

DEVELOPMENT OF NEW TYPE OF GAS ABSORBER, INDUSTRIAL APPLICATIONS

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The performance of a new type of gas absorber was investigated. Laboratory absorption experiments on different absorption systems such as ethyl–thiol, acetone–water, ethanol–water, methylene chloride–festo oil and H₂S–NaOH were carried out under reduced air pressure. The absorption rate was investigated as a function of geometrical parameters and construction materials. The possibility of installing more than one gas absorber on the same absorption tank was investigated as well. It has been applied successfully in industry. In general, this unit improves the performance of existing absorption columns by absorbing 25–30% of the released gases or vapors, and this value may be higher in the case of chemisorption, which leads to higher environmental protection. Moreover, a ‘jet absorber’ has a simple structure, small size with low investment and operation costs; it is suggested that it is used to cope with any sudden increase of gas or vapor emission.

Keywords: gas absorption; jet absorbers; injection absorbers; Venturi scrubbers.

INTRODUCTION

Gas absorption columns are designed to meet special and defined absorption requirements. For a defined absorption process the operation conditions and the geometrical parameters are given and fixed. In industry where the improvement of the different processes is on-going, the risk of an abrupt change in the amount of the gases released from reactors is significant. The existing, installed, absorption columns are not flexible to such severe conditions; consequently, they will not be able to completely absorb the released gases, which leads to an increase in environmental pollution. In such cases there is an urgent need to solve such problems both technically and economically.

The traditional solution is to build another absorption column in series, or to replace the existing column with larger one. It is quite hard to accept such solutions, not because they are very expensive, but because in general there is no place or space to do so beside the existing absorbers. A practical solution is to install a jet absorber, which is small in size and inexpensive, beside the existing packed or tray column. It is clear that the released amounts of vapors or gases dictate the type of absorber needed. There are cases where the jet absorber is not the practical solution and adding another absorption column is the right decision.

This work was motivated by the need to stop immediately the emission of hydrogen sulfide gas and mercaptane vapors from existing absorption columns, which could not cope with the abrupt increase of released vapors. The jet absorber was developed to treat such cases (Figure 1). Similar gas absorption problems occur frequently in most fine chemical plants.

Treybal (1990) presented a general description of a Venturi scrubber, which has been successfully used for gas absorption in batch processes. Developed forms of Venturi scrubber, known as injection absorbers, are widespread in the pharmaceutical industry. Mustafa (2001) carried out absorption experiments on jet absorbers. Bekassy-Molnar *et al.* (1997) modeled the absorption mass transfer in a similar absorber, using oxygen absorption into water.

METHODS AND MATERIALS

Description of Jet Absorber

The jet absorber consists of two concentric pipes where the gas flows in the annular space between the two pipes, while the liquid flows in the inner one. When the liquid is sprayed out through narrow gaps (1 mm) in the form of a liquid jet, it produces close contact with the flowing gas (Figure 1). The jet absorber used is shown in Figure 1 while its geometrical and construction materials are shown in Table 1. The main characteristics of a jet absorber are:

- (1) any type of circulating pumps can be used without need for a special pump that produces high pressure, which is essential to the Venturi scrubber;
- (2) the gas–liquid flow can be directed in co-current or counter current, while the traditional Venturi scrubber operates with co-currents;
- (3) the jet absorber can be built easily and directly in line before the vacuum pumps to achieve recovery of the solvent;
- (4) the form and the shape of the nozzle of Venturi scrubber are dissimilar to those of the jet absorber;

