

## TWO-PHASE FLOW CHARACTERISTICS ON THE EXTENSIVE EXPANSION CHANNEL

Latif Ngudi Wibawanto<sup>1</sup>, Budi Santoso<sup>1</sup>, Wibawa Endra Juwana<sup>1</sup>

<sup>1</sup>Mechanical Engineering Department–Universitas Sebelas Maret

### Keywords:

Two phase flow  
Flow current  
Expansion  
Pressure recovery

### Abstract:

This research was conducted to find out the flow characteristic of two phases through channel with sudden expansion in the form of change of flow pattern and pressure recovery. The test was conducted with variation of superficial velocity of water 0.2-1.3 m / s and superficial air velocity of 0.2-1.9 m / s resulting in pattern of three flow patterns ie bubble, plug, and slug. The expansion channel resulted in some changes to the flow pattern that originally plugs in the upstream channel into bubble in the downstream channel and the slug becomes plug. Pressure recovery experimental results were compared with the homogeneous model flow equation and Wadle correlation, the two correlations had predictions with standard deviation values of 0.32 and 0.43.

### INTRODUCTION

The two-phase flow is part of a multi-phase flow. The flow of these different phases is commonly used in industrial processes, energy conversion system components such as heat exchangers, evaporators, and cooling cycles. These components are commonly applied components in industrial processes and nuclear power installations. The petroleum products transport which concerns in pipes has been become a number of studies object that construct design models of flow/ pattern type and pressure drops in vertical, horizontal, and tilted pipes. The particular flow pattern in Figure 1 is formed due to the velocity combination of the liquid and gas phases that depending on the pipe gravitational interaction, inertia, and surface tension. It is believed that the squared flow mechanisms and a small diameter of circular cross-section (mini channels) differ from channels with larger diameters (conventional channels).

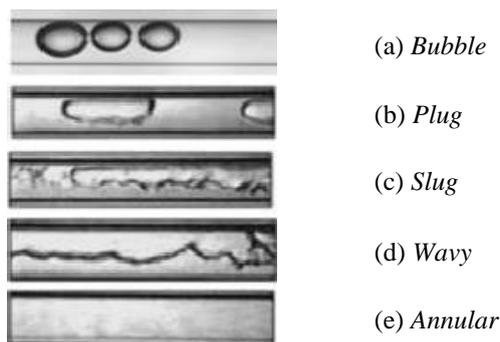


Figure 1. Two-phase flow pattern on the horizontal channel

This flow pattern affects the pressure distribution along the channel, its pressure drop and pressure recovery which have a contraction and expansion.

The flow pattern type on heat exchange system influences the heat transfer coefficients.

The transition area of bubble-plug flow pattern can be predicted by recognizing the value of  $d_b/D_h$  that lies between 0.03-0.4. It depends on the bubble pattern vacuum fraction value at the area around the transition boundary which is obtained from the following equation:

$$\alpha_{cr} = 0,6-2,32 \cdot d_b/D_h \quad (1)$$

$$J_g = u_g \cdot \alpha \quad (2)$$

The fluid disposition is generally performed by utilizing piping systems in some industries such as chemical industry. It require major pipes, it also need several pipeline components, such as pipe bends, elbows, valves, expansion channel, compression channel, and combinations channel. In large pipeline systems, the pipe components losses are usually a minor (minor loss) loss compared to friction losses along the channel (major losses). However, to the contrary system, the pipe component losses can be a major disadvantage to total losses along the flowing path. Pressure recovery develops quick expansion on channel area, i.e., the greater pressure after the expansion due to the fluid velocity significantly decreased and the pressure will do so. Apparatus designing process become necessarily to estimate the two-phase flow drop characteristics. The pressure recovery value is calculated to determine the piping system total losses. The pressure recovery research of two-phase flow has been accomplished to obtain the technical guidance and practical design in components procedure of energy conversion system as in the pump specifications selection which is used on the system. In this experiment, it will be carried out by using a mini-sized square-sectional test channel on conventional upstream and rectangular channels in the downstream channel utilizing air and

water as the working fluid. The pressure recovery value, due to the expansion is defined as the pressure difference when the pressure gradient line at the flow conditions developing full upstream and downstream is extrapolated to the channel extension point (P1 and P2) shown in Figure 2. This study is to predict the pressure recovery value using homogeneous flow method (Equation 3) and the Wadle Equation (1988) (Equation 4).

