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2021-2022 FALL SEMESTER

FIXED AND FLUIDIZED BED

1. INTRODUCTION

Liquids and gases flow through beds of solid particles in several technical processes such as filtration, ion-exchange and catalytic reactors. The resistance to the flow of fluid through the voids in a bed of solids is the resultant of total drag of all the particles in the bed. Depending on the Reynolds number laminar flow, turbulent flow, form drag, separation and wake formation occur. As in the drag of single solid particle, there is no sharp transition between laminar and turbulent flow like that occurring in flow through the conduits of constant cross section. (1)

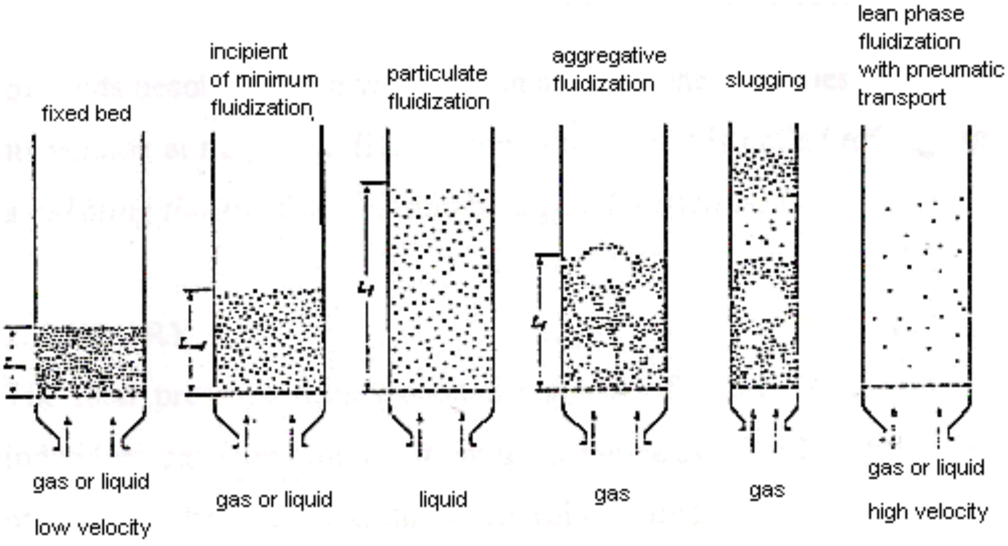

Figure 1. Various kinds of contacting of solids by fluid.(2)

As shown in Figure. 1 when a fluid passes upward through bed of fine particles at a low flow rate, fluid merely percolates through the void spaces between stationary particles. This is a. fixed bed. With an increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted regions. This is expanded bed. Until this point the bed shows the fixed bed behaviors and the pressure drop through the bed increases.

At a still higher velocity, a point is reached when the particles are all just suspended in the upward flowing gas or liquid. At this point the frictional force between the particle and fluid counterbalances the weight of the particle, the vertical component of the compressive force between adjacent particles disappear, and the pressure drop through any section of the bed about equals the weight of fluid and particles in that section. The bed is considered to be just

fluidized and is referred to as an incipiently fluidized bed or a bed at minimum fluidization.
In liquid-solid systems an increase in flow rate above minimum fluidization usually results in a smooth, progressive expansion of the bed. Gross flow instabilities are damped and remain small, and large scale bubbling or heterogeneity is not observed under normal conditions. A bed such as this is called a homogeneously fluidized bed or simply a liquid fluidized bed.

Gas solid systems generally behave in a quite different manner. With an increase flow rate beyond minimum fluidization, large instabilities with bubbling and channeling of gas are observed. At higher flow rates agitations become more violent and movement of solids becomes more vigorous. In addition the bed doesn't expand much beyond its volume at minimum fluidization. Such a bed is called an aggregative fluidized bed. a bubbling fluidized bed or simply a gas fluidized bed. (2)

2. THEORY

The total pressure drop trough the bed of solids is related with the drag of the individual particles, the most common methods of correlation are based on estimates of the total drag of the fluid on the solid boundaries of tortuous channels through the bed particles.