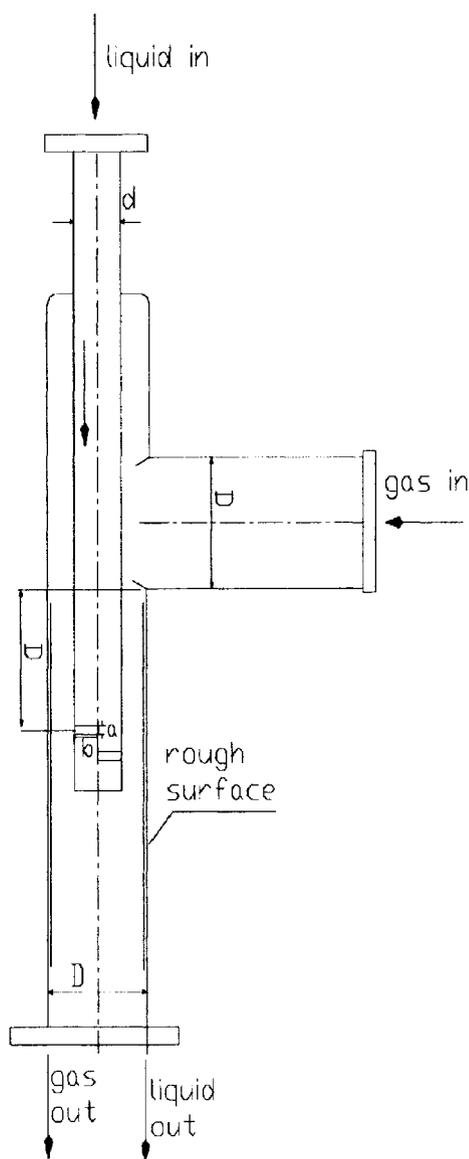


Figure 1. New type of jet absorber.

- (5) it is possible to install more than one jet absorber at once on the same absorption tank.

Experiments

Experimental set-up

The absorption experiments were carried out first by using a laboratory simulation (Raschig packed) column

Table 2. The geometrical parameters and operation conditions of the simulation Raschig-packed column.

| | | | |
|--|-------|--|-------------------------|
| Height of packing (m) | 0.60 | Dimensions of packing (mm) | $10 \times 10 \times 2$ |
| Diameter of column (m) | 0.08 | Air flow rate ($\text{m}^3 \text{h}^{-1}$) | 1.9 |
| Cross section of column (m^2) | 0.005 | Circulating liquid flowrate ($\text{m}^3 \text{m}^{-2} \text{h}^{-1}$) | 4.9 |

(Mustafa, 2001) and then by using the jet absorber under the same conditions. The geometrical and operating conditions of the Raschig absorber are given in Table 2. A Raschig-packed column was used in this work for quantitative comparison purposes.

Chemisorption experiments were carried out on H_2S – NaOH and ethyl-thiol– NaOCl systems, while physical absorption experiments were carried out using mainly ethanol–air–water and acetone–air–water systems. An acetone vapor–air–water system was used by Mustafa (Mustafa, 2001; Mustafa and Bekassy-Molnar, 1995; Mustafa *et al.*, 1999) to study the performance of different types of trays and by Marki *et al.* (2001) in a packed column.

Methylene chloride–festo oil and methylene chloride–cooking oil systems were also used to test the performance of the jet absorber.

Absorption and chemisorption experiments

The absorption experiments were carried out under constant pressure (0.34, 0.74 bar). The inlet solvent vapor concentration was controlled by airflow rate ($G = 0.140$ – $0.800 \text{m}^3 \text{h}^{-1}$).

The absorption experimental apparatus is shown in Figure 2. The gas flow rate (G) was controlled and measured by gas rotameter (1) and directed towards the flask of solvent (2) under the effect of the vacuum pump. The solvent consumed in the absorption process was measured as a function of time by using a digital balance (3). The air–solvent–vapor was sucked by vacuum pump towards the absorber (4), which fitted in the vessel (7). It contained 1 l of tap water. The water was circulated to the jet absorber by using a circulating pump (5). The inlet and outlet solvent vapor concentrations were measured by means of FID analyzer (6), and liquid concentrations were determined by gas chromatography. The value of the vacuum was measured by mercury pressure gage (8).

The same apparatus was applied to carry out the chemisorption experiments. The required H_2S gas concentration was prepared by mixing known flow rates of H_2S with air.

