

# A NEW CLUSTER REGIME OF GAS-LIQUID FLOW IN VERTICAL COLUMNS (PHYSICAL MODELING)

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The subject of our studies includes a most frequently met type of volcanic activity – Strombolian. A Strombolian explosion is a powerful, abrupt and, as a rule, unexpected event. Explosions occur during summit, subsidiary and flank eruptions. An average in capacity basaltic explosion throws out to the surface about 30-50 tons of solid magmatic products, a strong one - 250-1000 tons.

Since there is no unambiguous universal explanation of the causes of Strombolian explosions we have conducted a cycle of experimental studies that allowed us to understand the mechanism of Strombolian activity. Laboratory experiments with two-phase mixtures were started in 2002 and during 5 years we constructed 9 versions of gas-hydrodynamic experimental settings. As a result author has created Complex Apparatus for Modeling Basaltic Explosions – CAMBE.

The goal of the present study is to reveal the causes of discrete regime of eruption of basaltic magmas in the form of rhythmic explosions. Experimental studies with CAMBE included investigation of kinetics of gas-liquid two-phase mixtures in vertical pipes (from the moment of nucleation of the first bubbles to formation of mature stable gas structures) and the comparison of the data obtained with real volcanic events.

## EXPERIMENTAL RESEARCH

While constructing the complex apparatus we did our best to consider the parameters of real feeding magma systems; the Klyuchevskoi volcano which located on Kamchatka, Russia, has been accepted as a basis – a typical basaltic volcano. Besides we tried to avoid any possible structural and energy barriers, capable to affect the character of movement of the substance. The setting is constructed in the building of the Institute of Volcanology and Seismology, Far East Division, Russian Academy of Science. The overall height of CAMBE is 18 meters. The complex apparatus consists of two systems – modeling and registrating (Fig. 1).

**The modeling system** includes a reservoir for preparation of gas-saturated model liquid (magma chamber), a transparent hose (feeding conduit), a plexiglass tank for reception of acting model liquid (crater area /vent) (Fig. 1). In work we used a liquid and two kinds of gas. As a liquid we used water ( $H_2O$ ). As a dissolved gas we used carbonic gas ( $CO_2$ ). Nitrogen ( $N_2$ ) was used as a piston which squeezes out the model liquid from the tank. As a result of preliminary experiments we have inferred that the full spectrum of gas-hydrodynamic regimes is achieved at saturation pressure of 1,6 bars.

**Register system.** It includes a system of dynamic video tracking, an electronic altimeter and a speed meter, a block of video registration, a block of acoustic registration, a synchronizing device and a shutdown system (Fig. 1).

During experiments while gas-saturated liquid moved in a vertical column we observed the reconstruction of the model liquid. We registered sequentially arising gas-hydrodynamic regimes – liquid, bubbly, cluster and slug. It is necessary to add that any of established gas-hydrodynamic regimes can be realized on the top cut depending on saturation pressure, which enables one to model different volcanic eruptions.

Special attention has been given to the earlier undescribed regime that unites a bubbly and slug regimes. This is a new, morphologically stable gas-hydrodynamic regime – a cluster regime.

## DISCUSSION OF RESULTS

I. In the experiments gas-saturated one-phase model liquid during rising in the column turns into a two-phase system and in the course of evolution four gas-hydrodynamic regimes consistently and naturally (from below upwards) are realized: liquid, bubbly, cluster and slug (Fig. 2).

II. As a result of experimental studies, previously unknown necessary link has been established connecting bubbly and slug regimes. We suggest naming it a cluster regime (Fig. 2, 13th and 14th meters). This is a new, morphologically steady gas-hydrodynamic regime. We will not be