2.1. Mechanics of particle motion

The movement of particle through a fluid requires external force acting on the particle. This force may come from a density difference between the particle and the fluid or it may be the result of electric or magnetic fields. In this section only gravitational or centrifugal forces arise from density differences will be considered. Three forces act on a particle moving through a fluid: (1) the external force, gravitational or centrifugal; (2) the buoyant force, which acts parallel with the external force but in the opposite direction; and (3) the drag force, which appears whenever there is relative motion between the particle and the fluid. The drag force acts to oppose the motion and acts parallel with the direction of movement but in the opposite direction. (3)

2.2. Determination of forces acting on the particles

Consider a particle of mass m moving through a fluid under the action of external force F_e. Let the velocity of particle relative to fluid be V. Let the buoyant force on the particle be F_b and let the drag be F_d. Then the resultant force on the particle is (3) ;

$$F_T = F_e - F_b - F_d \qquad (1)$$

The external force can be expressed as a product of the mass and acceleration of the particle from this force and

$$F_e = mg \qquad (2)$$

The buoyant force is, by Archimedes' principle, the product of the mass of the fluid displaced by the particle and the acceleration from the external force and

$$F_b = \frac{m\rho_L g}{\rho_p} \qquad (3)$$

$$F_d = \frac{CdV^2 \rho_L A_p}{2} \qquad (4)$$

here; m mass of particles (kg), p_p and p_L density of particle and liquid (kg/m^3), V fluid velocity (m/s), Ap cross sectional area of particle (m^2), C_d drag coefficient acceleration of the particle and whole equation is $^{(3)}$:

$$m\frac{dv}{dt} = F_e - F_b - F_d \qquad (5)$$

$$m\frac{dv}{dt} = mg - \frac{m\rho_L g}{\rho_p} - \frac{CdV^2 \rho_L A_p}{2} \qquad (6)$$

if this equation is arranged;

$$\frac{dv}{dt} = \left(\frac{\rho_p - \rho_L}{\rho_p}\right) g - \frac{CdV^2 \rho_L A_p}{2m} \qquad (7)$$

2.3. Terminal velocity

In gravitational settling, g is constant. Also, the drag always increases with velocity. Equation (7) shows that the acceleration decreases with time and and approaches zero. The particle quickly reaches a constant velocity, which is the maximum attainable under the circumstances, and which is called terminal velocity. The equation for the terminal velocity V_t is found, for gravitational settling, by taking $dv/dt = 0$. then from equation (7) terminal velocity is $^{(3)}$:

$$V_t = \sqrt{\frac{2(\rho_p - \rho_L)}{C_d \rho_L A_p \rho_p} mg} \qquad (8)$$

If the particle is spheres of diameter D_p

$$A_p = \frac{\pi D_p^2}{4} \qquad (9)$$

Substituting m and A_P to Equation (8)

$$V_t = \sqrt{\frac{4\left(\rho_p - \rho_L\right)D_p}{3C_d\rho_L}g} \qquad (10)$$

$$\mathrm{Re}_p = \frac{D_p\rho_L V_t}{\mu} \qquad (11)$$

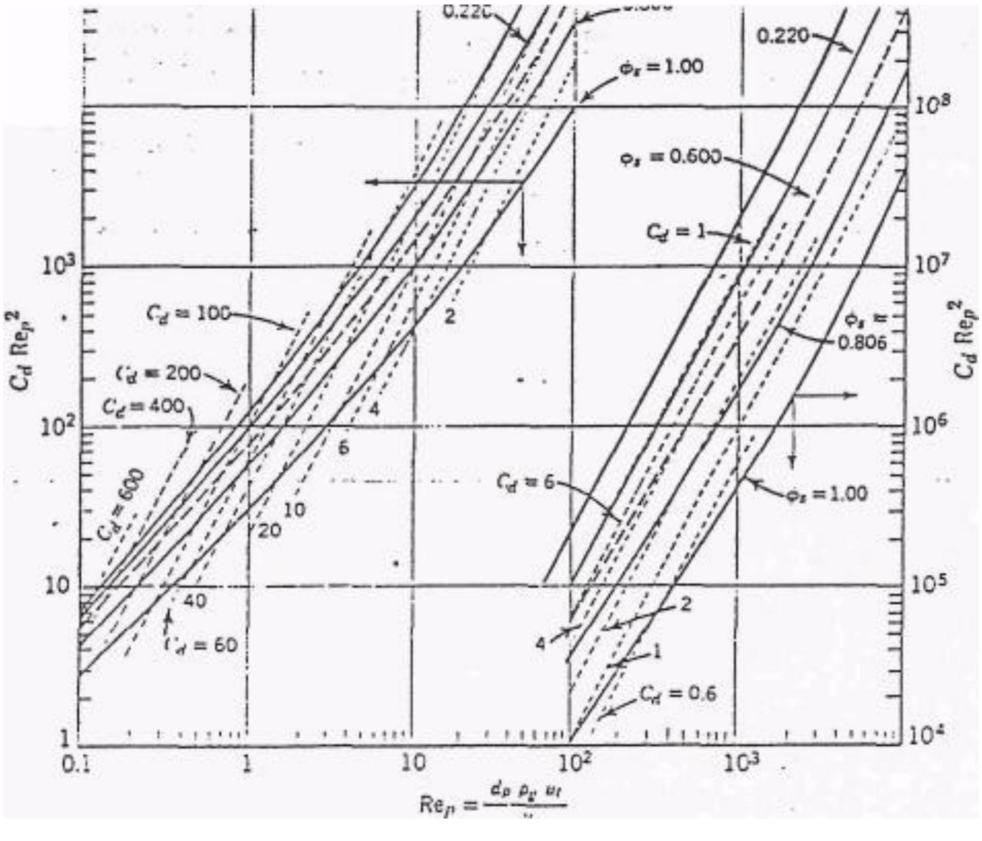

Figure 2. Chart for calculating the terminal velocity of particles falling through fluids (2) .

