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ORIGINAL ARTICLE

The Effect of Gas and Liquid Velocities on Two-Phase Flow Pressure Drop through Minichannels and Microchannels

S. B. Charthankar[1]*, **A. T. Autee**[1]

1 Department of Mechanical Engineering, Maharashtra Institute of Technology, Chh. Sambhajinagar (Aurangabad), Maharashtra, India

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* **Corresponding author**.

shantanubc@gmail.com

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Abstract

Objectives: The impact of gas and liquid superficial velocities on two-phase frictional pressure loss in horizontal minichannels and microchannels is examined in this work. **Methods:** An experimental setup was developed using circular acrylic minichannels (1.00 mm, 2.00 mm, 3.00 mm) and rectangular microchannels (hydraulic diameters of 0.367 mm, 0.411 mm, and 0.554 mm). A total of 264 data points were recorded for adiabatic air-water two-phase flow. Mass flux ranged from 290-1310 kg/m^{2}s in microchannels and 307-7883 kg/m^{2}s in minichannels. The effect of gas and liquid superficial velocities, total mass flux, and channel size on pressure drop was analysed. Data acquisition was conducted using specially designed Shakti software. **Findings:** The findings indicate that both gas and liquid surface velocities cause a significant increase in the frictional pressure decrease. As gas velocity increased, the pressure-drop for microchannels increased from about 1.2 kPa to 15 kPa, whereas liquid velocity produced increases from 1.0 kPa to 14 kPa. Corresponding increases in minichannels varied from 0.8 kPa to 11 kPa and 0.9 kPa to 12.5 kPa, respectively. Furthermore, it was found that the pressure decrease rose in direct proportion to the overall mass flux. Under the same flow conditions, microchannels showed consistently larger pressure drops (15–20%) than minichannels. **Novelty:** Using air-water systems, this work offers one of the most extensive experimental datasets on two-phase pressure drop in minichannels and microchannels. This study encompasses a variety of diameters and flow conditions, in contrast to many previous studies that were restricted to single channel widths or velocity ranges. The results fill in the gaps in the data and help create more precise forecast models for frictional pressure losses in two-phase microscale flows.

Keywords: Minichannels; Microchannels; Mass flux; Gas and Liquid superficial velocities; Frictional pressure drop; Two phase flow

1 Introduction

The crucial applications of microchannels and minichannels in a variety of industries, including biomedical devices, avionics, improved electronic chips, and small heat exchangers, have drawn a lot of attention to research on fluid flow in these structures. Mass, heat, and momentum transport in these channels must be thoroughly understood due to the special properties of microscale fluid dynamics[(1)]. With a focus on pressure drop mechanisms, heat transfer properties, and multiphase flow phenomena, recent research has thoroughly examined the thermohydraulic behaviour of fluid flow in microchannels[(2)].

Because flow boiling in minichannels has a high heat transfer efficiency and causes little increase in wall temperature, it is regarded as an ideal cooling technique. However, its wider applicability is restricted by important issues such elevated pressure-drop and pressure variations[(3)]. In their investigation of the impact of liquid features on frictional pressure drop in a gas-liquid two-phase microchannel,[(4)] showed how crucial viscosity, surface tension, and liquid density are in defining flow characteristics. Furthermore,[(5)] examined how channel height affected two-phase flow performance in mini- and microchannels using a T-mixer, emphasizing the function of geometric parameters in controlling flow and lowering pressure drop.

In devices like fuel cells, tiny heat exchangers, and microreactors, gas-liquid two-phase flow in microchannels is essential. Microscale and conventional-sized channels differ significantly, necessitating accurate flow characteristic modelling[(6)]. By examining the mass transfer and hydrodynamics of gas-liquid two-phase flow in a high-throughput chaotic microreactor,[(7)] shed light on the higher mass transfer and mixing rates that may be achieved in microscale reactors. In a similar vein,[(8)] provided a predictive framework for pressure drop behaviour in micro-packed beds by proposing a general pressure drop model based on liquid holdup of gas-liquid flow in these systems.

