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NOTE

CAVITY FORMATION IN TURBINE STIRRED GAS-LIQUID DISPERSION SYSTEM

Ho-Ryong Lee, Yun-Jun Huh, Cheong-Song Choi and Won-Hong Lee***

Department of Chemical Engineering, Sogang University, C.P.O. 1142, Seoul, Korea
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Abstract—To detect the cavities formed behind the impeller blades, the electrical resistivity technique was employed in this study. The transition conditions between large cavity and clinging cavity were easily detected by the proposed method and the reliabilty of the probe was confirmed by the comparison with literature. The characterististics of the cavities were observed as a function of impeller rotational speed and air flow rate. As the air flow rates increase, the type of cavities are changed from clinging cavities to large cavities. Large cavities were not observed in behind the impeller blades at high impeller speeds. In the region of the formation of alternate large and clinging cavities, the shapes of cavities were not changed and the positions of cavities were rarely shifted to other positions.

INTRODUCTION

The system of gas dispersion in liquid by mechanical agitation has been widely used in chemical and biochemical industries. Although the gas-liquid agitated system has been investigated [1-3] for a long time, it has not been clearly understood because of the complexities of the effect of the impeller rotation on the bubbles in bulk flow. Of the concepts concerning gas-liquid dispersion, the cavity concept has the excellence in way to describe the nature of the gas-liquid dispersion [4]. By means of cavity concept, it has been known that the cavities formed behind the impeller blades have relation with the power consumption, bulk flow patterns, and mass transfer coefficients [5, 6]. Since the observation of the phenomena around the impeller and the relationship of the cavities with the bulk flow motion of bubbles are necessary to design a tank and to obtain an optimal operating condition, the observation of the cavity configuration is very important for the study of the gas-liquid agitated system.

During the last ten years many researches about the cavity structure in the gas-liquid dispersion system have been done [7]. It has been known that the cavities have different configurations in shape and size as a function of the operating conditions, gassing rate and impeller rotational speed. Nienow and Wisdom [8] and van't Riet and Smith [9] demonstrated how the configurations of the cavities change with gassing rates and impeller speeds. Warmoeskerken and Smith [10] have reported a flow regime map for the gas cavities of the flat bladed disk type turbine under gassing operations in an agitated tank. However, the classification of cavity structures has been mainly given according to visual appearance in the general literature, with very little supporting data which describe the nature of gas cavities.

Recently, the variation of cavity structure has been observed by many investigators. To observe the cavities, photograph [11], power consumption [12, 13] and micro-propeller [14] were used. Lu and Ju [15] suggested a direct method to measure the cavity configuration by a constant temperature anemometer (CTA), which measures the instantaneous rate of heat transfer between the sensor tip and the fluid. But CTA is very expensive and needs many incidental equipments. In this study, to develop a technique which permits continuous on-line monitoring of cavity structure in various operating conditions, a simple method based on the electrical conductivity difference between air and water was proposed.

EXPERIMENTAL

The experiments were carried out in a flat-bottomed, acrylic glass cylindrical tank of 200 mm ID. The

*To whom all correspondence should be addressed.
**Current Address: Central Research Lab.. TongYang Nylon Co.

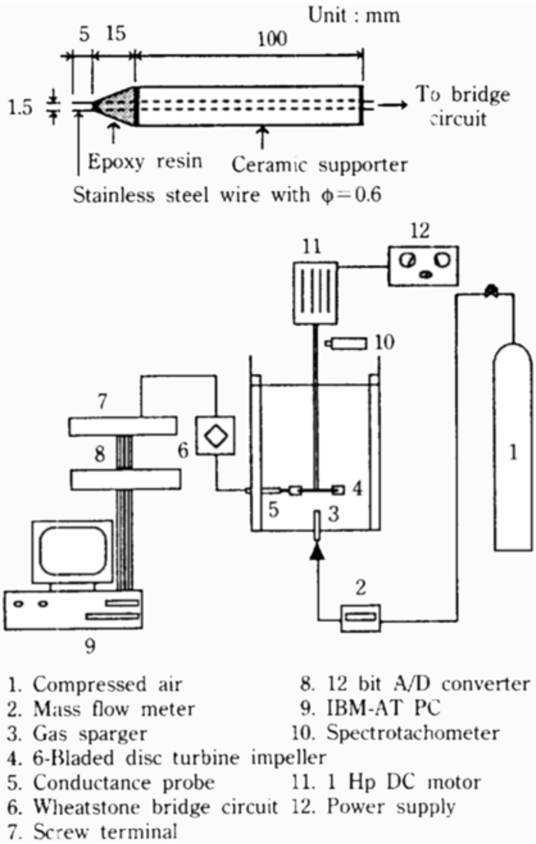

Fig. 1. Schematic diagram of experimental apparatus.

