# Investigating the Effect of Replacing Modern High Effective Random Packings on Natural Gas Purification


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Received: December 9, 2014 / Accepted: June 6, 2015


## Abstract

**This investigation attempts to evaluate and compare the effect of packing type on the mass transfer and pressure drop along the gas sweetening absorption column. To this aim, modern packings such as Super Ring, Ralu Ring, Ralu Flow and the second-generation packing (Pall Ring), have been used in simulated columns by using of Aspen HYSYS modeling software. Flooding calculation is made possible by linking Aspen HYSYS with MATLAB programing. The selected models validity is checked by comparison to empirical data from a real gas plant. It should be noted that empirical data is available just for second-generation packing. Comparison of these packings performance shows that Super Rings provide low pressure drop, Ralu Rings lead to high mass transfer and Ralu Flow packings can provide high mass transfer and low pressure drop in absorption columns. According to results, the capacity of gas treatment units can be significantly increased by replacing Pall Ring with Ralu Flow.**


**Keywords:** Natural gas sweetening, absorption column, packing, mass transfer, pressure drop

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## Introduction

Nowadays, one of the most common methods to increase the capacity of a plant for gas purification is absorption column internal modification which is usually realized through replacement of packed beds. Development of packings initiated in 1950 when the second-generation Pall Ring and Intalox packings were designed and later continued by creating the third-generation International Metal Tower Packing (IMTP) and Cascade Mini-Ring (CMR). Due to packing key role in absorption and desorption processes, packings developed in recent years have been widely employed. Super Rings, Ralu Rings and Ralu Flows are the fourth-generation packings which have prominent characteristics compared to the other types. Billet and Schultes (1999) made an effort to predict the mass transfer in columns with dumped and arranged packings. Schultes (2003) investigated the characteristics of some third-generation packings including Nutter Ring, CMR, IMTP and also Super Ring as a fourth-generation packing. Darakchiev et al. (2005) compared the gas distribution in packed columns with IMTP and Ralu Flow packings. Nako et al. (2007) compared the effective areas of some highly effective packing. Darakchiev and Semko (2008) investigated the effect of modern high effective packings on water-ethanol rectification. Mackowiak (2009) predicted the pressure drop of some packings by extended channel model.

Arachchige et al. (2012) compared the effect of second-generation packings on energy consumption of $CO_2$ capture processes by using of Aspen Plus. As previous studies have been based on predicting the characteristics of packings and assessing the performance of second and third generation packings, this paper investigates the effect of replacing fourth generation random packings on energy consumption and capacity of gas purification plants (MDEA-based). To this aim, Aspen HYSYS simulation software (V8.3) is used for modeling of packed column.

## Rate-based modeling and validation

In this paper, a real life case study data (BIDBOLAND gas refinery, Iran) has been used for validation of simulation results. The entire refinery has four parallel gas treatment units (GTU) with 4 absorbers and 4 regenerators. The absorbers have an internal diameter of 2.9 meters and two sections. Each section is 6.54 meters in height and filled with plastic random packing (2-inch Pall rings). The regenerator column has 17 sieve trays and internal diameter of 3.96 meters. Based on tray spacing of 27 inch, the height of the column is 11.66 m. Table 1 shows the current operation conditions of the mentioned units.

The traditional approach of modeling absorption and Regenerator columns is using the equilibrium stages. In this model the column is divided into a number of stages and it assumes that the vapor and liquid phase leaving a stage are at equilibrium. This assumption is used to simplify the modeling and rarely happens in reality.