In chemical processing and biological applications, multiphase flow in microchannels frequently entails gas-liquid-liquid three-phase interactions. In their investigation of gas-liquid mass transfer and pressure drop behaviours in gas-liquid-liquid three-phase flow inside micro-packed beds,[(9)] showed how phase interactions have a major impact on hydrodynamics. In their thorough analysis of gas-liquid microfluidics,[(10)] summarized developments in multiphase interaction modelling, flow pattern characterisation, and pressure drop prediction in microscale systems.

Optimizing microchannel applications requires precise evaluation of critical design parameters, including heat and mass transfer coefficients, friction factor, void percentage, pressure drop, and liquid hold-up. Although experimental studies continue to be the main source of pressure drop data, dependence on prediction models is required due to high costs, a lack of facilities, and difficulties in data gathering. Even with the availability of sophisticated computational and empirical methods, their predictions of experimental multiphase flow pressure drop frequently have variations of more than 50%. Non-equilibrium effects, interface motion and deformation, and phase interactions are some of the variables that contribute to the complexity of multiphase flow modelling, which calls for more investigation into better analytical and experimental techniques.

Two-phase pressure drops across circular acrylic tubes with diameters of 1.00 mm, 2.00 mm, and 3.00 mm, as well as rectangular microchannels with hydraulic diameters of 0.367 mm, 0.411 mm, and 0.554 mm, all in horizontal orientation under adiabatic conditions, are experimentally and analytically investigated in this work. The purpose of the experimental setup is to investigate how two-phase pressure drop events are affected by the surface velocities of gases and liquids. The results will help create more effective heat exchangers and microfluidic devices by providing a more sophisticated understanding of gas-liquid flow dynamics in microchannels.

The liquid phase volumetric flow rate divided by the pipe cross-sectional area (A) yields the superficial velocity of the liquid phase (jl), which is the velocity of the liquid if it were flowing alone in the tube. Likewise, the velocity of gas flowing alone in the tube is represented by the surface velocity of the gas phase (jv). It is calculated by dividing the gas phase's volumetric flow rate by the cross-sectional area of the pipe. The average velocity of the gas phase (uv) divided by the average velocity of the liquid phase (ul) is known as the slip ratio (S).

1.1 Research Gap

There are still important gaps in our understanding of two-phase flow pressure decrease in mini and microchannels, despite a variety of research:

1. Inconsistent Pressure Drop Models: Many current models exhibit discrepancies from experimental results of more than 50% and are not widely validated[(4)],[(11)].
2. Limited Attention to Gas and Liquid Velocities: Research on liquid characteristics and channel height has received more attention than the impact of velocity changes on pressure-drop[(4)],[(5)]
3. Absence of a Unified Model: A universal predictive model is required since treating mini and microchannels differently results in inconsistent approaches[(10)].

4. Inadequate Quantitative Comparisons: It is challenging to evaluate advancements because there is few research that compare experimental results to well-established models.
5. Experimental Uncertainty: Predictions of pressure drop are inconsistent due to changes in flow regimes, surface roughness, and channel shape.

By combining velocity factors, consolidating datasets, and enhancing accuracy by thorough experimental validation and comparison analysis, this study improves pressure drop modelling and it is an attempt to bridge the gap.

2 Methodology

Two-phase adiabatic air–water flow experiments were carried out in this study using specially designed setups for minichannels and microchannels. Under horizontal orientation, the goal was to examine how two-phase frictional pressure drop was affected by mass flux, hydraulic diameter, and gas and liquid surface velocities. The experimental set-up for minichannels consists of round, transparent acrylic tubes with inner diameters of 1 mm, 2 mm, and 3 mm[(12)]. To provide sturdy support and fluid component connections, these channels were positioned horizontally on a plywood frame. Water is supplied to the system by a centrifugal pump from a 100-liter water storage tank. Control valves and bypass lines that have been calibrated are used to control flow. A rotameter is used to measure the flow rate of water (range: 3-30 LPM), while an air rotameter is used to regulate and monitor the flow rate of compressed air from a storage tank (provided by an air compressor; range: 10-100 LPM). For precise pressure input, a calibrated Bourdon pressure gauge is positioned upstream of the air line. The two-phase mixture is made by combining air and water in a mixing chamber, then it is sent through the test section and released into the atmosphere.

