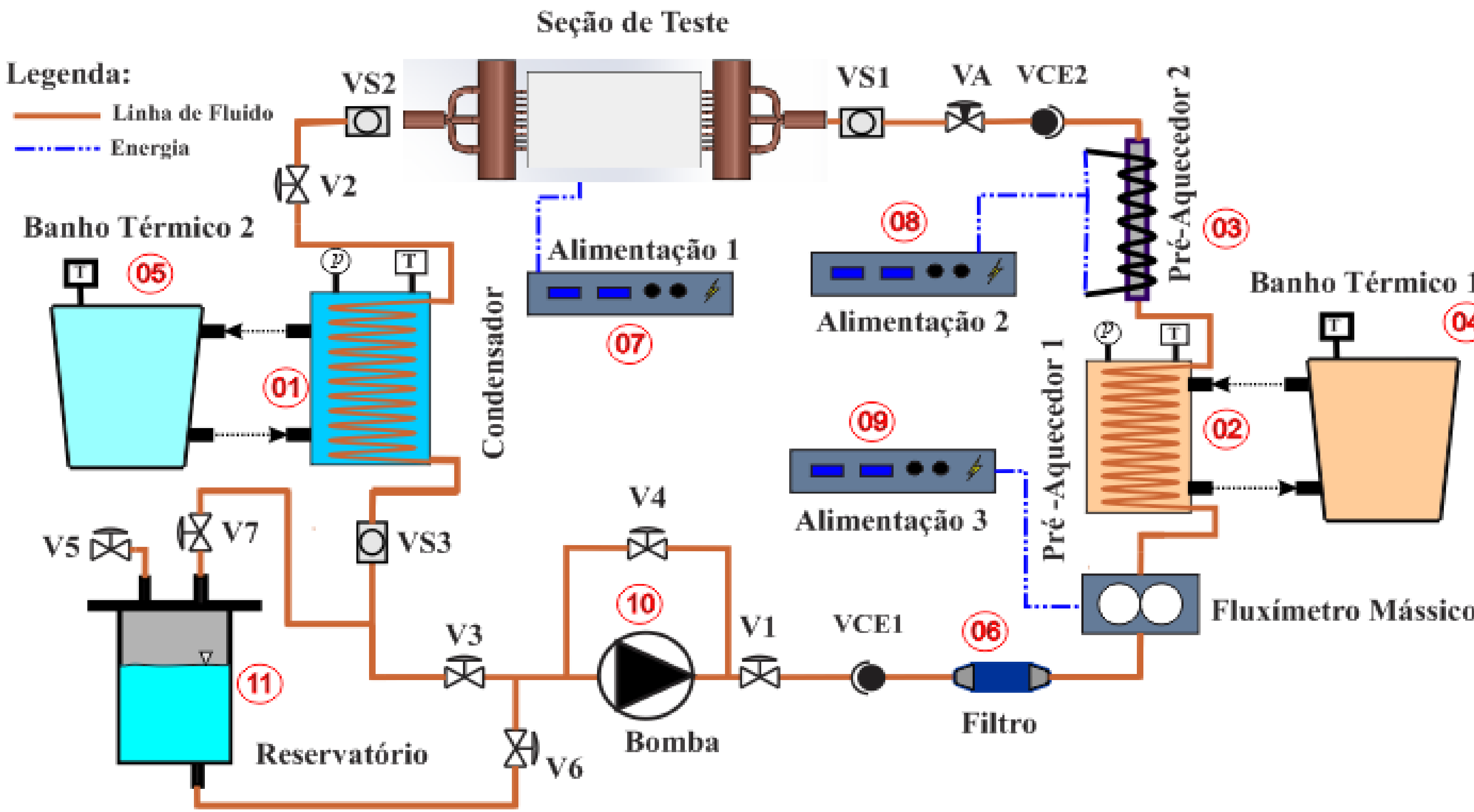
Different trends were found:



h vs. x behaviors identified in the literature by Agostini and Thome (2005)

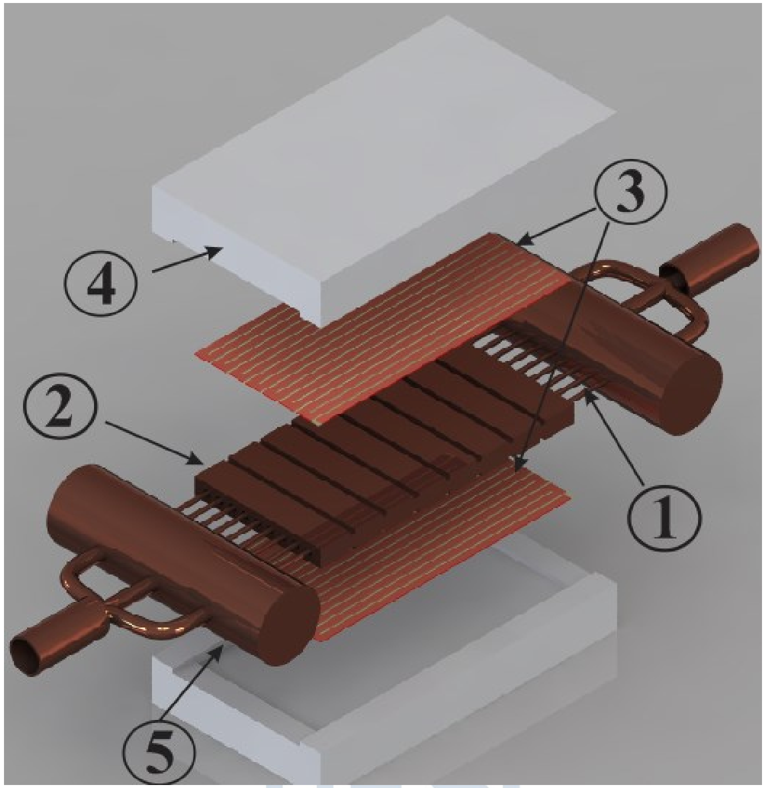
✓Part A: Materials and Methods

Experimental Setup:

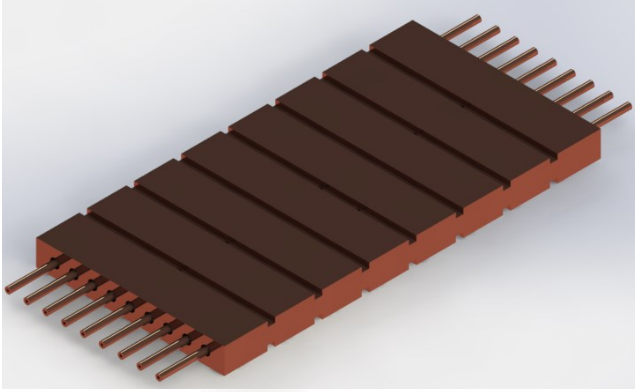


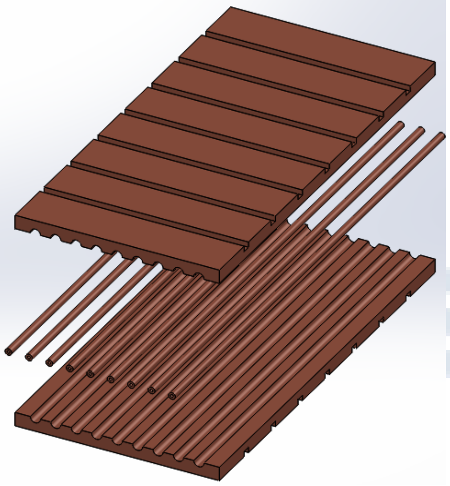
✓Part A: Materials and Methods

Test Section:



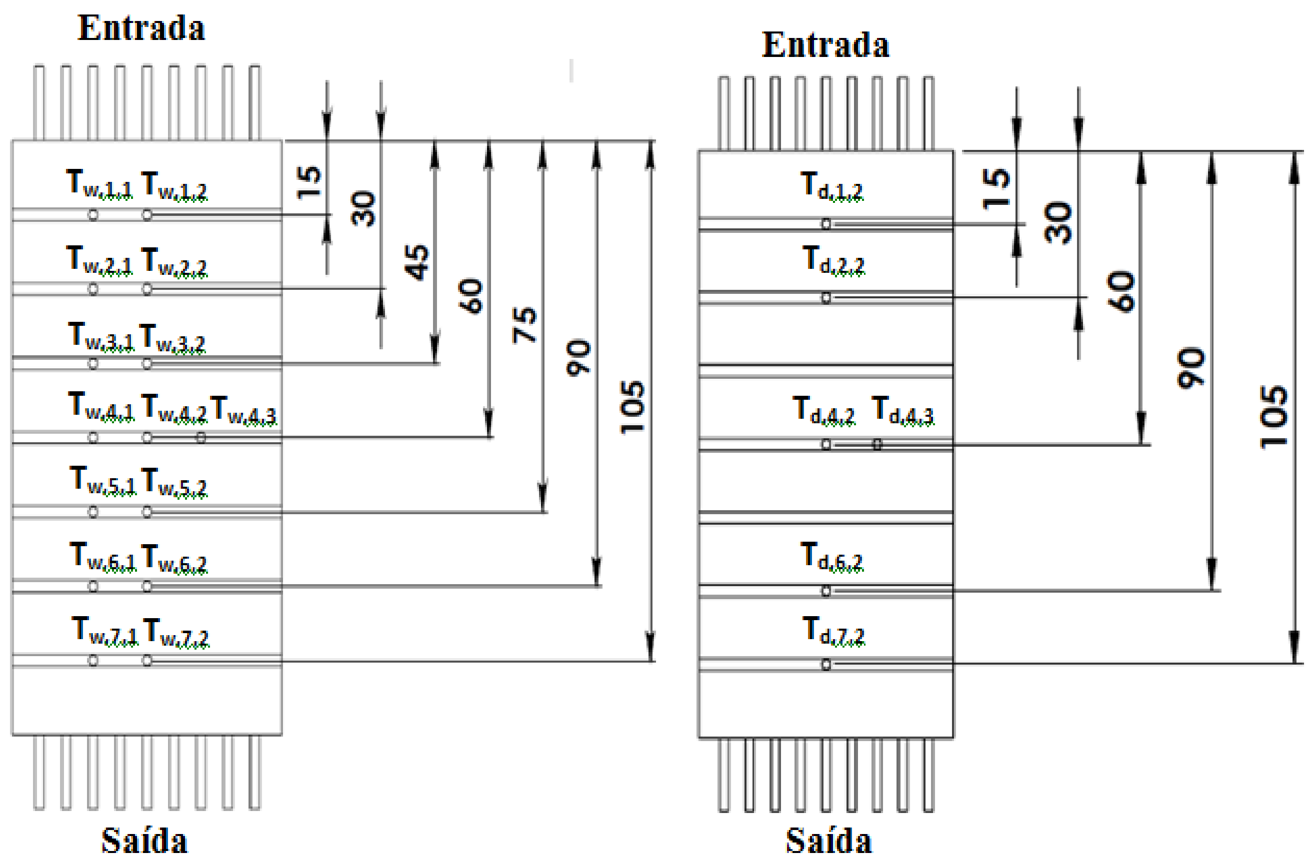
(1) microchannels; (2) cooper plate; (3) skin heaters; (4)Teflon blocks; 5) Plenum





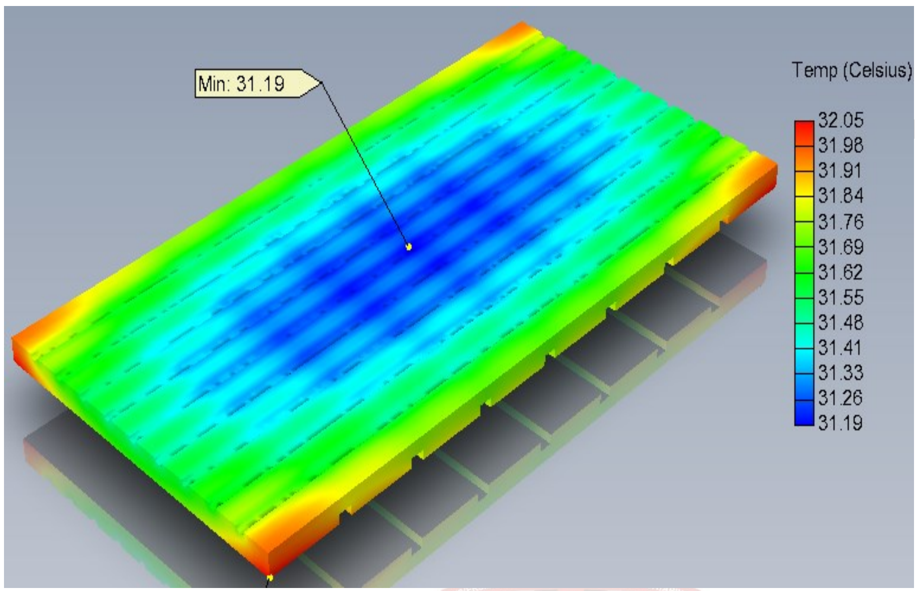
✓Part A: Materials and Methods

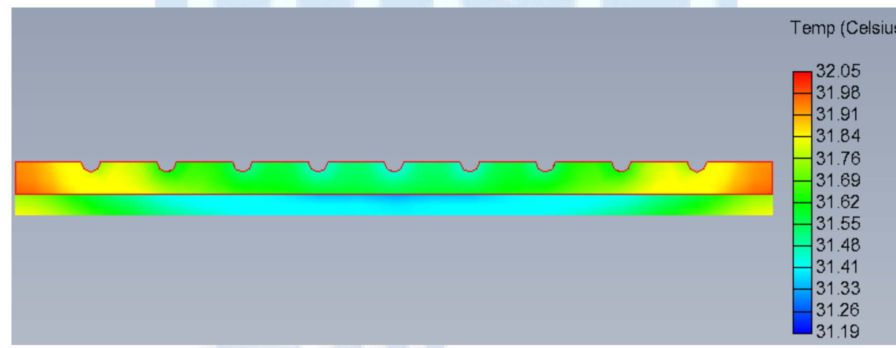
Thermocouples position in test section:



✓Part A: Materials and Methods

Conduction heat transfer simulation in the plate with microchannels:





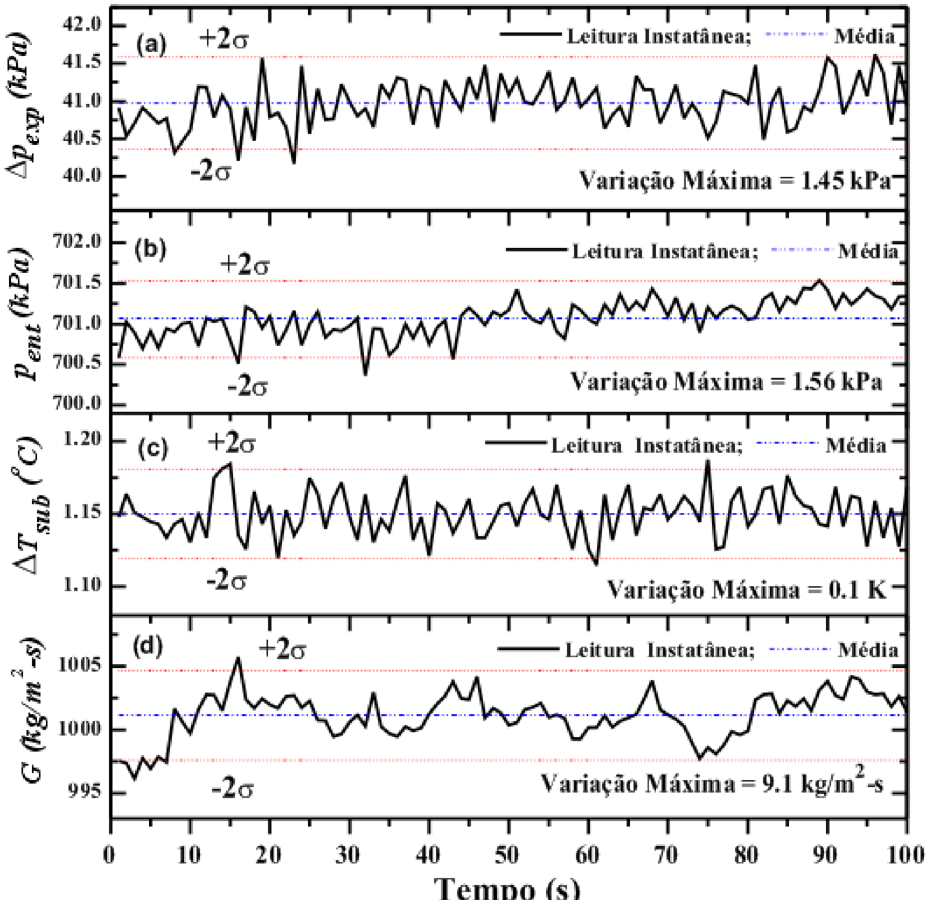
$T_f = 25°C$, $h = 6\ kW/m^2K$, $P = 100\ W$

(a) 3D view

(b) Cross section

✓Part A: Materials and Methods

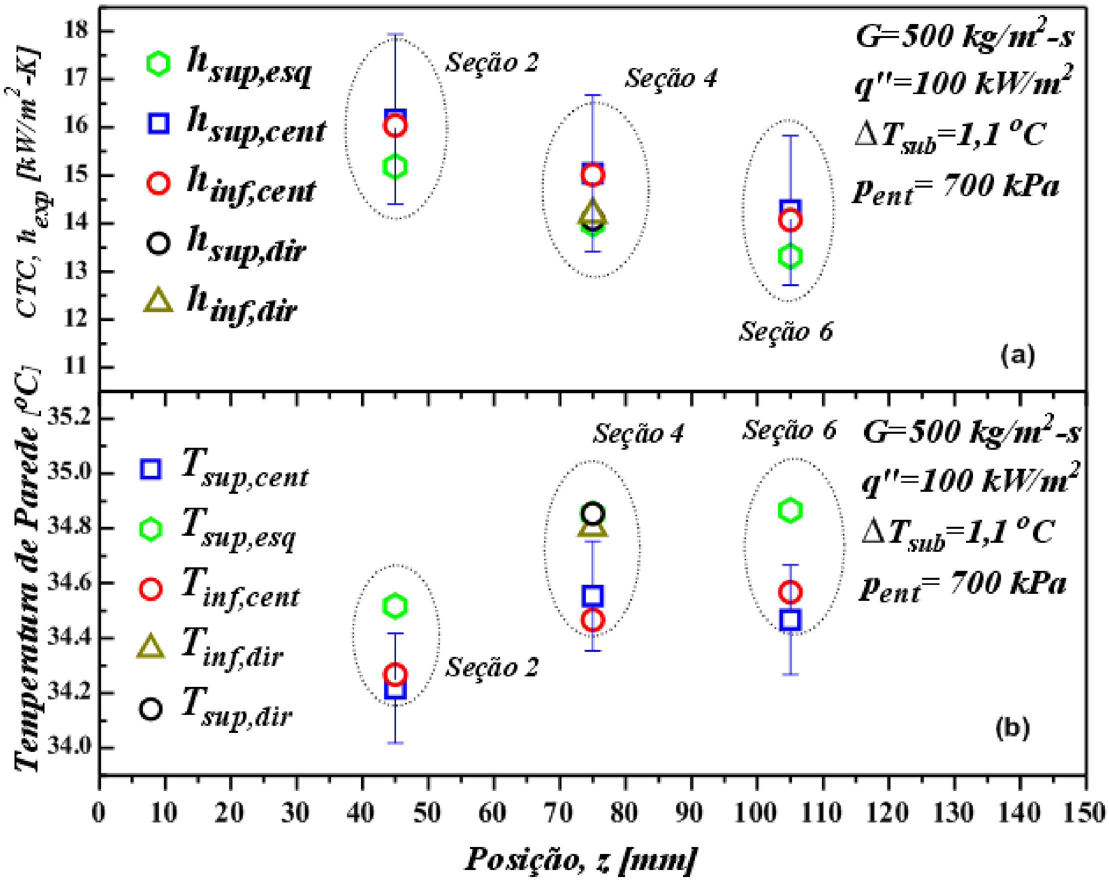
Evaluation of stability during tests:



G=1001 kg/m²-s; p_{ent}=701 kPa; ΔT_{sub}=1,2 °C;
Δp_{exp}=40,9 kPa; q''=170 kW/m²

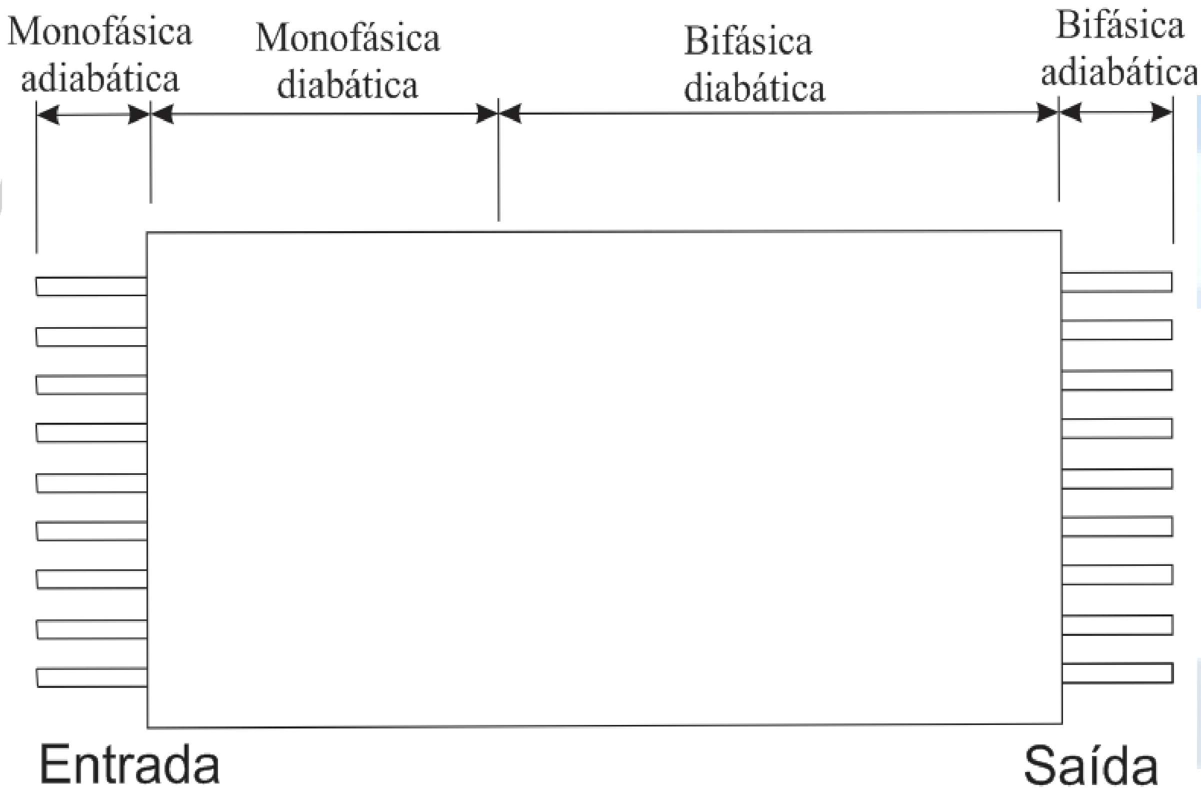
✓Part A: Materials and Methods

Uniformity of heat distribution:



✓Part A: Materials and Methods

Data reduction:



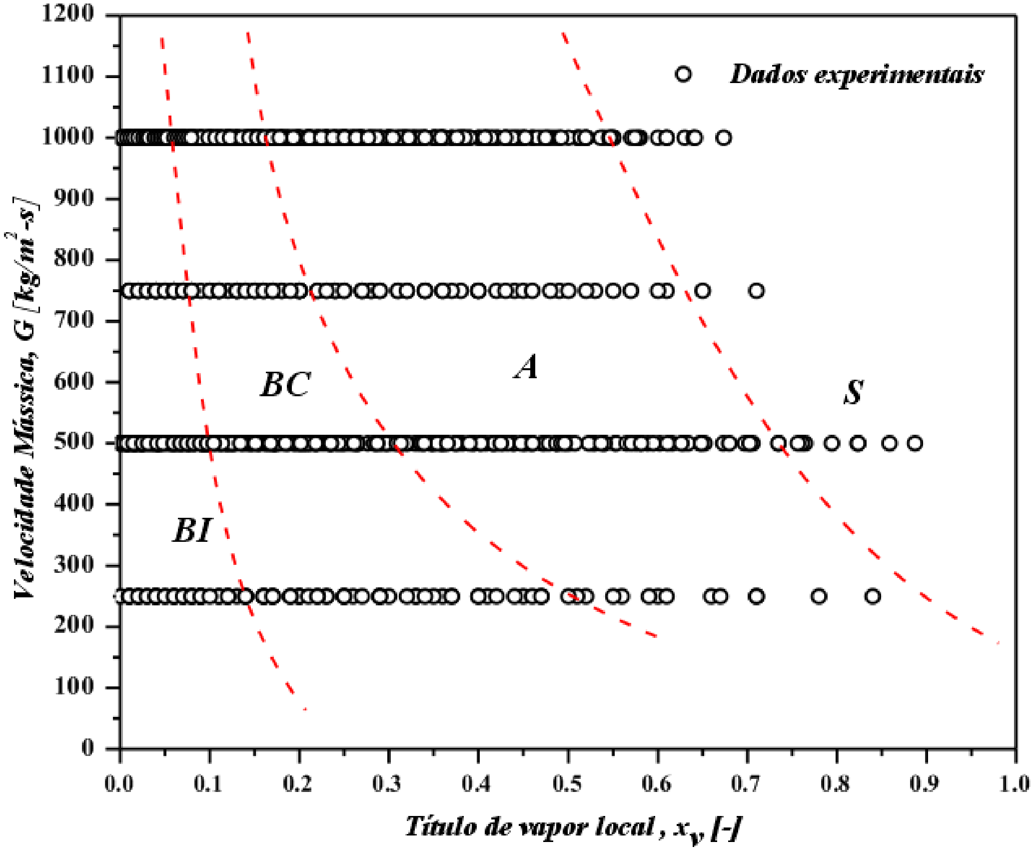
✓Part A: Analysis of results

Characterization of the test conditions:

Parameters	Values
Mass Velocity, G [kg/m^2-s]	250; 500; 750 e 1000
Heat Flux , q” [kW/m^2]	5,0 - 220,0
Vapor quality; x_v [-]	0 – 0,89
Inlet Pressure, p_{ent} [kPa]	600; 700 e 900
Saturation Temperature, T_{sat} [^{o}C]	21,55; 26,7 e 31,5
Subcooled degree, ΔT_{sub} [^{o}C]	1,0; 10,0 e 20,0

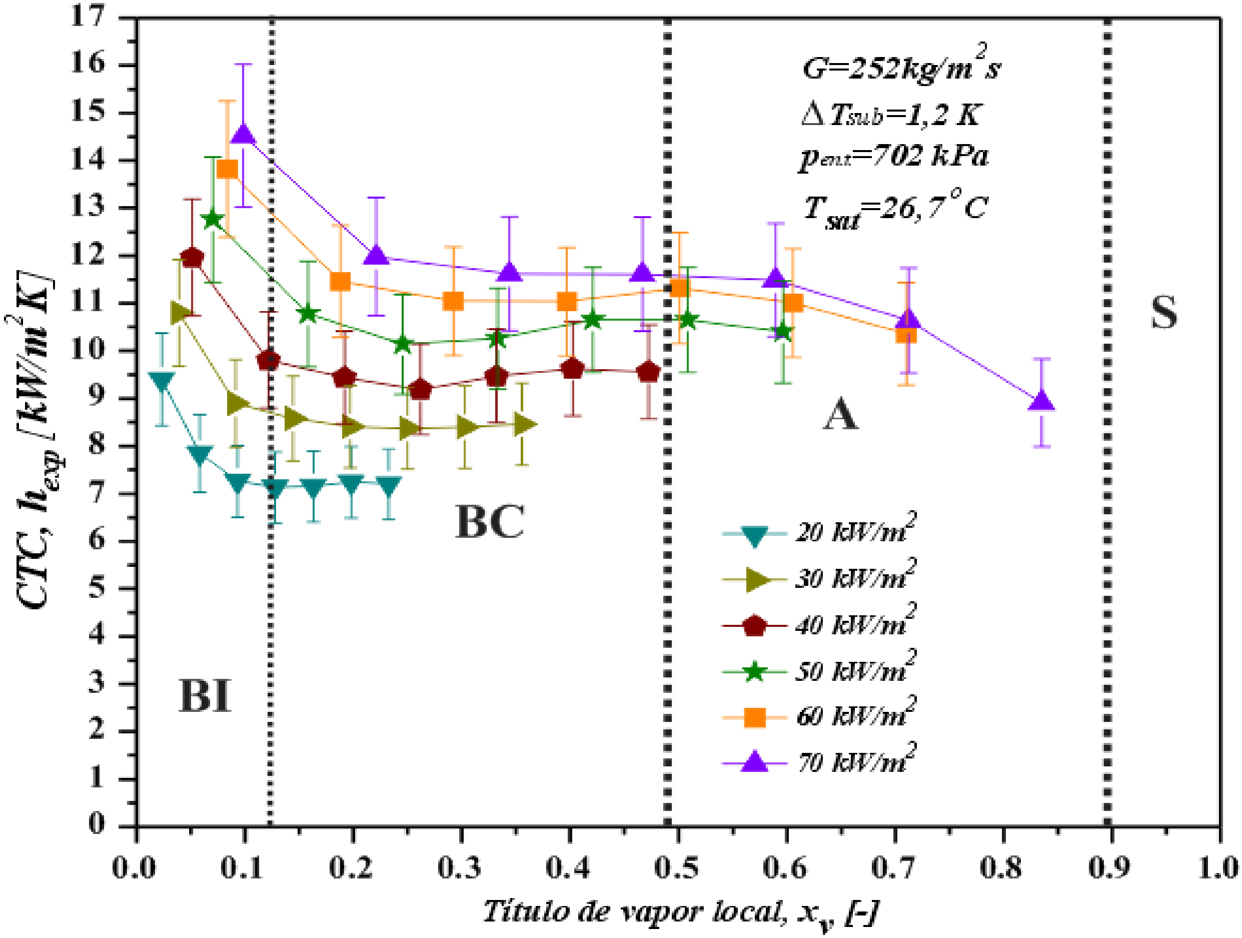
✓Part A: Analysis of results

Experimental data on flow pattern map of Revellin and Thome (2007a) :



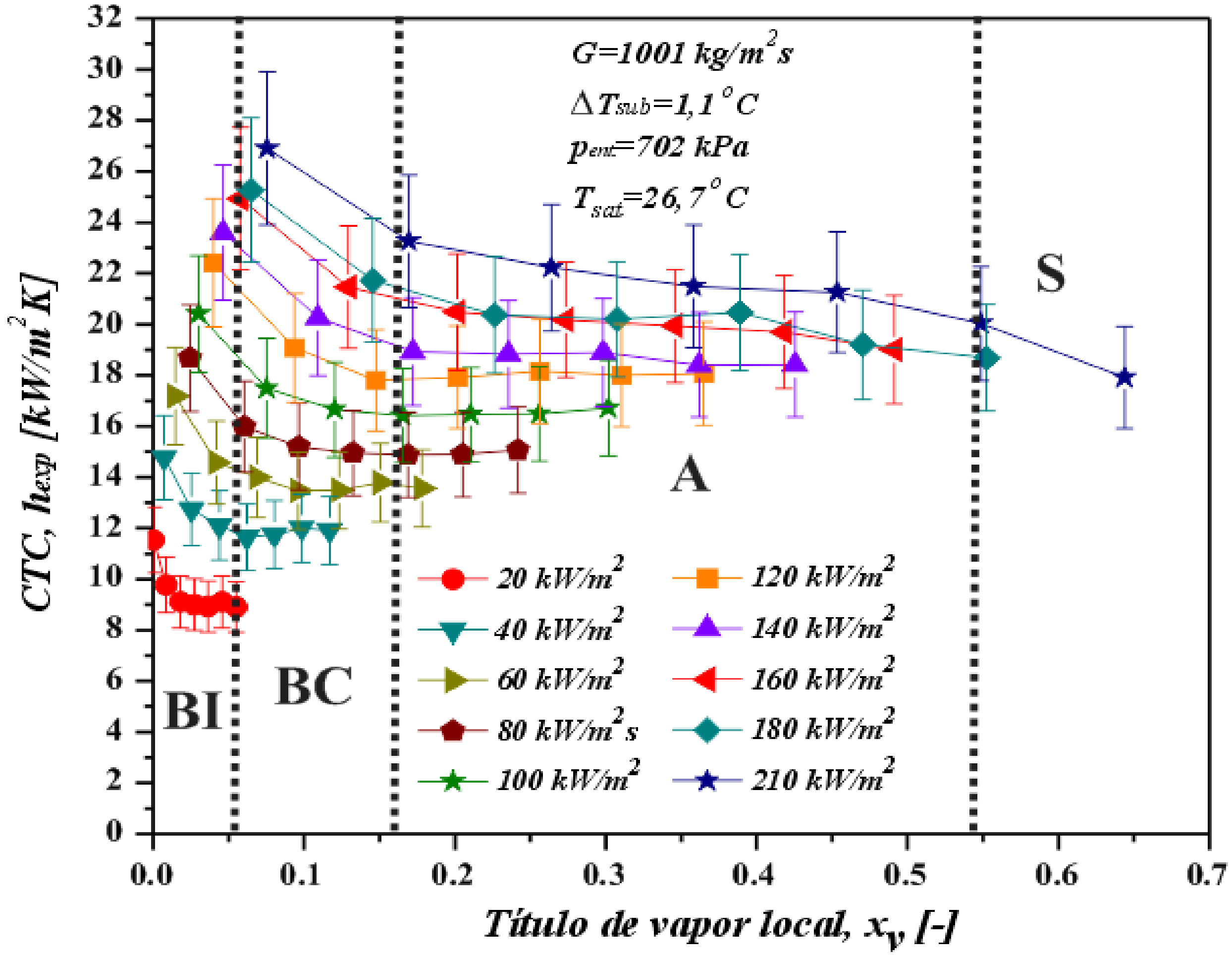
✓Part A: Analysis of results

Heat transfer : Influence of flow regime on the heat transfer:



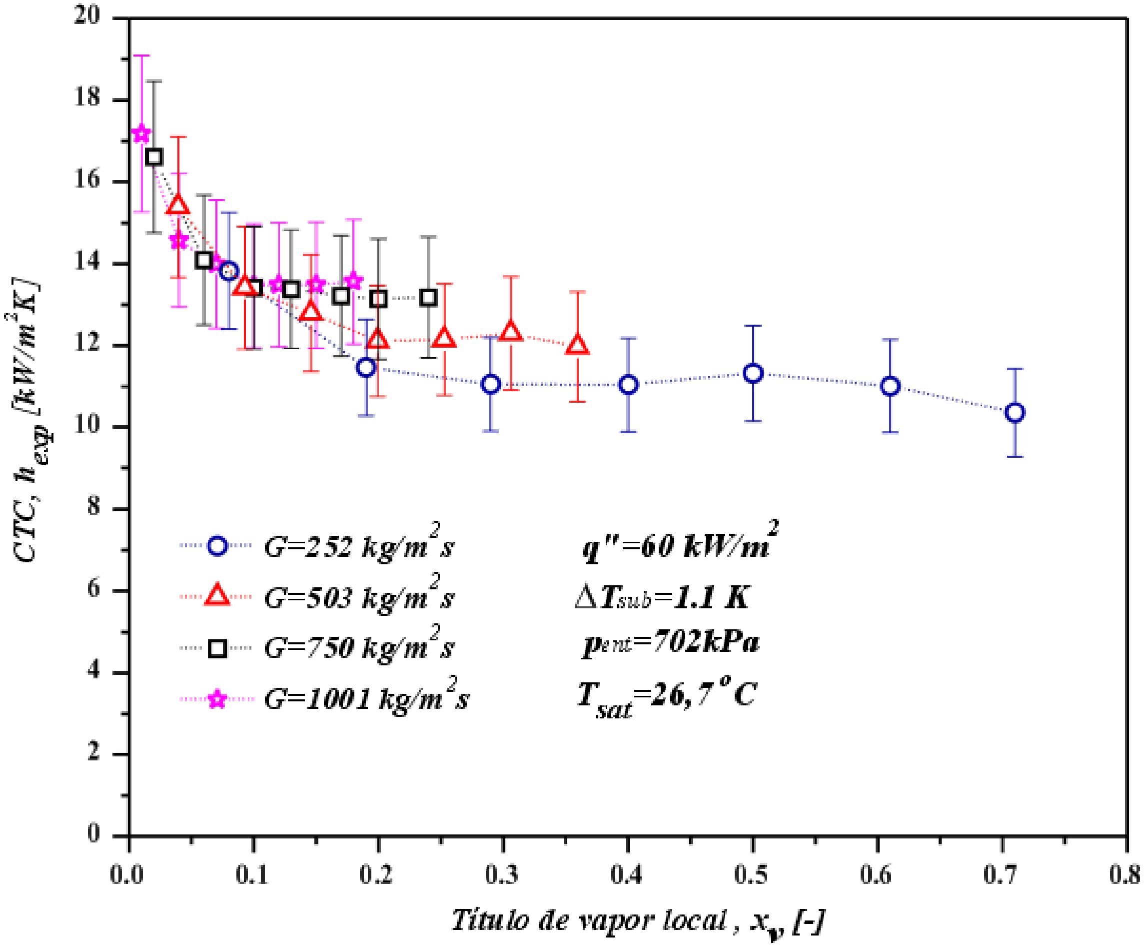
✓Part A: Analysis of results

Heat transfer : Influence of flow regime on the heat transfer:



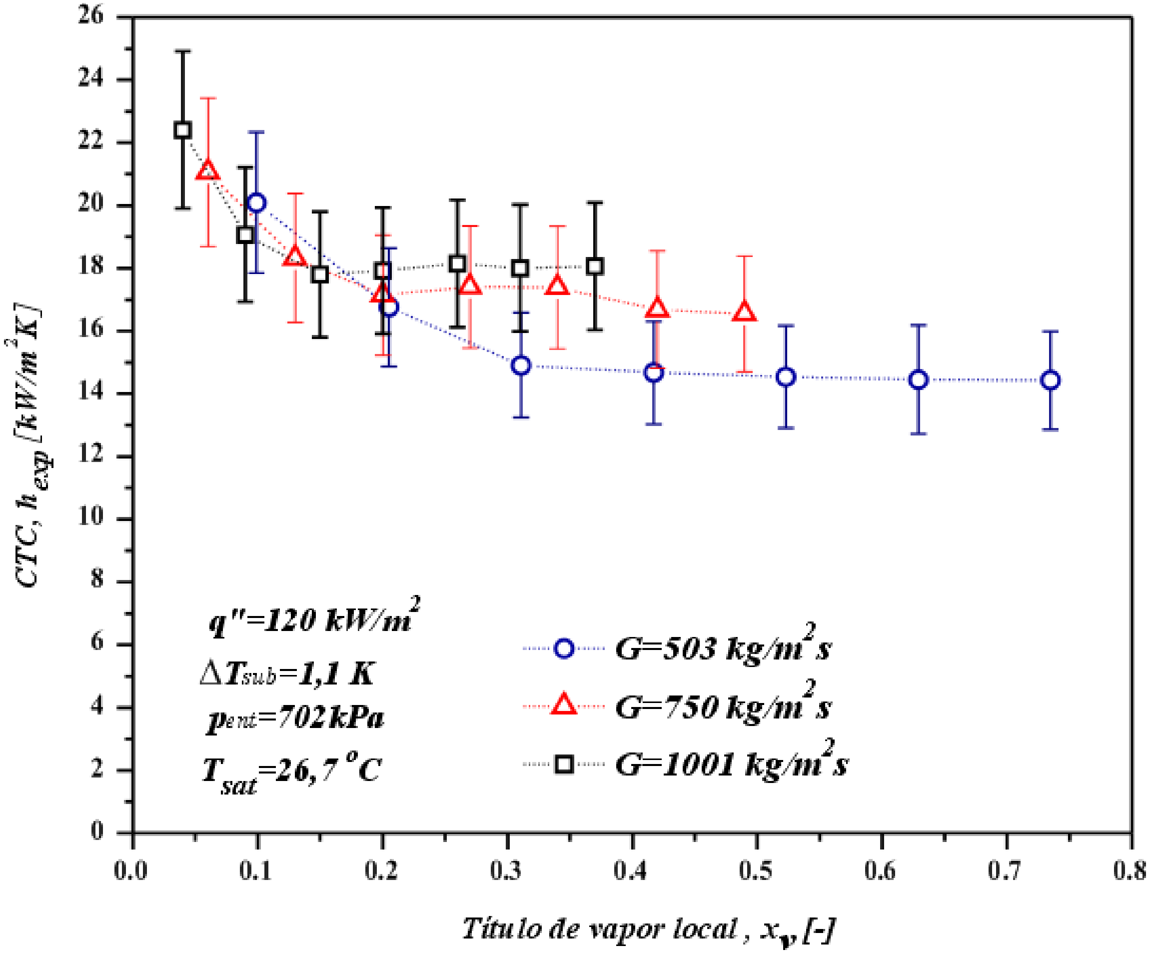
✓Part A: Analysis of results

Heat transfer : Influence of mass velocity on the heat transfer



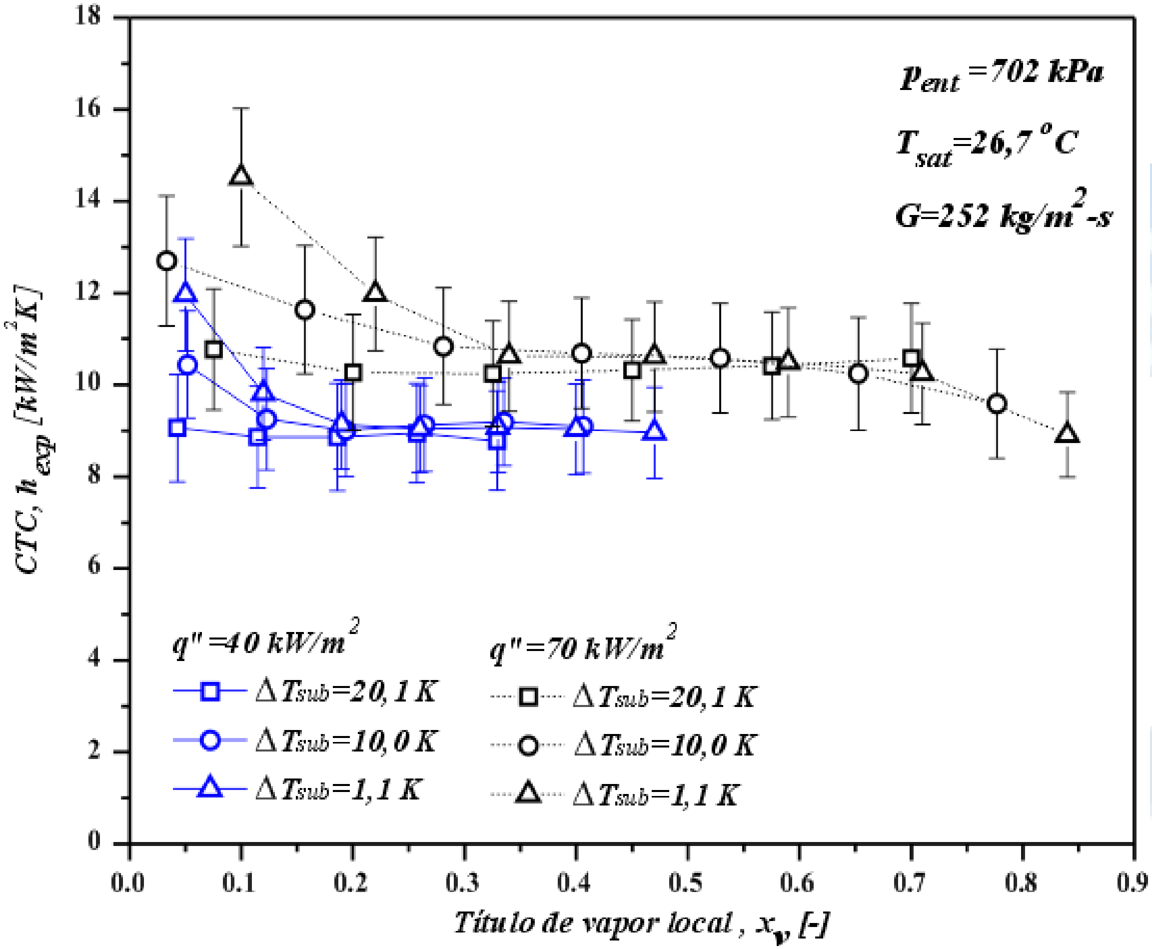
✓Part A: Analysis of results

Heat transfer : Influence of mass velocity on the heat transfer



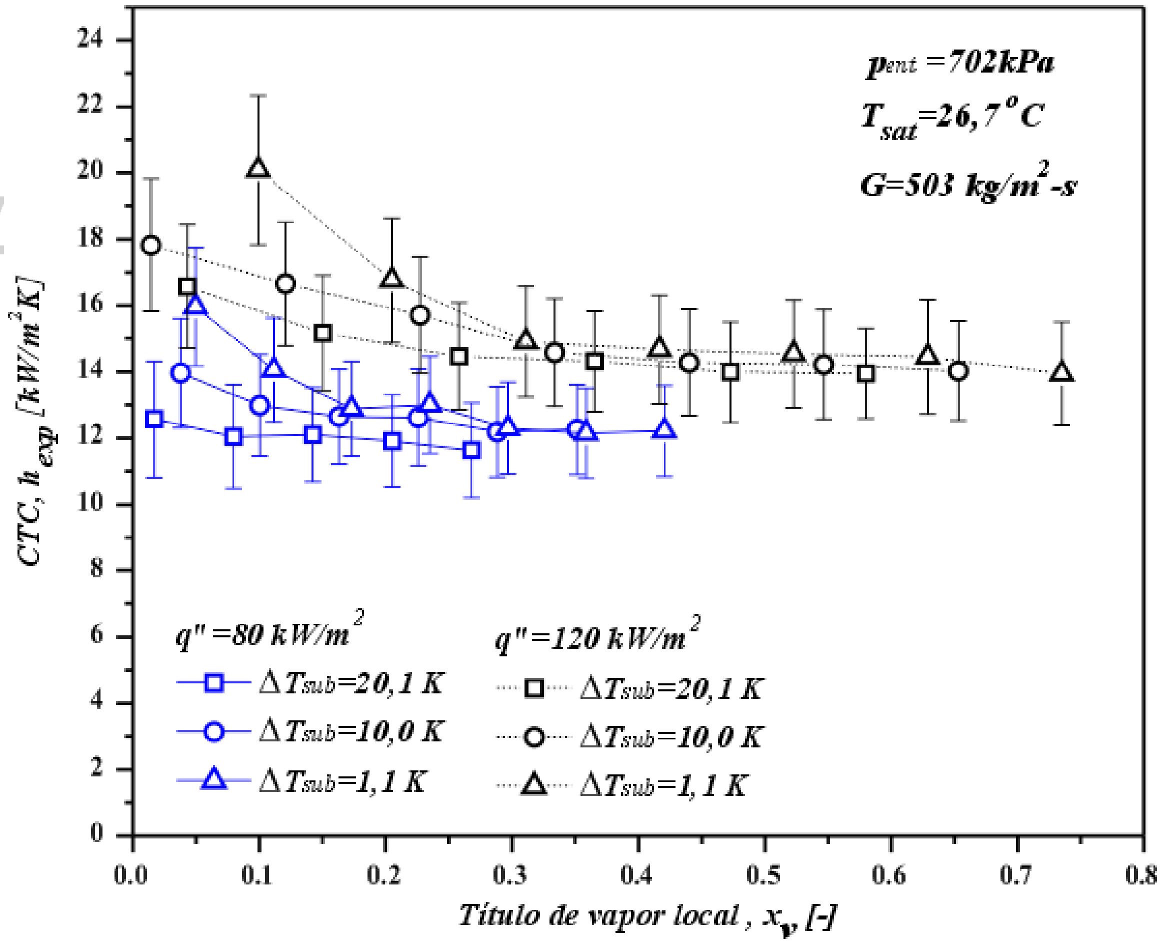
✓Part A: Analysis of results

Heat transfer : Influence of subcooled degree on the heat transfer



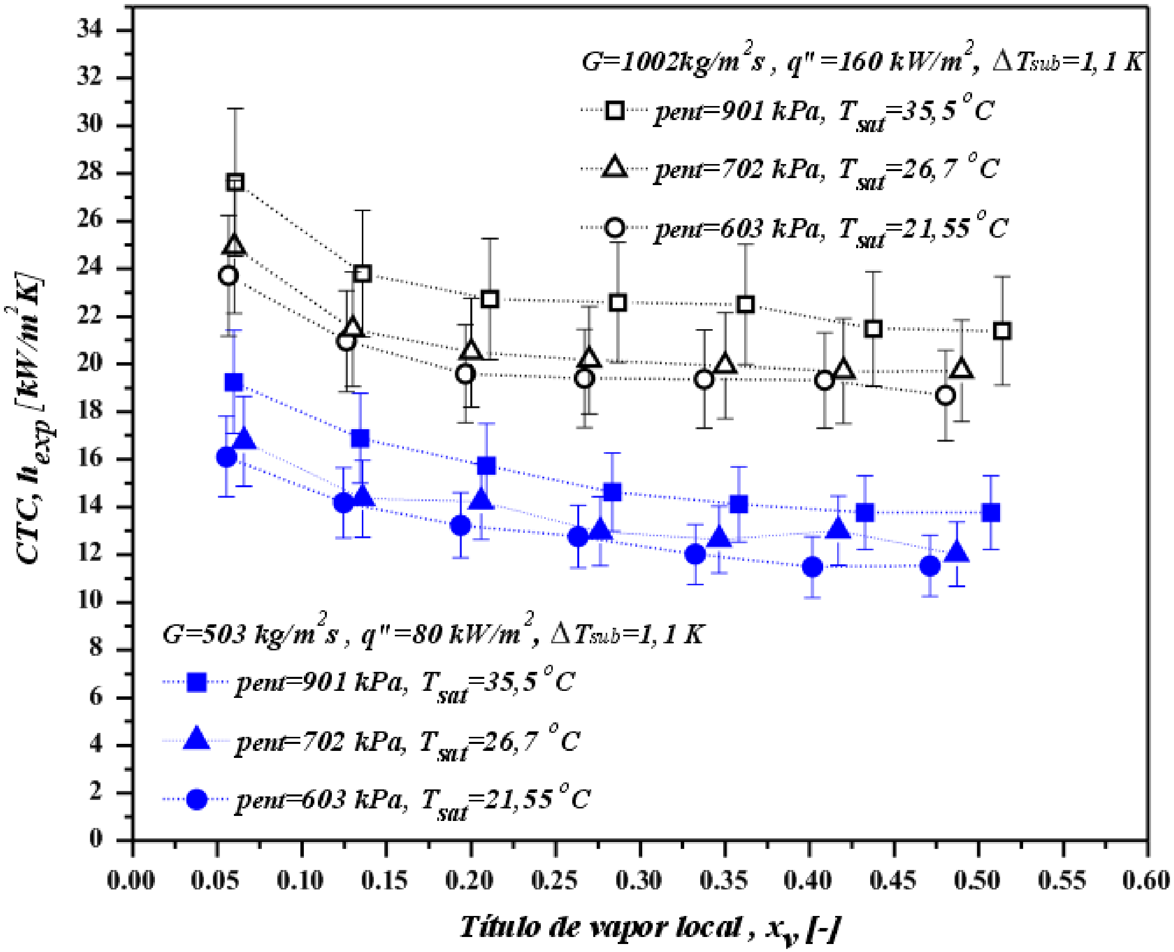
✓Part A: Analysis of results

Heat transfer : Influence of subcooled degree on the heat transfer



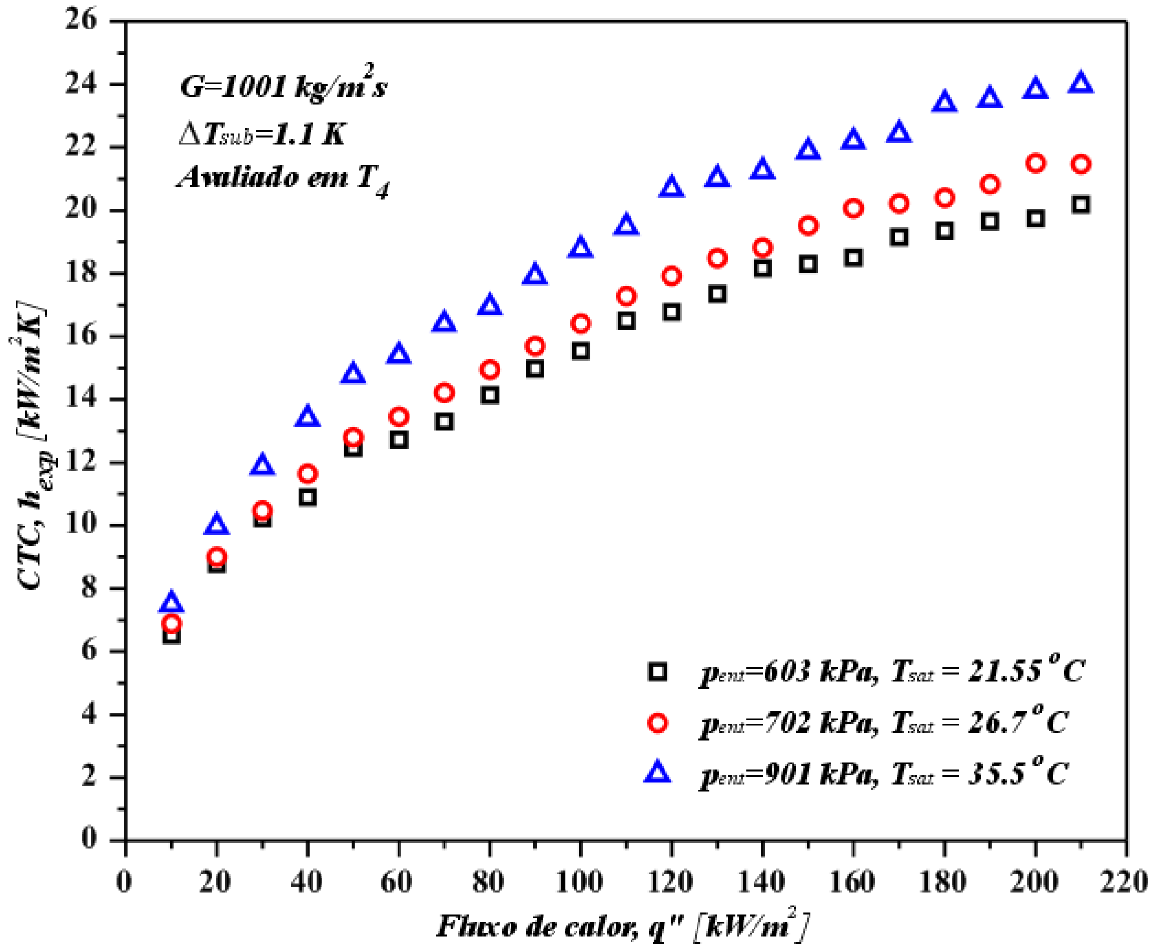
✓Part A: Analysis of results

Heat transfer : Influence of inlet pressure on the heat transfer:



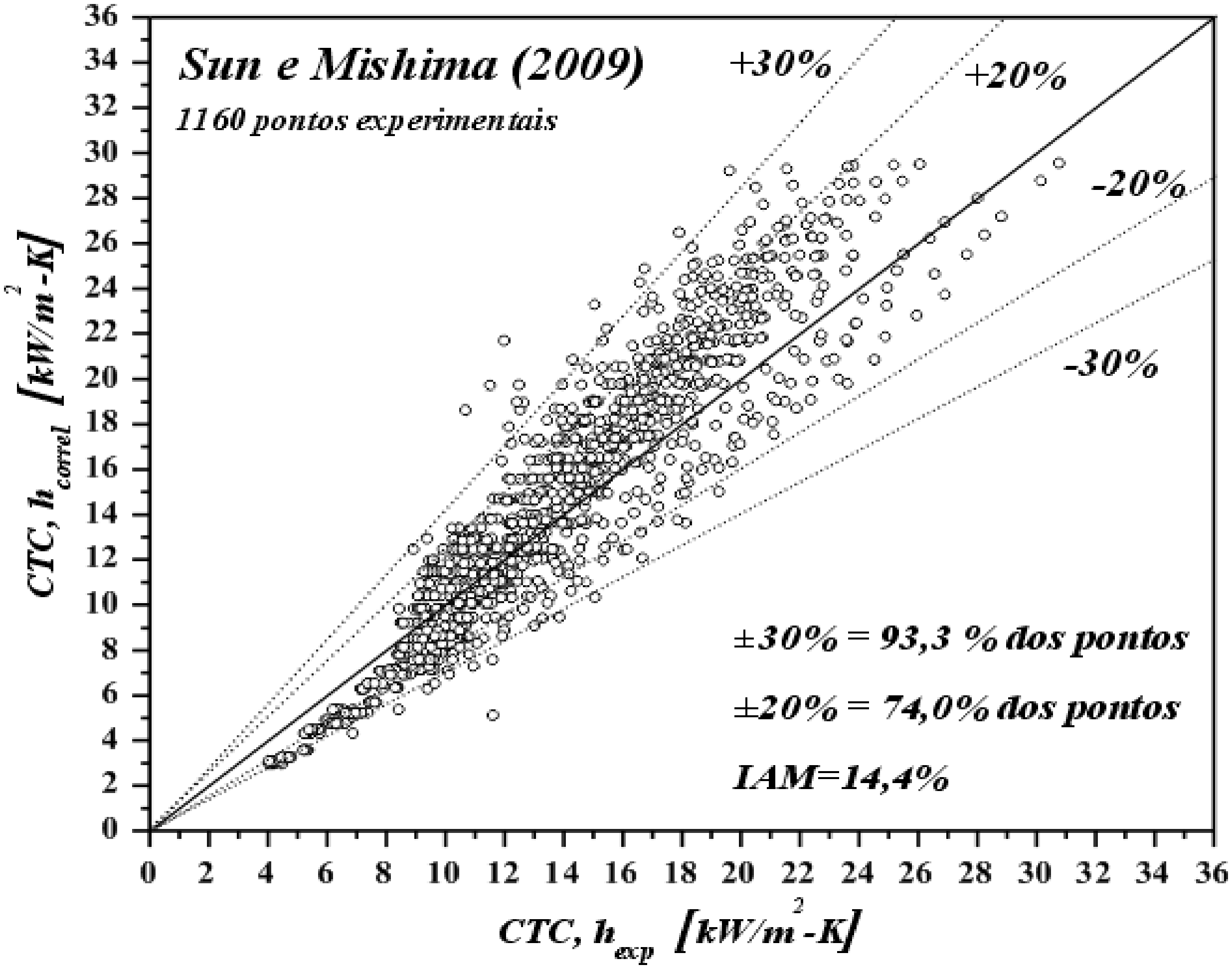
✓Part A: Analysis of results

Heat transfer : Influence of inlet pressure on the heat transfer:



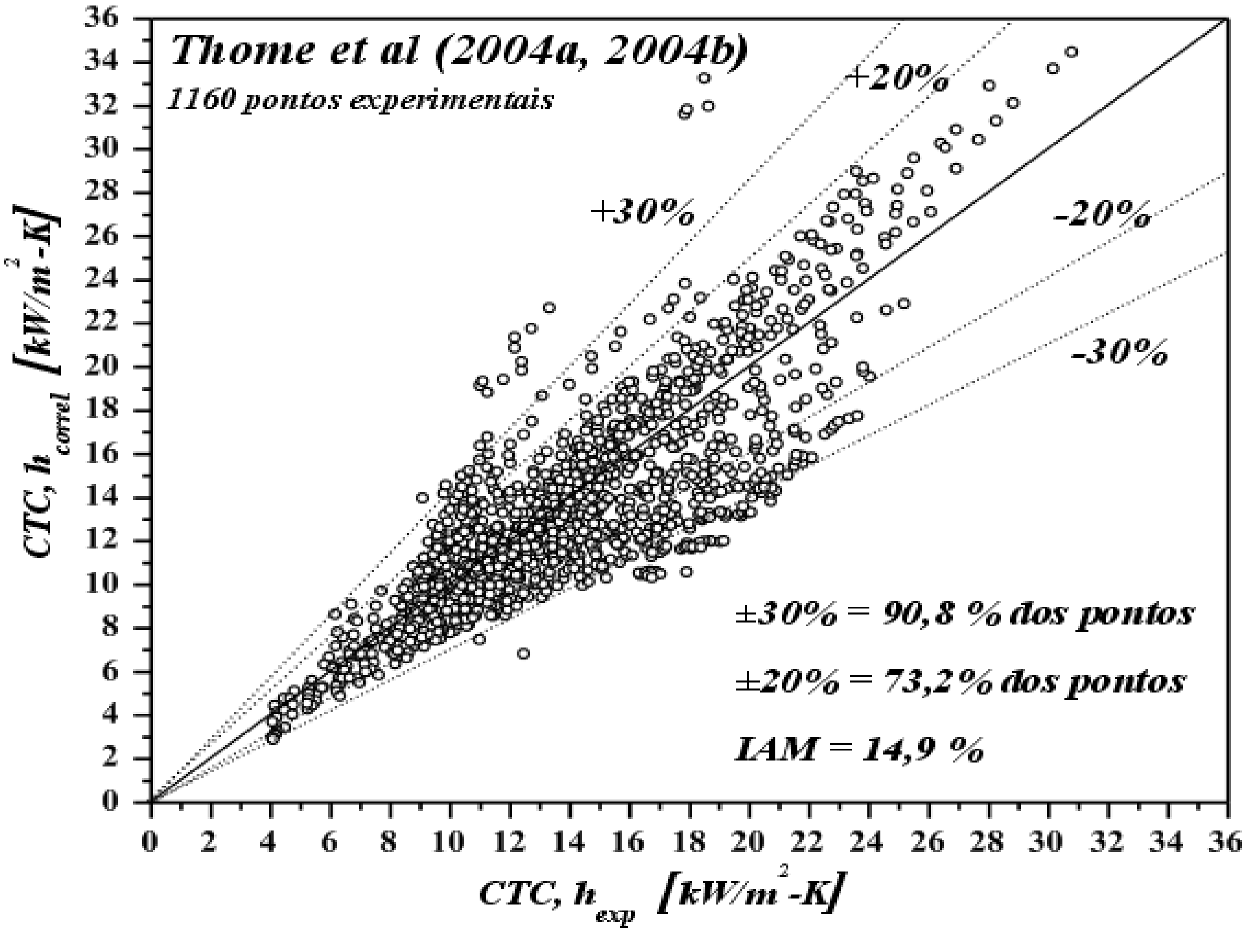
✓Part A: Analysis of results

Heat transfer : correlations and models evaluation



✓Part A: Analysis of results

Heat transfer : correlations and models evaluation



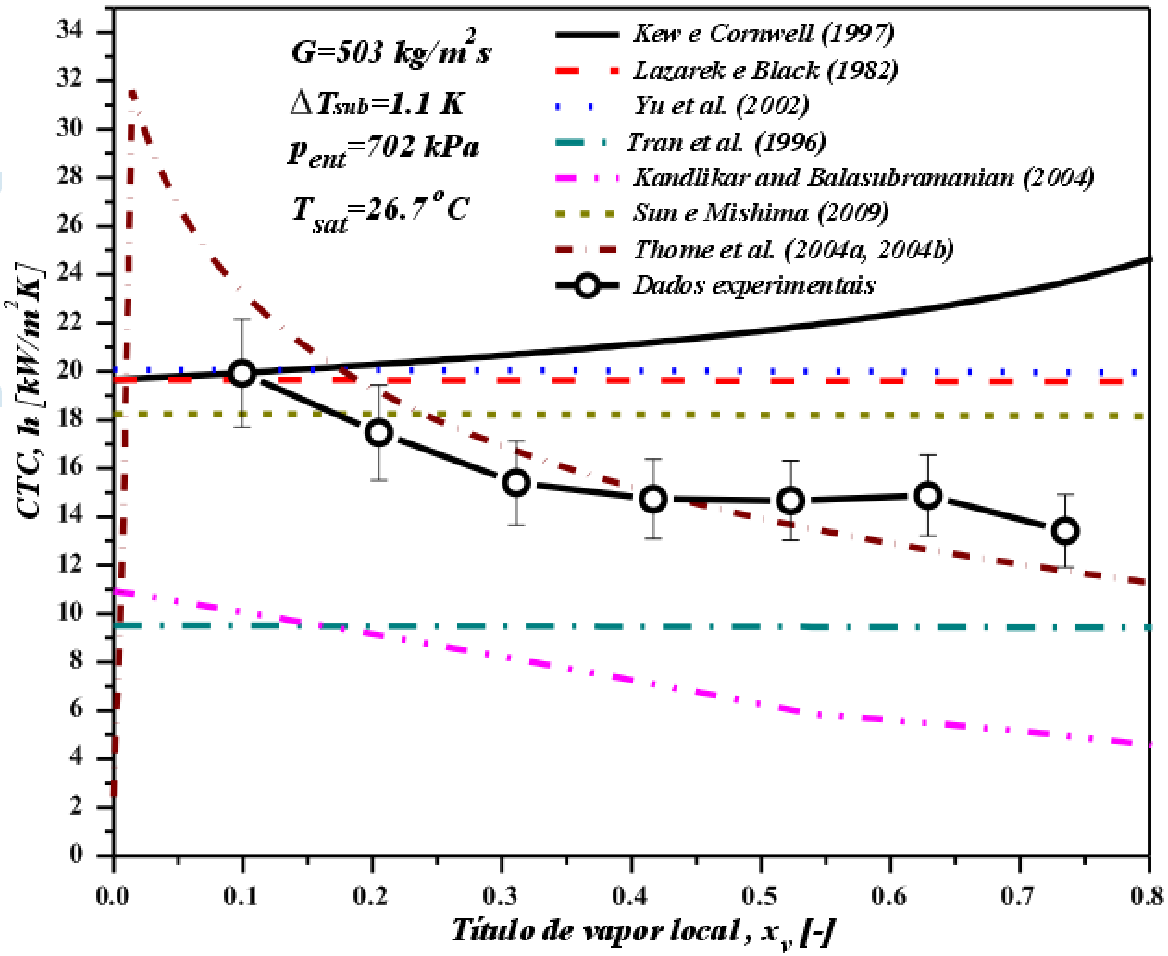
✓Part A: Analysis of results

Heat transfer : Statistic evaluation of correlations and models

Models and Correlations	IAM	Data % (±30%)	Data % (±20%)
Lazarek e Black (1982)	23,2 %	67,4 %	49,0 %
Kandlikar e Balasubramanian (2004)	**37,53 %**	**37,2 %**	-
Sun e Mishima (2009)	**14,4 %**	**93,3 %**	74,9 %
Kew e Cornwell (1997)	27,8 %	59,9 %	-
Thome et al. (2004)	**14,9 %**	**90,8 %**	73,2 %
Tran et al. (1996)	**48,4 %**	**3,5 %**	-
Yu et al. (2002)	18,2 %	81,9 %	62,5 %

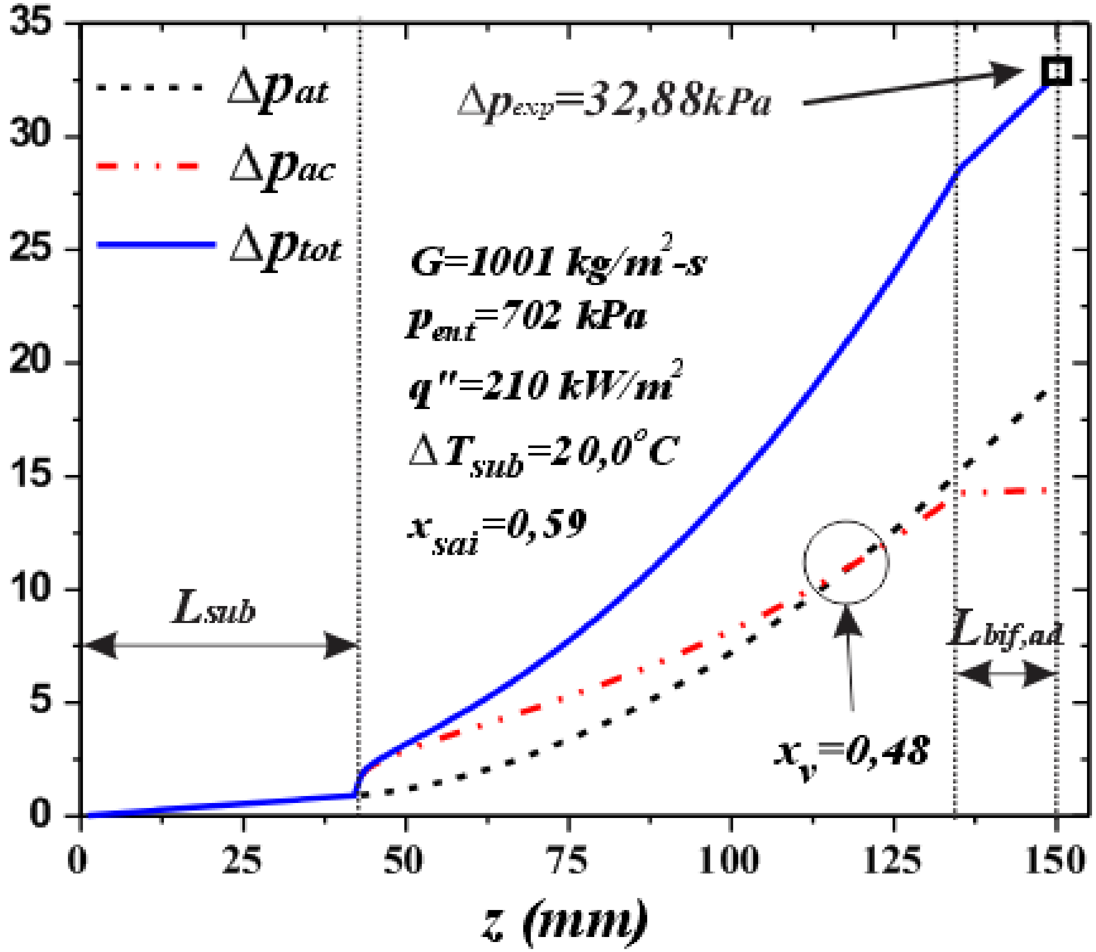
✓Part A: Analysis of results

Heat transfer : Behavior of the correlations and models :



