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Comparison and Modeling of Various Packing Materials in a Packed Column Using Two Slightly Soluble Solute Gases

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ABSTRACT: Comparison of various packing's on the basis of their materials using two different solute gases, CO2 and O2, is being presented. Calculations were done on the liquid side and height of transfer units as well as number of transfer units obtained for various flow rates. The result shows superiority of steel Raschig rings over ceramic, glass and plastic rings. Results were analyzed considering material properties such as wettability, surface area offered per square inch, packing factor and voidage. The operating conditions were Temperature = 25°C and Pressure = 1atm. The values of effective interfacial area offered by Raschig rings of different materials vary to some extent. Steel rings hold sway over ceramic rings but the difference is not much. Glass rings and plastic rings come third and fourth respectively and are way behind in perform- mince. The high density of ceramic Ranching rings and steel rings provides each ring with high me- chemical strength and can thus be stacked in larger quantities within your column to further boost the required process. In Ranching rings ceramic is a bet- term option than plastic or metals due to high tolerance levels against high heat and strong acids.

KEYWORDS: Packing, effectiveness of packing, material of packing, absorption, height of transfer units, modeling of packing materials, O2 absorption.

1 INTRODUCTION

Absorption is a mass transfer phenomenon which occurs due to a concentration difference between liquid and gas phase. It depends upon the solubility of solute vapor from the mixture in the liquid. It is controlled by the following four factors

1. Ratio of liquid flow to gas flow (Lm/Gm)
2. Contact time between two fluids
3. Temperature of the heavier liquid flow
4. Reflux stream near the middle of the column

Packed columns have been used extensively on industries for mass transfer processes like gas absorption and distillation. For over 100 years, the factors which govern the rate of absorption of gases by liquids have interested Chemical engineers. In about 1830, for instance, William Gossage filled a derelict windmill with brushwood and ran water over it in order to absorb hydrochloric acid vapor from the manufacture of alkali. This perhaps marks the invention of the first practical absorption tower. A British patent of 1836, incidentally, protected the principle. The chemical and process industries have a lot of examples where absorption of a gas by a liquid is necessary, e.g.; Absorption of nitrous gases in water or nitric acid, during nitric acid manufacture, Absorption of chlorine by alkaline solutions to give hypo chlorites, absorption of oxygen by fermentation broths, removal of carbon dioxide from water-gas by absorption in water or in solutions of alkalis or amines, removal of carbon monoxide from water-gas by absorption in solutions of copper complexes, absorption of hydrogen by petroleum fractions in processes to remove sulphur as hydrogen sulphide, absorption of chlorine and propylene in water to give the chlorohydrin. Packing material should be chemically inert to fluids, strong enough without excessive weight, provide good contact between liquid and gas, be reasonable in cost and provide adequate passage without excessive hold up or pressure drop. Most of the published results for transfer coefficients in packed towers are for small laboratory units of 50-250mm diameter, and there is some uncertainty in extending the data for use in industrial units. Although shapes have a larger impact on the effectiveness of packing, the effect of material cannot be denied. Kowalke, Hougen and Watson determined mass transfer coefficient for absorption of ammonia in water with a packing 1-2m deep in 1925 [1]. Borden and Squires studied the absorption of ammonia in a ring-packed tower with gas mass velocity ranging from 0.07-0.69 Kg/m^2.sec and liquid mass velocity ranging from 0.572-2.67 Kg/m^2.sec [2]. Fellinger studied the absorption of ammonia in water and acids in various standard packing by using 450mm diameter stoneware column in which a perforated packing support was fitted with 20 down comers extending to within 25mm at the bottom of the tower and 120 risers were fitted extending 31mm above the upper surface [3]. He used Raschig rings of different sizes and compared their effectiveness in mass transfer. His results indicated that smaller sized Raschig rings gave comparatively smaller values of height of transfer units and thus higher mass transfer coefficients. Norman performed experiments on the absorption of ammonia in water as well as evaporation of water in an air stream, using packing of carbon slates having volume 11250mm^3 with V-notches as distributor [4]. His findings backed the earlier results presented by Kowalke. Molstad, Mckinney, and Abbey measured the absorption of ammonia in water using a tower of 384 mm side packed with wood grids, or with rings or saddles [5]. They were able to measure mass transfer coefficient by direct experiment. Cooper [6] established that, at high liquid rates and low gas rates used in practice, and with a tower packed to a depth of 2.2m, the transfer rates were much lower than those determined earlier. Traditional methods of assessing the capacity of tower packing, involving the use of a specific surface area S and void age e, were useful for a packed bed of granular material, such as granite, limestone and coke. With the introduction of Raschig rings and other specially shaped packing, it was necessary to introduce new methods which could be used to compare their relative efficiencies. Shulman [7] in the early 1950s showed that the total area offered by Raschig rings was not used and varied considerably with hydraulic loading. Further evidence of the importance of the wetted fraction of the total area came with the introduction of pall rings. It was established that the effectiveness of packing depends upon its amount of wetting. Later, Semmelbauer [8] presented equations to evaluate HG and HL for Raschig rings and berl saddles. Morris and Jackson [9] presented values of the heights of individual film transfer units for various rings. Coughlin [10] reported data for overall liquid side mass transfer coefficient of 3/8 in. Raschig rings made of ceramic, polyethylene and Saran. The values for overall liquid side mass transfer coefficients were same for both Saran and polyethylene rings while those for ceramic rings were 25% higher. Whitney and Vivian [11] reported some data on absorption of lean SO2 in water in a packed column provided with 1 in. ceramic Raschig rings and found that kGa varies as $L^{0.25}$. Dwyer and Dodge [12] reported that kGa varies as $L^{0.20}$.