In the general case the terminal velocity can be found by trial and error after guessing Re_p to get an initial estimate of C_d For the limiting cases of very low or very high Reynolds numbers, equation can be used to get V_t directly. Both spherical and nonspherical particles the terminal velocity V_t can be obtained from Fig.2.

The pressure drop in fixed bed can be calculated by some correlations such as Ergun equation, Blake-Plummer equation and Kozeny-Carman equation depending on the value of Reynolds number.

Ergun equation can be expressed in the form (4);

$$\frac{\Delta P}{L}\frac{Dp}{\rho(Vsm)^2}\frac{\varepsilon^3}{(1-\varepsilon)} = 150\frac{(1-\varepsilon)}{\mathrm{Re}} + 1.75$$

where

Dp :Size of particles in micron (m)

L :Height of bed (m)

μ_W :Viscosity of fluid (water) (10^{-3} Nsm^{-2})

v_W :Kinamatic viscosity of liquid (water) (lO^{-6} Nsm^{-2})

ρ_L :Density of liquid (kg m^{-3})

ρ_p :Particle density (kg m^{-3})

ε :Bed voidage = l-(Mass of particles / (Particle density x Total bed volume))

Re : Average Reynolds number based on superficial velocity ($D_p V_{sm} \rho_W / \mu_W$) which is dimensionless.

If the flow rate Q is measured in L/second and V_{sm} is average superficial velocity in ms^{-1}, then

$$V_{sm} = \frac{Q \times 10^{-3}}{A}$$

A : Bed cross-sectional area (m^2)

As the pressure drop (h) across the bed is measured in mmH$_2$O then

$$\frac{\Delta P}{\rho_w g} = h \times 10^{-3}$$

Where g = 9.81 (Nm^{-2})

Then our original equation becomes

$$h = \left[\frac{150L(1-\varepsilon)^2 (V_{sm})\mu_w}{D_p^2 \varepsilon^3 \rho_w g} + \frac{1.75(V_{sm})^2 (1-\varepsilon)}{D_p \varepsilon^3 g}\right] \times 10^3\, mmH_2O \qquad (14)$$

The pressure drop at fluidization can be predicted by using the equation (2);

$$\Delta P = L(1-\varepsilon)(\rho_S - \rho_W)g \qquad (15)$$

$$h = L(1-\varepsilon)\left(\frac{\rho_S - \rho_W}{\rho_W}\right)\times 10^3 \, mmH_2O \qquad (16)$$

The values μ_W and V_w can be obtained from data Sheet
Minimum fluidization velocity can be expressed as;
For small particles and $Re_p < 20$ (2)

$$V_{mf} = \frac{D_p^2(\rho_p - \rho_L)g}{1650\mu} \qquad (17)$$

For large particles and $Re_p > 1000$ (2)

$$(V_{mf})^2 = \frac{D_p(\rho_p - \rho_L)g}{24.5\rho_w} \qquad (18)$$

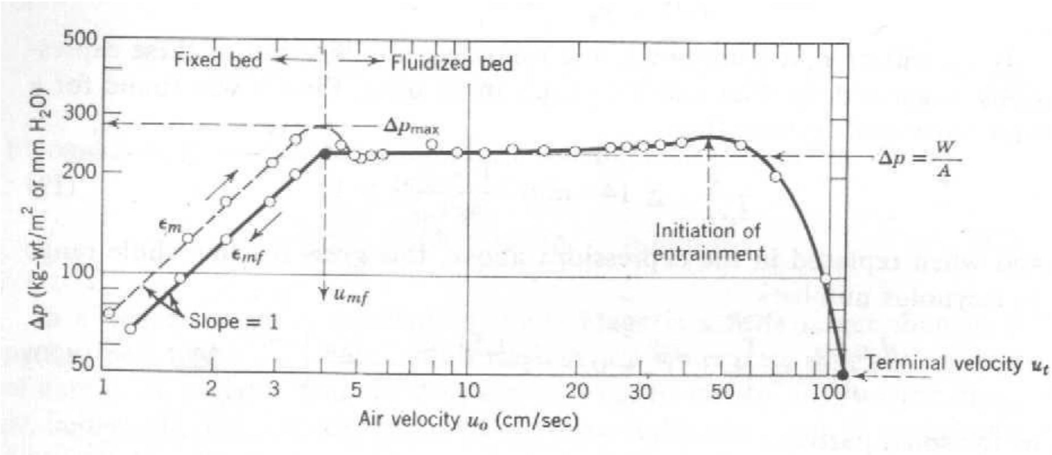

Figure 3. Pressure drop versus fluid velocity for a bed of uniformly sized particles (2)

Figure 3 shows that the bed behaviour with pressure drop through the bed. For the relatively low flow rates in packed bed the pressure drop is approximately proportional to fluid velocity, usually reaching a maximum value $\Delta P_{\max}$ slightly higher than the static pressure of the bed.

