

Design Steam Strippers for Water Treatment

The high liquid-to-vapor ratios used and the possibility of fouling by organic and inorganic materials are among the challenges designers face.

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A very prevalent water pollution problem is contamination by volatile organic compounds (VOCs). Many VOCs are only partially miscible with water, but in general they all present a certain solubility.

Some of the VOCs commonly found in water include benzene, toluene, xylene, naphthlene, acetone, and a wide range of chlorinated hydrocarbons. Contamination stems from such sources as gasoline leaks, solvent spills, and process spills and discharges. The problem of reducing VOCs in water applies to groundwaters, surface waters, and wastewaters alike; however, the origin of the water has some important design implications (which will be discussed later).

This article first reviews the basics of steam stripping. It then discusses the key issues and challenges faced by an engineer in designing a stripping system for water treatment (Table 1).

Why use steam stripping?

Dilute mixtures of organic materials in water can be concentrated by steam stripping. The end products of this operation are a clean water stream almost devoid of organic materials, and a highly concentrated organic stream suitable for recycle to a process or for disposal. The use of heat in the form of steam as a separating agent offers significant advantages over other methods, such as inert gas or air stripping.

Steam stripping for water cleanup is essentially a distillation process, where the heavy product is water and the light product is a mixture of volatile organics. These

organics are present in the feed water in relatively small concentrations.

Steam stripping takes place at higher temperatures than air stripping, usually very close to the boiling point of water. Since the volatility of the organics is a very strong function of temperature, the high temperatures inherent in steam stripping allow for the removal of heavier, more-soluble organics that are not strippable with air.

Another advantage of steam stripping is that minimal secondary pollutants are generated. No off-gas treatment is needed. And, the only waste stream generated is a small amount of very concentrated organics, which are easily dealt with by incineration, biological treatment, or recycling back to the process.

Steam stripping can often achieve very high removals (more than 99%) and low effluent concentrations (below 5 ppb). It is the most economical removal technique at feed concentrations above 0.1% weight organics, and it is cost-effective at feed concentrations as low as 2 ppm. Depending on process needs, it can be operated at vacuum or pressure with little penalty. And, it can be made very energy efficient with heat recovery. However, a major drawback is that fouling is a continuous concern.

In summary, steam stripping is a good solution for wastewater streams that contain fairly soluble, semivolatiles and where no off-gas stream is desired. On the other hand, steam stripping does necessitate the presence of steam (or process heat) and tends to be more capital-intensive than air stripping. Ideal settings for steam stripping are petroleum refineries and petrochemical and chemical plants.

What is steam stripping?

A wastewater stream is heated and put in intimate contact with steam in a packed or trayed tower. The combined effects of the steam and heat or temperature cause organic material to transfer from the liquid to the vapor phase. This material is then carried out with the vapor. As contacting proceeds down the tower, the wastewater becomes leaner in the organic material while the vapor phase becomes more enriched as it travels up the tower.

Steam is injected at the bottom of the tower to provide heat and vapor flow and the wastewater is fed at the top of the tower. Clean water leaves the bottom of the tower and the steam leaves the top heavily laden with organic material. The latter stream is condensed and processed further to separate the steam and organics. The net effect achieved in the steam stripper and condenser is that a contaminated wastewater and steam are injected into the tower and a clean water stream is obtained. A low-volume but concentrated water/organic mixture is also obtained as a byproduct.

The stripping tower employs either trays or packing to facilitate contact between the contaminated wastewater and the steam. Metal (stainless steel) random packings are suitable for most applications. Plastic (glass-reinforced polypropylene, polypropylene oxide, polyvinylidene fluoride, or polytetrafluoroethylene) random packings can handle acids. Metal (stainless steel or aluminum) structured packings provide higher efficiency or capacity. Stainless steel sieve trays may be used for fouling service. Column internals include distributors, redistributors, supports, and mist eliminators.

The configuration of a steam stripping unit can vary depending on the characteristics of the organic material to be removed and on what is to be done with it (that is, disposal or recycle). As a minimum, a steam stripping system will look like the unit depicted in Figure 1. It is important to note that heat recovery from the bottoms product is necessary for economical opera-

Table 1. Stripper design issues.

