In equation 12.12, $k_L$ is the liquid-film transfer coefficient, which is usually expressed in kmol/s m$^2$(kmol/m$^3$) = m/s. For dilute concentrations:

$$k_L = \frac{D_L}{z_L}$$

### 12.3.5. Rate of absorption

In a steady-state process of absorption, the rate of transfer of material through the gas film will be the same as that through the liquid film, and the general equation for mass transfer of a component **A** may be written as:

$$N'_A = k_G(P_{AG} - P_{Ai}) = k_L(C_{Ai} - C_{AL}) \tag{12.13}$$

where $P_{AG}$ is the partial pressure in the bulk of the gas, $C_{AL}$ is the concentration in the bulk of the liquid, and $P_{Ai}$ and $C_{Ai}$ are the values of concentration at the interface where equilibrium conditions are assumed to exist. Therefore:

$$\frac{k_G}{k_L} = \frac{C_{Ai} - C_{AL}}{P_{AG} - P_{Ai}} \tag{12.14}$$

These conditions may be illustrated graphically as in Figure 12.2, where ABF is the equilibrium curve for the soluble component **A**.

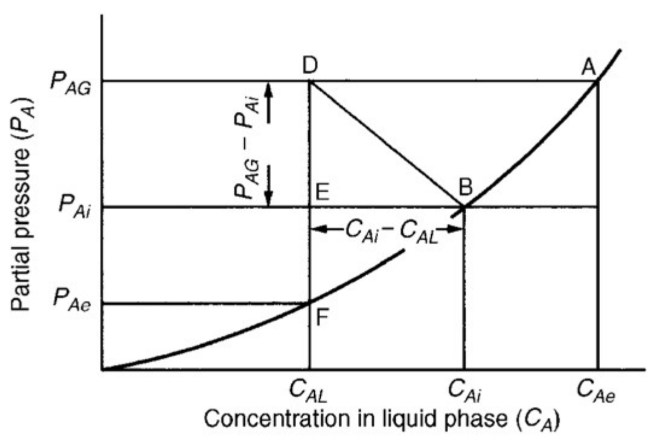


Figure 12.2. Driving forces in the gas and liquid phases

Point D ($C_{AL}$, $P_{AG}$) represents conditions in the bulk of the gas and liquid.
$P_{AG}$) is the partial pressure of **A** in the main bulk of the gas stream, and
$C_{AL}$) is the average concentration of **A** in the main bulk of the liquid stream.
Point A ($C_{Ae}$, $P_{AG}$) represents a concentration of $C_{Ae}$ in the liquid in equilibrium with $P_{AG}$ in the gas.

Point B ($C_{Ai}$, $P_{Ai}$) represents the concentration of $C_{Ai}$ in the liquid in equilibrium with $P_{Ai}$ in the gas, and gives conditions at the interface.

Point F ($C_{AL}$, $P_{Ae}$) represents a partial pressure $P_{Ae}$ in the gas phase in equilibrium with $C_{AL}$ in the liquid.

Then, the driving force causing transfer in the gas phase is:

$$(P_{AG} - P_{Ai}) \equiv \text{DE}$$

and the driving force causing transfer in the liquid phase is:

$$(C_{Ai} - C_{AL}) \equiv \text{BE}$$

Then:

$$\frac{P_{AG} - P_{Ai}}{C_{Ai} - C_{AL}} = \frac{k_L}{k_G}$$

and the concentrations at the interface (point B) are found by drawing a line through D of slope $-k_L/k_G$ to cut the equilibrium curve in B.

### Overall coefficients

In order to obtain a direct measurement of the values of $k_L$ and $k_G$ the measurement of the concentration at the interface would be necessary. These values can only be obtained in very special circumstances, and it has been found of considerable value to use two overall coefficients $K_G$ and $K_L$ defined by:

$$N'_A = K_G(P_{AG} - P_{Ae}) = K_L(C_{Ae} - C_{AL}) \tag{12.15}$$

$K_G$ and $K_L$ are known as the overall gas and liquid phase coefficients, respectively.

### Relation between film and overall coefficients

The rate of transfer of **A** may now be written as:

$$N'_A = k_G[P_{AG} - P_{Ai}] = k_L[C_{Ai} - C_{AL}] = K_G[P_{AG} - P_{Ae}] = K_L[C_{Ae} - C_{AL}]$$

Thus:

$$\frac{1}{K_G} = \frac{1}{k_G}\left[\frac{P_{AG} - P_{Ae}}{P_{AG} - P_{Ai}}\right] \tag{12.16}$$

$$= \frac{1}{k_G}\left[\frac{P_{AG} - P_{Ai}}{P_{AG} - P_{Ai}}\right] + \frac{1}{k_G}\left[\frac{P_{Ai} - P_{Ae}}{P_{AG} - P_{Ai}}\right]$$

From the previous discussion:

$$\frac{1}{k_G} = \frac{1}{k_L}\left[\frac{P_{AG} - P_{Ai}}{C_{Ai} - C_{AL}}\right]$$

