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DIXON RINGS – A REVOLUTIONARY RANDOM COLUMN PACKING

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Dixon rings were developed in 1946 by Dr Olaf George Dixon while working for ICI and are currently used where high performance is essential. There are a number of published papers on the characterisation of Dixon rings as used in distillation applications; however, there is little published work on the countercurrent (scrubbing) performance of Dixon rings. Croft Engineering Services have developed a revolutionary manufacturing method for Dixon rings that can be used in both countercurrent absorption (scrubbing columns) including scrubbing of CO_2 from air, as well as hard distillation separations such as tritium from water. This cylindrical mesh item of small size in comparison to the market leaders (Pall rings, Intalox saddles) offers superior performance in a range of applications. The current paper contains a detailed analysis of Dixon rings in a random column packing operating within countercurrent absorption applications.

INTRODUCTION

Packed columns utilising filter media for chemical exchange are amongst the most common devices used in the chemical industry for reactant contact optimisation. Dixon rings, manufactured from stainless steel woven wire mesh with a cross member, offer significant performance advantages to alternative random column packings, particularly where space is critical and so small diameter high efficiency columns are vital. The performance of Dixon rings is comparable to that of structured packing which is extremely column specific, and carries large installation and other costs. Dixon rings comparable performance comes with the ease of 'dumping' the packing in, which reduces the initial installation cost as well as offering cost savings when cleaning or replacement is required. Dixon rings can also be used in retrofits where the performance of the current packing is not delivering that required.

Dixon rings can be used in countercurrent absorption applications, including waste gas scrubbing, acid gas removal, and carbon capture. They can also be used for distillation applications and are specifically used for 'difficult' separations where the boiling points of the constituent parts are very close such as in tritium/water separation at 101.4ºC/100.0ºC, respectively.

Filter Media

Dixon rings are formed from flat sections of 100x100 mesh or 60x60 mesh (Figures 1 and 2). The mesh is then wound to form a cylindrical shape with the cross bar to both provide rigidity to the ring, to avoid crushing and to provide extra surface area. Woven wire mesh is used in a multitude of filtration applications to remove physical particulates from a liquid stream, however, here the woven wire mesh is being utilised for the generation of a liquid film which provides a chemical separation without the requirement for additional energy to promote the separation. Rather, the process of separation (or transfer) occurs through 'intimate' contact between liquid and gas. The photographs show the mesh both in unwound flat form and fully formed Dixon ring shape.

PACKED COLUMNS

Packed columns are used within a range of industries to allow intimate contact between two immiscible/partly immiscible fluids which can be liquid/liquid or liquid/gas. The fluids are usually passed in countercurrent flow through the column with the gas or liquid entering at the base of the column and a liquid entering from

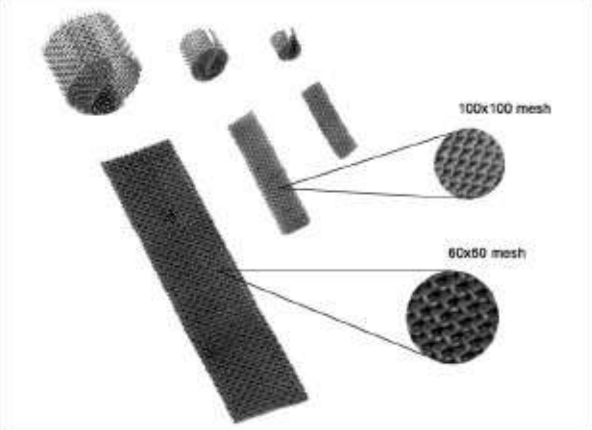

Figure1: Photographs of 1/16", 1/8" and 1/4" Dixon rings, both preformed and formed.

Figure 2: Photographs of 1/8" Dixon rings.

the top. The example studied in this paper is that of a liquid/gas absorption process where soluble carbon dioxide is passed into the base of the column and water passes into the top of the column, the soluble gases being scrubbed by means of the water. Packed columns can also be used for distillation where the more volatile components of a mixture, (in simplest form, binary mixture) undergo transformation due to input of heat into the vapour phase. The less volatile compound will condense out into the liquid phase and can be removed, providing an efficient means of separation. Packed columns as mentioned above can also be used for liquid/liquid extractions where the solute is transferred between solvents.

Flow

To obtain an effective mass transfer within a single column it is essential that a packing is selected which will support a large surface area for mass transfer between the two phases. It is also essential that the flow is not just laminar flow through the column; the packing must promote the formation of a turbulent flow. Time and resources must be put into selection of the most appropriate packing for the application that produces turbulent flow and sufficient surface area.

