

2016#

Inprocess Operator Training Programme

ABSORPTION COLUMN

These exercises are intended to provide an understanding of absorption columns and the fundamental principles they use to eliminate pollutants

ABSORPTION COLUMN

INTRODUCTION

The absorption process is based on the transfer of a pollutant from a gaseous current in which it is present in a high concentration, to a liquid with a low vapour pressure and a lower concentration of the compound, in which it is highly soluble. So the driving force that generates the separation will be the difference in the concentrations. Absorption may be physical if the separation is by dissolution or chemical, if the compound to be eliminated reacts to the selected solvent.

To achieve maximum efficiency, it is necessary to find the maximum contact surface between the residual gas and the eliminator liquid. In addition, the materials used to build the equipment must be resistant to corrosion, due to the acidity of the pollutants. There is a wide range of equipment designed for this purpose, including sieve plate columns, packed columns, aspersion boxes, Venturi separators, etc. In this particular case, the study is conducted in a packed column fitted with a plate at the bottom of the column (sump) that acts like a hydraulic seal and allows the liquid level to be controlled.

Counter-current stacked columns are cylindrical and contain a filling that maximises the contact surface between the gas and the liquid. Packed columns have higher gas absorption efficiencies than other types of equipment and they can handle higher residual gas flow rates and lower quantities of cleaning fluids; however the pressure losses are high and the equipment, operating and maintenance costs incurred may be considerable.

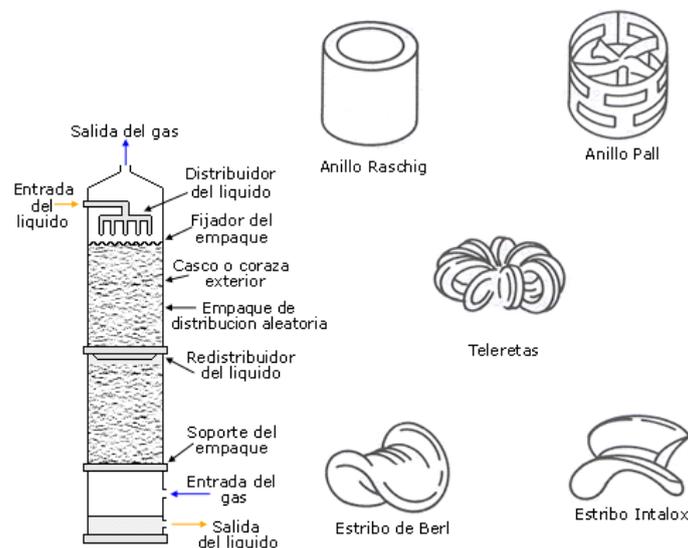


Figure 1. Packed column structure and types of filling

PURPOSE OF THE EXERCISES

The main objective of the programmed exercises is to observe and analyse how changes in the operational variables affect this type of equipment, including those caused by a change executed by the operator (e.g., a hypothetical optimisation in the absorbing liquid requirements) and those caused by an undesirable change provoked by the process (for instance, an increase in the concentration of the pollutant gas present in the gaseous current).

CASE STUDY DESCRIPTION

The following case is presented to conduct this study. One of the products obtained during a chemical process is an air current that contains a specific quantity of hydrochloric acid. The ultimate objective is to eliminate that current or release it into the atmosphere. Under the current conditions, that emission is not feasible, as the hydrochloric acid concentration exceeds the limit established by the pollutant agent emission regulations. At this point, it is decided to eliminate this pollutant from the gaseous current, and for this purpose we will use an absorption column in which the absorbent agent is water. The process is performed in a counter-current packed column in which the liquid enters through the top part of the column, while the gaseous mixture enters through the bottom. The outlet of both currents will be on the opposite side to the inlet, and so the water that takes the pollutant will emerge from the bottom of the column and the air that is free of it will emerge through the top. In addition, the presence of a plate at the base of the column, which acts like a hydraulic seal, allows the liquid level at the bottom of the column to be controlled.

