PICKLE LINE FUME CONTROL WITH PLATE SCRUBBERS

by

Neil Stone

Chief Engineer,

Esco Engineering, Kingsville,

Ontario Canada

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ABSTRACT

Plate-type scrubbers require less maintenance and generate less effluent than conventional packed scrubbers when removing acid gases such as hydrogen chloride, hydrogen fluoride and nitric acid from pickle line fume exhaust streams. This paper discusses the advantages of plate scrubbers over packed and other types of scrubbers, the limitations of plate-type scrubbers, their design, construction and installation requirements and methods and materials of construction. Actual performance data for installations in the steel industry are presented, and installation and operating problems are discussed.

Pollution control requirements have become so strict now, that many manufacturers are realising that the best effluent is no effluent, and that the 'zero discharge' concept has many attractions. In order to have zero discharge, the established ways of doing things must be re-thought and improved with this object in mind.

Traditionally, fume scrubbers for pickle lines have used large volumes of water. This paper is about plate scrubbers, which use very small amounts of water, and produce a relatively strong acid, that can be returned to the pickling process, instead of having to be neutralised. Most of the discussion will refer to hydrochloric acid (HCl) scrubbers, because this acid is the most widely used pickling acid, and HCl is targeted as one of the regulated compounds of Title III of the United States' 1990 Clean Air Act. However, plate scrubbers can be used for other acids, too.

Better scrubbers are only a part of the solution; improved fume control systems which minimise the exhaust flows and contaminant loadings are just as important - the 'fumeless pickler' used on strand galvanisers is the ultimate design - but detailed discussion of fume exhaust system design is beyond the scope of this paper.

WHAT FUME SCRUBBERS DO

Fume scrubbers are devices to minimise contaminant discharges to the atmosphere. No scrubber can be 100% efficient, although the efficiency can be as close to 100% as the owner can afford. Fume control in pickle lines is achieved by drawing a flow of air from the hoods over the tanks; with proper design, this flow is just enough to prevent the acidic vapors which are generated by the hot acid from escaping into the plant working area.

The hydrochloric acid which is purchased for pickling (usually 20 Bé) is actually a solution of the gas hydrogen chloride (HCl) in water, containing 32% by weight of HCl. When this acid is heated, some of the gas boils out of solution, and creates the choking smell so familiar to picklers.

Inevitably, the air flow which controls the fumes carries some of the acid vapors with it - typically, the exhaust from a continuous pickle line contains 200-2000 ppmv of HCl, depending on operating conditions and hood design. The TLV for HCl is 5 ppmv, and many administrations that control HCl emissions have discharge limits of 5-10 ppmv. Clearly, then, a substantial part - between 98% and 99.8% - of the HCl in the exhaust air must be removed.

Fume scrubbers remove HCl by contacting the air with water. HCl gas is extremely soluble in water - this is why it is so corrosive in the plant environment, because it dissolves in the smallest trace of condensation. A fume scrubber is a device to create intimate contact of the air with the water, and ensure efficient removal of the HCl. Unfortunately, fume scrubbers do not 'get rid' of HCl - they merely convert a contaminated air stream to a contaminated water stream! The liquid effluent from the scrubber still requires treatment, and disposal.

TYPES OF SCRUBBER

The most familiar type of fume scrubber is the packed scrubber; this may be of the vertical tower type, Figure 1A, (in which the liquid flows down, and the gas flows up) or the crossflow type, Figure 1B, (in which the liquid flows down, and the gas flows horizontally). In either case, the gas passes through a bed of random packing, which consists of small, irregularly-shaped plastic moldings, that creates a multitude of tortuous paths through which the gas must flow. The scrubbing water which flows over the packing is constantly splashed and mixed, thus giving good contact with the gas.

In order for a packed scrubber to work efficiently, a certain minimum flow rate of water is needed to completely wet the packing. Otherwise, the water only flows in some of the channels, and unscrubbed gas can pass through the others. Typically, the minimum water rate required for wetting packing is about 3-4 gpm[1] per square foot of liquid flow area. For a typical vertical tower, where the area for liquid and gas flows are the same, this amounts to about 1 gpm for each 100 cfm of air - or 100 gpm for a 10,000 cfm capacity scrubber. Most packed scrubbers use a circulation pump, Figure 2, to return effluent water to the top of the scrubber - this maintains a high liquid rate, but may result in lower scrubbing efficiency, for reasons to be explained later.