Process Characteristic	Recommendation
Use of air or steam	<ul style="list-style-type: none"> - Use steam if the organic is soluble or if recovery is feasible. - Steam could be more economical if air post-treatment is required.
Operating pressure for steam strippers	<ul style="list-style-type: none"> - As low as possible to minimize steam use and reduce fouling. - Limited by disposal of noncondensibles.
Fouling and foaming	<ul style="list-style-type: none"> - Use packed towers for foaming service; check for foaming tendencies under actual process conditions. - Steam strippers are prone to calcium fouling. - Air strippers are prone to iron and biological fouling. - Address water chemistry early in design and always consider pretreatment.
Vapor/liquid equilibria	<ul style="list-style-type: none"> - Consider interactions between components. - Use reliable data and activity models. - Consider dissolved gases and pH.
Mass-transfer efficiency	<ul style="list-style-type: none"> - Do not use conventional distillation efficiencies. - Use the HTU/NTU approach in packed towers. - Consider the effects of surface-active agents.
Materials of construction	<ul style="list-style-type: none"> - Fouling prevention technique could have a large impact on material selection. - Consider strippable gases such as H_2S, CO_2, and O_2.

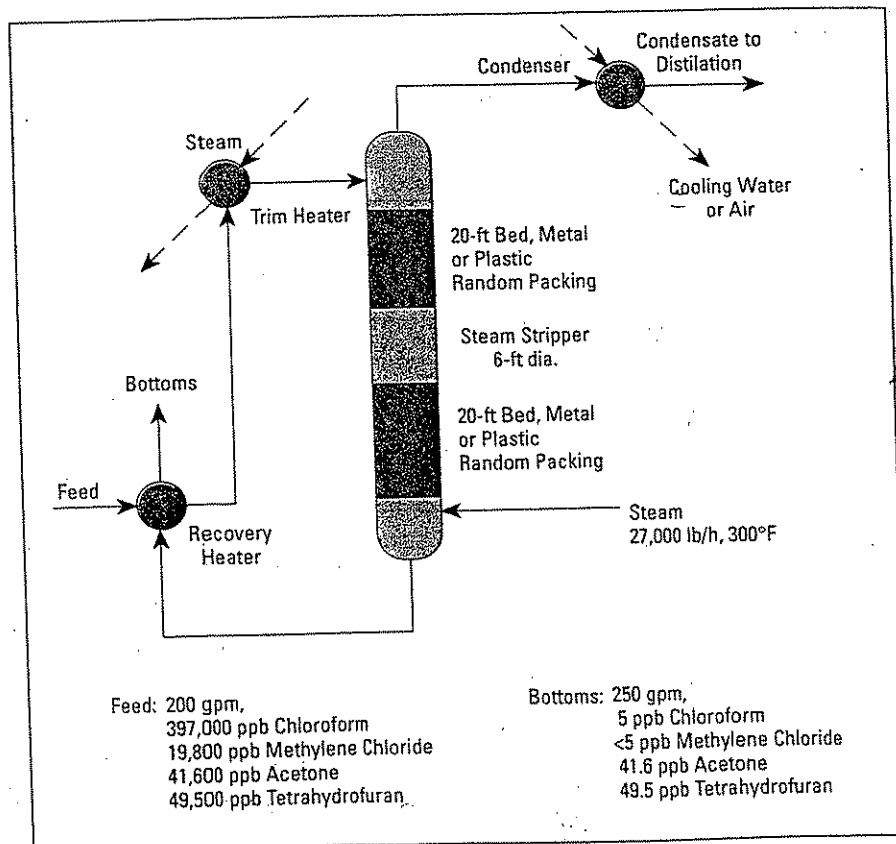


Figure 1. Simple steam stripper with no solvent recovery.

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tion. Operations at reduced pressure do not need recovery exchangers and operate at lower temperatures. The towers also tend to be a bit larger in vacuum operations.

Steam requirements for stripping vary with the operating pressure, the type of organic, and the degree of organic removal or recovery. Further steam requirements for heat balance purposes need to be accounted for as well. A very important consideration in the design of a steam stripper is the fact that the column must be capable of handling enough steam flow to operate without the recovery exchanger; this will be necessary during startup and when the exchanger is out of service for cleaning.

Some organic materials are not totally miscible in water and separate into a distinct organic phase when the concentration exceeds the solubility limit. Most aromatics and halogenated organics fall in this category. Steam stripping applications for these types of compounds can be very effective, since much of the concentration of the organic can be accomplished in a decanter, as indicated in Figure 2. In this case, the water layer is recycled to the stripping column for reprocessing.

The design of the decanter poses some interesting questions, since the water flow is generally significantly larger than the organic flow. Furthermore, in some cases (for example, benzene and toluene), the organic layer is the lighter of the two liquid phases. In applications involving halogenated organics, the organic liquid is heavier than water. Needless to say, good models to predict the phase behavior of the system in question are essential.

Different arrangements are needed when better organic recoveries are required from more dilute streams.