Prior to the entry of the water in the column there is an air refrigerant that cools the water. This substance will subsequently act like a separating agent.

Open the base case: To open the case, in the **Modules** menu, go to the **Runtime** submenu, and in it, select **Open**. Open the **Absorption Column** case. Observe the following image:

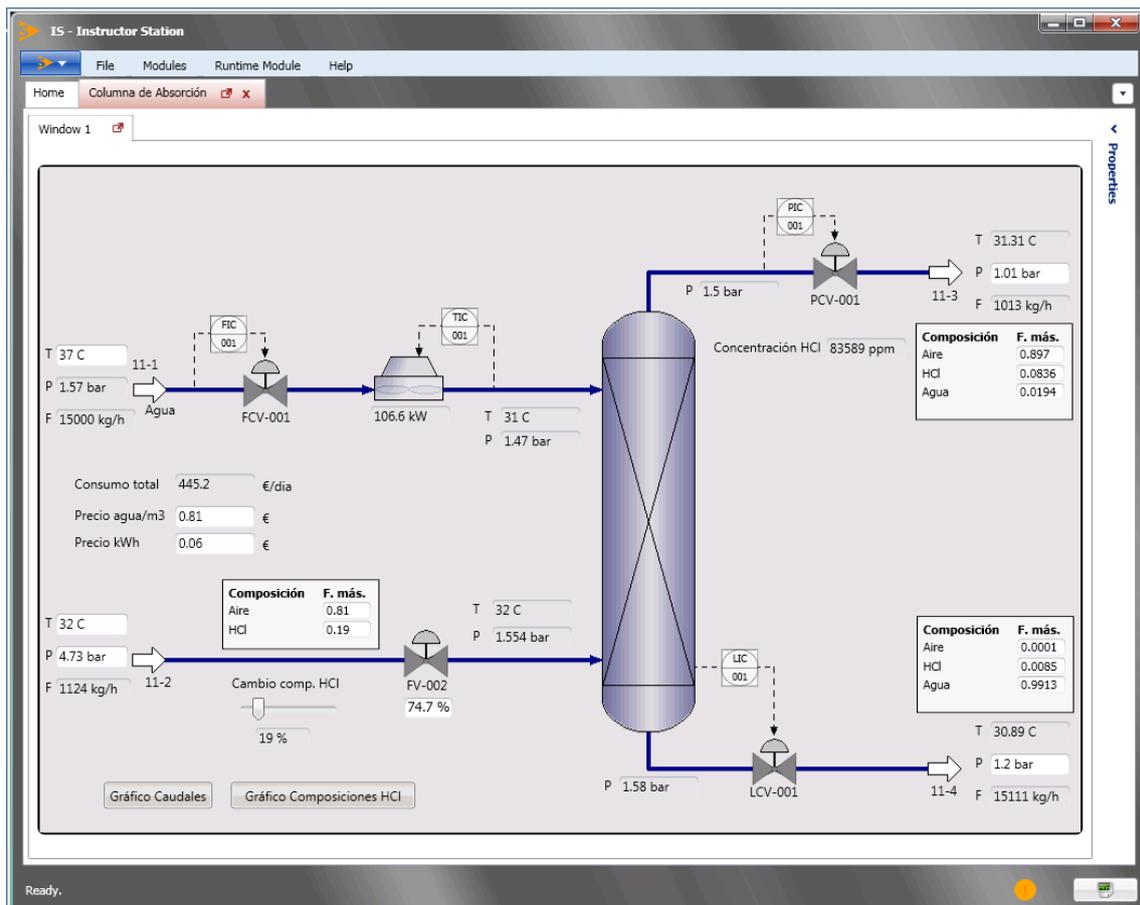


Figure 2. Base case showing the initial values

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Once the case has been loaded, the base case will appear with the different values of the variables:

- Pressure, temperature and flow rate of the liquid current and the gaseous current at their inlets and outlets.
- Pressure at the top and bottom parts of the column.
- Aperture of the valves.
- Compositions of the different currents.
- Total consumption, depending on the water and kW/h cost.
- Air refrigerant consumption, depending on the desired temperature at the outlet.