Table 1. Geometrical and construction data of jet absorber (see Figure 1).

| | External tube diameter, D (mm) | Internal tube diameter, d (mm) | Gap dimensions ($L \times W$) in mm or number of holes and construction material of internal tubes | Construction material of external tube |
|---|----------------------------------|----------------------------------|--|--|
| 1 | 16 | 8 | 40 holes, Teflon | Glass |
| 2 | 12 | 8 | 80 holes, Teflon | Smooth steel |
| 3 | 16 | 8 | $2(0.6 \times 8)$, steel | Glass |
| 4 | 12 | 8 | $2(0.6 \times 8)$, steel | Smooth steel |
| 5 | 12 | 8 | $2(0.6 \times 8)$, steel | Rough internal surface, steel |
| 6 | 12 | 8 | $2(0.6 \times 8)$, steel | Threaded internal surface, steel |

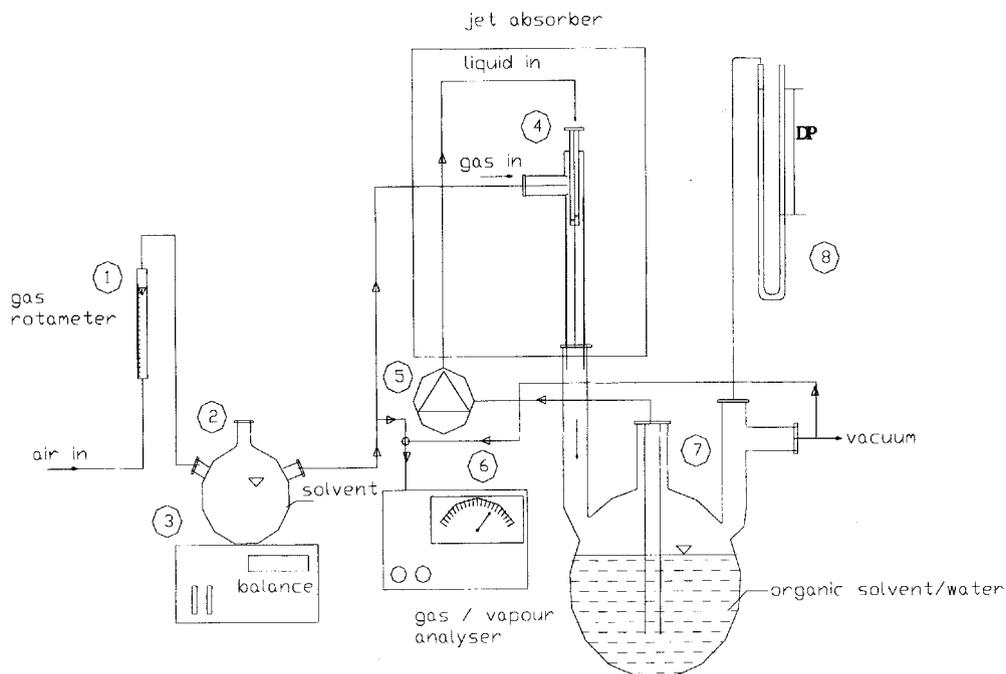


Figure 2. Experimental apparatus: gas absorption by using jet absorber.

The absorbent was 1 N NaOH solution. The outlet concentration of H_2S was measured by Auer Mini H_2S gas analyzer, which was equipped with an alarm at 10 ppm concentration, because at this level the H_2S gas becomes seriously harmful to human health.

Other absorption systems used were: as ethyl-thiol; acetone-water; and methylene chloride-festo oil. The same experiments were carried out when gas and liquid flows were directed as counter-currents. The connection technique is shown in Figure 3. A puffer vessel was

used for collecting the liquid which was sucked by the vacuum.