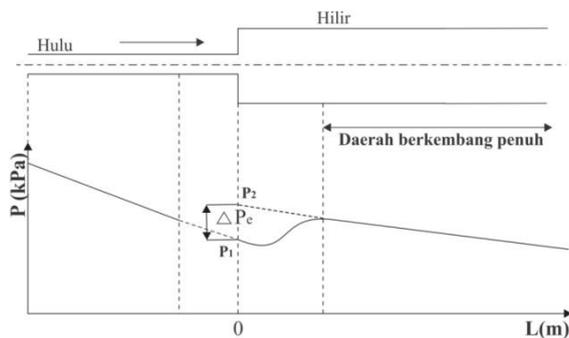


Figure 2. The pressure distribution on the channel of instant expansion.

The pressure recovery value is determined by the following equation:

$$\Delta P_e = (1 - \sigma^2) \frac{1}{2} G_{\text{total}}^2 K \left[ \frac{x}{\rho_g} + \frac{1-x}{\rho_l} \right] \quad (3)$$

$$\Delta P_e = (1 - \sigma^2) \frac{1}{2} G_{\text{total}}^2 K \left[ \frac{(1-x)^2}{\rho_l} + \frac{x^2}{\rho_g} \right] \quad (4)$$

where,

- $\sigma$  = gas quality
- $A$  = expansion ratio ( $A_1/A_2$ )
- $A$  = channel area,  $m^2$
- $G$  = mass flux phase,  $kg/m^2s$
- $\rho$  = mixture density,  $kg/m^3$
- $\Delta P_e$  = pressure recovery, kPa
- $\sigma$  = empiric phase air-water (0,83)

Subscript,

- 1 = upstream channel
- 2 = downstream, channel
- l = liquid phase (air)
- g = gas phase (udara)

### RESEARCH METHODOLOGY

The test was performed by using variation of  $J_1$  0.2-1.3 m/s of superficial water velocity and  $J_g$  0.2-1.9 m/s of superficial air velocity. The test and instrumentation scheme are shown in Fig. 3 and Fig. 4. The two-phase flow pattern in each variation, the camera is placed over the channel that is on the upstream channel to observe its value, expansion area, and downstream with 3 seconds of recording duration. A lamp was placed under the test channel to make the image obtained more clearly, the camera which was used in this study has 1000 fps of shooting speed. The two-phase flow recording video

was processed using Phantom 630 software to determine the gas phase actual speed ( $u_g$ ). The pressure measurements were performed on full fledged areas. It was taken at of 0.6-1.3 m/s of water superficial velocity. The test line has five pressure taps as a pressure measuring point on each upstream and downstream channel. The PA500-501G Copal pressure sensor was used to measure the pressure at the first pressure gauge and the MPXV4006DP pressure sensor was used to measure the pressure difference between the first pressure measuring point and the next measuring point.

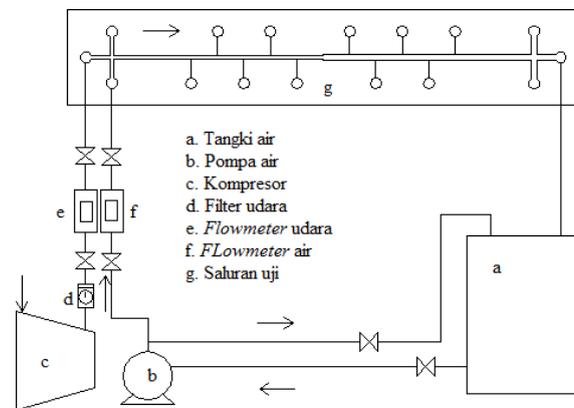


Figure 3. Test scheme

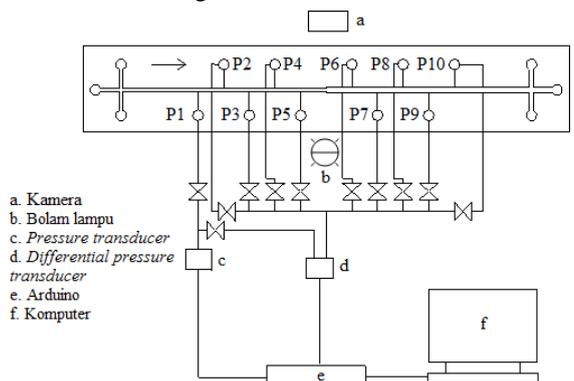


Figure 4. Instrumentation scheme

**RESULT AND DISCUSSION**

**1. Two-phase flow pattern**

The identified results flow patterns of this study are as follows:

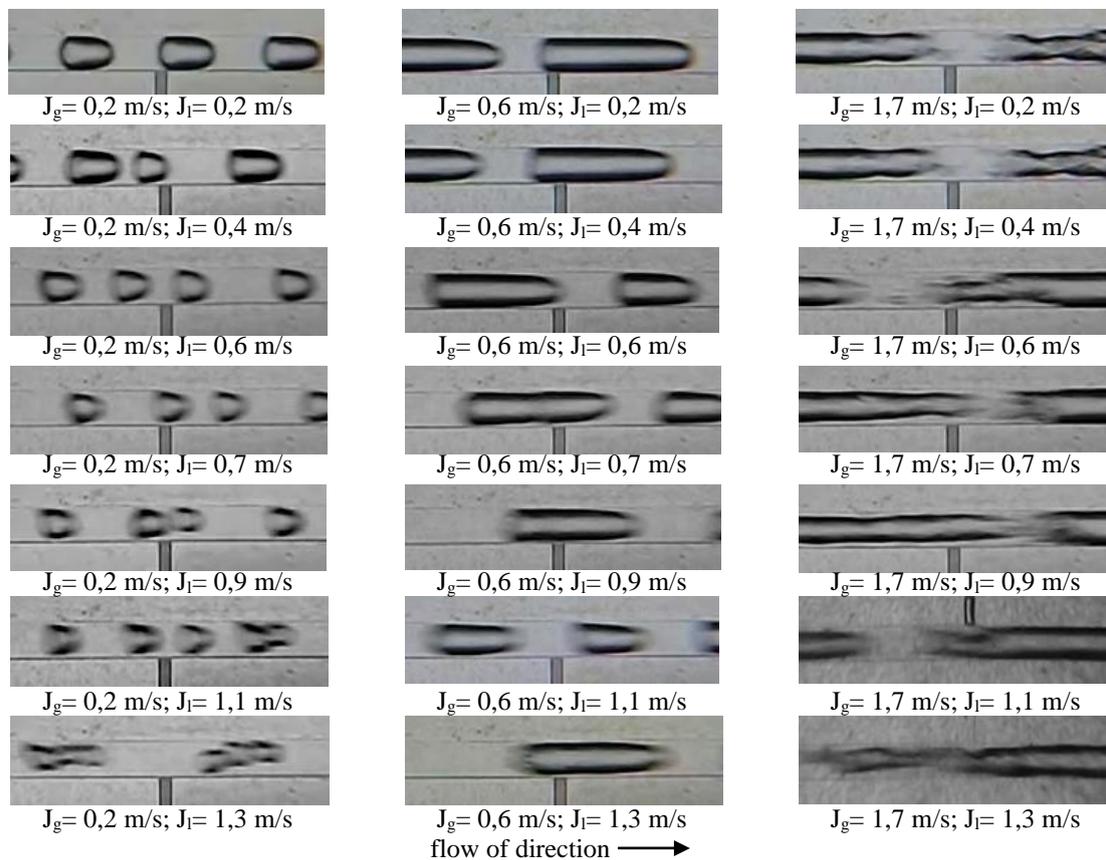


Figure 5. Two-phase flow pattern on the channel

In this research, there were three different flow patterns, namely bubble, plug, and slug, while wavy and annular flow patterns were not found in this study. Figure 5 shows some flow patterns that exist in this study. The bubble flow pattern begins to be found in a water flow variation of 300 ml/min at a superficial velocity of 0.6 m/s, this pattern is formed only at 0.2 m/s and 0.4 m/s of low superficial air velocities. At the superficial velocity variations 0.2 m/s and 0.4 m/s bubble flow patterns were not found even at low superficial air velocities. Bubble becomes more elongated which then turns into a plug along with increasing superficial air velocity at the same superficial water velocity. The slug flow pattern was formed at a superficial high air velocity variation. The slug flow pattern was started to form at 1.7 m/s and 0.2 m/s of superficial velocity.