The buttons in the bottom left-hand corner of the screen open the graphs that display the different flow rates and the HCl composition of each current.

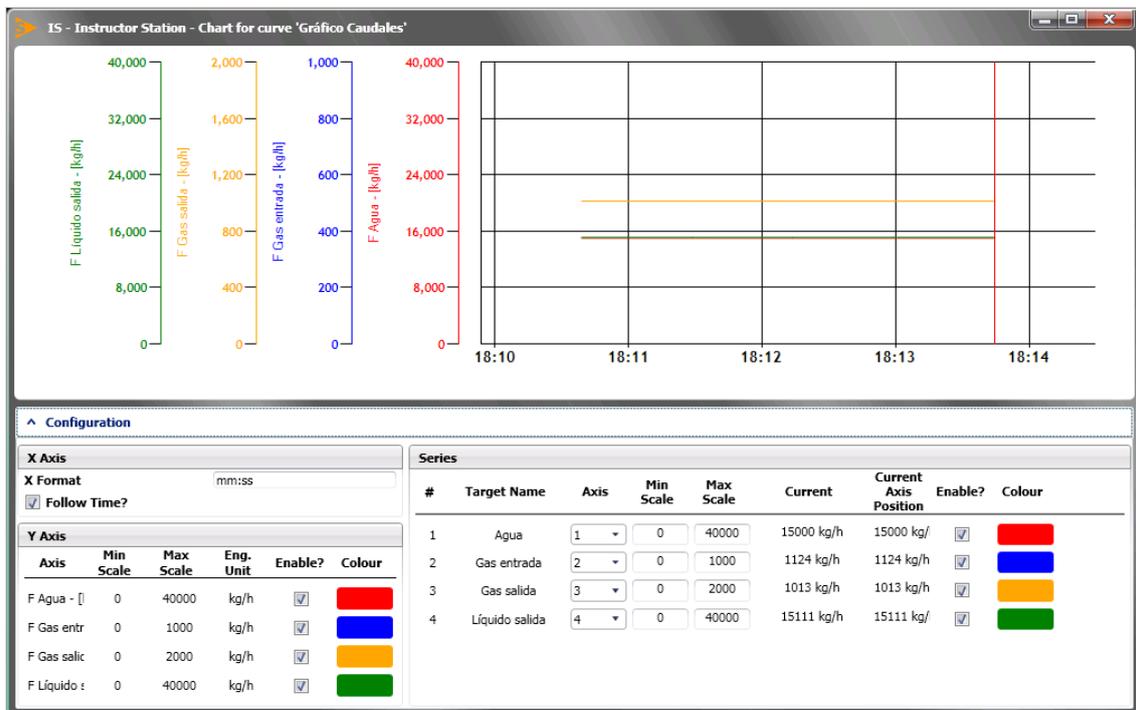


Figure 3. Example of graph showing flow rate changes

Modification of operating variables After opening the case study, the user can change different variables in order to perform the desired study. These variables are:

- Temperature of the fluids at the operating inlet.
- Water flow rate entering the column.
- Desired temperature at the air refrigerant outlet.
- Composition of the gaseous current.
- Pressure at the column head (top part).
- Liquid level in the column.