With a further increase in fluid velocity, the voidage increases resulting decreases in pressure drop to the static pressure of the bed.

3. EXPERIMENTAL PROCEDURE

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1- Fill the air test column to height of 300mm with coarse grade of ballotini.
2- Close water flow control valve.
3- Check that the manometers reads zero.
4- Switch on air pump.
5- Adjust air flow control valve to give a flowrate of 1 L/min.
6- Record height of bed, manometer reading, and state of bed.
7- Repeat entire experiment using the finer ballotini.

CALCULATIONS

1- Draw a graph of bed pressure drop against water flowrate from experimental values obtained. Compare the predicted fluidization point with actual fluidization point obtained from graph.
2- Draw a graph of bed pressure drop against air flowrate from experimental values obtained. Compare the predicted fluidization point with actual fluidization point obtained from graph.
3- Calculate predicted fluidization point by using different correlations and compare them to fit with experimental results for each section.
4- Determine the relations of flowrate, pressure drop and bed height both experimentally and theoretically.

DATA SHEET

AIR SIDE 1			
Flow rate (L/min)	Height of bed (cm)	Pressure drop (cm H_2O)	Bed state

AIR SIDE 2			
Flow rate (L/min)	Height of bed (cm)	Pressure drop (cm H_2O)	Bed state

SYMBOLS

A	Bed cross-sectional area (m^2)
Ap	Cross sectional area of particle (m^2)
ε	Bed voidage
Cd	Drag coefficient
Dp	Size of particles in micron (m)
L	Height of bed (m)
m	Mass of particles (kg)
Q	Flow rate ($m^3\ s^{-1}$)
Re	Reynolds number
V	Fluid velocity ($m\ s^{-1}$)
Vsm	Average superficial velocity ($m\ s^{-1}$)
μ_W	Viscosity of fluid (water) ($N\ s\ m^{-2}$)
v_w	Kinematic viscosity of liquid (water) ($N\ s\ m^{-2}$)
ρ_L	Density of liquid ($kg\ m^{-3}$)
ρ_p	Particle density ($kg\ m^{-3}$)
ΔP	Pressure drop

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FIXED BED GAS ADSORPTION COLUMN

1. OBJECTIVE

The Computer Controlled Fixed Bed Adsorption Unit, "QALFC", is an adsorption column that is jacketed for the purpose of thermal control and is designed to demonstrate the gas adsorption phenomenon using a Fixed Bed Adsorption Column. The Computer Controlled Fixed Bed Adsorption Unit, "QALFC", is designed to demonstrate the gas adsorption phenomenon using a fixed adsorption column. In the adsorption process, the separation of CO_2 from Helium is produced, because the CO_2 is adsorbed in the activated carbon. In the desorption process, a Helium flow circulates through the column and the separation of CO_2 from activated carbon is produced. The column is jacketed for the purpose of studying the temperature influence in the adsorption process.

The overall objective of this unit is to analyze the behaviour of the adsorption breakthrough and desorption elution curves associated with the separation of CO_2 from He using activated carbon.

The equilibrium adsorption capacity of this activated carbon will be determined from this analysis and used to model the experimental breakthrough and elution curves.

2. INTRODUCTION

The equipment is designed to demonstrate the gas adsorption phenomenon using a Fixed Bed Adsorption Column. Adsorption and Absorption are easily confused. Adsorption is the attraction between the outer surface of a solid particle and a contaminant, which is held on the surface of the particle by surface forces, whereas absorption is the uptake of the contaminant into the physical structure of the solid.

