NEW HIGHSPEED MASS-TRANSFER TRAYS

Prof. Dr.-Ing. habil. Dr.h.c. Klaus Hartmann

GESIP - Information and Process Technologies, Technical University Berlin

ABSTRACT

The mass-transfer trays *HighspeedTray*, *HighFlexiTray* and *SieveTray* belong to a new generation of mass transfer trays that enable increase the capacity-efficiency profile and the flexibility of tray columns significantly. This increase is achieved by a special vapor and liquid distribution and contact systems installed on these trays and a combination of two different tray designs. These trays cover gas/vapor load factors F up to 12 $Pa^{0.5}$ and turndowns up to 1:20. They offer a miniaturization of columns, which results in significant savings of equipment costs. The trays can be used for new mass transfer equipment as well as for revamp of existing columns.

INTRODUCTION

Some fundamentally new designs in column internals have been developed and introduced during the last years. These new internals offer a dramatic gain in efficiency and capacity for separation columns. These internals are characterized by optimal capacity-efficiency profiles, improved operation properties and low costs. Bravo [1] wrote recently about this development „the 1990s are the decade of high performance tray".

Especially fractionation trays have a large potential for significant improvements, using new principles for the organization of the contact between the phases on the trays which allow to increase the process intensity and efficiency.

Another direction for increasing the capacity-efficiency profiles of mass transfer columns is to combine new tray constructions with conventional ones in such a way that the new design gains the benefits of both trays and the new internals possess the best properties of the highspeed tray as well as the good properties of the conventional trays.

In this paper are presented new tray designs and tray combinations. One design, the HighspeedTray, is characterized by special contact and separating elements (CSE) on the trays. In the inner of these CSE mass- and heat transfer take place in cocurrent flow. The combination of highspeed trays with valve trays offer a new mass transfer column design the new HighFlexiTray with a very high flexibility (turndown).

Another way of increasing the capacity-efficiency profile of conventional fractionation trays consists in enlarging the mass transfer surface area and its permanent renewal.

The SieveTray represents a conventional sieve tray with a special froth stabilizer which allows to increase the capacity of sieve columns up to twofold.

THE HIGHSPEED MASS-TRANSFER TRAY

The high-speed mass transfer tray [2-5] (Fig. 1) is a tray with weir and downcomer. It is equipped with contact and separating elements fixed into the opening of the tray plate. The CSE consists of a vertical cylinder with an annular row of holes in its lower section. The axial swirler, which is firmly attached to the inside of the cylinder has inclined vanes in the upper section and is provided with a net of ribs arranged straightly along the nozzle axis at the lower section. The mass exchange zone is directly above the swirler. The cyclone separator with the concentric annular slot separates the liquid from the gas/vapor phase. Deflection rings have to prevent the short-circuit of the liquid after the mass transfer.