MANUAL / AUTOMATIC CONTROL

To make the changes to the mode and set point of the controllers, click on the controller of interest. The controller information is shown in the *Properties* tab on the right-hand side of the screen, in accordance with the following figure:

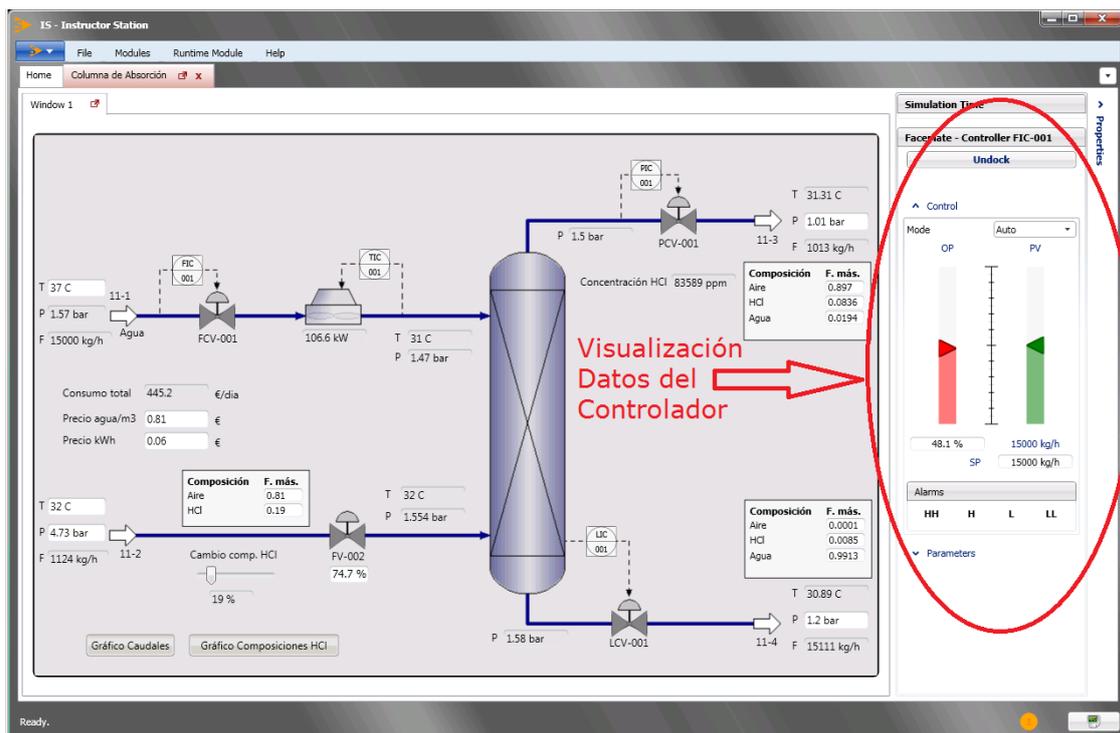


Figure 4. Flow rate controller data

The operating mode is on **Automatic** (Auto), meaning that the controller will adjust the valve aperture in accordance with the *Set Point* specified in the respective cell. In the event of wanting to change to the **Manual** mode, in the *Mode* window, select the Manual option, which allows the valve aperture to be changed (controller OP).

EXERCISE 1. STEADY STATE (BASE CASE)

After starting up the simulation by pressing the **Run** button in the **Runtime Module** tab, the steady state shown in the base case corresponds to the processing of 1,124 kg/h of gas with a composition of 19% HCl and 81% air, at a temperature of 32 °C. In the base case, 15,000 kg/h of water are processed. It reaches a temperature of 37 °C and is cooled to 31 °C by the air refrigerant located in front of the column inlet. The operating pressure is 1.5 bar at the column head and the level of the liquid inside it is no more than 50%. Given these conditions, it is observed that at the top outlet (the air outlet with a lower concentration of pollutant as compared to the inlet), HCl still remains at a concentration of approximately 83,500 ppm(wt).

In the following exercises it is seen that when the operating variables are changed, this concentration also changes. These variables are the ones shown in Figure 5.