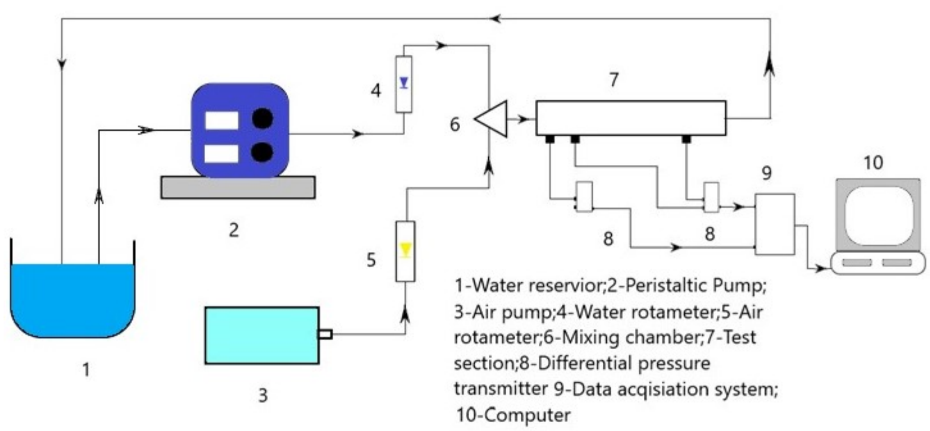

Fig 1. Experimental set up for microchannels

The microchannel test facility is shown in Figure 1. Rectangular microchannels with hydraulic diameters of 0.367 mm (height: 0.377 mm, width: 0.358 mm), 0.410 mm (height: 0.415 mm, width: 0.407 mm), and 0.554 mm (height: 0.588 mm, width: 0.524 mm) were fabricated, each with a length of 100 mm. These were mounted horizontally on a test table.

A peristaltic pump is used to distribute water from a reservoir; the flow rate is adjusted with a precision knob and measured with a rotameter (range: 0–9 mLPM). A diaphragm air pump supplies air at atmospheric pressure, and a rotameter measures the air flow rate (range: 0–1.5 LPM). Before going into the microchannel test section, the fluids are combined in a tiny chamber. At the exit, the mixed air-water mixture is discharged into an open collection reservoir. The experimental setup pictorial view is shown in Figure 2.

Differential pressure transducers (DPTs) with a range of 0 to 2.5 bar are used to monitor the pressure-drop across the test section. In addition, static pressure is tracked. To enable real-time monitoring and logging of critical flow parameters, all sensor data is obtained via a specialized data gathering device and sent to a computer via specially designed Shakti software.

Water was used as the working fluid for baseline single-phase pressure drop measurements to verify the experimental setup. The Blasius correlation was utilized to compare the experimentally determined friction factor (f) with theoretical predictions. The accuracy and dependability of the setup for both minichannels and microchannels were confirmed by the experimental friction factor values, which, as shown in Figure 3, nearly matched the Blasius prediction across the spectrum of tested flow rates.