THE COLUMN

The actual column itself can be constructed from a range of materials depending on the application; materials include ceramic, glass, metals and plastics. The column is mounted vertically causing a water flow (as illustrated later in Figure 3). This prevents the liquid all flowing to one side resulting in ineffective use of some areas of the column.

The packing within the column rests on packing supports which has the greatest free area possible to promote constant flow out of the column with minimal resistance. The simplest support is a grid consisting of bars evenly spaced slightly smaller than the slimmest unit of packing. The gas inlet is designed so that the liquid flowing out of the column and the gas are not competing which would promote unstable operation as the gas bubbles through in bursts, against the water, instead the gas inlet is positioned above the level of the liquid drain. At the top of the column a liquid distributor is installed to promote homogeneous separation of the liquid over the whole packed bed. A similar arrangement may be required within the packed bed to redistribute the flow. The gas inlet is also designed to promote the uniform distribution across the cross section of the column.

Column diameters vary from 25 mm for small laboratory columns up to 4.5 m for large industrial columns which can also be up to 30 m tall. The pressure within these columns varies from vacuum to extremely high pressure.

TYPES OF PACKINGS

Packings can be divided into three main classes: Broken solids which are the cheapest type of packing available in sizes of about 10-100 mm; Shaped packing including Raschig rings and Pall rings, which are used due to their high performance characteristics and low pressure drop; and structured (grid packings). Although broken solids offer good corrosion resistance they do not offer the same liquid flow or effective surface area that is offered by shaped packings. Packings should be of uniform size to produce a bed of standard characteristics with the desired performance.

The size of packing used determines the column size parameters, performance and more noticeable initially, the cost. Generally as the size of the packing increases the cost and pressure drop decrease. However, this tends to be accompanied by a decrease in mass transfer coefficient, leading to a decrease in performance, so to obtain the required overall column performance, large towers are required. Thus, an increase in packing size does not always result in a decrease in overall cost. Normally column diameters should be at least 8 times that of the packing size. In columns of smaller diameter liquid distribution is poor leading to a decrease in performance.

Structured packings which are relatively easy to manufacture are usually used in sections in columns. They can be fabricated from a number of materials and because of relatively large gaps between the grids, they give low pressure drops. This large open area also allows structured packing to accept liquid with suspended solids. However, structured packing tends to promote laminar flow where the liquid flows at high flow rates from grid to grid without being broken up into droplets, the latter of which is of course desired for efficient separations.

For applications where high performance is essential (usually laboratory purposes) column packings such as the Dixon ring, Lessing ring, and knitted mesh (a fine wire mesh) have been developed. These packings are superior to larger packings, in that they offer a very large surface area, which once pre-wetted, is all available for mass transfer to occur. These packings have been used in columns up to 500 mm in diameter.

THEORY OF APPLICATION

Carbon dioxide is a greenhouse gas, and a major contributor at that. It is a by-product in the burning of fossil fuels and an effective method of scrubbing this carbon dioxide is often an essential requirement to prevent it escaping to the atmosphere. Investigation of packing performance in countercurrent mass transfer applications using carbon dioxide and water is therefore relevant and topical.

Design and Operating Requirements

Design Requirements

To maximise the efficiency of a column packed with Dixon rings the diameter must be a minimum of six times that of a singular unit. Therefore, when working with 1/8" (3.175 mm) Dixon rings the column must be a minimum of 20 mm, however, it is advisable to design columns with greater diameter than this. The column must also have an easy access both top and bottom for filling and emptying the Dixon rings, although this will be an infrequent requirement.

Operating Requirements

The principle behind the countercurrent application of Dixon rings is the formation of a liquid film over the rings, in which the gas passing up and over this film is 'scrubbed'. One specific requirement of Dixon rings then is the need for pre-wetting. If operation is started without pre-wetting the rings, efficiency is greatly reduced. Pre-wetting is achieved by flooding the column slowly (i.e. over a period of at least an hour); the bottom valve is shut and the liquid allowed to run in and 'flood the column' at a low flow which both stops air locks and allows all the Dixon rings to be thoroughly wetted. It is advisable to leave the column flooded between uses. Once the column is fully flooded the valve at the base of the column is opened slowly and the desired liquid flow selected. The column is then left for a further hour to reach equilibrium before any gases, clean or dirty, are shown to the column.

