The Analysis of Gas-liquid Two-phase Flow Patterns Based on Variation Coefficient of Image Connected Regions and Line-Correlation Algorithm

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Abstract

Five typical flow patterns are shot in the horizontal pipe test section by high-speed photography technology. Then the connected regions of flow pattern images are obtained. The connected region is different from the gray texture. Connectivity characteristics are morphological characteristics of the images, no influence by light and shade of the images, can explore deeply the image structural information. To analysis result, the influence of the standard deviation and the average of five typical flow patterns is eliminated through the combination of the images, the characteristics of four kinds of coefficient of variation and the statistical characteristics of the two connected regions. And the flowing mechanism of gas-liquid two-phase flow is more deeply characterized. From simple points and complex point, the gas-liquid two-phase flow patterns are comprehensively analyzed by the combination of two characteristic parameters of the straightness (straight line similarity and intermittent degrees).

Keywords: gas-liquid two-phase flow; connected regions; line-correlation; variation coefficient

1. Introduction

The phenomenons of two-phase / multiphase flow widely exist in nature and industrial systems. The measurements of two-phase flow patterns are very important for the study on the interaction between liquid and gas, which is a difficult point. In the previous two-phase study, there are pressure signal, conductivity signal, ray attenuation signal and other more analysis methods\textsuperscript{[1-4]}. There have some results for the study on two-phase flow. Especially about the identification of two-phase flow patterns, there are

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lots of emergences of mathematical method. With the development of computer vision technology, image processing techniques are gradually applied to the study of two-phase flow, including the identification of flow patterns and the measurement of flow field. More and more two-phase flow image feature extraction methods have been proposed, but most of them confined to texture, or texture variant, including the affine moment invariant features, gray co-occurrence matrix features and contour features, etc [5-7]. By comparison, a number of features mentioned above, without exception, are from the gray texture aspects of images. The effect is quite obvious for the surfacial identification of the flow pattern, but the features mentioned above effect is not very effective if we want to deeply analyze the mechanism of two-phase flow patterns. The extraction of image connected region is more and more used to the analysis of tool state. The wear of tools can be determined by the surfacial characteristics extracted from image processing, and the results are very obvious [8-10]. If this method is applied to two-phase flow image, it has important significance to further analysis of the image information and the mechanism of two-phase flows.

2. Image Processing

The processing based on connected regions of the image is shown in Figure 1.

![Image processing flow chart](image)

3. Morphological Variant Coefficient

The variant coefficient is a variant index expressed by the form of relative numbers. It is obtained by the comparison of the total distance, mean difference or standard deviation and average value. The ratio of standard deviation and the average value is known as the variant coefficient, denoted \( CV \). The impact of the comparison of the variant coefficients of two or more data affected by the difference of unit and (or) the average value. Variation coefficient is calculated as:

\[
CV = \frac{S}{x} \times 100\%
\]  

(1)

In the equation, \( S \) is standard deviation, \( \bar{x} \) is the average value. In this paper, the feature parameters of six connected regions are analyzed, of which four are the variant coefficient, shown in Table 1.

About the calculation of line-related please refer to documents[11].

<table>
<thead>
<tr>
<th>Name (the variant coefficient with *)</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eccentricity *</td>
<td>The ellipse eccentricity of second-order central moments with the same of the regions</td>
</tr>
<tr>
<td>Area *</td>
<td>The total pixels of each connected region</td>
</tr>
<tr>
<td>MinorAxisLength *</td>
<td>The minor axis length of the ellipse of the standard second order central moments equivalent to area</td>
</tr>
<tr>
<td>EquivDiameter *</td>
<td>A scalar, equivalent diameter, The formula is: ( \sqrt{4 \times \text{Area}/\pi} )</td>
</tr>
<tr>
<td>Number</td>
<td>The number of connected regions</td>
</tr>
</tbody>
</table>

TABLE 1. Feature parameters
4. Experiment and Results

4.1. Experiment

Experiments are carried out by the air-water two-phase flow experimental system which is composed of fluid control equipments and image acquisition equipments. The experimental liquid is water, and experimental gas is air. The schema of this experimental system is shown in Fig. 2. We select a transparent plexiglass tube. Because of the liquid and gas are transparent, in the image acquisition process we used the backlight illumination [12]. Its inner diameter is 30mm, and the length is 2m. The range of its water volume flow is 0.007~3.180m$^3$/s. The range of its air volume flow is 0.500~4.585m$^3$/s. The environmental pressure is 1.01×10$^5$ Pa, and the environmental temperature is 20°C. The images of three typical kinds of flow patterns are intercepted in the video of flow patterns in the horizontal plexiglass tube. The size of the video is 1536×1024. The frame rate of the video is 500 frame/s. The images and their gray-scale pulse signals of five kinds of flow patterns are showed in Fig. 3.

![Experimental system of air-water two-phase flow](image)

Figure 2. Experimental system of air-water two-phase flow

4.2. Result analysis

The numerical value of the six parameters in the table 1 gets from the connected regional maps of the five kinds of the flow pattern figures, whose trend following the increasing speed of superficial gas phase is shown in the figure 4.