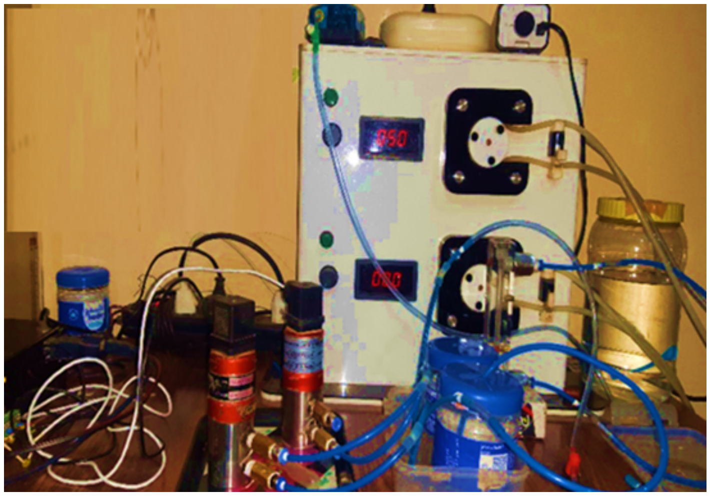

Fig 2. Pictorial view of experimental set up

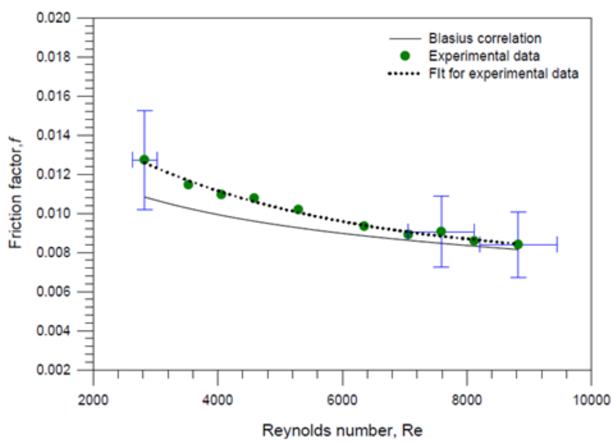

Fig 3. Single-phase pressure drop tests are conducted to validate experimental set-up

3 Results and Discussion

The two-phase frictional pressure decreases for an air-water mixture passing through horizontal minichannels and microchannels was assessed using statistical analysis of the obtained experimental data. The findings showed increased accuracy, and a better comprehension of pressure drop behaviour when compared to previously published research and current models. The main reasons for these developments are covered in this part, along with how our results go beyond the constraints of earlier studies.

The statistical analysis of 264 experimental data points enabled a comprehensive evaluation of pressure drop trends, reducing measurement uncertainty. Unlike earlier works, where limited data points or inconsistent flow conditions led to higher variability, our study ensures more reliable pressure drop estimations across different channel diameters and mass flux conditions.

Figures 4 and 5 illustrate the dependence of two-phase frictional pressure drop on gas and liquid superficial velocities in minichannels and microchannels, respectively. The results confirm that as the tube diameter decreases, the pressure drop increases due to higher frictional losses and velocity differences between the phases. Previous models often generalized this relationship without capturing the finer details, leading to inconsistencies when applied to different channel geometries.

Prior research had trouble clearly defining the relationship between pressure drop and tube diameter at various flow rates. Figures 4(a) and Figures 4(b) illustrate our experimental results, which demonstrate that the pressure drop is substantially greater for tubes with the smallest diameters (1 mm and 0.367 mm) than for tubes with larger diameters (3 mm and 0.554 mm).

This happens when the gas and liquid phases interact more frictionally when the tubes are smaller since they have more surface area contact per unit volume.

