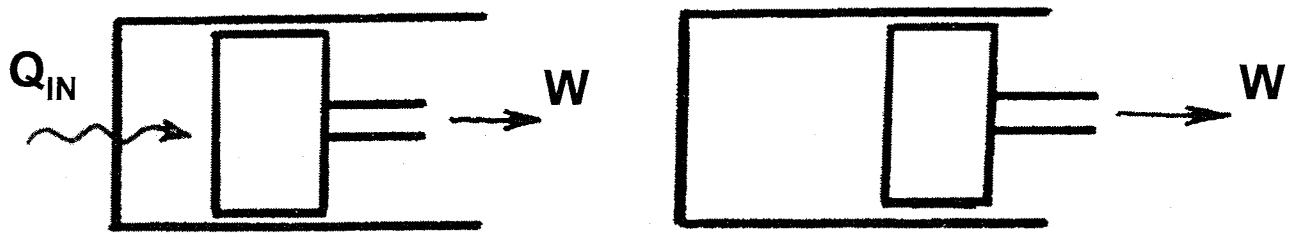
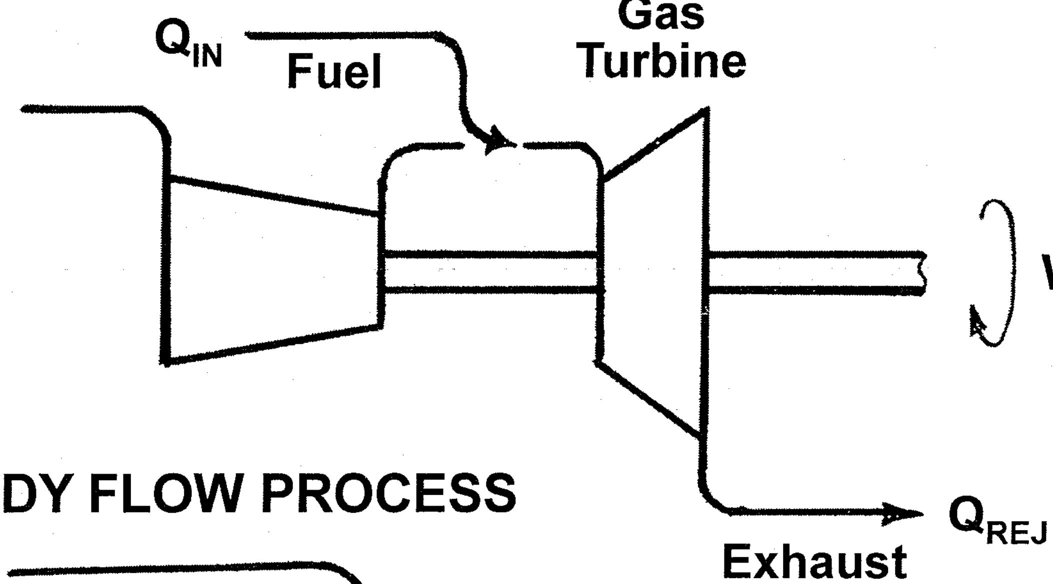
STEADY FLOW PROCESSES