Can be seen from the figure 4, the trend of the four kinds of the coefficient of variation is roughly equal with the gas phase superficial velocity’s, and the number of the connected regions and the trend of the equivalent elliptic centrifugal rate are nearly alike. First, we analyze the changes in the number of the connected regions. Stratified flows often happen in the case of the small superficial velocity of the gas-liquid two-phase. From the flow image taken by the high speed photography, we can also see that, the
liquid flows along the bottom of piping while the gas flows along the top of piping because of the pull of gravity. At the moment, we calculate the divided connected regions. Due to its simple frame structure, the number of the connected regions is smaller than other flow patterns. As the gas superficial velocity increase, the interface of the gas-liquid two-phase of the stratified flow fluctuates. While, with the gas velocity increasing and pressuring, the liquid is no longer attached to the bottom of the flow pipeline by rule, but fills it gradually. Because the gas velocity is not too great, only a small amount of bubbles disperse in the liquid phase intermediate, which forms the bubbly flow. Bubbles disperse in the continuous liquid and tend to gather near the top of the pipe. From the flow images, we can conclude that, the frame structure is too messy, so the number of connected regions obtained is significantly higher than the stratified flow. The gas superficial velocity continues to increase, making the continuity of the liquid weaker than before, leading to that the bubbles contact, coalesce, and gradually produce some large gas plug like "bullet" flowing along the top of the pipe. And as the reason that the gas velocity is not very large, some small bubbles do not crash together, which creates the so-called transitional flow. At this point the flow pattern’s frame structure is more complex than the true slug flow, but more simple than bubbly flow, so the number of its connected regions is between both of them. To a certain gas velocity, all the dispersive bubbles coalesce together, become a gas plug and flow along the top of the pipeline, which forms the typical slug flow. To achieve greater gas flow rate, the rapid gas flow breaks up the continuous liquid, and the gas only can disperse in the continuous liquid phase only in the form of tiny bubbles, but couldn’t gather together. Even if some coalesce together, they will be scattered by the rapid gas flow, which is the mist flow’s characteristics. At this time, the picture is the most complex and messy in all kinds of the flow patterns. However, the masses of many small bubbles disperse in the continuous liquid phase of the pipeline, we couldn’t tell the gap between the liquid phase by sight, which makes the number of the segmentation of the connected regions is less than bubbly flow but more than the other flow patterns.

We do not describe too much about the equivalent ellipse eccentricity of the connected regions here.

Figure 4. The six connected region parameters changes with the $U_g$ trends under $U_l=0.1 \text{m/s}$
In figure 4 (c) - (f), you can see the trend of the four kind of the variation coefficient is very similar. The variation coefficient, which is also known as the "standard slip", is an important statistic used as a measure of data variation of the observations. As can be seen from Figure 4, the biggest variation coefficient in the five typical flow patterns is the slug, and the trend of several other flow is that from stratified flow to bubbly flow, the trend is decreasing and reaches the minimum point when it is bubbly flow, that the trend is rising from bubbly flow to slug flow and the slug is the biggest and that during the process from slug flow to mist flow, it shows a downward trend again. Viewing from the overall standard deviation or average, we can also distinguish the characteristics of different flow, however, some influences which caused by the conditions of some experiments can be eliminated if the we consider the use of the variation coefficient, such as the light of experiment, the jitter level test section and so on.

Figure 5 shows the relationship between the straightness and the gas apparent velocity, which after related calculations. The trend of the image morphology of the straightness in gas-liquid two-phase flow is from decrease to increase and then to decrease. The connected image of five kinds of flow pattern in diagram 4 can identify the size of straightness obviously. The interface of stratified flow is the most close with straight line, it is inevitable that the straightness in its connected regions is maximum. The distribution of bubbly flow of the connected regions is more scattered due to bubbles’ dispersion, so the straightness is destroyed seriously, and this can be clearly judged by intermittent degree of straight line; In the process of transiting to slug flow, bubbles coalesce gradually, which makes straightness of the connected regions have significant improvements and achieve a new level when getting to slug flow. Next up mist flow, the destroy to straightness is more serious due to the scattered distribution of micro-bubbles, which makes straightness accuracy reach a new low level.

![Figure 5: The correlation straightness of line versus gas superficial velocity](image)

5. Conclusion

a) The high-speed photography applied to the analysis of the mechanism of gas-liquid two-phase flow patterns in the paper, gaining the more clear images of five kinds of two-phase flow patterns. At the same the segmentation of connected region is used to the analysis of the mechanism of flow patterns. The connected regions belong to the morphological feature of the images, different from gray texture feature. Its the greatest advantage is that the structure mechanism of image morphological can be searched more deeply and fight the impact of the image light, film quality and other factors.

b) The connected images of gas-liquid two-phase flow are relatively calculated, and the obtained straightness parameters can well reflect the change process of the flow patterns. The images of gas-liquid two-phase flow patterns are comprehensively analyzed and instructed from simplicity to complexity. The straightness parameters are a effective auxiliary diagnosis tool to understand the dynamic characteristics of two-phase flow, as well as a useful complement, reference and support to study on flow patterns by other information characterization method.

References

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