Measuring Absorption Equilibrium Data

The inlet concentration of ethanol vapor in the gas phase was kept constant by allowing a measured quantity of air (G) to enter the system through a gas flowmeter (Figure 2). The measurement of absorption equilibrium

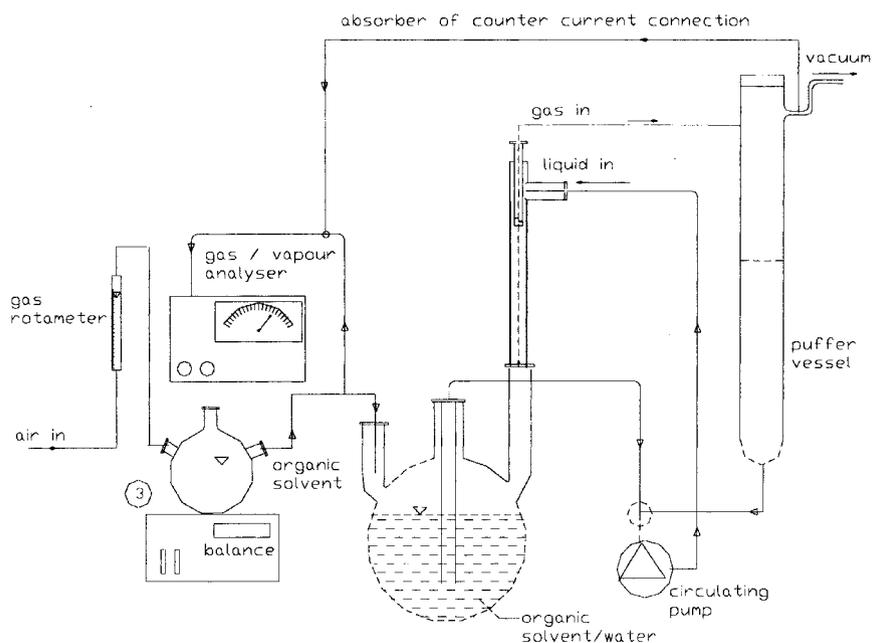


Figure 3. Experimental apparatus: gas absorption with counter currents.

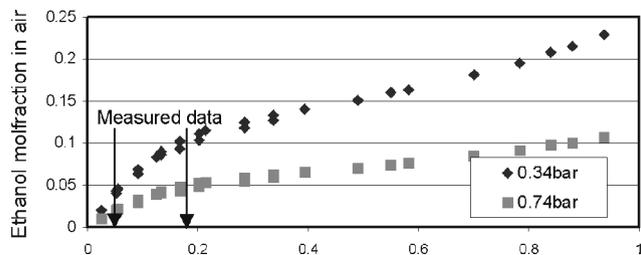


Figure 4. Ethanol–water vapor absorption data, based on vapor–liquid equilibrium ‘VLE’ data.

data occurred at constant pressure (0.34, 0.74 bar) and at constant temperature (25°C). The pressure was kept constant by fixing the value of airflow rate (G) entering the system through gas manometer. The absorption process continued under these defined conditions, until the ethanol concentration in the liquid phase became constant (reached the equilibrium value). The measured and calculated absorption data values are presented in Figure 4.

RESULTS AND ANALYSIS

For the experimental conditions described above, the measured parameter in the case of physical absorption is the change of the concentration of organic solvent in liquid phase during a limited period of time. In the different set-up of physical absorption experiments, the time necessary to attain the liquid equilibrium concentration at any fixed gas phase concentration was measured. This is a direct method for comparing the output of different absorption experiments. This method is preferable, especially in the case of the batch process, where the inlet liquid concentration of jet absorber varies continuously, and there is no way to express directly the performance of jet absorber in theoretical stages. A Raschig packed column was used in this work for quantitative comparison purposes.

Some absorption data of ethanol–water system (Gmehling *et al.*, 1971) at 25°C (and 0.34, 0.74 bar) was calculated from its distillation equilibrium data at the same temperature. The calculated absorption data are shown in Figure 4, while the calculation method is presented in Appendix A. The measured equilibrium points lie at the beginning of the equilibrium curve.

