# THERMODYNAMIC THEORY

# EQUATION OF STATE

## CHARLES' EQUATION

$$p_1V_1 / T_1 = p_2V_2 / T_2 = \text{constant}$$

## EQUATION OF STATE (IDEAL GAS)

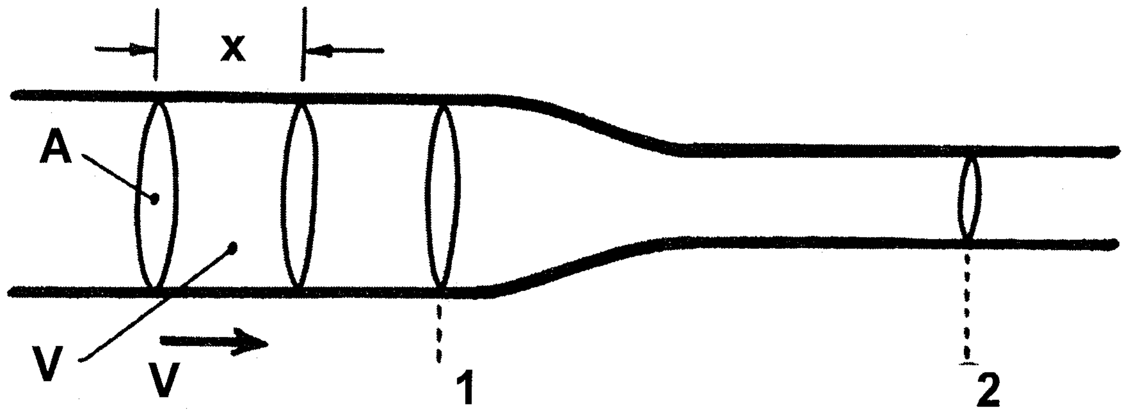
$$pV = \text{constant } T$$
$$pv = \text{constant } T / \text{mass}$$
$$pv = RT$$

## EQUATION OF STATE (NON-IDEAL GAS)

$$pv = z R T$$
$$z = \text{compressibility factor}$$

# CONTINUITY EQUATION

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




| | | | | |
|---|---|---|---|---|
| **Volume** | $V$ | = | $A\,x$ | ($m^3$) |
| **Density** | $\rho$ | | | ($kg/m^3$) |
| **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**