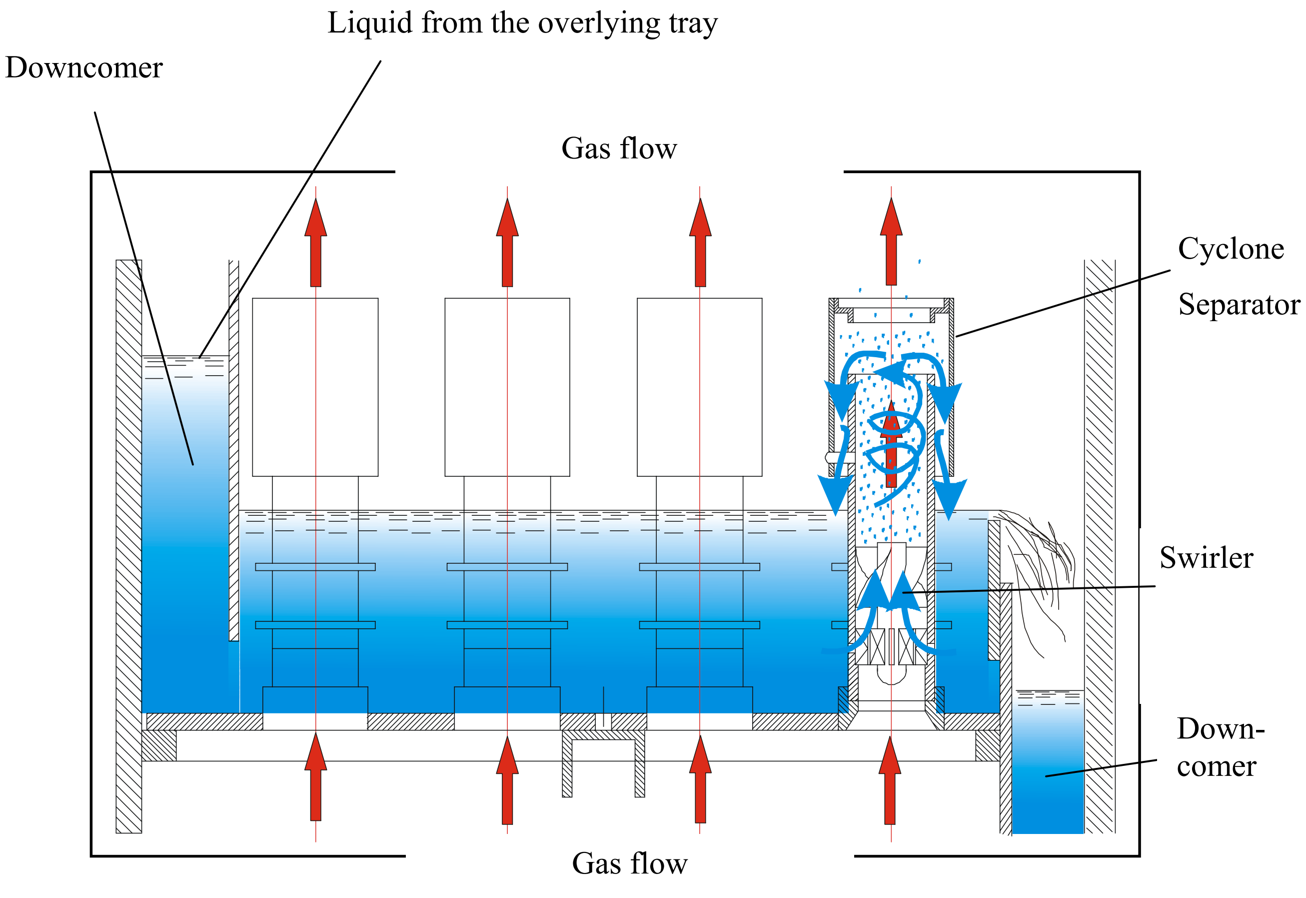

Fig 1: HighspeedTray with contact and separating elements

The liquid entering through the annular row of holes in the grid zone of the vertical blades is dispersed into small droplets. To maintain a continuous flow of liquid through the annular row of holes, a constant liquid level has to be present on the tray plate. The liquid droplets move in axial direction together with the gas within the CSE, flow towards the top until the two phases reach the blades of the axial swirler. The liquid-gas flow is subject to a rotary motion when passing through this zone whereby part of the drops are flung at the inside wall of the CSE. This creates a rotating liquid film, which moves upward due to the frictional forces of the gas flow. The final separation of the liquid drops and the liquid film from the gas flow takes place in the separation zone.

The separated gas exits the separator via a deflection ring, which prevents entrainment of the liquid. The separated liquid flows through a concentric annular ring slot on the tray.

The high flow velocities in the CSE guarantee an intensive atomization of the liquid and, thus, a high intensity of mass transfer and a good phase separation in the turbulently swirled flow.

The most important performance features of the columns with this highspeed tray are

- Increase of the volume-specific efficiency of mass transfer equipment of up to 1.2 to 5 times due to a 1.5 to 2-fold increase of the gas-liquid interfacial area of the tray.
- Realization of 1.5 to 2 theoretical trays for each meter of column height, while maintaining a tray spacing of 400 to 500 mm.
- High level of flexibility concerning a higher solid content for the gas-liquid mixtures to be separated
- Realization of highly compact, multifunctional mass transfer columns, especially for the high-pressure dehydration and separation of gases.
- Indifference to deviations from the horizontal (unlevelness) during column operation, a factor especially important for offshore facilities.
- Maximum liquid load of up to 100 m^3/m^2 h, the result of the foam suppressing characteristic of the CSE elements (no foaming, clear, vapor –free liquid in the downcomer)
- A miniaturization of the columns leads to considerable equip- ment savings with special advantages for offshore facilities (reduction of as much as one-fifth of the column mass compa-red with traditional constructions).
- This tray can be used to revamp existing columns as well as in combination with other mass transfer equipment.