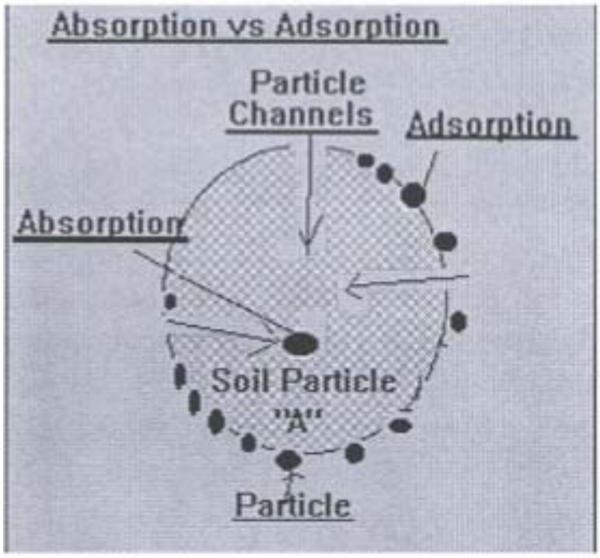

Figure 1. Adsorption and Desorption

Fixed bed adsorption processes are ubiquitous in the chemical process and other industries. Applications include air purification, gas dehydration, solvent or hydrocarbon vapor recovery, water purification, and many others.

The fixed bed adsorption processes utilize a solid mass separating agent packed inside a column to effect separation of one or more components from a mixture in a gas or liquid stream as it flows through the packed bed. In this experiment the gas mixture of carbon dioxide and helium is separated.

The amount of carbon dioxide adsorbed increases with increasing CO_2 partial pressure, and decreases with increasing temperature. Completely isothermal behavior, in reality, is impossible to achieve unless the feed concentration is extremely dilute (in the ppm range).

3. THEORY

3.1 Adsorption vs. Absorption

Adsorption and absorption are easily confused. Adsorption is the attraction between the outer surface of a solid particle and a contaminant, which is held on the surface of the particle by surface forces, whereas absorption is the uptake of the contaminant into the physical structure of the solid.

Adsorption attraction force can be affected by such things as temperature, molecular weight and the boiling point of the compound to be adsorbed.

3.2 Adsorption processes

In an adsorption process one or more constituents of a gas or liquid current are adsorbed on the surface of a solid, resulting in the separation of those constituents. In commercial processes, the adsorbent generally consists of small particles on a fixed bed. The fluid passes through the bed and the solid particles adsorb its components. When the bed is saturated or almost saturated, the flow stops and the bed is regenerated, either thermally or by any other method, so a desertion takes place. Thus, the adsorbed material is recovered (adsorbate) and the solid adsorbent is ready for its use in another adsorption cycle.

The solid is referred to as the adsorbent and the adsorbed component as the adsorbate. Where possible, the adsorbent should only bond the adsorbate and not the other compo- nents in the mixture to be separated. Other important require- ments for the adsorbent are a large specific surface (high porosity) and good regeneration properties. Activated carbon is a frequently used adsorbent.

Some of the applications of the liquid-phase adsorption are: removal of organic compounds from water or organic solutions, removal of colored impurities from organic substances and removal of several fermentation products from fermenters discharges. These separations include the separation of paraffin from aromatic compounds and the separation of fructose from glucose using zeolites.

Some of the applications of gas-phase adsorption are: removal of water from gaseous hydrocarbons, removal of sulfur compounds from natural gas, removal of solvents from air and other gases and removal of odors from air. As adsorption is enhanced by low temperature and high pressure, high temperature and low pressure are used to promote regeneration, i.e. desorption. This means that water vapour or hot inert gas can be used to regenerate the adsorbent.

3.2.1 Physical properties of adsorbents

There are many adsorbents used to cover a wide range of separations. In general, absorbents are granular shaped, and their sizes range from 0.1 to 12 mm, being bigger particles used in packed beds. An adsorbent particle has a very porous structure, with numerous small pores, whose volume reaches up to 50% of the particle's total volume.

Adsorption takes place as a single film over the pores' surface, although several films are sometimes formed. Physical adsorption, or Van der Waals adsorption, usually takes place between adsorbed molecules and the inner solid surface of the pore and is easily reversible.

There are several commercial adsorbents. Some of the main ones are described below. They are characterized by big surface areas of the pores, which range from 100 to 2000 m2/g:

- **Activated carbon:** It is a microcrystalline material that comes from the thermal decomposition of wood, barks, charcoal, etc. and has a surface area from 300 to 1200 m2/g with an average pore diameter from 10 to 60 Å. Organic substances are generally adsorbed in the activated carbon.
- **Silica gel:** This adsorbent is obtained by treating a sodium silicate solution with acid and then drying it. It has a surface area which ranges from 600 to 800 m2/g and a pore average diameter from 20 to 50 Å. It is mainly used to dehydrate liquid gases and fractionate hydrocarbons.
- **Activated alumina:** This material is obtained by activating hydrated aluminum oxide, heating it to extract the water. It is used to dry gases and liquids. Surface areas range from 200 to 500 m2/g., with a pore average diameter from 20 to 140 Å.
- **Zeolite molecular sieve:** They are porous crystalline aluminosilicates, which form an open crystalline network with pores of a precise and uniform size. The size of the zeolites' pores range from 3 to 10 Å. They are used for drying, processes, hydrocarbons and mixtures separation, etc.
- **Polymers or synthetic resins:** They are made by polymerizing two types of monomers: those obtained from aromatic compounds (styrene

and divinylbenzene), used to adsorb nonpolar organic compounds from aqueous solutions and those coming from acrylic esters, used for more polar solutes in aqueous solutions.