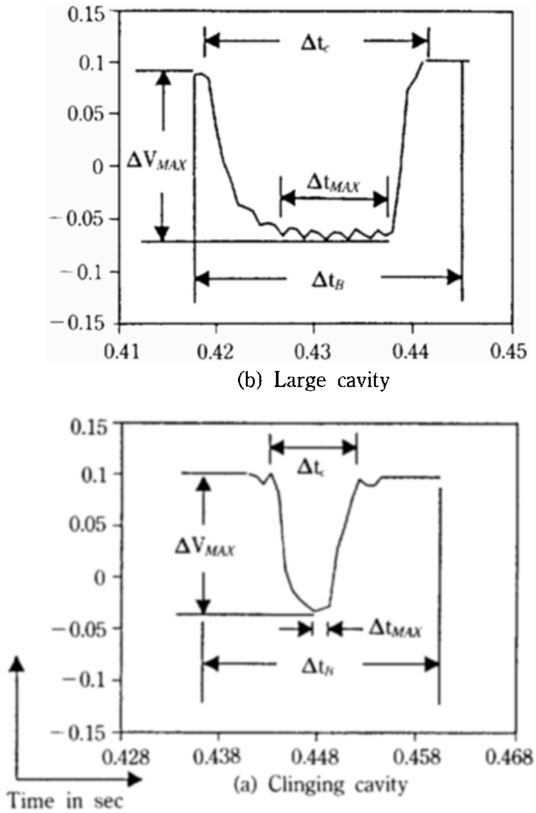

Fig. 2. Experimentally measured signals of a clinging and a large cavities and the parameters used in the criterion of cavity shapes.

tank was fitted with the four T/10 width symmetrical wall baffles. The 6-bladed disc turbine impeller, D=T/3, was used (blade height=D/5, disc diameter=5D/6, thickness=1.5 mm) and the clearance was T/3. Gas sparger was a single nozzle type with a hole of 2 mm ID. Working fluids were filtered tap water and compressed air. Air flow rate was measured by a digital mass flow meter of MATHSON Co. In order to measure impeller rotational speeds, a spectrotachometer was used. The experimental apparatus and the geometry of the conductance probe are shown in Fig. 1.

The output signal from the conductance probe was transformed into the changes of voltage through a wheatstone bridge, and then the changes of voltage were passed to a personal computer through an A/D converter (Analog Design Co. ADL-1000M) in order to analyze the data. The sampling rate of the computer software program for the digital data acquisition was designed to synchronize with the impeller rotational speeds for an adequate duration of time. A samplaing rate of 1200 divisions per impeller revolution was chosen for the cavity observations and the sampling was continued until 5 impeller revolutions because of the limit of the computer memory. The experiments were performed for the case of ninety operating conditions.

RESULTS AND DISCUSSION

1. Shapes of Cavities

In an ungassed system, roll vorticies are developed behind the impeller blades [16]. Due to the rotation of roll vorticies, an area of low pressure is developed along the axis of rotation. In this state, when the gas is introduced in the reactor, the pressure difference across the vortex provides the driving force necessary for the introduction of gas into the center of the vortex thus creating a cavity. When the impeller rotates, the cavity formed behind the impeller blade shifts to the radial direction by centrifugal force. Since the turning radius of cavities is larger than that of impeller blades, the conductance probe tip which is very close to the

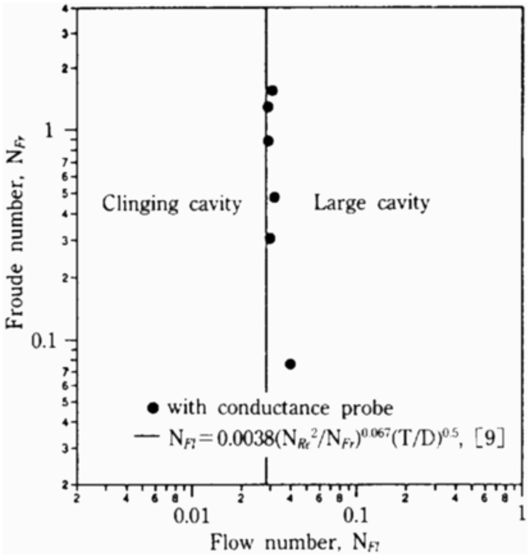

Fig. 3. The 3-3 cavity formation conditions, for T=0.2 and T/D=3. solid line: correlation equation adapted from Warmoeskerken and Smith [9], solid points: with conductance probe.

outer edge of impeller blade can contact with the cavities.