This can be accomplished using a separate recovery column (Figure 3a) or an integrated distillation/stripping column (Figure 3b). The selection between these two designs depends solely on the equipment sizing — the arrangement shown in Figure 3a is used when required steam flows are larger (that is, when the contaminants are less volatile).

Other variations on these flowsheets include the use of reboilers instead of direct steam injection, and operation at

high temperatures, extensive interactions between components, and the existence of two liquid phases.

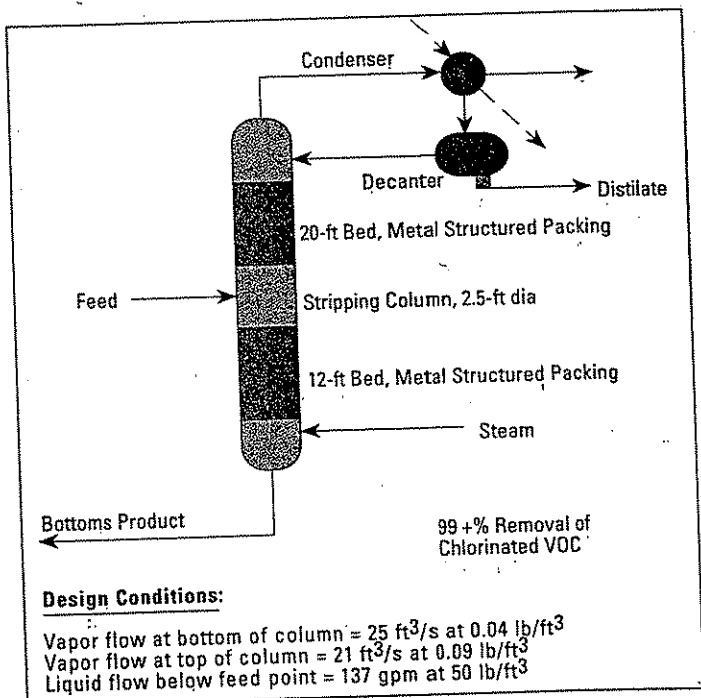
The thermodynamic model of choice for steam stripping systems is one based on activity coefficients that can predict immiscibility. No model fits this function better than the non-random two liquid (NRTL) activity coefficient model (3). Pilot and laboratory tests to establish the adjustable parameters in the NRTL model for the mixture in question are advisable, but solubility and vapor pressure data can suffice as a good approximation.

Wastewaters can be very fouling, especially when the temperature is raised and inorganic salts precipitate. In typical steam stripping configurations, most of the fouling will occur in the recovery exchanger, so the system design must include provisions to allow for frequent cleaning.

In the absence of a recovery exchanger, the stripper will bear the brunt of the fouling. In such cases, the use of trays can avoid plugging even though packings would yield better performance. The use of sequestering agents is also a good solution for reliable and lengthy operation.

Materials of construction should be some grade of stainless steel or a high performance plastic due to the varied and changing nature of the water chemistry. Capital savings achieved by using lesser-quality materials of construction generally translate into severe problems and added expense later.

Startup of any steam stripper requires heating of the feed water to the operating temperature. This added heat has to be supplied in the form of steam at the bottom of the stripper. Design provisions must be made to accommodate this larger, but tempo-



■ Figure 2. Steam stripper using structured packing; water (light phase) is recycled as reflux at top of stripper.

reduced pressure to lower operating temperature.

Important design considerations

Several aspects of the design of steam stripping systems are very crucial and not immediately obvious.

First, as in any distillation process, is the accuracy and reliability of equilibrium data. Steam stripping is a situation where the old reliable Henry's law (1, 2) needs to be used with care due to the broad concentration ranges,