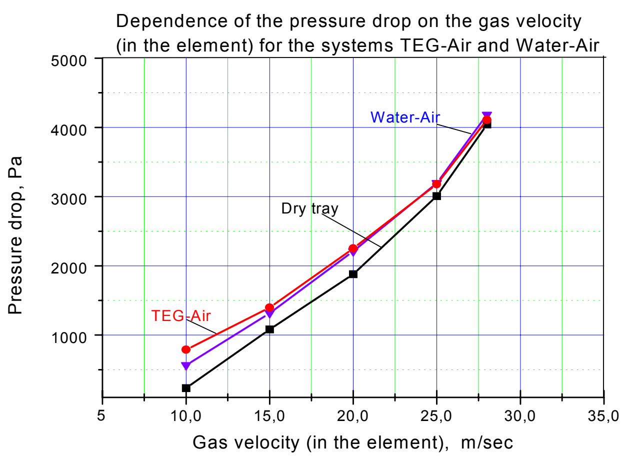

Fig. 2: Pressure Drop for the high-speed tray

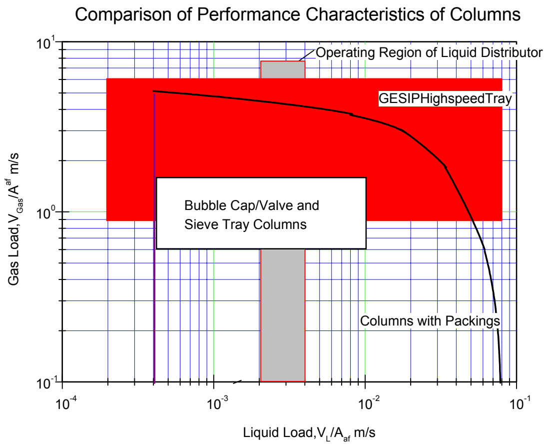

Fig.3: Performance Characteristics

• This tray can also be used as a high-speed mist eliminator (High-speed Demister [6]).

The next figures present data of the main tray characteristics. The pressure drop (Fig. 2) is about 30 mbar per tray under normal operation conditions in a high pressure column. Fig. 3 shows the performance characteristics compared to other tray types.
Mass-transfer trays with swirl tubes based on the similar principles but need an about 10-20% higher column diameter.
The mass-transfer tray efficiency for some processes is shown in the Figures 4 and 5. The preferred application fields are the natural gas, oil and petrochemical industries for onshore but especially of off-shore plants, the gas processing under high pressure as dehydration in glycol columns, gas sweeting, absorption and desorption processes, the rectification of hydrocarbon or other mixtures and in environmental technologies for gas scrubbing.

