Effects of relative motion between gas and liquid on dynamics of explosive eruptions

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In gas-liquid multiphase flow, relative motion between gas and liquid largely affects the global features of bulk flow. We analytically investigated the effects of relative motion between gas and liquid on the dynamics of explosive eruptions on the basis of a model for 1-dimensional steady flow in volcanic conduits. As magma ascends and decompresses, volatiles are exsolved and volume fraction of gas increases. As a result, magma fragmentation occurs and the flow changes from bubbly flow to gas-pyroclast flow. In our model, the vertical relative motion between gas and liquid is allowed and a new transitional zone ('fractured-turbulent flow zone') is introduced between bubbly flow zone and gas-pyroclast flow zone. In this zone, both the gas and the liquid are continuous phases, allowing the increase of relative velocity between the two phases.

Our results show that the flow in conduit is divided into five flow regions as the magma ascends. Region 1 is a bubbly flow which is characterized by a small relative velocity due to large viscosity of magma. Region 2 is a fractured-turbulent flow in which gas can efficiently flow through the permeable structure, so that the relative velocity increases significantly. It can be analytically clarified that the value of the relative velocity in this region is determined by the balance between the liquid-gas interaction force and the liquid-wall friction force. Region 4 is a gas-pyroclast flow where the relative velocity reaches a constant value which is determined by the terminal velocity of particles in the gas phase. In the transitional region from Region 2 to Region 4 (Region 3), pyroclasts accelerate due to drag force from flowing gas, and the relative velocity decreases suddenly. As the flow approaches the choking condition, the gas velocity increases towards the sound velocity of the gas, whereas the increase of the liquid velocity is suppressed. As a result, the relative velocity increases again. We call this region as Region 5. The force balance which determines the pressure gradient also changes as the magma ascends. In Region 1 and Region 2, the pressure gradient is mainly determined by the wall friction and the mixture weight. In Region 4, the pressure gradient is mainly determined by the mixture weight. In Region 3 and Region 5, the pressure gradient is mainly determined by the acceleration term. The lengths of Region 3 and Region 5 are very small compared with that of other regions.

The steady solution of the conduit flow is obtained by equating the sum of the lengths of Regions 1 to 5 with the total length of the conduit under a given boundary condition. The length of the regions before magma fragmentation (Region 1 and Region 2) and the length of the regions after magma fragmentation (Regions 3 to 5) as a function of magma properties and geological conditions are semi-analytically determined by using the mechanical balance in each region. As the relative velocity in Region 2 increases, the pressure at the fragmentation decreases. As a result, the length of the regions before fragmentation increases, whereas the length of the regions after fragmentation decreases. As the relative velocity in Region 4 increases, the length of the regions after fragmentation decreases due to the increase of the mixture density. The features of the flow are explained by the variation of these lengths.