

Gas exchange Processes

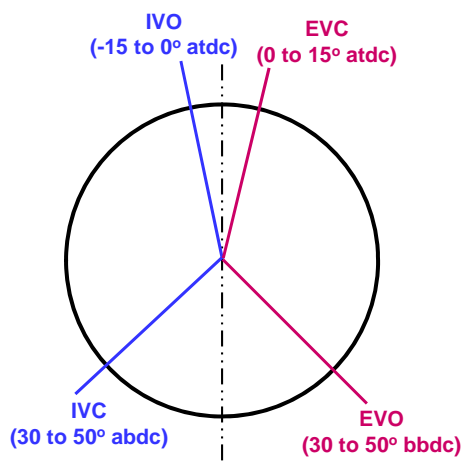
To move working fluid in and out of engine

- Engine performance is air limited
- Engines are usually optimized for maximum power at high speed

Considerations

- 4-stroke engine: volumetric efficiency
- 2-stroke engine: scavenging/ trapping efficiency
- Charge motion control; tuning; noise

Typical valve timing diagram



- Early EVO
 - Facilitates exhaust gas outflow via blow down
 - Incomplete expansion
- Late IVC
 - High speed: ram effect augments induction
 - Low speed: air loss by displacement flow
 - Lower effective compression ratio

Note that for typical passenger car engine, max piston speed is at ~70° from TDC

Volumetric efficiency: quasi-static effects

- Residual gas
 - Affected by:
 - Compression ratio
 - Exhaust gas temperature
 - Exhaust to intake pressure ratio
 - Impact:
 - Volumetric efficiency
 - Charge composition
 - Charge temperature

Volumetric efficiency: quasi-static effects

(cont.)

- Evaporative cooling effect
 - Higher charge density increases volumetric efficiency
 - Adiabatic evaporation in air to form $\lambda=1$ mixture:
 - Iso-octane: $\Delta T = -19^\circ\text{C}$
 - Ethanol: $\Delta T = -80^\circ\text{C}$
 - Methanol: $\Delta T = -128^\circ\text{C}$
- From both higher latent heat, lower LHV, and lower stoichiometric air/fuel ratio
- In practice, most heat from the wall unless direct injection is used

Volumetric efficiency: quasi-static effects

(cont.)

- Air displacement by fuel and water vapor

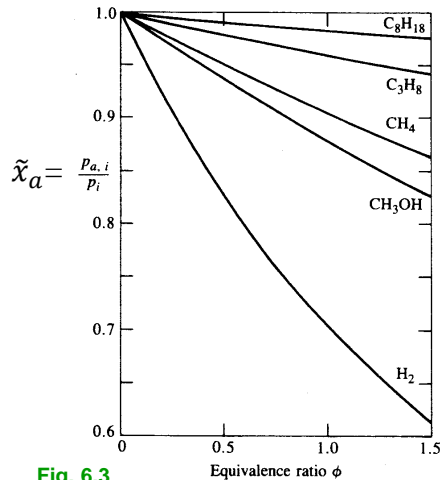


Fig. 6.3

V_i is volume inducted

P_i is intake pressure

$$m_a = \left(\frac{P_i V_i}{RT} \right) \tilde{x}_a W_a$$

$$\tilde{x}_a + \tilde{x}_f + \tilde{x}_w = 1$$

$$\begin{aligned} \tilde{x}_a &= \frac{1}{1 + \frac{\tilde{x}_f}{\tilde{x}_a} + \frac{\tilde{x}_w}{\tilde{x}_a}} \\ &= \frac{1}{1 + \frac{m_f}{m_a} \frac{W_a}{W_f} + \frac{\tilde{x}_w}{\tilde{x}_a}} \end{aligned}$$

Volumetric Efficiency: dynamic effects

Friction

- Component i pressure drop due to friction:

➤ V_i = Fluid velocity

➤ ξ_i = Loss coefficient

$$\Delta P_i = \xi_i \rho v_i^2$$

Scaling:

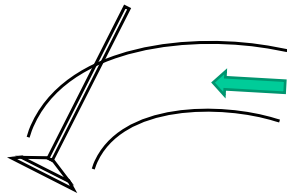
$$v_i \propto S_P \frac{A_P}{A_i}; \quad \xi_i \propto \frac{\ell}{D_i}$$

$$\Delta P_i \sim \rho S_P^2 \frac{1}{A_i^{2.5}} \text{ or } \propto \rho S_P^2 \frac{1}{D_i^5}$$

Volumetric Efficiency: dynamic effects cont.

