Clean Energy for Sustainable Economy and Environment

A Computational Methodology to Predict Gas-Liquid Distribution in Packed Beds Generated by Industrial Distributor Trays

Ekta Jain[1], Madhusudan Sau[2], Vivek Buwa[1*]
1. Department of Chemical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India
2. R&D Centre, Indian Oil Corporation Limited, Sector 13, Faridabad 121006, India

Chemical Engineering

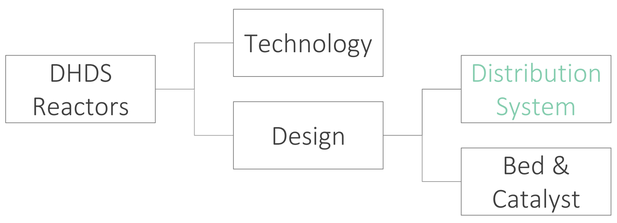
INTRODUCTION

Background:

THE OIL INDUSTRY NEEDS COST EFFECTIVE WAYS

- Trickle bed reactors (TBRs): widely used in oil industry for hydro-treating, hydro-cracking and hydro-desulphurization processes.
- Shift of technology from Euro 5 to Euro 6 is of utmost importance- involves humongous cost for R&D and implementation for production of ULSD.
- Liquid distribution generated by industrial gas-liquid distributors is not available in the open literature or not disclosed by licensors.

Levels of application based R&D for ULSD production



Motivation:

NEED FOR A METHODOLOGY TO PREDICT GAS-LIQUID DISTRIBUTION INSIDE THE BED FROM A SINGLE DISTRIBUTOR UNIT'S DATA

- Ease in designing a configuration of tray arrangement for specific number of distributor units, based on single unit's coverage span and liquid discharge pattern.
- Possibility to optimize the distributor tray configuration for different operating conditions.
- Possibility to choose the required length of bed for a specific tray configuration to obtain uniform liquid distribution.

Objectives:

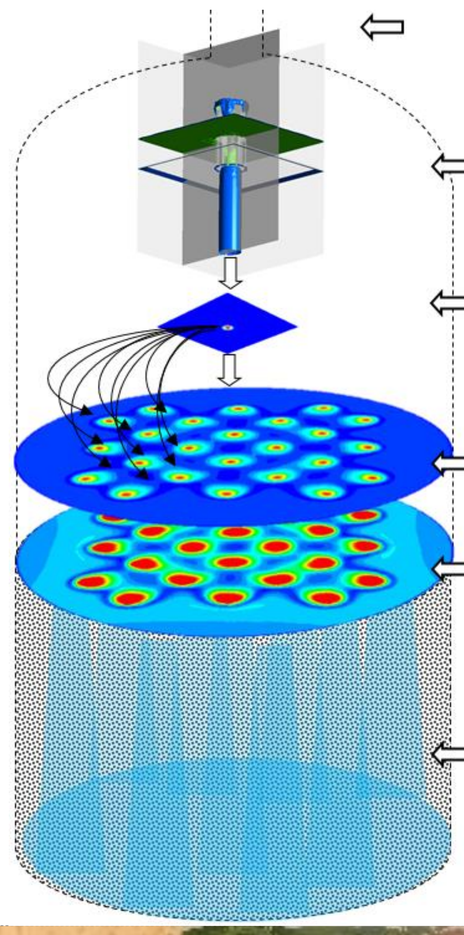
DEVELOPMENT OF A COMPUTATIONAL METHODOLOGY

- To simulate the flow through a single unit of gas-liquid distributor using two-phase Euler-Euler model developed as a part of our previous work [1].
- To generate liquid distribution through the corresponding distributor tray under industrial operating conditions.
- To simulate the flow through packed bed using gas-liquid distribution data from the above information.

METHODOLOGY

Computational Methodology:

STUDY OF LIQUID DISTRIBUTION IN A PACKED BED USING SINGLE DISTRIBUTOR'S DATA [2]



(a) Gas + liquid mixture through primary distributor/inlet

(b) Single unit of gas-liquid distributor

(c) Gas and liquid distribution data for a single distributor unit, at the outlet of distributor unit

(d) Scaling up the obtained data for the distribution at the inlet of open space below distributor tray

(e) CFD simulation of gas-liquid distribution at the top of the packed bed

(f) CFD simulation of flow inside packed bed

Computational Model:

TWO-PHASE MULTI-REGIME FLOW

(inside and below the distributor units)

- Mass conservation:

$$\frac{\partial(\alpha_w\rho_w)}{\partial t} + \nabla.(\alpha_w\rho_w\overline{U}_w) = 0,\ \frac{\partial(\alpha_a\rho_a)}{\partial t} + \nabla.(\alpha_a\rho_a\overline{U}_a) = 0$$