CHARACTERISATION OF PACKING PERFORMANCE

Surface Area

The surface area of Dixon rings was obtained through BET surface area analysis using krypton. Although the surface area of Dixon rings is large in comparison to other packing materials, it is still on the lower end of the operating range of typical BET surface area measurement equipment. The surface area of a 1/8" ring was quantified as 2378 m^2/m^3, almost triple that of the common 10 mm Pall ring.

Pressure Drop

The pressure drop is known to be very low for Dixon rings, which allows them to be used in reduced pressure applications as well as allowing energy savings in terms of energy consumption of pumps and blowers. The pressure drop was calculated by Dixon[1] as 49.82-647.63 Pa per 305 mm of packing for vapour flow rates of 30-274 mm/s. In the apparatus described here, the pressure drop was considered to be negligibly small.

Mass Transfer Coefficient

The Height Equivalent of a Theoretical Plate (HETP) was reported by Dixon[1] to be as high as 200 plates in a 914 mm length, 258 mm diameter, column (an HETP of 4.57 mm). The mass transfer coefficient in this work was determined to be in the region of 463.22 mg/l/min.

Liquid Holdup

The quantification of both dynamic and static liquid holdup is required. The dynamic liquid hold up is the volume of water in the column at any one point during normal operation. This quantity is very important due to its relation with wetted area, pressure drop, flooding characteristics and transient behaviour of the column. This quantity is measured by closing both the inlet and outlet flows and then collecting the liquid in the column. Most packings promote the path of water to the outer walls of the column resulting in a decrease in efficiency meaning that regular redistributor plates are required. Dixon rings, however, promote the funnelling of liquid into the centre of the column causing a visual effect of a very low dynamic holdup, although at maximum operating flow the column is approximately 80% full. Dixon[1] measured the dynamic liquid holdup to be between 10-48 g per 645 mm^2 of the column.

Most previous research, including Gilath et al.[2], King[3], Leva[4], Norman and Hu[5] and Shulman et al.[6] found that for a given packing, the liquid holdup is proportional to the liquid mass flow rate to a power of between 0.5 and 0.7. It is known (Norman and Hu[5]) that the thickness of a film of liquid flowing down a plate is proportional to the cube root of the liquid flow rate. When the packing has undergone pre-wetting, the wetted areas and the static holdup should reach a constant value. Change in the liquid flow rate should then affect only the dynamic holdup as a result of the change in film thickness. The difference between the experimentally found power of 0.5 to 0.7 and the theoretical one of 0.33 is attributed by Norman and Hu[5] to changes in the wetted areas of the packing.[2]

Static liquid holdup is the volume of liquid that remains in the column after it has drained. This is the liquid that is still forming a film over the Dixon rings. The measurement of static liquid holdup is performed by draining the column as usual, however, once the liquid flow has stopped (or become very slow, i.e. dripping) the drain valve is shut and the column is left for 24 hours and during this period the water runs down the column. As with dynamic liquid holdup, the liquid is then drained off to give a value for static liquid holdup.

Within the current research the dynamic liquid hold up was determined to be 0.71932 mm^3/mm^3 of column and the static liquid holdup was determined to be 0.17325 mm^3/mm^3 of column.

EXPERIMENTAL

The purpose of the current research was to fully characterise Dixon rings within countercurrent mass transfer applications. The Dixon rings used in this work had the characteristics shown in Table 1. A column operated under countercurrent flow of air and water is eas-

Size of Dixon ring	1/16”	1/8”	1/4”
Stainless steel grade	316 (1.4401)	316 (1.4401)	316 (1.4401)
Mesh	100 x 100	100 x 100	60 x 60
Wire diameter (µm)	112	112	160
Gauge	42	42	38
Aperture (µm)	152	152	271
Open area of mesh (%)	36	36	40
Width of mesh per Dixon ring (mm)	1.60	3.20	6.35
Length of mesh per Dixon ring (mm)	7.50	15.00	30.00

Table 1: Structural data for Dixon rings.

ier to operate than under distillation conditions, but under correct operation can simulate some of the conditions experienced in a distillation application. The columns operated for this research were 24 mm and 54 mm internal diameter by 1000 mm height packed with 1/8” Dixon rings. The apparatus used along with the principal elements is shown in Figure 3.