Plate (or tray) scrubbers work on an entirely different principle - by allowing the gas to bubble through pools of liquid on the plates. Each plate (Figure 3) consists of: an inlet weir area, which distributes the incoming liquid flow uniformly across the plate; a perforated area, where the gas bubbles through the liquid; and an outlet weir, where the liquid is separated from the air, and flows down to the plate below. By designing for a sufficiently high air velocity, the liquid is prevented from flowing through the holes in the perforated area. By having several plate stacked one above the other (Figure 4), with the gas flowing upwards in series, and the liquid flowing downwards from plate to plate, a countercurrent flow results, with the gas contacting cleaner and cleaner water as it rises up the scrubber. Scrubber efficiency can be increased by increasing the number of plates.

In the perforated area, the high gas velocity effectively stops up the holes in the plate, and each hole generates a small geyser of liquid that is shot into the space above the plate. Thus, the plate acts like a myriad of small venturi scrubbers in parallel (Figure 5). The sealing of the holes by the gas is not perfect, and a small amount of liquid weeps through the holes, so a certain minimum amount of water must be used to compensate for this weeping. As long as this minimum is exceeded, the level of water on the plates is fixed by the height of the outlet weir - typically, plate scrubbers need 1 gpm of liquid for each 5000-10,000 cfm of air; this is 50 to 100 times less than the liquid flow required for a packed scrubber.

ADVANTAGES OF PLATE SCRUBBERS

The main advantages of plate scrubbers are:

- **no packing to plug up.** Plant air usually contains quite a lot of dirt, and the packing material acts as an effective gas cleaner, with consequent accumulation of solids in the bed. This can result in the bed plugging, or even collapsing, and may require replacement of the packing, which is quite expensive, and disposal of the dirty packing as hazardous waste.

- **true countercurrent flow**. The fresh scrubbing water enters the top of the scrubber, and flows countercurrent to the liquid flow, leaving as acid from the bottom. This is the most efficient form of contacting, especially when low outlet gas concentrations are required.

- **no circulating pump to install or maintain.** If the scrubber needs a pump, which has to handle acidic water, there is a significant cost for: installation, piping, motor control and wiring; power consumption ($350/yr per hp); and maintenance, which is notoriously high for HCl pumps.

- **low effluent flow with relatively high acid concentration.** The effluent can usually be added to the pickle tank to replace some of the water used to dilute the fresh acid, or lost by evaporation, so that the acid in the scrubber effluent is returned to the pickler. This can represent quite a substantial cost recovery, too - it is not unusual for a large continuous pickler to discharge over $50,000/yr of acid into the fume scrubber, to which must be added the cost of the neutralizing agent for this acid when it gets to the waste treatment plant.

- **very little maintenance needed.** There are no moving parts, and no packing to plug, so maintenance is usually limited to washing out annually.

HOW FUME SCRUBBERS WORK

Some explanation of the operating principle of gas scrubbing is necessary in order to understand the essential differences between plate and packed scrubbers.

Solutions of gases in water have a vapor pressure of the gas above the solution - this vapor pressure increases with increasing temperature, and with increasing concentration. The vapor pressure is usually expressed in mmHg (Figure 6), and the graph showing the relationship of the vapor pressure to the liquid concentration is called the equilibrium curve. In order for the liquid to absorb the gas, the partial pressure (which is a measure of the concentration) of the contaminant in the gas stream must be greater than the vapor pressure of the gas over the scrubbing solution. In Figure 6, scrubbing a gas with an HCl concentration of 5 ppmv is feasible at point A, where the liquid contains 2% HCl, but not at point B, where the liquid contains 4% HCl (because at this point the equilibrium curve pressure exceeds the gas pressure).

The change of liquid composition as it flows through the scrubber can also be shown, in the form of an 'operating line', on the same graph as the equilibrium curve . As long as the operating line is above the equilibrium curve, the scrubber will work - the larger the area between the operating line and the equilibrium curve, the easier the separation is, and the less the amount of packing or plates needed. The operating lines in Figure 6 are for a scrubber with 250 ppm inlet gas concentration, 5ppm outlet gas concentration, and a liquid flow rate of 1 gpm/10,000 cfm for a plate scrubber, and 100 gpm/10,000 cfm for a packed scrubber.

