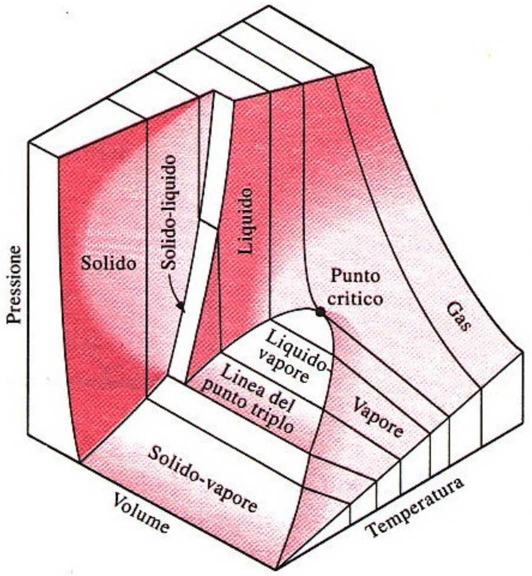
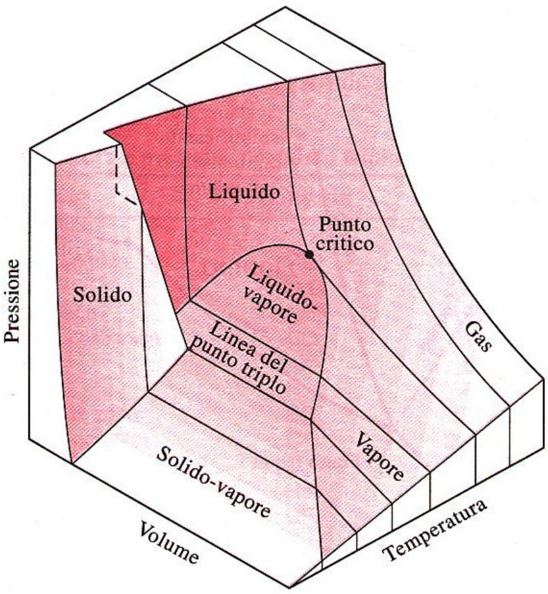
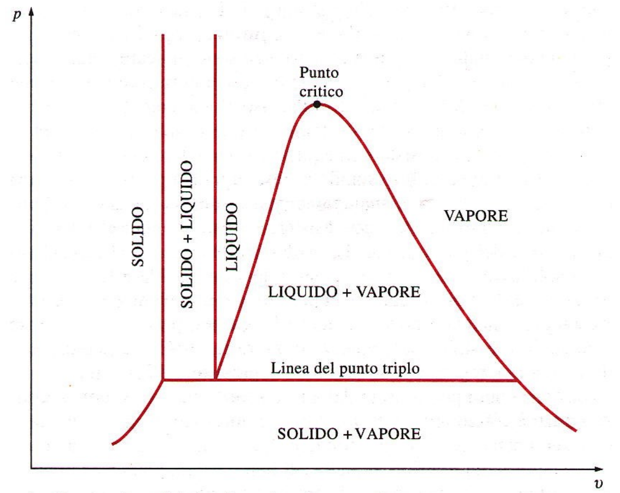
PROPRIETA' DELLE SOSTANZE PURE

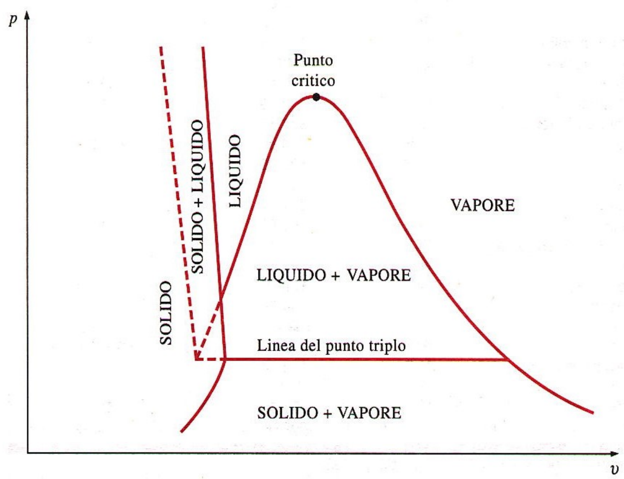
Solidi - Liquidi - Vapori saturi
Gas perfetti e reali
Miscele di gas

Y. A. Çengel, Termodinamica e trasmissione del calore, McGraw-Hill, Milano 1998.


Pressione
Solido
Solido-liquido
Liquido
Punto
critico
Gas
Liquido-
vapore
Linea del
punto triplo
Vapore
Solido-vapore
Volume
Temperatura