NON-FLOW AND STEADY FLOW

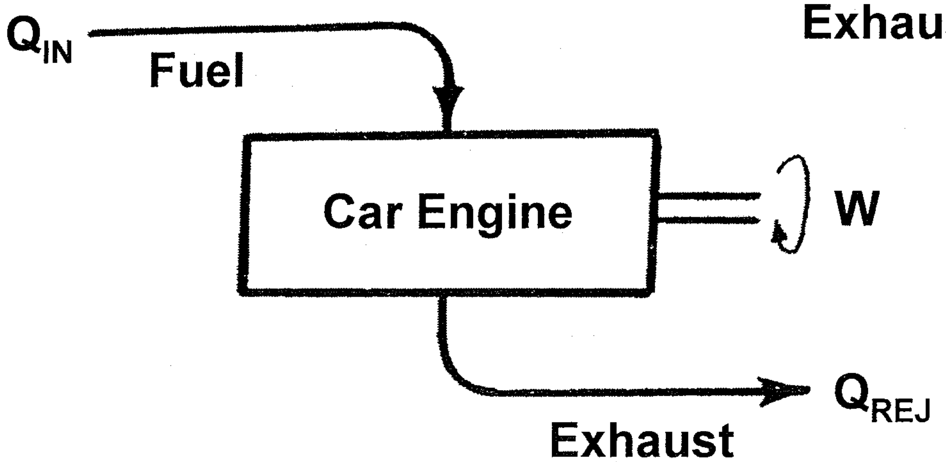
NON-FLOW PROCESS



STEADY FLOW PROCESS

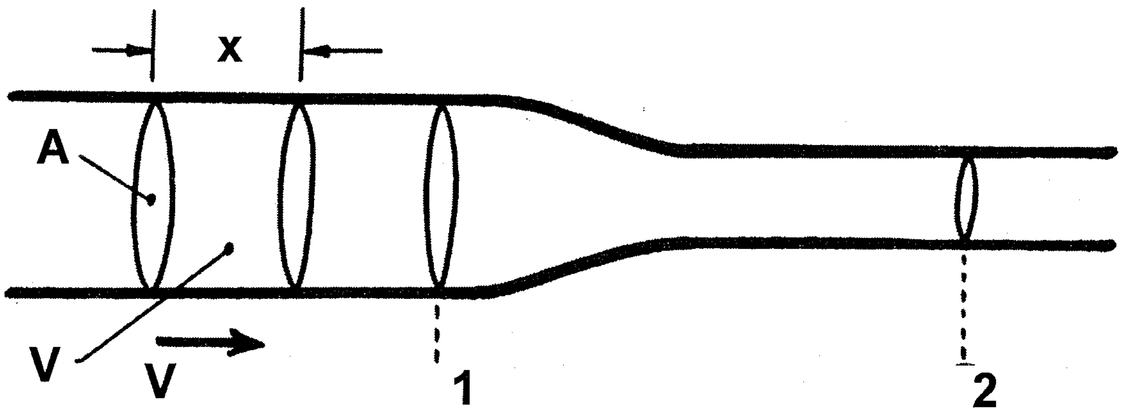


STEADY FLOW PROCESS



CONTINUITY EQUATION

(WHAT GOES IN..... MUST COME OUT)



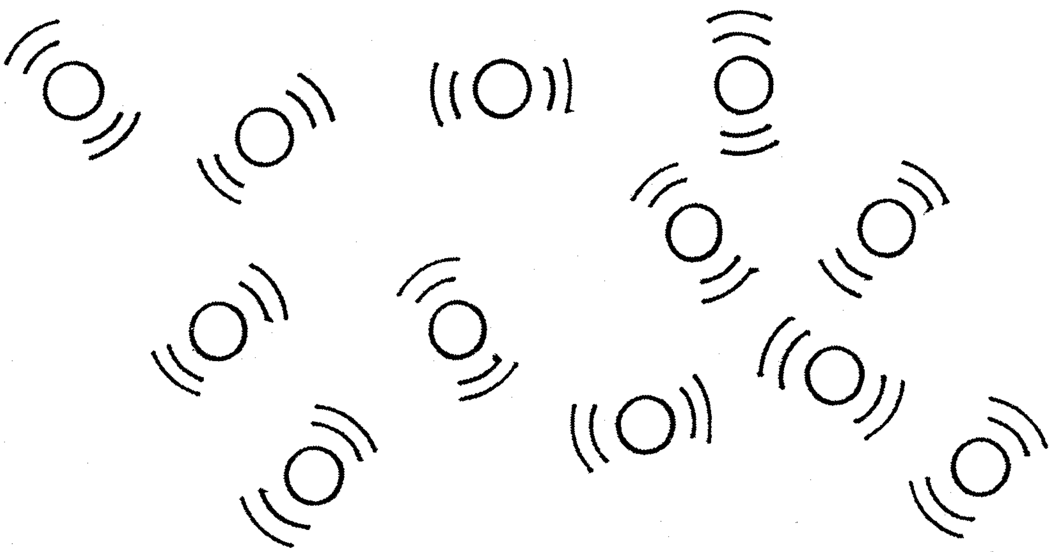
Volume	V	=	$A\,x$	(m^3)
Density	ρ			(kg/m^3)
Mass	m	=	$\rho\,V = \rho\,A\,x$	(kg)
Velocity	V	=	x / t	(m/s)
	x	=	$V\,t$	
Mass	m	=	$\rho\,A\,V\,t$	(kg)
Mass Flow	M	=	$\rho\,A\,V$	(kg/s)

Continuity Equation states that:

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

for steady mass flow rate of M

INTERNAL ENERGY

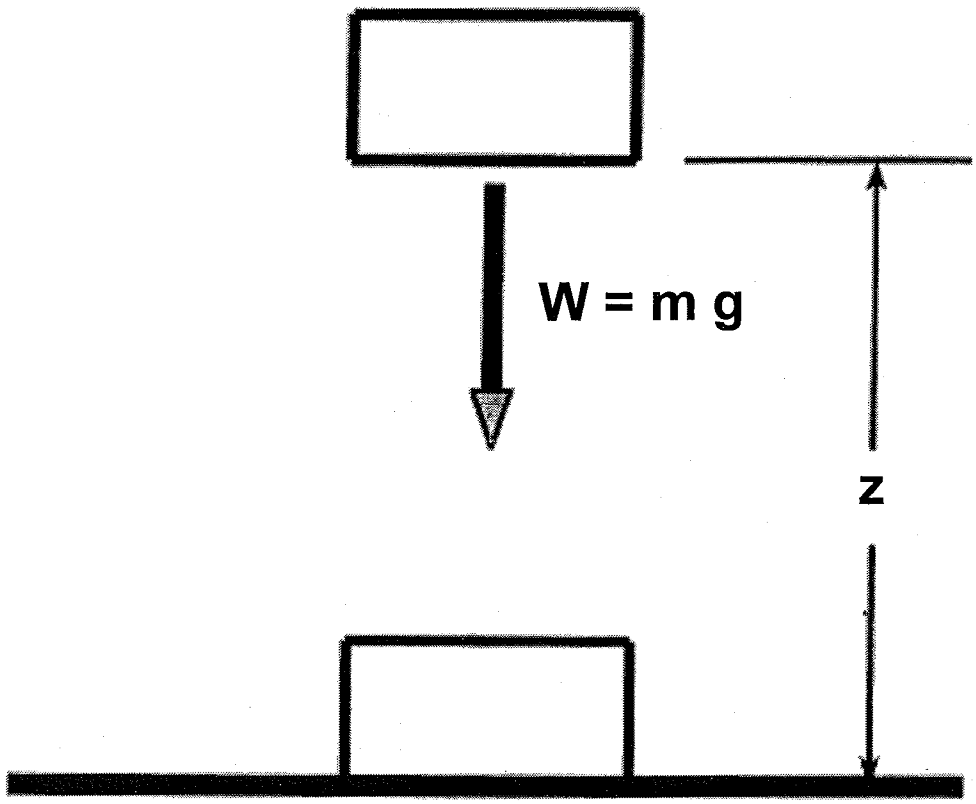


Internal Energy is due to the motion of the molecules and internal attractive and repulsive forces.

POTENTIAL ENERGY

Mass m at elevation z above datum plane

Energy = work in lifting mass above datum



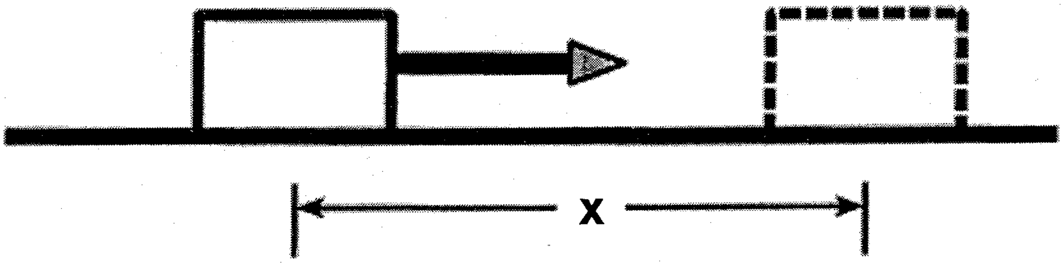
Potential Energy = mass x elevation x g

$$= m\,g\,z$$

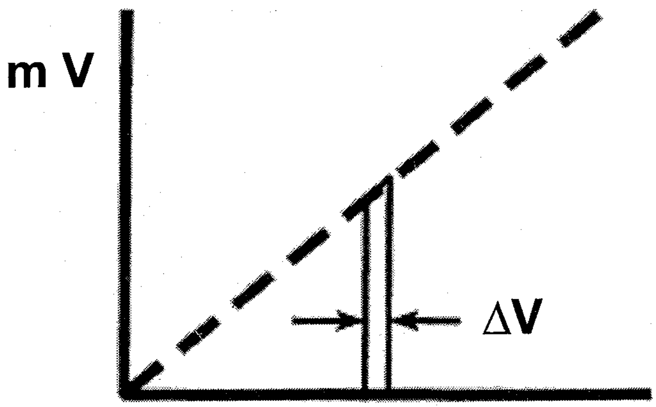
KINETIC ENERGY

Kinetic Energy of mass m at Velocity V

$V = x / \Delta t$ $\qquad$ $a = \Delta V / \Delta t$ $\qquad$ $\Delta t = \Delta V / a$