Figure 6 also shows the difference between a packed scrubber with liquid recycle, and a plate scrubber with true countercurrent flow. Owing to the high absolute flow rate needed for packed scrubbers, the change in liquid concentration through the tower is very small, and the operating line is very steep. The liquid composition at the bottom of the line, corresponding to the inlet concentration, is limited by the need to stay above the equilibrium curve - thus, the outlet concentration is also limited. A packed tower cannot operate with effluent liquid corresponding to 'B', but a plate tower can produce this strength, or even higher, without difficulty.

One special case occurs when the scrubber is supplied with caustic soda solution, instead of water. In this case, the equilibrium curve is the X axis (i.e. there is no HCl vapor pressure above the solution), so that recycling solution to the top of the scrubber has no adverse effect. However, using caustic soda as scrubbing medium increases operating costs, and also precludes the recovery of the contained acid from the effluent.

The hydraulic design procedure for plate towers is complex, although there is a published computer program[2] to do the calculations. At low concentrations of liquid i.e. in the region before the equilibrium curves of figure 6 start to curve up, the efficiency of a plate tower can be approximated as:

$$E = 1 - (1-e)^n$$

where

E is the fraction of the HCl removed in the tower
e is the efficiency of a single plate
n is the number of plates in the tower

The single plate efficiency depends on a number of design factors, in particular the liquid and gas flow rates, and the spacing between plates; e is usually in the range 0.6 to 0.75.

CONSTRUCTION OF PLATE SCRUBBERS

A scrubber consists of a shell, usually cylindrical, although it can be rectangular, inside which is a stack of perforated plates. Each plate consists of three zones (Figure 3): an inlet zone, where the liquid enters the plate; a perforated zone, where the gas contacts the liquid; and an outlet zone, where the liquid leaves the plate.

In the inlet zone there are no perforations, and the liquid is distributed across the width of the plate by the inlet weir. For low liquid flow rates, this may be serrated. Usually, the inlet weir is slightly higher than the outlet weir, and, if the plate is not the top one, the downcomer pipe from the plate above will extend below the top of the inlet weir to create a liquid seal, which stops the gas from by-passing the plate.

In the perforated zone, the gas passes into the liquid through the holes in the plate. This part of the plate is subjected to an upwards bending force, created by the pressure drop across the plate, but must be stiff enough to remain level within about +/- 1/8", in order to avoid substantial weeping through the plate due to local pooling of the liquid. A level of liquid on the plate is maintained by an outlet weir, which is lower than the inlet weir; again, this may be serrated to give even distribution with low liquid flows.

The outlet zone allows the liquid to separate from the gas, and run down to the next plate (or to the sump) through the downcomer pipe. This area, too, is unperforated. The downcomer pipes must be sized for the maximum anticipated liquid flow, and must allow for proper separation of the liquid from entrained gas.

In addition to the plates, the scrubber (Figure 4) will typically have an entrainment eliminator before the top outlet - experience has shown chevron type eliminators to be much more reliable, and maintenance-free, than the mesh type. At the bottom of the scrubber, the liquid is usually drained out immediately. However, it is important to remember that, if the scrubber is operating under negative pressure (as is usually the case), a U-seal, and sufficient liquid head to overcome the negative pressure, is needed to ensure that the liquid flows away properly.

In order to facilitate set up and flow adjustment, it is normal to provide an access manhole on each plate. This is usually equipped with a transparent cover, to allow visual inspection of the operation of the tower.

Advances in non-metallic materials of construction over the past 20 or so years have made it possible to construct plate-type acid scrubbers entirely from plastics. Preferred material for the internal parts is polypropylene, which is satisfactory up to about 180° F, while the shell may be of polypropylene, with or without an FRP overlay, or of plain FRP. For low temperature applications, (below 120° F), PVC may be used instead of polypropylene.

Experience has shown that a polypropylene, or polypro-lined FRP shell construction is superior to FRP because, in time, HCl gradually penetrates the FRP corrosion barrier, whereas polypropylene is unaffected. Furthermore, the use of polypropylene shells makes plate installation simpler. A major problem with plastics is the high coefficient of thermal expansion, which causes severe plate warping problems in scrubbers that run hot (as is the case for many pickle line scrubbers), because the plates expand more than the colder shell. In these cases, some form of expansion joint is needed, and the low coefficient of friction, and weldability of polypropylene makes this easier to construct.