Thus:
$$\frac{1}{K_G} = \frac{1}{k_G} + \frac{1}{k_L}\left[\frac{P_{AG} - P_{Ai}}{C_{Ai} - C_{AL}}\right]\left[\frac{P_{Ai} - P_{Ae}}{P_{AG} - P_{Ai}}\right]$$
$$= \frac{1}{k_G} + \frac{1}{k_L}\left[\frac{P_{Ai} - P_{Ae}}{C_{Ai} - C_{AL}}\right]$$

$(P_{Ai} - P_{Ae})/(C_{Ai} - C_{AL})$ is the average slope of the equilibrium curve and, when the solution obeys Henry's law, $\mathscr{H} = \mathrm{d}P_A/\mathrm{d}C_A \approx (P_{Ai} - P_{Ae})/(C_{Ai} - C_{AL})$.

Therefore:
$$\frac{1}{K_G} = \frac{1}{k_G} + \frac{\mathscr{H}}{k_L} \tag{12.17}$$

Similarly:
$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{\mathscr{H}k_G} \tag{12.18}$$

and:
$$\frac{1}{K_G} = \frac{\mathscr{H}}{K_L} \tag{12.19}$$

A more detailed discussion of the relationship between film and overall coefficients is given in Volume 1, Chapter 10.

The validity of using equations 12.17 and 12.18 in order to obtain an overall transfer coefficient has been examined in detail by KING(17). He has pointed out that the equilibrium constant $\mathscr{H}$ must be constant, there must be no significant interfacial resistance, and there must be no interdependence of the values of the two film-coefficients.

### Rates of absorption in terms of mole fractions

The mass transfer equations can be written as:

$$N'_A = k''_G(y_A - y_{Ai}) = K''_G(y_A - y_{Ae}) \tag{12.20}$$

and:
$$N'_A = k''_L(x_{Ai} - x_A) = K''_L(x_{Ae} - x_A) \tag{12.21}$$

where $x_A$, $y_A$ are the mole fractions of the soluble component **A** in the liquid and gas phases, respectively.

$k''_G$, $k''_L$, $K''_G$, $K''_L$ are transfer coefficients defined in terms of mole fractions by equations 12.20 and 12.21.

If $m$ is the slope of the equilibrium curve [approximately $(y_{Ai} - y_{Ae})/(x_{Ai} - x_A)$], it can then be shown that:

$$\frac{1}{K''_G} = \frac{1}{k''_G} + \frac{m}{k''_L} \tag{12.22}$$

which is similar to equation 11.151 used for distillation.

### Factors influencing the transfer coefficient

The influence of the solubility of the gas on the shape of the equilibrium curve, and the effect on the film and overall coefficients, may be seen by considering three cases in turn — very soluble, almost insoluble, and moderately soluble gases.

(a) *Very soluble gas*. Here the equilibrium curve lies close to the concentration-axis and the points E and F are very close to one another as shown in Figure 12.2. The driving force over the gas film (DE) is then approximately equal to the overall driving force (DF), so that $k_G$ is approximately equal to $K_G$.

(b) *Almost insoluble gas*. Here the equilibrium curve rises very steeply so that the driving force $(C_{Ai} - C_{AL})$ (EB) in the liquid film becomes approximately equal to the overall driving force $(C_{Ae} - C_{AL})$ (AD). In this case $k_L$ will be approximately equal to $K_L$.

(c) *Moderately soluble gas*. Here both films offer an appreciable resistance, and the point B at the interface must be located by drawing a line through D of slope $-(k_L/k_G) = -(P_{AG} - P_{Ai})/(C_{Ai} - C_{AL})$.

In most experimental work, the concentration at the interface cannot be measured directly, and only the overall coefficients are therefore found. To obtain values for the film coefficients, the relations between $k_G$, $k_L$ and $K_G$ are utilised as discussed previously.

## 12.4. DETERMINATION OF TRANSFER COEFFICIENTS

In the design of an absorption tower, the most important single factor is the value of the transfer coefficient or the height of the transfer unit. Whilst the total flowrates of the gas and liquid streams are fixed by the process, it is necessary to determine the most suitable flow per unit area through the column. The gas flow is limited by the fact that the flooding rate must not be exceeded and there will be a serious drop in performance if the liquid rate is very low. It is convenient to examine the effects of flowrates of the gas and liquid on the transfer coefficients, and also to investigate the influence of variables such as temperature, pressure, and diffusivity.

In the laboratory, wetted-wall columns have been used by a number of workers and they have proved valuable in determining the importance of the various factors, and have served as a basis from which correlations have been developed for packed towers.

### 12.4.1. Wetted-wall columns

In many early studies, the rate of vaporisation of liquids into an air stream was measured in a wetted-wall column, similar to that shown in Figure 12.3. Logarithmic plots of $d/z_G$ and $Re = du\rho/\mu$ gave a series of approximately straight lines and $d/z_G$ was proportional to $Re^{0.83}$

where: $d$ is the diameter of tube,
$z_G$ is the thickness of gas film,
$u$ is the gas velocity,
$\rho$ is the gas density,
$\mu$ is the gas viscosity, and
$B$ is a constant.