Substituting: $V = x\,a / \Delta V$



$V\,\Delta V = a\,x$

$m\,V\,\Delta V = m\,a\,x$

$F\,x = m\,V\,\Delta V$

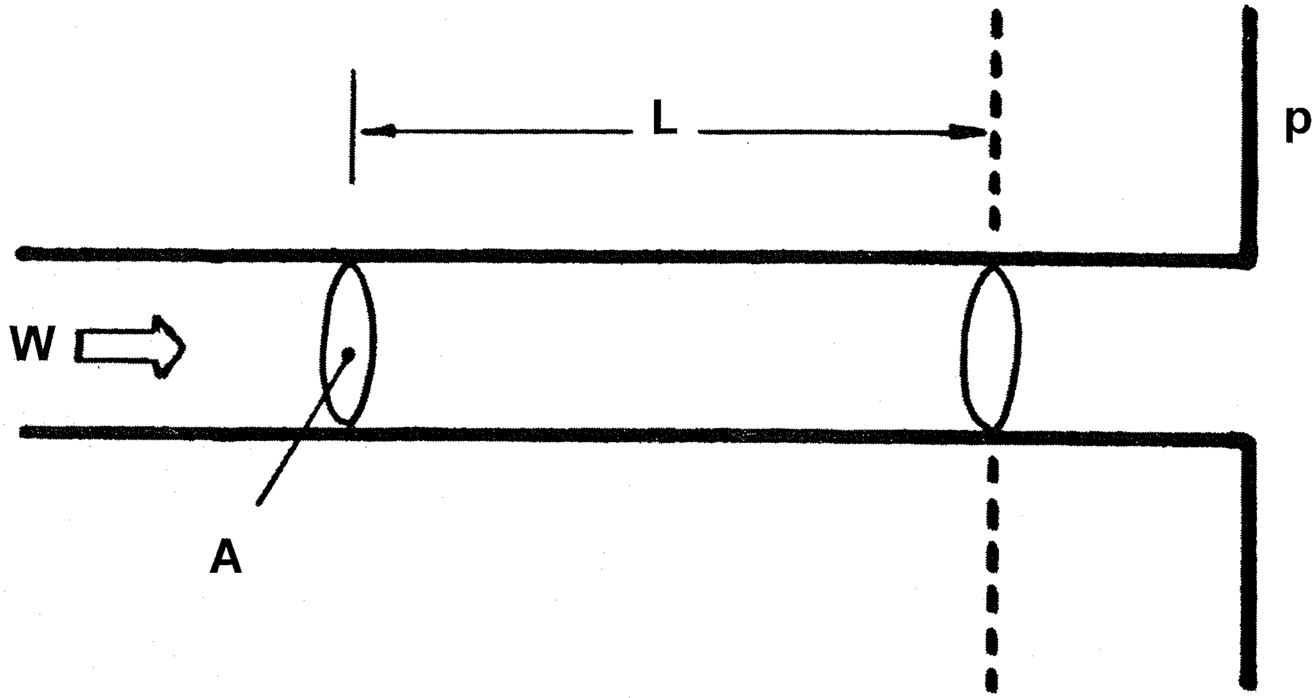
$\text{Work} = m\,V\,\Delta V$

$= \tfrac{1}{2}\,m\,V^2$

Kinetic Energy = ½ mass x velocity^2

$= \tfrac{1}{2}\,m\,V^2$

FLOW WORK



Work to push plug of fluid through System Boundary is:

$$W = \text{force} \times \text{distance} \quad (\text{Nm})$$
$$= p\,A\,L$$
$$= p\,V \quad (\text{Nm})$$
$$w = p\,v \quad (\text{Nm/kg})$$