2 EXPERIMENTAL

Specifications of the column designed: diameter of the column = 6.35 cm height of the column = 110 cm height of packing = 74 cm Surface area of the column = 1475.486 cm^2 volume of packing = 3.5 L packing size = 10*10 mm air flow meter range = 20-180 L/min water flow meter range = 1-22 L/min gas flow meter range = 1-10 L/min air compressor capacity = 0.15m^3/min @ 0.3bar void fraction = 0.40

Absorption column was installed as shown in figure 1. Water was showered from the top and gas injected from the bottom. When equilibrium was attained, a sample was withdrawn. In the case of CO2, KOH was instantly mixed in the sample to prevent CO2 from escaping during titration. With CO2, the titration method was adopted to find the concentration of CO2 absorbed in the sample. HCl was taken in the burette as the titrant. The first end point was colorless using phenolphthalein indicator and second was reddish orange using methyl orange as an indicator. From the volume, first concentration and then the number of transfer units were calculated. With O2 as the solute, DO meter was used to calculate the dissolved Oxygen in the sample. From the concentration obtained, transfer units were calculated.

3 RESULTS AND DISCUSSION

3.1 HEIGHT OF TRANSFER UNIT

The height of transfer unit is the defining factor with regards to the efficiency of the packing used. It measures the separation effectiveness of a particular packing for a separation process. The more efficient packing gives smaller value of HTU. The values of HTU can be estimated from empirical correlations or pilot plant tests, but the applications are rather restricted. Figure-1 shows that steel rings and ceramic rings have lower values of HoL as compared to plastic and glass rings and hence they give better mass transfer in the case of CO_2 absorption. It is also seen that height of transfer unit values dip at the start and after reaching their lowest ebb, start rising. This shows that the flow rates reach an optimum value and after those loading and flooding conditions start making their presence felt. In both the cases, steel rings give the best results followed by ceramic rings while plastic and glass rings lag behind. Figure-2 shows the effect of gas flow rate on the height of transfer unit in case of O_2 absorption. Again the results paint the same picture. Although the difference is not as much as the ones observed with CO_2 absorption, still the order remains the same with steel rings offering the minimum height of transfer unit followed by ceramic, plastic and glass rings respectively. Equation of straight lines is also given which makes it possible to calculate HoL at any flow rate. Table-1 shows the exponential relationship between height of transfer unit and gas flow rate for various rings in the case of CO_2 absorption. Table-2 shows the exponential relationship between height of transfer unit and gas flow rate for various rings in the case of O_2 absorption.

