The Impact of Tower Internals on Packing Performance

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Dedicated to Dr. Ralf Goedecke on the occasion of his 70th birthday

The overall tower performance is influenced by the type of both tower internals and random packing. The Raschig GmbH's most recent development is the Raschig Super-Ring®, the fourth generation of random packings. In 1998, the Raschig Super-Ring No. 2 was tested at the facilities of Fractional Research Inc. A significantly improved capacity and pressure drop over other random packing was observed without reducing the efficiency. A recent retesting of Raschig Super-Ring No.2 using new tower internals revealed that the revised tower internals further improved the performance. Raschig has noticeable experience in designing liquid distributors.

Keywords: Liquid distributor, Process optimization, Random packings, Raschig Super-Ring, Tower internals

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1 Introduction

The first generation of metal random packings was developed by Fritz Raschig, the founder of the company Raschig in Ludwigshafen, Germany. This packing was called Raschig's Ringe®, which currently is a synonym for random packings. This material is a cylindrically shaped metal packing whose height equals its diameter (Fig. 1). The development of Raschig's Ringe significantly improved the distillation of tar. In 1920, after the Raschig Ring was patented [1–3], Fritz Raschig began to market Raschig's Ringe and established a mass transfer business line in his company in 1921, the Keramische Werke Raschig AG [4]. Today, this division is known worldwide as a specialist in mass transfer column design using high performance products for grassroots and revamping cases.

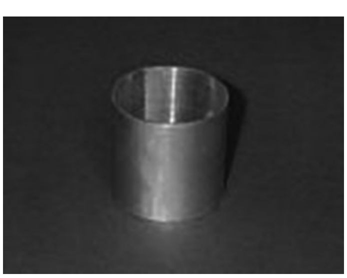

Figure 1. Raschig Ring.

The second generation of random metal packings was brought to market over 30 years later. At BASF, Ludwigshafen, the chemist Wilhelm Pfannmüller developed the Pall-Ring® (Fig. 2) [5]. As opposed to the Raschig Ring, the Pall-Ring features an open cylinder generated by punching strips from the circumference to the inside of the cylinder. This development noticeably improved the capacity and reduced the pressure drop.

Figure 2. Pall-Ring.

After another 30 years, the third generation high performance random packings were developed in the 1980s. These materials are known as Nutter Rings [6], CMR Rings, and IMTP® Rings, and are currently widely used in industry.

In 1995, Raschig developed a new random packing known as the Raschig Super-Ring (RSR, Fig. 3). The RSR was developed based on fundamental new studies concerning the countercurrent fluid-dynamic flow behavior of gases and liquids in packed columns. These studies were influenced by the development of structured packings, which demonstrated very low pressure drops and high capacities by minimizing droplet creation inside the packing and assuring a liquid film flow countercurrent to the rising gas.

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Figure 3. Raschig Super-Ring.

The RSR was the first random packing that maximized the film flow performance by utilizing continuous, multi-wavy strip geometry as shown in Fig. 3. This design concept offers the most homogeneous distribution of gas and liquid flow in a column cross-sectional area. The superior performance of the RSR has been repeatedly proven in industrial columns; thus, it became the first fourth generation random packing.

2 Impact of Tower Internals on Packing Performance

Direct comparison of random packings from different companies is often not possible, as variations in the testing conditions will influence the outcome. Therefore, testing at an independent institute allows for direct comparison of random packings under the same conditions. Fractionation Research Inc. (FRI, Stillwater, OK) is one of the most modern independent test institutes that examines tray, random packing and structured packing tests under rectification conditions in an industrial scale test column. FRI has been testing random packings for over 60 years under low, medium and high pressure conditions and has created one of the world's largest databases for comparing tray and packing efficiencies, pressure drops, and capacities. Until 1998, the most intensively tested random packing at FRI had been Pall-Rings. Pall-Rings became increasingly popular in the 1960s, but repeatedly failed in industrial applications. Based on a research program in 1982, FRI verified that the design of liquid distributors noticeably impacts the performance of Pall-Rings. This research was ultimately published in 1987 [7] and indicated that a trough type distributor with V-notches did not adequately distribute the liquid and consequently resulted in lower separation efficiency than the newly developed Tubed Drip Pan (TDP) distributor with ground holes. Therefore, the TDP distributor has been used for all random packing tests at FRI since 1982.

