Experimental plant for studying hydrodynamics and heat and mass exchange processes in packing contact devices

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Abstract. The paper provides a description of the developed experimental plant for studying hydrodynamic and heat and mass exchange processes in packing devices of all kinds of configuration, examples of the obtained data and original classification methods for processing experimental data. The authors describe hydrodynamic characteristics allowing carrying out classification studies and obtaining the necessary data to complete the developed methods for calculating mass exchange devices: the retaining capacity of packing devices at liquid and gas phases in particular. The authors provide the criteria function $\lambda = f(Re_m)$ which gives a direction for industrial application of packing contact devises. The function is based on the analysis and generalization of the experimental data obtained in express studies of single-phase filtration curves. The paper also covers an example of the experimental data of the response function in case of recognizing flow structures of contact phases which allow obtaining necessary data to complete the developed diffusion models of mass exchange processes and implement calculations of mass exchange packing with a high precision.

1. Introduction

Filtration flows in the form of two-phase gas-liquid and liquid-vapor flows through a layer of packing are widely used in the industry [1-5]. As for the chemical sector they are processes of absorption, extraction and rectification occurring in packing column mass-exchange apparatus, as for the heat power engineering sector they are evaporative water cooling in cooling towers, as for the ecological sector this is purification of gas emissions in absorbers and scrubbers [6-10]. For all of the differences and specific features of the processes going in the mentioned technological equipment, the general purpose of their contact devices is to create such conditions of gas and liquid phase interaction which provide the highest efficiency of processes going inside the equipment with the lowest energy costs [11-17]. With a big variety of mode factors, chemical and thermophysical properties of contacting flows the efficiency of contact devices, as shown by the industrial experience and experiential research, depends on the intrinsic geometry and structural design of the pack forming a hydrodynamic environment in the two-phase filtration flow. The development of the new high-performance pack, as works [18-23] show, is a time-consuming process connected with constructive meeting of necessary and at the same time opposed requirements.
A large number of industrial packs and packs that could be used in the industry have been described in works [24, 25]. The selection of the known packs and the development of new packs for contact devices of technological equipment is always connected with the need to evaluate their effectiveness for the conditions of a particular process. Due to the high specificity of processes implemented in the two-phase filtration flow it’s impossible to select the most effective pack in a unique manner. One of our main tasks is to develop classification methods for the experimental data processing [26-28].

2. Experimental part
For the full range of experimental studies and comparing the characteristics of packing devices of different configurations the authors have developed an experimental modular type plant with the cartridge system of replaceable packs (Figure 1, 2, 5), the plant allows carrying out very fast and exact study of heat and mass exchange and hydromechanical characteristics.

![Figure 1. Experimental plant for studying of hydrodynamic and heat and mass exchange characteristics of packing devices of various configurations: 1 – module for studying traditional hydraulic and heat and mass exchange characteristics of packs; 2 – module for studying the liquid and gas flow structures; 3 – module for adapting packing devices for actual industrial conditions.](image)

The experimental plant consists of three main modules each of which is responsible for some special study. Each module contains a cartridge system of changeable packs. It allows changing packs fast and supplies stable reproducibility of the experimental data in repeated experiments. The cartridges are transparent glass cylindrical and prismatic columns. The geometric configuration of the cartridge depends on the pack type and the method of manufacturing its pilot sample since many structured packs require very clear spatial fixation. The prismatic cartridges with internal structural elements (frames) greatly simplify this task.
The first module (Figure 1) implements a wide range of traditional experimental studies (Figure 3), such as hydraulic resistances of dry and irrigated packs, retaining liquid and gas capacity, hydraulic modes and optimal ranges of flow rates of liquid and gas, and heat and mass transfer coefficients etc. Along with the traditional criteria we are interested in studying retaining liquid and gas capacity, which is a reflection of the accumulating capacity of the pack and allows calculating the residence time of the contacting phases in the apparatus and identifying the total heat and mass transfer surface for a number of packs [29].

![Figure 2](image)

**Figure 2.** Spatial scheme of the experimental plant for studying hydrodynamic and heat and mass exchange characteristics of packing devices:
1 – the module of the research of traditional hydraulic and heat and mass exchange characteristics of packs; 2 – the module of the research of the liquid and gas flow structures;
3 – the module for adapting packs for actual industrial conditions.

A very important confirmed function of the experimental measurement of retaining capacity is its capability to show the existence of stagnant zones in packs. This method is the impulse blowing of packing devices after the first measurement of the retaining capacity. The amount of the residual liquid will show the relative percentage of stagnant zones in the pack volume. It should be noted that in the first module both the studied cartridge packs and the upper part of the structural column are changeable. Figure 3 shows an example of characteristics being studied with the use the first module.
Figure 3. An example of the obtained experimental data with the use of the first module of the experimental plant: 1 – hydraulic resistances of dry and irrigated packing devices; 2 – retaining capacity of packs of various configurations [6], 3 – comparative classification of heat and mass exchange packing devices according to the mode range [26-28].

The second module of the experimental plant (Figure 1) is for studying liquid and gas flow structures through packing devices of any configurations. The obtained data of the flow structures allow completing the calculation of mass exchange devices for cellular, diffusion and combined models [30, 31]. An example of the measured response curves for different packing devices is presented in figure 4. The methodology of studying structural packing devices allows getting necessary correct experimental data which add the calculated mathematical models of processes and also being one of the most important classification characteristics it allows classifying packs. In addition, the experimental measurement of actual flow structures through packing layers allows finding out stagnant zones in the volume of the packs.
Figure 4. Curves of response to the impulsive perturbation of the liquid flow at the inlet in dimensionless coordinates (dimensionless time - dimensionless concentration), showing the actual flow patterns of heat and mass exchange packing devices obtained using the 2nd module of the experimental plant.

