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Prospect of open-cell solid foams for floating-platform multiphase reactor applications – Maldistribution susceptibility and hydrodynamic behavior

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ABSTRACT

Open-cell solid foams are tested for the first time as prospective structured packings in floating columns to evaluate their potential for offshore multiphase reactor applications. Using a hexapod ship motion simulator and low-intrusive wire-mesh sensors, the effect of floating vessel motions on the hydrodynamic behavior of SiSiC foam packed beds operated with concurrent descending gas-liquid flow was comprehensively investigated. The response of gas-liquid distribution, overall bed pressure drop, and liquid axial dispersion to column tilts as well as translational and rotational motions was acquired and compared to their corresponding stationary (onshore) analog configuration. Maldistribution sensitivity and susceptibility of solid-foam packed beds subject to ship tilts and accelerations were interpreted in terms of fluid uniformity factor. Moreover, a stimulus-response tracer pulse technique and a macro-mixing model were used to estimate the liquid mean residence time and Péclet number. Similar to random packings, fluid maldistribution was found to prevail in solid-foam beds with deviations from uniformity greater for rotational than for translational perturbations. Vessel tilts and oscillations adversely affect open-cell foam bed hydrodynamic performance yielding transient gas-liquid segregated flow regimes, oscillations of pressure drop and uniformity factor, as well as notable deviation from liquid plug flow.

1. Introduction

The chemical and petrochemical industries widely rely on multiphase packed-bed reactors with descending gas-liquid flow through random catalyst packings to carry out a large spectrum of catalytic reactions, including Fischer-Tropsch synthesis from syngas, catalytic hydrogenation of unsaturated hydrocarbons, hydroprocessing of crude oil, and so forth [1]. The quality of fluid distribution across such porous structures is known to directly control the reactor performance [2] where phase maldistribution entails reactor dysfunction through sub-optimal catalyst utilization, poor mass transfer access to active sites, or restricted heat withdrawal which in return favors pellet dry-out and formation of local hotspots for exothermic reactions [3]. Therefore, the initial fluid distribution and packing characteristics are key factors which are recognized to influence the gas-liquid distribution throughout the entire packed bed on account of the underlying fluid dynamics [4]. In recent decades, extensive research on various designs of fluid distributors, distributor location, and various types and configurations of packing has been conducted to comprehend their effect on the behavior of fluid phase distribution inside packed bed reactors (see, for example, [5–8]).

In the context of offshore industrial applications, packed beds are embarked on mobile sea platforms such as floating production, storage and offloading (FPSO) and floating liquefied natural gas (FLNG) units for onboard treatment and refining operations of hydrocarbons tapped from undersea reservoirs nearby their extraction sites [9,10]. However, unlike the classical instance of motionless land-based oil and gas processing units, the fluid distribution in packed-bed reactors and contactors onboard FPSO units is likely to be altered by the oscillations from the hosting ships which only partially filter out the marine dynamics stemming from wind and swells [11,12]. Therefore, offshore conditions compulsorily require consideration in the design stage of carefully conducted representative piloting tests to prove (or to debar) implementation of *ad-hoc* onboard packed bed systems for hydrocarbon treatment in deep water.

A few published works are hitherto available in the literature on the gas-liquid distribution and flow dynamics specific to offshore floating packed beds. These studies can be classified mainly into two groups, those with focus: (1) on the design of adapted feed distributors or on the selection of appropriate packings to curb the fluid maldistribution arising out of ship excitations [11,13–16] and (2) on the elucidation of the hydrodynamics prevailing inside floating packed beds [12,17–24].

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Nomenclature

A_p	amplitude (°/mm)
D	dispersion coefficient (m^2/s)
F	frequency (Hz)
H	axial distance from the top of packing
L	axial distance between the wire-mesh sensors (m)
NP	number of pixels in bed cross-section (–)
Pe	Péclet number (U_lL/ε_LD_{ax})
t	time (s)
T	period (s)
U	superficial velocity (m/s)

Greek letters

θ	tilt angle/angular position during tilting motion (°)
β	spatial-averaged liquid saturation
β_i	ith pixel liquid saturation
ϕ	phase lag
χ	degree of uniformity (–)
τ	residence time (s)

Subscripts

ax	axial
g	gas
l	liquid

Abbreviations

ADM	axial dispersion model
PDF	probability density function
RTD	residence time distribution
WMS	wire-mesh sensor
1-D	one-dimensional
2-D	two-dimensional

The first group's endeavors have been to ensure that fluid distribution remains as much as possible unaltered during column tilts and roll motions through developing uniform crisscross structured liquid distributors in which both collector and distributor are connected *via* one or several relatively long vertical pipes [13,15], partitioned distributor trays consisting of gas-passing chimneys and liquid-passing perforations [16], or through designing cross-corrugated packings comprising a stack of vertical corrugated strips with corrugations alternately inclined in opposite directions [14]. Interestingly, the findings from the second group's works have been revealing that column oscillations and stationary tilts extend the fluid maldistribution from top to bottom of the packed bed on account of the lowered downhill-slope and transverse inertial forces [12,17,20,24].