Ideally, one would be able to construct a continuous countercurrent system, but moving solids is tricky. Instead, most commercial applications use small particles of adsorbent in a fixed bed. Fluid passes down through the bed (down instead of up to avoid fluidization) and components adsorb onto the solid. The steps can be summarized:

- ✓ solute diffuses through the fluid to an area near the solid particle surface
- ✓ solute diffuses into the pores of the particle
- ✓ solute diffuses to the pore wall
- ✓ solute adsorbs to the pore wall surface

Ion exchange is a similar process; however, in this case ions create complexes with the solid instead of adsorbing.When a bed nears saturation, the flow is stopped and the bed is regenerated to cause desorption. The adsorbate can thus be recovered and the adsorbent reused.

3.2.2 Breakthrough Curves

Adsorption is a transient process. The amount of material adsorbed within a bed depends both on position and time. Consider the time dependence. As fluid enters the bed, it comes in contact with the first few layers of absorbent. Solute adsorbs, filling up some of the available sites. Soon, the adsorbent near the entrance is saturated and the fluid penetrates farther into the bed before all solute is removed. Thus the active region shifts down through the bed as time goes on.

Adsorption Profile vs. Length

The fluid emerging from the bed will have little or no solute remaining -- at least until the bulk of the bed becomes saturated. The break point occurs when the concentration of the fluid leaving the bed spikes as unadsorbed solute begins to emerge. The bed has become ineffective. Usually, a breakpoint composition is set to be the maximum amount of solute that can be acceptably lost, typically something between 1 and 5 percent.

As the concentration wave moves through the bed, most of the mass transfer is occurring in a fairly small region. This mass transfer zone moves down the bed until it "breaks through". The shape of the mass transfer zone depends on the adsorption isotherm (equilibrium expression), flow rate, and the diffusion characteristics. Usually, the shape must be determined experimentally.

Adsorption Profile vs. Time

The wave front may change shape as it moves through the bed, and the mass transfer zone may broaden or diminish. Unfavorable and linear isotherms tend to broaden. Favorable Langmuir and Freundlich isotherms may broaden at first, but quickly achieve a constant pattern front, an asymptotic shape. This means that the mass transfer zone is constant with respect to both position and time. When dealing with a constant pattern front, one can make measurements on a small scale apparatus and scale-up the results to a full- size adsorber bed.

Calculations

When scaling up an adsorber, the key design parameter is the length of the bed. The total length is split into the "required length" of an "ideal" fixed bed process and a segment of "unused bed" that is the length leftover at breakthrough. By adding these together, you obtain a bed that can achieve the needed removal, but not waste solute. The diameter of the bed is calculated from the fluid flow rate and the desired cycle time. Usually, superficial velocities on the order of 0.15 to 0.45 m/s are targeted.

Capacity calculations are made based on plots of the composition vs. time (usually near the exit of the bed). Curves are integrated (analytically, numerically, or graphically) to obtain capacities (measured in time units, or how long a bed can run). The time required for a bed to become totally saturated is obtained by integrating as time goes to infinity:

In operation, you want to stop the process before solute breaks through, so integration to the breakpoint time gives the "usable" capacity. Most of the time the breakthrough time is very close to the time elapsed at usable capacity.

4. PRACTICAL EXERCISES MANUAL

The Computer Controlled Fixed Bed Adsorption Unit, “QALFC”, is designed to demonstrate the gas adsorption phenomenon using a fixed adsorption column (Figure 4). The overall objective of this unit is to analyze the behavior of the adsorption breakthrough and desorption elution curves associated with the separation of CO2 from Helium using activated carbon. The equilibrium adsorption capacity of this activated carbon will be determined from this analysis and used to model the experimental breakthrough and elution curves.

To achieve this objective, a gas mixture (composed by CO2 and Helium) is fed to a fixed bed adsorption column with activated carbon. In the adsorption process, the separation of CO2 from Helium is produced, because the CO2 is adsorbed in the activated carbon.

In the desorption process, a Helium flow circulates through the column and the separation of CO2 from activated carbon is produced. The column is jacketed for the purpose of studying the temperature influence in the adsorption process.