Pressione
Solido
Liquido
Punto
critico
Liquido-
vapore
Linea del
punto triplo
Gas
Vapore
Solido-vapore
Volume
Temperatura


p
Punto
critico
SOLIDO
SOLIDO + LIQUIDO
LIQUIDO
VAPORE
LIQUIDO + VAPORE
Linea del punto triplo
SOLIDO +VAPORE
v


p
Punto
critico
SOLIDO + LIQUIDO
LIQUIDO
VAPORE
LIQUIDO + VAPORE
SOLIDO
Linea del punto triplo
SOLIDO + VAPORE
v

LIQUIDI

Saturi:

$$du = \delta q - \delta l \cdots \Rightarrow \cdots u_2 = u_1 + \int_1^2 c_l dT - \int_1^2 p\ dv \approx u_1 + c_l(T_2 - T_1)$$

$$dh = \delta q + v\ dp \cdots \Rightarrow \cdots h_2 = h_1 + \int_1^2 c_l dT + \int_1^2 v\ dp \approx h_1 + c_l(T_2 - T_1)$$

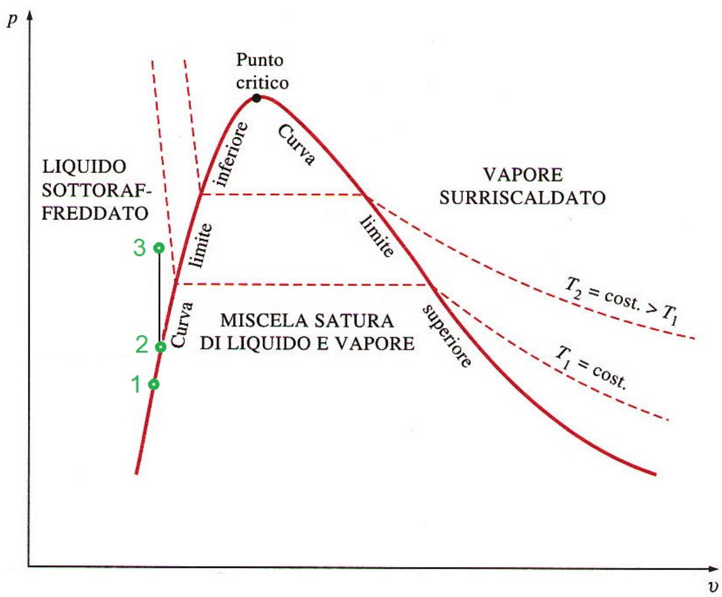
$$ds = \frac{\delta q}{T} \cdots \Rightarrow \cdots s_2 = s_1 + \int_1^2 c_l \frac{dT}{T} \approx s_1 + c_l \ln\frac{T_2}{T_1}$$

Sottoraffreddati:

$$du = \delta q - \delta l \cdots \Rightarrow \cdots u_3 = u_2 + \int_2^3 c_v dT - \int_2^3 p\ dv \approx u_2$$

$$dh = \delta q + v\ dp \cdots \Rightarrow \cdots h_3 = h_2 + \int_2^3 c_v dT + \int_2^3 v\ dp \approx h_2 + v(p_3 - p_2)$$

$$ds = \frac{\delta q}{T} \cdots \Rightarrow \cdots s_3 = s_2 + \int_2^3 c_v \frac{dT}{T} \approx s_2$$



VAPORI SATURI

$$x = \frac{M_v}{M_l + M_v}$$

$$M_v = x\ (M_l + M_v) \qquad M_l = (1-x)\ (M_l + M_v)$$

$$V_x = V_l + V_v \qquad M_x = M_l + M_v$$

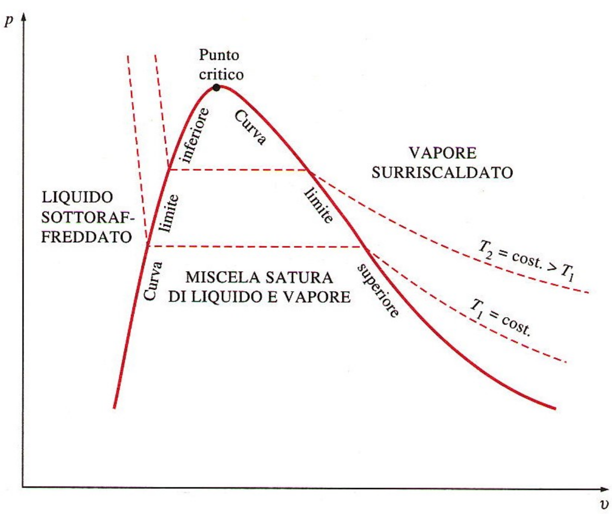
$$v_x = \frac{V_x}{M_x} = \frac{V_l + V_v}{M_x} = \frac{v_l M_l + v_v M_v}{M_x} = \frac{v_l (1-x)\ M_x + v_v x\ M_x}{M_x}$$

