Sizing of Packed Towers in Acid Plants

Packed towers are key components in sulfuric acid plants. Drying of the sulfur furnace air is necessary to avoid acid condensation and corrosion in downstream equipment and to minimize mist formation. Absorption of SO$_3$ in the Interpass and Final Towers recovers the product sulfuric acid. Great attention to detail is required in the design of packed towers to achieve the necessary absorption efficiency. In many ways, the sulfuric acid industry is unique in that packed towers of exceptionally large diameters with relatively small packing height are common. In addition, the use of large size ceramic packing has become the industry standard. A result of the unusual features of packed towers employed in acid plant service is that truly applicable design data are not readily available and that discrepancies reveal themselves when the designs of different technology suppliers are compared. For the engineer facing the task of sizing a packed tower or selecting a supplier, it is tempting to assume that the design techniques for acid plant towers are well proven and that differences in supplier's offers simply reflect differences is design conservatism.

Figure 1: A Typical Sulfuric Acid Plant Layout

Sizing of Packed Towers in Acid Plants
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Presented at The Chemical Engineers’ Resource Page
It is suggested, however, to take into consideration the following points:

- A standard three inch saddle is available from a number of suppliers at relatively low costs. This saddle has been used for over thirty years in the sulfuric acid industry. Only modest profit margins in making and supplying this type of packing can be expected, not sufficient to commission significant development work on packing performance in large towers, especially when competing suppliers would gain the benefit of the development at no cost. Contractors are in a similar position, leaving the owners as the only party likely to gain from development work. Where new packing is proposed, there is a need to compare it with existing packing to see if there is an improvement which justifies the development expense or makes the changeover of packing attractive to the owners. This economic reality has limited the introduction of new packing over the past twenty years.

- Engineers involved in sizing towers have at their disposal a number of different techniques for tower sizing, ranging from rules of thumb based on gas velocity and irrigation rate, to dated theoretical work in the handbooks, to software programs from packing vendors, and finally to proprietary in-house design techniques. The resulting tower sizes vary significantly, as this paper will show. In addition, there is a need for design approaches which can be used with new packing for which there is little data. Most of the experimental work on packing pressure drop was carried out over forty years ago, almost exclusively in small pilot towers. Norton, for example, did much of their early work using thirty inch diameter towers while Koch used a thirty-six inch diameter tower. When the packing sizes were relatively small, the effect of the tower diameter on the packing density was minimal, but when larger packings were used in these pilot towers, there were significant edge effects and the void fraction in the test column was much larger than that found in large towers typical in acid plants with the same packing. The result was very optimistic predictions of pressure drop. Figure 2, reproduced from a brochure published by VFF Industries, shows the relative number of pieces of packing per unit volume, the packing density, as a function of the ratio of the tower diameter to the characteristic dimension of the packing. The curve uses a reference packing density in a tower with a diameter twenty times the nominal size of the packing. For a three inch nominal size saddle, this would give a tower diameter of six feet. For a three foot tower, the packing density would be ninety seven percent of that of the reference tower, while for a twenty foot tower, the actual packing density would approach one hundred and ten percent of the reference case. The packing void fraction will vary accordingly with high packing densities resulting in low void fractions. The packed tower pressure drop and flooding limits are very sensitive to the void fraction, as will be shown later in this paper. It has been found that the pressure drop for a given large size packing in a plant scale tower can exceed twice the pressure drop measured in a pilot tower under identical process conditions.
• The Generalized Pressure Drop Correlation (GPDC) is the classic sizing method for packed towers and is used in many industries. It is, however, based mostly on the small pilot tower data. As long as the correlation is applied to small packing, it appears to give reasonable results, but when the performance of large packing in large towers is assessed, then the results appear overly optimistic. A second rule of thumb method is to size the tower based on a packing exit gas velocity of 8 ft/s with an acid irrigation rate of 10 USGPM/ft². Most often the velocity used in sizing the tower is that of the gas leaving the packing. Different techniques should be applied to the tower bottom depending on the temperature of the inlet gas and the relative acid flow. A third sizing approach is to use the published pressure drop curves for the air and water system which are publicized in the suppliers’ literature. Figure 3 shows one such plot published by U.S. Stoneware. This approach is more practical but, as previously discussed, the data were again mostly developed in small pilot towers, even when large packing was studied. On the basis of proprietary design approaches, one from a packing supplier, and the second from a chemical company, a design approach was developed by CECEBE based on ideas originally proposed by Dr. Max Leva. Field
data were carefully taken in full sized towers to refine the correlations and design methods. The method of Dr. Leva starts with dry bed pressure drop, which is then corrected for the liquid flow through the packing and also for loading. With moderate gas flows and pressure losses, the incremental increase in pressure drop due to liquid irrigation depends on the liquid flow but does not change with gas velocity. Greater liquid flow causes greater liquid hold-up and higher interstitial gas velocities. These two effects combine to result in higher pressure drop. In this range of moderate gas and liquid flow rates, pressure drop curves for irrigated packing run parallel to the dry gas pressure drop curve. Further increases in gas and liquid flow, beyond a critical limit called "loading point", result in a rapid increase in the liquid hold-up due to spray re-entrainment and causes increased pressure loss. Eventually, the liquid hold-up fills a significant part of the packing void and it becomes difficult to force gas flow through the packing. The tower ultimately floods.