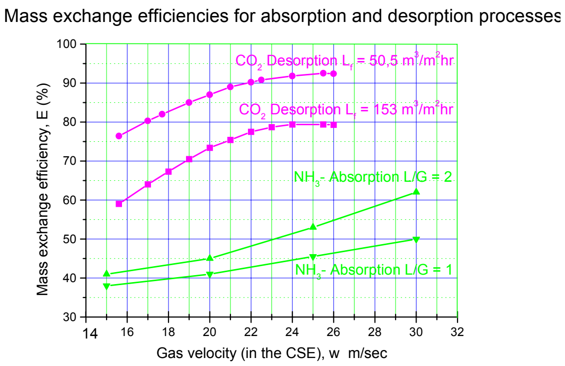

Fig. 4 Mass transfer efficiency for absorption/ desorption processes

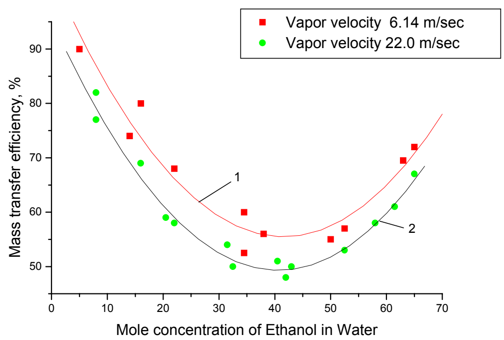

Fig. 5: Mass transfer efficiency for a distillation process

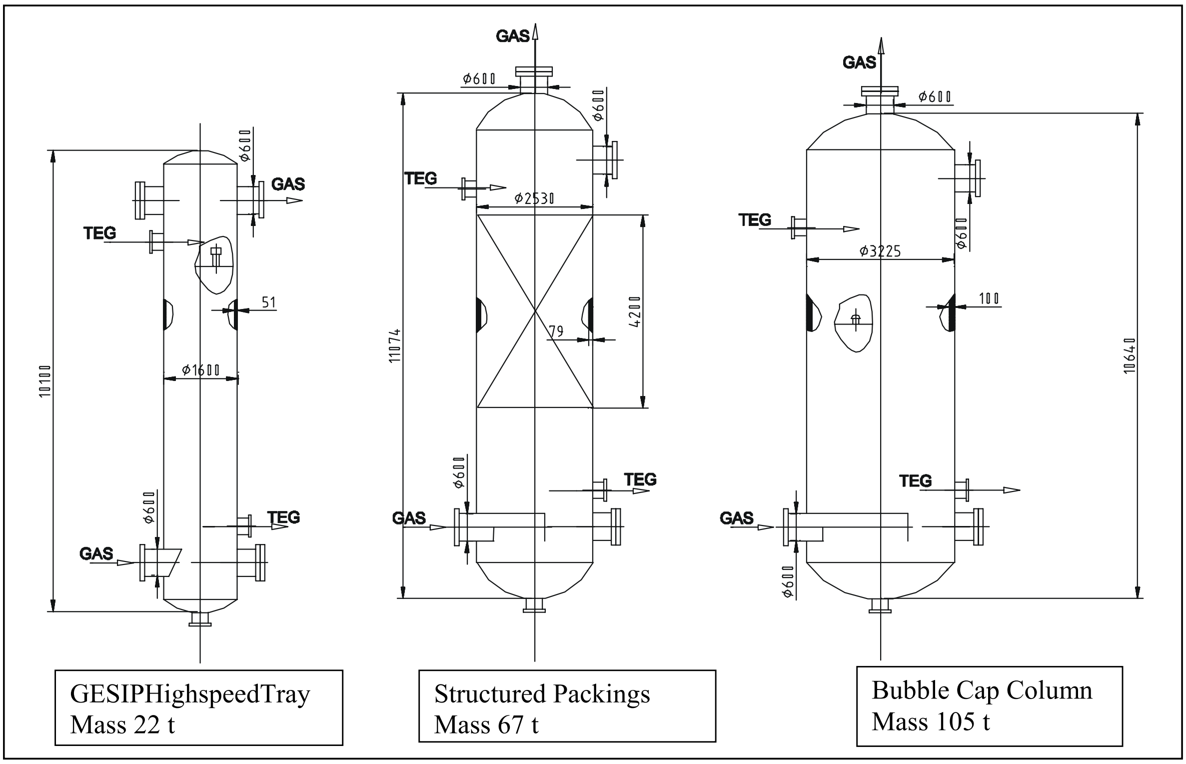

Fig.6: Comparison of column sizes and weight for the dehydration of natural gas (10 Mio Nm^3/d, at 30°C and 60 bar)

A comparison of column sizes of different column designs for the dehydration of natural gas with glycol (10 Mio Nm^3/d, at 30°C and 60 bar) is given in Fig. 6.