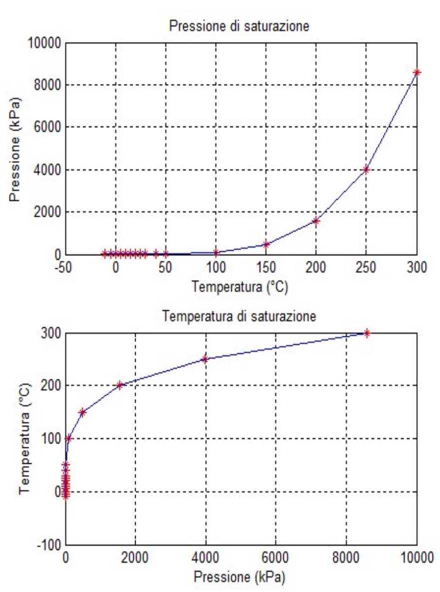
$$v_x = v_l (1-x) + v_v x = v_l + x\ (v_v - v_l) = v_l + x\ v_d$$

$$u_x = u_l (1-x) + u_v x = u_l + x[(h - p\ v)_v - (h - p\ v)_l] = u_l + x(r - p\ v_d)$$

$$h_x = h_l (1-x) + h_v x = h_l + x\ (h_v - h_l) = h_l + x\ r$$

$$s_x = s_l (1-x) + s_v x = s_l + x\ (s_v - s_l) = s_l + x\ \frac{r}{T}$$





VAPORI SURRISCALDATI

$$du = \delta q - \delta l \cdots \Rightarrow$$

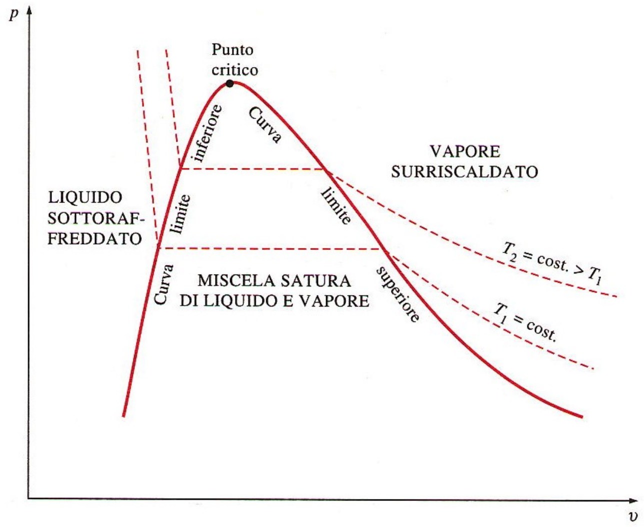
$$u_{sur} = u_{sat} + \int_{sat}^{sur} c_p dT - \int_{sat}^{sur} p\ dv \approx u_{sat} + c_p (T_{sur} - T_{sat}) - p\ (v_{sur} - v_{sat})$$

$$dh = \delta q + v\ dp \cdots \Rightarrow$$

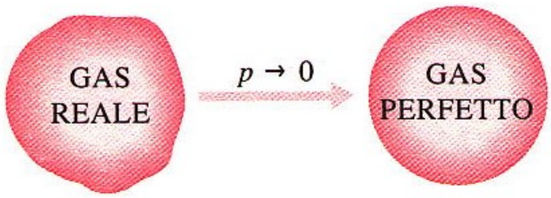
$$h_{sur} = h_{sat} + \int_{sat}^{sur} c_p dT + \int_{sat}^{sur} v\ dp \approx h_{sat} + c_p (T_{sur} - T_{sat})$$