# 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: $u + pv = h$**

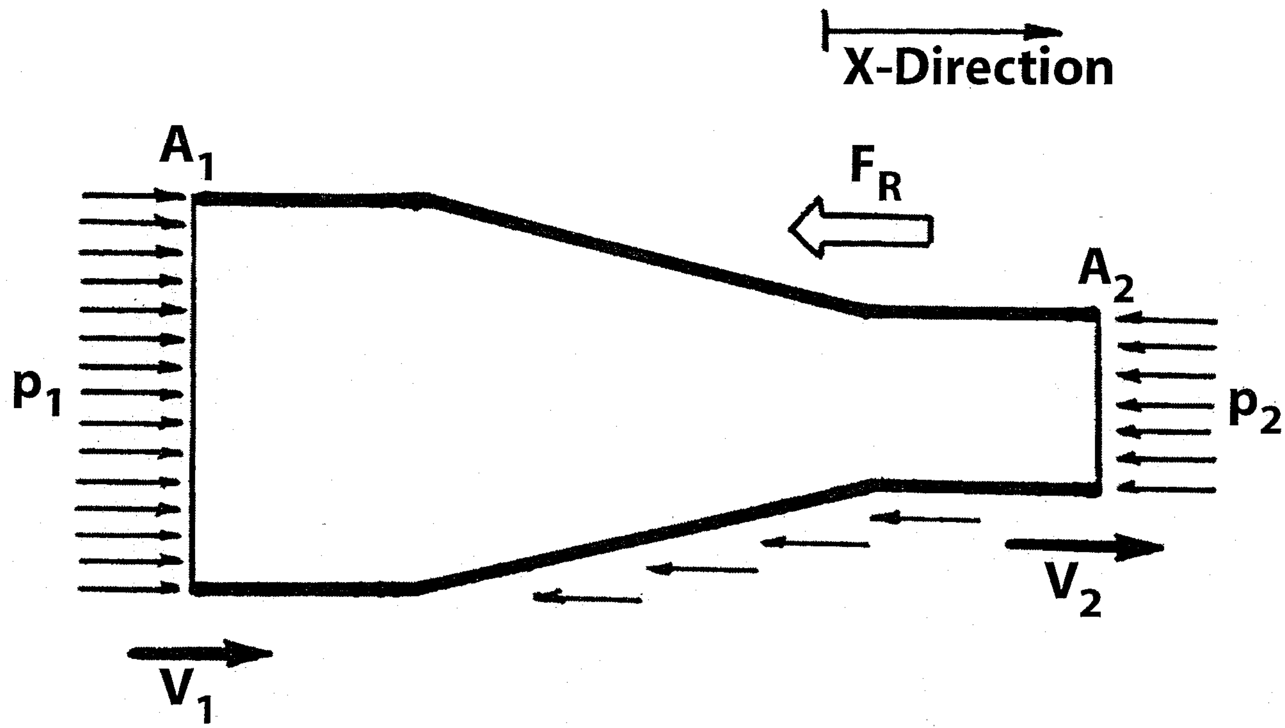
**Hence rewriting gives:**

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

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

# APPLICATIONS

## CONICAL PIPE




**Forces in X - Direction (on fluid)**

$$\Sigma F_x = p_1 A_1 - p_2 A_2 - F_R = \rho Q \Delta V_x$$

**Reaction**

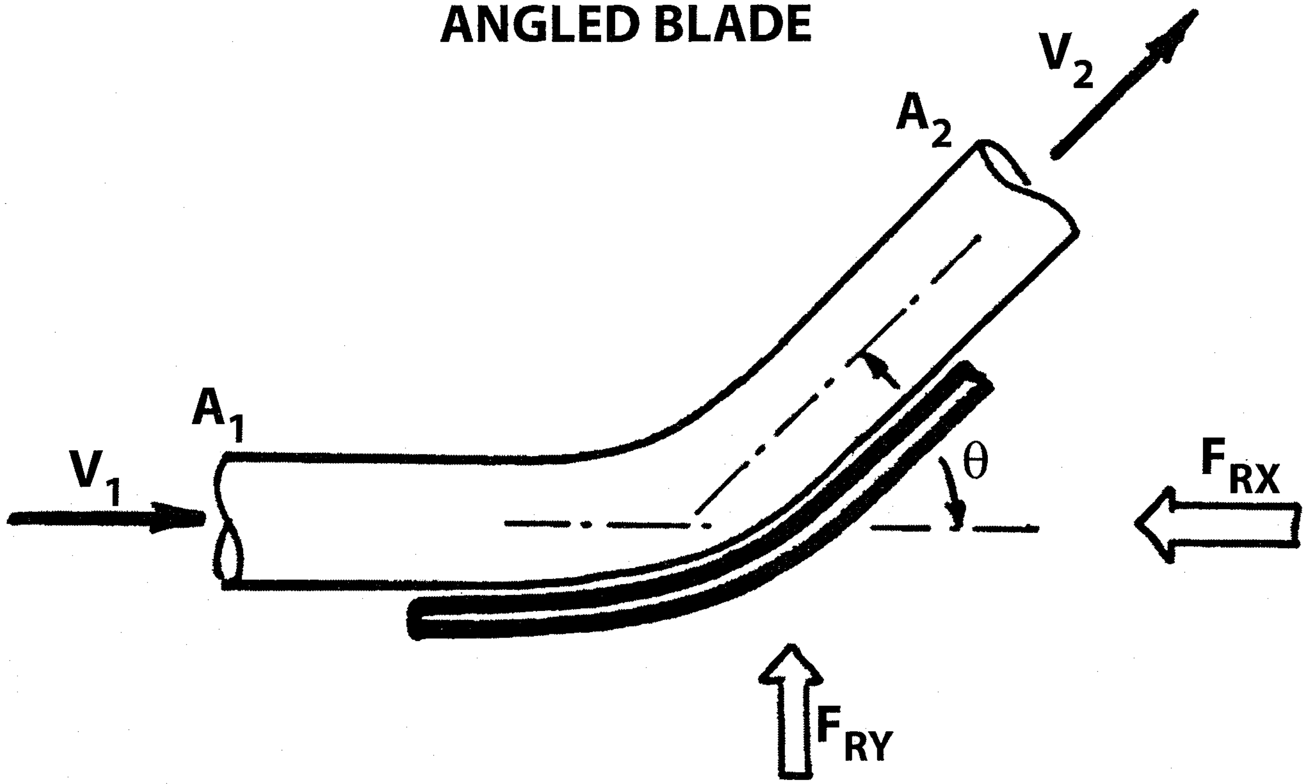
* $$F_R = p_1 A_1 - p_2 A_2 - \rho Q(V_2 - V_1)$$