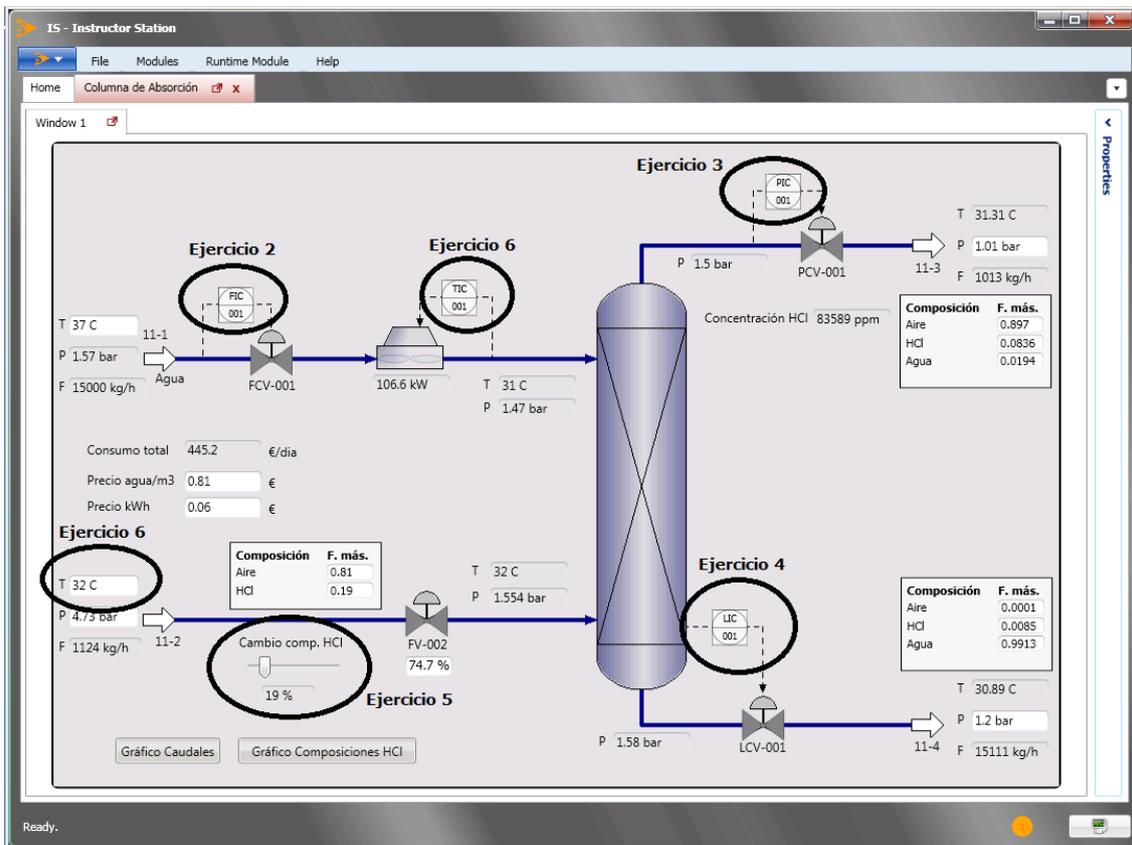


Figure 5. Base case with the variables to be studied and analysed

Q1.1: How many kg/h of HCl are recovered in the aqueous phase?

Q1.2: If 213.56 kg/h of the total 1,124 kg in the incoming current are HCL, what percentage is recovered? Use the value obtained in the previous question.

How would you rate the column efficiency based on the result obtained?

Q1.3: In the event of only having the gaseous outlet data and not the aqueous current data, would it still be possible to calculate the recovery? How?

EXERCISE 2. CHANGE IN THE ABSORBENT AGENT FLOW RATE

In the base case it was seen that, under the conditions given to the simulator as the initial values, a small percentage of HCl that was to be separated from the air current still exists in the gas outlet current. To a certain extent, it is seen that a large part of this pollutant was dragged by the aqueous current, and so the initial objective could be considered accomplished. In most cases, this is not sufficient. One clear example of this is whether it is desirable to emit this current into the atmosphere. This is regulated by the law, and thus a maximum limit would be required in the outgoing concentration. In this exercise we will assume that in the case of HCl, its emission below 500 ppm is permitted.