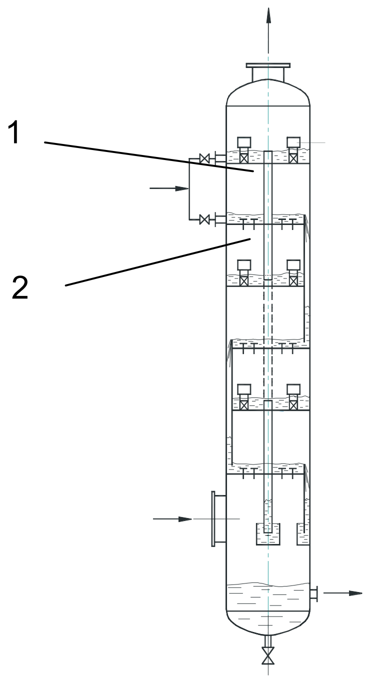

Fig. 7: Scheme of the HighFlexyTray
1-HighspeedTray
2-Valve Tray

THE HIGHFLEXITRAY

The recently patented HighFlexiTray [7] is a mass-transfer apparatus with trays arranged in pairs of two different constructions. One tray is equipped with high-speed elements and the other tray with conventional valves. The number of tray pairs in a column depends on the requirement of the separation quality. The tray with high-speed elements is always located above the valve tray. This construction allows to increase the flexibility (turndown) of a Highspeed-Tray from 1:3 up to 1:18 depending on the valve type. This new design has the high capacity and efficiency of a highspeed tray, guarantees a high degree of foam reduction and good entrainment characteristics.

Only trays of the same construction are connected by liquid streams, the high-

speed trays are connected by downcomers in the form of a tube in the centre of the trays. The tube end on the trays represents the weirs. Since the liquid on the high-speed trays is clear, the downcomer tube needs only a small cross sectional area. The liquid velocity in this tube may reach up to 1 m/s. These downcomer tubes cross the valve trays liquid-tight and end in the column bottom with a siphon. On the valve trays a two-phase mixture of liquid and vapor is present. Hence downcomers have to be designed with a larger cross sectional area typically by choosing segmental downcomers (liquid velocity not more than 0.3 m/s). These segmental downcomers connect the valve trays only and the downcomer from the bottom valve tray ends in the column bottom with a siphon too. For an optimal operation of such a column a special liquid distribution control is necessary for distributing the liquid properly between the first highspeed tray and the first valve tray. This distribution of the liquid load depends on the gas throughput of the column. In the case of high and very high gas throughputs (gas load F-factors from 6 to 10) the whole liquid is fed on the first highspeed tray. The valve trays are dry and are not involved in the mass transfer process. At low gas throughputs (F-factors from 3 to 0.55) the liquid is fed on the first valve tray and only the subsystem of the valve trays is involved in the mass transfer process and the highspeed trays work as mist eliminators. At intermediate gas throughputs (F-factors from 3 to 6) both tray types are involved in the mass transfer process and the liquid is distributed between the first highspeed tray and the first valve tray. The result of this tray combination is a column with very high turndown up to 1:20 depending on the type of the used valves. This column is capable of running at high as well as at very low vapor loads. It differs by their main characteristics as very high gas throughput, high gas velocities and turndown significantly from the Shell ConSep Tray a combination of Shell swirl tubes and Shell Hifi (sieve tray) trays.
These requirements have to fulfill glycol columns for natural gas drying for underground storages. The gas loading rate in these drying columns is changes seasonally and daily with broad ranges of operation.
The liquid load can adopt very broad changes from very low values up to very high liquid loads (200 m^3/m^2h and more).

THE SIEVE TRAY WITH FROTH STABILIZER [6,8]

The sieve tray *GESIP*SieveTray is a dual-flow sieve tray without downcomer and with a special froth stabilizer (Fig. 8). This new tray design improves the flow characteristics and increases the mass transfer significantly. The efficient froth stabilizer is located directly on the tray plate. The stabilizer has a special construction consisting of two different right-angled cellular systems.