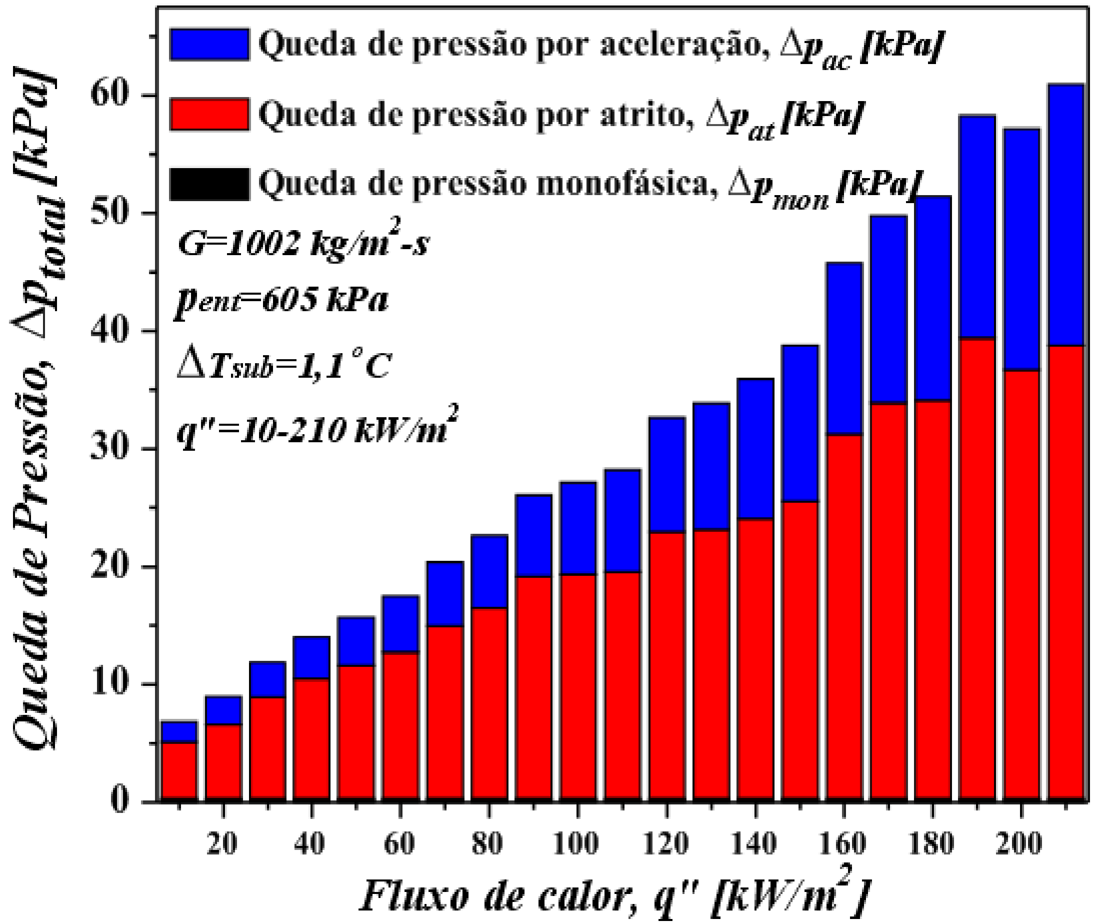
✓Part A: Analysis of results

Pressure Drop: Contributions



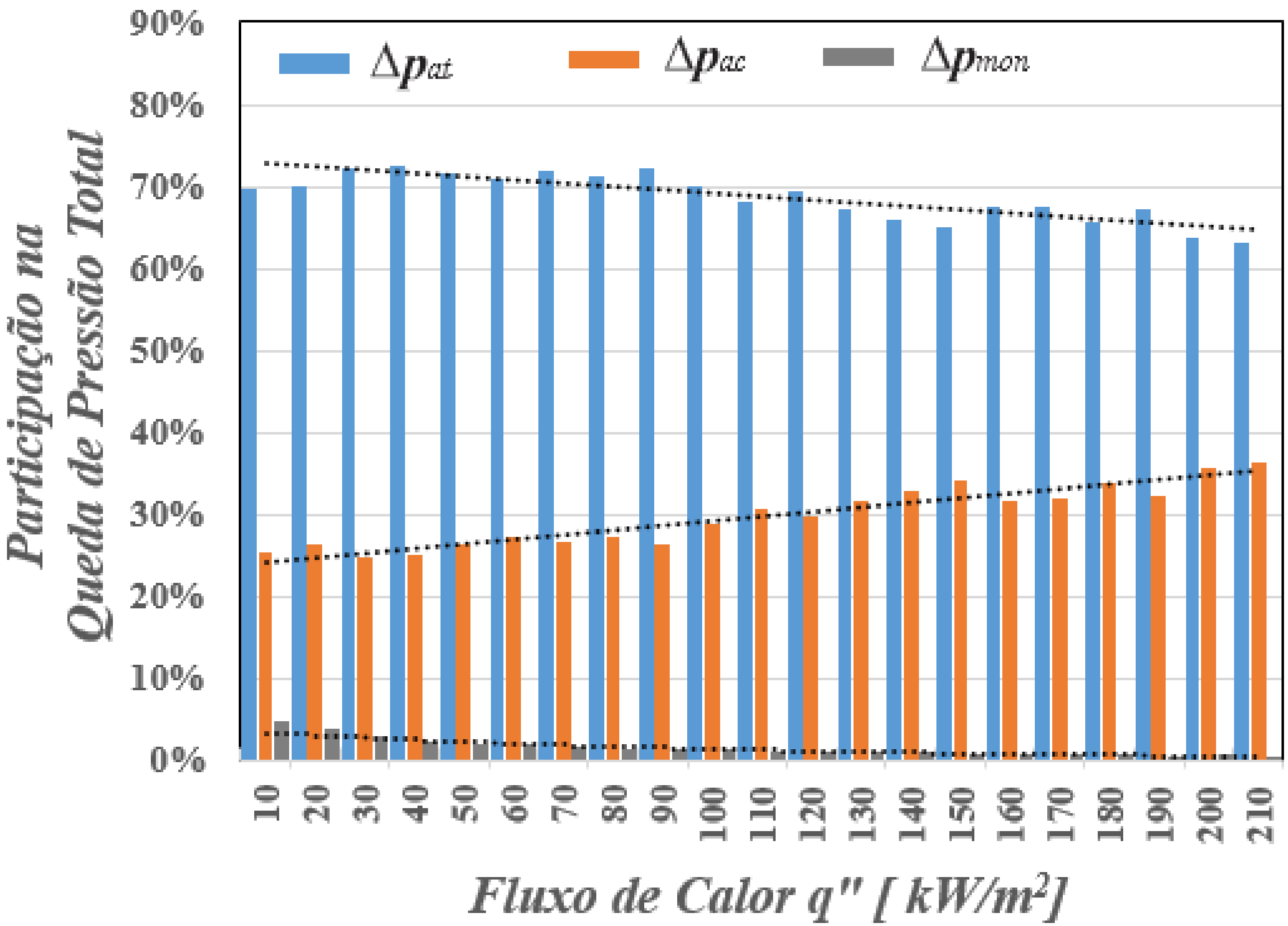
✓Part A: Analysis of results

Pressure Drop: Contributions



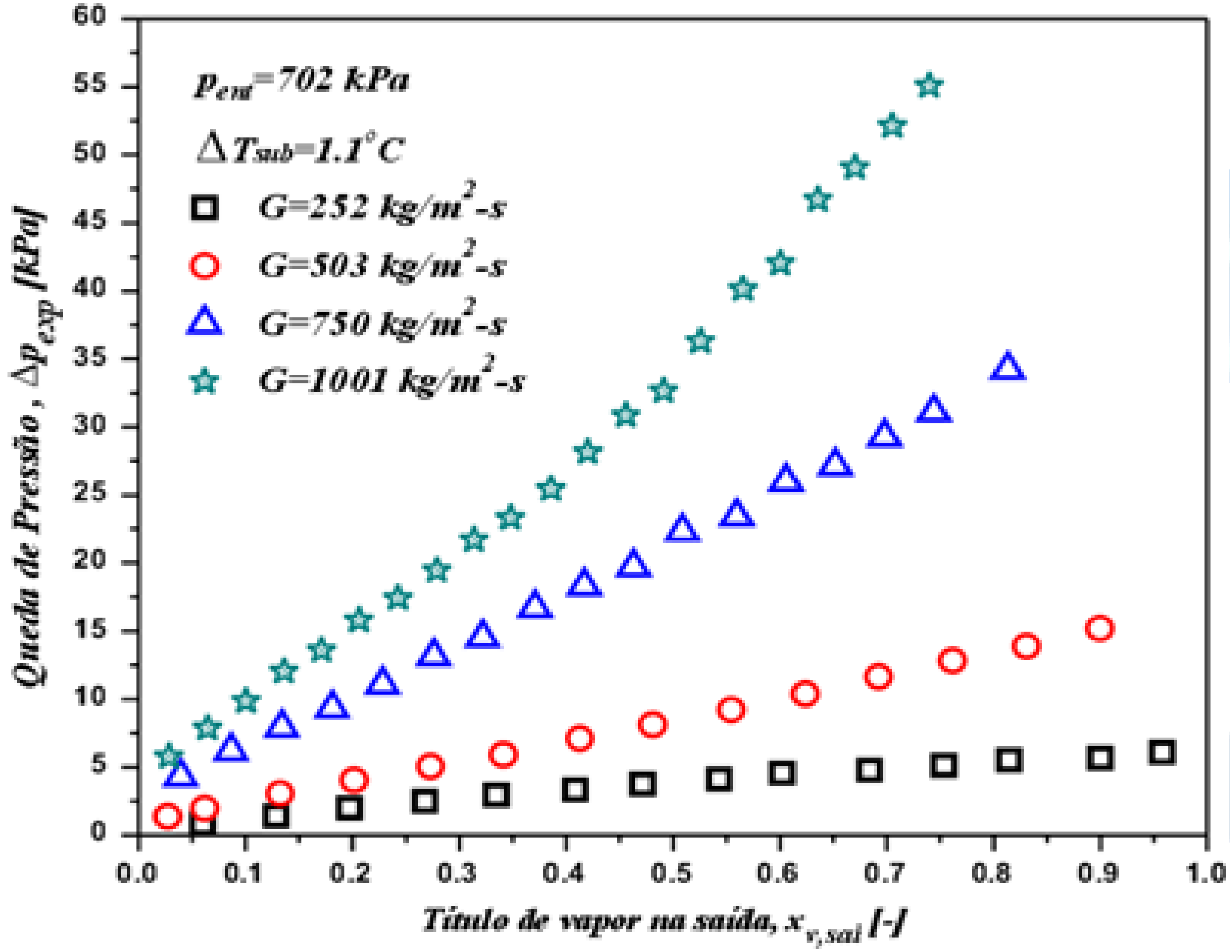
✓Part A: Analysis of results

Pressure Drop: Contributions



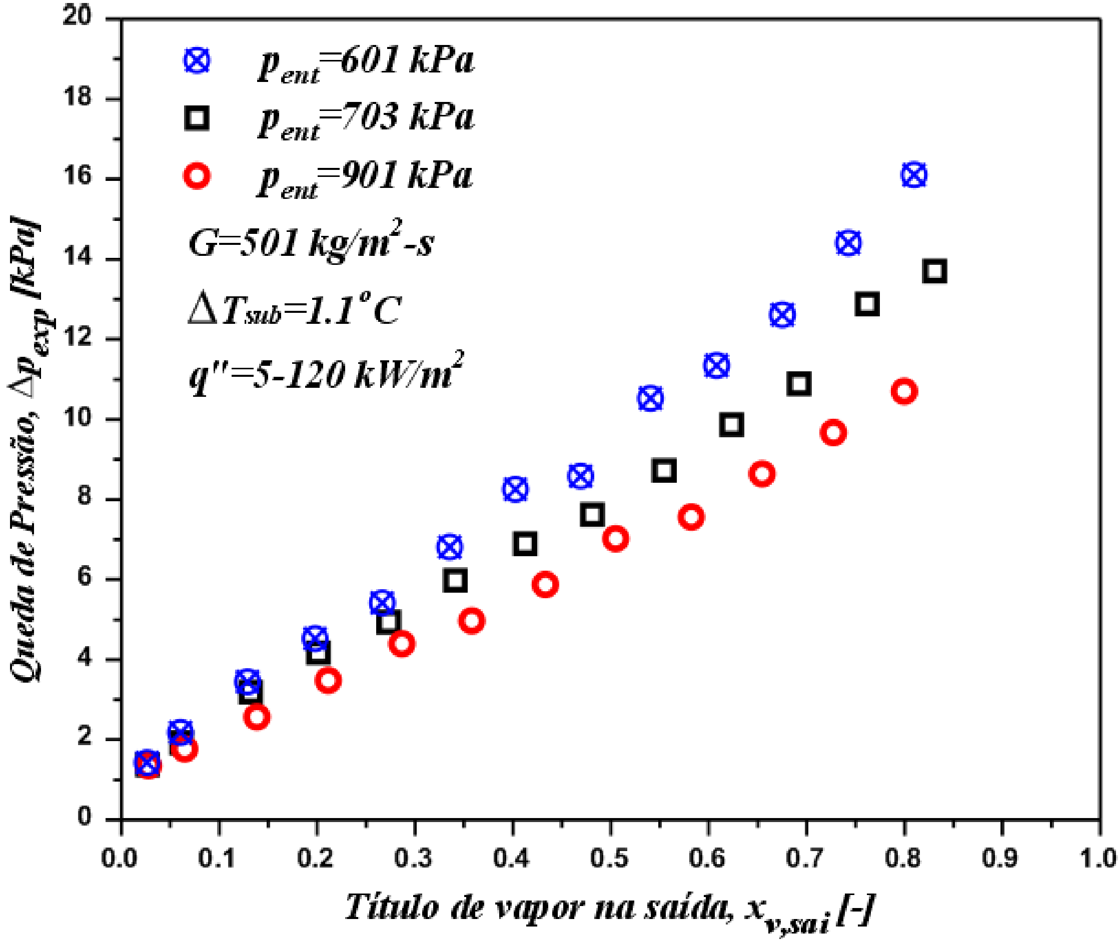
✓Part A: Analysis of results

Pressure Drop: Influence of mass velocity on the pressure drop



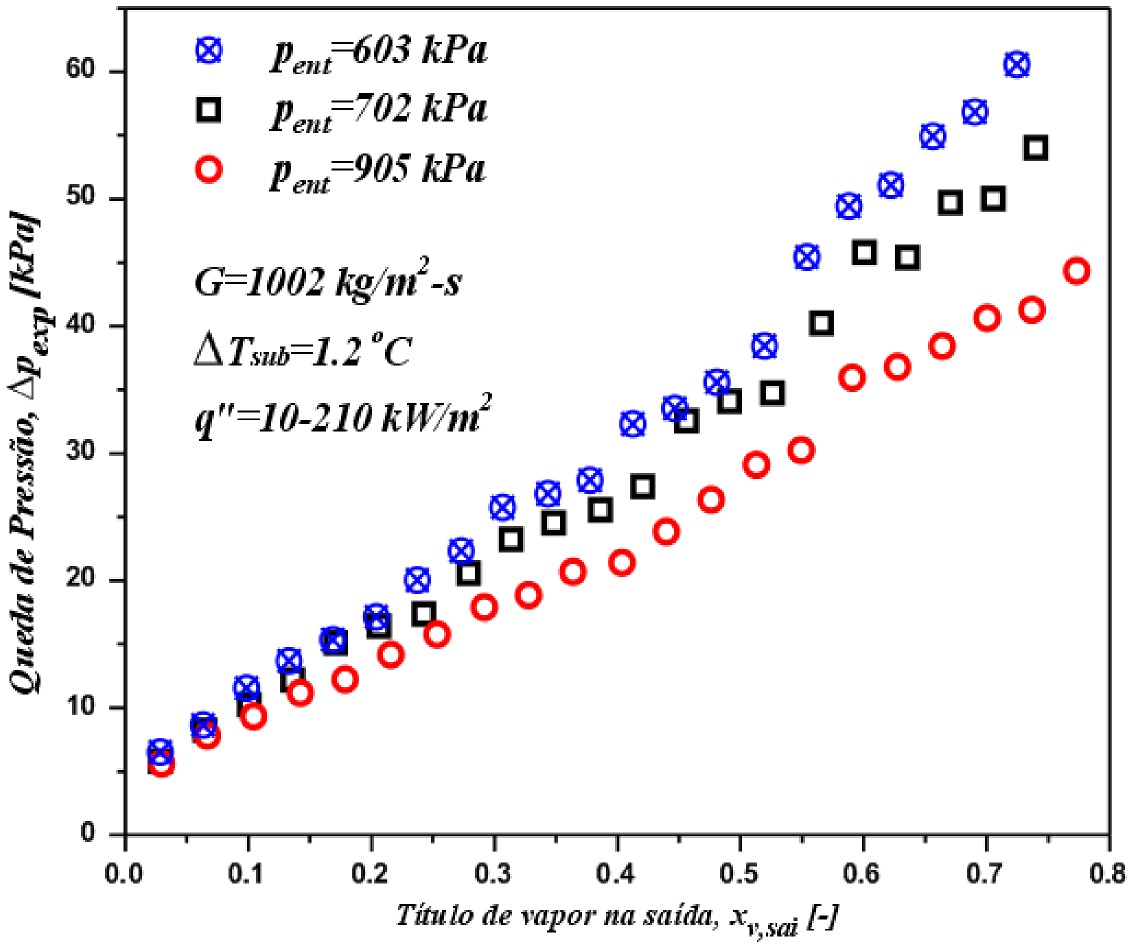
✓Part A: Analysis of results

Pressure Drop: Influence of the inlet pressure on the pressure drop



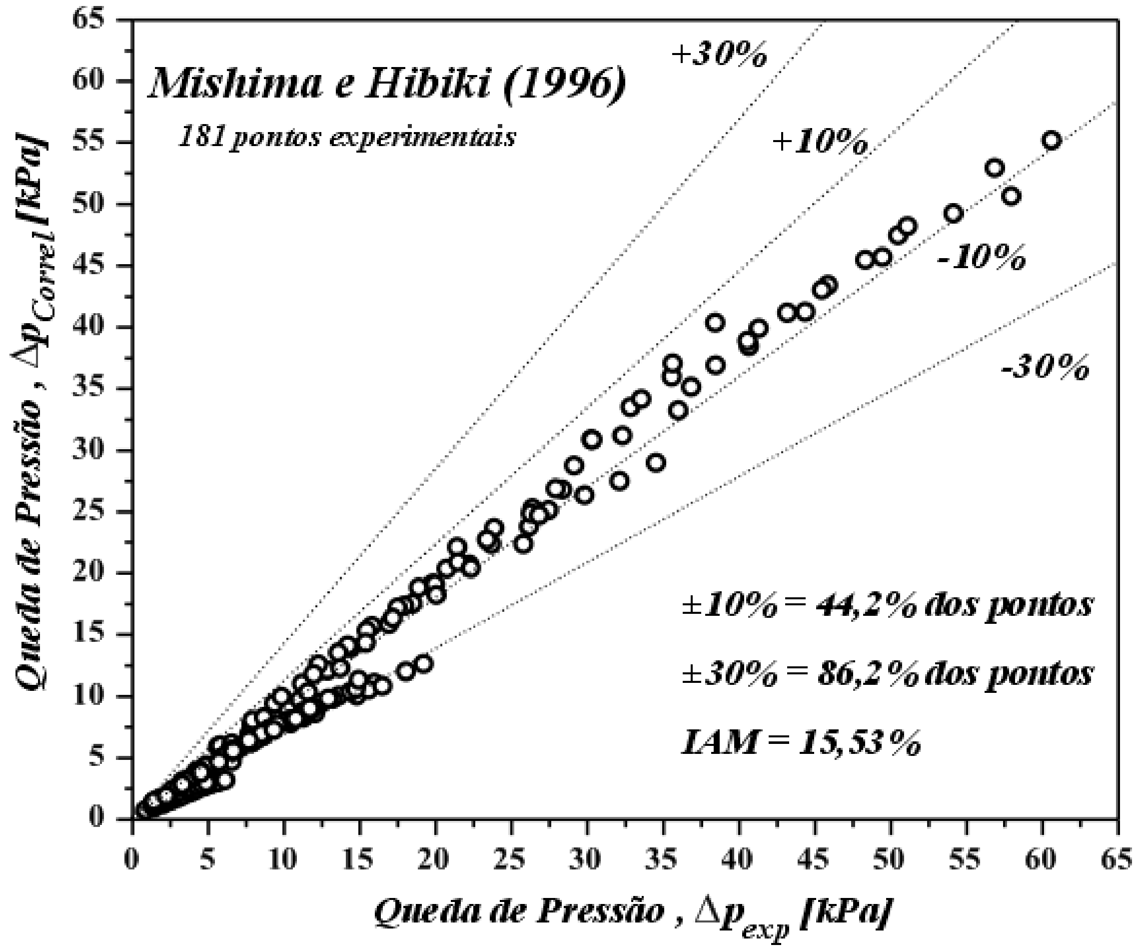
✓Part A: Analysis of results

Pressure Drop: Influence of the inlet pressure on the pressure drop



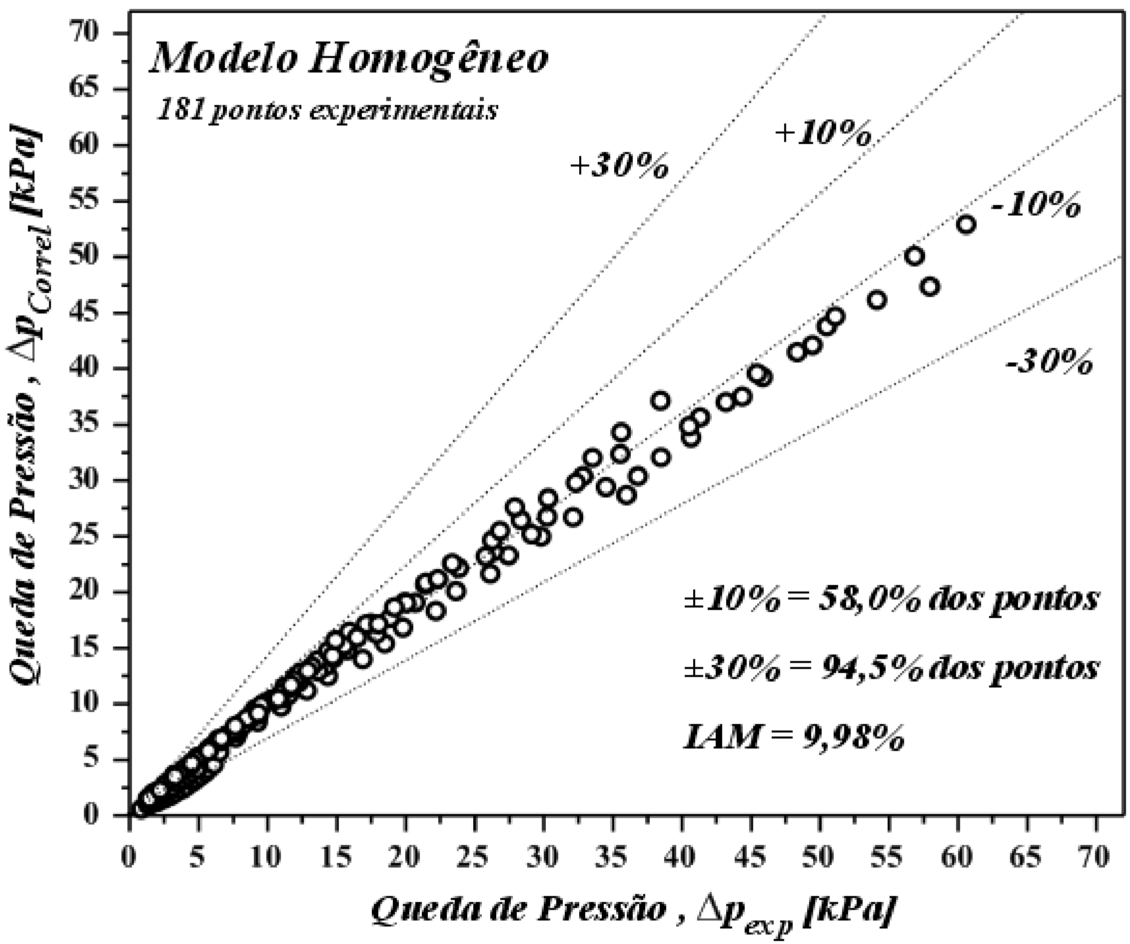
✓Part A: Analysis of results

Pressure Drop: correlations and models evaluation



✓Part A: Analysis of results

Pressure Drop: correlations and models evaluation



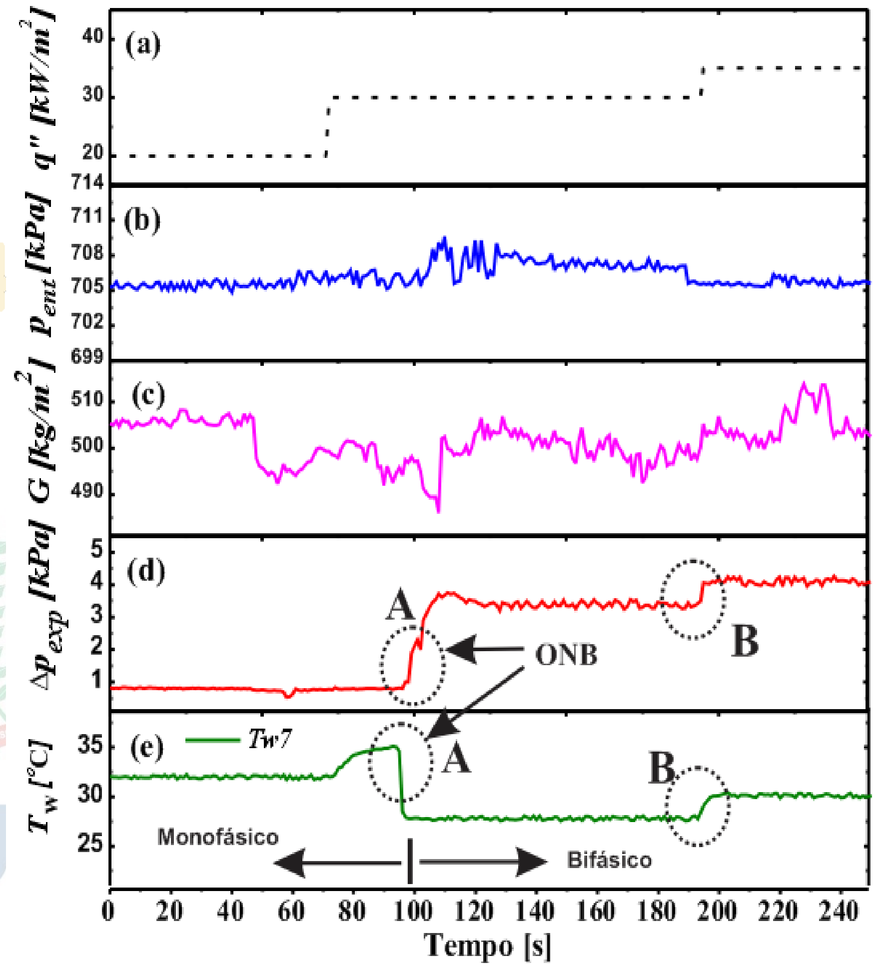
✓Part A: Analysis of results

Pressure Drop: Statistic evaluation of correlations and models

Models and Correlations	IAM	Data % (±30%)	Data % (±20%)
Friedel (1979)	*19,9 %*	*82,3 %*	*8,8 %*
Müller-Steinhagen e Heck (1986)	***16,3 %***	***87,8 %***	*37,2 %*
Zhang e Webb (2001)	*20,7 %*	*73,5 %*	*20,5 %*
Lee e Mudawar (2005a)	*86,0 %*	*27,2 %*	*11,6 %*
Modelo Homogêneo	***10,0 %***	***94,5 %***	*58,0 %*
Mishima e Hibiki (1996)	***15,5 %***	**86,2 %**	*44,2 %*

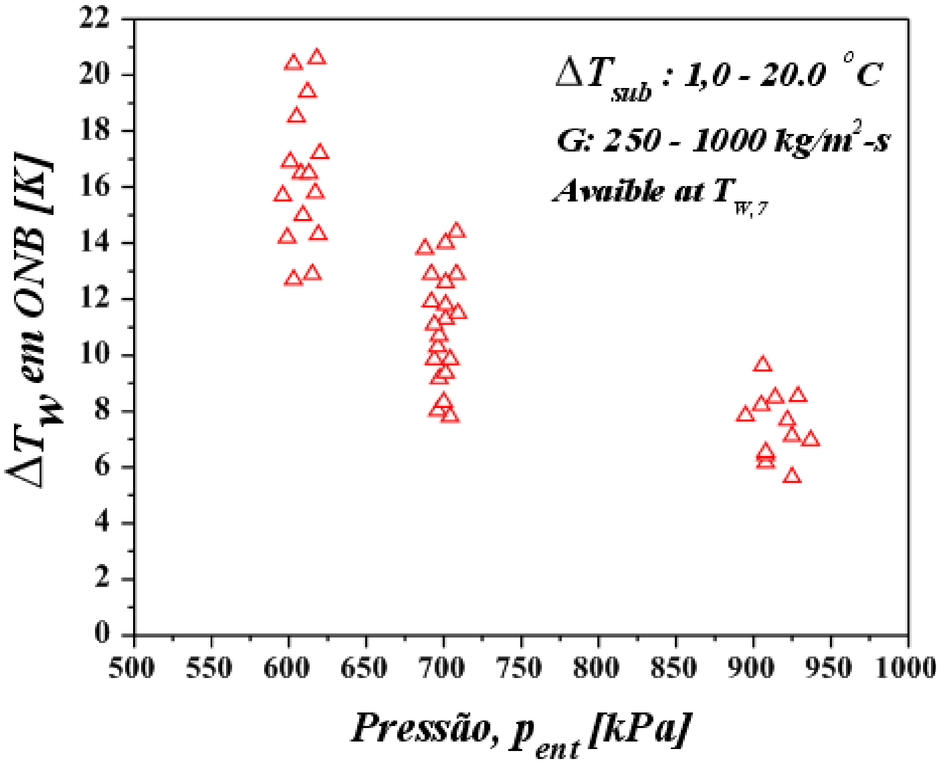
✓Part A: Analysis of results

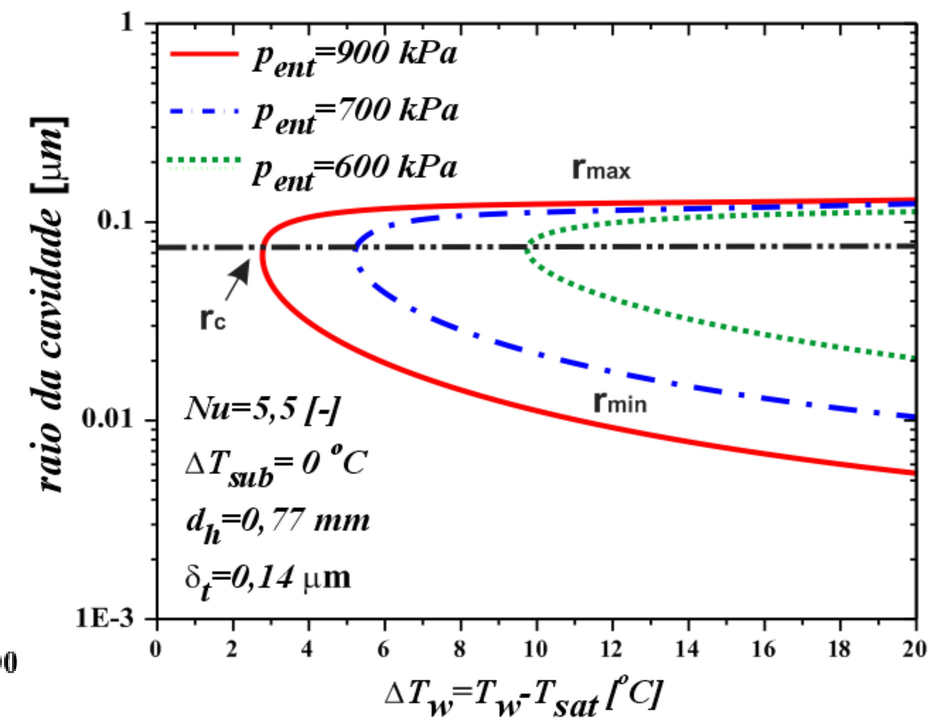
ONB: Behavior



✓Part A: Analysis of results

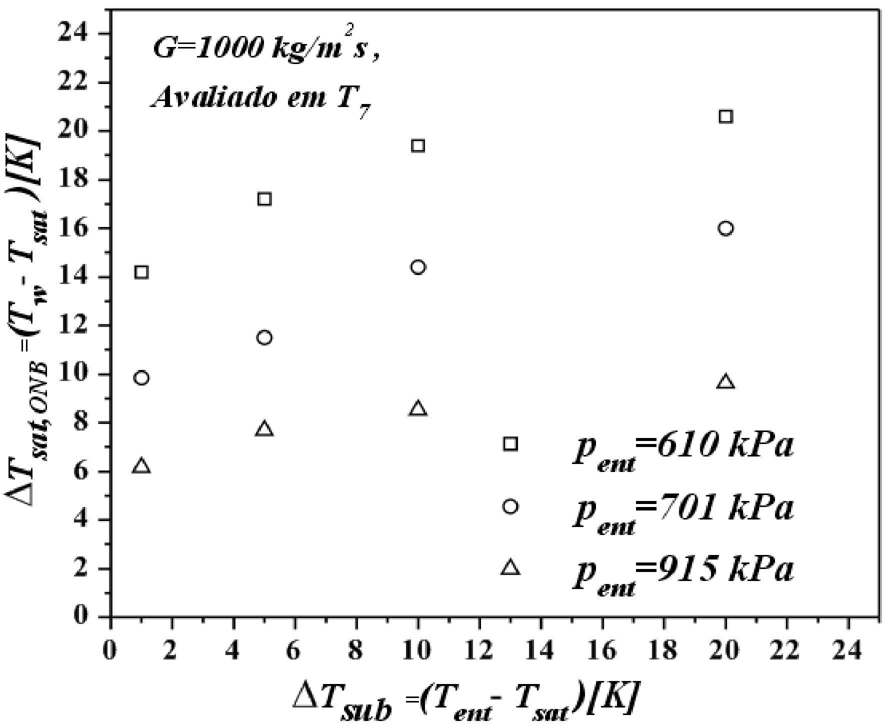
ONB: Influence of pressure on ONB

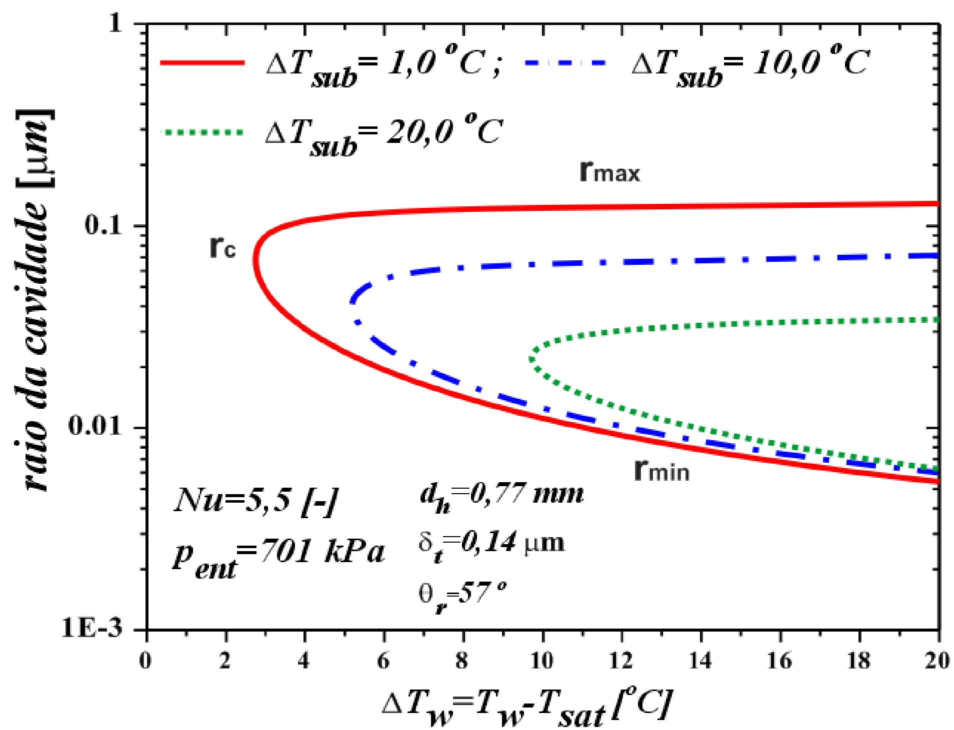




✓Part A: Analysis of results

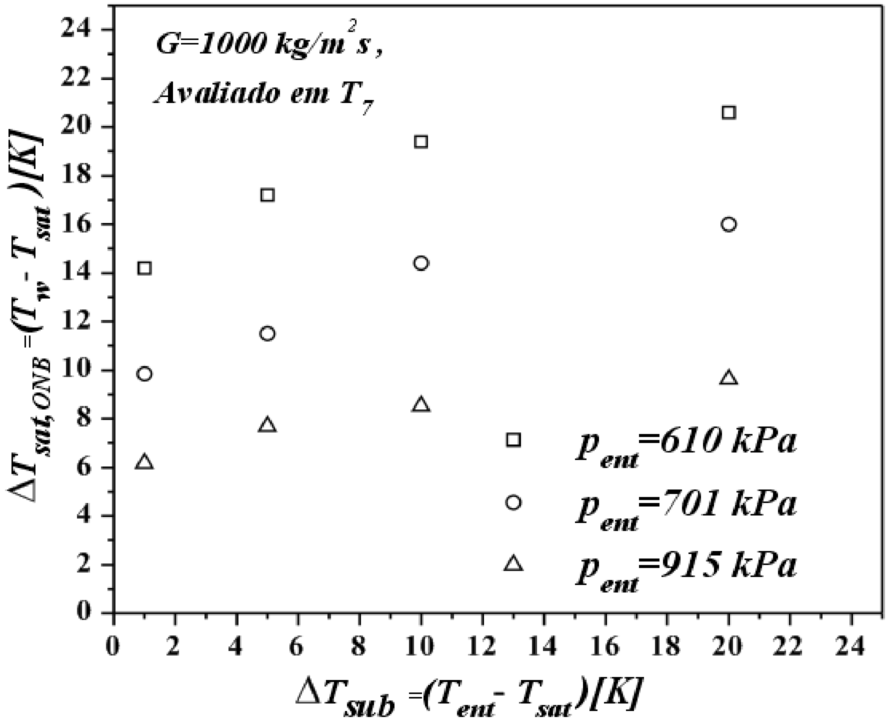
ONB: Influence of subcooled degree on ONB

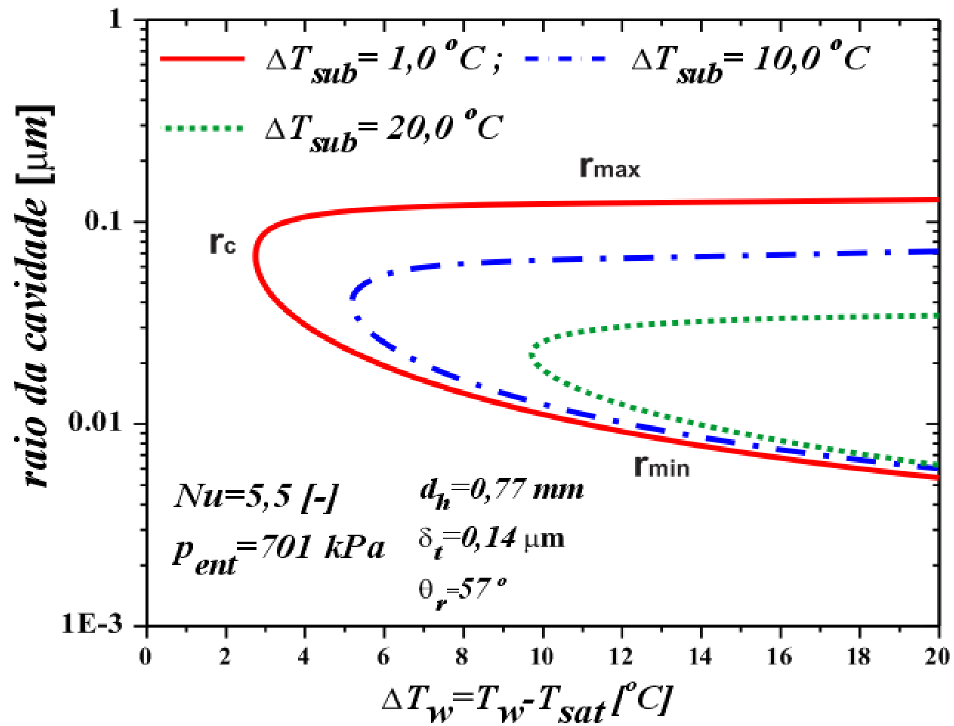




✓Part A: Analysis of results

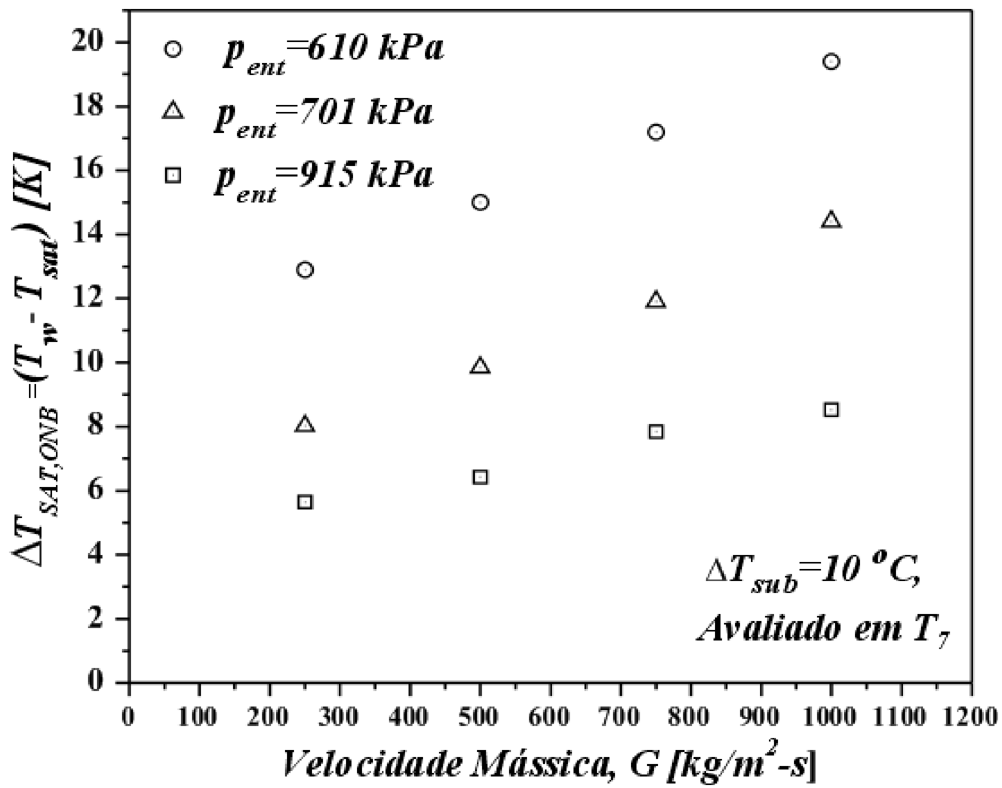
ONB: Influence of subcooled degree on ONB





✓Part A: Analysis of results

ONB: Influence of mass velocity on ONB



✓Part A: Conclusions

Main conclusions :

- ✓ It was verified with the help of the map flow pattern of Revellin and Thome (2007a) that the flow pattern influence on the heat transfer coefficient (CTC) during flow boiling in microchannels;