- Momentum conservation:

$$\frac{\partial(\alpha_w\rho_w\overline{U}_w)}{\partial t} + \nabla.(\alpha_w\rho_w\overline{U}_w\overline{U}_w) = -\alpha_w\nabla P - \nabla.\overline{\overline{\tau_w}} + \alpha_w\rho_w\vec{g} + \overline{M}_{wa}$$

$$\frac{\partial(\alpha_a\rho_a\overline{U}_a)}{\partial t} + \nabla.(\alpha_a\rho_a\overline{U}_a\overline{U}_a) = -\alpha_a\nabla P - \nabla.\overline{\overline{\tau_a}} + \alpha_a\rho_a\vec{g} + \overline{M}_{aw}$$

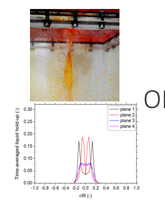
- Inter-momentum exchange: Modified weighted drag force (Tomiyama et al., 1995) for *multi-regime flow* domain

MULTI-PHASE FLOW INSIDE PACKED BED

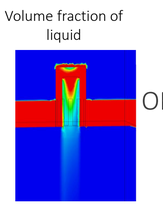
- The multi-phase Eulerian model and Capillary Pressure force model was used as suggested by Dhanraj and Buwa (2018) [3]

This methodology can work for packed beds with the following inputs:

- Fluid properties, flow rates and operating conditions
- Design of single unit of distributor/ liquid distribution measurements
- Characteristics of packed bed



OR



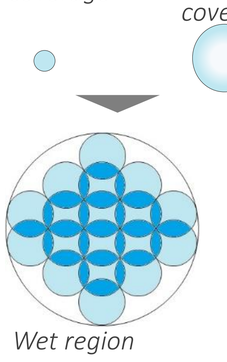
OR

Experimental measurements | *Validated CFD predictions* | *Geometry of distributor*

APPLICATIONS

Types of liquid discharge patterns within single distributor's coverage-span

Uniform coverage | *Non-uniform positive gradient coverage* | *Non-uniform negative gradient coverage*



Can we investigate the effect of operating conditions on the liquid distribution inside the bed?

Is more number of distributor units causing over-flow of fluids inside the bed? Or are the units too close to the reactor wall?

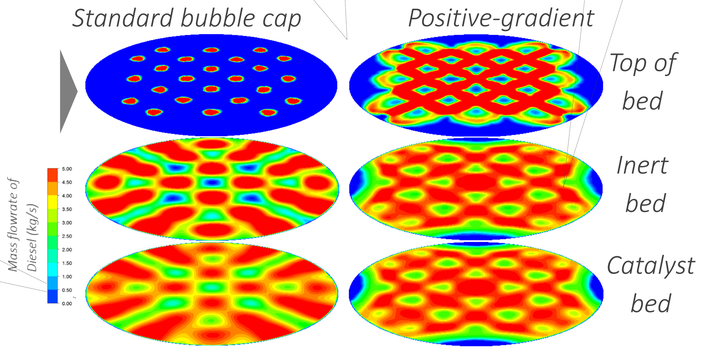
What length of packed bed will be required if the tray is retrofitted with new type of distributor unit?

Can the height of inert packing be reduced?

How many distributor units would be enough to install on the tray?

Does the packing require to be changed if the distributor design is changed?

Can overlapping be optimized by changing the pitch?



OUTCOME

The methodology developed in the present study will not only help in evaluating the liquid distribution proposed for any commercial distributor tray, but will also in choosing a better tray arrangement for any given gas-liquid distributor on the basis of single distributor's performance.

References:

[1] E. Jain, V.V. Buwa and M. Sau, Gas-liquid Flow through Chimney and Bubble-cap Distributors, presented in 13th International Conference on Gas–Liquid and Gas–Liquid–Solid Reactor Engineering (GLS13), Brussels, Belgium (2017).

[2] E. Jain, M. Sau and V.V. Buwa, A Methodology to Simulate Gas-liquid Distribution through Distributor-trays using Two-phase Eulerian Model, to be presented in 10th International Conference on Multiphase Flow (ICMF 2019), Rio de Janeiro, Brazil (2019).

[3] D.I.A. Dhanraj and V.V. Buwa, Effect of Capillary Pressure Force on Local Liquid Distribution in a Trickle Bed, Chem. Eng, Sci., 191, 115-133 (2018)

*corresponding author (Tel: +91 11 2659 1027, email: vvbuwa@iitd.ac.in)

One of the authors, Ekta Jain, is thankful to the R&D Division, IOCL, Faridabad for research fellowship.