Plates must be of an isotropic material like polypropylene or PVC - FRP is not suitable, because of the difficulty of sealing the glass fibers in the numerous holes. Typically, holes are 1/8" to 1/4" diameter, and the plate may have in excess of 1000 holes per square foot, so punching is an attractive fabricating method. Unfortunately, punching leads to curling of the plate, and is limited to plate thicknesses about equal to one hole diameter - the use of thicker plates, and drilling of the holes is preferred as it leads to a stiffer and flatter construction.

Design of the shell and heads is usually complicated because most scrubbers are located on the suction side of the fume exhaust fan. Plastics have low elastic moduli, and are quite susceptible to collapse under vacuum - for this reason, the shell and ends require careful stress analysis and additional stiffening.

INSTALLATION

The most important installation factor is to ensure that the plates are level, even if this means that the tower shell is not truly vertical. In one installation, an out-of-level installation resulted in all the liquid running down one side of the scrubber, and all the gas passing up the other, with consequent very poor contacting and efficiency.

Plate scrubbers may be installed indoors or outdoors - the plates are inherently self-draining, and small drain holes in the weir areas prevent liquid residues which could freeze in the northern winter. For outdoor installation in these areas, the acid outlet needs to be made self-draining, too, but insulation is not needed, because the warm air flow through the tower, and the insulating nature of plastics prevents freezing under even sub-zero temperature conditions.

Installation usually involves just connecting the air ducts, the water supply, and the acid outlet pipe. Normally, a variable area flowmeter is installed on the water inlet, for set-up and routine control. Figure 7 shows a typical installation of two scrubbers at Worthington Steel Corp., Monroe, Ohio.

PERFORMANCE

As indicated above, the design of plate scrubbers involves a balancing of flow rates, efficiency, and physical parameters. Typically, pickle line scrubbers will contain between two and five plates, depending on the efficiency required.

Pressure drop through plate scrubbers is usually in the range 0.8" to 1.2" of water per plate.

Theoretically, there is no limit on the size and capacity of individual scrubbers, but the plate levelling requirements make scrubbers over about 7' dia (about 20,000 cfm capacity) difficult to install - for large capacities, multiple modules are a better solution. Actual installations vary in capacity from 700 cfm to 60,000 cfm.

In the past 17 years about 40 plate scrubbers have been installed on various applications, of which over half have been on HCl pickling. Some typical test results for these scrubbers are:

		Concentration of HCl in gas, ppmv dry	
Capacity acfm	No. of plates	Inlet	Outlet
8400	2	280	1.5
15000	2	140	6
3000	5	100+	1.5
4450	10	1550	<1
13500	5	660*	4.2
12600	5	660*	0.9
5000	3	50*	ND
12700	5	660*	ND
14000	5	660*	ND
6300	3	50*	ND
7400	5	700	7.7
8400	5	84	1.4

* is estimated
ND - not detectable

Many of the above results were obtained by stack testing using EPA-approved methods. However, it is important to realise that sampling methods, especially in hot humid gases, are rather uncertain, and wide variations in test results are normal. HCl sampling methods should improve as a result of this gas being a targetted substance under the Clean Air Act.

A complicating factor in HCl scrubber design and testing is the presence of HCl mist. Under certain, not very well understood circumstances, systems containing HCl and water vapor produce an aerosol of very fine (about 0.3 μm dia) droplets of concentrated HCl solution. Generation of this aerosol is characterised by a foggy appearance - often, the fog is so dense that the gas is opaque. The aerosol will be captured during sampling, and will show up as HCl content, but will pass straight through a scrubber with very little being removed. This is because the mechanism required to remove aerosols is not absorption but rather interception, and sub-micron particles are almost impossible to intercept in a low-energy scrubber. If mist is present in a system, it is possible to agglomerate and remove it using a wet fabric filter, but this solution is not practical for pickle line exhaust, where the particulate in the gas rapidly plugs the filter pores. On a pickle line, either a change in operating conditions to prevent formation of the mist, or use of a cooled scrubber, to agglomerate and remove the aerosol are the best solutions.

OTHER SYSTEMS

Plate scrubbers are appropriate for any water-soluble gas, and have been used successfully for hydrofluoric acid and nitric acid vapors. They have also been used for sulfuric acid exhaust systems, although a wet fibre agglomerator is better for this application, because sulfuric acid pickling produces acid droplets, not vapors.