Figure 3: Pressure drop vs. gas rate (1 1/2-in. Intalox saddles--ceramic)
The various design approaches described earlier have been used in this paper in a standard absorber to predict the tower size on the basis of operating with standard packing. In addition, tower sizes were developed for both the HP™ Saddle Packing developed by CECEBE Technologies and the Flexeramic Structured Packing developed by Kock.

PACKING DESCRIPTIONS

The highly corrosive nature of sulfuric acid has restricted the materials that can be used economically in acid plants to ceramics. In the pioneering days of the industry, quartz rock or crushed brick were often used in packed towers. In due course these packings, which are very inefficient, were replaced by ceramic Raschig rings and by grid tile. The author has had personal experience with a situation where one tower with quartz rock was still found to be in operation while the others were filled with three inch cross-partition rings. Ceramic Pall Rings were also used in early days, but soon ceramic saddles became the industry standard. Originally 1.5" saddles were used, followed later by 2" saddles, and finally by 3" saddles. Recently, CECEBE introduced the HP™ Saddle Packing, which has more open structure and, therefore, has a much lower pressure drop with greater capacity. It is made of much stronger porcelain which has less tendency to form chips. Structured Ceramic Packing and Wave Packing have been introduced by other suppliers and design techniques need to be disclosed for these new packings. Surprisingly, the actual performance of the standard 3" saddle in a large tower also remains to be firmed up.

PHYSICAL FACTORS

Void Fraction

Since gas in an acid plant packed tower flows up and the liquid flows down to achieve the required gas-liquid contact, the packing functions as a liquid surface generation device. While good mixing action by the packing is a desired feature in that it promotes mass transfer, packing must not cause the tower to fill with liquid and prevent gas counterflow. The void fraction of packing, which is the space available for the gas and liquid to flow, depends on many factors. These factors include the shape of the packing, the diameter of the tower relative to the size of the packing, the degree of packing chips or sulfate accumulation and the liquid flow rate. Figure 2 illustrates the variation of packing density with the ratio of the tower diameter to packing characteristic dimension. Ceramic packings typically have void fractions around 0.75, although a number of references from small sized towers have declared 0.80 void fraction for the same packing. This small difference is significant in that a 0.05 decrease in void fraction will add over fifty percent to the pressure drop. Fouling with sulfate or chips can easily double the pressure drop as well and it may be desirable at the initial design stage to make an allowance for such fouling.
Effective Surface

While the actual surface of the packing pieces can be deduced from geometry, tests with Raschig rings have demonstrated that a significant portion of the surface is not wetted by the circulating liquid and is, therefore, ineffective. The same conclusion is not necessarily true for other packings. The HP™ saddle and Pall Ring both have less surface than their predecessors but their surface is much more effective. With an identical shape, the surface required for satisfactory mass transfer is similar for small or large packing. The smaller packings, however, typically have a much larger surface area per unit packing volume and, therefore, will need less packing height. The penalty is that smaller packing has a larger pressure drop so that the tower diameter must be increased to handle a given gas and liquid flow rate. Note that liquid distribution also becomes more difficult as the diameter of a tower increases. In addition, tower costs are mostly a function of diameter and not of height. It is therefore, not economical to use small packing.

Gas Passage Size

For a given packing height, the number of time the gas must detour around a packing piece depends on the size of the packing, while the mass transfer depends to a significant degree on the extent to which the gas stream is split and contacts the liquid. The larger the packing, the higher is the height required for the mass transfer duty and the smaller the required tower diameter. The pressure drop depends largely on the number of gas detours as the gas passes through the packing.