The flow pattern data visualization of research results on the upstream channel was plotted on the flow pattern map made by Zhao (Figure 6) which equally used mini sized channel yet utilizing different channel hydraulic diameter.

Based on the experimental data and flow pattern map, there was a slight difference (shift) of the transition region between the bubble and the plug. This difference can be due to the diameter of the hydraulic channel which was used in this study three times greater than the channel used by Zhao.

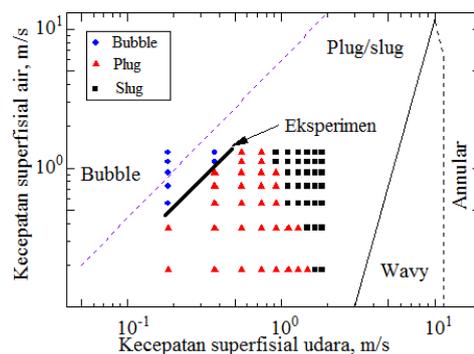


Figure 6. The research results flow pattern was plotted on the flow pattern map Zhao (2004)

The transition region of the bubble-plug flow pattern can be predicted by knowing the value  $d_b/D_h$  between 0.03-0.4 shown in Table 1.

Table 1. Dimensionless parameter data  $d_b/$  at bubble-plug transition region

$J_i$ , m/s	$J_g$ , m/s	$u_g$ , m/s		pola aliran	$d_b/D_h$
0,6	0,2	1,4	0,13	Bubble	0,20
0,7	0,2	1,6	0,11	Bubble	0,21
0,9	0,2	2,1	0,09	Bubble	0,22
1,1	0,4	2,4	0,16	Bubble	0,19
1,3	0,4	2,7	0,14	Bubble	0,20