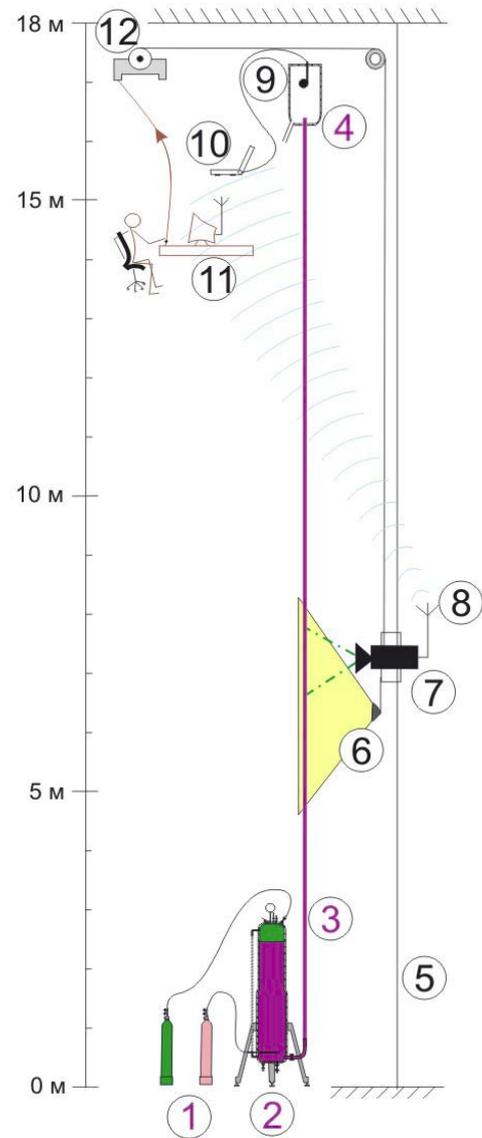
able to find the description of this regime in generalizing monographs by Kutateladze and Nakoryakov, 1984, Prandtl-Fihrer durch die Stromungslehre, 2001 and Wallis, 1969.

III. We shall present below the basic characteristics of the cluster regime: 1 - the main component is a bubble cluster representing a volume of a liquid with high concentration of bubbles; from above and from below it is separated by a liquid containing no free gas phase; 2 - a series of bubble clusters following one after another at a certain distance, creates a cluster regime; 3 - it is always manifested between bubbly and slug regimes; 4 - cluster structures at certain column intervals have steady, repeating character; 5 - morphologically clusters of two types - open and blocked are distinguished; 6 - ascent rate of clusters is lower, than that of mature bubbly and slug regimes; 7 - life term of a cluster regime is comparable with that of bubbly and slug regimes; 8 - a cluster regime arises in a wide range of hydrodynamic conditions - in a bubble column (static and having no gas phase liquid), in the gas-saturated column (in the range of initial ascent rates from 1-10 cm/s); 9 - the mechanism of formation of clusters is related to the interaction of large gas structures with the walls of the channel, to the effects of self-locking and braking.

The author believes that a cluster regime is inherent not only in volcanic processes; it should be considered more widely, as an independent regime in the physics of gas-liquid mixtures, for example at natural objects (hydrothermal systems and mud volcanism), at modeling of boreholes (hydrothermal and oil) and in chemical industry.

IV. We shall describe now the ascent rate parameters of a two-phase flow whose evolution results in formation of clusters and slugs. As a result of our experimental studies it has been established, that structurization of a gas phase to gas clusters and slugs can occur in a wide range of ascent rates (initial rate of a liquid from 1 to 10 cm/s). This testifies to the fact that identified dynamic gas structures are integral in vertical gas-liquid systems and are realized in a wide speed range. This allows us to infer, that in real basaltic feeding conduits a gas phase undergoes similar structural evolution, like in the experiments which we conducted.

Appearance of the cluster and slug regimes leads to essential redistribution of potential energy in the magma column, and with other parameters being equal, with increase of viscosity of the melt the intensity of a gas pulse should increase essentially, up to real explosions.



**Figure 1.** A complex apparatus for modeling basaltic eruptions – CAMBE. Scheme of modeling (1-4) and recording (5-12) systems of CAMBE. 1 – high-pressure gas cylinders with CO<sub>2</sub> and N<sub>2</sub>; 2 – reservoir for preparation of a model liquid; 3 – transparent hose; 4 – an aquarium for reception of the liquid; 5 – a cable directing movement of a platform of dynamic video tracking; 6 light source; 7 – a video camera; 8 – transmitter and the telemetering antenna; 9 – microphone; 10 – a computer; 11 – receiver of a video signal and a monitor; 12 – electric motor. In the upper part of the figure one can see the operator whose functions include adjustment of speed of movement of the block of video tracking.