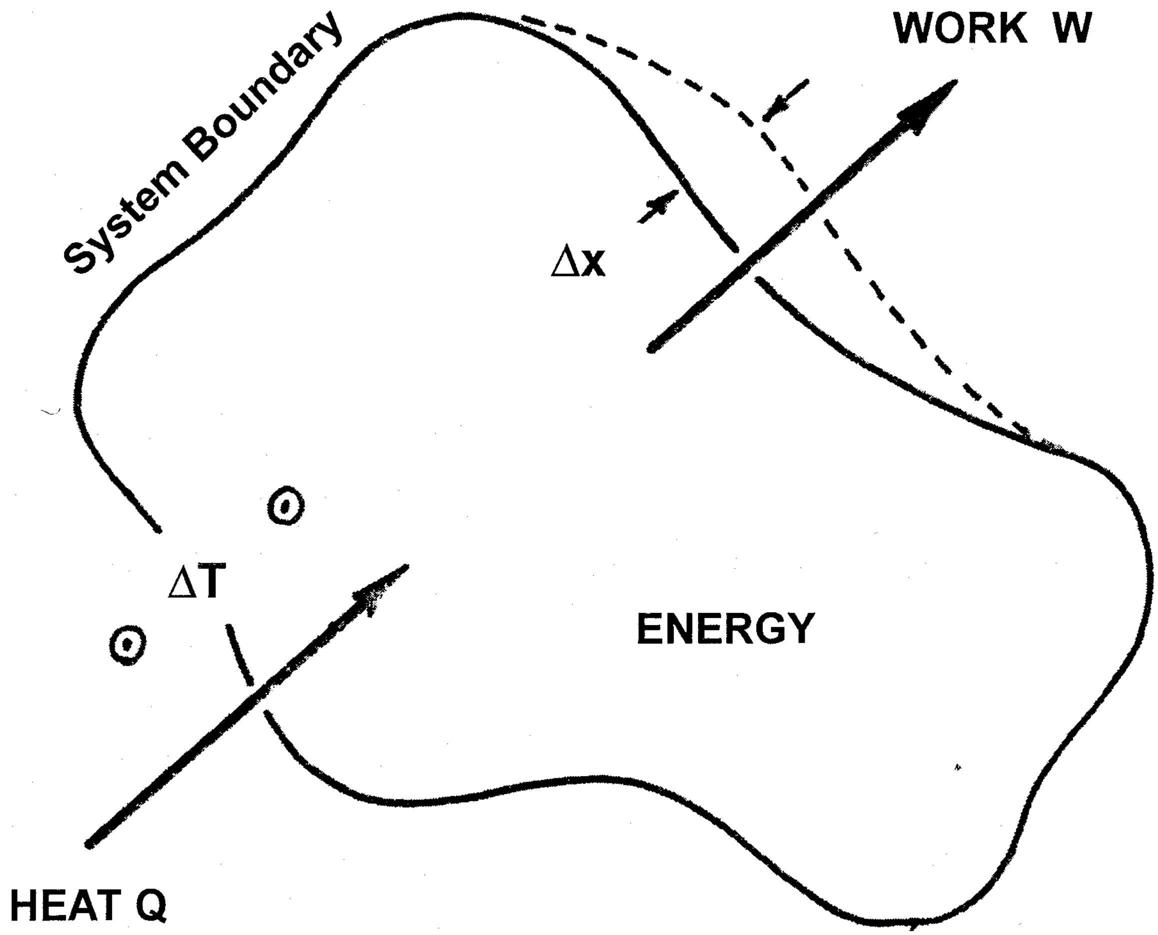
Flow work:

$$w = p\,v \quad (\text{J/kg})$$

Generally:

$$w = \Delta\,(pv)$$

THERMODYNAMIC RELATIONS
HEAT - ENERGY - WORK



Change in Internal Energy = Heat Input - Work Output

$$\Delta U = Q - W$$

FIRST LAW OF THERMODYNAMICS
(CONSERVATION OF ENERGY)

Energy can neither be created nor destroyed but only converted from one form to another.