The departure from equilibrium is corrected by applying tray efficiency like the Murphree efficiency for tray columns or the height equivalent to a theoretical plate (HETP) for packed columns. For reactive separation processes, the deviations from the equilibrium model are very large and the use of efficiencies does not work well. Hence, rate-based models are suggested for modeling these systems. This model assumes that the vapour-liquid equilibrium occurs only at interface. In this work, the RadFrac distillation model was used to model the absorber and stripper columns. It is a rigorous model for simulating absorption and stripping where chemical reactions are occurring. The rate-based mode of RadFrac, called ASPEN RateSep, allows for the rate-based modeling of absorption and desorption columns and uses the two-film theory in mass and heat transfer models. According to the above-mentioned, the validity of the simulation results depends heavily on selection of equilibrium and mass transfer models used in simulation. In this study, the ACID GAS thermodynamic package and

Table 1. Current operation conditions of BIDBOLAND gas refinery units

| Absorption Column | |
|---|---|
| Type of packing<br>Number of section | 2-inch, Pall ring<br>2 |
| Column Pressure, bar | 54 |
| $H_2S$ in Gas Feed, ppm | 1950 |
| %$CO_2$ in Gas Feed, mole | 1.74 |
| Gas Feed Temperature, °C | 30.0 |
| %Amine Conc. in Solvent, wt | 40 |
| Inlet lean Amine Temperature, °C | 34 |
| Amine Flow Rate, kmol.h$^{-1}$ | 4615 |
| Feed Gas Flow Rate, kmol.h$^{-1}$ | 15860 |

Table 1. Current operation conditions of BIDBOLAND gas refinery units (cont'd)

| Regenerator Column | |
|---|---|
| Column Pressure, bar | 1.4 |
| Condenser Temperature, °C | 33.0 |
| Feed Temperature, °C | 93.60 |
| Bottom Temperature, °C | 116.70 |

ELECNRTL package (PMDEA Data package) are selected for process simulation in Aspen HYSYS (V 8.3) and Aspen Plus (V 8.2), respectively. It should be noted that both of these packages use electrolyte NRTL models in the property package for the thermodynamics, and also use a mass-and-heat transfer rate-based calculation method. Aspen Rate-Based distilation uses well known and accepted correlations to calculate binary mass transfer coefficients for the vapour and liquid phases, interfacial areas, heat transfer coefficients and liquid holdup. The simulation results and operating data of the BIDBOLAND treatment unit are provided in Table 2. As seen in Table 2, ACID GAS Package which has been inserted in Aspen HYSYS (V 8.3) software simulated the treatment unit with an acceptable accuracy and this simulator is used for the following investigation steps. It should be mentioned that selected mass transfer and interfacial models that provide best results are shown in Table 3.

Table 2. Simulation results of BIDBOLAND GTU using ELECNRTL and ACID GAS packages

| Parameters | Plant Data | ACID GAS | ELECNRTL |
|---|---|---|---|
| $H_2S$ in Sweet Gas, ppm | 4.00 | 4.02 | 3.12 |
| % $CO_2$ in Sweet Gas, mole | 1.1065 | 0.9834 | 1.4893 |
| Rich Amine Temperature, °C | 21.20 | 20.81 | 20.67 |
| (Acid Gas Loading*(Rich amine | 0.328 | 0.327 | 0.294 |
| Reboiler Duty, $kJ.hr^{-1}$ | $10^{8}\times1.19$ | $10^{8}\times1.08$ | $10^{8}\times1.05$ |

*moles of acid gases per mole of amine

Table 3. Mass transfer and interfacial models (ACID GAS and ELECNRTL)

| Models | Absorbtion column | | Regenerator column | |
|---|---|---|---|---|
| | Section 1 | Section 2 | Bubble cap | Sieve tray |
| Mass transfer | onda | Hanley | Gerster | Chen & Chuang |
| Interfacial | onda | Hanley | Scheffe | Zuiderweg |

## Results and discussion

### *Replacing the Fourth-Generation Packings*

In this study, the method of Billet and Schultes (1999) has been used for calculating flooding percentage. This calculation has been done by written MATLAB Code that linked to Aspen HYSYS. Table 4 shows the characteristics of used packings as well as required constants for calculation of flooding percentage. It should be noted that attempts have been made to avoid using metal packings due to occurrence of corrosion in amine sweetening units. The simulation results are shown in Figs.1, 2, 3 and 4 in order to study the effect of used packings on sweetening and energy consumption of gas treatment units of BIDBOLAND refinery.

