TEMPERATURE FLUCTUATIONS AT THE SURFACE OF A FLUIDIZATION BED WITH GAS COMBUSTION

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Results are shown of temperature measurements at the bed surface under various fluidization modes, which explain the mechanism of gas combustion in a fluidization bed.

Temperature fluctuations recorded by a bare thermocouple buried in a nonhomogeneous fluidization bed are due to the existence here of two phases: a gaseous phase of bubbles almost completely free of solid particles and a continuous phase (emulsion) [1]. Such fluctuations were recorded in [2] for the first time, apparently, with a copper-constantan microthermocouple in a protective capron mesh and connected to a model KVT electronic potentiometer. The test procedure (the inertia of the heat probe and of the potentiometer [3, 4]) did not make a frequency and amplitude analysis of these fluctuations feasible, neither made it possible to correlate them with the bed hydrodynamics. Meanwhile, an analysis of these fluctuations may provide the key to understanding the mechanism of combustion of a gaseous fuel in a fluidization bed.

Our test apparatus is shown schematically in Fig. 1. An enlarged laboratory oven 0.6 × 0.3 m in cross section was filled with white corundum (electrocorundum), particle size 320 μm. The top of the bed was 200 mm above the holes in the gas distributor grid. Natural gas burned inside the oven directly in the bed of solid material. The bed temperature was measured with a Chromel—Alumel or a PtRh-Pt thermocouple doubly sheathed for protection (porcelain plus grade 1Kh18N9T steel). After the desired mode of operation had been reached inside the oven, a bare Chromel—Alumel or PtRh-Pt microthermocouple (wires 0.1 mm in diameter, junction bead 0.3 mm in diameter) was dropped on the top surface of the bed. This microthermocouple was connected with the immersed thermocouple into a differential circuit and the difference between their readings was recorded on a model N-700 oscillograph. For zero setting the oscillograph, a universal model UPL-60-2 potentiometer with an internal resistance of 14 was connected in series into the differential circuit. The oscillograph was supplied from the 220 V ac line through an RNO-250-5 voltage transformer and a VSA-5 rectifier. The filament of the time-base tube in the oscillograph was supplied with 13 V ac from an RNSh regulator with a model D-523 voltmeter for control.

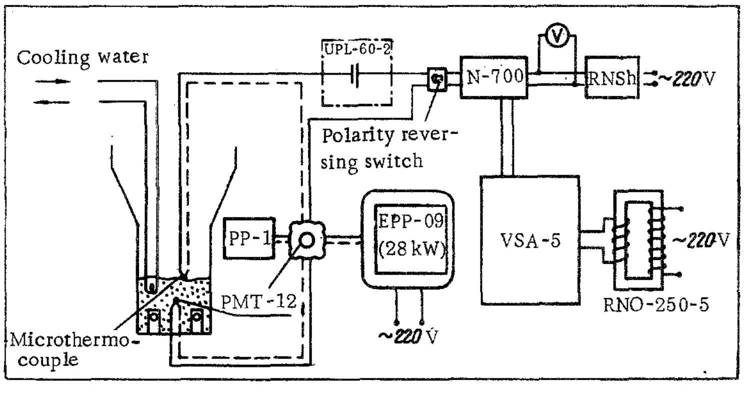

Fig. 1. Schematic diagram of the test apparatus for studying temperature fluctuations at the surface of a fluidization bed.

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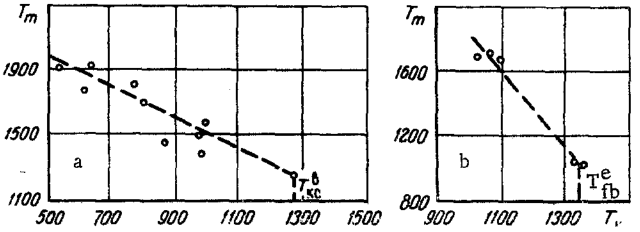

Fig. 2

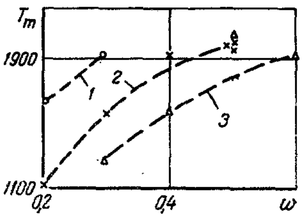

Fig. 3

Fig. 2. Maximum temperature T_m (°K) in a bubble burning at the bed surface, as a function of the bed temperature ($\alpha = 1$) at (a) w = 0.3 m/sec and (b) w = 0.5 m/sec.

Fig. 3. Maximum temperature T_m (°K) in a bubble burning at the bed surface, as a function of the fluidization rate ($\alpha = 1$): T_{fb} = 1) 540-565°K; 2) 1030-1090°K; 3) 1270°K.

The auxiliary instruments for measuring the bed temperature included a portable model PP-1 potentiometer as well as fast-response electronic potentiometers model ÉPP-09-3M (for PtRh-Pt thermocouples) and model KVT (for Chromel—Alumel thermocouples).

The tests were performed during combustion of natural gas in air with a relative flow rate α = 1.2, 1.0, 0.5, and 0.385.