Therefore

$$dE = \delta Q - \delta W$$

where

dE = small change in E

δQ = small amount of Q

δW = small amount of W

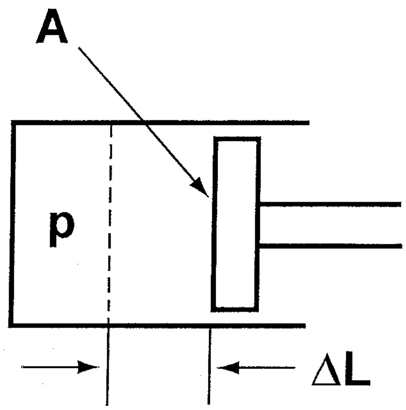
For a system absorbing heat and doing work

$$dE = \delta Q - \delta W$$

ENTHALPY DEFINITION

From First Law

$$dU = \delta Q - \delta W$$
$$U_2 - U_1 = Q - W$$
$$u_2 - u_1 = q - w$$



Consider piston in cylinder

$$W = \text{Force x Distance}$$
$$= F \times \Delta L$$
$$= pA\Delta L$$
$$= p\Delta V$$
$$w = p\Delta v$$

Substituting and considering p to be constant

$$u_2 - u_1 = q - p\Delta V$$
$$= q - p(v_2 - v_1)$$
$$q = u_2 - u_1 + p_2v_2 - p_1v_1$$
$$= (u_2 + p_2v_2) - (u_1 + p_1v_1)$$
$$= h_2 - h_1 = \Delta h$$

where $\boxed{h = u + pv}$ is Enthalpy

SPECIFIC HEAT

$$\text{Specific Heat} = \frac{\text{Heat Transferred / Unit Mass}}{\text{Change in Temperature}} = \frac{\text{J / kg}}{°\text{C}}$$

Specific heat at constant pressure

$$c_p = \left(\frac{q}{\Delta T}\right)_p$$

$q = h_2 - h_1$ at constant pressure

$$c_p = \left(\frac{\Delta h}{\Delta T}\right)_p$$

$$q = \Delta h = c_p \Delta T$$

Specific heat at constant volume

$$c_v = \left(\frac{q}{\Delta T}\right)_v$$

$q = u_2 - u_1$ at constant volume

$$c_v = \left(\frac{\Delta u}{\Delta T}\right)_v$$

$$q = \Delta u = c_v \Delta T$$

Which is greater : c_p or c_v?

$$k = \frac{c_p}{c_v}$$

TABLE 2.2
ENERGY BALANCE

	ENERGY IN (Btu/lb)	*ENERGY IN (SI)*	*ENERGY OUT (Btu/lb)*	*ENERGY OUT (SI)*
Potential energy	$\frac{Z_1 g}{J g_c}$	$Z_1 g$	$\frac{Z_2 g}{J g_c}$	$Z_2 g$
Kinetic energy	$\frac{V_1^2}{2 g_c J}$	$\frac{V_1^2}{2}$	$\frac{V_2^2}{2 g_c J}$	$\frac{V_2^2}{2}$
Internal energy	u_1	u_1	u_2	u_2
Flow work	$\frac{p_1 v_1}{J}$	$p_1 v_1$	$\frac{p_2 v_2}{J}$	$p_2 v_2$
Work	$\frac{W_{in}}{J}$	W_{in}	$\frac{W_{out}}{J}$	W_{out}
Heat	q_{in}	q_{in}	q_{out}	q_{out}

ENERGY EQUATION

THE FIRST LAW OF THERMODYNAMICS STATES THAT ENERGY IS NEITHER CREATED NOR DESTROYED...

Combining all types of energy into a single equation gives:

$$z_1g + V_1^2/2 + u_1 + p_1v_1 + w_{IN} + q_{IN}$$
$$= z_2g + V_2^2/2 + u_2 + p_2v_2 + w_{OUT} + q_{OUT}$$

For constant u and no w or q this equation reduces to the Bernoulli Equation

$$z_1g + V_1^2/2 + p_1v_1 = z_2g + V_2^2/2 + p_2v_2$$

$$z_1 + V_1^2/2g + p_1/\rho g = z_2 + V_2^2/2g + p_2/\rho g$$

Note that: $u + pv = h$

Hence rewriting gives:

$$(z_1 - z_2)g + (V_1^2 - V_2^2)/2 + (h_1 - h_2) + (w_{IN} - w_{OUT})$$
$$+ (q_{IN} - q_{OUT}) = 0$$

This equation can be adapted to all flow processes by substituting appropriate values.