- ✓ For isolated bubbles (IB) has been found that the nucleate boiling is predominant. However, for bubbles confined (BC) and annular (A), it was concluded that the convective boiling regime is predominant;
- ✓ The heat transfer coefficient increases with the increase of mass velocity for high vapor quality ;
- ✓ The heat transfer coefficient is influenced by the subcooling degree at low levels of vapor quality;

✓Part A: Conclusions

Main conclusions :

- ✓ The heat transfer coefficient increases with the increase of the inlet pressure;
- ✓ The correlations of Sun and Mishima (2009) and Thome et al (2004) to the heat transfer coefficient predict very well the experimental results;
- ✓ The homogeneous model is one that adequately predicts the experimental results of pressure drop;
- ✓ The pressure drop in convective boiling within microchannels can be also estimated correctly using the homogeneous model and the correlations of Müller-Steinhagen and Heck (1986) or Friedel (1979);

✓Part A: Conclusions

Main conclusions :

- ✓ The high degree of superheat required for the occurrence of ONB and consequently high hysteresis effect is due to the high wettability of the refrigerant R134a and characteristics of roughness in the wall heated;
- ✓ The increase in the inlet pressure favor the onset of nucleate boiling, ONB, due to the increasing of the range of radius of cavities that can be activated;
- ✓ Higher mass velocities require a higher superheat degree for the onset nucleate boiling, ONB;

PARTE B

DISTRIBUTION ANALYSIS OF AIR-WATER TWO PHASE FLOW IN AN DISTRIBUTOR COUPLED TO MICROCHANNELS

✓Part B: Introduction

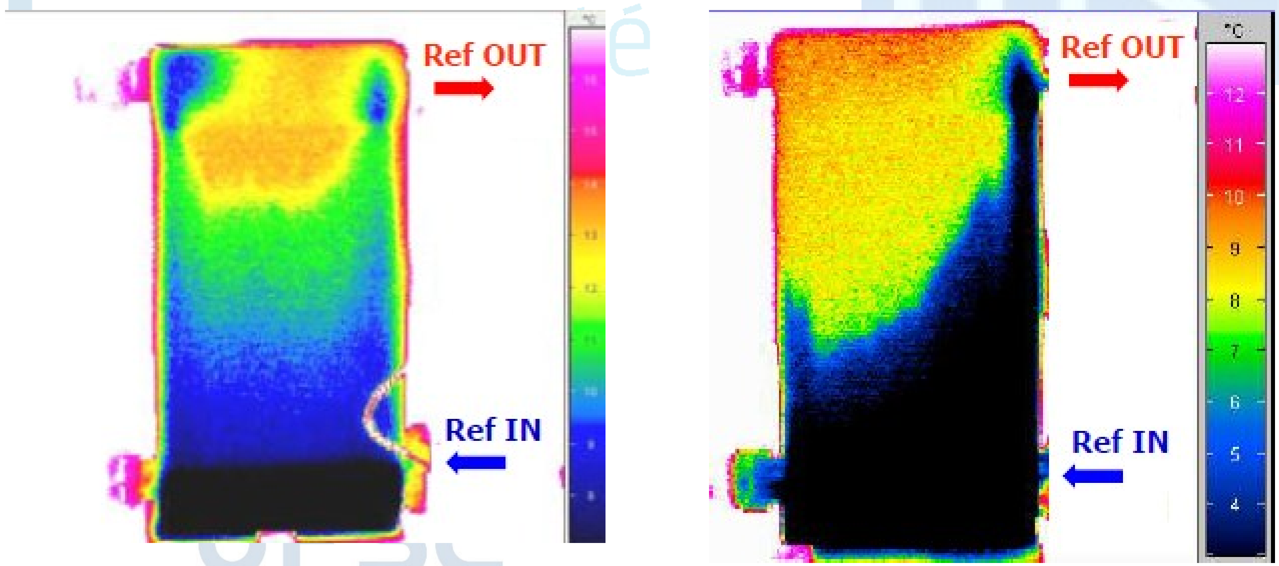
Motivations:

- ✓ One of the factors that most strongly influence the performances of compact heat exchangers is the degree of uniformity of the flow feeding the various parallel channels of which they are composed;
- ✓ In evaporators, uniform distribution is essential in order to avoid dry-out phenomena and the resulting poor heat exchange performance;
- ✓ In condensers, unequal distribution of liquid could create zones of reduced heat transfer due to high liquid loading. Thus, in designing compact heat exchangers, understanding separation phenomena in the manifolds is of great importance;

✓Part B: Introduction

Motivations:

- ✓ Uneven two-phase distribution can occur both inside any channel and among the parallel channels, owing to the separation of the two-phase mixture in the header-channel junctions.



