Vibro Packed Column Equipment for Mass Transfer Processes

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Abstract. Modern oil-processing industry is based on development of the real sector of economy of any state. Cardinal equipment modernization is necessary for increase in efficiency and acceleration of rates of oil processing. In this regard development of new designs of contact devices for mass-exchanged processes is the most urgent task. For her decision in this article the design of the vibronozzle mass-exchanged device for carrying out process of extraction is offered. The feature of the developed design consists in sectioning of the interdish-shaped space filled with layers of a floating pack that allows to prevent cross hashing of the interacting components in devices even of big diameter and to provide counterflow carrying out process in the conditions of vibration influences. For assessment of efficiency of the upgraded device process of crushing of a disperse phase at back and forth motion is investigated and also process of formation of a surface of contact of phases for each operating mode of the device – the vibropulsation, vibropump and vibroboiling is considered. During the researches on height of volume of interdish-shaped space of the device three pronounced zones differing in the impact on the considered liquid drop have been revealed. Also as a result of the done work expression of dependence of diameter of drops in the device is received from the geometrical sizes of mass-exchanged devices and from physical and chemical properties of phases.

1. Introduction

Within development of oil-processing industry finding solutions, the mass-exchanged processes promoting increase in intensity involving need of constant improvement of the equipment, in particular – devices of columned type is continuously conducted. In the present article the design of the vibropack mass-exchanged device for carrying out process of extraction is offered.

The idea of the pulsation influences closely correlates with the principle of discrete and pulse input and transformation of energy which main idea consists in that previously permanently entered and arbitrarily to accumulate the energy distributed in working volume (to concentrate) in locally separated discrete points of system and further pulsewise to realize for achievement of necessary physical effects [1-3]. Considerable success in a research of the main regularities and introduction of both the pulsation, and mass-exchanged device with vibrating packs in the industry is so far achieved [4-8].

Studying of regularities of crushing of drops in vibro tray extractor has revealed a number of essential shortcomings. It has turned out that with increase in intensity of vibration in the device conditions for stratification of phases disappear, excessive crushing of drops is observed. It causes, in
turn, longitudinal hashing and ablation of phases, the emulsifiability of system increases, productivity of the device decreases and comes his premature flooding [9, 10].

As a way of fight against the revealed shortcomings it was offered to partition vibro tray extractor the pack layers placed in interdish-shaped space and further researches of the vibrating extractor with a floating pack of vibro pack extractor (VPE). In this case the double effect is reached – sectioning promotes not only to reduction of longitudinal hashing and cross unevenness, but, along with formation of the developed surface of contact of phases, creates conditions for their stratifying with the subsequent redispergation and continuous updating of a surface of contact of phases.

It has turned out that under vibration depending on its intensity the pack can be in various states – either in vibrofluidised, or in a condition of vibroboiling.

It should be noted that the boiling layer and with success is applied for a long time to an intensification of various mass-exchanged processes, such, for example, as adsorption, drying, crystallization, rectification [11-13].

2. Research efficiency vibro packed column extractor

For studying of hydrodynamics of streams of liquids in a vibration extractor with a pack laboratory extraction installation which scheme is provided on has been mounted (Figure 1).

![Figure 1](https://via.placeholder.com/150)

Figure 1. Technological scheme of installation: 1 extractor, 2a and 2b pressure head capacity, 3a and 3b-reception capacities, 4a and 4b-rotameters, 5 compressor, 6 electric motor.

Installation consists of an extractor (1), pressure head (2) and reception (3) capacities, rotameters (4), the compressor (5). As the drive of all tested extractors serves the asynchronous electric motor (6). The drive provided regulation of number of the courses of the vibrating trays from 15 to 400 rpm. Amplitude of vibration changed by means of a set of replaceable cams with various sizes of eccentricity.

The easy phase came to an extraction column (1) from pressure head capacity (2a) via rotameters (4a). From the top settling zone of the device an easy phase gathered on an exit in reception capacities (3a) from where were pumped over by the compressor (5) in pressure head capacities (2a).

The heavy phase from pressure head capacity (2b) via rotameters (4b) moved in a column from it through which pack which was placed between the mesh trays (1) vibrating in the vertical plane which are rigidly fixed on a rod (2) went either to the sewerage, or to reception capacity. The rod was set in motion by means of the vibrodrive (4) (Figure 2).
As a result of the conducted researches it is established that under certain conditions, characterized by the corresponding values of live section and diameter of openings of trays, a ratio of height of a layer of a pack in steady state to diameter of the device, depending on intensity of vibrations it is possible to allocate not two, but three modes – the vibropulsation, vibropump and vibroboiling. As a result of a combination of the vibrating punched disks and a floating pack at the movement of a drop on a column it can be exposed to all scale of possible actions – to dispergating, crushing, a koalestsention [14, 15].