TURBINE

ENERGY EQUATION

$$z_1g + V_1^2/2 + u_1 + p_1v_1 + w_{IN} + q_{IN}$$
$$= z_2g + V_2^2/2 + u_2 + p_2v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work input	$w_{IN} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

TURBINE EQUATION

$$u_1 + p_1v_1 = u_2 + p_2v_2 + w_{OUT}$$
$$h_1 = h_2 + w_{OUT}$$

$$w_{OUT} = h_1 - h_2$$

Generally

$$w_{OUT} = \Delta h$$

FOR GAS TURBINE

$$w_{OUT} = c_p \Delta T$$

BOILER

ENERGY EQUATION (STEAM SIDE)

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{IN} + q_{IN}$$
$$= z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work input	$w_{IN} = 0$
No work output	$w_{OUT} = 0$
No heat output from steam	$q_{OUT} = 0$

BOILER EQUATION

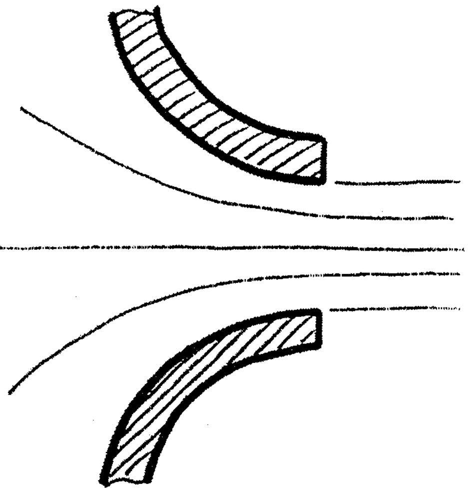
$$u_1 + p_1 v_1 + q_{IN} = u_2 + p_2 v_2$$
$$h_1 + q_{IN} = h_2$$

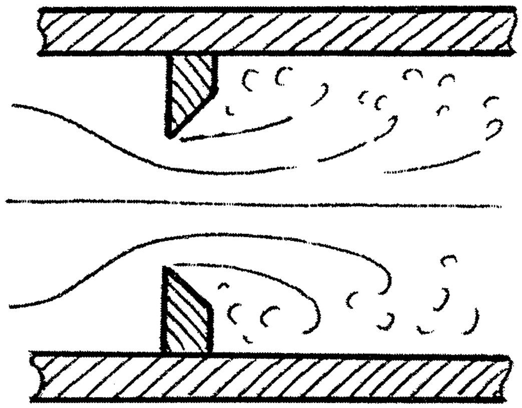
$$q_{IN} = h_2 - h_1$$

Generally

Heat in = Δh

NOZZLE AND THROTTLE





NOZZLE	THROTTLE
No work	No work
No heat transfer	No heat transfer
No friction	Friction due to turbulence
Reversible adiabatic (isentropic)	Irreversible adiabatic (isenthalpic)
PURPOSE: To produce high velocity flow	PURPOSE: To reduce pressure or restrict flow

NOZZLE

ENERGY EQUATION

$$z_1g + V_1^2/2 + u_1 + p_1v_1 + w_{IN} + q_{IN}$$
$$= z_2g + V_2^2/2 + u_2 + p_2v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
No work input	$w_{IN} = 0$
No work output	$w_{OUT} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

NOZZLE EQUATION

$$V_1^2/2 + u_1 + p_1v_1 = V_2^2/2 + u_2 + p_2v_2$$

$$V_1^2/2 + h_1 = V_2^2/2 + h_2$$

$$V_2^2 - V_1^2 = 2(h_1 - h_2)$$

If initial velocity is negligible

$$V_2 = \sqrt{2(h_1 - h_2)}$$

For gas flow: $V_2 = \sqrt{2c_p\Delta T}$

Generally: Velocity = Function of $\sqrt{\Delta h}$

THROTTLE

ENERGY EQUATION

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{IN} + q_{IN}$$
$$= z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work input	$w_{IN} = 0$
No work ouput	$w_{OUT} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

THROTTLE EQUATION

$$u_1 + p_1 v_1 = u_2 + p_2 v_2$$

$$h_1 = h_2$$

CONSTANT ENTHALPY PROCESS

The Throttling Process involves acceleration of the fluid in a constriction (as in a nozzle) followed by turbulent deceleration with frictional heating as the flow velocity returns to normal.