The Raschig Super-Ring No. 2 (RSR 2) was first tested at FRI in 1998. Based on the results from 1987 [7], the TDP distributor was selected for the FRI performance test. A high-capacity FRI support grid and a corresponding FRI hold down grid were also used for the tests. The results showed that the RSR significantly improved the capacity and pressure drop over 2“ Pall-Rings. This improvement did not reduce efficiency [8, 9].

In 2012, Raschig decided to retest RSR 2 using a contemporary narrow trough-type distributor that was more accessible to the gas phase than the TDP distributor (Fig. 4) used in the previous test. In addition to the high-performance DT-S distributor, a modern Raschig support system and hold down device was used. In addition to the development of modern packing materials over the past few decades, tower internals, e.g., distributors, hold-down and support plates, have undergone significant design improvements. The high-performance tower internals used in mass transfer columns 10 or 20 years ago are currently considered to be low or standard performance devices, especially when used with high performance packings.

Figure 4. FRI's Tubed Drip Pan Distributor, open area: approx. 14 %.

2.1 Comparison of Packing Performance Using Different Tower Internals

In this paper, the performance data of the RSR 2 using the old-fashioned high-performance TDP distributor (FRI tower internals, 1998 test) is compared to the contemporary, modern high-performance DT-S trough type liquid distributor (Raschig tower internals, 2012 test, Fig. 5) to show how the tower internals influence the performance of the highly developed random packings.

Figure 5. Raschig's DT-S Distributor, open area approx. 50 %.

The TDP distributor affects the performance of the RSR 2. The conditions and observations from the 1998 test have been published previously [8, 9]. In summary, 14 % of the TDP distributor area was open to the gas phase. A sub-cooled reflux was fed into the distributor via a spray nozzle system. At high reflux rates, the liquid pool in the distributor cooled the whole pan, which caused heavy vapor condensation on the outside of the distributor. The gas velocity increased 7-fold to pass the distributor through round gas risers and the gap to the column wall due to the limited open area. At high loading capacities, the cold condensate could no longer flow down the gas risers and the distributor periphery countercurrent to the rising vapor. Consequently, the condensate was entrained into the column overhead and partly jettisoned down into the packed bed in the form of heavy showers. This effect reduced the efficiency and limited the packing capacity (Fig. 6).

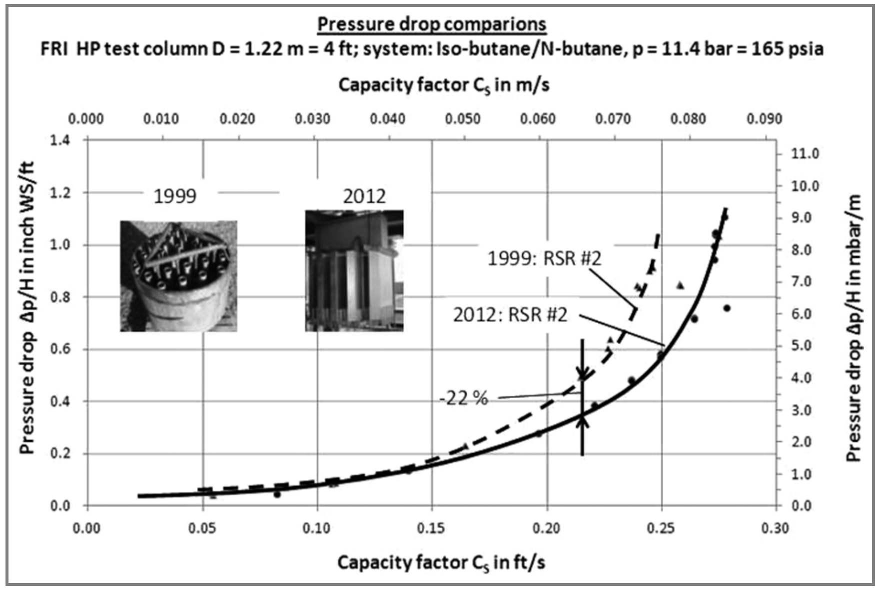

Figure 7. Raschig Super-Ring pressure drop and capacity comparison for the isobutane/*n*-butane pressure distillation system at 11.4 bar (165 psia).