Random Orientation

Packing can be structured or random. Structured packing is a relatively new development. It still remains expensive and difficult to install. Its capacity is, however, marginally higher than the standard 3” saddle. A serious shortcoming of structured packing is that good initial liquid distribution is absolutely necessary to achieve the required mass transfer efficiency. In other applications involving structured packing, ten irrigation points per square foot are commonly specified. In acid tower applications, a layer of saddle packing is often used on top of the structured packing to achieve adequate liquid distribution. This requirement voids the potentially higher capacity of structured packing. Most packings used in the sulfuric acid industry are random and the standard 3” saddle is a good example. The Berl Saddle, which preceded it, can stack in a tower and is now rarely used for that reason. The Raschig ring and derivatives are also good random shapes. For effective use, a packing dimension should be small compared to the tower in which it is installed and preferably packing should not have a long and thin shape. Such a geometry can lead to gas bypassing at the wall of the tower.
Mechanical Strength

Ceramic packing can break easily if it is not properly fabricated. The two techniques by which such packing is made are by extrusion and by slip casting. Extrusion is the most common technique as it is relatively inexpensive. Slip casting produces a saddle of greater density, which has much lower rates of absorption of acid and water and which is much harder to break. In addition, the packing shape must be designed to provide sufficiently thick cross sections to minimize breakage. The CECEBE HP\textsuperscript{TM} saddle benefits from both thick sections and the slip casting technique to give a packing that is exceptionally strong, nearly three times stronger than conventional ceramic 3" saddles. Structured packing uses thin sheets which are fragile.

A further factor affecting strength in general is the clay that is used in the manufacture. Most packing is made from mined clay with little further preparation and the clay composition can very depending on where in the pit it comes from. Clay used for porcelain or domestic fixtures is normally formulated to a specified grain size distribution and chemical composition and results in a stronger and more homogenous saddle. The HP\textsuperscript{TM} saddle, for example, uses the same clay that is used in the fabrication of toilets and sinks. It is of a much higher quality than the clay mined directly from the pit. This is important to an owner because packing can be broken during installation or during operation, resulting in chip generation which will then lead to excess pump wear, plugging of acid coolers and distributors, higher pressure drop, and expensive downtime for cleaning.

Acid Absorption

Where ceramics have been produced by extrusion, voids in the packing must be expected. This results in significant absorption of acid into the packing and extended acid weeping on shutdown, making access and maintenance difficult. Voids in slip cast ceramics are much less common. This difference reveals itself in the specific gravity of packing which can range from 2.3 in the extruded product to 2.7 in the slip cast porcelain.
PRESSURE DROP PREDICTION

When packed towers were initially introduced as mass transfer devices, the dry gas pressure drop across them was the first criterion which was evaluated and work by Ergun and Leva resulted in a correlation for dry bed pressure drop of the following form:

\[
\Delta P = \frac{(2f_m G^2 L (1 - \varepsilon)^{3-n})}{D_p g_e \rho_g \Phi^{3-n} \varepsilon^3}
\]  

(1)

where

- \( \Delta P \) = pressure drop (inch W.C.)
- \( f_m \) = modified friction factor (Perry's Figure 5 - 67)
- \( G \) = gas mass velocity (lb/ft\(^2\) h)
- \( L \) = bed depth (ft)
- \( \varepsilon \) = void fraction
- \( n \) = exponent, function of Reynolds number
- \( D_p \) = characteristic particle dimension
- \( g_e = 32.2 \) (ft/s\(^2\))
- \( \rho_g \) = gas density (lb/ft\(^3\))
- \( \Phi \) = shape factor
- \( Re \) = Reynolds number, needed for \( f_m \) and \( n \)

A detailed definition of Equation 1 can be found in Perry's Chemical Engineers' Handbook, 6th Edition. For packed towers using large size packing, the flow is generally turbulent, which results in "n" being equal to 2. Equation 1 can thus be simplified to:

\[
\frac{\Delta P}{L} = C_2 \frac{(1 - \varepsilon)}{\varepsilon^3} G^2 \frac{1}{\rho_g}
\]  

(2)