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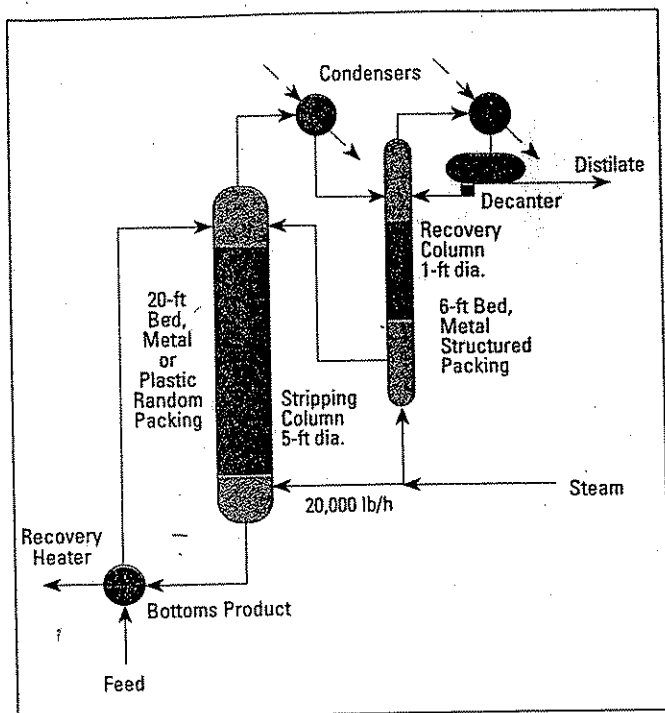
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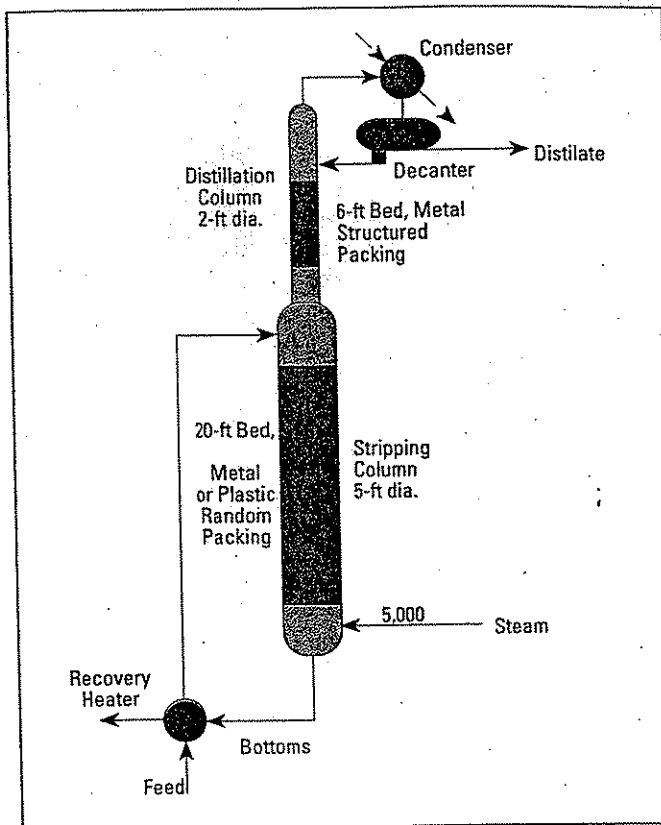
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Materials of construction should be some grade of stainless steel or a high performance plastic due to the varied and changing nature of the water chemistry. Capital savings achieved by using lesser-quality materials of construction generally translate into severe problems and added expense later.



■ Figure 3a (above). Steam stripper and recovery column for moderately volatile and immiscible systems.

■ Figure 3b (right). Steam stripper and recovery column combination for volatile and immiscible systems.



rary, steam flow in the stripper. This capability is also desirable to allow for continued operation while cleaning of a fouled recovery exchanger takes place.

Design at low stripping steam rates is desirable since it reduces the downstream processing requirements. Optimum designs require stripping factors between 1.5 and 6. These stripping factors mandate more stages for separation and taller packed heights. Design under these conditions becomes very sensitive to the reliability of the equilibrium data and the mass-transfer models. And, in this regime, excellent packings and internals are necessary, and vendor experience in the design of steam stripping systems is extremely valuable.

Henry's law constant

The value of the Henry's law constant plays an important part in determining the required steam-to-water ratio in the stripper. It can also

be important in the determination of the number of transfer units and the height of a transfer unit through its effect on the stripping factor. Henry's law would not apply to an entire stripper, but it can be used locally at each stage, allowing for variations of the constant from stage to stage depending on temperature and concentration.

Reliable data on Henry's constants (H) are not easy to find, especially since these constants are dramatically affected by temperature and other solutes present in the water. In general, H increases with temperature and with the concentration of inorganic salts in the water. The effect of temperature should always be considered, whereas the effect of inorganic salts is usually neglected since this represents a conservative assumption. The effect of additional organic solutes, on the other hand, can be very important, as indicated in Table 2 for benzene. Reliable activity coefficient data and

models are indispensable in these cases.

Henry's law is usually expressed as:

$$yP = Hx \quad (1)$$

where y is the mole fraction in the gas phase, x is the mole fraction in the liquid phase, P is the total pressure, and H is Henry's constant in pressure units (atm).

Table 2 lists some estimates of values of H for some common VOCs at ambient temperature. Note that the value of H would be much higher under steam stripping conditions. Also, these values are for ideal situations, where no interactions between solutes are present, and are for dilute conditions. These data appear to be conservative and can be used for design.