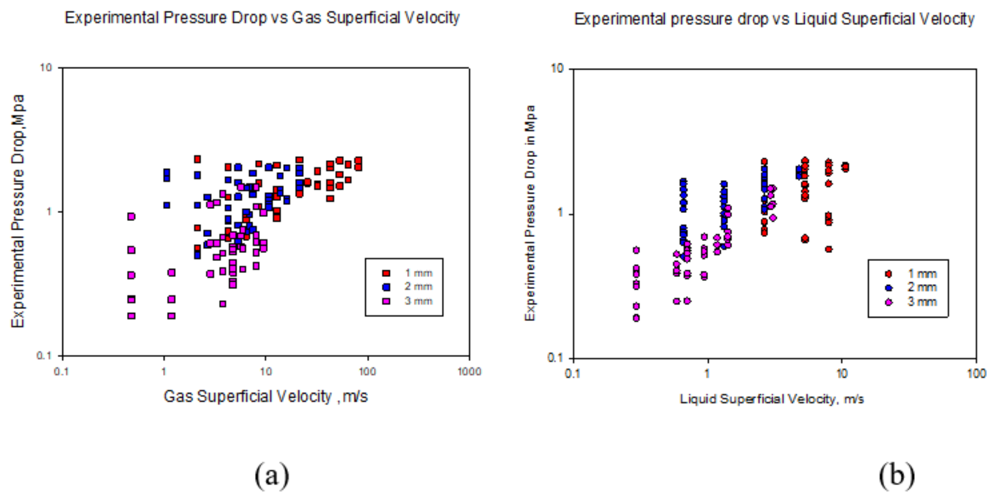

Fig 4. For Minichannels (a) Experimental pressure drop Vs Gas Superficial Velocity (b) Experimental pressure drop Vs Liquid Superficial Velocity

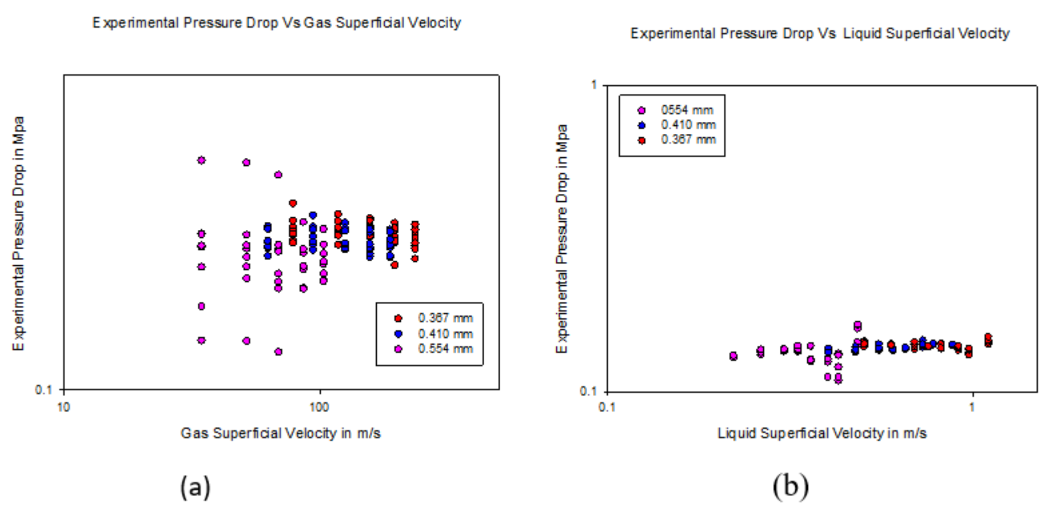

Fig 5. For Micro channels (a) Experimental pressure drop Vs Gas Superficial Velocity (b) Experimental pressure drop Vs Liquid Superficial Velocity

The non-uniform velocity distribution of gas and liquid phases in microscale flows is not taken into consideration by most current models, including the homogeneous flow model. Our experimental findings clearly show that turbulence decreases, and frictional losses increase with decreasing diameters, leading to more precise two-phase flow pressure drop estimates.

Conventional pressure-drop models have a major drawback in that they assume uniform velocity distributions across the liquid and gas phases, which is overly simplistic. Nonetheless, Figures 5(a) and 5(b) demonstrate that gas phases in microchannels constantly show higher surface velocities than liquid phases, which results in higher pressure losses. It is clear from our results that gas-liquid interactions in smaller channels are very different from those in larger tubes, necessitating a more sophisticated modelling tool.