\( C_2 \) combines the constants of Equation 1 and the characteristic packing dimension \( D_p \).
Tower packings typically have a void fraction of 0.6 to 0.8, which makes the void fraction term in the denominator very significant. The gas velocity $G$ can be replaced by the empty tower approach velocity, $V$. The term $V/\varepsilon$ gives the interstitial gas velocity in the tower $V_i$ so that Equation 2 can be re-written as:

$$\frac{\Delta P}{L} = C_2 \left( 1 - \varepsilon \right) \frac{V_i^2}{\rho_g} \frac{1}{\varepsilon}$$

(3)

Introducing a characteristic term $F_s$, where

$$F_s = \frac{V}{\sqrt[3]{\rho \varepsilon}}$$

(4)

results in

$$\frac{\Delta P}{L} = C_2 \left( 1 - \varepsilon \right) F_s^2 \frac{V_i^2}{\varepsilon^3}$$

(5)

Figure 4 shows dry bed pressure drop curves for a variety of packings. These curves are based on both plant measurements and published data, but differ from handbook information in that the data have been adjusted to apply to full sized towers. The correction to the data has resulted in significantly higher pressure losses for the larger packings. It is seen that each packing has an associated constant to express the relationship between the pressure drop and the gas velocity.
As already mentioned and shown in Figure 3, irrigating the packing with liquid results in liquid filling part of the void space and constricting the passages for gas flow. Leva introduced an exponential term for this phenomenon from experimental pressure drop data and CECEBE has continued with this approach and has further refined the equations based on full scale plant measurements. The equation resulting from this evaluation for the liquid correction is the following:

\[ \text{LC} = \exp \left( C_3 \, V_L \right) \]  \hspace{1cm} (6)

where

\[ \text{LC} = "\text{Liquid Correction}" \] factor associated with irrigation below the loading point  
\[ V_L = \text{irrigation rate (ft/s) based on an empty tower} \]  
\[ C_3 = \text{packing specific constant} \]
The irrigated packing pressure drop is then,

$$\frac{\Delta P_{\text{IRR}}}{L} = \left(\frac{\Delta P}{L}\right) (L C) = C_2 \left(\frac{(1-\varepsilon)}{\varepsilon^3}\right) F_t^2 \left[\exp \left(C_3 V_L\right)\right]$$  \hfill (7)

Values of $C_2$ and $C_3$ for various packings were developed by correcting published pilot tower data for the smaller void fractions expected in full sized towers. The results are shown in Table 1.

**Table 1: Coefficients for Pressure Drop Prediction**

<table>
<thead>
<tr>
<th>Packing Type</th>
<th>Size</th>
<th>$C_2$</th>
<th>$C_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Saddle</td>
<td>1.0”</td>
<td>0.69</td>
<td>22.33</td>
</tr>
<tr>
<td>Standard Saddle</td>
<td>1.5”</td>
<td>0.38</td>
<td>22.33</td>
</tr>
<tr>
<td>Standard Saddle</td>
<td>2.0”</td>
<td>0.21</td>
<td>22.33</td>
</tr>
<tr>
<td>Standard Saddle</td>
<td>3.0”</td>
<td>0.15</td>
<td>22.33</td>
</tr>
<tr>
<td>CECEBE HP$^{TM}$ Saddle</td>
<td>#3</td>
<td>0.08</td>
<td>18.88</td>
</tr>
</tbody>
</table>

The above constants and Equation 7 apply to the irrigation region below the "loading point".

When pressure drop curves for irrigated packing are examined, initially the liquid hold-up is solely dependent on the irrigation rate and the packing characteristics and this is shown by the irrigated pressure drop curves which parallel the dry bed pressure drop curve on the logarithmic plot. As the gas velocity is increased beyond a critical value, the "loading point", the pressure drop rises more rapidly as the flow of liquid through the packing is impeded by the upward high velocity gas flow.

It is possible, from published data, to develop a correction method for the increase in pressure drop due to liquid loading and, based on the pressure drop calculated on the basis of no loading, to make a reasonable estimate of the pressure drop in the lower part of the loading region. When the calculated pressure drop rises well above one inch per foot, however, the tower may or may not flood, either locally or totally, such that a further extension of the proposed loading correction needs to be treated with caution. These comments apply to the large saddle packing, which is almost impossible to flood under industrial conditions. Massive acid carry-over to the mist eliminators would normally make a tower inoperable well before it floods. As is the case for the effect of irrigation, an exponential function is likely to best fit the data and a relationship can be formulated as follows:
The relationship between the square of the irrigated pressure drop and the correction factor for the loading region is based on data from the standard saddle but should apply in general. For the HP™ and other saddles, the best estimate is that $C_4$ is equal to 1.6. For this numerical value of $C_4$, the pressure drop in the loading regime rises sharply as the calculated irrigated pressure drop rises beyond 0.6" W.C. per foot.