The value of H is strongly dependent on temperature because both the activity coefficient and the vapor pressure are a function of temperature. Extrapolation to different temperature requires good reliable models for vapor pressure and activity coefficients.

In more general terms, one can express equilibrium at low pressures (that is, for an ideal gas) by:

$$yP = gP^o x \quad (2)$$

with

$$H = gP^o \quad (3)$$

where g is the activity coefficient and P^o is the vapor pressure. This means that the temperature and concentration dependency of H can be described by g and P^o .

The NRTL model for activity coefficients was developed for partially miscible systems and appears to be the best for stripping applications. Its range of application covers air and steam stripping, and the interaction parameters for many of these VOCs are readily available (see (4)). When the actual binary parameters are not available, they can be inferred from mutual solubility data as provided in (5). As always, the Antoine equation for vapor pressure provides adequate temperature dependency.

Selecting operating pressure

The operating pressure of a steam stripper can have a large impact on efficiency and reliability. Lower pressures (vacuum stripping) mean enhanced volatility and lower operating temperatures. These two factors combined can mean in some cases less fouling by inorganic precipitation and lower heat-recovery requirements. Vacuum strippers can also be very energy efficient since the feed need not be heated to high temperatures. Furthermore, vacuum strippers offer the ability to use plastic internals at moderate temperatures, to deal with corrosive systems effectively.

On the other hand, vacuum strippers require the use of vacuum pumps or ejector systems. In pressurized stripping, the pressure of the stripper is determined by the pressure in the reflux accumulators, which will be "riding" on the pressure of the vent header. Pressure strippers operate hotter, but do not require a vacuum system.

Vacuum stripping is normally performed at around 2 psia to prevent inor-

Table 2. Typical values of Henry's constant for various VOCs at 20°C.

Compound	H, atm
Carbon Tetrachloride	1183
Chloroform	180
Methylene Chloride	125
Trichloroethylene	500
Perchloroethylene	600
1,1-Dichloroethane	200
1,2-Dichloroethane	20
Benzene	240
Benzene in the presence of 2%wt. isopropanol	15
Ethylbenzene	389
Dichlorobenzene	71
Methyl-Isobutyl Ketone	71
Methyl-Ethyl Ketone	17

ganic precipitation, whereas pressure stripping is often run at 5 to 10 psig.

The stripping factor

The stripping factor (S) is defined by:

$$S = mG_m/L_m = (H/P)G_m/L_m \quad (4)$$

where G_m and L_m are the molar flow rates of gas and liquid, respectively. The slope of the equilibrium line (m) is numerically equal to the Henry's law constant (H) expressed in atmospheres when the operating pressure of the stripper (P) is 1 atm.

The stripping factor is the most important design variable in a stripper. Higher stripping factors are conducive to more efficient stripping. The stripping factor for design purposes should always be greater than unity. In cases where reducing the amount of stripping medium is important, one can design for stripping factors between 3 and 6. The designer should always be aware of the reliability of the design value of H , since it has a major impact on the value of the stripping factor. This is why the use of S values below 3 is not recommended.

For steam stripping, in many cases the stripping factor can be set by the heat balance of the system. When cool water is introduced to the stripper, steam will be needed to bring it to the stripping temperature. The amount of steam required will be proportional to the degree of subcooling of the feed. In many cases, the steam required to heat the water far exceeds that required to strip the VOC. The designer should always keep in mind the steam requirements for heat balance purposes.

Trays or packing?

One of the early decisions that the engineer faces is whether to use a packed or a trayed column. This subject is explored at length in (6) and so won't be covered in detail here. Table 3 characterizes the applicability of trays and packings under a variety of process conditions.

This article will address some of the important guidelines that need to be observed when designing packed strippers. Many of the concepts are also applicable to trayed columns.

The use of high L/V ratios

The most economical stripper designs are those where the amount of stripping medium (air or steam) is minimized and the tower is designed to operate at the maximum possible liquid load. The diameter of the tower is usually dictated by the liquid flow. Stripping towers are not commonly designed using an "approach to flood."

Liquid loads in excess of 35 gpm/ft² are common and are coupled with gas F factors (gas velocity times the square root of gas density) as low as 0.5 ft/s•(lb/ft³)^{0.5}. This means L/V ratios as high as 50 on a mass basis.

The implications with respect to the selection of the proper predictive tools for column hydraulics and the design of liquid and gas distributors are significant.

Mass-transfer efficiency for packed towers

There are several ways to predict the mass-transfer performance of a

given packing under the required operating conditions. In every case, the required height of packing will be the product of the number of transfer units (*NTU*) and the height of a transfer unit (*HTU*). The values of *HTU* and *NTU* to be used will depend on the stripping factor and the inherent efficiency of the packing. *NTU* is a variable that relates exclusively to the stripping factor and the degree of removal. *HTU* relates to the stripping factor, liquid load, and the packing efficiency.