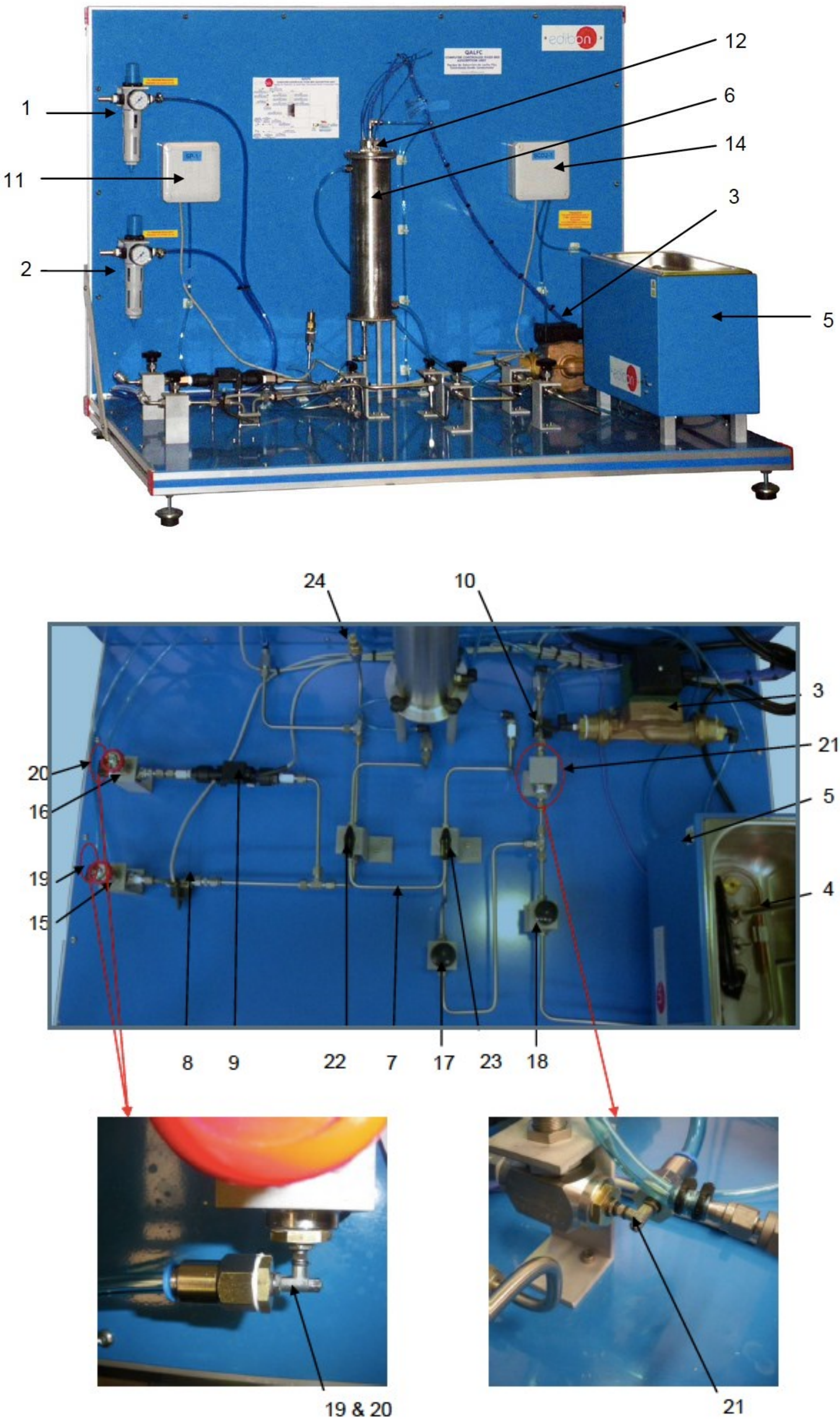

Figure 4. Description of the unit

1. PR-1: CO_2 pressure regulator.
2. PR-2: Helium pressure regulator.
3. AB-1: Water pump.
4. AR-1: Heating element.
5. BT-1: Thermostatic bath.
6. FBAC-1: Fixed bed adsorption column.
7. B-1: Bypass.
8. SC-1: CO_2 flow sensor.
9. SC-2: Helium flow sensor.
10. SC-3: Flow sensor for the gas stream.
11. SP-1: Pressure sensor.
12. ST-1 – ST-6: Temperature sensors.
13. ST-7: Temperature sensor of the thermostatic bath.
14. SCO2-1: CO_2 concentration sensor.
15. VR-1: Regulation valve for the CO_2 flow.
16. VR-2: Regulation valve for the Helium flow.
17. VR-3: Regulation valve for the pressure circuit.
18. VR-4: Regulation valve to control the flow that circulates through the SCO2-1 and to discharge part of the gas stream to the atmosphere.
19. VC-1: CO_2 flow control valve. This valve is fixed and must not be regulated.
20. VC-2: Helium flow control valve. This valve is fixed and must not be regulated.
21. VC-3: Flow control valve of the gas stream. This valve is fixed and must not be regulated.
22. VT-1: 3-way directional valve to divert the gas stream between the fixed bed adsorption column and the bypass.
23. VT-2: 3-way directional valve to circulate the gas stream from the fixed bed adsorption column or the bypass to the VR-3 regulation valve.
24. VS-1: Safety valve.