Q2.1: How do you think the HCl composition in the outgoing gaseous current will change if the absorbent flow rate increases? Should the water flow rate be increased or decreased for the HCl content in the outgoing gas current to be within the permitted limits?

1. Open the base case. Start it up by clicking on **Run**. Open all the tables to see the initial values in the steady state and the graphs showing the temporary evolution of the variables using the respective buttons.
2. Change the water flow rate value with the FIC-001 controller *Set Point* based on the values proposed in table 2.1.
3. Take note of the results observed in the table once the system has reached the steady state (all the variables remain constant).

Absorbent flow rate (kg/h)	Gas inlet		Gas outlet		HCl recovery (%)
	[HCl] (mass fraction)	Flow rate (kg/h)	[HCl] (ppm(wt))	Flow rate (kg/h)	
13,000					
15,000					
17,000					

Q2.2: What is the required water flow rate to eliminate the HCl up to the limits permitted by the hypothetical legislation? What is the cost?

Clue: Use the results obtained in the exercise to obtain a rough idea of the required water flow rate.

EXERCISE 3. CHANGE IN THE PRESSURE OF THE COLUMN HEAD

In the base case, the top part of the column is operating at a pressure of 1.5 bar. As explained previously, a ratio exists between the operating pressure and the solubility of a solute in an absorbent. The objective of this exercise is to check this ratio experimentally by changing the operating pressure of the column.

1. Open the base case. Start it up by clicking on **Run**. Open all the tables to see the initial values in the steady state.
2. Change the FIC-001 controller SP value corresponding to the mass fraction of water, so that the new set point is the base value, 15,000 kg/h. Let the value stabilise.
3. Change the value of the pressure in the column head (see Figure 5) with the first value in the following table by changing the Set Point (SP) value of the pressure controller.
4. Wait for a stable response and take note of the HCl concentration at the outlet.
5. Repeat steps 3 and 4 for the following pressure.

Table 3.1. Results of the change in the pressure of the column head					
Case	Gas inlet		Gas outlet		HCl recovery (%)
	[HCl] (mass fraction)	Flow rate (kg/h)	[HCl] (ppm(wt))	Flow rate (kg/h)	
Reduction P (1.45 bar)					
Base case (1.5 bar)					
Increase in P (1.55 bar)					

Q3.1: How has the increase in pressure affected the column efficacy? Why?

6. Leave the pressure value that has given the lowest HCl concentration.

Q3.2: Now what is the water flow rate required to eliminate the HCl below 500 ppm? What is the cost? What economic savings are obtained by working at the new pressure?

EXERCISE 4. CHANGE IN LEVEL AT THE BOTTOM OF THE COLUMN

It is seen that in the base case steady state, the values shown remain unaltered over time.

To obtain the following scenario, it is assumed that the level at the bottom of the column has increased or decreased and then we will see the effects of this change on the HCl concentration at the outlet.

1. Open the base case. Start it up by clicking on **Run**. Open all the tables to see the initial values in the steady state and the graphs showing the temporary evolution of the variables.
2. Increase the column level controller Set Point (see Figure 5) to 70%.

Q4.1: What happens to the HCl concentration at the gas outlet as soon as the change takes place?

3. Let the system reach a new steady state (the concentration value at the outlet must be constant and unaltered) and take note of the HCl concentration value at the outlet in table 4.1 below.
4. Reduce the column level controller Set Point (see Figure 5) to 30% and also take note of the value obtained in the steady state.

Q4.2: What happens to the HCl concentration at the gas outlet in this case?