The equation to determine the value of *NTU_{ol}* (number of transfer units referenced to the liquid phase) for a VOC stripper is:

$$NTU_{ol} = \left(\frac{S}{S-1} \right) \times \ln \left[\left(1 - \frac{1}{S} \right) \frac{x_{in}}{x_{out}} + \frac{1}{S} \right] \quad (5)$$

where *x_{in}* and *x_{out}* are the inlet and outlet concentrations, respectively.

At values of *S* = 12 or above, Eq. 5 can be approximated by:

$$NTU_{ol} \approx \ln(x_{in}/x_{out}) \quad (6)$$

To determine *HTU_{ol}*, one can use a correlation or experimental data adapted to the conditions of the design and applicable to the packing being considered. Methods based on correlations can be fairly reliable if applied carefully to systems within the proven limits of the correlations. The best method currently available to the public is a modification of the Onda method that was developed by the Separations Research Program at the University of Texas at Austin (7).

The packed bed depth required to achieve a separation will then be:

$$H = HTU_{ol} \times NTU_{ol} \quad (7)$$

Experimental data are difficult to obtain and difficult to validate, but they represent the best basis for design. It is always advisable to compare a design based on experimental data with a correlation method, as this will provide a good sense of the importance of the different variables on the design.

Typical design values of *HTU_{ol}* derived from performance data on ran-

Table 3. Applicability of trayed and packed strippers.

Process Characteristic	Trays	Packings	Notes
Biological Fouling	A	A	Pretreatment required
Inorganic Fouling	A	A	Pretreatment required
Foaming	NA	VA	Packings recommended
Vacuum	MA	VA	Pressure drop crucial
High Removal	VA	VA	
Heat Recovery	A	VA	Pressure drop crucial
Corrosiveness	MA	VA	Plastic packings and internals
Turndown	A	A	Equal for trays or packing
Initial Cost	Lower	Higher	

Key: VA = Very Applicable; A = Applicable With Limitations; MA = Marginally Applicable But Not Recommended; NA = Not Applicable

Table 4. *HTU_{ol}* values for typical packings in VOC steam stripping.

Packing	<i>S</i>	Liquid Load gpm/ft ²	<i>HTU_{ol}</i> , ft
2-in. Polypropylene Spherical Packing	6	25	2.9
	9	35	3.2
3 1/2-in. Polypropylene Spherical Packing	6	25	3.4
	9	35	3.7
40-mm Stainless Steel Ring-Type Packing	6	25	3.2
	9	35	3.6

**HTU_{ol}* values as indicated include a safety factor and can be used for design. They assume excellent liquid distribution and clean packing.

dom packings are shown in Table 4. The reader should understand that the selection of the proper value of *HTU_{ol}* for design should be done by the packing supplier, since a process guarantee is often associated with a design.

It should be noted here that the use of the height equivalent to a theoretical plate (*HETP*) in these types of applications is extremely tricky. Values of *HETP* for conventional random and structured packings can be several times those found in conventional distillation. This is because *HETP* is defined (as a distillation variable) in terms of the height of a transfer unit in the gas phase. *HETP* is a variable that is well-suited for systems where the resistance to mass transfer is in the gas phase. Stripping systems frequently exhibit the majority of the resistance to mass transfer in the liquid phase. Thus, when the values of *HTU_{ol}* are converted to *HETP* values,

one obtains *HETP*-values in the 6- to 12-ft range. It should be noted that this effect is caused by the shift in resistance of the system and not by an inherent inefficiency in the packings.

Estimation of pressure drop is important in stripping applications, particularly in vacuum steam stripping. The bottoms pressure in the stripper has a pronounced effect on the bottoms temperature and on the volatility of the organic compound. Packed towers operate at significantly lower pressure drops than tray towers and are more desirable for low-pressure stripping applications.