* Note sign convention

# FORCES IN FREE JETS

## MOMENTUM EQUATION APPLIED TO BLADES

### ANGLED BLADE




**Use Previous Equation for Flow in Pressure Conduit**

**Reaction in X - Direction**

$$F_{RX} = p_1A_1 - p_2A_2\cos\theta - \rho Q(V_2\cos\theta - V_1)$$

**Since $p_1$ and $p_2$ are zero**

$$F_{RX} = -\rho Q(V_2\cos\theta - V_1)$$

**Reaction in Y - Direction**

$$F_{RY} = p_2A_2\sin\theta + \rho QV_2\sin\theta$$

**Since $p_1$ and $p_2$ are zero**

$$F_{RY} = \rho QV_2\sin\theta$$

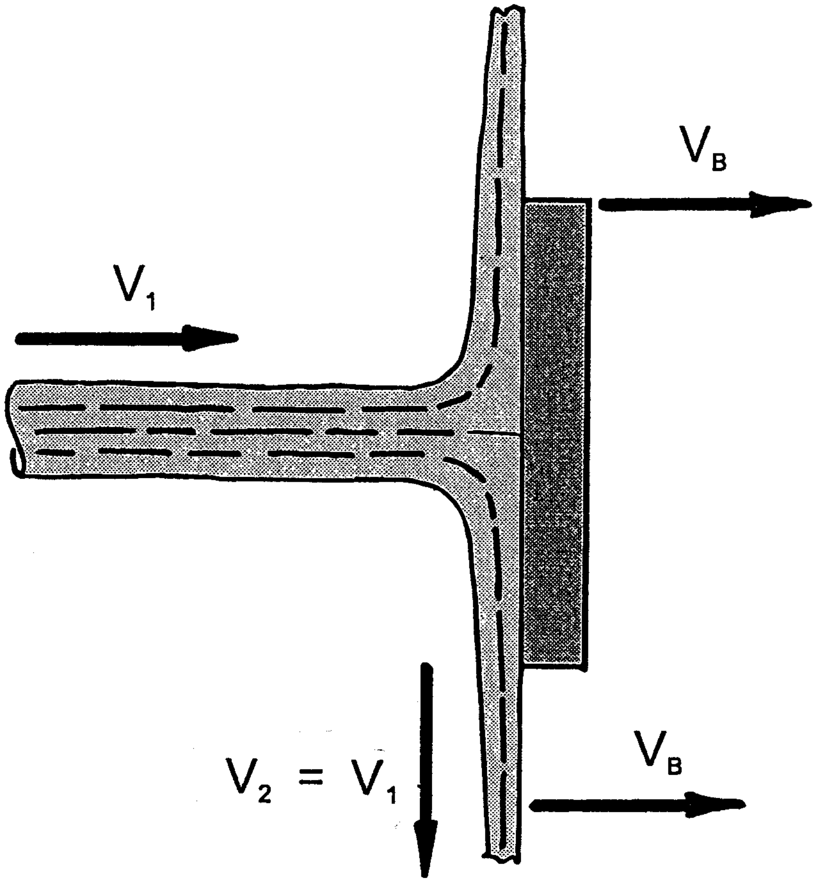



**Figure 1 Jet impinging upon a flat moving plate**

# RESULTANT FORCE

$$F = ma$$

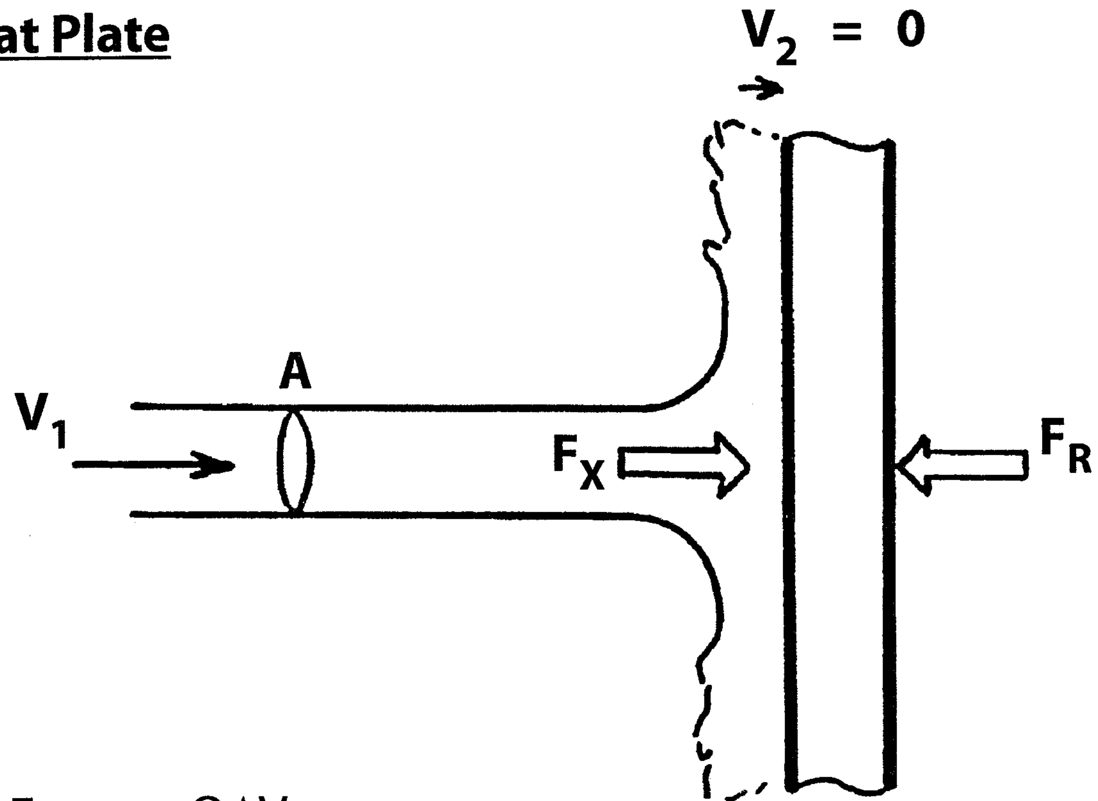
$$F = \rho Q \Delta V$$

$$F_X = \rho Q \Delta V_X$$

$$F_Y = \rho Q \Delta V_Y$$

$$F_Z = \rho Q \Delta V_Z$$

**Flat Plate**



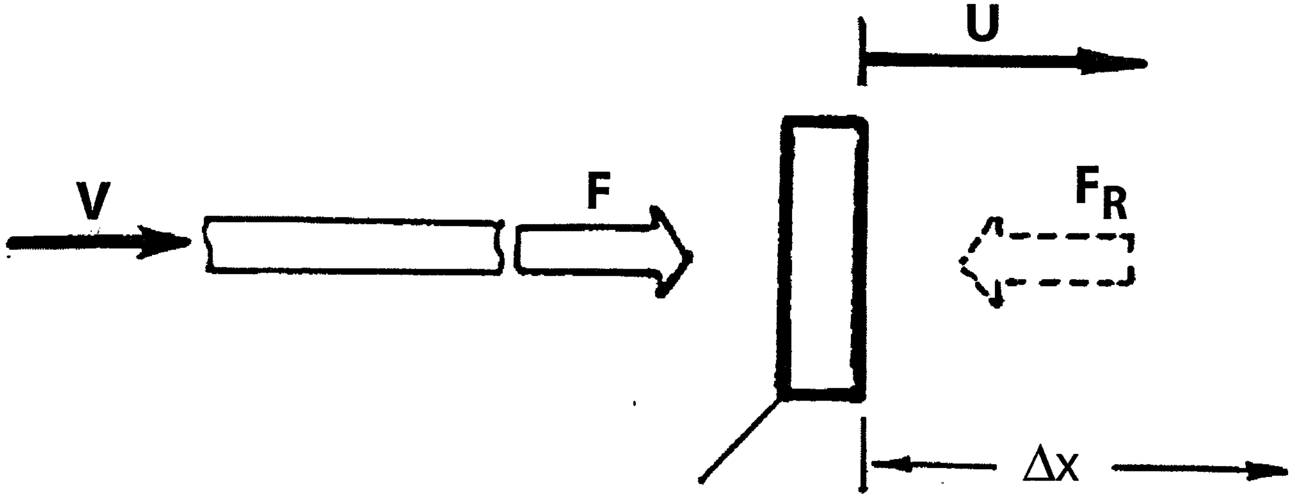

$$F_X = \rho Q \Delta V_X$$

$$= \rho Q(V_1 - V_2)$$

$$= \rho Q(V_1)$$

$$F_R = F_X$$

# WORK AND POWER




**Force on blade** $F = \rho Q \Delta V$ (N)

**Work on blade** $W = \text{Force} \times \text{Distance}$

$= F\Delta x$

$= \rho Q \Delta V \Delta x$ (Nm)

**Power to blade** $P = \text{Work} / \text{Time}$

$= F\Delta x / \Delta t$

$= FU$

$= \rho Q \Delta V\, U$ (J / s)

Now since $\Delta V = (V - U)$

**Power to blade** $P = \rho Q(V - U)U$

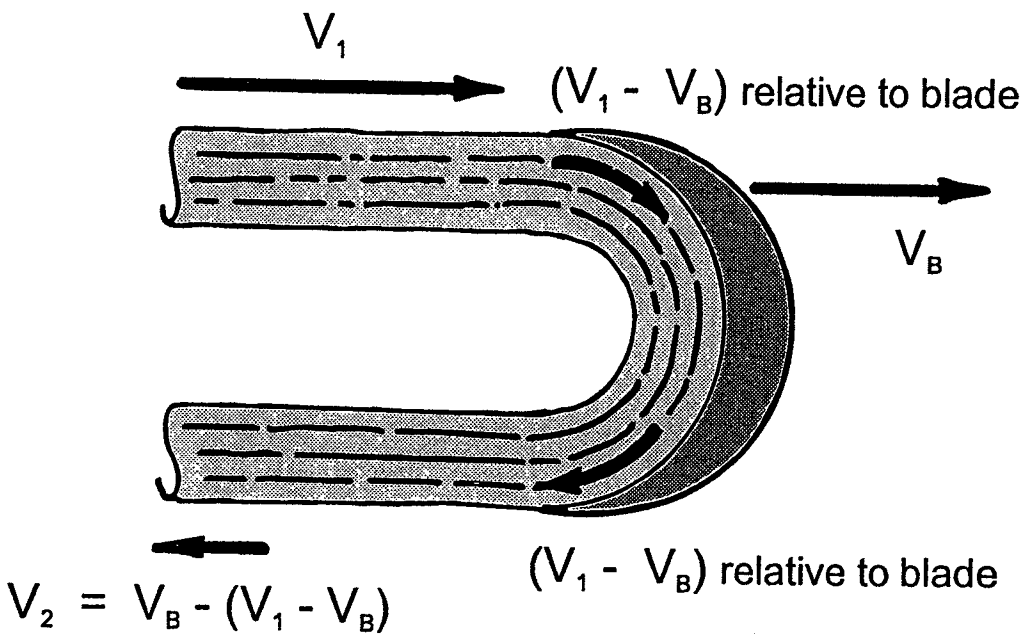



**Figure 2 Jet impinging upon a curved moving plate**

# 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

$\delta Q$ = small amount of Q

$\delta W$ = small amount of W

**For a system absorbing heat and doing work**

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

# SECOND LAW OF THERMODYNAMICS

## (CONVERSION OF HEAT TO WORK)

**No heat engine can generate work without net rejection of heat to a low-temperature reservoir.**

**If the cold reservoir could be at absolute zero (no molecular motion and hence no internal energy) then the efficiency of the carnot cycle would be 100% and all the heat would be converted into work.**

**The second law thus defines a portion of heat which is *unavailable* for conversion into work under ambient conditions.**