LIMITATIONS

Plate scrubbers are not a universal answer to scrubbing problems, and there are some situations where they are not appropriate. The hydraulics of the plates at low liquid flows results in a rather limited operating range of gas flow - thus, systems where the gas flow rate varies widely are not appropriate applications for plate scrubbers. The scrubbers are also somewhat more complex to construct, and are therefore slightly more expensive than packed scrubbers. Thus, if the effluent is not to be recovered, or if the scrubber is to be operated using caustic soda as a scrubbing agent, the major benefits of the plate scrubber may be lost.

One application where the plate-type scrubber is not suitable is in removal of NO_2 generated in nitric/HF pickling. This gas is very sparingly soluble in water, and its removal involves a complex series of chemical reactions which seem to work better in a packed bed.

CONCLUSION

Plate scrubbers, which are simple to construct and operate, and have low maintenance requirements, can reduce total plant losses of hydrochloric acid, and make feasible the recovery of the acid contained in the fume exhaust air. In addition, recovery of this acid works towards the ultimate goal of zero discharge. Experience on over 20 installations has shown that the air can be cleaned to very low levels of HCl, with only a small flow of water.

There are not many pollution control devices that can pay for themselves with savings - plate scrubbers can!

REFERENCES

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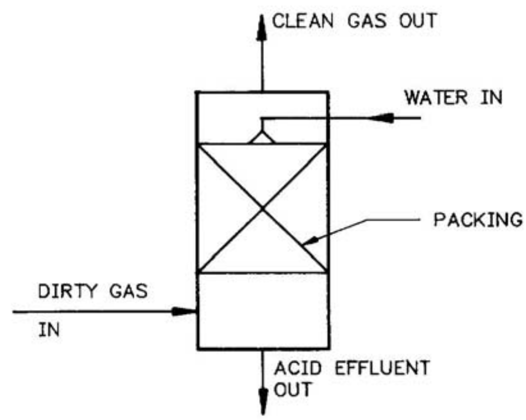
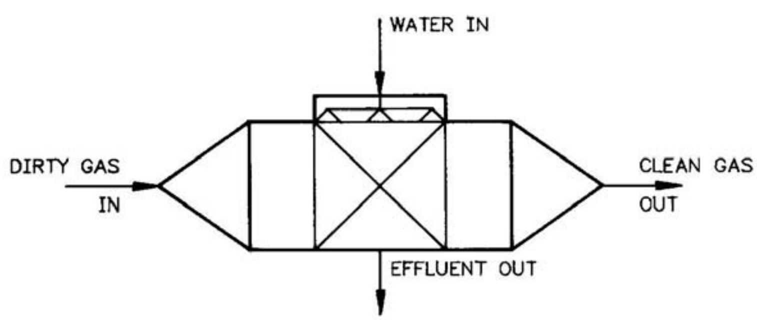
2) 'Sieve tray design', J.N.Stone, Access, 3, (6), 10 (Nov/Dec 1984)
3) 'Perry's Chemical Engineers Handbook', R.H. Perry and D. Green, McGraw-Hill, 1984, p3-64.
4) 'Vapor Pressure of Aqueous Hydrogen Chloride Solutions, 0 to 50°C', Fritz & Fuget, Ind. Eng. Chem., Chem and Eng Data, 1, (1), 10 (1956)



