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Instability of aerosol boundary accelerated in a direction perpendicular to its plane

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ABSTRACT

Theory of Rayleigh–Taylor instability (RTI) is extended for the case of a dilute aerosol system. Equations of interpenetrating continua are investigated on stability to small perturbations by the method of normal modes. In contrast with homogeneous, equations of two-phase, two-velocity medium possess three types of disturbances: an entropy-vorticity one along with two acoustic ones. The difference in the amplitude constant signs of these types is able to affect the disturbance shape and phase convection inside mixing layer. The acoustic branch of solution is responsible for mechanism of instability, while the entropy-vorticity one determines damping mechanism. Instability of a plane accelerating surface, which separates aerosol and homogeneous incompressible fluid, is then investigated. Dispersion relation of the boundary-value problem for perturbations has two aperiodic unstable roots; one of them coincides with the classic R–T root in the particle absence limit, another is able to compete with only at huge accelerations. Instability is governed by modified Shields and Atwood numbers. As applications, systems with different aerosol densities are considered: atmospheric dust, mist around atomizing drop and explosively dispersed powder. Conclusion is done that a suspension somewhat destabilizes the system at small particle volume concentrations, while at a denser content it has essential damping influence on RTI.

1. Introduction

One of the characteristics of multiphase flow with which the operation of process units has to contend is that they frequently manifest instabilities that have no equivalence in a single-phase flow. These instabilities result often in operational and safety problems: the occurrence of large pressure, flow rate or volume fraction oscillations that at best disrupts the expected behavior of the multiphase flow system (and thus decreases the reliability and lifetime of the components) and, at worst, can lead to a serious flow stoppage or structural failure (Alane & Heggs, 2007). Two-phase instabilities work in many of phenomena, such as laser implosion of deuterium-tritium fusion targets (Emery Gardner & Boris, 1982), a pedestrian flow (Nakayama Hasebe & Sugiyama, 2005), a surprising macroscopic behavior of granular matter (Lange, Schroter, Scherer, Engel & Rehberg, 1998), the overturn of outer portion of the collapsed core of a massive star (Smarr, Wilson, Barton & Bowers, 1981), formation of high-luminosity twin-exhaust jets in rotating gas clouds (Norman, Smarr, Wilson & Smith, 1981), in the supernova implosions and explosions (Wang & Chevalier, 2000). In geophysical context the instabilities may lead to redistribution of an unstable density stratification and ocean waters mixing, volcano ash sedimentation (Dalziel, 1993); to the bulk motion of aerosols and cloud settling that have essentially different settling velocity than that one according to the Stokes law (Hinds, Ashley, Kennedy & Bucknam, 2002), which affect the fall out of the industrial pollutions contaminants. They are the dominant mechanism in sedimentation process found in lakes, reservoirs, estuaries

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Nomenclature

$A_k, B_k, C_k, D_k, E_0, F_k, P_k, R_k$	amplitude constants
a	particle radius
At	Atwood number
c_p, c_v	thermal capacities
e	internal energy
F_{gr}, F_{in}	gravitational and inertia forces;
f_μ	viscous friction per particle
$\vec{g}$	acceleration;
g_y	acceleration due to mass force
G, H, I, J, K	coefficients
h	wavenumber
n	particle number density
p	pressure
$\mathbb{R}_c$	gas constant
Re(Z)	real part of Z
S	entropy
Sd_*	Shields number
t	time
T	temperature
V	velocity
$V_* = \sqrt{a\vert g\vert}$	characteristic velocity
x, y	Cartesian coordinates
Z	dimensionless growth rate
z_i	coefficients in expansion (13).

Greek symbols:

α	volumetric concentration; $\Gamma = g_y/V_*^2 h$;
γ	solution branch amplifier;
λ	wavelength
ε	surface disturbance
σ	surface tension coefficient
ρ	volumetric density
$\tau_i = \vert\omega(h_m)\vert^{-1}$	induction time of fastest wave amplitude growth
ω (h)	growth rate of the corresponding mode.

Sub-indices:

a	air in domain **II**
c	continuous phase
d	dispersed phase;
gr	gravity;
i	induction;
in	inertia;
k	disturbance type index;
m	maximum;
RT	Rayleigh–Tailor instability;
0	initial values.

Super-index:

0	true (own) phase density;
asterisk	parameter disturbance;
I-VI	root number of Eq. (11).

(Chou, Wu & Shih, 2014). As well, they contribute considerably in a wide range of modern technologies: in secondary oil recovery processes (Patel, Mehta & Patel, 2012); in tube boiling systems (Alane & Heggs, 2007; Kakac & Bon, 2008); in designing of efficient, high-gain capsules for inertial confinement fusion (Di Luchio, 2012). Two-phase flow boiling in micro-channels is one of the most promising cooling technologies able to cope with high heat fluxes produced by the next generation of central processor units (Bogojevich et al., 2011).

This common theme running through a wide range of important subjects (including geophysics, plasma and low-temperature

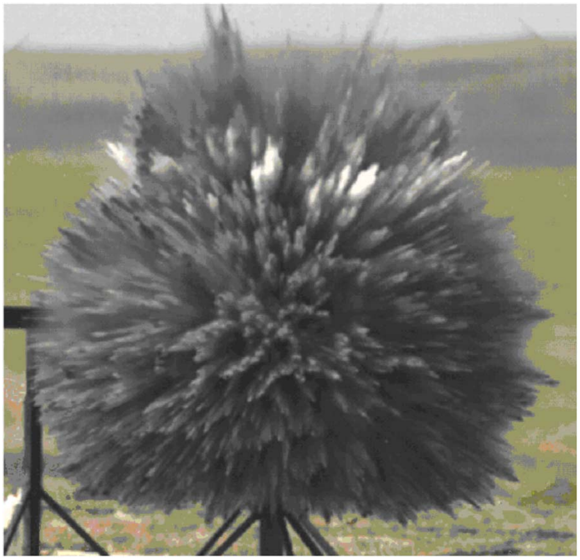

Fig. 1. Spike system at explosive powder dispersion (Frost et al., 2011).