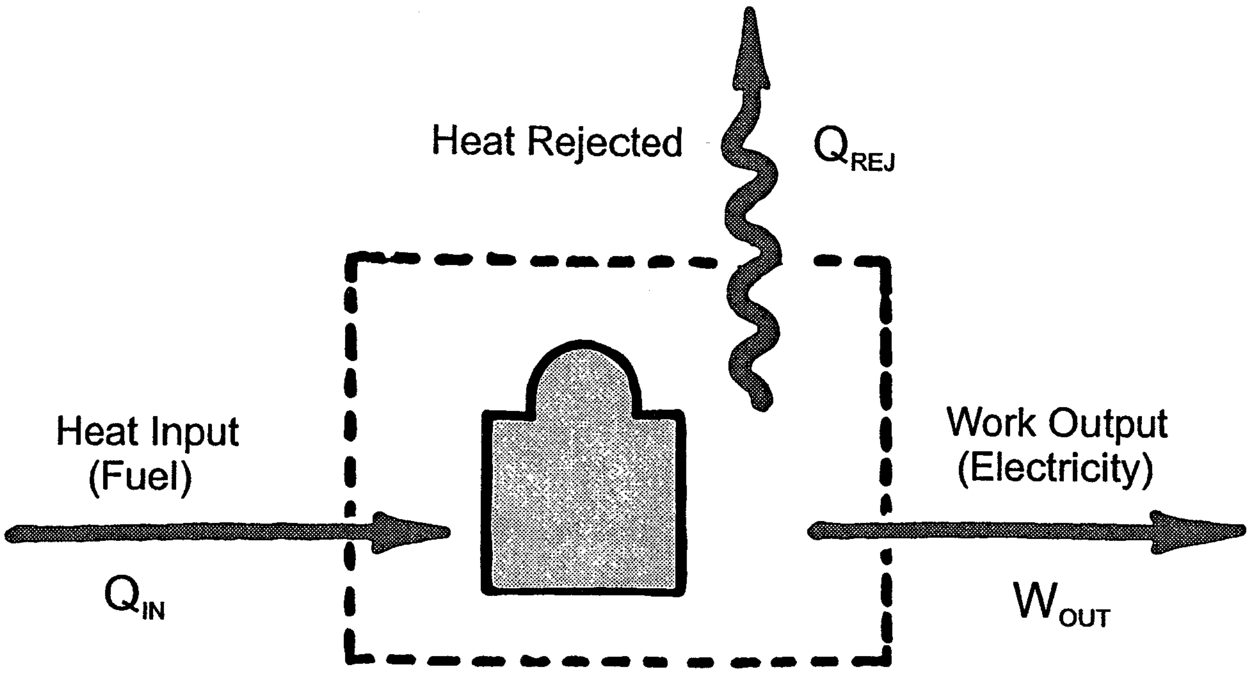



**Figure 3 Heat and work flow in a heat engine**

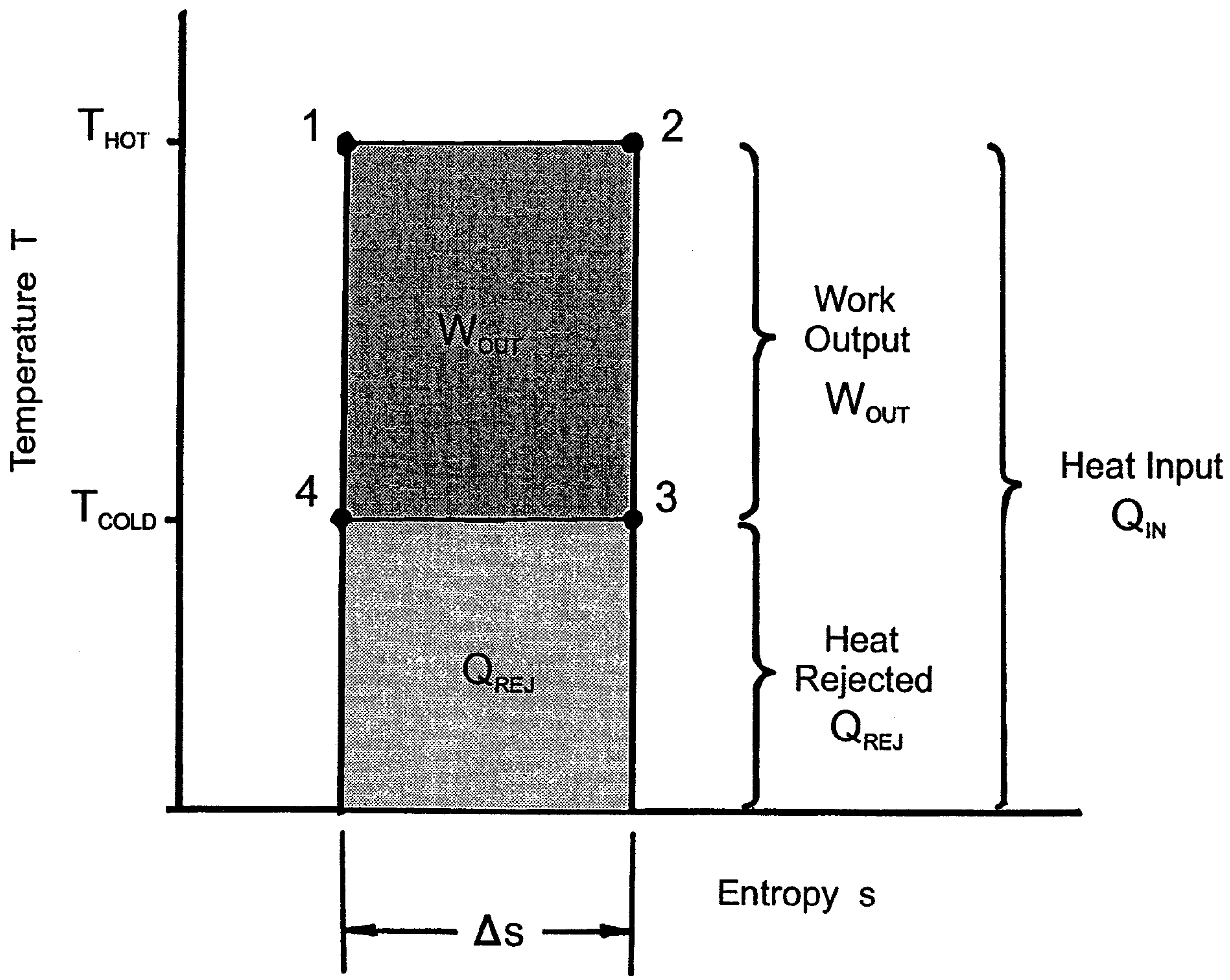



