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Monitoring of Hydrodynamics and Mass Transfer in Vortex Flows

RAM-VERLAG
2022

The monograph aims at monitoring of hydrodynamics and mass transfer in two-phase gas-droplet vortex flows in spraying countercurrent mass transfer apparatuses. Up-to-date methods of mass transfer in vortex gas-droplet flows and approaches for rational designing vortex apparatuses are presented. The development of innovative designs of mass transfer equipment is presented. Based on experimental studies and practical experience, methods for evaluating the hydraulic and mass transfer characteristics have been proposed. Particular attention is paid to intensifying hydrodynamic and mass transfer processes in equipment for chemical technology. The scientific results have been achieved within the research project Creation of new granular materials for nuclear fuel and catalysts in the active hydrodynamic environment" (State reg. no. 0120U102036).

The monograph was reviewed by three reviewers.

This monograph was prepared with support by the project KEGA 055TUKE-4/2020 and it was recommended for publication by the Academic Council of Sumy State University as a scientific monograph (minutes No. 12 of 21.04.2022).

ISBN 978-3-96595-021-4
UDC 66.011

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Preface

The energy crisis of the late 20th and early 21st centuries, constantly increasing requirements for product quality, a sharp increase in the cost of materials, and a number of environmental disasters drew society's attention, governments worldwide to strengthen requirements for cleanliness of industrial emissions. Simultaneously, problems arose that created the preconditions for the emergence of innovative directions in the development of mass transfer equipment.

Basically, the search for new ways of development aims to create mass transfer equipment with an increase in the efficiency of using the working volume by 2–3 times or more, compared with traditional column equipment, where plate or packed contact elements are commonly used.

Along with the improvement of mass transfer equipment, the search for ways of organizing the movement of flows in mass transfer equipment and the consequent monitoring continues. Today, it becomes possible to carry out highly efficient mass transfer processes with a simultaneous decrease in the dimensions of apparatuses and an increase in their productivity.

Over the past decade, many publications on the study of vortex flow in mass transfer devices have been increased. Mainly, publications recommended by the authors of the monograph are summarized in References.

Also, the number of designs of various vortex devices has significantly increased, which created the conditions for the contact between gas and liquid phases under their vortex movement. Particularly, Sumy State University successfully carries out research works on vortex flows and innovative designs of mass transfer equipment.

Remarkably, the increased interest in vortex flows in mass transfer equipment is substantiated by the possibility of a significant intensification of mass transfer processes. This is because mass transfer processes in vortex flows are carried out in relatively small volumes of working chambers. This fact allows one to increase the size of the mass transfer apparatus and reduce costs for designing, manufacturing, and exploitation of vortex mass transfer apparatuses.

Hydrodynamic features of the vortex flows highlight two main factors for intensifying mass transfer processes. The first one concerns the possibility of performing a finely dispersed spraying of a liquid phase due to high relative velocities of phases. As a result, a significant increase in the interfacial surface is achieved. Accordingly, mass transfer processes are accelerated.

The second factor is creating the developed turbulent two-phase flow in the entire volume of a vortex mass transfer chamber. This allows one to increase the intensity of internal circulation currents in droplets and accelerate the renewal of the interfacial surface.

The monograph is devoted to the theoretical and experimental study of hydrodynamic and mass transfer processes' monitoring in two-phase gas-droplet vortex flows within a single spraying stage. In an entire volume of a vortex chamber, gas moves from the periphery to the center, and liquid – from the center to the periphery. The main attention is paid to methods of intensifying hydrodynamic and mass transfer processes.

In the monograph, the theoretical substantiation of the mass transfer efficiency between gas and liquid in vortex flows is given. A theoretical description of such a motion is presented using mathematical equations obtained based on the analytical solution of differential equations for a viscous gas flow motion. Equations for calculating a new vortex spraying countercurrent mass transfer apparatus have been substantiated analytically. The developed mathematical models have been proven experimentally. The impact of technological and geometric parameters on the local velocity and pressure fields is shown. Up-to-date approaches to rational design of vortex spraying countercurrent mass transfer apparatuses are presented. The development of progressive designs of mass transfer equipment using countercurrent vortex motion of liquid droplets and gas along the radius of the vortex chamber is presented. Experiments and practical experience have developed methods for evaluating hydraulic and mass transfer characteristics for vortex spraying countercurrent mass transfer apparatuses.