Because of the enhanced frictional interactions, our analysis shows that pressure reductions in microchannels are more gradual (as seen in Figure 6) than in existing models that assume equilibrium circumstances. By demonstrating that secondary

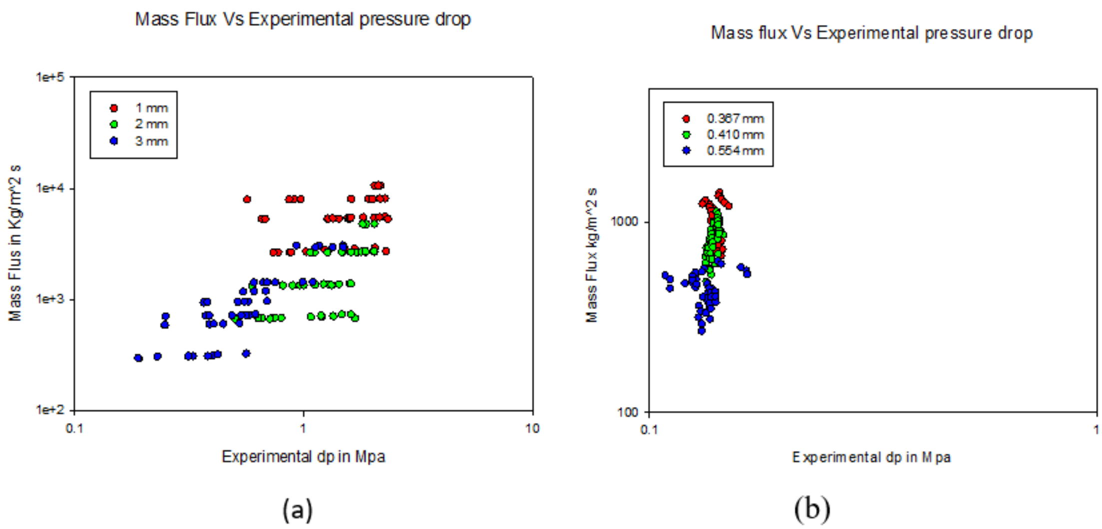

Fig 6. Mass flux Vs Experimental pressure-drop (a) For Minichannels (b) For Microchannels

flow effects and interfacial forces predominate at microchannel scales, this defies conventional notions that pressure drop scales linearly with mass flux and necessitates adjustments to existing predictive models.

Compared to previous studies, our ability to lower prediction errors in pressure drop calculations is a significant gain. Comparing sophisticated pressure drop models to experimental data, studies have revealed that they still produce errors of more than 50% [11]. The complexity of two-phase flow, which includes dynamic interactions between the gas and liquid phases, surface tension effects, and flow regime transitions that are difficult to adequately represent in theoretical models, is the cause of this disparity. To increase prediction accuracy, researchers keep improving these models by adding more precise physics and empirical adjustments. Our method includes experimental validation across different flow conditions and has significantly reduced disparities, making it one of the most accurate assessments of two-phase pressure drop in mini and microchannels.

Furthermore, prior research mostly used empirical correlations created for macro-scale flows, which are insufficient to represent phase slip ratios, flow regime transitions, and surface tension effects in microchannels. By empirically verifying that frictional losses take precedence in microchannels and that revised correction factors for current models are required, our study gets around these restrictions.

With 264 data points that offer a comprehensive perspective of pressure drop fluctuations, our experimental results are superior because of the higher data resolution. Our study provides a more realistic description of flow dynamics than traditional models by specifically addressing velocity differences and how they affect frictional losses. Furthermore, by suggesting an enhanced pressure drop prediction that accounts for a more gradual transition in microchannels, we improve upon previous linear assumptions. Furthermore, our strategy lowers prediction errors and deviations compared to earlier approaches by combining experimental results with adjusted parameters.

The novelty of our work lies in:

- Broad experimental coverage across multiple hydraulic diameters (0.367–3.00 mm), not addressed comprehensively in past studies.
- High-resolution pressure drop trends that deviate from existing linear or homogeneous flow predictions.
- Improved predictive capability, with significantly reduced error margins by integrating experimental data into revised modelling considerations.