Since the size of a large cavity is larger than that of a clinging cavity, the contacting time of a large cavity with probe tip is longer than that of a clinging cavity and the contacing area of a large cavity is wider than that of a clinging cavity. The signal of a large cavity has the wider portion in the time domain and has high maximum voltage than that of a clinging cavity. As shown in Fig. 2, large cavities are easily differentiated from clinging cavities. The parameters on the Fig. 2 are used in the criterion of cavity shapes. The large cavity formation conditions obtained with this method are plotted in Fig. 3, in which a comparison with a published correlation equation of Warmoeskerken and Smith [9] was made. The large cavity formation conditions obtained with this method are denoted by the black solid symbols and those obtained with a correlation equation are denoted by the solid line. From the figure, it was realised that the proposed method had a good reliabilty in the detection of cavities.

2. Characteristics of Cavity Formation

Fig. 4 shows the measured signals for the effect of air flow rate at a constant impeller speed, 5 rps. For every figure, the impeller rotates five times. As the gas flow rates increase, Fig. 4(a)→4(c), the number of cavities formed behind the impeller blade increases. At lower air flow rates, the large cavities are rarely developed so that almost clinging cavities are formed as shown in Fig. 4(a). In this state, the frequency of cavity formation is not constant and the cavities are formed at random sequence. With continued increases in the gassing rate, the cavities are developed on the

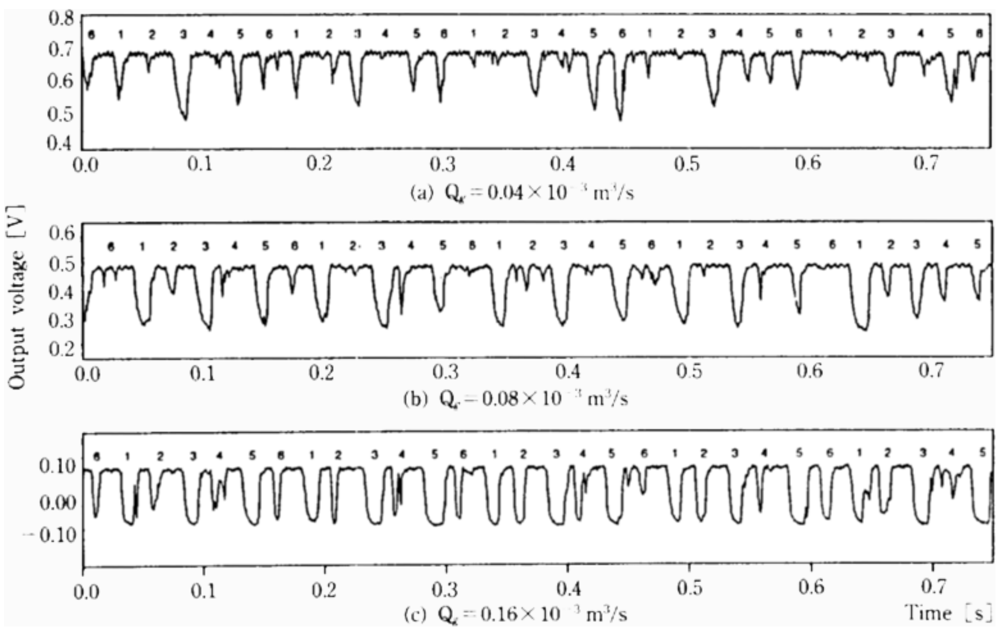

Fig. 4. The effect of gas flow rate on the cavity structures at a constant impeller rotational speed, N=5 rps.