1A – VERTICAL PACKED TOWER



1B – HORIZONTAL, CROSS–FLOW SCRUBBER

FIGURE 1 – TYPES OF PACKED SCRUBBER

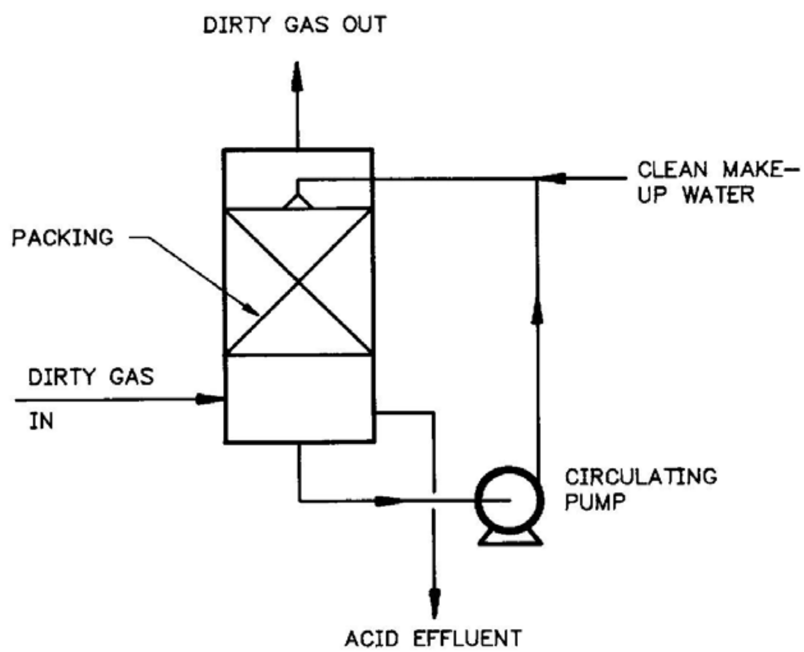


FIGURE 2
PACKED SCRUBBER WITH RECIRCULATION