**Figure 4 Carnot cycle**

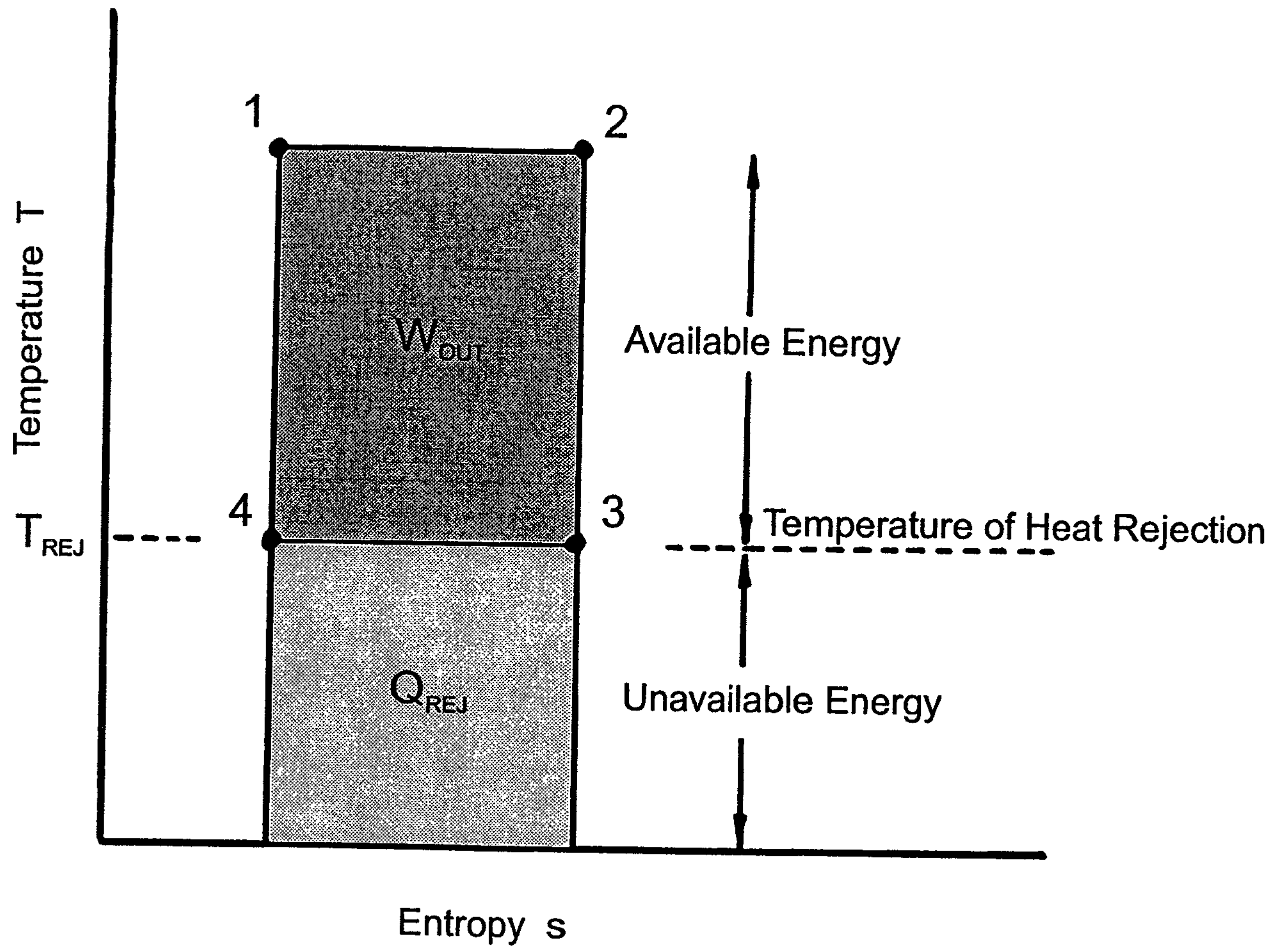
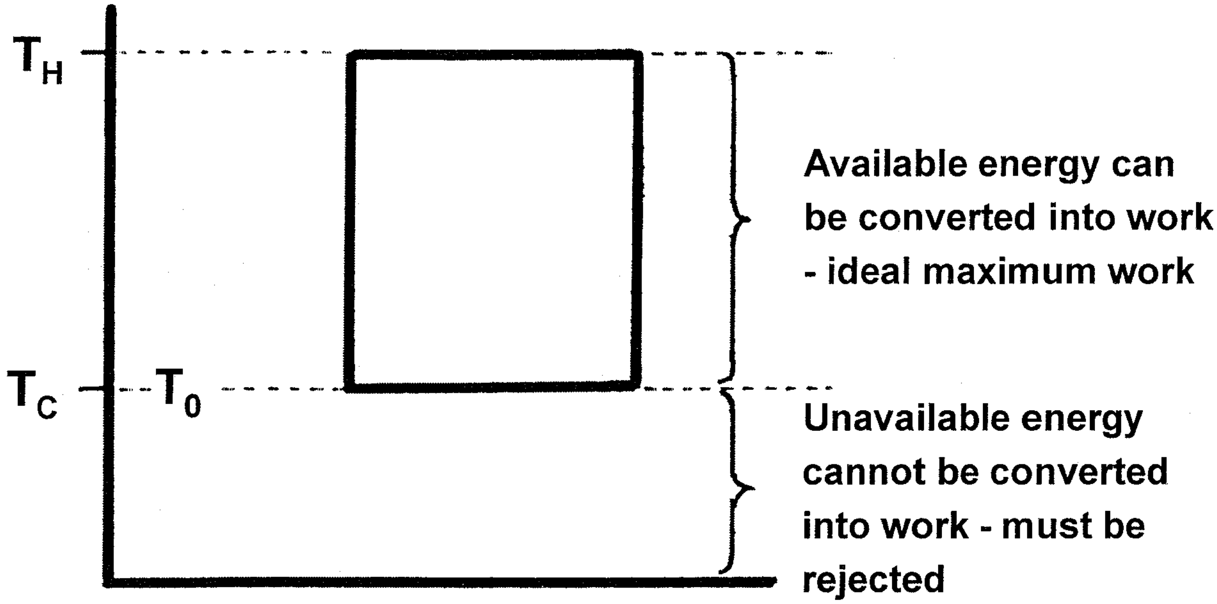
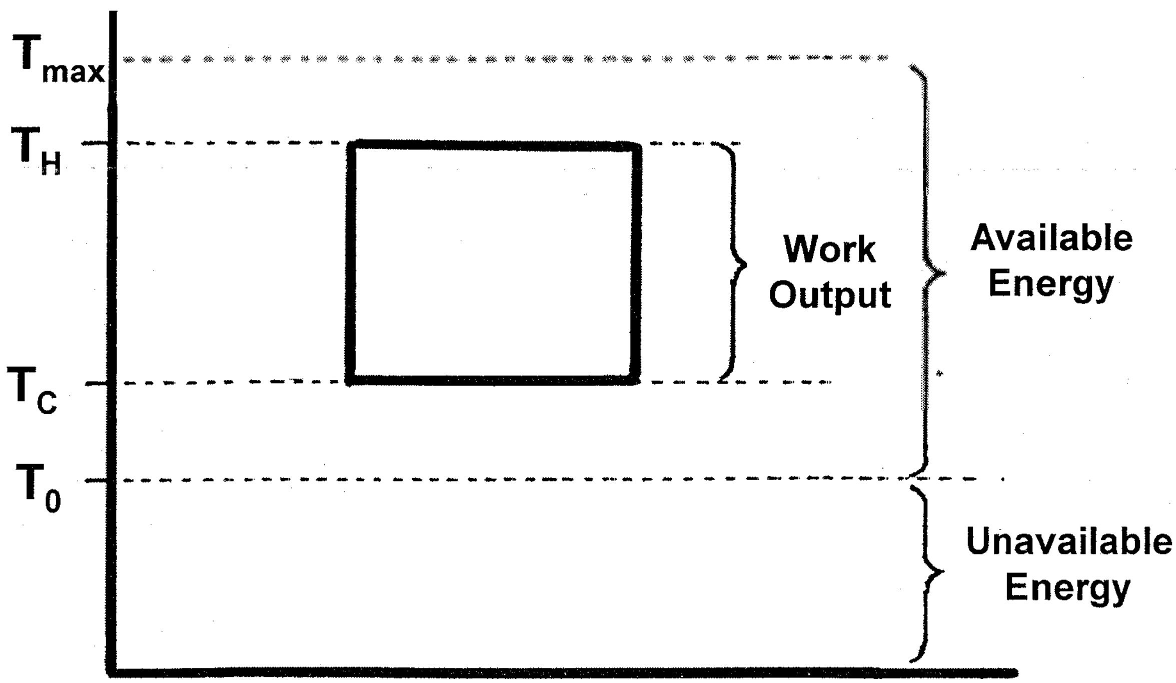