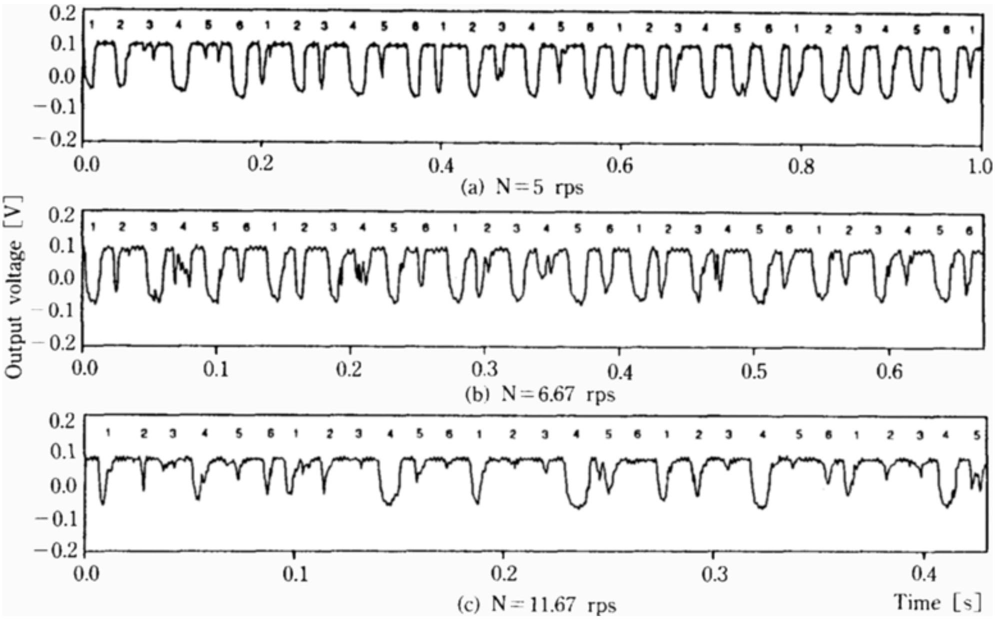

Fig. 5. The effect of impeller rotational speed on the cavity structures at a constant gas flow rate, $Q=0.12\times10^{-3}$ m^3/s.

almost all of the six blade, but the cavities formed behind the six blades are different in shape and size with each other, Fig. 4(b). A further increase in the gassing rate results in the formation of alternate clinging and large cavities on the backside of the six blades, as shown in Fig. 4(c). The formation of alternate clinging and large cavities is called a 3-3 structure. This phenomena might be happened by the balance of the centrifugal force developed by the rotation of impeller with the buoyancy force generated by the introduced air. It is known from Fig. 4(c) that once a three clinging cavities and three large cavities are formed behind the six impeller blades, the clinging cavities and the large cavities are always fixed to an alternate way.

In Fig. 5(a), there are more than two large cavities formed on backside of the impeller-blade. The large cavity formation indicates that the power input is still not enough to produce well-dispersed bubbles at a given gas flow rate. As impeller rotational speed increases at constant air flow rate, the cavities formed behind the impeller blades are gradually come apart from impeller blades because of the increase in centrifugal force. Thus some of large cavities are changed into clinging cavities and it is occurred that the clinging and large cavities are alternate formed, so called 3-3 structure. Once the condition of a three large cavities and a three clinging cavities is established, the large cavities and the clinging cavities are always arranged in an alternate way. It is known from Fig. 5(b) that the 3-3 structure is stable, i.e. no change in position with each other. Recently, 3-3 structure has been emphasized as to its importance in gas dispersion and mass transfer [3, 5]. The clinging cavities are predominantly observed with increasing the rotation velocity as shown in Fig. 5(c). The formation of clinging cavity indicates the increase of the liquid density around impeller. As the liquid density around the impeller increases, the power consumption increases rapidly. Although the gas hold-up increases as impeller speed increases, the power consumption has to be considered to determine the optimal operating conditions.

The 3-3 cavity structure is more stable than any other cavity configurations in a gas-liquid agitated system with a six-bladed disc style turbine impeller. The 3-3 structure spans some ranges in impeller rotation speed and gassing rate. The characteristics of the 3-3 structure and the hydrodynamics of gas-liquid dispersion from it can be changed with gassing rate and impeller rotational speed. The change in the nature of the 3-3 cavity structure as a function of gassing rate and impeller rotational speed also reflected on the changes in mass transfer between gas and liquid phases. So the characteristics of cavities in the 3-3 structure region is important to the design and scale-up of the gas-liquid agitated system. The proposed method is suitable for the detection of the shapes of cavities and the on-line investigation of the characteristics of cavities in the 3-3 structure region.

ACKNOWLEDGEMENT

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NOMENCLATURE

D : impeller diameter [mm]
N : impeller rotational speed [rps]
N_{Fl} : gas flow number (Q/ND) [-]
N_{Fr} : Froude number (ND/g) [-]
N_{Re} : Reynolds number ($\rho ND^2/\mu$) [-]
Q : gas flow rate [m^3/s]
T : tank diameter [mm]
Δt_B : time duration which each blade passes by the tip of probe [s]
Δt_c : time duration which signal is detected [s]
Δt_{MAX} : time duration which maximum voltage is maintained [s]
ΔV_{MAX}: maximum voltage change [volts]

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