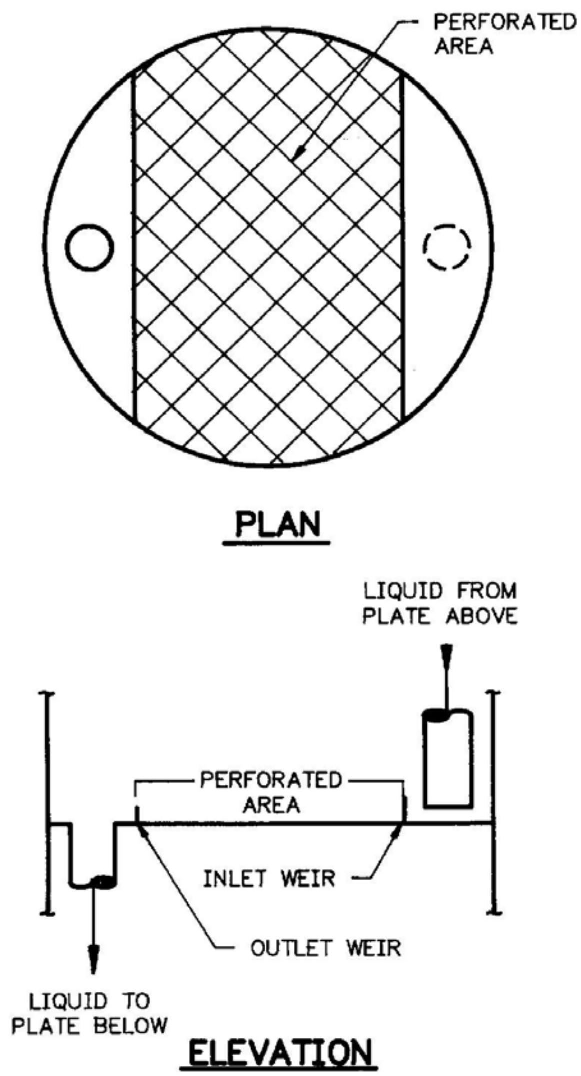


FIGURE 3 – PLATE LAYOUT

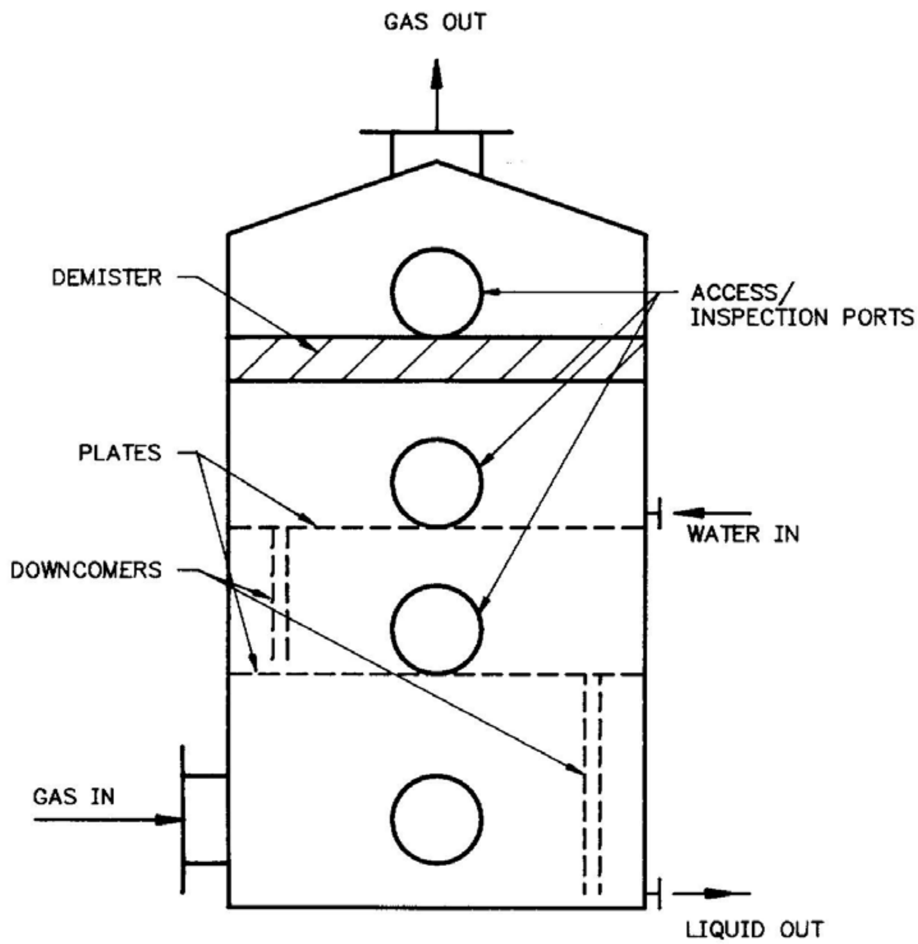


FIGURE 4
TYPICAL PLATE SCRUBBER ARRANGEMENT

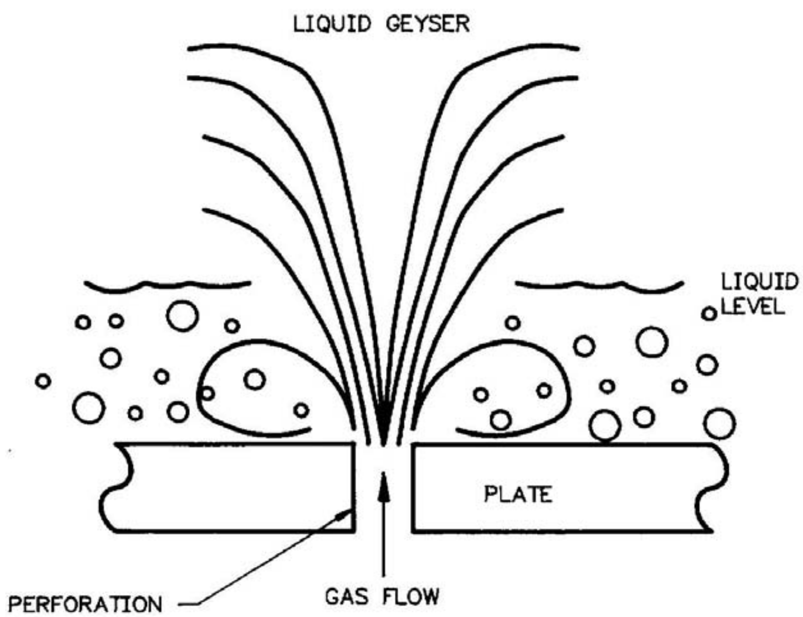


FIGURE 5
LIQUID JETTING AT PERFORATIONS