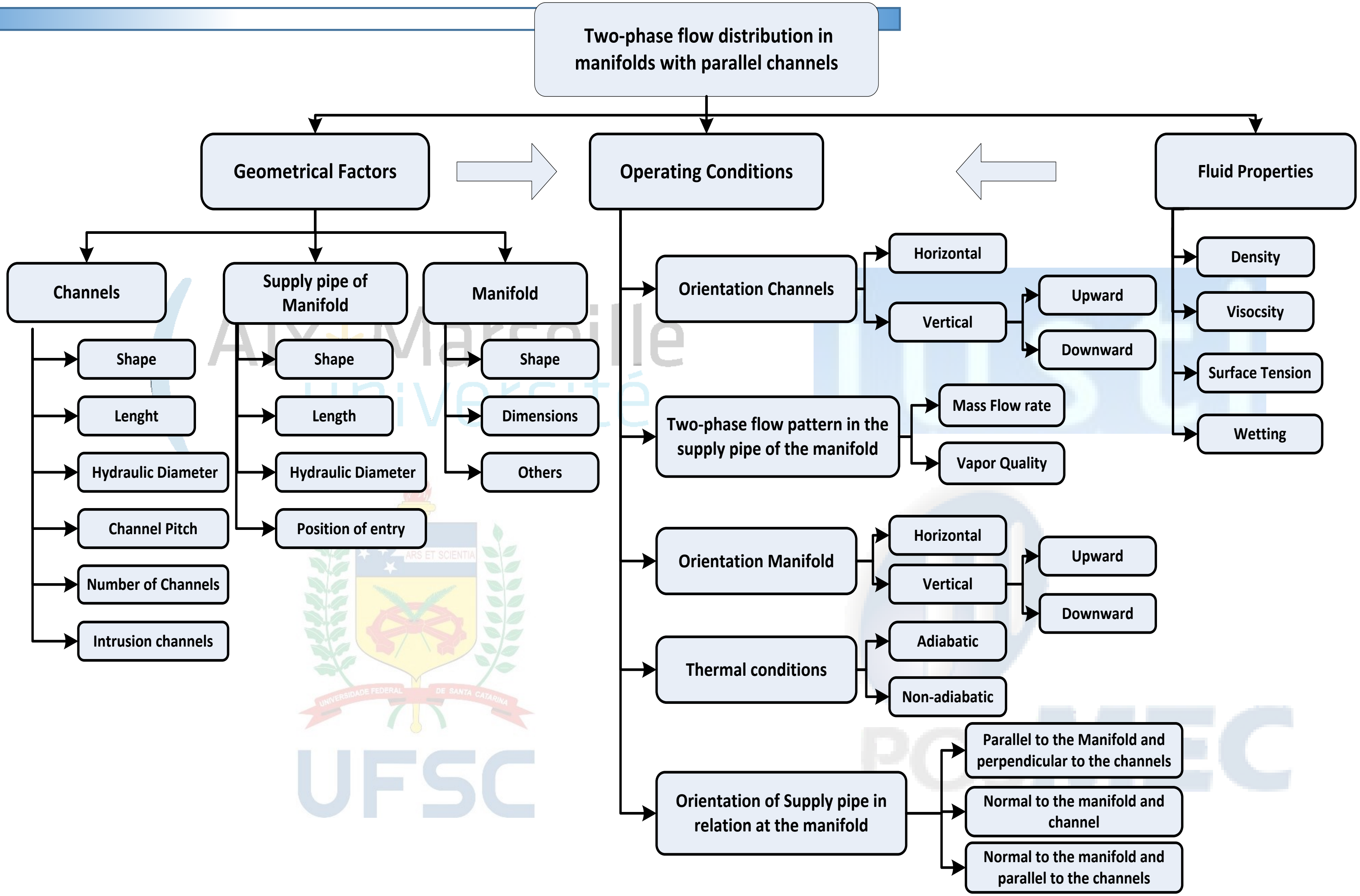
Infrared images of surface temperature distribution in plate heat exchangers, Yazdani et al (2010)

✓Part B: Introduction

Objectives:

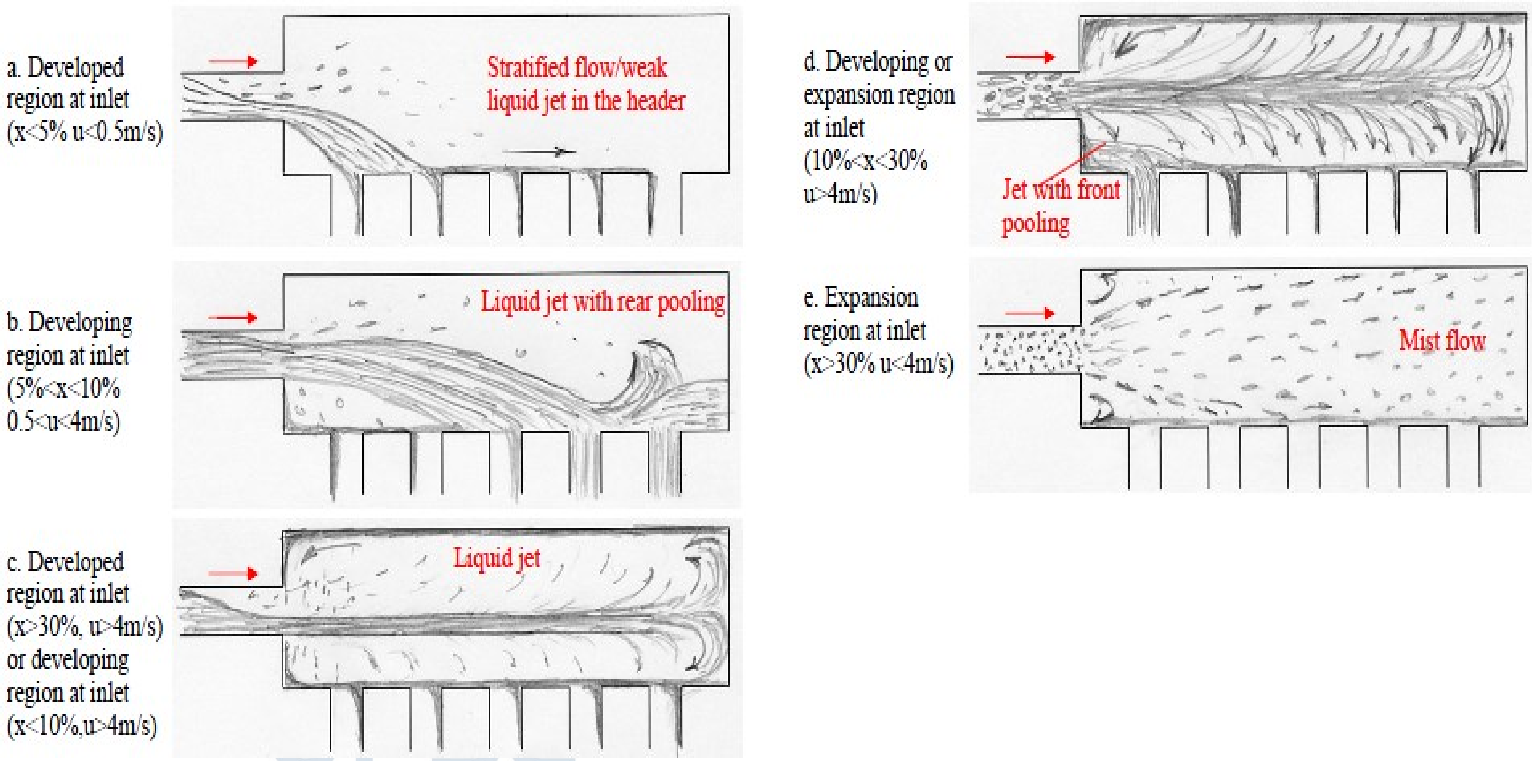
- ✓ To measure the flow distribution of a two-phase flow in a compact heat exchanger, under real operating conditions;
- ✓ To investigate the performance of two phase flow distribution at varying operating conditions (location and orientation of the feeding tube, orientation of parallel channels and header);
- ✓ To improve the understanding of the relationship between the distribution of two-phase flows and header geometry;
- ✓ To verify which parameters have the greatest importance in the two phase flow distribution among parallel channels;

✓Part B: Brief Literature review



✓Part B: Brief Literature review

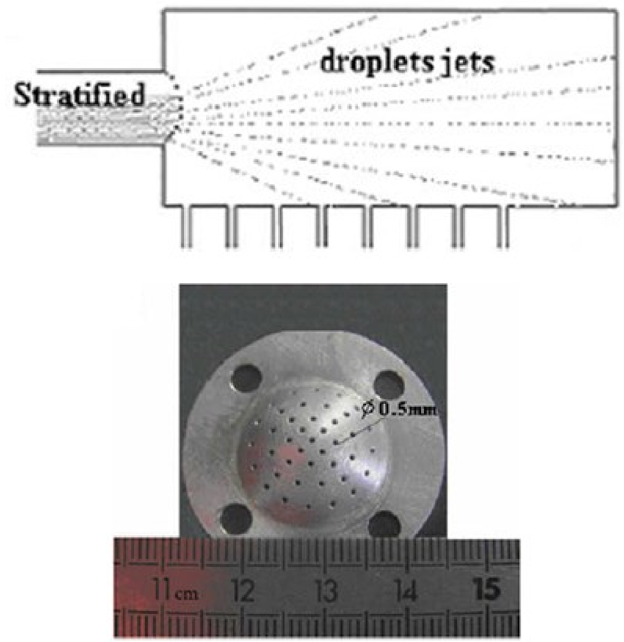
Different structures can be created in the header due to different flow structure in the feeding tube :



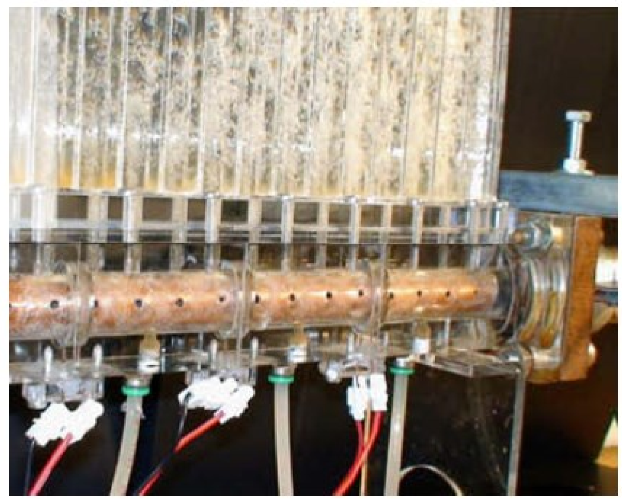
Fei et al. (2002)

✓Part B: Brief Literature review

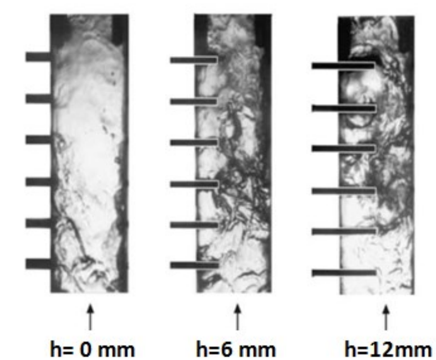
Header design two-phase flow distribution improvement:



Ahmad et al. (2009)



Marchitto et al. (2009)

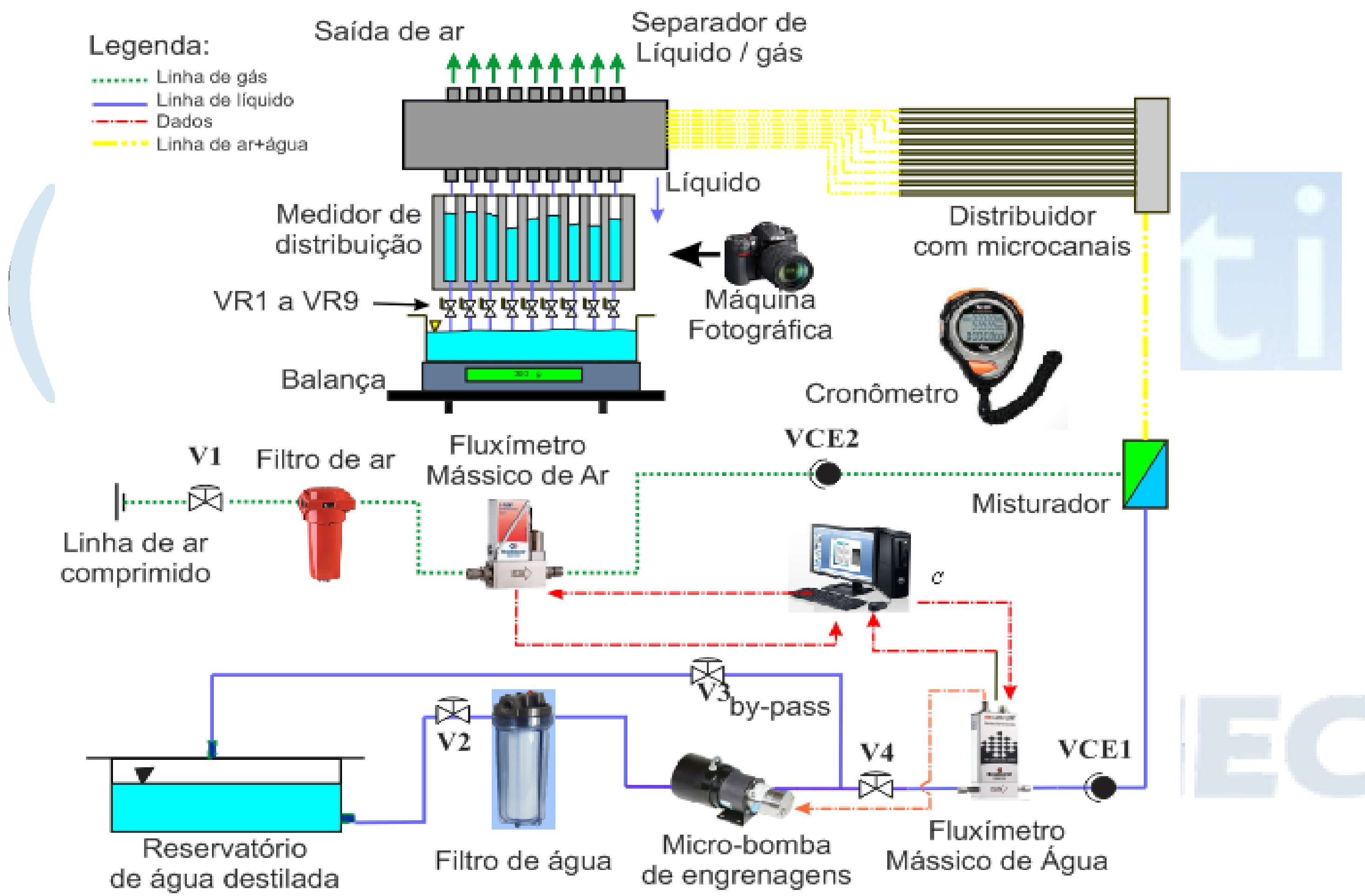


Images for header for three different level of intrusion

Lee and Lee (2004)

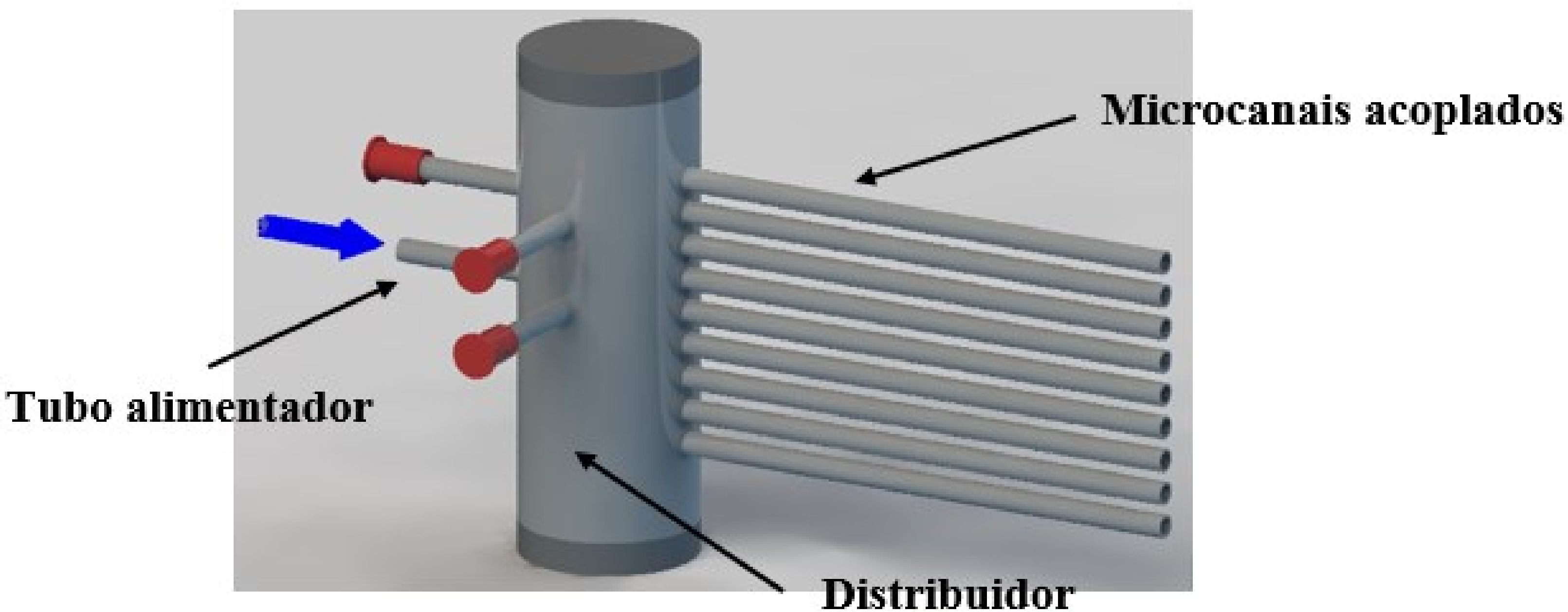
✓Part B: Materials and Methods

Experimental Setup:



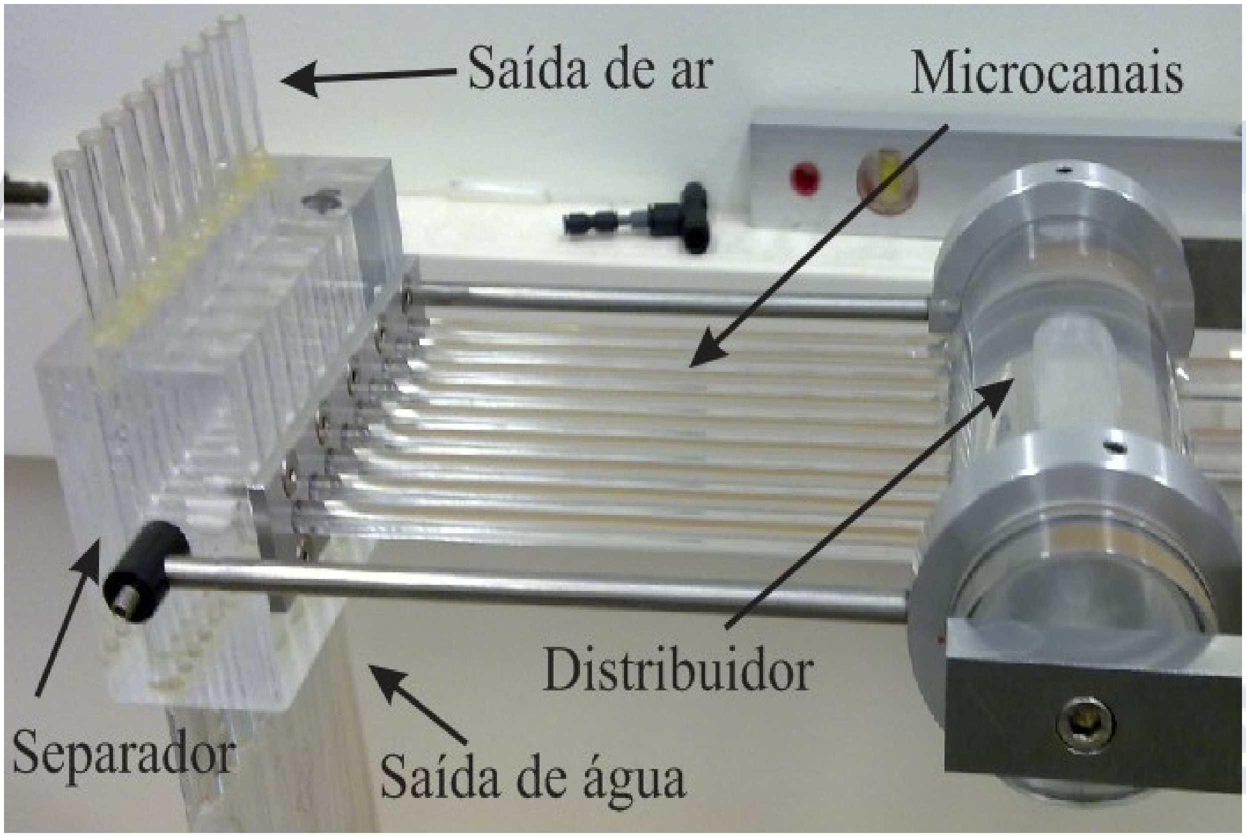
✓Part B: Materials and Methods

Test Section:



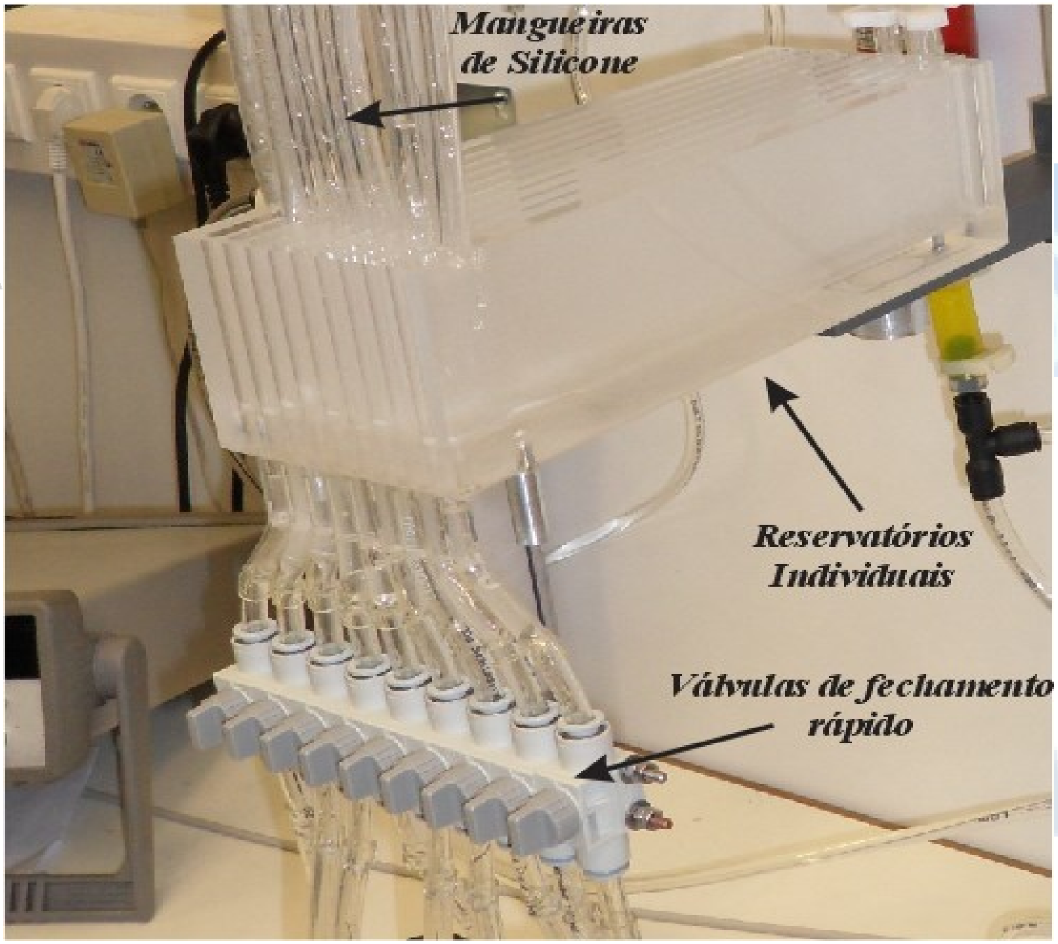
✓Part B: Materials and Methods

Test Section:



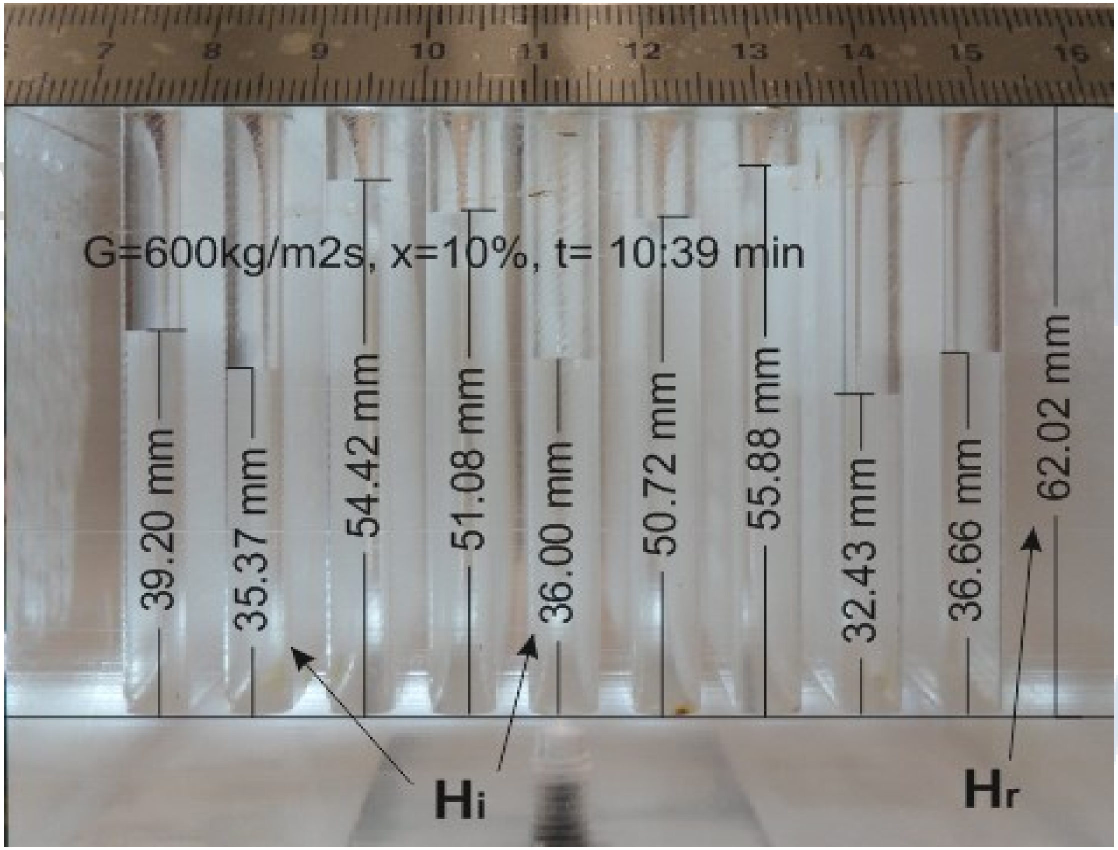
✓Part B: Materials and Methods

Experimental apparatus:



✓Part B: Materials and Methods

Measure system :



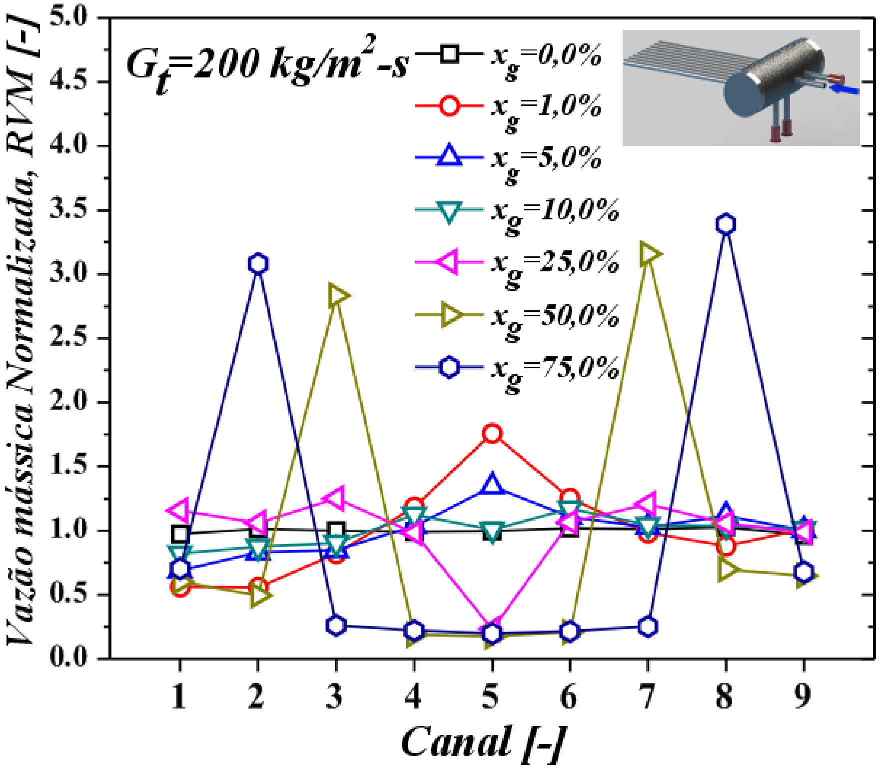
✓Part B: Analysis of results

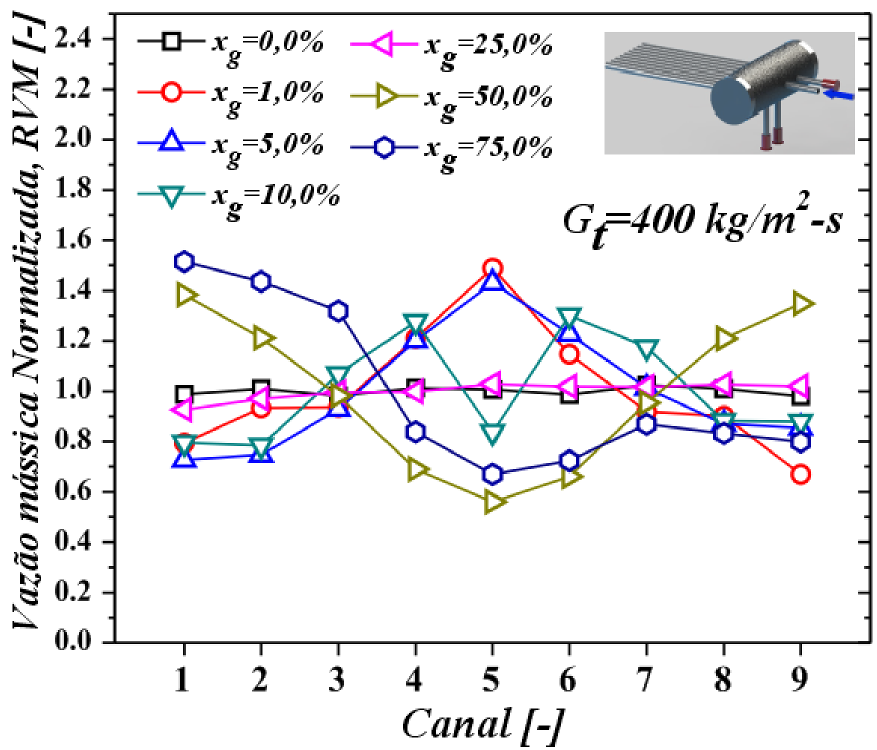
Characterization of the test conditions:

- Gas quality ranging from: 0 to 0.75;
- Average mass velocities in microchannels: 200, 400 and 600 kg/m^2s;
- Fifteen position settings of the header and tube feeder;

✓Part B: Analysis of results

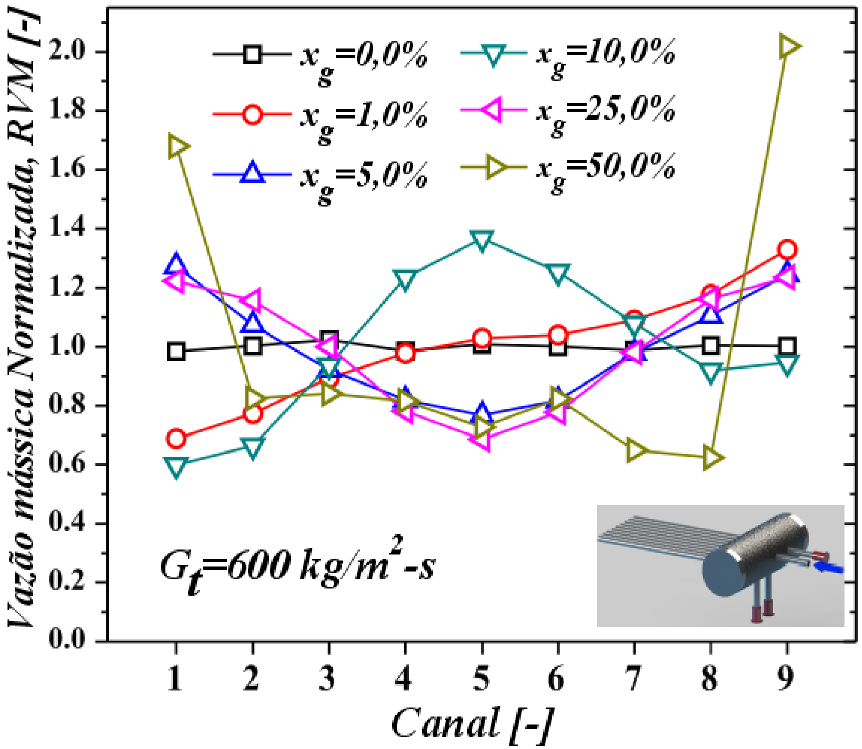
Effects of mass velocity et gas quality:
Horizontal - header and channels

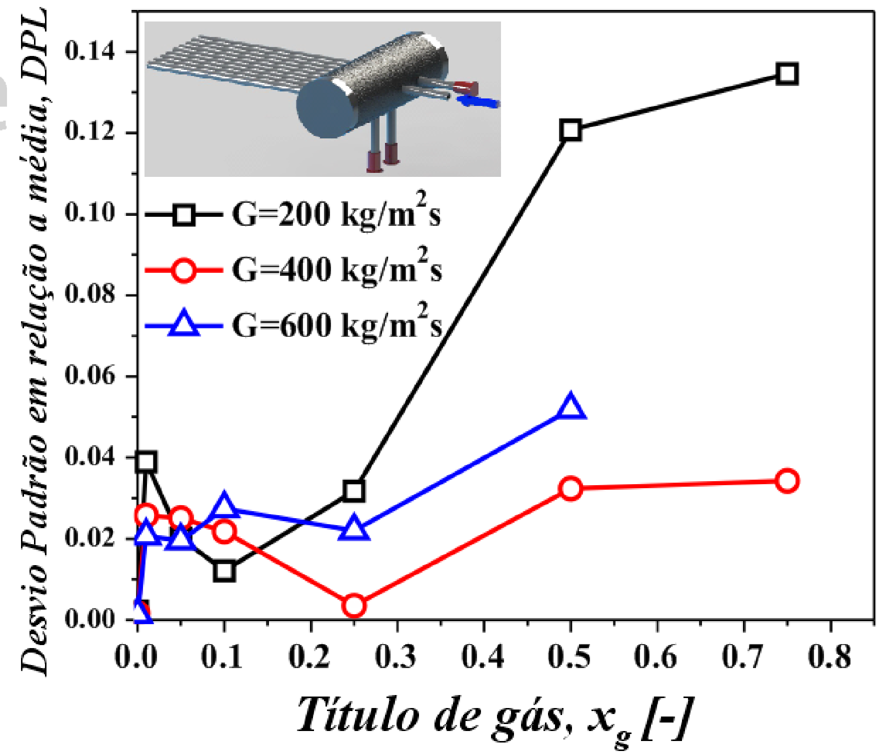




✓Part B: Analysis of results

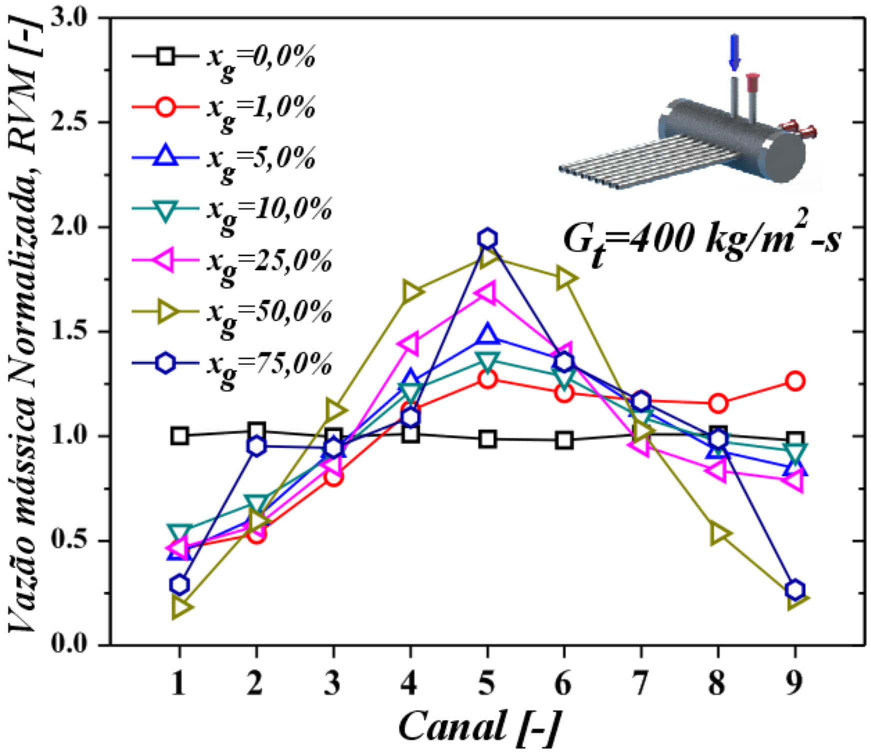
Effects of mass velocity et gas quality: Horizontal - header and channels

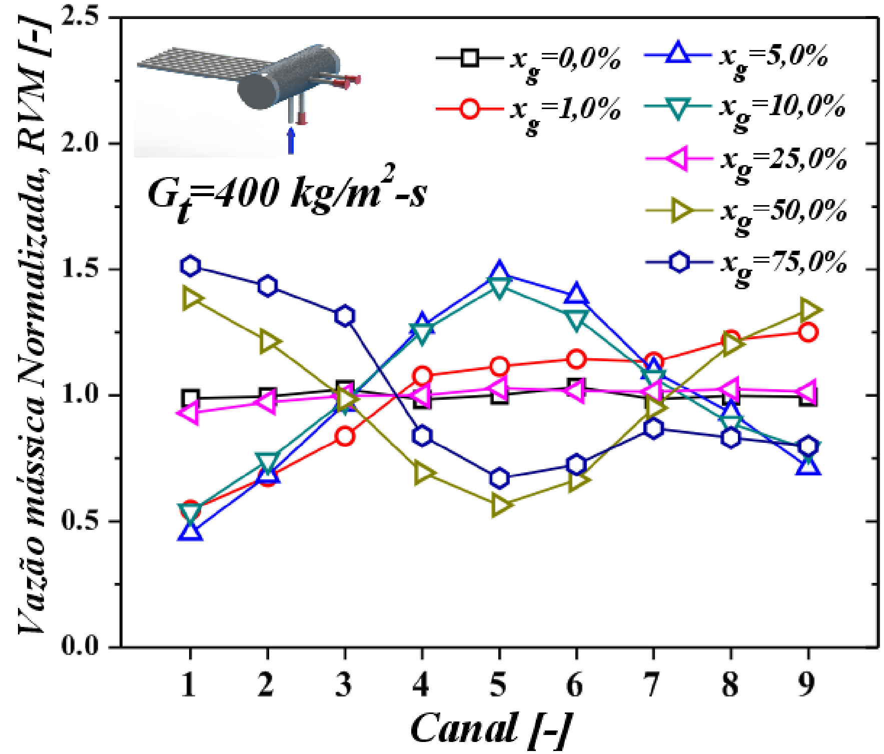




✓Part B: Analysis of results

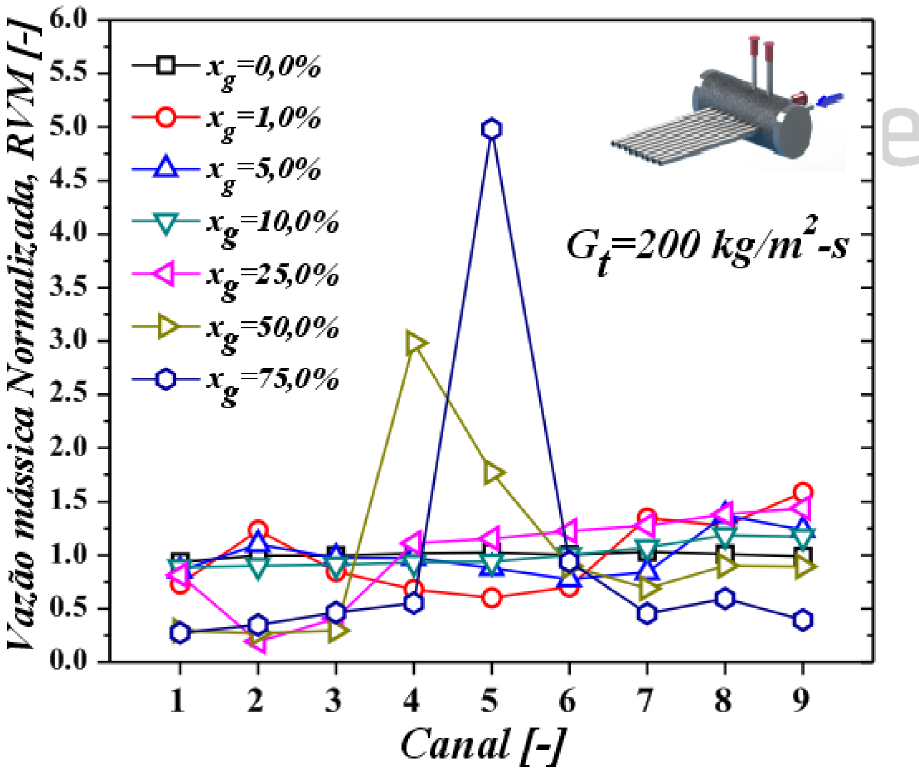
Effects of direction feeding tube:
Horizontal - header and channels