It was found that both the jet absorber and the Raschig-packed column attained equilibrium concentration at nearly the same time under the same operational conditions. These results were helpful to benchmark the absorption behavior of the jet absorber. It is important to mention here that the Raschig-packed column was tested separately under steady-state conditions using an air–acetone vapor–water system. The absorption results showed that the tested Raschig column was equivalent to two theoretical stages.

Determination of optimum external tube diameter (D)

The absorption rate was measured with different external tube diameters ($D = 12, 16$ and 20 mm) and with constant internal tube diameter ($d = 8$ mm). At co-current measurements the best results obtained when $D/d = 1.5$, or

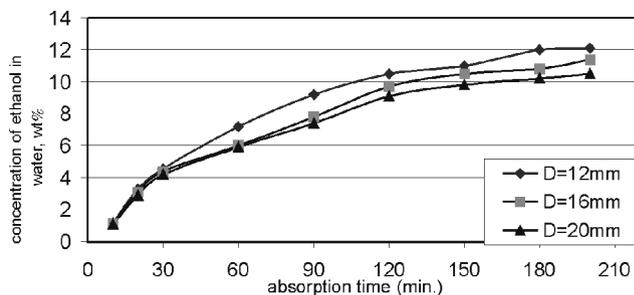


Figure 5. The effect of tube diameter on the absorption rate. Construction material, glass; pressure, 0.74 bar; liquid flowrate, 15 h^{-1} .

$D = 12$ mm, while at counter current measurements it was found that the ratio between external tube diameter and internal tube diameter should be higher than 2 ($D/d > 2$). From Figure 5, the highest absorption rate was obtained when the diameter of external tube $D = 12$ mm ($D/d = 1.5$).

Selection of construction material of jet absorber

Experiments on jet absorbers made from different materials (glass, Teflon and steel) were carried out. The tubes with smooth internal surfaces produced lower absorption rates than those with rough surfaces. Higher absorption rates were obtained (Figure 6), when the internal area of the external tube was scratched. The highest absorption rate was obtained when the internal area of external tube was threaded with a thread milling machine. In this case the absorption rate values were about 8–20% higher than that of smooth surfaces.

Configurations of jet absorbers

The jet absorber could be installed alone, or beside another jet absorber or beside an absorption column. Laboratory experiments were carried out in all of these cases. In the case of installing one jet absorber (glass, $P = 0.74$ bar see Figures 2, 5 and 6), the liquid phase reached the equilibrium concentration (12 wt%) after three hours of absorption time.

In the case of installing one jet absorber with counter current flow (see Figures 3 and 7), the absorption rate was improved by about 10–25% and the absorption time was reduced to 2 h. The disadvantage of applying a counter current layout is the difficulty of adjusting to stable operation conditions.

Experiments were carried out in the case of installing two jet absorbers on the same equipment; the gas and liquid flow was co-current at both of them. The connection of the jet absorbers was in parallel and not in series. The absorption rate was improved by about 25–35% compared with that of one jet absorber (Figure 8), while the absorption time was reduced to 2 h.

The results of chemisorption of H_2S and air in 1 N NaOH solution are shown in Table 3. The experiments were carried out on both on a jet absorber and on a Raschig absorber under the same absorption conditions. The performance of the two absorbers was similar.

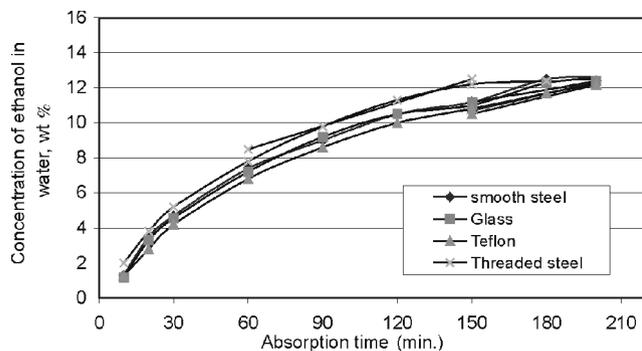


Figure 6. The effect of construction material on absorption rate. Pressure, 0.74 bar; $G=0.28\text{ m}^3\text{ h}^{-1}$; liquid flowrate, 151 h^{-1} .