**Figure 5 Available and unavailable energy**

# AVAILABLE AND UNAVAILABLE ENERGY



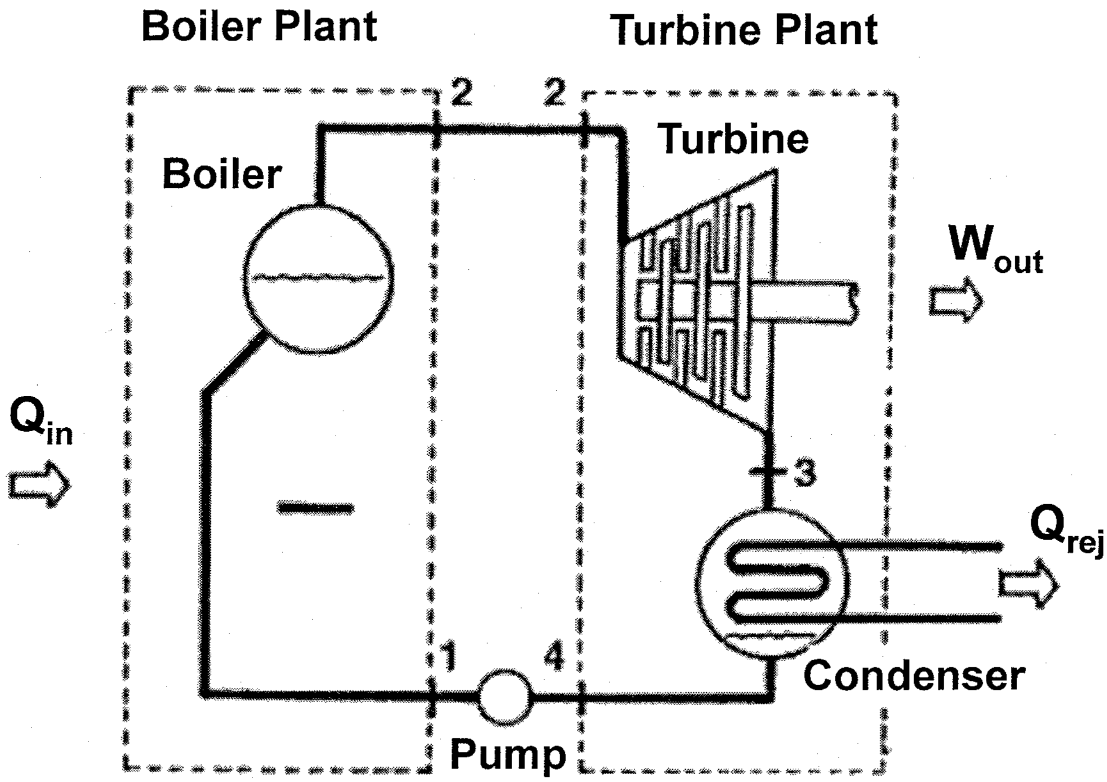




$T_0$ = Ambient Temperature (Heat Sink)

$T_{max}$ = Maximum Temperature of Heat source

$T_H$ & $T_C$ = Cycle Working Fluid Temperatures

# STEAM BOILER AND TURBINE




| Component | Process |
|---|---|
| Boiler | 1 - 2 |
| Turbine | 2 - 3 |
| Condenser | 3 - 4 |
| Pump | 4 - 1 |