Fig. 7 shows the pressure drop observed for the RSR 2 tested in 1998 using FRI's high-capacity TDP pan-type distributor and compares it to that from tests in 2012 using Raschig's high-performance DT-S distributor. The packing performance comparison is shown for an isobutane/*n*-butane distillation system at 11.4 bar (165 psia). Fig. 8 shows the pressure drop comparison for the cyclohexane/*n*-heptane distillation system at 1.62 bar (24 psia). For the test systems shown, the pressure drop decreases by 22 – 37 % when using the DT-S distributor. The DT-S distributor clearly offers an increased area that is open to the gas phase which facilitates gas flow and consequently impacts the pressure drop measurement.

Figs. 9 compares the efficiency of RSR 2 for the isobutane/*n*-butane systems tested in 1998 and 2012. Fig. 10 shows the efficiency comparison for the cyclohexane/*n*-heptane rectification system at 1.62 bar (24 psia). The capacities of the isobutane/*n*-butane system and cyclohexane/*n*-heptane system increased by 13 % and 18 %, respectively. These systems also showed an efficiency improvement of 6 – 14 % using the modern DT-S distributor.

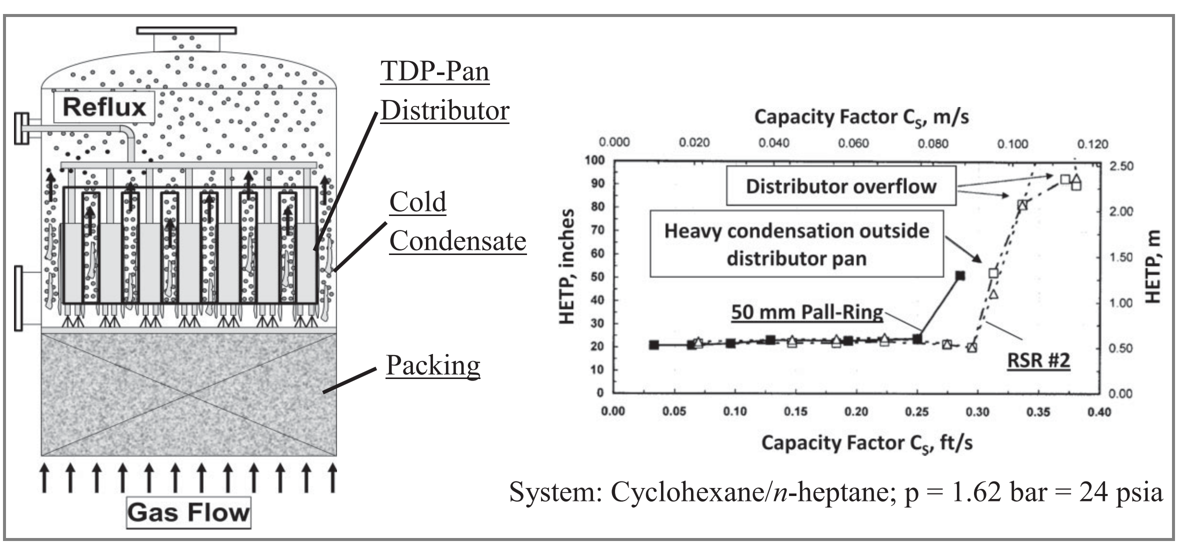

Figure 6. Left side: column top configuration with cold reflux into the TDP distributor and heavy condensation effects. Right side: separation efficiency in terms of HETP-value above the gas capacity factor; heavy condensation resulted in early loss in efficiency and distributor overflow.