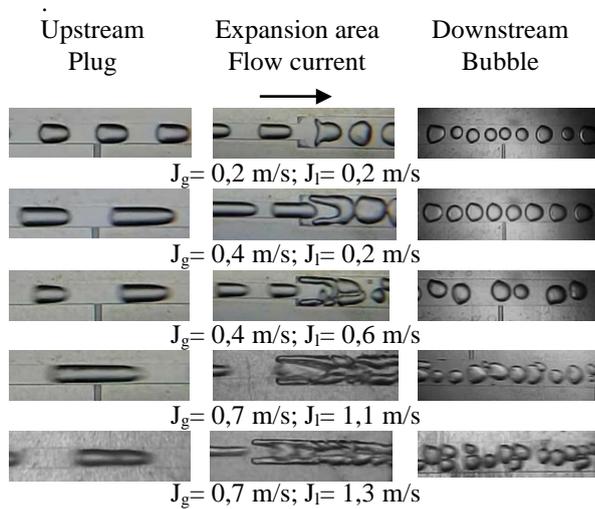


Figure 7. Plug flow pattern transformation to bubble

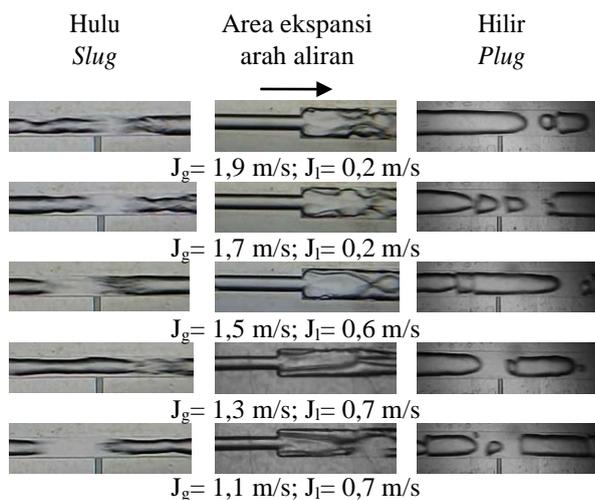


Figure 8. Slug flow pattern transformation to plug

Channel expansion results in some flow patterns transformation to different pattern types was performed by this research. Such as,  $J_i = 0,2$  m/s,  $J_g = 0,4$  m/s dan  $J_i = 0,6$  m/s,  $J_g = 0,4$  m/s of flow patterns that were originally plug turned into bubble as shown in Figure 7. The bubble flow pattern on the downstream channel was more common than before the flow passes through the expansion (in the upstream channel). At  $J_i = 0,2$  m/s,  $J_g = 1,9$  m/s dan  $J_i = 0,7$  m/s;  $J_g = 1,1$  m/s the flow pattern originally slugs

into a plug is shown in Figure 8. The plug flow pattern on the downstream channel was less than before the flow goes through the expansion

## 2. Pressure recovery

The transition region length ( $L_d$ ) at the instant expansion channel which shown at Table 2 is a function of the Reynolds number on the upstream channel ( $Re_1$ ). The transition region length gets bigger as the Reynolds number increases. The comparison value between the transition region length and the channel diameter ( $L_d/D_h$ ) on the expansion channel can be correlated based on Reynolds number and expansion ratio. In this study, pressure measurements were taken at a distance of 30 mm after expansion. The Reynolds number used was the total Reynolds number of each phase. Based on Equation 5, the distance was already in full developing region therefore in Figure 9 the pressure distribution before in the transition region was unknown.

$$(5)$$

The pressure recovery value, since the expansion was defined as the pressure difference when the pressure gradient line at the flow condition was fully developed upstream and downstream was extrapolated to zero on the extension channel. Figure 10 shows that the greater the superficial velocity of water, the greater the pressure recovery value. At the same superficial water velocity the larger quality of the pressure recovery gas quality value also tends to be bigger. From the figure 9 can be seen that the value of pressure recovery research results were closer to the recovery pressure value obtained from the homogeneous flow model equation than the correlation Wadle (1988).

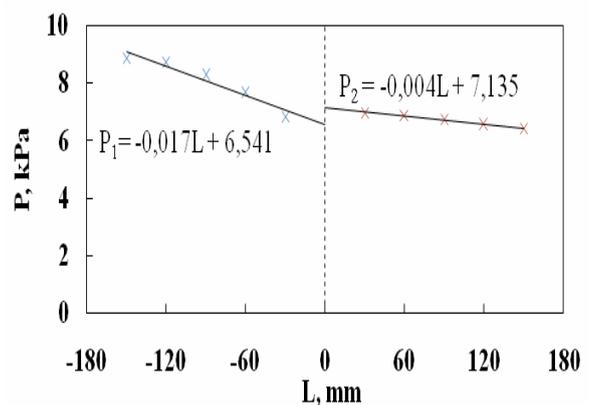


Figure 9. Pressure distribution along the channel of instant expansion of  $J_i = 0,9$  m/s,  $J_g = 0,6$  m/s

Table 2. The expansion channel length at ransition region.

	$J_g$ , m/s	Re udara	Re total	$L_d$ , mm
$J_1$ , m/s	0,7	139,2	2220,1	23,2
0,6	0,9	174,0	2254,9	23,2
Re air	1,1	208,8	2289,7	23,3
2080,	1,7	313,2	2394,1	23,4
9				
$J_1$ , m/s	0,6	104,4	3572,5	24,4
0,9	0,7	139,2	3607,3	24,4
Re air	0,9	174,0	3642,1	24,5
3468,	1,1	208,8	3676,9	24,5
1	1,7	313,2	3781,3	24,6
$J_1$ , m/s	0,2	34,8	5583,8	25,6
1,3	0,4	69,6	5618,6	25,7
	0,6	104,4	5653,4	25,7
Re air	0,7	139,2	5688,2	25,7
5549,	0,9	174,0	5723,0	25,7
0	1,1	208,8	5757,8	25,7
	1,5	313,2	5792,6	25,8