Ram effect

- Due to fluid inertia
- Intake and exhaust flow both exhibit effect



S_p Mean piston speed
 ℓ Runner length
 L Stroke

$$\Delta P = \rho \int \frac{du}{dt} \cdot d\ell$$

$$\sim \rho \frac{S_p}{1} \left(\frac{A_p}{A_{intake}} \right) \ell$$

$$= \rho S_p^2 \left(\frac{A_p}{A_{intake}} \right) \frac{\ell}{L}$$

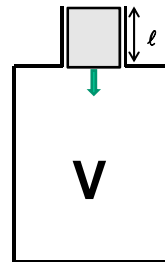
Volumetric Efficiency: dynamic effects cont.

Tuning

- Helmholtz frequency $N = \frac{a}{2\pi} \sqrt{\frac{A}{\ell V}}$

- a sound velocity
- ℓ runner length
- V volume

- Application:
 - V taken as $V/2$
 - Correction factor $k=2$

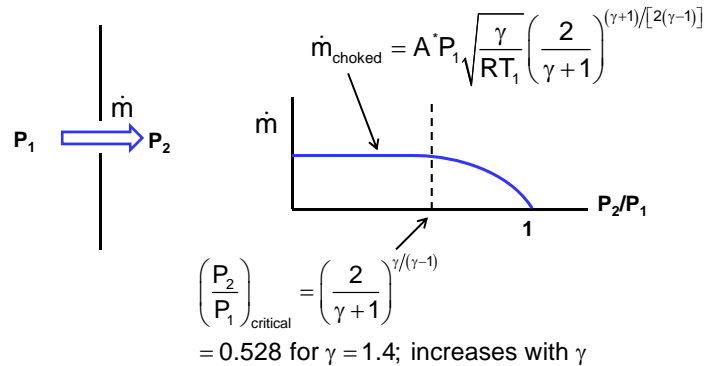


$$N = \frac{a}{2\pi} \sqrt{\frac{A}{\ell V} \frac{1}{K}}$$

Volumetric Efficiency: dynamic effects cont.

Choking effect

- Velocity becomes sonic at “throat”



Volumetric Efficiency: dynamic effects cont.

Overlap back flow

- Back flow of burned gas from exhaust/cylinder to intake port
- Increases residual gas fraction
- Prominent at low speed and load

Heat transfer

- Loss in η_v because intake charge is heated up by the hot walls
- Prominent at low speed because of longer time (overrides lower rate)