The third module of the experimental plant (Figure 1) allows, partially smoothing out the scale change, testing packing devices in a larger column close to a real plant of low productivity. It consists of gas-distributing and water collectors on which changeable columns with test samples of packs are installed.

We shall consider the scheme (Figure 5) and the operation principle of the developed experimental plant.

Figure 5. The scheme of the experimental plant:
1 – a supporting frame; 2 – a column body; 3 – a water and gas-distributing collector; 4 – studied packs in cartridges; 5 – a pressure air blower; 6 – frequency converters; 7 – an air-distributing duct; 8 – a gas flow meter indicating the speed and a volumetric flow rate; 9 – variable area flow meters; 10 – replaceable liquid distributors; 11 – a flow-through water heater; 12 – a potentiometer of adjusting the water heating; 13 – temperature sensors; 14 – microprocessor devices processing the signal of temperature sensors; 15 – moisture content sensors; 16 – differential pressure gages; 17 – liquid level indicators in the samplers; 18 – quick-detachable drain valves (necessary for experimental research of the holding capacity); 19 – a block for reading response curves for the flow structures interpretation; 20 – a mechanical measure feeder of indicator solutions; 21 – changeable electrode groups; 22 – a screen for applying calibration charts (presented in the photo); 23 – a pipe for draining water into the sewer system.
The experimental plant consists of supporting frames 1 and column bodies 2 installed on them, attached on the water and gas-distributing collectors 3. The body of column 2 performs the bearing function; changeable cartridges with packing devices are placed into it 4. The cartridge is filled with the studied packs and placed into the body of column 2. The cartridge is a transparent cylindrical or prismatic channel with the support grid. It should be noted that the column bodies 2 are quick-detachable, for replacement depending on the shape of the installed cartridge 4.

The walls of the column bodies 2 are made flat (cylindrical) and transparent, that allows to observe the work of the pack in different hydrodynamic modes without distortion and to shoot with a slow-motion camera. Packs are irrigated with liquid by means of irrigator with replaceable distributors 10, the liquid flow rate is regulated with variable area flow meters 9. The gas flow moves through the pack 4 in counter-flow through the air distribution channel 7. The gas flow rate is regulated with the gas flow meter 8 that shows the speed and volumetric flow rate. The gas flow rate is regulated with frequency converters 6, feeding a signal to the pressure air blower 5 (vortex turbocharger).

The parameters under control are: the flow rate of water supplied for irrigation, controlled with variable area flow meters 9 and heated with the flow-through water heater 11, a heat output of which is controlled with the potentiometer 12. Water temperatures are controlled using temperature sensors 13 (RT 105-Pt100.A3) at the input and output, the signal from which is processed in microprocessor-controlled units 14 (registration 2TRM0 and control TRM10), programmed over a very wide range of sensors. The temperature and humidity of the gas entering and leaving the columns are fixed using temperature sensors 13 and hygrometers (moisture content sensors) 15. The liquid resistance of the pack layer is measured using differential pressure gages 16 (liquid and electronic). The level of the liquid in the catchment and gas distribution samples 3 is controlled using level indicators 17.

The supply of liquid for irrigation of the pack and the regulation of its flow is carried out with the help of variable area flow meters 9, and its accumulation in the water containers and outflow is provided by the taps 18. The water from the water containers is drained into the sewage system through a hydraulic valve, removed easily from its tap fitting 23 that is necessary for conducting experiments to measure the holding capacity of the pack.

Registration of the flow structures in mass exchange packing devices 4 is carried out using replaceable electrode groups 21, the signal from which is processed in the microcircuit unit 19. To do this, preliminarily, indicator solutions are delivered impulsively into the liquid using a mechanical measure feeder 20 (Biohit ProLine).

3. Conclusions
The developed experimental plant allows qualitative studying heat and mass exchange contact devices in the mode of express studies with a comprehensive system for recording parameters. The applied modular principle and the cartridge system of interchangeable packing contact devices together with the developed classifying methods for processing the experimental data $\lambda=\lambda(Re,\phi)$ [26-28], allow conducting analysis in a quick and qualitative way with a large variety of contact devices (packing materials) and huge arrays of experimental data on the basis of which we can make a conclusion about the suitability of specific packing materials for a certain range of mass exchange processes or immediately conclude that this packing material is of no interest. This is particularly relevant when classifying packs in the form of industrial wastes from metalworking machines at machine-building enterprises, which we propose to use as mass exchange packing contact devices [6], which have already shown themselves well for the absorption processes of selective cleaning of gas heterogeneous systems and heat and exchange processes of evaporative cooling industrial recycled water.

It should also be noted that the presented experimental plant is available and can be easily improved for new methods of experimental studies and is particularly convenient for conducting experimental studies in the field of developing heat and mass exchange packing devices that are amenable to automated regulation of hydromechanical modes during operation and self-adjusting to the reference operating characteristics [6].
Thus, the developed experimental plant allows testing existing and newly engineered packing devices of any configurations and carrying out comparative (classificatory) analysis of the packs by means of the developed methods [26-28]. Also, the experimental plant allows to give the direction of their industrial application and to get necessary experimental data on liquid and gas flows structures through the pack layers completing developed mathematical models of the mass exchange processes [30, 31].

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