We will consider the principle of formation of a surface of contact of phases for each operating mode of the device – the vibropulsation, vibropump and vibroboiling, and we will establish what factors define dispersion of system in each case. At the same time it is necessary to consider the following features of VPE:

1. Placement of a pack under trays, imitating a retaining layer, creates prerequisites for stabilization of hydrodynamics in each vibrapack section. Therefore, the hydrodynamics of a vibration extractor with a floating pack can be estimated by a hydrodynamic situation in interdish-shaped space of any two trays, and results of researches are postponed for all device in general.

2. On height of volume of interdish-shaped space existence in the most general case of three pronounced zones differing in the impact on this drop is found: I – a zone of the granular environment, II – a zone of turbulent mixture, III – a zone of the jet expiration (figure 2)

3. Formation of various hydrodynamic situation within one cycle of fluctuations.

Vibropulsation mode. Existence of a retaining layer is characteristic of this mode. At the same time, if for stationary mesh extractors the beginning of teardrop is connected with a certain height of a retaining layer (h), in vibration devices of a drop begin to be formed irrespective of size h, at once after the message to trays of back and forth motion [16-20]. The disperse phase is pressed through openings of trays and it is dispersed. Visual observations have shown that at small speeds of vibration there is an education of ensemble of drops, and thus only at the time of the course of tray down. At the movement of trays up the drops which have come off a tray rise before contact with a pack layer where they coalesce and in space between elements of a pack the continuous layer of a disperse phase is formed.

At increase in intensity of vibrations the dispersed phase begins to follow in the form of the streams which are breaking up at some distance from exhaust outlets to separate drops.

Thus, in VPE in the studied mode two essentially various mechanisms of formation of drops – drop and jet are observed. And in the drop mode of the expiration in interdish-shaped space only two zones – the zone of turbulent mixture (zone II) filled with drops and a zone of the granular environment (zone I) with a retaining layer of a disperse phase h height are formed.
Existence of all three zones is characteristic of the jet expiration of a disperse phase. At the same time it is possible to assume that in the III zone there is neither koalestsentation, nor crushing of drops, and only formation of streams of a disperse phase to the subsequent their disintegration.

Vibropump mode. Zone I specifically influences drops of a disperse phase. At the time of the course of trays the top layer of a pack takes the drops which are in this zone and forces out them from above a layer which thus is kind of the "pump" transporting through itself a disperse phase. As a result of influence of the additional forces arising at the expense of pressure difference on layer borders process of a koalestsentation of drops accelerates. It is visually established that in this case there is an uneven local separation of drops from the top layer of a pack and formation of a retaining layer which thickness h can be not identical on the cross section of a column, and it is in certain cases equal to zero. At the course of trays down through their openings it is pressed through both a disperse phase in the form of single streams, and a continuous phase. That is, besides I zone in the studied mode there are II and III zones. In the third zone, along with dispersating process if to proceed from the model of crushing offered in work [21, 22] there has to be also a crushing of drops streams of a continuous phase. At the same time both small, and large drops depending on whether the drop which has left an opening of the vibrating tray, directly in a stream or in a zone between two next streams has got can be formed.

In this case in the II zone conditions for implementation of additional crushing of large drops, now according to Kolmogorov-Obukhova's theory are created. According to this theory crushing will be observed if the intensity of turbulence of a continuous phase is sufficient in order that the scale of whirlwinds has exceeded turbulence scale.

Rather interdrop koalestsentation in a stream of a continuous phase of the second zone can notice that in this mode of value of the holding ability are commensurable with delay size for the vibropulsation mode. Therefore the conclusions drawn in the analysis of the movement of drops in the mode of vibropulsations can be extended also to the considered mode.

Thus, in the specified mode degree of dispersion has to be defined generally by processes of dispersating and crushing both in II, and in the III zones, and the surface of phase contact, considering the conclusions drawn for a research of the vibropulsation mode, only a total surface of the drops which are in all three zones.

The vibroboiling mode. In this mode pack elements continuously move, the porosity of a layer is high. Some drops, getting to I zone, can be split up, hitting against elements of the lower layer. But the most part of these drops, having entered this zone and having faced pack elements, thanks to preferable wettability of material of a disperse phase coalesces with her, forming a film. Further the koalestsentation occurs already on a surface of this film. The last continuously leaves by a local separation of drops. Besides, strengthening of an interdrop koalestsentation is promoted by movement of elements as in this case there is a continuous change of distance between them, ways the traffic of drops are blocked off, their speed decreases, the possibility of collision in the subsequent a koalestsentation amplifies. The future of the drops which have left the first zone depends on a ratio of the sizes and diameter of openings of the punched vibrating trays of $d_0$.

3. Research of crushing of drops at the expiration through openings of vibration tray

When studying the movement of drops through the stationary punched trays it has been established that at the relation of diameter of openings to diameter of a drop $d_i/d_h$ more than 0,8, drops which don't moisten a tray surface pass through her without essential change in diameter. At $d_i/d_h < 0.4$ drops don't pass through openings, and gather under a tray. In case of $0.4 < d_i/d_h < 0.8$ drops can change in sizes and pass through openings if only kinetic energy of drops is higher than the energy which is required for their deformation.