The complete CECEBE correlation for the irrigated packing pressure drop in large towers at a pressure drop of 1" W.C. per foot of packing or less can now be written as:

$$\frac{\Delta P_L}{L} = 0.08 \left[ \frac{(1 - \varepsilon)}{\varepsilon^3} \right] \rho_g V_g \left[ \exp \left( 18.88 \frac{V_L}{\varepsilon} \right) \right] \left[ \exp \left( 1.6 \left( \frac{\Delta P_{IRR}}{L} \right) ^2 \right) \right]$$  \hspace{1cm} (10)

For clean HP™ packing in a large tower, $C_4$ is 0.75.

Figure 5 is a plot of Equation 10 of pressure drop in a tower as a function of superficial gas velocity for HPTM saddle packing and standard 3" saddle packing. For a given superficial gas velocity, say 5 ft/s, the savings is pressure drop in replacing standard 3" saddles with HPTM saddles will exceed 50%. Alternatively, for a given pressure drop, say 0.4" W.C./ft, the superficial velocity can be increased by over 40% flow rate.
This CECEBE HP™ design correlation has been verified through measurements in a number of large acid towers operating with gas velocities in excess of 10 ft/s. Separate measurements were made for the pressure drop in the tower nozzles and packing support. It should be noted that data with pressure drop above 0.6" W.C. is very limited. At present, it is not recommended to design a new tower to operate in the loading zone. The proposed correlations are useful, however, to assess the effect of fouling and to analyze the performance of a tower which is asked to accommodate an increase in production.

Additional plant operating data would be very useful to confirm or adjust the constants used for the proposed correlation. Since the Florida fertilizer industry has many acid towers in operation, there is probably no better source for both, realistic evaluations of the packing pieces needed per unit volume, and the pressure losses under plant conditions. Where new packings are used, the background equations also offer an opportunity for comparison with other packings in similar sized towers.

The rise in pressure drop due to irrigation and loading can also be used to assess the associated liquid hold-up. As the gas velocity increases, the kinetic energy in the gas allows liquid to be entrained by the gas and to be carried up to the next packing layer, thereby increasing the "apparent" internal irrigation rate between packing layers. This mechanism will increase significantly the liquid hold-up and the gas velocity in the bed, and the pressure drop will rise as illustrated in the previous section. Operation in the loading regime is normally avoided because good design techniques for this region are lacking. With good pressure drop data, it is possible to evaluate this phenomenon in more detail and perhaps extend the design and operating limits of packed towers.

Since the increase in gas pressure drop is associated with a reduction in the void fraction by liquid hold-up, it is also possible, by using the basic equations, to calculate the actual void fractions for operating towers and deduce both hold-up of liquid and fouling with packing chips or sulfate. In this case, void fraction is the gas space free of packing, liquid hold-up, and fouling deposits. Having available pressure drop data, gas and liquid flow rates and gas density allows the calculation of $E$ from Equation 10.
COMPARISON OF PACKING

When new towers are designed, an allowance for fouling should be made by adjusting the void fraction using Equation 2, for example by assuming that the void fraction is lowered by fouling. Similarly, when repacking a tower, the old packing probably will have a lower void fraction due to fouling or shrinkage, than when it was originally installed. The pressure drop and power saving associated with repacking as calculated by normal techniques will probably underestimate the benefits. Similarly, newer packings, for which full size tower data are available, can be more rigorously screened for economic viability. In many cases, the power savings from repacking with a lower pressure drop packing will often pay for packing premium costs in one or two years. If there are fewer chips, further savings will result, but these are harder to quantify. In general, the cheapest packing available is probably the worst bargain for the owner unless the towers had been grossly oversized to start with. This point has not yet been recognized by many owners.

Two-phase flow has been studied for many years, mostly in small towers. The common design methods advocated can generate significantly different solutions for the same packed tower duty depending on the methods used. Several different approaches to packed tower design were reviewed in preparing this paper.