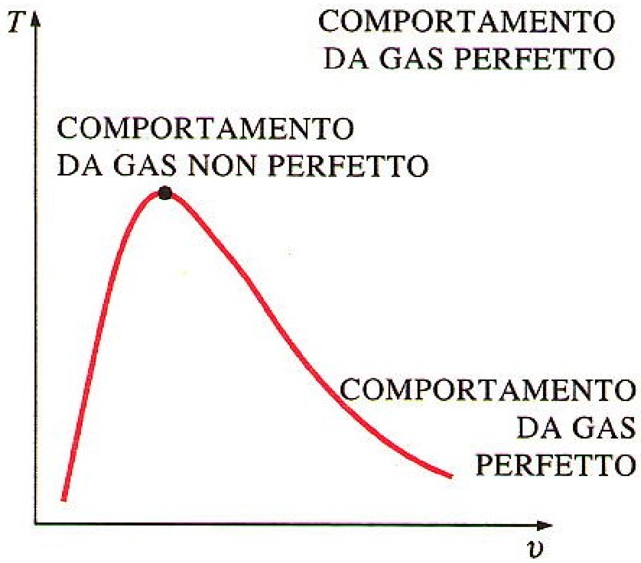
$$ds = \frac{\delta q}{T} \cdots \Rightarrow$$

$$s_{sur} = s_{sat} + \int_{sat}^{sur} c_p \frac{dT}{T} \approx s_{sat} + c_p \ln \frac{T_{sur}}{T_{sat}}$$



GAS PERFETTI

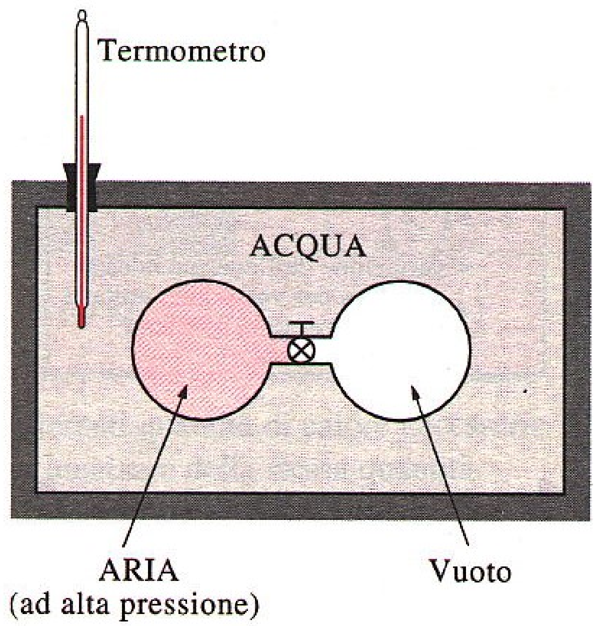




$$p\,V_m = R_0 T$$

$$p\,\frac{V}{n} = R_0 T \qquad \Rightarrow \qquad p\,V = n\,R_0 T$$

$$p\,\frac{vM}{n} = R_0 T \qquad \Rightarrow \qquad p\,v = \frac{n}{M} R_0 T = \frac{R_0}{m} T = R\,T$$



$$du = \delta q - \delta l \qquad\qquad dT = 0$$

$$du = \left(\frac{\partial u}{\partial T}\right)_p dT + \left(\frac{\partial u}{\partial p}\right)_T dp = 0 \qquad \Rightarrow \qquad \left(\frac{\partial u}{\partial p}\right)_T dp = 0$$

$$du = \left(\frac{\partial u}{\partial T}\right)_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv = 0 \qquad \Rightarrow \qquad \left(\frac{\partial u}{\partial v}\right)_T dv = 0$$

$$c_v = \frac{du}{dT} \qquad\qquad c_p = \frac{dh}{dT}$$

$$c_p = \frac{dh}{dT} = \frac{du}{dT} + \frac{d(pv)}{dT} = \frac{du}{dT} + \frac{d(RT)}{dT} = c_v + R$$

$$u = u_0 + \int_{T_0}^{T} c_v dT \approx u_0 + \bar{c}_v (T - T_0)$$

$$h = h_0 + \int_{T_0}^{T} c_p dT \approx h_0 + \bar{c}_p (T - T_0)$$

$$ds = \frac{\delta q}{T} = \frac{du + p\ dv}{T} = c_v \frac{dT}{T} + R \frac{dv}{v} \Rightarrow s \approx s_0 + \bar{c}_v \ln \frac{T}{T_0} + R\ \ln \frac{v}{v_0}$$

$$ds = \frac{\delta q}{T} = \frac{dh - v\ dp}{T} = c_p \frac{dT}{T} - R \frac{dp}{p} \Rightarrow s \approx s_0 + \bar{c}_p \ln \frac{T}{T_0} - R\ \ln \frac{p}{p_0}$$