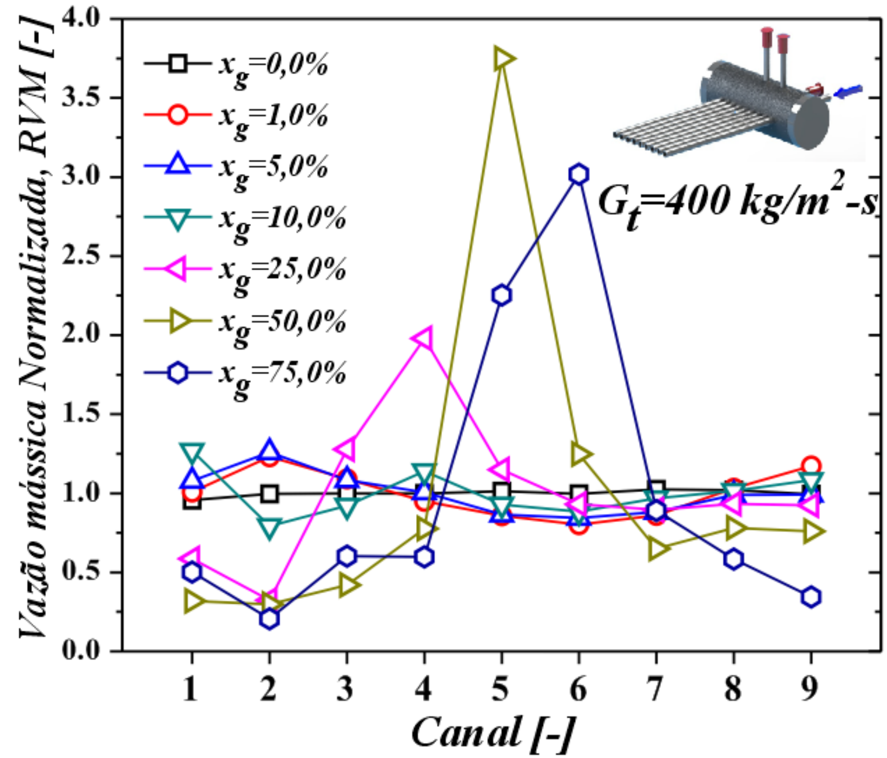




✓Part B: Analysis of results

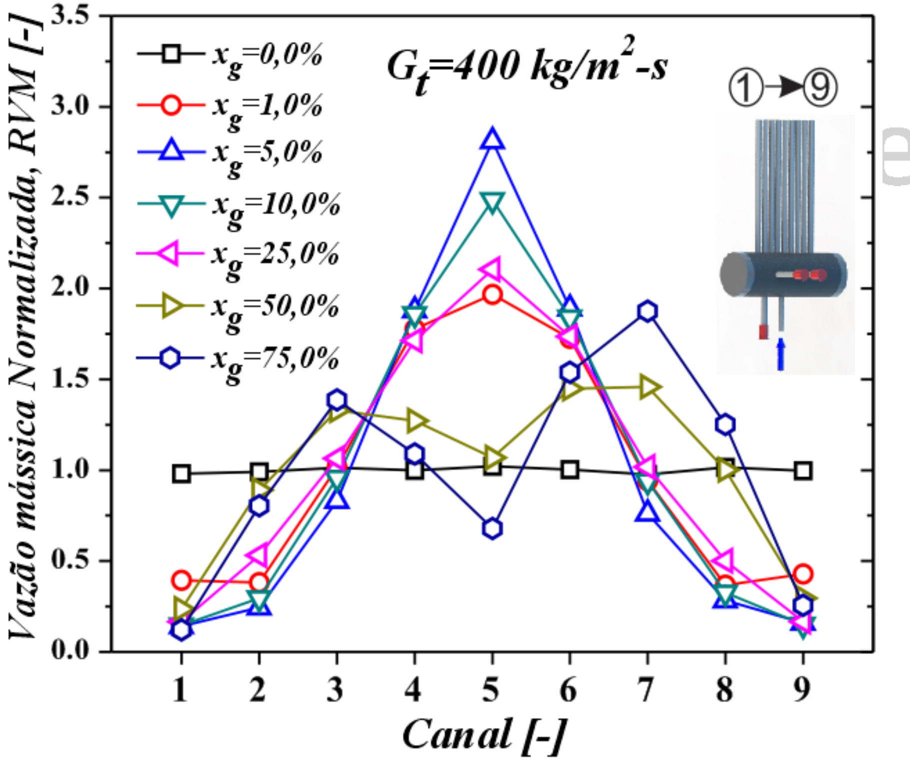
Effects of direction feeding tube:
Horizontal - header and channels

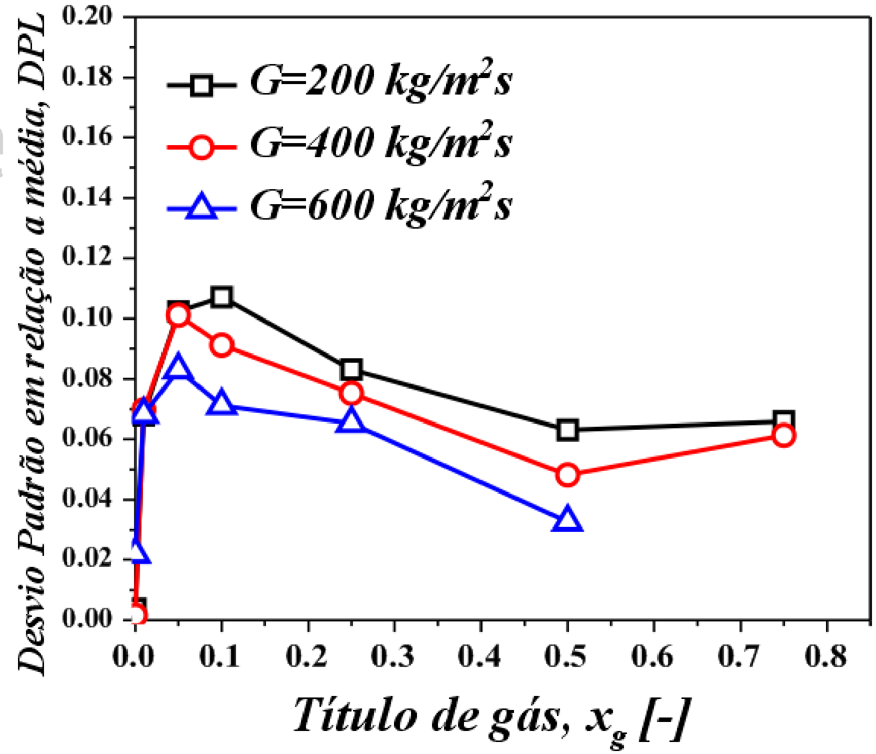




✓Part B: Analysis of results

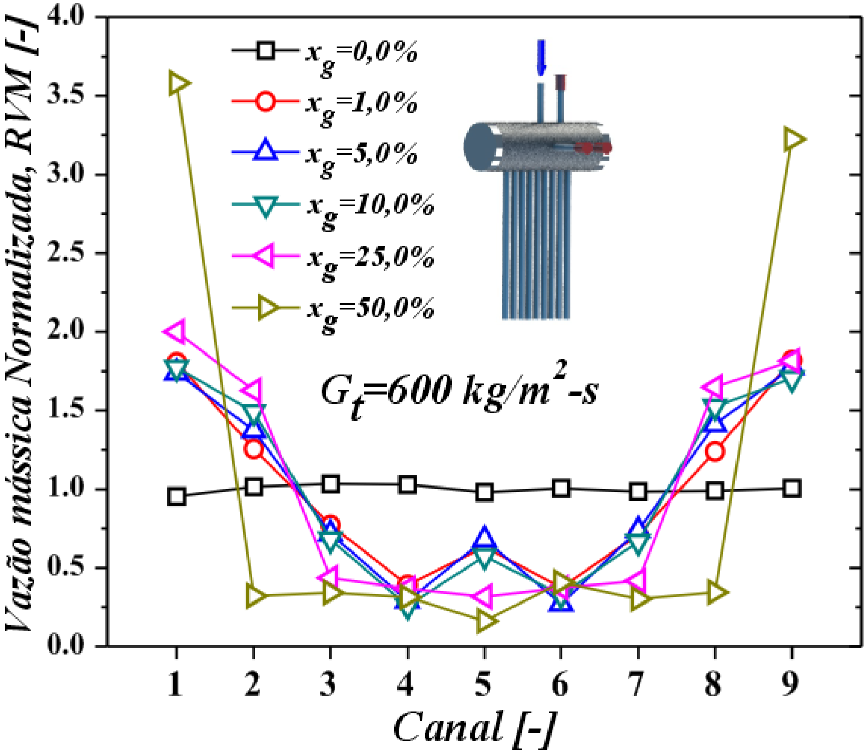
Upward flow - Horizontal header and vertical channels

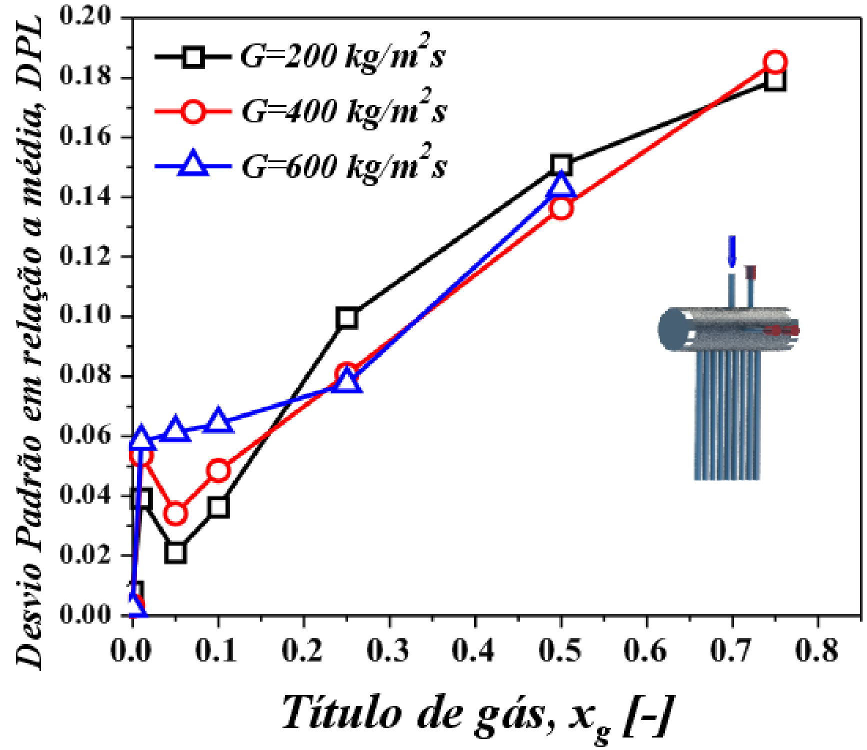




✓Part B: Analysis of results

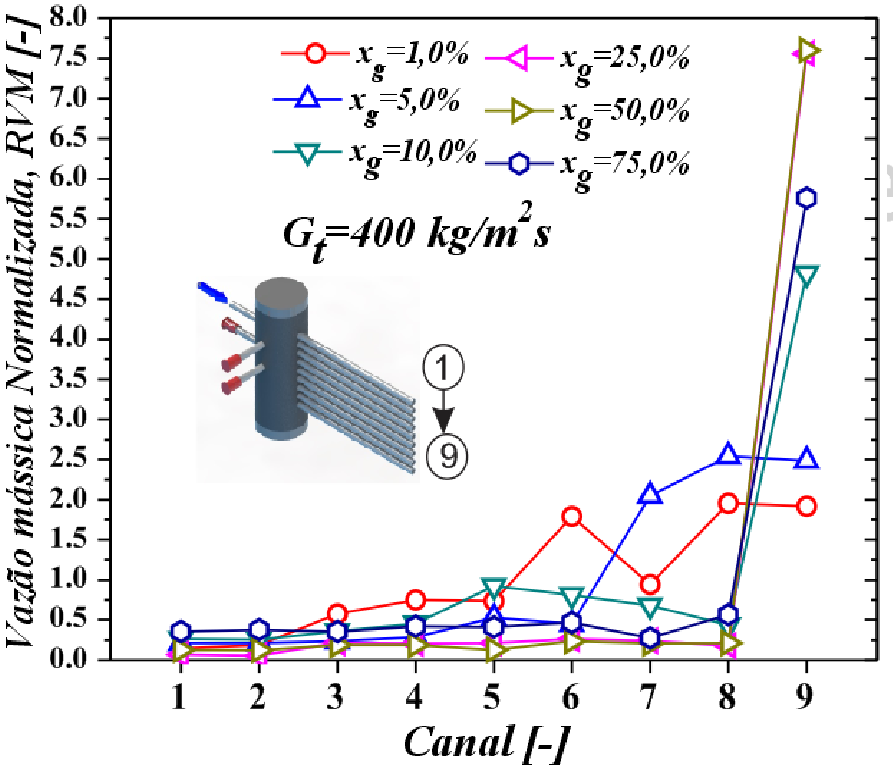
Downward flow - Horizontal header and vertical channels

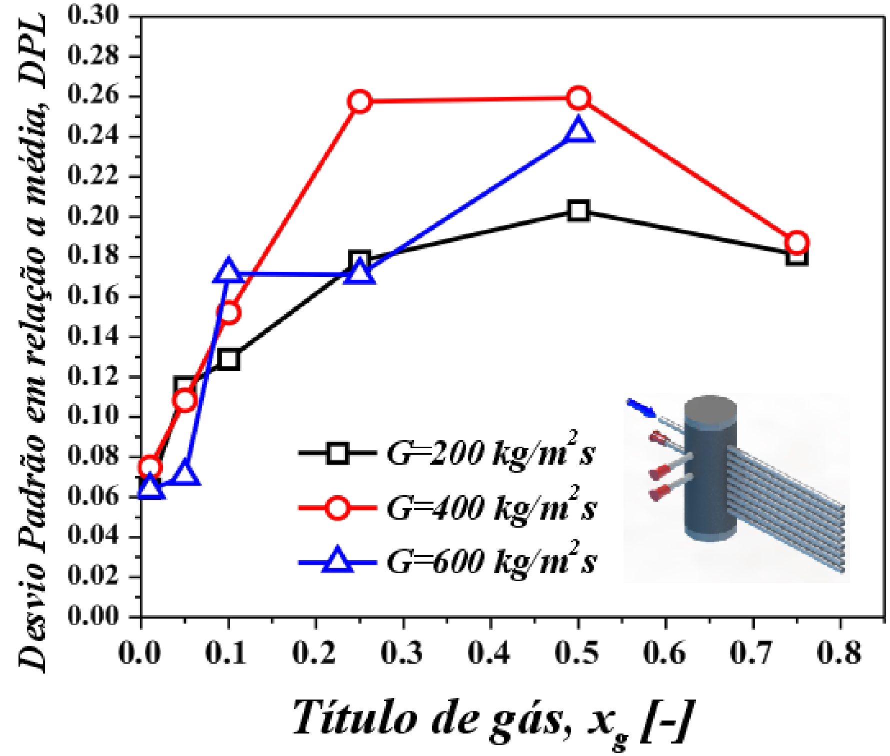




✓Part B: Analysis of results

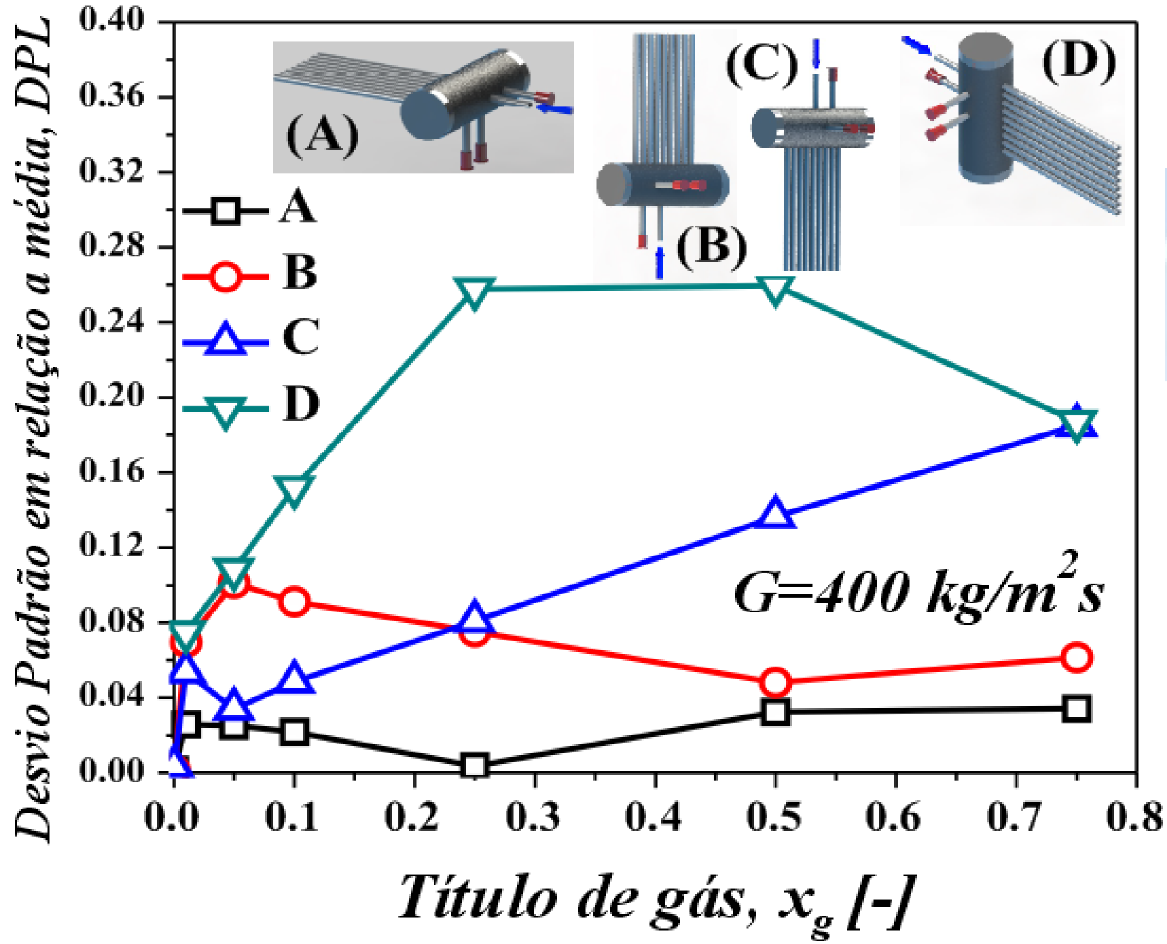
Vertical header and horizontal channels





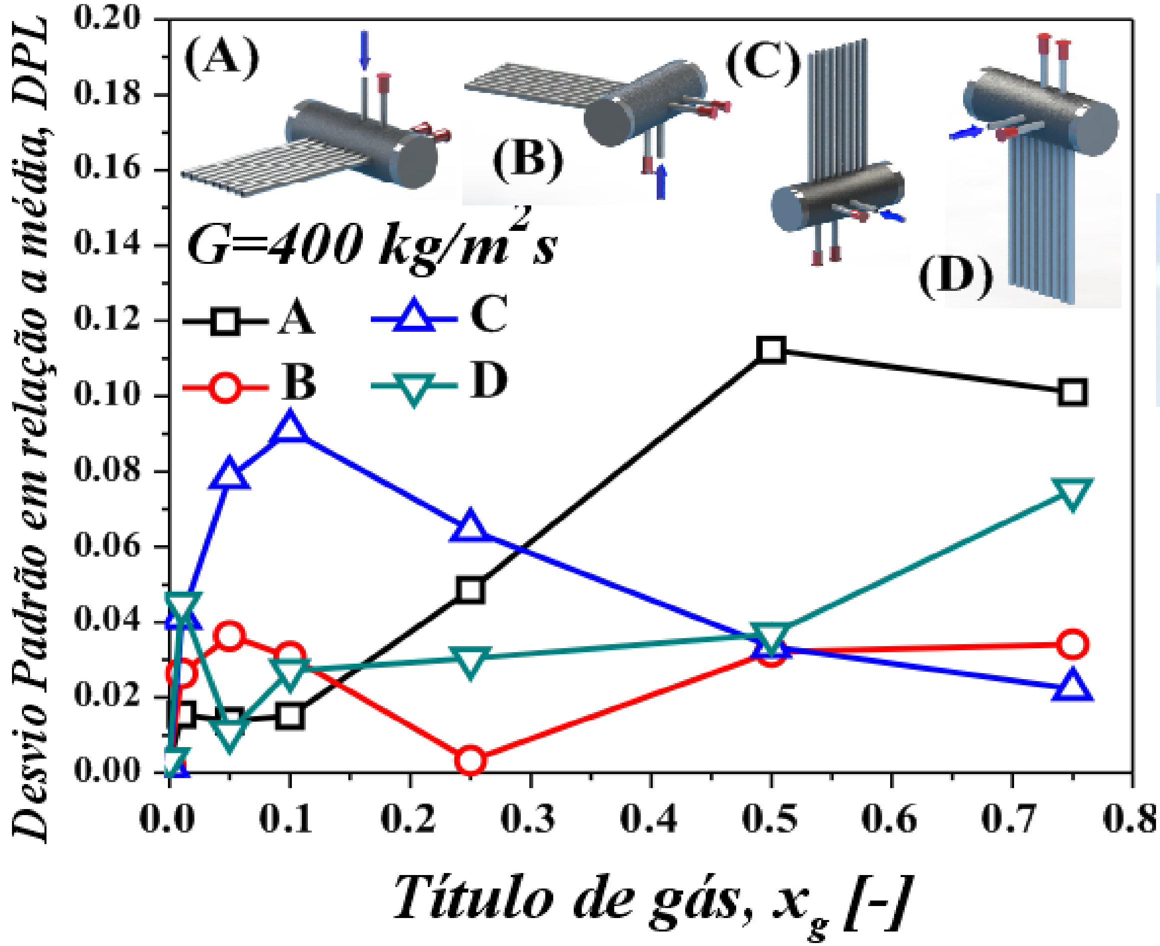
✓Part B: Analysis of results

Statistics analysis of the experimental results:



✓Part B: Analysis of results

Statistics analysis of the experimental results:



✓Part B: Conclusions

Main conclusions :

- ✓ The effects of the gas quality on liquid flow rates distribution changes considerably depending on the position of the whole (header - channels) ;
- ✓ The flow pattern in the header and the gas phase velocity, together with flow pattern in the feeding tube, determine the profile distribution of the liquid among the parallel channels;
- ✓ Different flow patterns in the header were found depending on the position of the whole (header - channel);
- ✓ The flow distribution improves when the feed tube was positioned perpendicular to the parallel microchannels for all tested configurations ;

✓Part B: Conclusions

Main conclusions :

- ✓ The level distribution between the branched channels showed better results when the feeding tube was positioned in the center of the distributor;
- ✓ In general, the liquid distribution was more even among the branch channels when the whole, microchannel and header, was positioned horizontally;
- ✓ The phases distribution is strongly influenced by the gravitational force on the liquid phase due to the stratification of the phases;
- ✓ For high gas quality, a more even distribution of the phases was achieved when the flow pattern in the header was mist-flow;

Acknowledgements