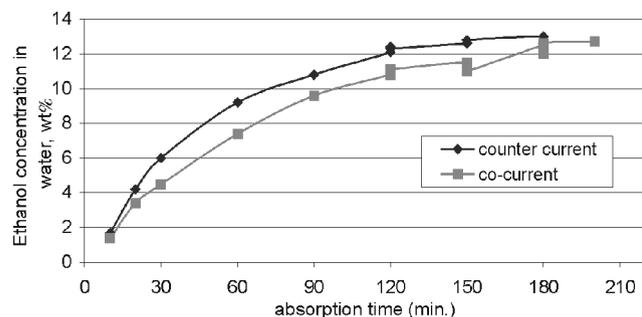


Figure 7. Comparison the performance of jet absorbers operating under co-current and counter current flows having same conditions. $G=0.58\text{ m}^3\text{ h}^{-1}$; liquid flowrate, 151 h^{-1} .

INDUSTRIAL APPLICATIONS

Absorption measurements of methylene chloride in festo oil and cooking oil were also carried out. The absorption curves obtained had the same tendency as those ethanol–water and acetone–water, therefore the detailed experimental data are not presented in this paper.

The aim of this work was to solve actual industrial problems, so the scaling up of the jet absorber was carried out, and has been applied successfully in industry. The diameter of outer tube was about 5 inches ($D=128.2\text{ mm}$),

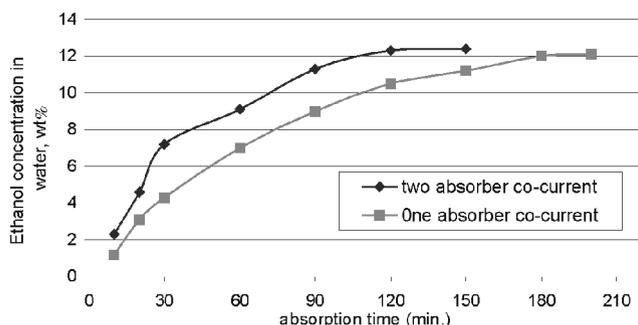


Figure 8. Comparison the performance of one jet absorber with that of two jet absorbers fitted in the same absorption tank. Pressure, 0.74 bar; liquid flowrate, 151 h^{-1} .

while the diameter of the inner one was about 3 inches ($d=77.9\text{ mm}$). The ratio of D/d was not far from the suggested values obtained in laboratory.

The jet absorber was installed beside different types of packed columns. The industrial applications of jet absorber were achieved in the systems: $\text{H}_2\text{S}-\text{NaOH}$; CH_2Cl_2 -oil; and ethyl-thiol- NaOCl .

The installation for absorption of ethyl-thiol in NaOCl is shown in Figure 9. This figure illustrates exactly where to fit the jet absorber. The jet absorber with counter current flow still requires more testing and developing before use on an industrial scale.

DISCUSSION AND CONCLUSIONS

It is important to use a well defined absorption apparatus for quantitative comparison purposes. A simulation packed column was used to achieve this goal. Absorption experiments were carried out on this column under steady-state conditions using an acetone vapor–air–water system to give two theoretical stages. The comparison of H_2S absorption results between a simulation-packed column and jet absorber are given in Table 3. Both of the two absorption systems achieved nearly the same absorption results. Physical absorption experiments were carried out on both of the two absorption units. The obtained absorption curves had the same tendency, with about 0–8% in favour of the simulation packed column.

This result is important, because the measured performance of simulation packed column is equivalent to two theoretical stages. In general most of absorption columns used for environmental purposes have about 4–6 theoretical stages. Thus, the performance of such a typical absorption column is improved by 25–30% using a jet absorber.