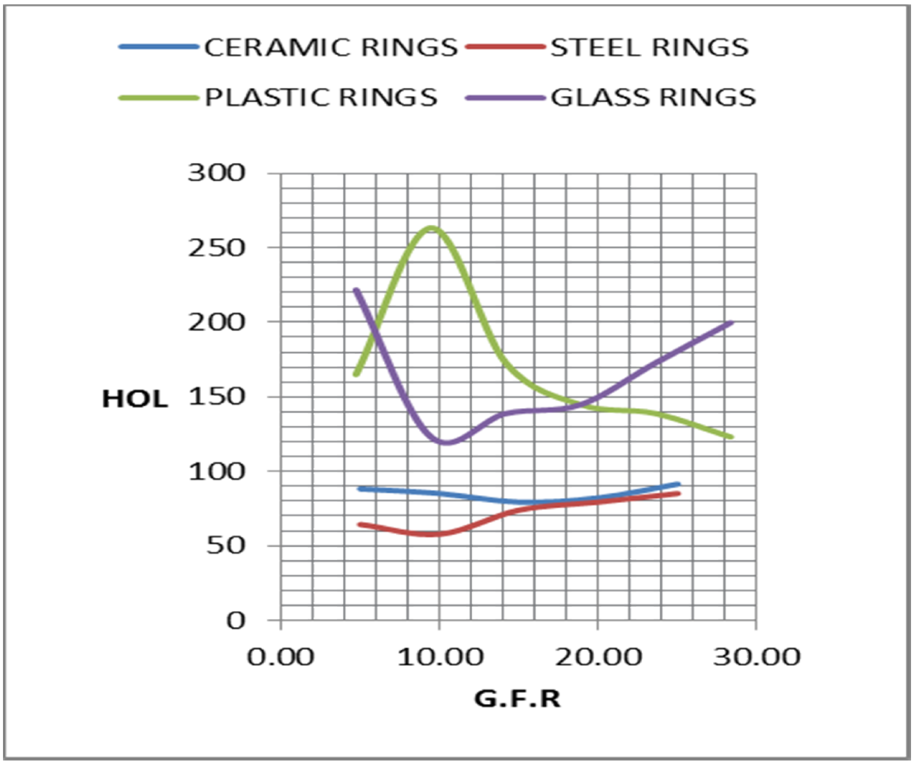

Figure 1 straight line equations and graphical trends of packing studied (CO2 absorption)