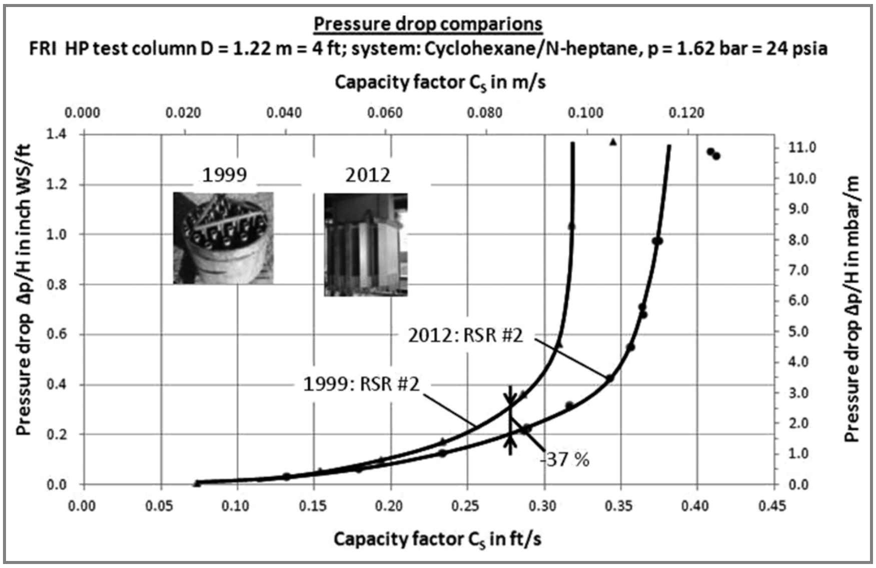

Figure 8. Raschig Super-Ring No. 2 pressure drop and capacity comparison for the cyclohexane/*n*-heptane rectification system at 1.62 bar (24 psia).

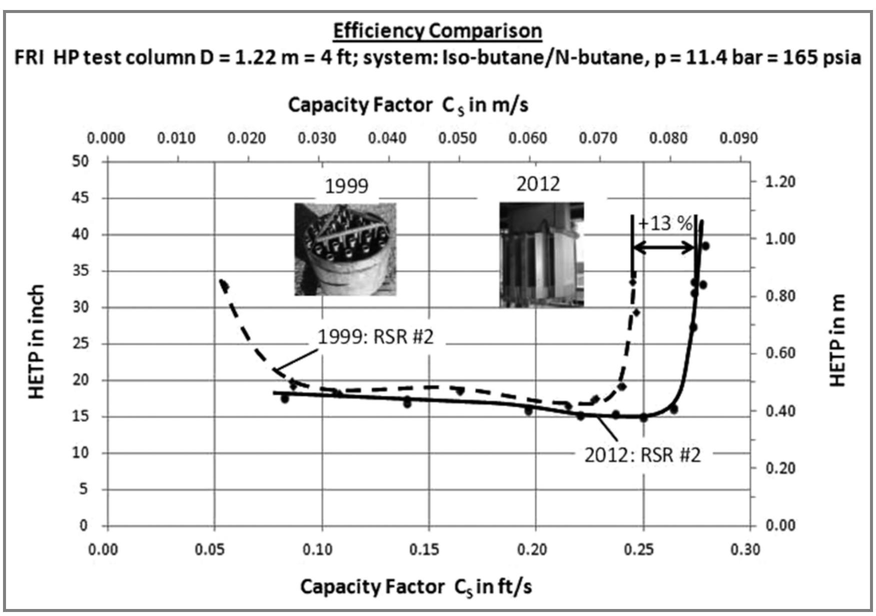

Figure 9. Raschig Super-Ring No. 2 efficiency and capacity comparison for the isobutane/*n*-butane pressure distillation system at 11.4 bar (165 psia).

The performance improvement of the RSR 2 is again related to the very open void fraction of the DT-S distributor. Although the tests in 2012 were also performed with an external sub-cooled condensate reflux, the DT-S distributor did not entrain the condensate and distributed it much more homogeneously over the column cross-sectional area.

3 Development of Large-Scale Liquid Distributor Test Center

The Raschig GmbH has noticeable expertise in the design of high-performance liquid distributors and tower internals. To test such liquid distributors, one of world's largest liquid distributor test centers was built in Germany. Here, liquid distributors up to 12 m in diameter can be tested in full scale. For larger column diameters, Raschig tests the distributors in partitions. Further smaller-scaled test facilities are available at the headquarters in Ludwigshafen, Germany.