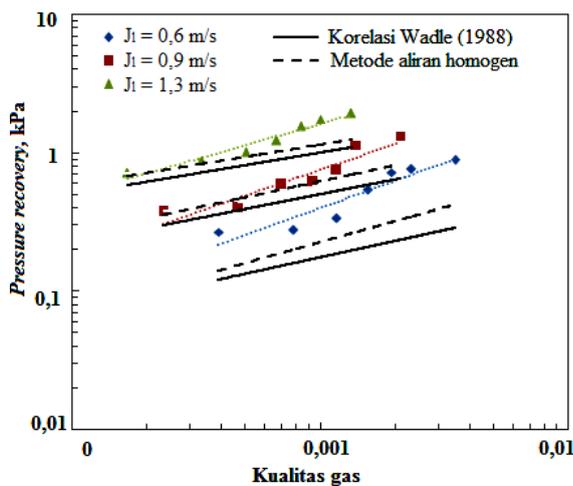
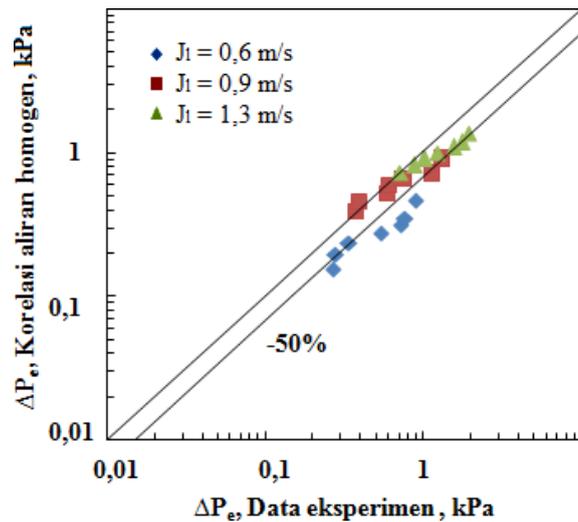


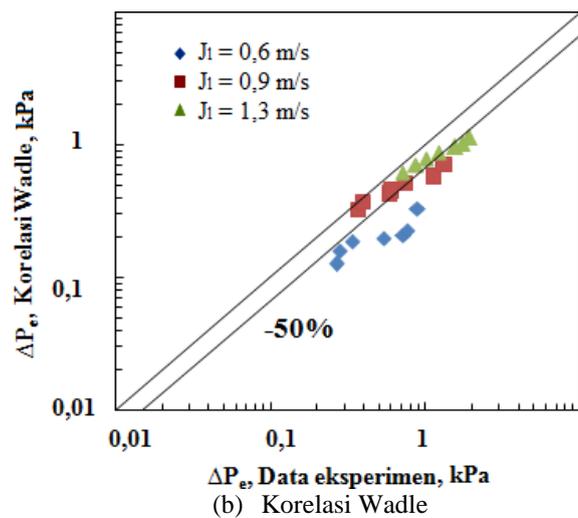
Figure 10. Pressure recovery  $p_r$  as a function of gas quality

Table 3. Standard deviation between pressure recovery research results and equations

Deviation	The homogeneous flow method equation	Wadle correlation (1988)
The mean of deviation value	0,24 kPa	0,35 kPa
Standard deviation (S)	0,32 kPa	0,43 kPa



(a) The homogeneous flow method correlation



(b) Korelasi Wadle

Figure 11. Comparison of  $p_{im}$  and  $\Delta p_e$  values to calculations

Pressure recovery results were compared to results which were obtained of the homogeneous flow method and Wadle correlation (1988). The comparison graph is shown in Figure 11. In this study, the homogeneous flow method gives a prediction using lower deviation value compared to the Wadle correlation (1988) shown in Table 3. The differences of the two correlations are based on the mixed mass density determination, mass flux as well as empirical constants which has been determined in the Wadle correlation (1988). At the superficial velocity variation of water 0.6 m/s can not be predicted well because the differential pressure transducer has a low accuracy on the condition.

## CONCLUSION

From the data and analysis that has been done can be concluded as follows:

1. In this research, two-phase bubble, plug, and slug flow patterns were obtained. Wavy and annular flow patterns were not found in this study.
2. In this two-phase flow study, the pressure recovery value based on homogeneous flow method and Wadle correlation tend to be lower than pressure recovery research results.
3. The comparison of Wadle correlation to the pressure recovery value based on homogeneous flow method gave a result that was closer to the pressure recovery research results.

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