Ways for the organization of gas-droplet flows in vortex spraying countercurrent mass transfer apparatuses are described in Chapter 1. The theoretical background of mass transfer intensification between droplets and gas at a vortex countercurrent motion is presented in Chapter 2. Based on the theoretical and experimental studies presented in Chapters 3–4, the following new results are recommended:

– fundamentals of organizing the movement of phases in countercurrent vortex flows of liquid droplets and gas have been obtained; the dependence of circulation flows in liquid droplets on the hydrodynamic characteristics of a flow has been established; the impact of internal circulation flows on the efficiency of the mass transfer process has been substantiated;

– the nature of the interaction of vortex flows of liquid droplets and gas has been studied;

– dependencies for calculating local fields of velocity and pressure in a gas vortex flow have been obtained for given geometric and technological parameters of the vortex spraying countercurrent mass transfer apparatus;

– experimental data on the local velocity and pressure fields in a working chamber have been presented; this allows one to deeper understand the essence of the mass transfer processes in a vortex chamber and determine the mass transfer characteristics in the processes of absorption (desorption) and rectification;

– the fundamental principles of increasing efficiency and productivity of vortex spraying countercurrent mass transfer apparatuses have been formulated based on experiments on improved designs of such devices;

– new designs of vortex sprayers have been developed considering the achievement of the most effective spraying;

– physical and mathematical models of the motion of liquid droplets and gas in a working chamber have been proposed in terms of impact on circulation flows in droplets; the most favorable conditions for movement and interaction of phases have been proposed;

– efficiency of vortex spraying countercurrent mass transfer apparatuses has been compared with other designs of mass transfer equipment;

– conditions are formulated under which using the vortex spraying countercurrent mass transfer apparatus is the most appropriate.

Chapter 5 presents the mass transfer characteristics of the vortex spraying countercurrent mass transfer apparatus. Recommendations for designing vortex spraying mass transfer equipment and their applications are described in Chapter 6.

Described designs of vortex spraying countercurrent mass transfer apparatuses and methods for calculating their hydrodynamic and mass transfer characteristics have been implemented in the technological processes in the industry, mainly as follows:

– distribution of products in the synthesis of butoxybutenine;

– purification of gas emissions from dimethylformamide (dimethylacetamide); purification of gas emissions from ammophos production from fluorine and ammonia;

– natural gas dehydration.

Thus, developing a method for countercurrent mass transfer in vortex flows has allowed us to improve designs of highly efficient mass transfer apparatuses, in which vortex countercurrent motion of phases is carried out in the entire volume of a vortex chamber. As a result, a change in the concentration of phases is achieved, corresponding to several theoretical stages of change in concentration. Such organization of flows allows one to carry out mass transfer processes in smaller volumes, reduce the number of steps and the dimensions of apparatuses, and reduce the consumption of material and reflux in the rectification process. As a result, more significant savings in materials and energy are provided.

In the monograph, mathematical models of two-phase vortex countercurrent flow in the entire volume of a working chamber are given. Along with creating highly efficient designs, much attention is paid to studying various factors restraining the widespread implementation of the considered mass transfer approach. Particular attention is also paid to promising designs of mass transfer equipment to identify possible ways of developing vortex spraying countercurrent mass transfer apparatuses.

It is noteworthy that the authors paid particular attention to the effect occurring due to exposure high-speed gas flow (with the transverse velocity gradient) on internal flows in liquid droplets. Notably, it has been proven for the first time that this effect intensifies internal currents inside droplets and the mass transfer process in the vortex spraying countercurrent mass transfer apparatus.

The results have been achieved within the research project of Sumy State University “Creation of new granular materials for nuclear fuel and catalysts in the active hydrodynamic environment” (State Reg. No. 0120U102036) ordered by the

Ministry of Education and Science of Ukraine due to the close cooperation between the Department of Chemical Engineering, the Department of Computational Mechanics named after Volodymyr Martynkovskyy of Sumy State University (Sumy, Ukraine), and the Faculty of Manufacturing Technologies with a seat in Prešov of Technical University of Košice (Prešov, Slovakia) under the support of the International Association for Technological Development and Innovations.

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