5. OPERATING CAPACITY

5.1 Valves operation

During the practical exercises, the VT-1 and VT-2 valves position changes in function of the process:

Process	Position of the VT-1 valve	Position of the VT-2 valve
Pressurization of the bypass line	↓	↓
Pressurization of the column	↑	↑
Adsorption	↑	↑
Desorption	↑	↑

5.2 Process to pressurize the bypass line

1. Check that the VR-1, VR-2, VR-3 and VR-4 valves are closed and that the VT-1 and VT-2 valves are set to their correct positions.
2. Open the VR-2 valve and regulate the helium flow to the set value. Use the VR-3 valve with the set value, measured with the SP-1 sensor. NOTE: setting the pressure will affect the flow so you may have to readjust the flow again.

5.3 Process to pressurize the column

1. Change simultaneously the VT-1 and VT-2 to their positions so the helium flows through the column. Adjust the VR-3 valve so the pressure through the column is the set value. You may have to readjust the Helium flow with the VR-2 valve.

5.4 Adsorption process

1. Divert the flow mixture to the column setting simultaneously the VT-1 and VT-2 valves to their correct positions. Make small adjustments to set the selected values of helium flow, CO_2 flow and the circuit pressure using the VR-1, VR-2 and VR-3 valves. **Record the instant when the gases mixture starts flowing through the column; in this moment, the adsorption process has started.**
2. If necessary, check and adjust periodically the flows of Helium and CO_2 during the adsorption process with the VR-1 and VR-2 valves. For different instants, record the values of the temperatures along the column and the CO_2 concentration.
3. During the adsorption process, the CO_2 concentration at the outlet of the column decreases until reaching the value of zero, approximately. When the activated carbon begins to saturate, the CO_2 concentration at the outlet of the column begins to increase until reaching the maximum value of CO_2 concentration.
4. Wait until the CO_2 concentration reaches its maximum concentration and the temperature inside the column is uniform. At this point, the bed of activated carbon is completely saturated with CO_2 and the gas and adsorbed phases are in equilibrium. This indicates that breakthrough has occurred. Let the gases (CO_2 and Helium) continue flowing through the column for another five minutes.

5.5 Desorption process

1. After breakthrough has occurred, desorption process starts. Stop the flow of CO_2 closing the VR-1 valve, so only helium is flowing through the system. **Note the moment when the CO_2 stops flowing through the column.**

2. During the desorption process, the CO_2 concentration at the outlet of the column decreases until reaching the value of zero, approximately. In this moment, the desorption process is complete. **Note the time when it reaches zero.**

3. At the flow rates given above, desorption process will take about 30 minutes. Let the desorption process continue for another five minutes.

Data sheet

Conditions of the practical exercise:

· _ST-7 (ºC): __________

· _SP-1 (bar): ___________

· _Maximum concentration CO_2 (%):____________

· _Moment when the adsorption process starts: ______________

· _Moment when the CO_2 stops flowing through the column: ______________

· _Moment when the desorption process finishes: ______________

Instant (s)	S-T$_1$ (^{0}C)	S-T$_2$ (^{0}C)	S-T$_3$ (^{0}C)	S-T$_4$ (^{0}C)	S-T$_5$ (^{0}C)	S-T$_6$ (^{0}C)	S-T$_7$ (^{0}C)	SCO$_2$-1 (%)

Conditions of the practical exercise:

· _ST-7 (ºC): __________

· _SP-1 (bar): ___________

· _Maximum concentration CO_2 (%): ____________

· _Moment when the adsorption process starts: ______________

· _Moment when the CO_2 stops flowing through the column: ______________

· _Moment when the desorption process finishes: ______________

Instant (s)	S-T_1 (^{0}C)	S-T_2 (^{0}C)	S-T_3 (^{0}C)	S-T_4 (^{0}C)	S-T_5 (^{0}C)	S-T_6 (^{0}C)	S-T_7 (^{0}C)	SCO_2-1 (%)

Sample Calculation

-Plot the CO_2 concentration versus time. The adsorption process is finished when the CO_2 concentration reaches the maximum value and the desorption process is finished when the CO_2 concentration is zero.

-Plot the temperature at every temperature sensor located along the column versus time elapsed during the adsorption/desorption process. Adsorption is an exothermic process and desorption is endothermic process. It means that during the adsorption it can be observed that the temperature increases as the activated carbon is saturated; and during the desorption, it can be observed that the temperature decreases.