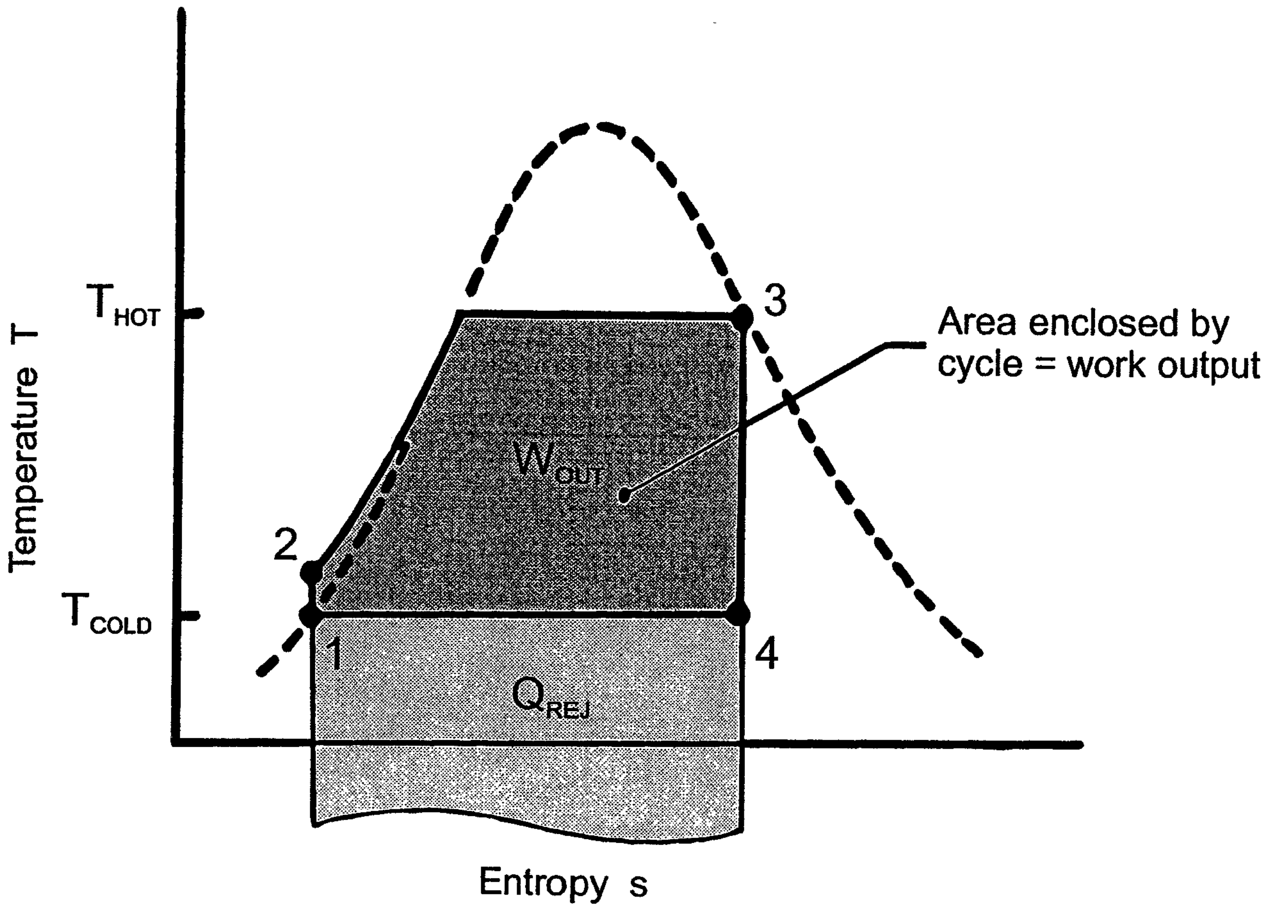



**Figure 6 Rankine cycle for steam turbine**

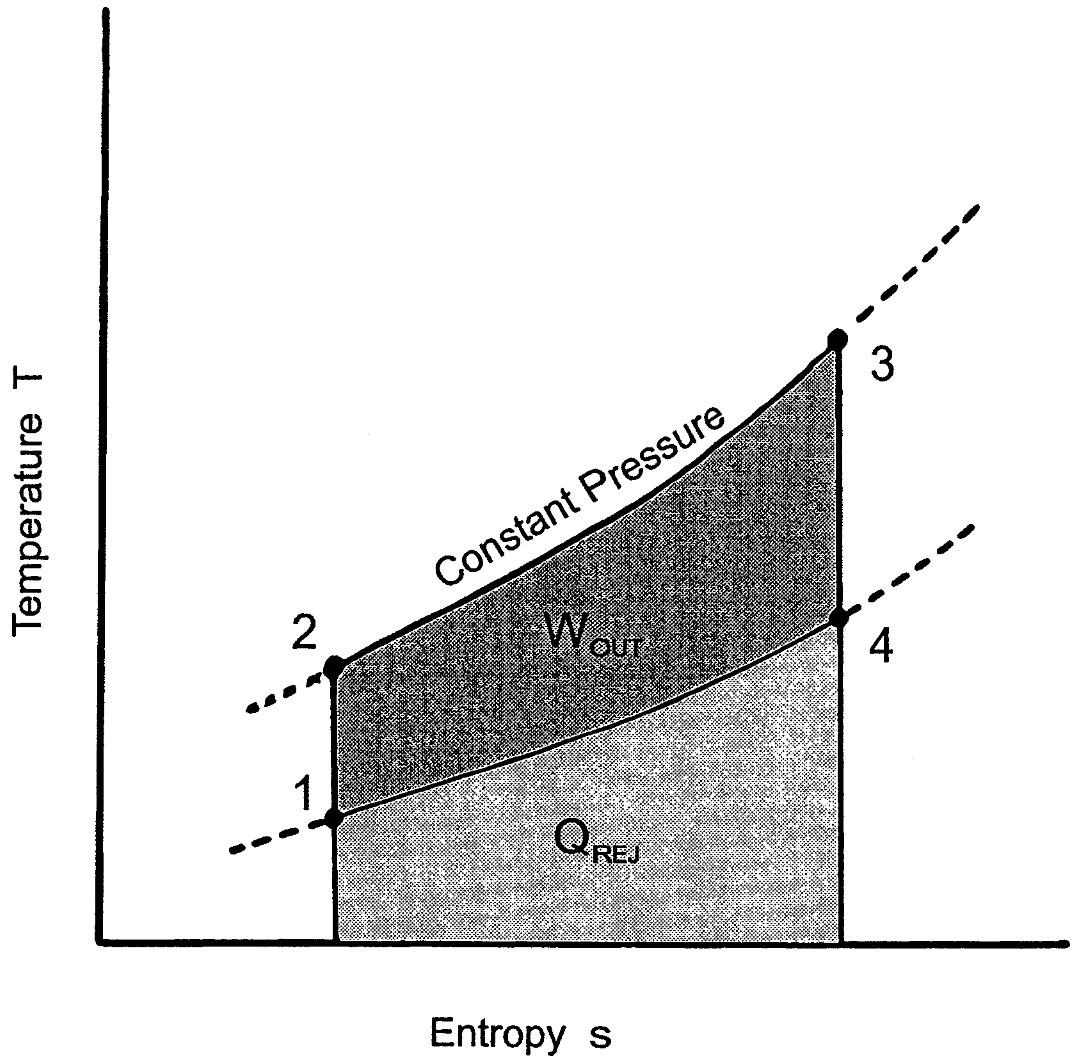



**Figure 7 Brayton cycle for gas turbines**

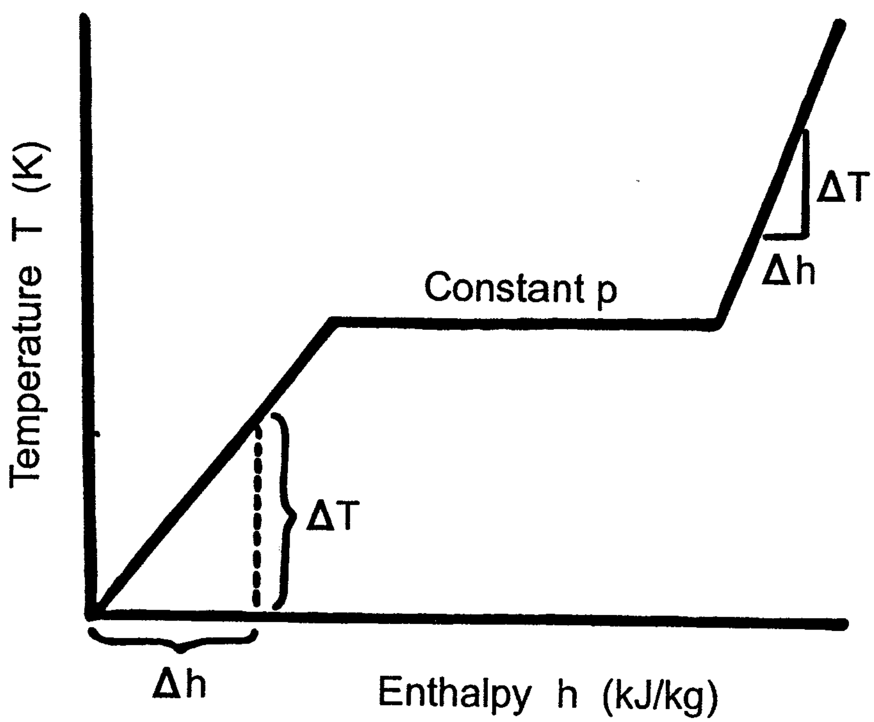