GAS REALI

Fattore di compressibilità:

$$Z = \frac{p\ v}{R\ T}$$

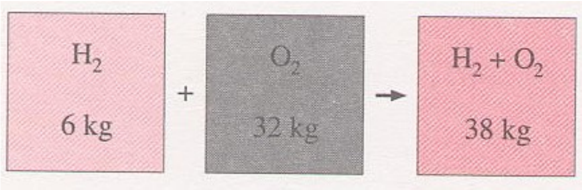
$$p\ v = Z\ R\ T$$

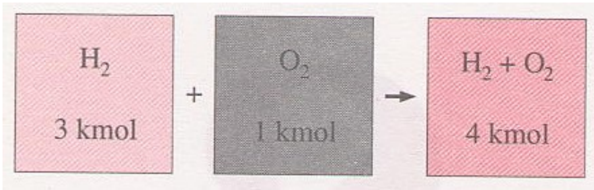
Equazione di Van der Waals:

$$\left(p + \frac{a}{v^2}\right)(v - b) = R\ T$$

MISCELE DI GAS

$$x_i = \frac{M_i}{M} \qquad M = \sum_i M_i \qquad y_i = \frac{n_i}{n} \qquad n = \sum_i n_i$$





$$U = \sum_i U_i \qquad u = \frac{U}{M} = \frac{\sum_i U_i}{M} = \frac{\sum_i M_i u_i}{M} = \sum_i x_i u_i$$

$$u_m = \frac{U}{n} = \frac{\sum_i U_i}{n} = \frac{\sum_i n_i u_{m_i}}{n} = \sum_i y_i u_{m_i}$$

$$H = \sum_i H_i \qquad h = \frac{H}{M} = \frac{\sum_i H_i}{M} = \frac{\sum_i M_i h_i}{M} = \sum_i x_i h_i$$

$$h_m = \frac{H}{n} = \frac{\sum_i H_i}{n} = \frac{\sum_i n_i h_{m_i}}{n} = \sum_i y_i h_{m_i}$$

$$c_v = \sum_i x_i c_{v_i} \qquad c_p = \sum_i x_i c_{p_i}$$

Legge di Dalton

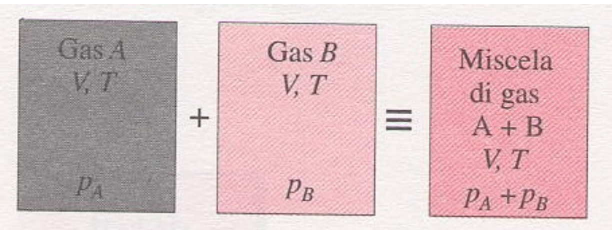
$$p_i = \frac{n_i R_0 T}{V} \qquad p = \sum_i p_i$$

$$\sum_i p_i = \sum \frac{n_i R_0 T}{V} = \frac{R_0 T}{V} \sum_i n_i$$

Legge di Agamat

$$V_i = \frac{n_i R_0 T}{p} \qquad V = \sum_i V_i$$

$$\sum_i V_i = \sum \frac{n_i R_0 T}{p} = \frac{R_0 T}{p} \sum_i n_i$$



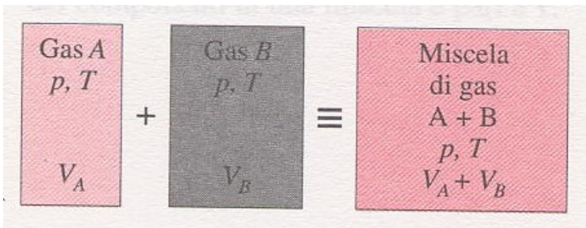


Tabella 4.5. *Principali relazioni che intervengono nelle trasformazioni usuali per i gas perfetti.*

Trasformazione	*Relazioni* $p,\ v,\ T$	*Calore specifico*	*Esponente* n	$s_2 - s_1$
$T = \text{cost}$	$pv = \text{cost}$	∞	1	$R\ ln\dfrac{p_1}{p_2}$
$p = \text{cost}$	$\dfrac{T}{v} = \text{cost}$	c_p	0	$c_p ln\dfrac{T_2}{T_1}$
$v = \text{cost}$	$\dfrac{T}{p} = \text{cost}$	c_v	∞	$c_v ln\dfrac{T_2}{T_1}$
$s = \text{cost}$	$pv^{\gamma} = \text{cost}$ $Tv^{\gamma - 1} = \text{cost}$ $pT^{\gamma/(1-\gamma)} = \text{cost}$	0	γ	0
Politropica	$pv^{n} = \text{cost}$ $Tv^{n-1} = \text{cost}$ $pT^{n/(1-n)} = \text{cost}$	$c_n = c_v\dfrac{n-\gamma}{n-1}$	n	$c_n ln\dfrac{T_2}{T_1}$ $c_n(n-1)\ ln\dfrac{v_1}{v_2}$ $c_n\dfrac{n-1}{n} ln\dfrac{p_2}{p_1}$