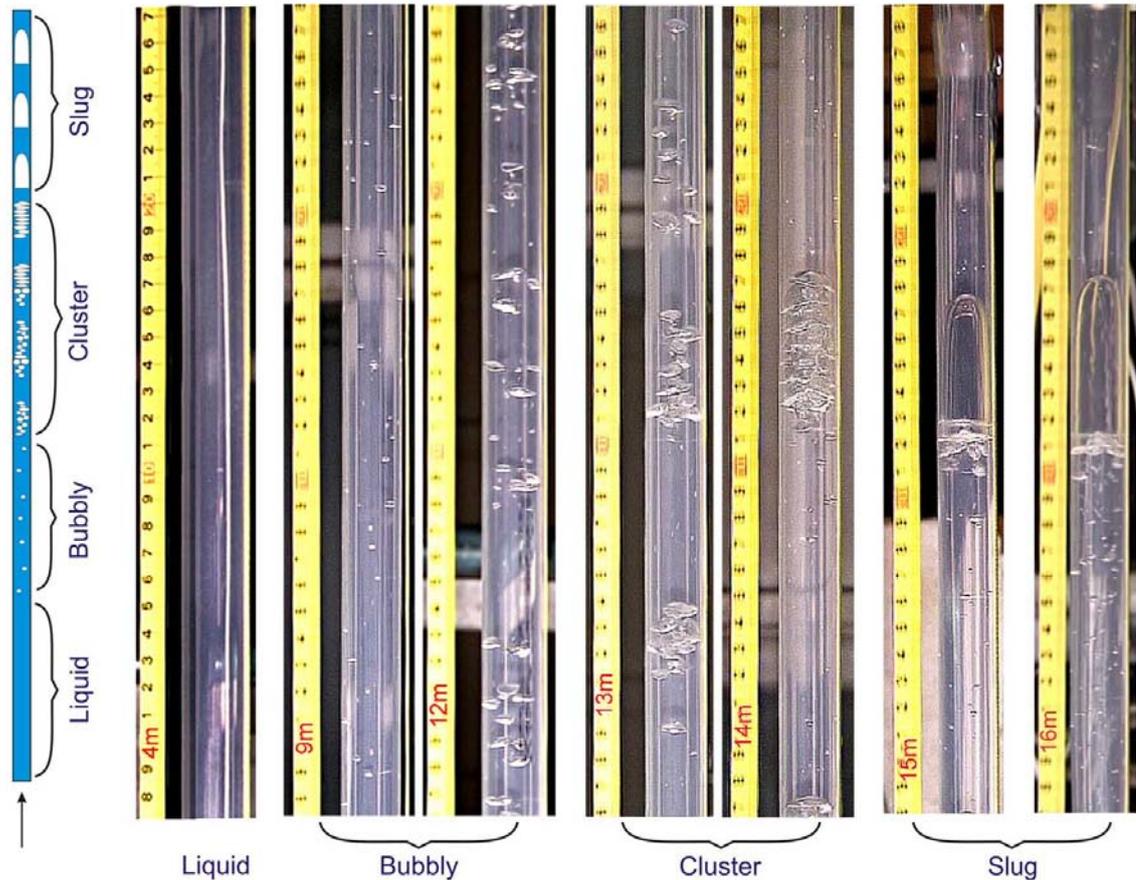


Figure 2. Fragments of the gas-hydrodynamic regimes originating during ascent of gas-saturated liquid in a vertical transparent hose. Schematic view of location of gas-hydrodynamic regimes in the column. Snapshots of the gas-saturated model liquid flow regimes in the vertical channel. To the left from the hose – a measuring tape (scale division value – 1 mm), with the indication of height in meters for each shot (figures are red). Every shot corresponds to 30 cm window of video recording. All shots of consequently evolving model liquid were received during one travel of a video camera along the column, with the speed of a moving gas phase.

## CONCLUSIONS

1. To study the character of movement of magma melt in a feeding system of a volcano, the complex apparatus for modeling basaltic eruptions (CAMBE) has been constructed;
2. The analysis of diversity of flow regimes of one and the same model liquid has shown that the four regimes of the flow – liquid, bubble, cluster and slug – result from natural evolution of gas saturated flow and that each of the regimes has its own specific features;
3. During experiments we have identified and described previously unknown regime of a two-phase mixture flow in a vertical column – a cluster regime, characterized by natural alternation of dense concentrations of gas bubbles (clusters), separated from each other by a liquid containing no free gas phase. The mechanism of formation of clusters is accounted for by interaction of large gas structures with the walls of the channel as a result of which the effect of braking and self-locking arises and a new, slowly moving structure originates - gas plug - cluster;
4. A complex of studies accomplished has allowed us to offer a new model of gas-hydrodynamic evolutionary movement of a magma melt in the conduit of a basaltic volcano. Realization on the surface of this or that regime results in a variety of explosive events in a volcanic crater.