Selection of Geometrical Parameters and Construction Materials of Jet Absorbers

In the case of co-current flow, the ratio of jet absorber external tube diameter (D) to its internal tube diameter (d) should be selected not more than 1.5 ($D/d=1.5$). The annular space between the two pipes should be optimal for producing the proper degree of mixing or turbulence, so the absorber behaves as an ideal single stage. For further optimization of this parameter more experiments and analysis are needed to find a way to express the turbulence quantitatively with Reynold's number, bearing in mind that the velocity of liquid jet in the annular space is not constant.

This ratio should be higher ($D/d > 2$) in the case of counter current flow to hinder and stop the entrainment of liquid droplets with the sucked air stream. The purpose of using puffer vessel in Figure 3 is for settling and collecting the entrained droplets of liquid. The measured absorption points on the different curves significantly maintained their increasing tendency in spite of the closeness of these curves to each other (within 12%). The counter current flow system may have an optimistic future, but it still needs more study and optimization.

Experiments on jet absorber made of different materials (glass, Teflon and steel) were carried out. The selection of glass material makes it easy to observe what is going on inside the absorber. The tubes with smooth internal surfaces hinder the scattering of water jets and the liquid flows down

Table 3. Chemisorption of H₂S in jet absorber and in Raschig ring absorber.

| No. of experiments | NaOH absorbent flowrate (lh ⁻¹) | Flowrate of H ₂ S and air (lh ⁻¹) | Inlet concentration of H ₂ S in air (vol%) | Outlet concentration of H ₂ S in air (ppm) | |
|--------------------|---|--|---|---|------------------|
| | | | | Jet absorber | Raschig absorber |
| 1 | 15 | 1300 | 4.6 | 0-2 | 1 |
| 2 | 30 | 1300 | 10.8 | 1-2 | 2 |
| 3 | 15 | 1300 | 10.8 | 2 | 2 |
| 4 | 15 | 1000 | 11.5 | 2 | 2 |
| 5 | 10 | 1000 | 10.0 | 2 | 2 |

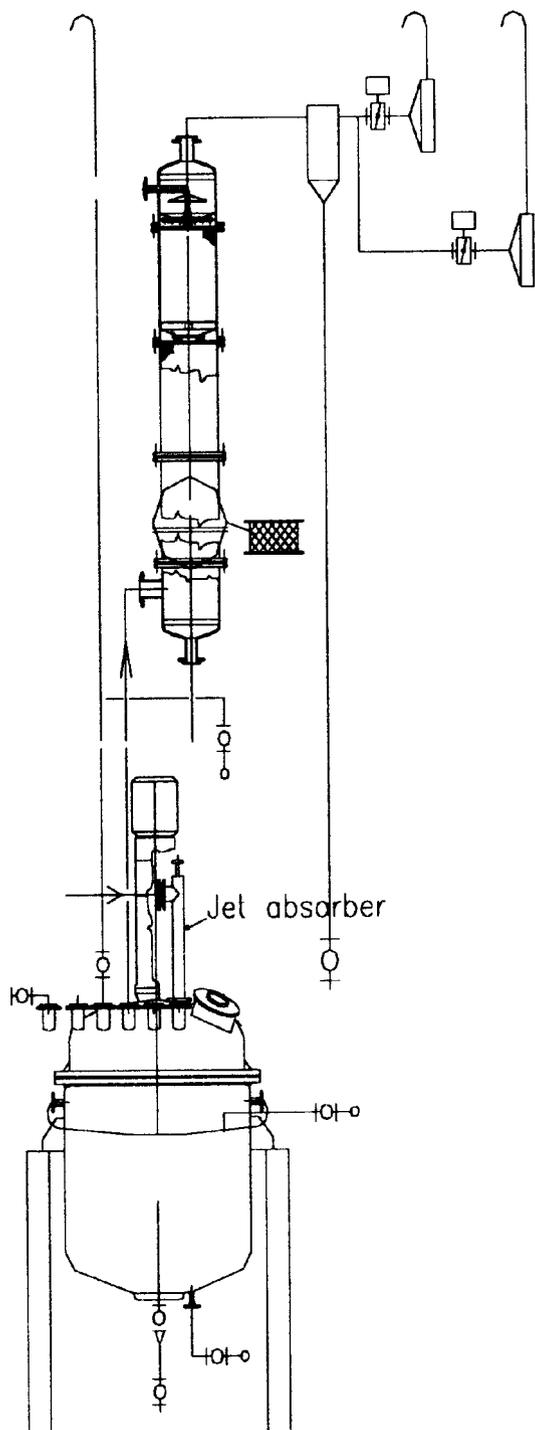


Figure 9. Industrial application of jet absorber placed beside the existing packed column. Absorption of ethyl thiol in alkaline solution.

