Abstract. The paper proposes a method to decide the selection of the process to stripping volatile compounds from water, between air or steam stripping. It is based onto the operative and the capital cost of the installation. The ammonia desorption from water is presented as a case study.

Keywords. Environmental Engineering; air stripping; V.O.C. stripping.

1. Introduction.

One process used to recover water contaminated with V.O.C. or other volatile compounds is stripping. This process can be carried out by steam, as direct injection or to the reboiler, or by air.

To select the best alternative, factors such as thermodynamic of the mixture to be treated, operative and installation costs, maintenance and robustness of the installation and the construction material of the equipment must be considered. In several cases, the stripped product recovery at certain concentration as by-product is important, in contrast with others in where the final disposition of the compound is the main problem of the process.

A discussion based on the most convenient criteria to select the best alternative to volatile compounds stripping from water, and a general conclusion are presented in this work.

Starting from the analysis of elements that could influence the final process selection and following with equations to solve a case and a number of criteria to non-quantitative estimation (fuzzy parameters) the discussion concludes with application examples: a typical V.O.C. stripping task is compared with an ammonia stripping case from water, in order to select air stripping or steam stripping process for each one.

2.- Process Description.

The proposed task in the example is a desorption of ammonia from water, in a first case of concentration of 150 ppm. to 2 ppm. residual, and a
second case, of a concentration of 10,000 ppm of ammonia to 2 ppm. The liquid rate is 10,000 lt/hr. at ambient temperature.

2.1.- Air Stripping.

The air stripping process here adopted consists of a stripping column, with structured packing as internals. The air is provided by a fan; the exhaust air is treated with activated carbon to retain the desorbed ammonia. The recovery of the activated carbon bed is performed by heating with direct steam injection. This steam is condensed in a shell & tube heat exchanger, refrigerated with cooling water.

The inlet temperature of the liquid is 30 °C. Sodium hydroxide is added to the inlet liquid to rise the pH level to more than 10, and a strong acid is added to neutralize the outlet stream.

The stripping column are filled with structured packing.

2.2.- Steam Stripping.

The steam stripping is performed at 2 atm. of absolute pressure, by direct injection. A maximum heat recovery is required between the inlet and outlet liquid stream. A shell & tube heat exchanger performs this task. The exhaust stripping vapour is condensed in an other shell & tube exchanger, refrigerated with cooling water.

The stripping column are filled with structured packing.

3.- Cost Structure.

The objective function to select the better option is:

\[
C_{TOT} = C_C + C_R + C_{IC} + C_{CV} + C_V + C_A + C_{FN} + C_{C^*} + C_{REAC} + C_{AE} + C_{MANT.} + C_{PIP} + C_{AT} + C_{INST} + C_B + C_{CB} + C_F + C_{RECC^*} + C_{INSTC^*}
\]

The depreciation of all the equipment are fixed to 5 years.

The column and the internals cost are defined in function of the volume and the construction material. The cost is taking at market value of the columns and packing.

The steam cost is assumed at 8$/ton. value. The cooling water cost is assumed 0,011$/1000 lt.

The air blowing cost is calculated according Perry,

\[
P = 2.72,\text{E}-5 \cdot Q \cdot \Delta P
\] (2)

\[
P : \text{Required power, Kw.}
\]

\[
Q : \text{Gas flow, m}^3/\text{hr.}
\]
\( \Delta P \): Pressure gradient, as liquid height, cm. water.

The liquid pumping cost is calculated according Perry,

\[
P = \frac{H \cdot Q}{(3.67 \times 10^5 \cdot \xi)} \tag{3}
\]

\( P \): Required power, Kw.
\( H \): Liquid height, m. water.
\( Q \): Liquid flow, m\(^3\)/hr.
\( \xi \): Pump efficiency.

The electric energy price is 0.15 $/Kwh. The reactant costs are assumed 1$/kg. The activated carbon price is 4.5 $/kg.