Fig. 11 shows a design by Raschig for a large-scale DT-S trough-type distributor. The liquid is fed into the distributor via a liquid feed pipe header and a multiple parting box system. The test facility allows the measurement of the *drip point-related coefficient of variation* and the *drip area-related coefficient variations*. The measurements are supported by an automated collecting system.

Raschig can also test combined tower internal systems. For example, Fig. 12 shows a dummy shell erected to simulate a column section for a two-phase flashing feed. This column section consists of two 24" tangential feed lines directing the feed into a flashing gallery. Below the flashing gallery, a trough-type distributor was positioned to test its drip point-related coefficient of variation.

Flash galleries have been studied at Raschig's test center for a long time, which has resulted in several design improvements. These special design features are recommended, e.g., if the impulse of the flashing feed into the gallery must be broken to improve the liquid distributor performance below. In addition, an effective deaeration of flashing liquid is often important for critical services, such as high pressure distillations.

The Raschig test center also supports customers in their revamping studies. For example, a column was revamped with a flashing feed. The existing column set up before the remodeling is shown in Fig. 13 (left side). The flashing feed entered the column via a side nozzle into a V-notched trough that crosses the column diameter. By design, the

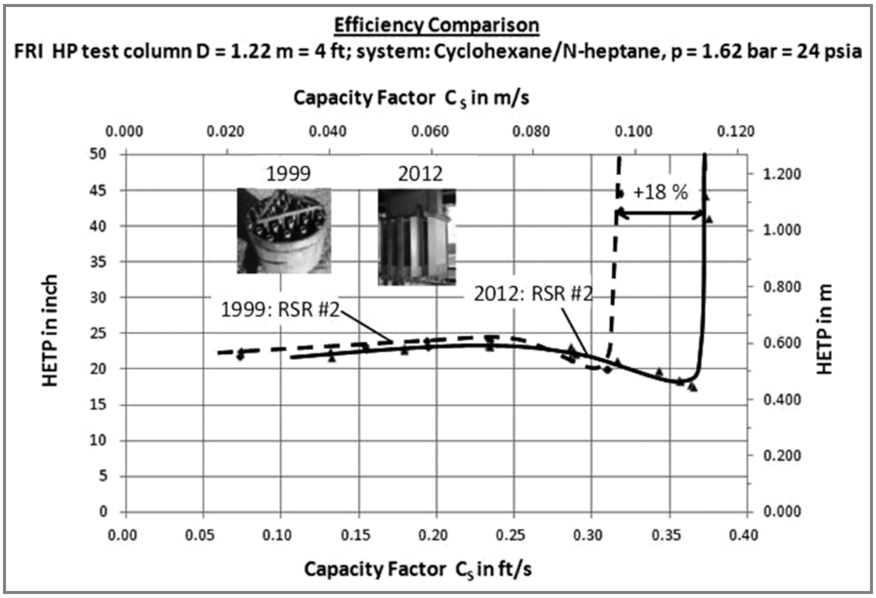

Figure 10. Raschig Super-Ring No. 2 efficiency and capacity comparison for the cyclohexane/n-heptane rectification system at 1.62 bar (24 psia).

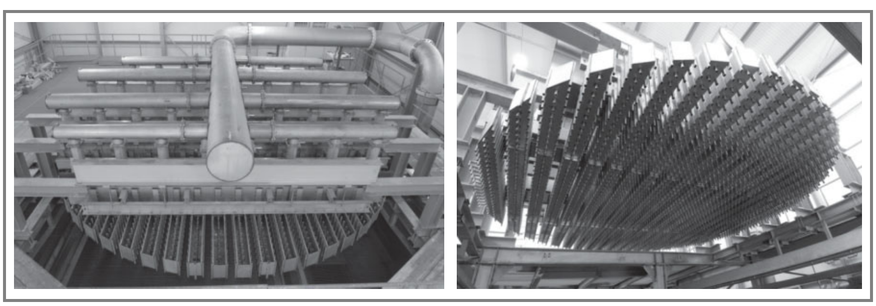

Figure 11. Large-scale DT-S distributor at Raschig's test facility in Leipzig, Germany.