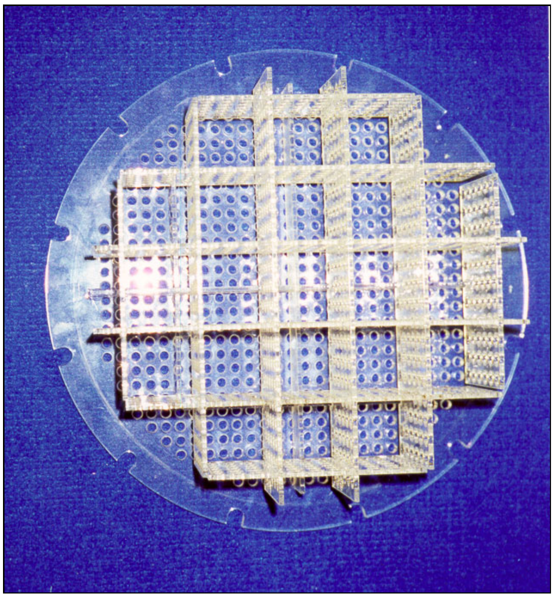

Fig. 8 : Sieve Tray with Froth Stabilizer

Fig.9: View of the Tray During Operation

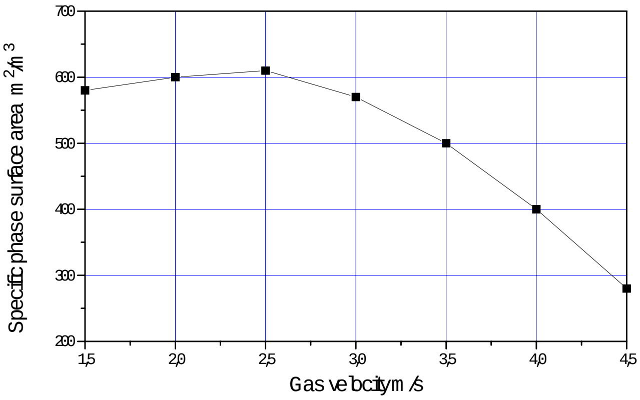

Fig.10: Dependence of the specific phase surface area (m^2/m^3) of the froth on the gas velocity (m/s)

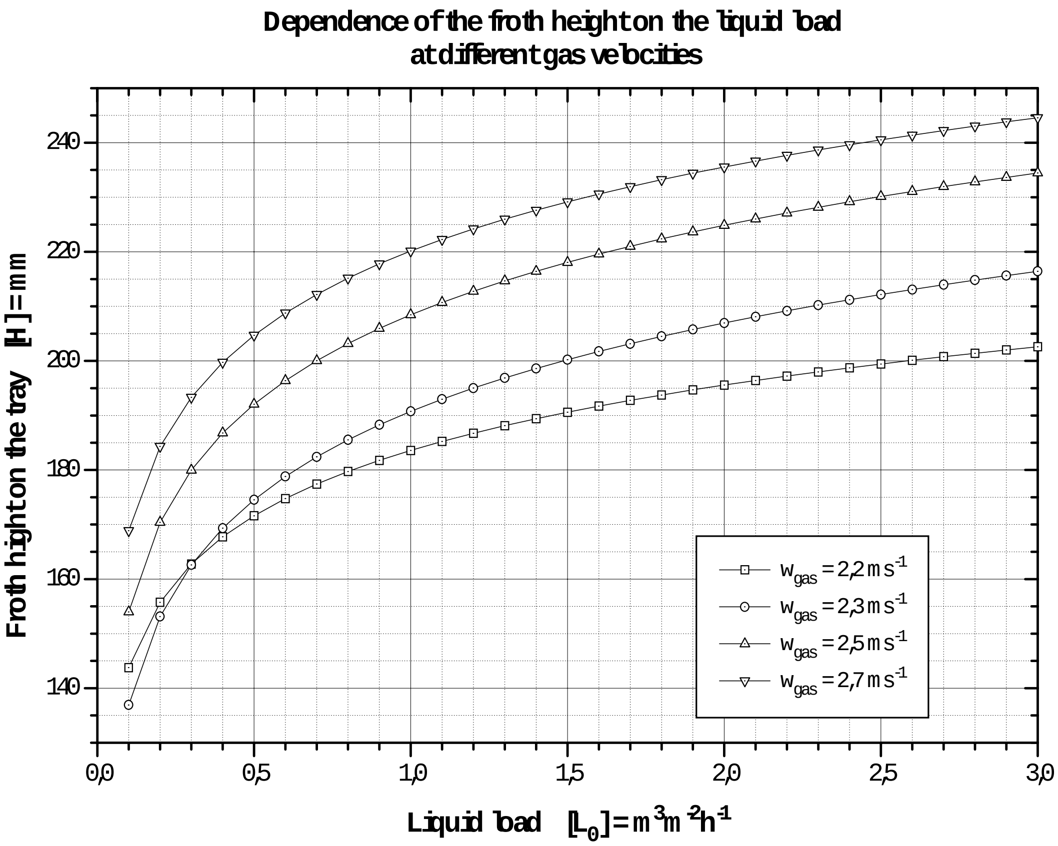

Fig.11: Froth Height on the Sieve Tray with Stabilizer as a Function of the Gas Velocity and the Liquid Load