Let us consider now the different methods of tower sizing in more detail. The most common approach is that described in Perry's Chemical Engineers' Handbook, 6th Edition. The GPDC is shown in Figure 18-38 in this reference and has been copied here from another reference as Figure 6. The packing factor "F" for Figure 6 are provided in Table 2. The data on which this figure is based were obtained in the fifties and sixties using a thirty inch diameter column. Packing factors are shown in a separate table. Sherwood, Holloway, and Eckert were the primary contributors to this work but Eckert is responsible for the form as it appears in Perry's. Initially the key characteristic of the packing was the ratio of the interfacial area (a) of the packing to the void fraction in the bed (a/ε³). Leva has also been given credit for this correlation, but he does not claim credit nor does he recommend it.
Figure 6: Generalized Pressure Drop Correlation

**NOTATION**

- \( a_p \): Surface Area of Packing
- \( D_p \): Packing diameter (ft)
- \( F \): Packing factor
- \( G \): Gas mass velocity (lb/ft\(^2\).h)
- \( L \): Liquid mass velocity (lb/ft\(^2\).h)
- \( V \): Superficial gas velocity (ft/s)
- \( \Delta P \): Pressure drop (in. H\(_2\)O/ft)
- \( \epsilon \): Void fraction
- \( \nu \): Kinematic liquid viscosity (cst)
- \( \rho_g \): Gas density (lb/ft\(^3\))
- \( \rho_l \): Liquid density (lb/ft\(^3\))
It is now known that using data derived from large packing in small towers introduces errors both in the interfacial area, more saddles in a cubic foot than predicted, and lower void fraction. For the same reason, drastically revised packing factors for the large packings might bring the correlations in line but to our knowledge, this correction has not been proposed. Such correction will likely result in a doubling of the packing factor for three inch saddles.

### Table 2: Packing Factors (F) -- Random Dumped Packings

<table>
<thead>
<tr>
<th>Nominal Packing Size (in.)</th>
<th>⅛</th>
<th>⅜</th>
<th>⅝</th>
<th>1</th>
<th>1¼</th>
<th>1½</th>
<th>2</th>
<th>3 or 3½</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMTP® Packing (Metal)</td>
<td>61</td>
<td>41</td>
<td>24</td>
<td>18</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hy-Pak® Packing (Metal)</td>
<td>45</td>
<td>32</td>
<td>26</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super Intalox® Saddles (Ceramic)</td>
<td>60</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super Intalox® Saddles (Plastic)</td>
<td>40</td>
<td>28</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intalox Snowflake® (Plastic)</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pall Rings (Plastic)</td>
<td>95</td>
<td>55</td>
<td>40</td>
<td>26</td>
<td>17</td>
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<td></td>
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<tr>
<td>Pall Rings (Metal)</td>
<td>81</td>
<td>56</td>
<td>40</td>
<td>27</td>
<td>18</td>
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<tr>
<td>Intalox® Saddles (Ceramic)</td>
<td>200</td>
<td>145</td>
<td>92</td>
<td>52</td>
<td>40</td>
<td>22</td>
<td></td>
<td></td>
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<tr>
<td>Raschig Rings (Ceramic)</td>
<td>580</td>
<td>380</td>
<td>255</td>
<td>179</td>
<td>125</td>
<td>93</td>
<td>65</td>
<td>37</td>
</tr>
<tr>
<td>Raschig Rings (1/2” Metal)</td>
<td>300</td>
<td>170</td>
<td>155</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raschig Rings (1/4” Metal)</td>
<td>410</td>
<td>300</td>
<td>220</td>
<td>144</td>
<td>110</td>
<td>83</td>
<td>57</td>
<td>32</td>
</tr>
<tr>
<td>Ber Saddles (Ceramic)</td>
<td>240</td>
<td>170</td>
<td>110</td>
<td>65</td>
<td>45</td>
<td></td>
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<tr>
<td>Tellerettes (Plastic)</td>
<td>35</td>
<td>24</td>
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</tbody>
</table>

A second method for design is to use gas pressure drop curves measured in water-air systems for the various packings and commonly included in packing brochures. A sample is shown in Figure 3. These graphs are specific to the packings in question. U.S. Stoneware provided a book of such curves, but unfortunately the three inch saddle had not been developed at that time so the only graphs in the Norton brochures are quite small. The data come again from small test towers. Adjustments of the data to larger tower is required.
A third proprietary approach follows more closely that suggested of Leva in calculating dry bed pressure drop with a correction factor for the effect of irrigation. The empty tower velocity head lost per unit height is calculated from the liquid flow per unit area and two proprietary constants. G. Morris of ICI, the designer of this technique, did not recommend using it with high gas flows and pressure drops and several constants are involved for each packing size. In our review, the approach of Leva is simpler with the dry bed pressure drop calculation involving the empty tower liquid velocity and one constant for each packing. An exponential term including the liquid mass velocity in the empty tower is then used to correct for the impedance of gas flow by the liquid. The correction for acid flow will range as high as 100% in main absorbers with high liquid flows and 50% in drying towers and final absorbers. Morris adjusted his void fractions to towers with diameters twenty to thirty times the packing size which corresponds to six to eight feet, a step in the right direction, though not far enough.