The operating temperature range in the fluidization bed was 400-1400°K, the fluidization rate varied from 0.2 to 0.7 m/sec. All data referred to temperature fluctuations due to the burst of gas bubbles at the bed surface. The oscillograph did not record any distinct and appreciable pulses over the entire temperature range while the microthermocouple was dropped deeper into the bed.

After completion of a test series, the thermocouple was calibrated by recording on the same strip chart with the reversed polarity of leads at the oscillograph input terminals and with the UPL-60-2 potentiometer used as a source of reference voltages.

In the evaluation of test data the magnitude of the maximum fluctuation on the oscillogram for a given mode of operation was taken into account corrected for changes in the resistance of the thermocouple wires and leads, inasmuch as the oscillogram had been calibrated with the microthermocouple removed from the oven. The random nature of fluctuations was disregarded in the evaluation.

In view of the short time of a gas explosion in a bubble (0.01-0.062 sec, according to high-speed film strips), the test values were recalculated including the inertia of the heat probe. The thermal time constant [5] was determined experimentally from the transient response characteristics of the microthermocouple as the latter was suddenly brought into the burnout zone of a Bunsen flame; the effect of radiation on the thermocouple was accounted for according to the calculations in [6]. For instance, in the case of a PtRh-Pt microthermocouple this thermal time constant ε_u was equal to 0.385 sec — much longer than the explosion time of gas in a bubble. In order to account for the inertia, it was necessary to solve the differential equation of heat balance in an ideal heat probe [5] at a mean-over-the-volume temperature T_V:

$$\frac{dT_v}{d\tau} + mT_v = mT, \tag{1}$$

with $m = 1/\varepsilon_u$.

For this we had to know the law according to which the gas temperature in a bubble varied with time, i.e., $T = f(\tau)$ after ignition. An analysis of the temperature variation in a bubble of burning methane under adiabatic conditions has shown, by analogy to [7], that the temperature T after ignition almost instantaneously rises to the near-adiabatic level and then, during the burnout of mixture components, rather slowly approaches the actual adiabatic level. For this reason, to the first approximation, we have assumed T = const. From the solution to Eq. (1) one can then determine the true maximum gas temperature in a bubble, if the mean temperature of the fluidization bed T_0 and the maximum fluctuation recorded on the oscillograph ΔT_m as well as the time of temperature rise — are known:

$$T_m = T_0 + \frac{\Delta T_m}{1 - \exp(-\tau m)}. \tag{2}$$

Despite the poor accuracy and the wide spread of test points, the results of the thus-evaluated fluctuation measurements (some of which are shown in Figs. 2 and 3) lead to the following conclusions:

1. During the burst of a gas bubble, after the latter has reached the surface of the fluidization bed, the temperatures here rise to up to 2000°K.

2. As the bed temperature rises from 540 to 1300°K (Fig. 2a, b), the noted tendency of the temperature recorded by the heat probe to drop is evidently due to ignition of bubbles inside the bed and subsequent cooling of the combustion products while the bubbles ascend to the bed surface.

3. The higher fluidization rate (Fig. 3) at the same bed temperature causes the maximum temperature recorded by the thermocouple to rise, as a result of the bubbles beginning to ignite in the space above the bed.

4. The appreciable increase in recorded fluctuations with decreasing α, at the same temperature of the fluidization bed T_{fb} = 1100-1120°K and the same fluidization rate, is related to the shifting of the bubble ignition from the depth of the bed up to its surface. At $\alpha = 0.385$ a temperature of 1970°K (T_{fb} = 1120°K) was recorded, typically, while the combustion temperature of natural gas under these conditions does not exceed 1900°K [8]. Two possible causes of this difference could be the nonuniformity of thermochemical reactions during a burst (incompleteness of endothermal reactions) and the participation of oxygen from the atmosphere above the bed in the combustion of bubbles.

5. At a 200 mm bed height with corundum particles of the 320 μm fraction, the ignition of a stoichiometric gas-air mixture in bubbles begins to shift into the bed at temperatures T_{fb} = 1020-1070°K. Temperature T^e_{fb} (Fig. 3) at the completion of the combustion process, in the case of a stoichiometric gas-air mixture in bubbles inside a bed is a function of the fluidization rate w, namely: when w = 0.2, 0.3, 0.4-0.6 m/sec, then T^e_{fb} is respectively 1080, 1270, 1340°K.

NOTATION

T	is the instantaneous temperature of gas in a bubble;
T_0	is the temperature of gas in a bubble leaving the bed;
T_{fb}	is the temperature of the fluidization bed;
T^e_{fb}	is the temperature of the fluidization bed when bubbles burn inside the bed;
T_o	is the mean-over-the-volume temperature of heat probe of the thermocouple;
T_m	is the maximum temperature of gas in a bubble;
w	is the fluidization rate (referred to empty vessel);
α	is the relative rate of air flow;
τ	is the time;
ε_u	is the time constant of heat probe (thermocouple).

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