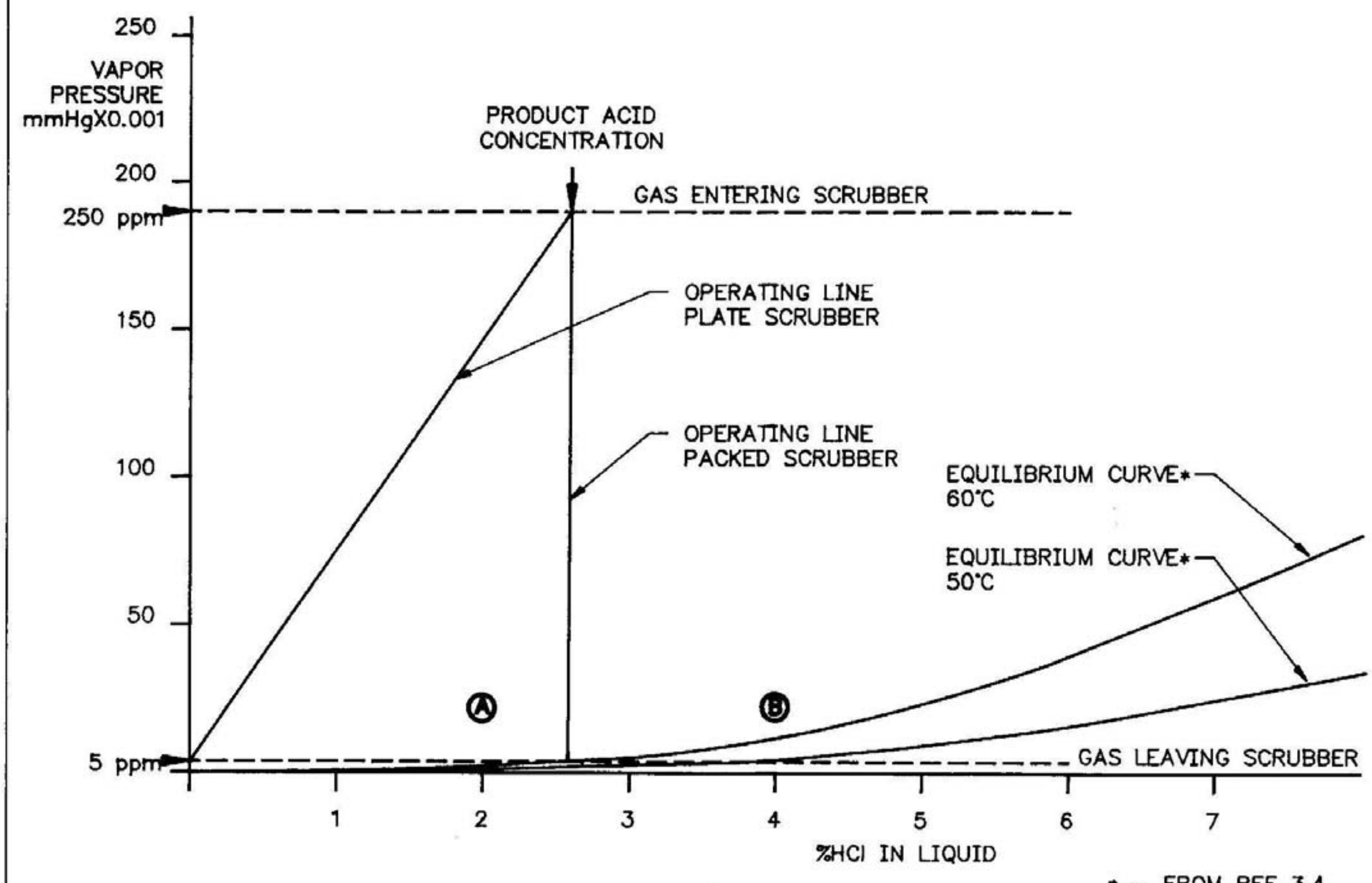


FIGURE 6 – HCL EQUILIBRIUM/OPERATING LINES

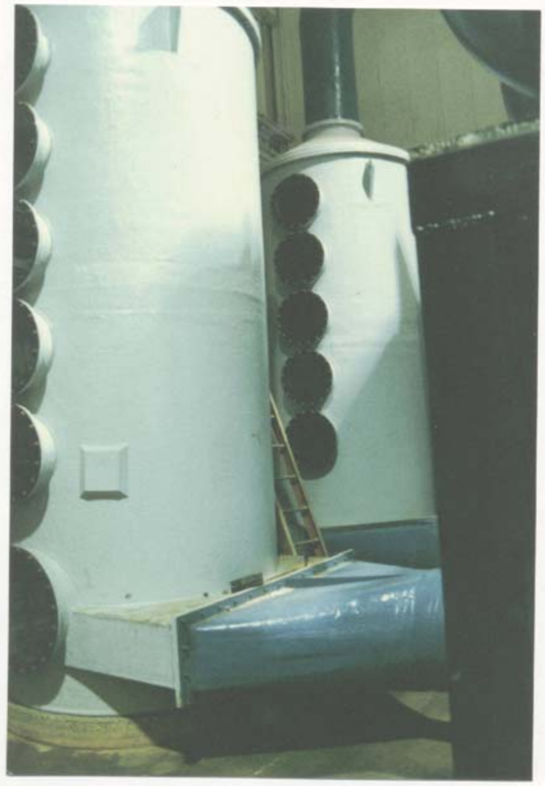


FIGURE 7

PLATE SCRUBBERS INSTALLED AT WORTHINGTON STEEL

MONROE, OHIO