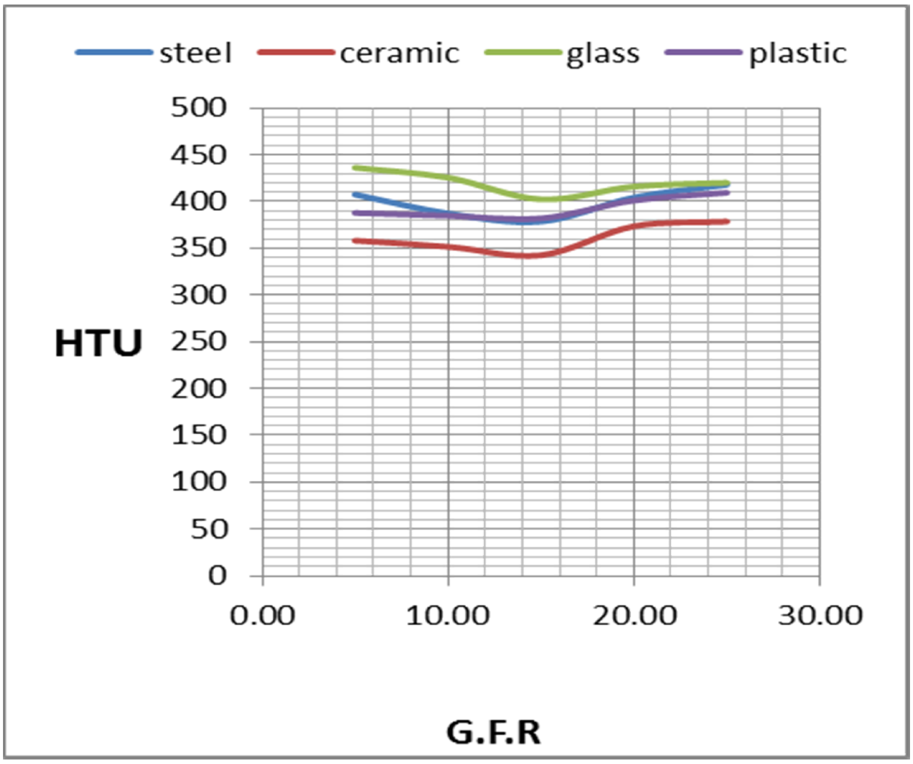

Figure 2 straight line equations and graphical trends of packing studied (O2 absorption)

Table 1 Relationship between G.F.R and H.T.U for the packing studied (CO2 absorption)

Type of packing	Relationship between GFR and HTU
Ceramic	$HoL = 84.249e^{0.0007GFR}$
Steel	$HoL = 54.797e^{0.0176GFR}$
Plastic	$HoL = 232.38e^{-0.022GFR}$
glass	$HoL = 154.78e^{0.0032GFR}$

Table 2 Relationship between G.F.R and H.T.U for the packing studied (O2 absorption)

Type of packing	Relationship between GFR and HTU
Ceramic	$HoL = 342.49e^{0.0034GFR}$
Steel	$HoL = 387.59e^{0.0019GFR}$
Plastic	$HoL = 375.47e^{0.003GFR}$
glass	$HoL = 432.33e^{-0.0022GFR}$

3.2 NUMBER OF TRANSFER UNITS

Higher the value of height of transfer unit, lower the value of number of transfer units and vice versa.

Results show that steel rings, when employed, require the highest number of transfer units and are more efficient than the other packing.

3.3 Surface area

Taking 0.5in size as an example, contact surface area is 368, 417, and 374 m^2/m^3 for ceramic, steel and carbon respectively. This clearly shows that metal rings offer better surface area and thus greater transfer characteristics. However, a packing providing a large surface area may not necessarily result in good mass transfer unless the liquid is distributed uniformly over the surface of the packing.

3.4 Wetting rate

Wetting rate = (volumetric liquid rate per unit cross sectional area of column)/ (packing surface area per unit volume of column). Wetting rate is critical because if it is too low per unit area or is unevenly applied, it will cause poor performance in all distillation and mass transfer columns. If an area of the packing goes dry, a hot spot will be created and the material will coke and plug up the packing. Wettability for a rough surface is greater than that for a smooth one. Better results for steel rings in our experiment can be attributed to their higher wetting rate as compared to other packing.

3.5 Free space

Although the free space in the case of metal rings is greater than that for ceramic rings (table-4), for small columns, this difference is not so significant.

4 Conclusions

The following conclusion can be deduced from the experiments performed: The values of effective interfacial area offered by Raschig rings of different materials vary to some extent. Steel rings hold sway over ceramic rings but the difference is not much. Glass rings and plastic rings come third and fourth respectively and are way behind in performance. Ceramic raschig rings and steel rings have high density and mechanical strength and can thus be stacked in larger quantities to improve the required process. In Raschig rings ceramic is a better option than plastic or metals due to high tolerance levels against high heat and strong acids. The right packing can be very helpful in increasing contact area as well as enhancing liquid gas distribution without sudden drop in pressure. This results in savings in energy as well as optimized mass transfer.

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