Many engineers, over the years, have developed correlations and programs for packing pressure drop from the published test tower data and used the correlations to predict pressure drop. One such program, generally made available by a supplier of packings, has been used to evaluate pressure drop for the test case for both standard 3” saddle packing and a structured ceramic packing.

Several comments need to be made about the data used in these evaluations. The first is that the number of pieces of packing in a unit volume of tower vary significantly with the ratio of tower diameter to packing size as was shown in Figure 2. Essentially all of the data used in the correlations were developed in towers in the 2.5 to 3 foot range. When the packing was small such as 1”, the number of pieces per unit volume was reasonably high and usable in large towers. With large saddles, however, the packing density was much lower than found in full size towers and the pressure losses were much lower. In packing supply quotes, the "so-called" settling allowance is simply a correction factor to ensure there are enough pieces of packing to fill the tower. In many cases know to the authors, packing purchased to refill a tower of specified volume was found to be insufficient to physically fill the tower, even though the exact tower dimensions were given to the supplier. A "shrinkage" of 1.5 ft out of a 12 ft packing height was not unusual, and often caused a very embarrassing start-up situation. It is on the basis of this experience that CECEBE went through the trouble of making a saddle count when packing a number of new towers. Similar data on standard saddles would also be very useful. It is also suggested that the quantity of packing normally supplied by manufacturers to fill a cubic foot of tower will actually normally not fill a cubic foot in a large tower and owners might have a legitimate case for a better definition of what is needed to fill a cubic foot of tower volume.
The tower diameter for the standard three inch saddle using the different design techniques are shown in Table 3 while the diameters for different packings are shown in Table 4.

### Table 3: Tower Sizing for Standard 3" Saddles

<table>
<thead>
<tr>
<th>Method of Calculation</th>
<th>Tower Brick I.D. (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generalized Pressure Drop Correlation</td>
<td>15.0</td>
</tr>
<tr>
<td>Air/Water DP Curves</td>
<td>18.0</td>
</tr>
<tr>
<td>Proprietary Program 1</td>
<td>19.0</td>
</tr>
<tr>
<td>Proprietary Program 2</td>
<td>19.0</td>
</tr>
<tr>
<td>Leva Method</td>
<td>22.4</td>
</tr>
</tbody>
</table>

### Table 4: Tower Sizing Using Leva Method

<table>
<thead>
<tr>
<th>Method of Calculation</th>
<th>Tower Brick I.D. (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5&quot; Standard Saddles</td>
<td>26.8</td>
</tr>
<tr>
<td>2.0&quot; Standard Saddles</td>
<td>23.9</td>
</tr>
<tr>
<td>3.0&quot; Standard Saddles</td>
<td>22.4</td>
</tr>
<tr>
<td>#3 CECEBE HP™ Saddles</td>
<td>19.5</td>
</tr>
<tr>
<td>Structured Ceramic Packing</td>
<td>18.0</td>
</tr>
</tbody>
</table>

What the above tables show is that various methods available for tower sizing give widely different answers (Table 3) and that there is significant capacity difference between different packing (Table 4). This capacity difference can be exploited when a plant is being expanded by repacking with higher performance packing.

**THE ECONOMIC COSTS OF PRESSURE DROP**

Packing performance can be assessed in terms of mass transfer but can also be assessed in terms of the power needed to push the gas through the tower. A more open tower with lower pressure drop will offer greater production capacity or less power consumption or less acid mist or a combination of all three. For the 2000 TPD case chosen, the overall plant pressure drop typically will be around 220" W.C. (atmospheric pressure is 406.8" W.C.). The pressure saving from high performance packing in one tower would amount to around 70 kW for a pressure drop saving of 5" W.C. This is worth between fifty and sixty thousand dollars per year based on $0.10/kW hr. For standard packing, around 3300 ft³ would be needed to fill the tower which, with an allowance for settling, would cost around sixty thousand dollars. The HP™ saddle will sell for a premium cost due to its more expensive manufacturing process and structured packing will cost still more. With the HP™ saddle, the power saving would pay for the extra packing cost in less than a year. A second important issue is the fact that, by using HP™ packing, in a tower repack case, additional acid production will become possible, not only because of its inherent lower pressure drop, but also because of its low breakage during installation. In one 13 ft acid tower with a bottom chimney screen, less than half a bucket of packing chips were collected during the first annual turn-around.
DISCUSSION OF RESULTS