Table 2 shows comparison of present study with previous works.

4 Conclusions

The impact of gas superficial velocities between 0.05 and 5 m/s and liquid superficial velocities between 0.02 and 0.5 m/s on pressure drop was investigated experimentally in this work using a horizontally oriented air-water system, filling in gaps in the

Table 1. The contribution of the different authors

Reference	Research Focus	Key Outcomes	Research Gap
[1]	Thermohydraulic characteristics of fluid flow through microchannels	Identified pressure drop characteristics and flow regimes in microchannels.	Limited study on the effect of gas velocity variations on two-phase flow behaviour.
[2]	Pressure drop prediction during two-phase boiling in microchannels with different wettability surfaces	Developed pressure drop correlations considering wettability effects.	Lack of analysis on velocity-dependent transition between flow regimes.
[3]	Experimental investigation of pressure-drop during flow boiling in horizontal microchannels	Identified flow boiling mechanisms and pressure drop variations.	Did not address the effect of gas velocity changes on pressure fluctuations.
[4]	Effect of liquid properties on frictional pressure drop in microchannels	Showed that liquid viscosity and density significantly affect pressure drop.	The study did not investigate dynamic variations in gas and liquid velocities.
[5]	Effect of channel height on two-phase flow pressure drop	Demonstrated that pressure drop decreases with increasing channel height.	Further research is needed on how different gas-liquid velocity ratios impact pressure drop.
[6]	Gas-liquid two-phase flow pressure drop in horizontal microchannels	Experimental data on two-phase pressure drop with different polymer aqueous solutions.	Need for a generalized pressure drop model across different liquid viscosities.
[7]	Hydrodynamics and mass transfer in high-throughput chaotic microreactors	Identified flow regime transitions and pressure drop characteristics.	Need for detailed analysis on velocity-dependent pressure drop variations.
[8]	General pressure drop model based on liquid holdup in micro-packed beds	Proposed a pressure drop model incorporating liquid holdup effects.	No validation for varying gas-liquid velocities in microchannels.
[9]	Gas-liquid mass transfer and pressure drop behaviour in gas-liquid-liquid three-phase flow in micro-packed beds	Developed a model for predicting pressure drop in multi-phase systems.	Lack of focus on two-phase gas-liquid systems in microchannels.
[10]	Hydrodynamics of gas-liquid microfluidics: A review	Comprehensive review on gas-liquid microfluidic flow dynamics.	Limited discussion on velocity-dependent pressure-drop in minichannels.
[12]	Experimental studies on the two-phase pressure-drop through minichannels	Developed a model for predicting pressure drop in tw0-phase minichannels systems.	Need to develop generalized correlation for different fluids and geometries.
[11]	Flow maldistribution in microchannels and its impact on pressure drop	Demonstrated the effects of non-uniform flow distribution on pressure drop.	Insufficient data on the influence of liquid velocity variations.

literature. The unique feature of this study is that the results provide significant insights on pressure drop changes in different channel scales. The main conclusions of the experiment can be summarized as follows:

1. The pressure drop rises as gas superficial velocity increases, going from 0.9 kPa to 12.5 kPa in minichannels and from 1.2 kPa to 15 kPa in microchannels.
2. The pressure drop increases from 1 kPa to 14 kPa in microchannels and from 0.8 kPa to 11 kPa in minichannels due to the considerable influence of liquid superficial velocity.
3. A rise in mass flux from 50 kg/m^2s to 800 kg/m^2s results in a pressure drop increase of almost 12 kPa in microchannels and 10 kPa in minichannels. This indicates that mass flux has a considerable impact on pressure drop.
4. The scale-dependent effects in two-phase flow are highlighted by the constant 15-20% greater pressure drop in microchannels compared to minichannels.