It provides a well-organized flow regime of the liquid phase as well as of the gaseous phase (or gas to be cleaned). The layout of this stabilizer on the sieve tray also provides optimal conditions for the development of a stable froth layer (Fig. 9). The stability of this froth layer is an essential prerequisite for a high efficiency of the entire column and it allows to increase the superficial gas velocity up to 3 m/s (Fig. 10). The upper parts of the stabilizer sheets are perforated to improve the mass transfer and thus increase the separation efficiency. The lower part without perforations requires an optimal ratio to the fractional hole area of the sieve tray: The perforated part of the stabilizer is 5-6 times higher than the part without perforation. The stabilizer height can reach the tray spacing. The height of the mobile froth on the tray is between 100 to 300 mm, so that a tray spacing of 250 to 300 mm, F-factors of 1.8-2.5 and liquid loads from 0.1 to 50 m^3/m^2h are possible in columns with large diameters. These columns operate very stably and efficiently with low liquid loads. This type of construction doubles the performance of sieve tray columns compared with the traditional construction. At the same time, it also improves operating characteristics and the degree of effectiveness. The mass-transfer tray efficiency increases up to 40 % in comparison with the conventional sieve trays, the surface area of the froth layer is about 600 m^2/m^3. Fig. 11 shows the height of the froth layer on the sieve tray with stabilizer on dependence of the gas velocity and the liquid load.

The sieve tray with froth stabilizer allows a trouble – free operation even in the case of out-levelness of the plates. This tray can be applied in industrial absorbers and gas washers for very high throughputs, e.g., natural gas treatment, petrochemistry, chemical industry, oil refining and gas cleaning, and as wet scrubbers for gas washing to remove atmospheric impurities and pollutants as well as dusts. It can be applied for washing of gases with very high content of solids as slurries or other systems. The pressure drop is very low and about 10% higher as on a conventional sieve trays (due to the higher froth layer).

TEST FACILITIES

Test facilities operate at the Technical University and the test field of GESIP in Berlin: These test columns are equipped with modern laboratory and measurement facilities to test the trays and their elements under a variety of application conditions as gas throughputs and liquid loads, various gas and liquid systems.
The idea of the test facilities based on providing conditions as close as possible to actual industrial applications. This requirement entailed the use of the same contact and separation elements and sieve trays as test elements as utilized in industrial applications. To enable industry-similar application conditions, i.e., ensuring gas velocities of up to 30 m/s within the free cross-section of the CS element, the test facilities for highspeedtrays were designed with one test element, because this allow the complete depiction of all high-speed tray conditions on an industrial scale on the one hand since the contact between the gas and liquid phase takes place only within the element itself and not on the tray, i.e., not in the gap between the elements (contrary to other tray column constructions, the tray itself is not used for any mass transfer since this contains only the liquid phase). A flowsheet of the test facility at the Technical University is shown in Fig. 12.
The test columns are shown in the Figures 13 (Sievetray with stabilizer) and 14 (HighspeedTray).