without intensive contact with the gas; this leads to a lower absorption rate. Higher absorption rates were obtained (Figure 6) when the internal area of external tube was scratched. The highest absorption rate was obtained, when the internal surface of the external tube was threaded with a thread milling machine. In this case the absorption rate values are about 15% higher than those of smooth surfaces.

The possibility of using more than one jet absorber on the same absorption tank increases the safety of the absorption process and makes it more flexible for operation and to meet unexpected risks.

The standard deviation of analyzing the same sample was 3–4.5% while the standard deviation of reproduction of measurements was 4–7%.

Finally, the jet absorber represents a cheap and safe alternative to protect our environment from any sudden changes in absorption process. It can be used as a separate absorption unit on vacuum pipes, or as an assisting absorption unit in an absorption system. The scaling up of the jet absorber was carried out easily, and has been applied successfully in industry. It may improve the performance of an existing absorption column by 25–30%, and in the case of chemisorption higher improvement of the column performance was achieved.

APPENDIX A

Calculation of Ethanol Vapor–air–Water Absorption Equilibrium Data

It is known that, in the case of distillation of ethanol–Water mixture at any absolute pressure, the vapor phase comprises ethanol and water vapors, but in the case of the absorption process the vapor phase is diluted with air. This leads to change in the value of P , absolute pressure, and consequently in the value of molfraction of ethanol in gas phase ($Y_{\text{absorption}}$). The ethanol–water equilibrium data is given in Gmehling *et al.*'s (1971) VLE data collection.

Example

Take equilibrium distillation point (Gmehling *et al.*, 1971) at 25°C, where the ethanol mole fraction in the ethanol–water mixture (X_1) = 0.055, and its mole fraction in vapor phase ($Y_{\text{distillation}}$) = 0.323, and absolute pressure $P = 0.044$ bar (33.33 torr). When the absolute pressure is raised with air (which is inert from an absorption point of view) to $P = 0.74$ bar, the ethanol vapor pressure will remain constant, while ethanol mole fraction in gas phase will change. Using Dalton's law, $P_{\text{alcohol}} = P * Y_{\text{distillation}}$. Substitution of the proper values in this equation gives $P_{\text{alcohol}} = 0.044 \text{ bar} * 0.323 = 0.0142 \text{ bar}$; this is the value of partial pressure of ethanol vapor. $P_{\text{alcohol}} = P * Y_{\text{absorption}}$.

since $P = 0.74 \text{ bar}$ and $P_{\text{alcohol}} = 0.0142 \text{ bar}$, thus $Y_{\text{absorption}} = 0.0192$. This value is a mole fraction of ethanol in the gas phase.

The measured points are fitted well at the beginning of equilibrium curve in Figure 4.

NOMENCLATURE

| | |
|---------------------------|---|
| d | diameter of internal tube of jet absorber, Figure 1 |
| D | diameter of external tube of jet absorber, Figure 1 |
| G | air flowrate, m^3h^{-1} |
| L | Length of the gap of jet absorber, see Figure 1 and Table 2 |
| P | absolute pressure, bar |
| P_{alcohol} | partial pressure of ethanol vapor in gas phase, bar |
| W | width of the gap of jet absorber, see Figure 1 and Table 2 |
| X | mole fraction of ethanol in water |
| $Y_{\text{absorption}}$ | mole fraction of ethanol vapor in gas phase |
| $Y_{\text{distillation}}$ | mole fraction of ethanol vapor in vapor phase |

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