Estimation of pressure drop and maximum capacity of the packed strippers is critical. The calculation methods presented in (8, 9) have proven to be the most reliable. Previously available methods described in the literature tend to fail in pressure drop and capacity predictions in steam stripping service

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Literature Cited

1. Carroll, J. J., "What is Henry's Law?," *Chem. Eng. Progress*, 87(9), pp. 48-52 (Sept. 1991).
2. Carroll, J. J., "Use Henry's Law for Multicomponent Mixtures," *Chem. Eng. Progress*, 88(8), pp. 53-58 (Aug. 1992).
3. Renon, H., and J. M. Prausnitz, "Local Compositions in Thermodynamic Excess Functions for Liquid Mixtures," *AIChE J.*, 14(1), pp. 135-144 (Jan. 1968).
4. Gmehling, et al., "Vapor-Liquid Equilibrium Data Collection," *Chemistry Data Series*, DECHEMA, Frankfurt (1977 to present).
5. Horvath, A. L., "Halogenated Hydrocarbons: Solubility-Miscibility with Water," Marcel Dekker, New York (1982).
6. Kister, H. Z., et al., "How Do Trays and Packings Stack Up?," *Chem. Eng. Progress*, 90(2), pp. 23-32 (Feb. 1994).
7. Bravo, J. L., and J. R. Fair, "Generalized Correlation for Mass Transfer in Packed Distillation Columns," *Ind. Eng. Chem. Proc. Des. Dev.*, 21, pp. 162-170 (1982).
8. Robbins, L. A., "Improve Pressure-Drop Prediction With a New Correlation," *Chem. Eng. Progress*, 87(5), pp. 87-91 (May 1991).
9. Kister, H., and D. R. Gill, "Packing Capacity and Pressure Drop: GPDC Interpolation Charts Atlas," Chapter 10, in "Distillation Design," McGraw-Hill, New York, pp. 585-652 (1992).
10. Kunesch, J., et al., "Experimental Determination of Tray Efficiency: Steam Stripping Toluene From Water in a 4-ft. Diameter Column," Presented at the Atlanta AIChE Spring National Meeting (Paper 90a), (Apr. 1994).
11. Chan, H., and J. R. Fair, "Prediction of Point Efficiencies on Sieve Trays: I. Binary Systems," *Ind. Eng. Chem. Proc. Des. Dev.*, 23, pp. 814-819 (1983).
12. Bonilla, J. A., "Don't Neglect Liquid Distributors," *Chem. Eng. Progress*, 89(3), pp. 47-61 (Mar. 1993).
13. Bravo, J. L., "Effectively Fight Fouling of Packing," *Chem. Eng. Progress*, 89(4), pp. 72-76 (Apr. 1993).

because the liquid-to-vapor ratio is generally significantly above the range of these older correlations.

Mass-transfer efficiency for trayed towers

When stripping operations are analyzed in terms of theoretical stage requirements, one usually finds that extremely high organic removals are possible in just a few theoretical stages. On the other hand, when one calculates tray efficiencies for these systems, tray efficiencies are often in the range of 25% to 40%. This has been corroborated by tests at Fractionation Research, Inc., on conventional sieve trays in toluene stripping service (10).

As with the case of HETPs, tray efficiencies have been defined for application in normal distillation, where resistance is in the gas phase, unlike steam strippers, where the preponderance of the mass-transfer resistance is in the liquid phase. Low efficiencies in stripping systems are caused by the extremely large volatilities and stripping factors encountered and by the fact that efficiency is defined in terms of gas-controlled systems. Current tray efficiency correlations that take into account transfer in both phases can deal with this problem properly (11).

Some pitfalls to avoid

Reliability of equilibrium data.

The design of a stripper depends heavily on the value of the activity coefficient or the Henry's constant for the target VOC. The literature abounds with experimental values of Henry's constants, but unfortunately they do not always agree with other published values or with values apparent from field trials and installations.

The Henry's constant is a thermodynamic variable that depends only on temperature and composition. Many misguided efforts have tried to link the value of Henry's constant to mass-transfer performance by regressing values of H from actual stripping data. This is wrong and dangerous, since a fundamental thermodynamic value is held dependent on totally unrelated things

such as liquid distribution, packing shape and size, column levelness, gas distribution, instrument accuracy, and so on. Values of H derived in such manner should never be used for design, since they will prove unreliable in scale-up and will undoubtedly lead to wrong answers.

The correct procedure is to determine values of H from good experimental data on volatility and solubility and to determine column efficiency separately using the proper value of H .

Liquid and gas distribution. The performance of a stripper is in many cases wrongly related only to the packing itself. In reality, the packing performs only as well as the initial liquid and gas distribution allows it to. Badly designed liquid distributors and inlet gas nozzles are the most common problems found in nonperforming strippers. Care should be taken to design and install proper distribution devices in the stripper.

Many stripper applications involve very large liquid loads, sometimes in excess of 30 gpm/ft², coupled with very low gas velocities ($F < 0.25$ ft/s • (lb/ft³)^{0.5}). In these cases, one finds a synergistic effect between liquid and gas distribution that can be disastrous in terms of mass-transfer performance. Uneven liquid distribution at very high loadings and liquid holdups produces large variations in void fraction across the bed. This causes severe gas maldistribution.