HYDRO TURBINE PLANT

ENERGY EQUATION (WHOLE PLANT)

$$z_1g + V_1^2/2 + u_1 + p_1v_1 + w_{IN} + q_{IN}$$
$$= z_2g + V_2^2/2 + u_2 + p_2v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

Small change in velocity	$V_2 = V_1$
Little change in internal energy	$u_2 = u_1$
No change in pressure	$p_2 = p_1$
Little change in specific volume	$v_2 = v_1$
No work input	$w_{IN} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

HYDRO TURBINE EQUATION

$$z_1 g = z_2 g + w_{OUT}$$
$$w_{OUT} = (z_1 - z_2)g$$

Generally

$$\text{Work out} = g\,\Delta z$$

Power

$$P = \rho g Q H \qquad \text{where } H = \Delta z$$

PUMP

(GENERAL EQUATION)

ENERGY EQUATION (ACROSS PUMP)

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{IN} + q_{IN}$$
$$= z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work output	$w_{OUT} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

PUMP EQUATION

$$u_1 + p_1 v_1 + w_{IN} = u_2 + p_2 v_2$$
$$h_1 + w_{IN} = h_2$$

$$w_{IN} = h_2 - h_1$$

Generally

Work in $= \Delta h$

COMPRESSOR

Energy Equation

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{in} + q_{in}$$

$$= \quad z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{out} + q_{out}$$

Assumptions

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work output	$w_{out} = 0$
No heat input	$q_{in} = 0$
No heat output	$q_{out} = 0$

Compressor Equation

$$u_1 + p_1 v_1 + w_{in} = u_2 + p_2 v_2$$

$$h_1 + w_{in} = h_2$$

$$w_{in} = h_2 - h_1$$

$$\text{Work in} = \Delta h$$

$$w_{in} = c_p (T_2 - T_1)$$

PUMP

ENERGY EQUATION

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{IN} + q_{IN}$$
$$= z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{OUT} + q_{OUT}$$

ASSUMPTIONS

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
Little change in internal energy	$u_2 = u_1$
Little change in specific volume	$v_2 = v_1 = v$
No work output	$w_{OUT} = 0$
No heat input	$q_{IN} = 0$
No heat output	$q_{OUT} = 0$

PUMP EQUATION

$$p_1 v + w_{IN} = p_2 v$$
$$w_{IN} = (p_2 - p_1) v$$
$$w_{IN} = (p_2 - p_1) / \rho$$

Generally

$$\text{Work in} = \Delta p / \rho$$

HEAT EXCHANGER

Energy Equation

$$z_1 g + V_1^2/2 + u_1 + p_1 v_1 + w_{in} + q_{in}$$

$$= \quad z_2 g + V_2^2/2 + u_2 + p_2 v_2 + w_{out} + q_{out}$$

Assumptions

No change in elevation	$z_2 = z_1$
Small change in velocity	$V_2 = V_1$
No work input	$w_{in} = 0$
No work output	$w_{out} = 0$

Equation for hot fluid

$u_1 + p_1v_1 + \cancel{q_{in}} = u_2 + p_2v_2 + q_{out}$

$h_1 - h_2 = q_{out}$ (J/kg)

$M_{hot} (h_1 - h_2)_{hot} = M_{hot} q_{out}$ (J/s)

Equation for cold fluid

$u_1 + p_1v_1 + q_{in} = u_2 + p_2v_2 + \cancel{q_{out}}$

$q_{in} = h_2 - h_1$ (J/kg)

$M_{cold} q_{in} = M_{cold}(h_2 - h_1)_{cold}$ (J/s)

$$\boxed{M_{hot} (h_1 - h_2)_{hot} = M_{cold} (h_2 - h_1)_{cold}}$$

ENERGY EQUATION APPLICATIONS THINGS TO REMEMBER

ENTHALPY h

$$u_1 + p_1 v_1 - u_2 - p_2 v_2 = h_1 - h_2$$

SPECIFIC HEAT c_p AND c_v

$$h_1 - h_2 = c_p (T_1 - T_2)$$

$$u_1 - u_2 = c_v (T_1 - T_2)$$

UNITS OF ENERGY EQUATION

J / kg (h and u are in kJ/kg)

KINETIC ENERGY $V^2/2$

$$\left(\frac{m}{s}\right)^2 = \frac{kg}{kg} \times \frac{m\,m}{s\ s} = \frac{Nm}{kg} = \frac{J}{kg}$$

RATE OF HEAT FLOW OR POWER

= energy x mass flow rate

$$= \frac{J}{kg} \times \frac{kg}{s} = \frac{J}{s} = W$$