Other related costs included are:
- Piping 61 % of equipment cost,
- Foundations 10 %, idem.
- Instruments 12 %, idem.

### 4.- Equipment Definition.

For this purpose, the column diameter is defined as a function of the Fv value, fixed at Fv = 2 for steam stripping and Fv = 1.8 for air stripping.

The column height is calculated according to:

\[
Z = Ntp \cdot \text{HETP} \tag{4}
\]

where the HETP is assumed for each case, and the Ntp is calculated as Kremser, in Treybal.

The adsorption bed is assumed adsorbs 40% volatiles in basis of its own weight. The regeneration demands 3 kg steam/kg volatile adsorbed. The bed life is assumed 4 years.

### 5.- An Example.

An interesting study case is the stripping of residual ammonia from effluent water. It is possible to remove the ammonia by both method of stripping, Fig. 1, and the more important question is: Which one is the better? Obviously, the answer is: The cheaper!

Some particular consideration are:

In the steam stripping case, the ammonia is obtained as diluted ammoniacal water. The column and its internal, so as the piping are made of
stainless steel. The maintenance is assumed as a desobstruction and cleaning of all the biofouling and hardness retained in the installation.

In the air stripping case, the column, its packing and associated piping are made of suitable plastic materials (polystyrene, polypropylene). In a different case, the column, its packing and the piping are made of stainless steel, to compare the alternative, in such a case the installation will be constructed in metal instead plastic. The packing is replaced each 3 years. The adsorption beds is C\textsuperscript{\textdia{t}}, regenerated with steam, which is condensed, obtaining finally the ammonia as diluted ammoniacal water.

The vapour-liquid equilibrium data are obtained from Edwards.

Comparative values for different cases:

<table>
<thead>
<tr>
<th>Costs in $/hr</th>
<th>Steam, 150 ppm NH\textsubscript{3}</th>
<th>Air, 150 ppm NH\textsubscript{3}</th>
<th>Air, 150 ppm NH\textsubscript{3}, Plastic</th>
<th>Steam, 10,000 ppm NH\textsubscript{3}</th>
<th>Air, 10,000 ppm NH\textsubscript{3}</th>
<th>Air, 10,000 ppm NH\textsubscript{3}, Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>0.1370</td>
<td>0.2283</td>
<td>0.6849</td>
<td>0.2294</td>
<td>0.3584</td>
<td>1.0752</td>
</tr>
<tr>
<td>Packing</td>
<td>0.1370</td>
<td>0.4566</td>
<td>1.9635</td>
<td>0.2871</td>
<td>1.1246</td>
<td>4.8361</td>
</tr>
<tr>
<td>Ther. isol.</td>
<td>0.0343</td>
<td>0.0</td>
<td>0.0799</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Heat exch</td>
<td>0.5936</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5936</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ther. isol.</td>
<td>0.0228</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0228</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pump</td>
<td>0.0228</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0228</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Air blow.</td>
<td>0.0</td>
<td>0.988</td>
<td>0.988</td>
<td>0.0</td>
<td>1.0020</td>
<td>1.0020</td>
</tr>
<tr>
<td>Fan</td>
<td>0.0</td>
<td>0.0891</td>
<td>0.0891</td>
<td>0.0</td>
<td>0.0891</td>
<td>0.0891</td>
</tr>
<tr>
<td>Str steam</td>
<td>8.9300</td>
<td>0.0</td>
<td>0.0</td>
<td>9.0320</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Condens.</td>
<td>0.3960</td>
<td>0.0</td>
<td>0.0</td>
<td>0.4011</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pumping</td>
<td>0.0584</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0584</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Reactants</td>
<td>0.0</td>
<td>0.0800</td>
<td>0.0800</td>
<td>0.0</td>
<td>0.0800</td>
<td>0.0800</td>
</tr>
<tr>
<td>Piping</td>
<td>0.5780</td>
<td>0.4178</td>
<td>1.6155</td>
<td>0.7537</td>
<td>0.9046</td>
<td>3.4978</td>
</tr>
<tr>
<td>Foundat.</td>
<td>0.0948</td>
<td>0.0685</td>
<td>0.0685</td>
<td>0.2648</td>
<td>0.1236</td>
<td>0.1483</td>
</tr>
<tr>
<td>Instrum.</td>
<td>0.1137</td>
<td>0.0822</td>
<td>0.0822</td>
<td>0.3178</td>
<td>0.1483</td>
<td>0.1780</td>
</tr>
<tr>
<td>Mainten.</td>
<td>0.1142</td>
<td>0.9513</td>
<td>0.9513</td>
<td>0.4566</td>
<td>0.1961</td>
<td>2.3443</td>
</tr>
<tr>
<td>C\textsuperscript{\textdia{t}}, invent.</td>
<td>0.0</td>
<td>0.1596</td>
<td>0.1596</td>
<td>0.0</td>
<td>1.5103</td>
<td>1.5103</td>
</tr>
<tr>
<td>C\textsuperscript{\textdia{t}}, recov.</td>
<td>0.0</td>
<td>0.0888</td>
<td>0.0888</td>
<td>0.0</td>
<td>2.5181</td>
<td>2.5181</td>
</tr>
<tr>
<td>C\textsuperscript{\textdia{t}}, equip</td>
<td>0.0</td>
<td>0.2283</td>
<td>0.2283</td>
<td>0.0</td>
<td>0.8792</td>
<td>0.8792</td>
</tr>
<tr>
<td>Cost, $/hr</td>
<td>11.2326</td>
<td>3.8437</td>
<td>6.9421</td>
<td>11.9488</td>
<td>11.1369</td>
<td>17.8745</td>
</tr>
<tr>
<td>Annual Cost, $/y.</td>
<td>98,397</td>
<td>33,671</td>
<td>60,813</td>
<td>104,671</td>
<td>97,559</td>
<td>156,581</td>
</tr>
</tbody>
</table>
6.- Conclusion.

