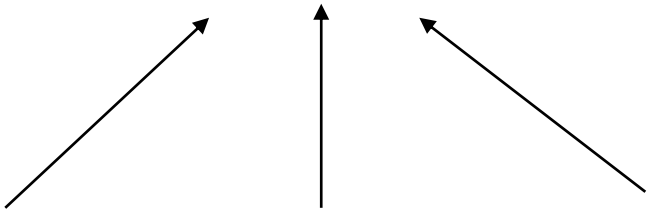
## Specification of Design Variables:

design variables => input.

Solution of separation problems requires specification of a sufficient number of design variables in order to determine unknown (output) variables by solving an equal number of independent equations. The process will then be uniquely specified if the input variables are correctly specified.

The number of design variables reflects the number of degrees of freedom ($N_D$ one has in correctly specifying a process. It is suggested that this number can be found as follows:

$$N_D = N_V - N_E$$



| -Independent design variables<br>-Degrees of Freedom<br>-Variance | All Pertinent Variables | Independent Equations<br>↳ component Balance dependent with tbw Balance |
|---|---|---|

### Number of Variables $N_V$:

The variables which can be counted in $N_V$ are:

- ✓ Intensive: Variables T, P, x, ….
- ✓ Extensive: Flow rates, Q, ….
- ✓ Equipment Parameters: Number of Stages

Physical properties such as Enthalpy, K are not counted

### Number of Independent Equations $N_E$:

Care must be taken in identification of independent equation

Types of Equations which can be used:

- ✓ Material Balances
- ✓ Energy Balances
- ✓ Phase Equilibrium Restrictions => such as $y_i = K_i x$
- ✓ Process Specifications => T, P
- ✓ Equipment configurations => counter current

Separation Equipment Consist of:

- ✓ Physically identifiable elements: Equilibrium stages, Condensers, Reboilers
- ✓ Stream Dividers
- ✓ Stream Mixers

**Examples:**

1- Stream Variables: => for flash calculations.

For single phase stream containing C components; the phase rule states that the intensive variables are:

$$C\text{-}\mathcal{P}+2 = C+1$$

These are C-1 concentrations (mole fractions or others), and to this we add Temperature and Pressure as intensive variables. To this number we add the flow rate (extensive variable).

**$N_V$:**

| Category | Variable | Number* | |
|---|---|---|---|
| Intensive | mole fractions | C | C-1 |
| | T | 1 | 1 |
| | P | 1 | 1 |
| | | | |
| Extensive | Flow rate | 1 | 1 |
| $N_V$ = | | C+3 | C+2 |

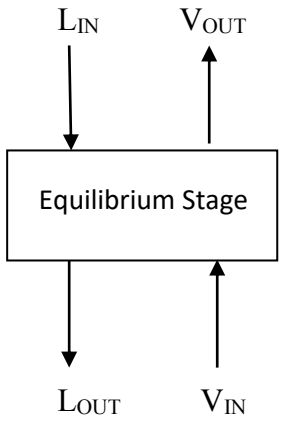
* In counting the number of intensive variables, usually C-1 concentrations specify all compositions since the remaining concentration is obtained by difference. However, we can specify all concentrations (C) in counting the number of intensive variables and include in the list of equations the summation of concentrations constraints, such as the summation of mole fractions:

$$\sum_{i=1}^{C} mole\ fractions = 1$$

Therefor:

$$N_V = C+3 \quad Or \quad N_V = C+2$$

## 2- Adiabatic Equilibrium Stage:




NV:

The only variables are those associated with streams:

$$N_V = 4(C+3) = 4C + 12 \qquad \text{Or} \qquad N_V = 4(C+2) = 4C + 8$$

for each stream. — Number of streams

$N_E$:

| Category | Number of Equations | |
|---|---|---|
| Equilibrium Restrictions: | | |
| $P_{VOUT} = P_{LOUT}$ | 1 | 1 |
| $T_{VOUT} = T_{LOUT}$ | 1 | 1 |
| Phase Equilibrium $(y_i)_{VOUT} = k_i (x_i)_{LOUT}$ | C | C |
| Component Balances | C-1 | C-1 |
| Total Material Balance | 1 | 1 |
| Adiabatic Enthalpy Balance | 1 | 1 |
| Mole Fraction Constraints (Sum of Mole Fractions) | 4 | - |
| NE = | 2C+7 | 2C+3 |

Component material balance:

$$L_{IN}(x_i)_{L_{IN}} + V_{IN}(y_i)_{V_{IN}} = L_{OUT}(x_i)_{L_{OUT}} + V_{OUT}(y_i)_{V_{OUT}}$$

Total material balance:

$$L_{IN} + V_{IN} = L_{OUT} + V_{OUT}$$

Adiabatic enthalpy balance:

$$H_{L_{IN}} L_{IN} + H_{V_{IN}} V_{IN} = H_{L_{OUT}} L_{OUT} + H_{V_{OUT}} V_{OUT}$$

Mole fraction constraints in any stream:

$$\sum_{i=1}^{C} mole\ fractions = 1$$

Design Variables, $N_D$:

| | | |
|---|---|---|
| $N_D = N_V - N_E$ | (4C+12) – (2C+7) | (4C +8) – (2C+3) |
| $N_D$ = | 2C + 5 | 2C + 5 |

Therefore (2C+5) variables must be specified.

Typical Set of Variables: Complete specification of the two incoming streams as well as stage pressure.

| Specified Variable | Number of Variables |
|---|---|
| Liquid IN mole fractions $(x_i)_{LIN}$ | C-1 |
| $L_{IN}$: Liquid IN flow rate | 1 |
| Vapor IN mole fractions $(y_i)_{VIN}$ | C-1 |
| $V_{IN}$: Vapor IN flow rate | 1 |
| Temperature and Pressure of $L_{IN}$ | 2 |
| Temperature and Pressure of $V_{IN}$ | 2 |
| Stage Pressure ($P_{VOUT}$ OR $P_{LOUT}$) | 1 |
| ND = | (2C+5) |