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Experimental and Numerical Study of Gas Outburst with Soil Under Gas Expansion

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The outburst fragmentation of soil caused by the dissociation of the gas hydrate was studied via experiments and numerical simulation. The dense discrete particle model combined with the kinetic theory of granular flow was presented to reveal the outburst morphology of soil, considering the interphase forces and frictional effect between soil particles. The numerical simulation results in geometric features are consistent with the experimental results. The diameter of the gas outburst with soil can be predicted by the model, and the rule of the particle velocity can be obtained by the simulation. Moreover, the effects of initial gas pressure and thicknesses of the overlying layer on the occurrence of gas outbursts were investigated in the experiments.

NOMENCLATURE

α	volume fraction
g	gas phase
s	solid phase
g	gravitational acceleration, $g = 9.81\ \mathrm{m/s^2}$
ρ	density, $\mathrm{kg/m^3}$
$\boldsymbol{u}$	velocity, m/s
P	gas phase pressure, Pa
τ	stress tensor, Pa
K_{sg}	interphase momentum exchange coefficient, $\mathrm{kg/(m^3 \cdot s)}$
x	particle position, m
τ_r	particle relaxation time, s
μ	shear viscosity, $\mathrm{Pa \cdot s}$
d_{s}	diameter of solid particles, m
λ_{s}	bulk viscosity, $\mathrm{Pa \cdot s}$
Θ	granular temperature, $\mathrm{m^2/s^2}$
Φ_{gs}	energy exchange of the gas–solid phase, J
P_{friction}	friction pressure, Pa
Δt	parcel time step, s
m_{p}	parcel mass, kg
$\dot{m}_{\mathrm{parcel}}$	parcel mass flow rate, kg/s

Dimensionless numbers

C_{D}	drag coefficient
Re_{s}	relative Reynolds number
$\mathbf{I}$	unit tensor
$\gamma_{\Theta\mathrm{s}}, k_{\Theta\mathrm{s}}$	collisional dissipation coefficient
e_{ss}	particle–particle restitution coefficient
φ	angle of internal friction
$g_{0,\mathrm{ss}}$	radial distribution function
h/H	thicknesses of the overlying layer
D/d_1	diameter of blasted pit
P/P_0	initial gas pressure
m/m_0	mass of soil sprayed
z/H	height in z direction
v_{p}/v_0	movement of particle velocity

INTRODUCTION

Gas hydrate (GH) has become an important strategic energy source in China because of its large reserve and little pollution. Many countries in the world have accelerated the exploration and development of GH. However, concerns about possible geological disasters, even hazard chains caused by exploitation activities, are increasing. The dissociation of GH from hydrate-bearing sediments during exploration can cause the softening of soils and the formation of excess pore gas pressure (Zhang et al., 2015). The hydrate sediments become a gas–liquid–solid phase slurry structure after the hydrate dissociation (Nair et al., 2019). If the accumulated pressure after the hydrate dissociation equals or exceeds the soil's resistance, plastic failure or gas outburst can occur.

Zhang et al. (2011) carried out hydrate dissociation experiments to observe the layer fracture failure and outburst by using tetrahydrofuran hydrate. The experimental results show that there are critical pressures closely related to the strength of sediments and boundary fraction. Zhang et al. (2015) proposed experiments on modeling the weakening and fracture of the sediment by heat-induced dissociation of tetrahydrofuran hydrate and obtained geometrical and mechanical similarities for the gas outburst by using an analytical model considering heat transform and soil deformation. Fan and Li (2017) presented a peridynamics model coupled with a modified smooth particle hydrodynamics model to predict soil fragmentation caused by blast loading. Zhou et al. (2020) established models of outbursts according to the energy transformation during the gas expansion process and quantitatively researched the gas dynamic characteristics of gas–solid two-phase flow in the initiation stage. Zhou et al. (2020) studied the gas dynamic characteristics of two-phase flow quantitatively by

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KEY WORDS: Gas–solid flow, gas outburst, DDPM-KTGF model, gas hydrate.