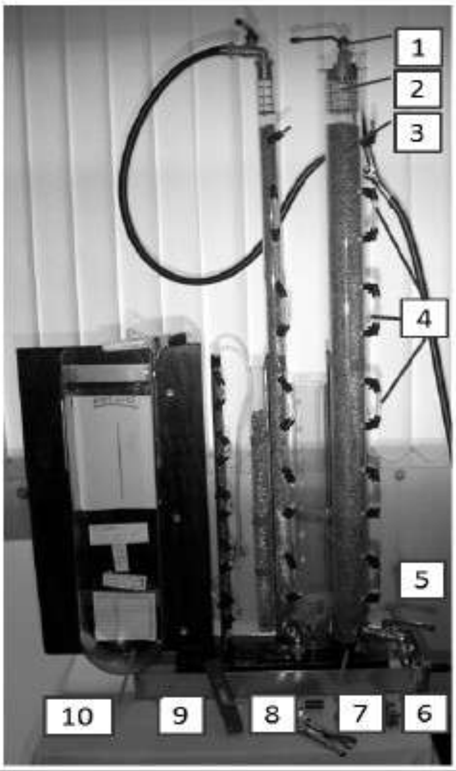

Figure 3: Photograph of rig on which measurements were taken. (1. Tap to control water flow; 2. Water diffuser; 3. Column packed with Dixon rings; 4. Sampling points on column connected with water level indicators; 5. Tap to control water flow out; 6. Drain; 7. Column inlet for CO_2 from cylinder; 8. pH meter to measure CO_2 absorption in water; 9. Water collecting tray where water sampling and analysis takes place; 10. U-tube differential pressure tubes to measure pressure drop and digital manometer.)

SUMMARY OF PERFORMANCE RESULTS

The physical properties of the Dixon rings used are summarised in Table 2.

Graphic Representation of Optimum Conditions
The performance characteristics of the column in relation to CO_2 absorption efficiency are represented in the form of a 3D contour surface in Figure 4. For the chosen column arrangement, the authors achieved optimum CO_2 absorption performance in excess of 400 ppm between water flow rates of 0.5 and 1.5 l/min and carbon dioxide flow rates of 4-10 l/min.

Raschig Rings
The Raschig ring tests were undertaken with 4.76 mm (3/16”) and 6.35 mm (1/4”) diameter rings. The best performance was lower than that of Dixon rings by at least a factor of 3 and only then in a very narrow operating envelope as shown on Figure 5. At water flows above 1.5 l/min the column began to overflow when carbon dioxide was added. This shows there is a small operating range over which the Raschig rings work efficiently within counter current absorption. The pressure drop was also far greater at the point just before flooding, i.e. a pressure drop of 2721.35 Pa/300 mm of packing. The maximum operating water flows are shown in Table 3.

These results clearly show the superior performance of Dixon rings, in comparison to an almost identical size ceramic packing.

CONCLUSIONS

The following conclusions can be drawn from the work:

1. The surface area of Dixon rings was calculated to

Property	1/16”	1/8”	1/4”
Surface area (m^2/m^3)	3550	2378	900
Void space (%)	94.63	90.98	90.73
Number per litre	102,200	24,400	2965

Table 2: Summary of Dixon ring physical properties.