The comparative cost values show that for the analysed study case, the alternative of air stripping is the best option. The steam stripping is better selection in the case when the air stripping equipment are constructed in stainless steel.

The presented method is general, applicable to any case of recovery contaminated water with volatile compounds.

7.- Nomenclature.

$C_{TOT}$ : Total cost, $/hr.

$C_C$ : Column cost, $/hr.

$C_R$ : Packing column cost, $/hr.

$C_{IC}$ : Heat recovery exchanger cost, $/hr.

$C_{CV}$ : Steam condenser cost, $/hr.

$C_V$ : Live steam cost, $/hr.

$C_A$ : Air blowing cost, $/hr.

$C_{FN}$ : Fan cost, $/hr.

$C_{CF}$ : Activated carbon bed cost, $/hr.

$C_{REAC}$ : Reactive cost, $/hr.

$C_{AE}$ : Cooling water cost, $/hr.

$C_{MANT.}$ : Maintenance costs, as replaced pieces and labour work, $/hr.
C_{PIP} : Piping cost, $/hr.
C_{AT} : Thermal isolation, $/hr.
C_{INST} : Instruments cost, $/hr.
C_{B} : Liquid recirculation pump cost, $/hr.
C_{CB} : Steam condenser of activated carbon bed stripping cost, $/hr.
C_{F} : Equipment foundation, $/hr.
C_{RECC^*} : Recovery of activated carbon bed (steam) cost, $/hr.
C_{INSTC^*} : Adsorption bed ancillary cost, $/hr.
F_{v} : Gas factor, sqrt(gas density). gas velocity, sqrt(kg/m^3). (m/s).
HETP : Height equivalent to a theoretical plate, m.
N_{tp} : Number of theoretical trays, ad.

7.- References.