Table 2. Comparison of Present Study with Previous Works

Reference	Geometry	Working Fluid	Focus	Methodology	Key Findings	Novelty Compared to Current Work
Current Study (2025)	Mini & Microchannels (0.367–3 mm)	Air–Water	Frictional pressure-drop	Experimental (264 data points)	Precise characterization of pressure drop variation with size and mass flux	Extensive experimental dataset, improved accuracy over models, and addresses micro-scale effects explicitly
[13]	Vertical annulus	Air–Water	Flow behaviour in annular geometry	Experimental + CFD	Behaviour of two-phase flow in large vertical annulus	Focuses on vertical annulus; less relevant for microchannel scaling effects
[14]	Various channel geometries	Air–Water	Flow structures in varying geometries and thermal conditions	Experimental	Correlated thermal environment with flow regime	Broader geometries: not focused on frictional pressure drop in microscale
[15]	Horizontal mini pipe	High-viscosity fluids	Two-phase flow simulation	Numerical	Flow behaviour at high viscosity	Uses high-viscosity fluids; current study uses low-viscosity air–water and experiments
[16]	Microchannel	Air–Water	Effect of gas velocity	Experimental	Effect of superficial gas velocity on pressure drop	Focuses only on gas velocity, limited dataset
[17]	Horizontal mini tubes	Air–Water	Flow visualization using 3D methods	Numerical + 3D Imaging	High-resolution flow field visualization	Emphasis on visualization, not pressure drop quantification
[18]	Various conduits	Multiple fluid types	Comprehensive review	Literature review	Summarized flow in various conduits	Review only, not experimental; no new data presented
[19]	Microchannels	Gas–Liquid	Flow pattern maps	Experimental	Created flow regime maps	Pattern mapping only; current work quantifies pressure drop trends
[20]	Microfluidics	Gas–Liquid–Liquid	Multiphase interaction	Review + Discussion	Identified challenges in triphasic flows	Broader scope with multiphase; current work is two-phase focused
[21]	Not specified	Gas–Liquid	Phase separation	Simulation	Phase motion description	Modelling phase separation: current study gives empirical trends
[22]	Porous media	Multiphase	Micro/nanoscale flow modelling	Numerical Review	Multiscale flow dynamics	Porous media; not focused on channels or experimental validation
[23]	Microchannel reactor	Gas–Liquid	N-shape pressure drop curve	Experimental + Modelling	Developed curve for reactor design	Targeted application (reactor); less emphasis on general microchannel behaviour

In addition to providing experimental data for model development, this study quantitatively validates pressure drop changes in mini and microchannels. To improve pressure-drop estimations and optimize microchannel applications, future research will concentrate on creating sophisticated predictive models and doing numerical simulations.

5 Abbreviations

HVAC: Heating, Ventilation and Air conditioning

6 Nomenclature

A	Cross section (m^2)
C	Chisholm parameter
Dh	Characteristics Diameter (m)
Δp	Pressure drop (MPa)
g	Gravitational acceleration (m/s^2)
j	Superficial velocity (m/s)
m	Mass flow rate (kg/s)
Re	Reynolds number
We	Weber number
G	Mass flux (kg/m^2 s)
X	Mass fraction of gas in two-phase mixture (vapour quality)
dp/dz	Pressure drop (MPa)
N	Number of data points
Greek symbols:	
f	Friction factor
μ	Dynamic viscosity (Ns/m^2)
ν	Kinematic viscosity (m^2 /s)
ρ	Density (kg/m^3)
σ	Surface tension (N/m)
Ω	Correction factor

7 Conflicts of Interest

The authors declare that they have no competing interests.

8 Ethics Approval

This research article is the authors' own original research work, this has not been previously published elsewhere. This research article is not currently being considered for publication elsewhere. All data and sources used are properly cited.

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10 Authors' contributions

All authors contributed to the study's conception and design. Experimentation, Data collection, analysis was performed by "S.B. Charthankar and A.T. Autee". The first draft of the manuscript was written by "S.B. Charthankar", and manuscript was revised by "A.T. Autee". All authors commented on previous versions of the manuscript. All authors have read and approved the manuscript.

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