**Figure 8 Temperature-enthalpy diagram**

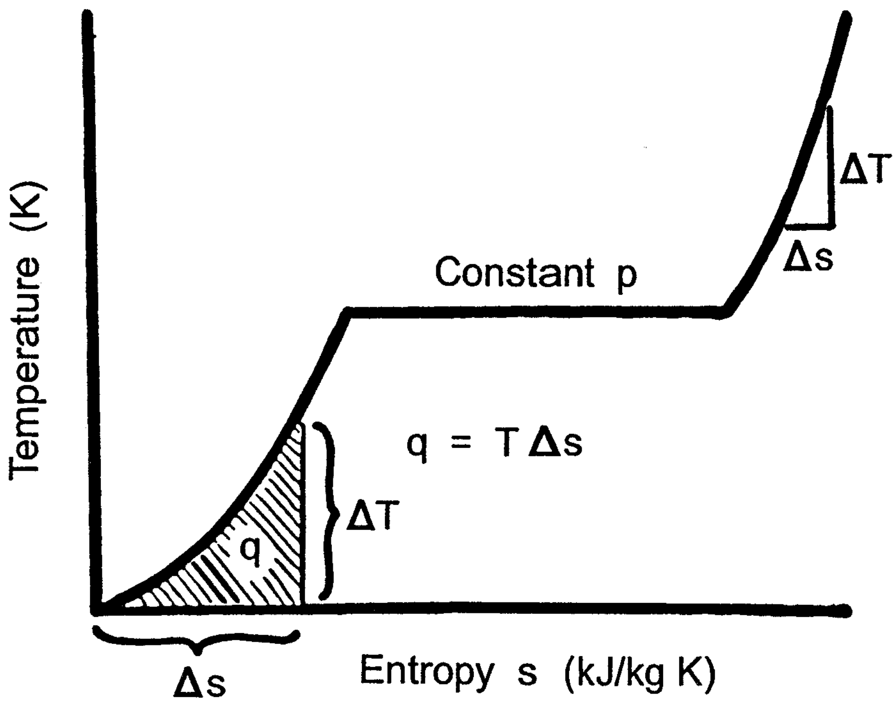



**Figure 9 Temperature-entropy diagram**

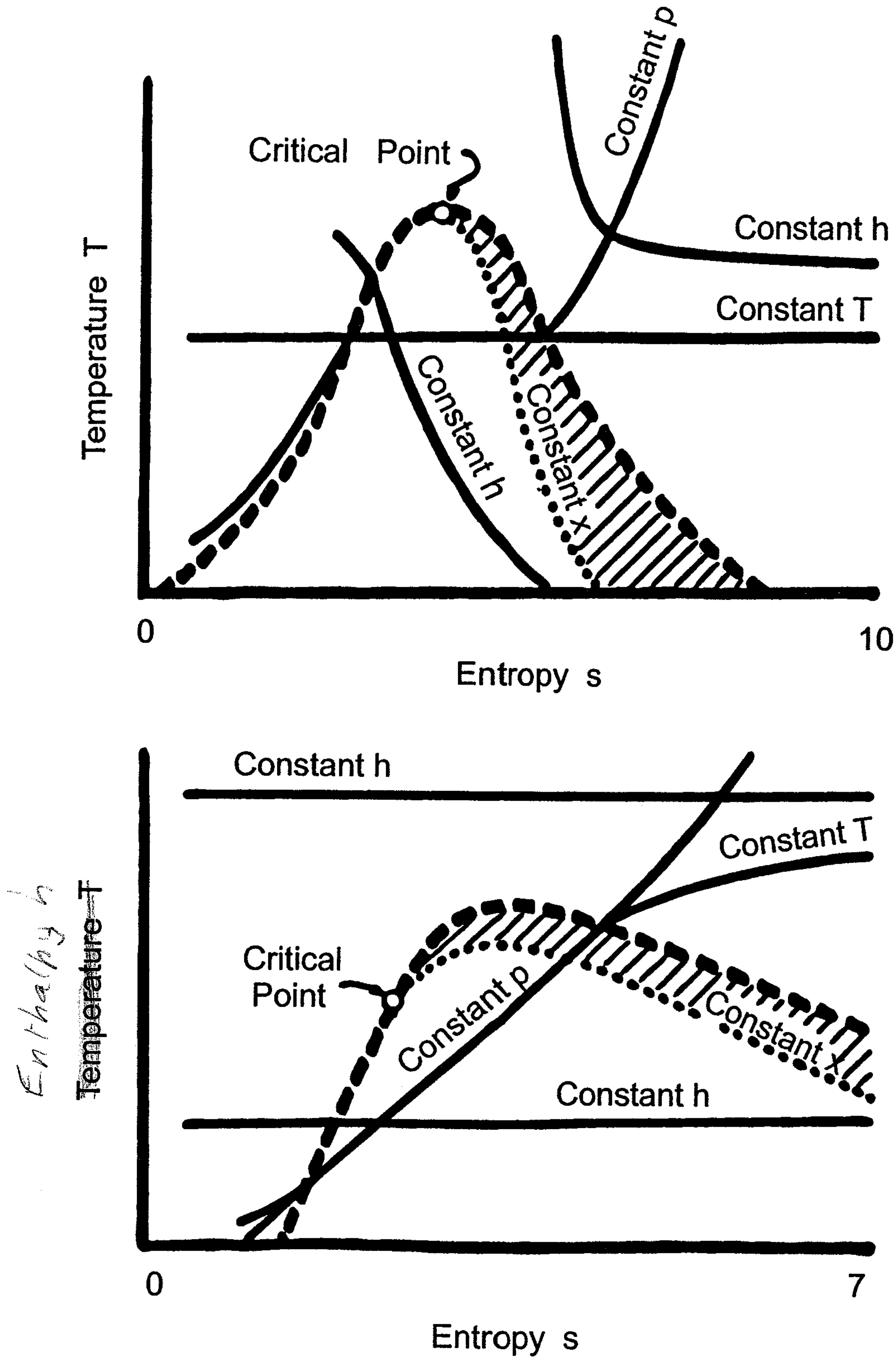



**Figure 10 Temperature-entropy and enthalpy-entropy diagrams**