Care needs to be taken in the design of the liquid distributor for evenness of flow as well as geometric coverage. The use of pour point densities of 10 points/ft² in this application is normal. The real trick is in producing very low coefficients of variation for the liquid flow. The coefficient of variation is defined as the ratio of the standard deviation to the mean flow for the pour points in the distributor. A deterioration in performance at high loads can be expected if this coefficient exceeds 0.2 for a random sample of 20% of the pour points. The recommendations in (12) regarding liquid distribution are certainly pertinent to strippers and care should be exercised in the design and installa-

tion of liquid distributors.

Initial gas distribution is also critical, because strippers generally operate at low pressure drop levels. The best way to produce an even initial gas distribution is by the use of pressure drop. Any device that can direct the gas stream across the section with a pressure loss of about 0.5 in. of water will be adequate. Gas spargers and orifice trays designed to produce even flow at these pressure drops are recommended; these devices must be able to deal with the liquid downflow as well.

A common mistake in the design of stripping towers is that the gas inlet nozzle is positioned too close to the packed bed and the gas entrance velocity is too high. This produces an uneven gas velocity profile entering the bed. Also, the beams that support the packed bed can severely interfere with gas distribution when the gas inlet is too close to the bed. Because of these effects, a sound design will incorporate a minimum distance between the center of the inlet nozzle and the bed equal to half the column diameter.

Strippers operating at very high liquid-to-gas ratios can exhibit poor performance when liquid distribution is uneven in spite of having proper pour point density. This unique sensitivity to uneven flow out of the pour points can be attributed to the fact that strippers operate very close to the loading region by virtue of the very high liquid loads. Small changes in local liquid rates caused by uneven distribution can produce significant changes in local liquid holdup and in the effective void fraction of the irrigated packing. This results in extremely large variations in local gas flows to maintain pressure drop equilibrium with the ensuing deterioration of mass-transfer performance. In essence, uneven liquid distribution can cause severe gas maldistribution.

Misuse of safety factors in design. Many performance specifications for strippers include healthy safety factors in the inlet and outlet concentration requirements. Typically, the effluent concentration is set at the detection limit of the VOC in question and the inlet concentra-

tion is an absolute maximum that will very rarely (if ever) present itself.

Unfortunately, some mass-transfer device suppliers take advantage of this fact when presenting a design in a competitive situation. Their designs will be based on removals that are below the specified ones with the "hope" that the specified levels will never present themselves and the performance of the stripper will never be challenged.

Under-designs such as these give the false and dangerous impression that a packing is far better in performance than others. In reality, these suppliers are cutting corners at the expense of performance reliability of the stripper and are providing designs that do not meet the specified removal but meet the effluent characteristic only.

The user must be aware of this practice and protect against it by strongly requiring and verifying that all calculations and designs be based on meeting the specified outlet concentration given the specified inlet concentration.

Fouling and plugging of packings. Paradoxically, the high mass-transfer efficiency provided by the packing in a stripper promotes the deposition of insoluble metal oxides and salts and bacterial growth. Packings with high surface areas will be more efficient but will promote fouling as well.

There is no magic cure for fouling. The composition of the water, the irrigation and vapor rates, and the operating temperature have much more to do with how rapidly a tower will foul than the type of packing used.

If the contaminated water contains free iron or other minerals, the action of the stripping gas could cause some of these compounds to precipitate out and foul the packing media. Organic contaminants promote biological growth that accentuates the fouling problem. The reality is that all VOC strippers will eventually lose some of their efficiency and capacity due to fouling if the water is not pretreated before entering the tower.

The degree of fouling as well as the amount of time for the fouling to affect the performance of a stripper is a func-

tion of all of the above factors plus other unique characteristics of a particular site. It must also be noted that in many cases the fouling process is so slow that a contaminated site is essentially cleaned before fouling is a problem.

The best answer to the problem of fouling is a combination of good design and pretreatment. Pretreatment involves the continuous addition of a chemical to the water to keep the minerals from precipitating and to prevent algae buildup during the stripping process.

Also important to keeping fouling to a minimum are good maintenance practices, good monitoring of process conditions, and good overall process design. A fouling problem will not be resolved by trying a different packing unless important compromises are made in mass-transfer efficiency. Severely fouled packed beds are inefficient and cause high pressure drop. They can also be very dangerous, since support plates are generally not designed to handle the weight of packing heavily laden with inorganic salts. In some extremes, the weight of the packed bed can increase by a factor of ten or more as the packing fouls.

Ref. (13) describes methods and techniques to effectively deal with the problem of fouling in packed towers, with emphasis on air and steam strippers. **SEP**

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