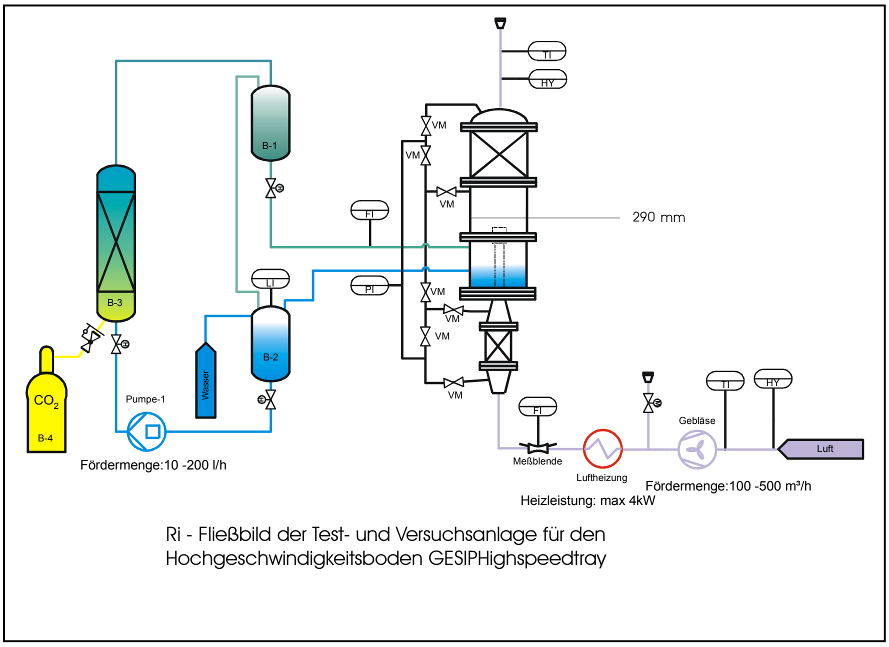

Fig. 12: Test Facility for the HighspeedTray at the Technical University Berlin

Fig.13: Test column with sieve tray with froth stabilizer

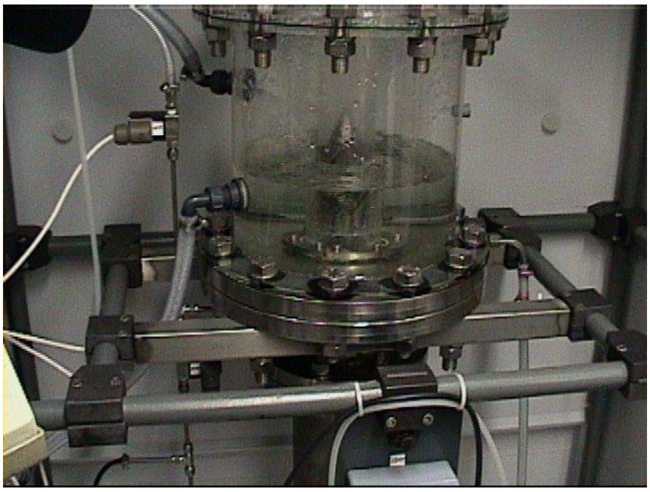

Fig.14: Column section with one high speed contact and separating element

Experimental data are obtained from different test facilities and for various mixtures. The main results for the systems water-air, wet air-TEG and CO_2- satured water/air and different hydrocarbons are presented in the Fig. 2-5 for the highspeedtray:

- Pressure drop
- Mass transfer efficiency
- Entrainment

and for the sieve tray

- Pressure drop
- Mass transfer efficiency
- Interfacial area between gas and liquid phase (Fig.10)
- Froth height (Fig. 11).

CONCLUSIONS

The HighspeedTray represents a new generation of mass transfer trays.This increase is achieved by a special vapor and fluid distribution and contact system within the contact and separation element (CSE) installed on the tray. The phase contact and the mass transfer occur in cocurrent flow according to the vortex jet principle. The construction offers miniaturization of the columns which results in significant savings of equipment costs. The preferred application fields are the natural gas and petroleum industries, especially for the dehydration of natural gas using glycol but also for sweetening (alkanolamine processes), absorption, desorption, as well as rectification of hydrocarbon mixtures or other mixtures.
The combination of HighspeedTrays with valve trays – the Highflexitray- opens the possibility for the design of columns with very high gas throughputs and a high flexibility, e.g. with a turndown up to 1:20.
The Sievetray is a dual-flow sieve tray with a special froth stabilizer. This tray design improves the flow characteristics and increases the mass transfer. The froth stabilizer is located directly on the tray plate. This guarantees a well-organized flow regime of the phases on the trays. This new type of construction doubles the performance of sieve tray columns compared with the traditional construction.

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