Table 3 shows that there is a wide discrepancy in tower diameter prediction when different sizing methods are used. From practical experience and discussion with colleagues, the GPDC approach appears sound but the packing factors published for large packings appear questionable. This is likely due to the use of the "void fraction effect" in small pilot towers. An adjustment of packing factors for all three of the larger size saddles would appear to be in order and could result in at least a doubling of the packing factors for the 3” saddle. Possibly the published packing densities of Figure 2 and the basis Leva equation would give sufficient guidance. The two proprietary programs gave similar results which suggested a similar logic basis but the details of the program were not available. Again, these programs are only as good as are the data used in the correlations. The question is, are these data obtained from a pilot tower or a full scale tower.

The last design approach listed in Table 3 is based on data collected by CECEBE and NORAM in a full size tower using the actual void fractions. There is some concern about designing to relatively high pressure drops as with any correlations when the pressure drop approaches 0.75" W. C. There is no benefit to the owner if a supplier is overly optimistic on packing performance only to have the owner ultimately suffer the consequences. Nevertheless, higher quality packing will give measurable and economically quantifiable performance advantages.

In Table 4, the void fractions have been adjusted to larger tower diameters and a number of packings have been evaluated on the basis of the CECEBE design techniques. As can be seen, larger standard saddles give smaller tower diameters just as one would expect. For the HP™ saddle, field data are available and a structured ceramic packing, for which a proprietary program was available, is also listed. Interestingly, the diameter associated with the HP™ saddle was essentially the same as that predicted from several of the programs for the standard saddle and well below that which one can expect for the standard 3” saddle. The structured ceramic program predicted a slightly smaller diameter but it is not backed by any published field data. However, the nature of this structured packing suggests that it is not significantly affected by tower size. As mentioned already, its major disadvantage is that it requires special attention to liquid distribution. No capacity benefit is gained if liquid distribution is implemented through a layer of standard 3” saddles.
If one is considering installation of new towers, the cost of the tower is one issue. The cost of packing is a second. Standard packing is sold normally on the basis of a definition of a piece density which falls short of what is needed to cover a "settling allowance". Often fifteen percent extra packing may be needed. Combining this with a large diameter tower can result in as much as fifty percent more packing being needed over more recent high performance packing to get an equivalent result. Combining this with the cost of the tower shell, sound economics would suggest that the best packing will probably give the best economic solution and the cheapest packing, possibly the worst solution. The difficulty has been the wide discrepancy in the ability to predict pressure drop in large packed towers. In several cases recently, HP™ saddles have been supplied to owners who were concerned about pressure drop and power consumption and could justify the expense on the power saved. With rising power costs, this incentive will become even more powerful. The discussion above on pressure drop offers data relevant to this issue.

**FURTHER WORK, REFERENCES, AND ACKNOWLEDGEMENTS**

**Further Work**

Additional work on towers with standard and new high performance packings is called for. In our view, the approach of Leva has many merits. Data from fertilizer plants would be very useful. Characterization of newer packings would also allow better comparisons which would help owners in deciding what to do. There is also an open question as to packing heights and the extent to which mist eliminators can be counted on to finish the mass transfer process. Similarly, using a large number of irrigation points has been advocated by some to allow much shorter packing heights. Candles can do a good job of removing residual sulfur trioxide but only if the candles are irrigated. This happens sometimes by default if the distributor generates spray if the tower is overloaded. Candles are more expensive than mesh pads and it may be less expensive to use more packing. More irrigation points, over one point per square foot, would clearly be desirable with smaller packing and also with mesh or similar packings where liquid tends to fall vertically. The value of high irrigation points counts with large saddles is debatable, especially as more points leads to systems which are more expensive and also much more easily plugged with chips because of smaller distributors holes or downcomers.
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Acknowledgements

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HPTM is a registered trademark of CECEBE Technologies Inc.

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