In VPE, unlike the specified case, drops at any ratios of $d_i/d_h$ will pass through openings of trays. But, also as well as for stationary trays, they, depending on this ratio, or won't be exposed to deformation and to pass through openings of trays without change when $d_0 > 0.8d_h$, or are deformed with the subsequent their dispersating by edges of openings and change of diameter at $d_i < 0.8d_h$.272
Having passed through openings of the punched disks, the drop gets to the III zone (in this mode it is also a zone of the jet expiration, but now a continuous phase) and further to the second zone – a zone of turbulent mixture of a continuous phase. The analysis of a hydrodynamic situation in VPE shows that impact of these zones on a particle of a disperse phase is similar to the impact made on a drop in EVT in the emulsion mode.

As the vibroextractor is an extractor of jet type and its interdish-shaped space has three zones with various intensity of hashing, it is natural to assume, as for VPE the gradient model of crushing is fair. According to this model crushing happens generally in jet, i.e. in the III zone.

Except effect of crushing in the studied mode there can be also an interdrop koalescence in the II zone if the constraint degree connected with growth of the holding ability raises and, as a result, the probability of collision of drops and their integration increases.

Thus, the carried-out analysis shows that in the vibroboiling mode in interdish-shaped space of VPE processes of crushing of drops in the first zone, a interdrop koalescence both on a pack, and in a zone of turbulent mixing at the same time coexist. The set of influence of the specified factors, apparently, will also determine the final size of drops.

The surface of contact of phases in this mode consists of a total surface of drops in I and II zones and a surface of the pack moistened with a disperse phase.

Visual observations have shown that in VPE in the vibroboiling mode when the pack is well moistened with a disperse phase, last sticks to a pack, envelops her on a surface and gradually sates. After the saturation moment the disperse phase begins drop-shaped or streams (depending on an expense) to separate from a pack surface.

For receiving a better understanding about processes of teardrop or crushing it is necessary to have data on regularities of change of the size of drops depending on process parameters. When studying influence on diameter of drops \(d_{\text{no}}\) of such parameters as live section \(\varepsilon_{t}\) and diameter of openings \(d_0\) of the vibrating trays has been established (figure 3) that higher values of the average size of drops were observed in case of great values \(\varepsilon_{t}\) and \(d_0\). And the dependence of \(d_{\text{no}}\) on live section has almost linear character, i.e.:

\[
d_{\text{no}} = A_{\varepsilon} \cdot \varepsilon_{t}
\]

\[
d_{\text{no}} = A_{\varepsilon} \cdot d_0^{0.5}
\]

\(\varepsilon_{t} = 0.15; \quad d_0 = 0.006\)

At creation of a curve of \(d_{\text{no}} = f(d_0)\) in logarithmic coordinates of a point laid down on a straight line which tangent of angle made \(\tan \alpha = 0.5\). Therefore, the dependence of the average size of drops on diameter of openings of trays can be expressed in the following look:
The reason of reduction of the size of drops at decrease $\varepsilon_t$ and $d_0$ according to gradient model of crushing consists in the following: speed of a stream ($W_0$) in a tray opening, as we know, is function $\varepsilon_t$ and with reduction $\varepsilon_t$ increases according to dependence:

$$\frac{dw}{dy} = \frac{\varepsilon_t}{b} - \frac{I}{d_0 \varepsilon_t} \tag{3}$$

Reduction $\varepsilon_t$ and $d_0$ has to cause increase of a gradient of speed of a stream of $dw/dy$ in section, perpendicular stream axes, and, respectively, dispersion degree, as is confirmed by an experiment.

Comparison of the regularities of change received in the real work $d_{no}$ dependences from $\varepsilon_t$ and $d_0$ with the turbulent pulsations established on the basis of the theory of crushing shows that influence of live section on $d_{no}$ in both cases is similar ($d_{no} \sim \varepsilon^{0.8}$). As for dependence of $d_{no}$ from $d_0$ according to this equation, the average diameter of drops has to decrease with increase in $d_0$ ($d_{no} \sim d_0^{-0.4}$), that is in an obvious contradiction with our data.

Proceeding from the above, it is possible to conclude that from the point of view of influence of design data of trays on $d_{no}$ most truly reflects the mechanism of crushing of drops in a vibropack extractor gradient model.

4. Conclusion

The analysis of regularities of crushing of drops in a vibropack extractor as a result of which is carried out it is established that existence of three pronounced zones – zones of the jet expiration, turbulent mixing and a zone of the sulphurous environment which impact on a drop variously is characteristic of interdish-shaped space of this device. Influence of various factors on dispersion degree in VPE is studied. In particular, it is established that crushing of drops happens on the basis of the gradient theory of crushing.

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