Figure 12. Large-scale flash gallery and distributor at Raschig's test facility in Leipzig, Germany.

flashing liquid should fall into and overflow the V-notched trough towards the distributor below, and the gas should exit to the bed above. Raschig rebuilt this existing flash design to improve the distribution quality of the distributor below the V-notched trough.

Fig. 13 (right top side) indicates that the flashing liquid entering the column was forced to flow to the opposite side of the flash nozzle in the existing design. Therefore, one side of the distributor was overloaded, while the other side was underloaded. This discrepancy resulted in significant liquid maldistribution below the distributor.

Therefore, the flashing feed device was rebuilt using a double shell flash box as in Fig. 13 (right bottom side). Special care was taken to break the impulse of the flashing feed inside the box and to direct the liquid onto the distributor below. Furthermore, it was considered to homogeneously distribute the flashing gas stream to the bed above.

4 Recent Industrial Applications of Raschig Super-Rings

Since 1998, Raschig has developed 9 different sizes of RSRs for industrial applications. Tab. 1 provides an overview of the packing characteristics for all RSRs. Three examples for application of Raschig Super-Rings are discussed in more detail.

Offshore application

For several years, RSRs have been used in industries where structured packings had originally been applied, such as offshore applications (Fig. 14). In the past, structured packings have often been used in offshore applications because they have been comprehensively studied under rocking applications. However, for high-pressure rectification processes, structured packings can only be applied with high safety margins, because they induce inefficient performances due to efficiency humps. Conversely, trays are very sensitive to column motion, which also makes them risky to use. Alternatively, random packings, i.e., RSR, can be used. Raschig has established a comprehensive test program for random packings in rocking column applications. As shown in Fig. 14, RSRs can be successfully used in rocking columns if special distributor and redistributor designs are applied.

Application in high pressure de-methanizer and de-ethanizer

Raschig Super-Rings also show an advantage when used in high-pressure de-methanizers and de-ethanizers. These columns often operate close to the critical pressure, and film flow preferring packings are favored to stabilize the column conditions. At high pressures, the surface tension is low, risking the formation of fine droplets and entrainment. Droplet-promoting packings support these effects, but RSRs

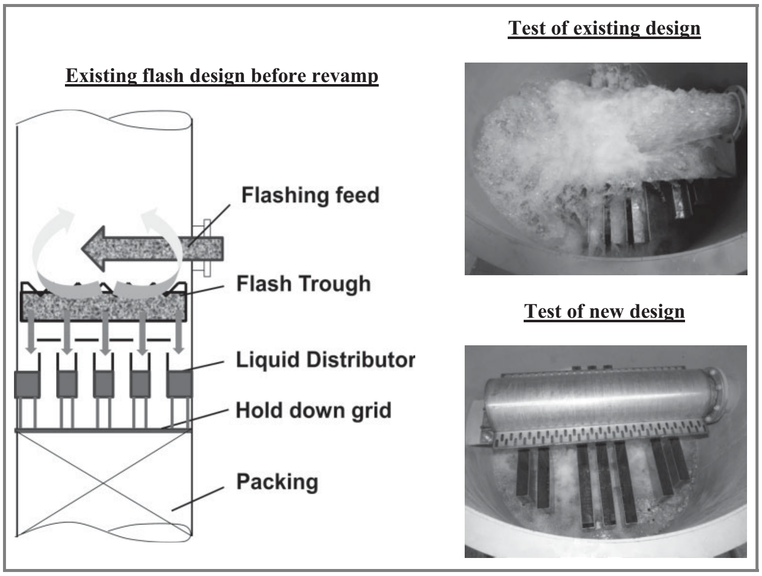

Figure 13. Revamp of a flashing feed device to enhance the liquid and gas distribution performance.

do not. Instead, they stabilize the film flow and therefore minimize droplet entrainment, resulting in high capacities and lower pressure drops.