### *Amine circulation rate*

Figure 1 shows the required amine circulation rate in presence of various packings for achieving 4ppm $H_2S$ in sweet gas stream. As it is observed, the required amine circulation rate in presence of Pall Ring (4615 $kmol.h^{-1}$) is not much different from that in presence of Super Ring (4810 $kmol.h^{-1}$), while amine consumption rate significantly decreases in presence of Ralu Ring (25mm) and Ralu Flow (NO-1).

Table 4. Constants and characteristics of used packings (Billet and Schultes, 1999)

| Packing Type(size) | Specific Area($m^2/m^3$) | Void Fraction | $C_h$ | $C_{fl}$ |
|---|---|---|---|---|
| Pall Ring(50mm) | 110 | 0.920 | 0.593 | 1.757 |
| Super-Ring(NO-2) | 100 | 0.960 | 0.720 | 2.096 |
| Ralu Ring(25mm) | 190 | 0.940 | 0.719 | 1.989 |
| Ralu Ring(38mm) | 150 | 0.930 | 0.640 | 1.812 |
| Ralu Flow(NO-1) | 165 | 0.940 | 0.640 | 2.401 |
| Ralu Flow(NO-2) | 100 | 0.945 | 0.640 | 2.174 |

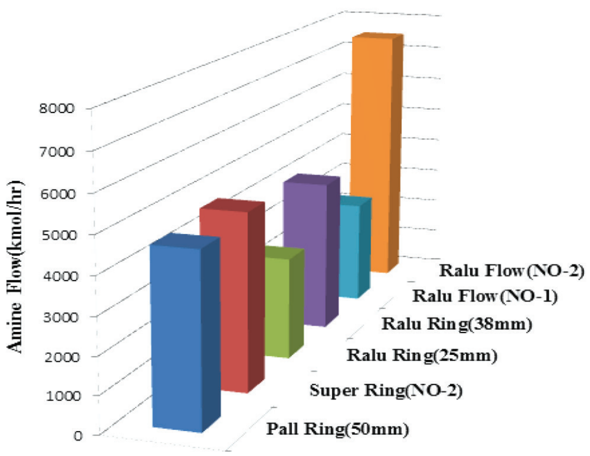


Figure 1. Required amine circulation rate in presence of various packings (4 ppm H2S in sweet gas stream)

## Energy consumption

Energy consumption of the unit in presence of various packings is presented in Figure 2. According to Figure 1, as in presence of Ralu Ring (25mm) and Ralu Flow (NO-1), the amine circulation rate is at lowest level; using these two packing types leads to maximum reduction in energy consumption of unit.

### *Operational constrains*

Although the main purpose of this paper is using appropriate packing to reduce sweetening unit energy consumption, investigating operating considerations and avoiding flooding phenomenon are among the most important aspects of this research. Figure 3 shows the calculated flooding percentage in absorption column of gas sweetening unit in presence of different packings. As seen in this diagram, using Ralu Ring packing (25mm) increases the risk of flooding in the column whereas there is no such drawback by selecting Ralu Flow (NO-1).

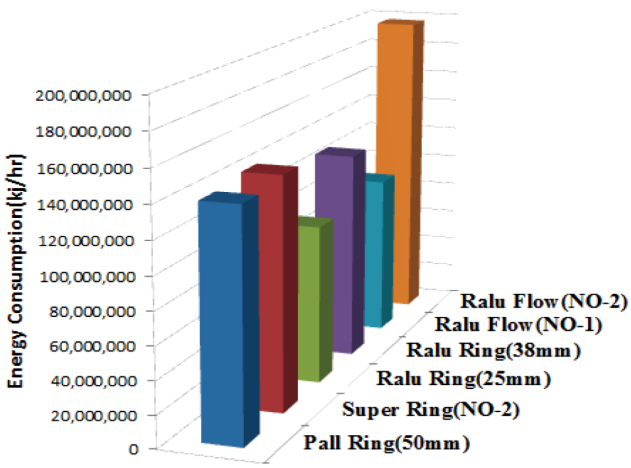


Figure 2. Unit energy consumption in presence of various packings
(4 ppm H2S in sweet gas stream)