Table 4.1. Results of the change in the column liquid level	
Case	Concentration (ppm(wt))
Increase in level (70%)	
Base case (50%)	
Decrease in level (30%)	

Q4.3: What is the conclusion regarding the effect of the change in level in the absorption column?

EXERCISE 5. CHANGE IN THE INCOMING GAS CURRENT CONDITIONS

In the base case, the contaminated gas flow reaching the absorption column had a composition of 19% HCl and 81% air. To do this exercise, the composition of the gas flow will be changed in order for us to see the effects if the other operating variables remain constant. The changes in composition are made by moving the *track-bar* at the bottom of the incoming current compositions table.

1. Open the base case. Start it up by clicking on **Run**. Open all the tables to see the initial values in the steady state.

Q5.1: Before starting the study, answer the following question: If there is less HCl in the gas inlet and the same quantity of water as in the base case for the absorption, do you think the absorption efficiency will be greater?

2. Change the value of the incoming composition until the HCl composition reaches 30%
3. Take note in the following table of the outgoing gas flow rate values and the HCl concentration in this current once these values are constant.
4. Change the value of the incoming composition until the HCl composition reaches 10%.
5. Take note in the following table of the outgoing gas flow rate values and the HCl concentration in this current once these values are constant. Calculate and take note of the HCl recovery and the kg of water used per kg of HCl recovered.

Table 5.1. Results of the change in the incoming current composition					
Incoming gas composition	Incoming gas flow rate (kg/h)	Gas outlet		Recov. HCl (%)	kg H2O / kg HCl rec.
		[HCl] (ppm(wt))	Flow rate (kg/h)		
10% HCl					
19% HCl					
30% HCl					

Q5.2: In which of the above three cases will there be a greater recovery of HCl at the gas outlet and thus better absorption efficiency?

EXERCISE 6. CHANGE IN THE EQUIPMENT INLET TEMPERATURES

As seen in the above cases, the gas flow rate entering the column enters at a temperature of 32° C. In this exercise we will analyse the effect of a change in the temperature of the incoming gas and liquid currents.

First, it is observed that there is a great difference between the flow rates entering the column, as the water flow rate is 15 times greater than the gas flow rate.

1. Open the base case. Start it up with the **Run** button or return the case to the initial values for the base case. Open all the tables to see the initial values in the steady state.
2. Increase the incoming gas current temperature to 38 °C.
3. Complete the following table to see the changes.

Table 6.1. Results of increasing the gaseous mixture temperature							
Air flow rate (kg/h)	Temp. Gas (C)	Air SP (C)	[HCl] (ppm(wt))	Air power (kW)	Total consumption (€/day)	Temp. Liquid outlet (C)	Temp. Gas outlet (C)

Q6.1: What has happened to the HCl concentration at the gas outlet?

4. Return the temperature of the gaseous mixture to its base case value (32 °C).
5. Reduce the temperature of the air refrigerant *Set Point* to 25 °C.
6. Complete the following table to see the changes.

Table 6.2. Results of reducing the temperature at the water inlet							
Air flow rate (kg/h)	Temp. Gas (C)	Air SP (C)	[HCl] (ppm(wt))	Air power (kW)	Total consumption (€/day)	Temp. Liquid outlet (C)	Temp. Gas outlet (C)

Q6.2: Does changing the temperature of the water at the absorption column inlet have the same effect as changing the gas temperature?

Why do you think that in one case it has a considerable effect and not in the other? See the initial introduction to Exercise 5.

As seen, a small change in the temperature of the water entering the column favours the absorption of HCl in the water.

Q6.3: What is the required water flow rate to eliminate the HCl up to the limits permitted by the hypothetical legislation (less than 500 ppm) with the new water temperature?

As commented earlier in the introduction to the exercise, a balance would have to be established between the advantages and disadvantages of the latter case. The advantage was already seen, a reduction in the pollutant in the outgoing gaseous current, but:

Q6.4: What disadvantage was caused by this change in temperature? How can this disadvantage be mitigated?

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