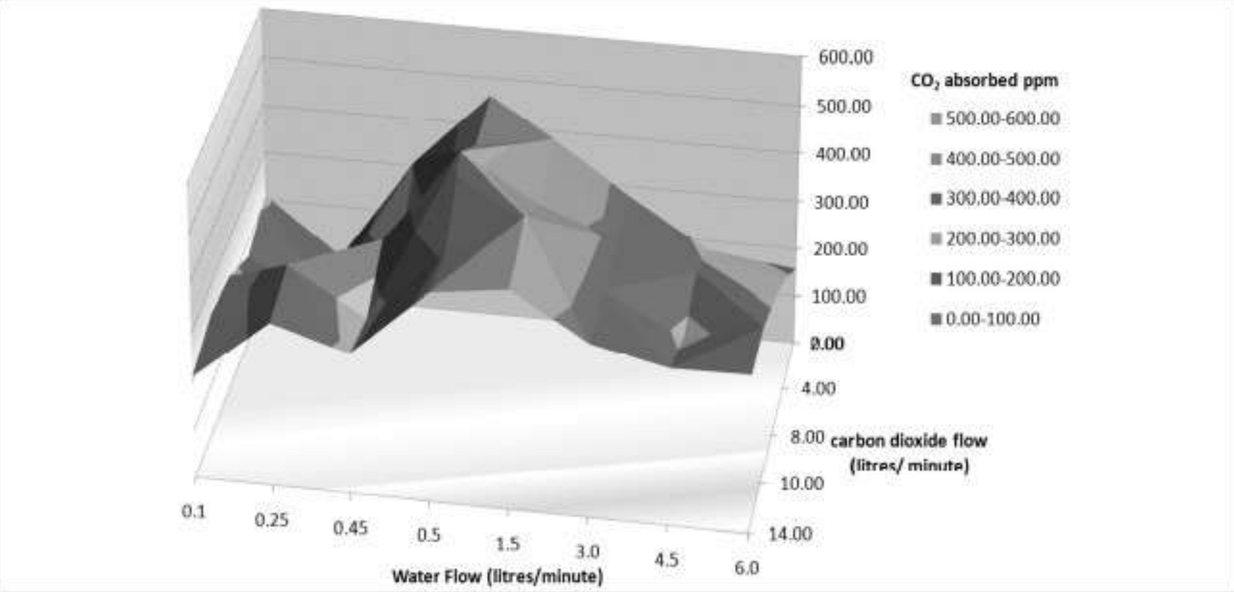

Figure 4: Graph of Dixon ring performance.

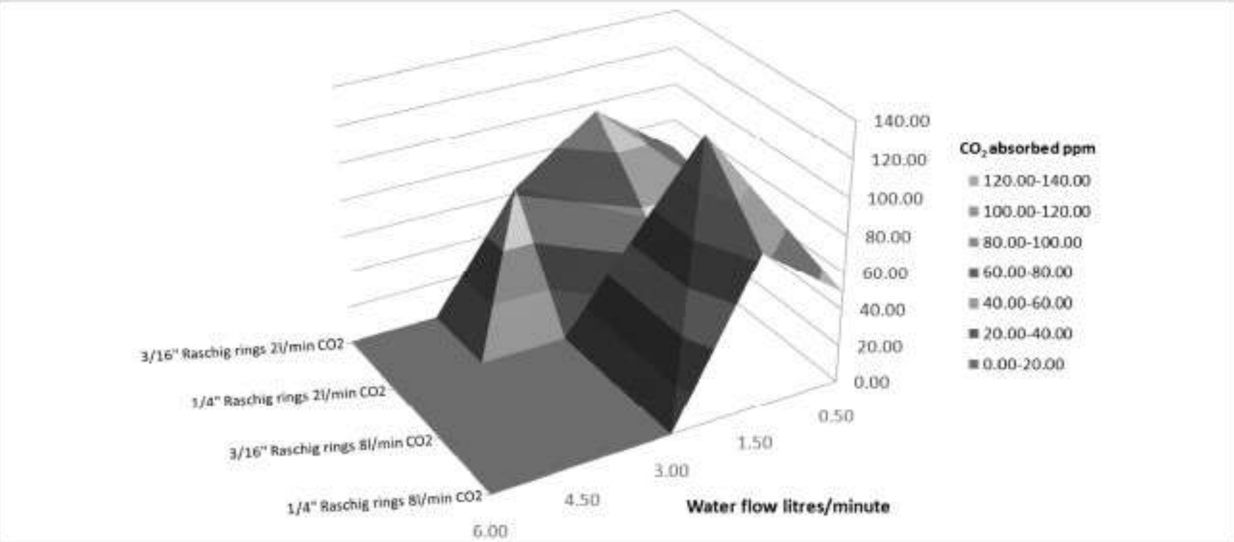

Figure 5: Graph of Raschig ring performance.

be 2378 m^2/m^3, with the surface area of the 5 mm Raschig rings only being 1000 m^2/m^3.

2. The performance of Dixon rings measured through the mass transfer coefficient was determined to be 463.22 mg/l/min, which far exceeds that of other common packings.

3. The dynamic liquid hold up was determined to be 0.71932 mm^3/mm^3 of column, and the static liquid holdup was 0.17325 mm^3/mm^3 of column.

Previous work has shed much light on the performance of random column packings and some of this is summarised here. In spite of the comprehensive early work of Dr Dixon, it is clear that there is limited information on the scrubbing and distillation capabilities of Dixon rings, which are both very important. The re-

Size	2 litres/min CO_2	8 litres/min CO_2
3/16" (4.76 mm)	2.31	1.67
1/4" (6.35 mm)	2.22	1.33

Table 3: Maximum operating conditions Raschig rings.

sults presented here demonstrate that in certain applications, the performance of Dixon rings clearly exceeds that of any of the other common random column packings. This performance advantage makes Dixon rings the ideal choice of packing for a number of very important applications including scrubbing of carbon dioxide from the air in critical applications such as CO_2 recovery in submersibles, difficult distillations such as that of tritium removal from water, small scale research and development where precise highly accurate results are required and more generally in the improvement of existing processes (for example, retrofitting columns containing inadequate packing with more superior Dixon rings).

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