Another important factor in selecting the type of packing is acid gas loading in rich

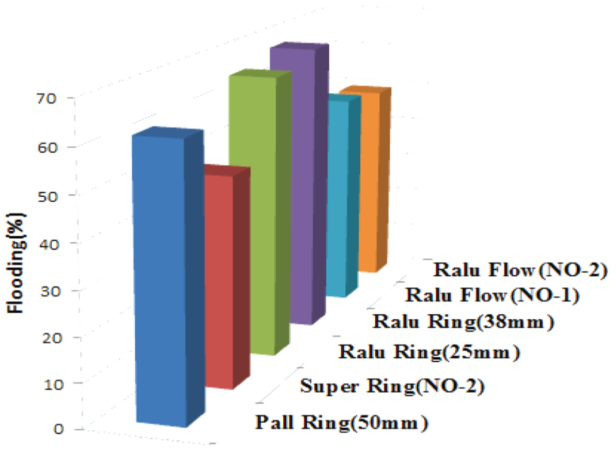


Figure 3. Predicted flooding percentage in presence of various packings (4 ppm H2S in sweet gas stream)

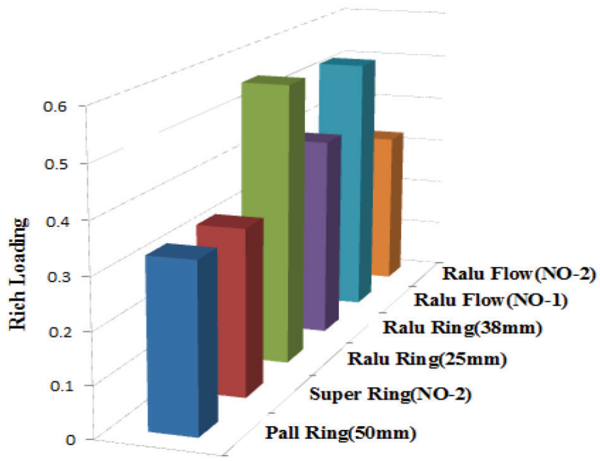


Figure 4. Acid gas loading in rich amine in presence of various packings (4 ppm H2S in sweet gas stream)

amine solution. According to Figure 4, if Ralu Flow packing is used to achieve 4ppm hydrogen sulfide in sweet gas stream, acid gas loading in rich amine will increase more than critical limit (0.5 mole/mole for MDEA) (Kohl and Nielsen, 1997). At the same time, as shown in Table 5, when concentration of 2 ppm is achieved for hydrogen sulfide, acid gas loading in rich amine will reach the allowed limit while the unit energy consumption will be lower than that using other types of packings in similar conditions.

### *Increasing capacity*

In this study, according to the performance of sweetening unit of BIDBOLAND refinery, flooding critical limit in absorption column is considered to be 65%.

According to this parameter and the results presented in Table 6, the refinery capacity can be increased up to 18% by replacing Pall Ring with Ralu Flow.