Fig. 15 shows a successful application of RSRs in a high-pressure de-methanizer column. Multiple flashing feeds enter the column at various feed locations. High gas and low liquid densities are typical for such applications and require special flashing feed designs to effectively separate the phases and feed the liquid to the distributor below. In addition, fine droplets can enter the column via the flashing feeds, which can be entrained to the column section above if special design precautions are not taken. Raschig is providing advanced design concepts for such cases.

Revamp of butadiene plant

Fig. 16 shows a revamp of the world's largest butadiene columns in 2012 from third-generation random packing to RSRs including an exchange of column internals. After startup, the customer stated great improvements to their process yield and column performance efficiency. This project was a follow-up to one of the most effective revamp projects Raschig has completed in Europe. Based on Lurgie's engineering package, the largest European butadiene plant was revamped in 2002 and 2007. After the revamp in 2007, the performance results showed significant advantages for the plant operator: the plant capacity was double that of the original tray design.

The use of Raschig Super-Rings in butadiene processes is superior, because these columns are sensitive to foaming and polymerization. Different test facilities found that the unique shape of the RSRs suppresses foam formation by promoting film flow characteristics [10]. The minimum static liquid hold-up of the RSRs further suppresses polymerization. Special tower internals/liquid distributors are used in such critical processes to maximize the packing efficiency and capacity.

5 Conclusion and Summary

- The performance of the Raschig Super-Ring No. 2, a fourth generation random packing, is superior to other random packings in industrial application. Based on most recent FRI test results from 2012, RSR 2 provides the highest capacity tested for a 2“ random packing and a surface area of $100\,m^2m^{-3}$. In addition, the RSR demon-

Table 1. Characteristic/standard packing specific data for Raschig Super-Rings; other material thicknesses are available and can change the values listed.

Raschig Super-Ring Size	Packing weight [$kg\,m^{-3}$]	Pieces [m^{-3}]	Specific surface area [m^2m^{-3}]	Void fraction [m^3m^{-3}]
0.1	321	505000	450	95
0.3	340	180000	315	96
0.5	275	145000	250	97
0.6	235	74000	215	98
0.7	240	45500	180	98
1.0	220	32000	150	98
1.5	170	13100	120	98
2.0	155	9500	100	98
3.0	150	4300	80	98

Figure 14. Raschig Super-Rings used for application at off-shore facilities.

strates the lowest pressure drop.

- The tower internals are as important as the type of packing used for optimum performance. For optimum conditions, the tower internals and random packings should be tailored to the desired application. The RSR 2 showed highest performance when combined with Raschig's most modern high quality DT-S distributor, packing support, and hold down grid. The DT-S distributor also improved the efficiency.
- Raschig's large-scale liquid distributor test center is used to enhance distributor design concepts for multiple industrial applications. In this center, liquid feed lines and gas/liquid flashing feed conditions are studied. Based on Raschig's experience, the real feed line arrangement or flash feed device to the distributor test setup must be included because these feed arrangements often initiate liquid maldistribution to the distributor.
- Raschig has used RSRs in many critical processes. Based on the expertise available to design tower internals, as shown in this paper, Raschig has demonstrated proven success in grass-roots design and revamping projects. Advanced design principles are very important for applications, such as high-pressure distillation, foaming processes and towers, that tend to polymerize.


Figure 15. High-pressure de-methanizers packed with Raschig Super-Rings.


Figure 16. Revamp of the world's largest butadiene plant with Raschig Super-Rings.

Symbols used

Cs	[m s^{-1}]	gas capacity factor: $u_V\sqrt{\frac{\rho_V}{\rho_L-\rho_V}}$
D	[m]	diameter
HETP	[m]	height equivalent to a theoretical stage
u_V	[m s^{-1}]	superficial gas velocity
ρ_L	[kg m^{-3}]	liquid density
ρ_V	[kg m^{-3}]	gas density

Abbreviations

CMR	cascade mini-ring
IMTP	INTALOX® Metal Tower Packing
RR	Raschig Ring
RSR	Raschig Super-Ring®

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The performance of random packings is improved by the choice of tower internals. Raschig Super-Ring No. 2 showed highest capacity when using modern tower internals. Using the DT-S distributor improved the efficiency. At Raschig's large-scale liquid distributor test center the design concepts are enhanced for industrial application.