The effect of various types of emulated ship motions on the hydrodynamics of gas-liquid downflow in porous media was investigated by means of a hexapod ship motion simulator and a capacitance wire-

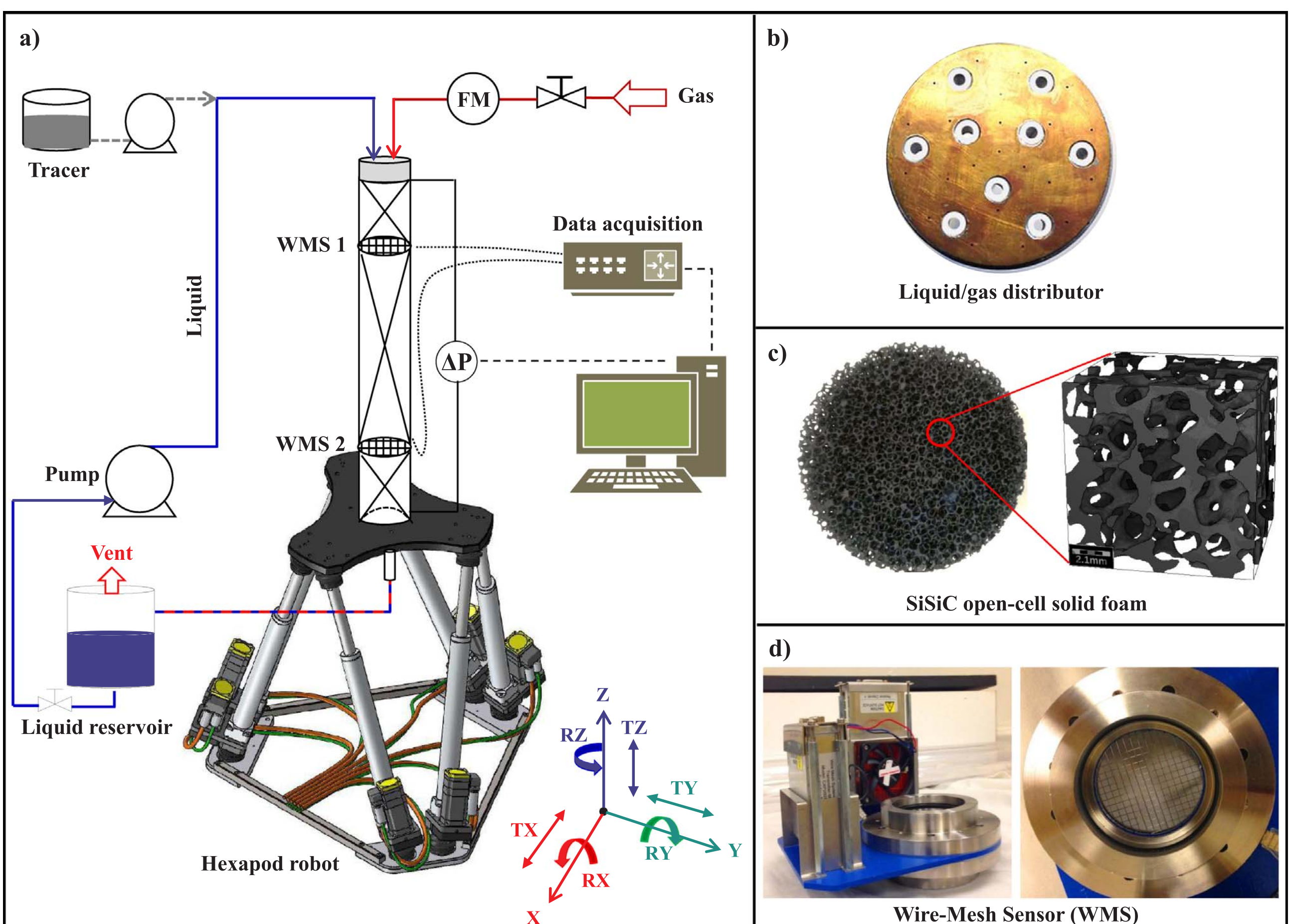

Fig. 1. (a) Experimental setup of the stationary-moving packed bed with gas-liquid cocurrent downflow mode embarked on hexapod robot emulator, (b) liquid/gas distributor, (c) SiSiC solid foam, and (d) wire-mesh sensor.