Table 5. Comparison of unit performance in presence of Ralu flow packing to achieve 2 and 4 ppm H2S in sweet gas stream (Sour gas flow: 9 MMSCMD)

| Packing Type | Amine Flow (kmol.h$^{-1}$) | $CO_2$ in sweet gas (mole %) | Rich Loading | Flooding (%) | Total Energy (kj/hr) |
|---|---|---|---|---|---|
| Ralu Flow (4 ppm) | 2894 | 1.0892 | 0.530 | 51.15 | 100836732 |
| Ralu Flow (2 ppm) | 3413 | 1.0397 | 0.479 | 53.08 | 123807485 |

Table 6. Comparison of unit performance in presence of Ralu flow packing to achieve 9 and 11 MMSCMD capacity (H2S concentration in sweet gas: 2 ppm)

| Sour Gas Flow (MMSCMD) | Amine Flow (kmol.h$^{-1}$) | $CO_2$ in sweet gas (mole %) | Rich Loading | Flooding (%) | Total Energy (kj/hr) |
|---|---|---|---|---|---|
| 9.00 | 3413 | 1.0397 | 0.479 | 53.08 | 123807485 |
| 11.00 | 3940 | 1.11735 | 0.467 | 62.41 | 142188391 |

## Conclusion

Analysis of simulation results of gas treatment unit of BIDBOLAND refinery shows that changing the type of packing in the absorption column can decrease not only flooding risk, but also energy consumption.

Comparing the performance of modern random packings of Super Ring, Ralu Ring, and Ralu Flow indicates the reduction of flooding risk in the absorption column in the presence of Super Ring packing.

The results reveal that using Super Ring packing will not make any change to the level of absorption of acid gases, energy consumption and the unit capacity compared to Pall ring packing.

At the same time, using Ralu Flow packings (NO-1) largely increases hydrogen sulfide absorption. Although this issue reduces the amine circulation rate, it raises the level of acid gases loading in rich amine solution over the allowed limit.

To solve this problem, amine circulation rate is increased which in turn reduces acid gases loading and increases sweet gas purity.

As seen in the results, using Ralu Flow packing (NO-1) in the absorption column decreases flooding and allows for increasing the unit capacity up to 1.18 times of the current capacity.

It should be noted that like Ralu Flow packing, using Ralu Ring packing (25mm) will decrease the unit energy consumption. However, due to its failure in decreasing flooding, it cannot increase the unit capacity.

## Acknowledgment

This project was carried out within the Research stream on optimization studies of BIDBOLAND Gas Refinery.

The authors wish to thank the refinery research unit officials for their valuable contributions, financial support of this research project and providing all necessary operating information.

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# بررسی اثر جایگزینی آکنه های مدرن با کارآئی بالا در فرآیند تصفیه گاز طبیعی


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## چکیــــــده

**در این تحقیق، اثر نوع آکنه بر نرخ انتقال جرم و میزان افت فشار در برج‌های شیرین سازی گاز طبیعی مورد ارزیابی قرار گرفته است. بدین منظور از میان آکنه های مدرن، انواع Ralu Flow، Ralu Ring، Super Ring و همچنین از میان نسل دوم آکنه‌های موجود، نوع Pall Ring انتخاب شده و اثر جایگزینی هریک از آنها درون برجهای تماس، توسط نرم افزار Aspen Hysys بررسی شده است. لازم بذکر است که با توسعه یک برنامه محاسباتی در MATLAB و فراخوانی آن توسط نرم افزار مذکور، امکان پیش‌بینی پدیده طغیان فراهم شده است. به منظور اعتبار سنجی مدل‌های انتخابی نیز، نتایج شبیه سازی با اطلاعات استخراج شده از یک واحد واقعی مقایسه گردیده، با این تفاوت که اطلاعات تجربی موجود مربوط به واحدی است که از آکنه Pall Ring (نسل دوم) در برجهای تماس استفاده نموده است. نتایج نشان می‌دهد که استفاده از آکنه Super Ring منجر به کاهش افت فشار و همچنین استفاده از نوع Ralu Ring باعث افزایش نرخ انتقال جرم خواهد شد. این درحالی است که استفاده آکنه Ralu Flow ، به تنهایی می تواند هر دو هدف را برآورده نموده و منجر به افزایش ظرفیت شیرین سازی گاز گردد.**


**واژگان کلیدی: شیرین سازی گاز طبیعی، ستون جذب، پرکن، انتقال جرم، افت فشار**