Volumetric efficiency: summary

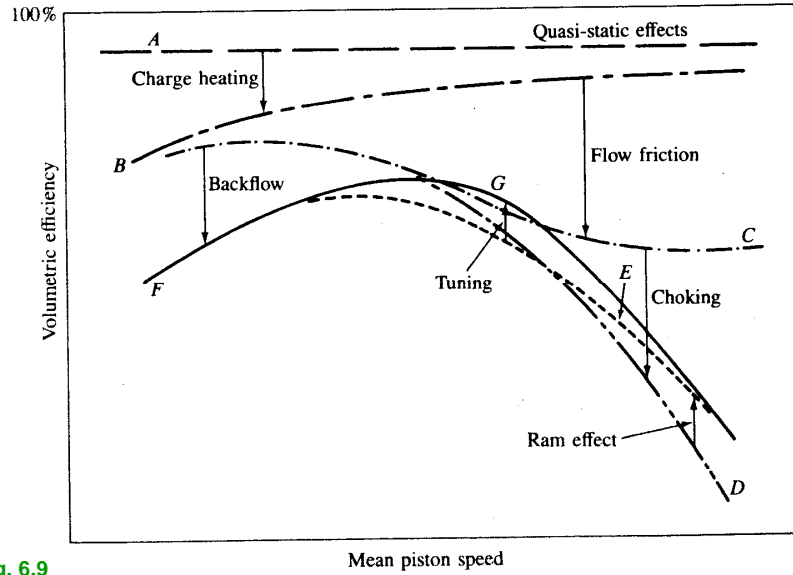


Fig. 6.9

Flow loss in gas exchange process

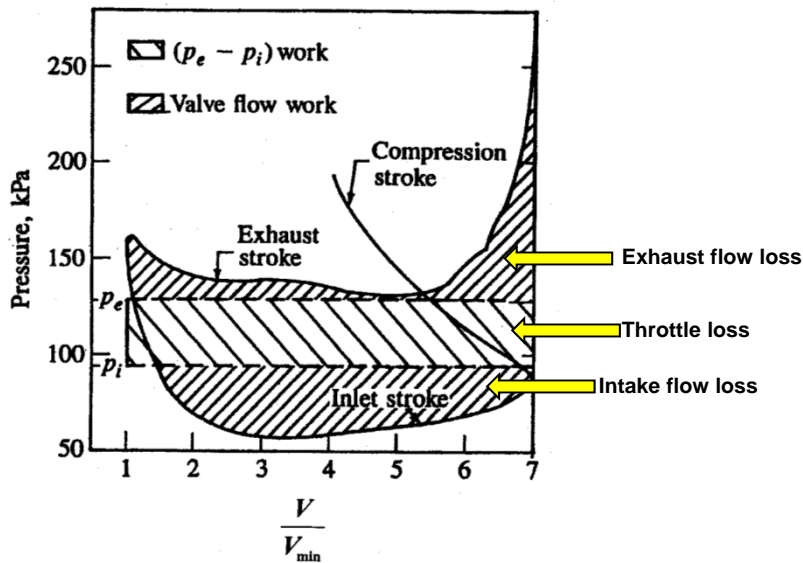


Fig. 13-15

2-Stroke engine gas exchange

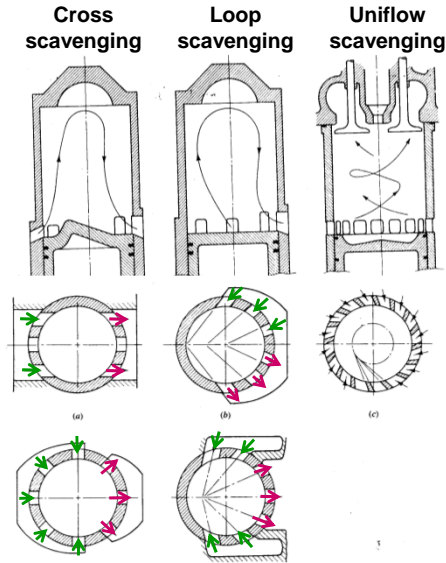
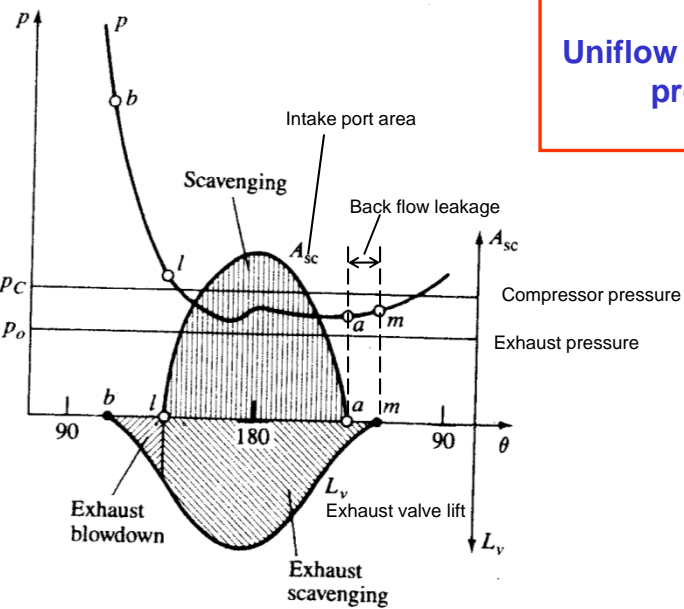


Fig. 6-23 & 24



2-Stroke engine gas exchange

Delivery ratio $\Lambda = \frac{\text{Air mass delivered per cycle}}{\rho_{a,0} V_D}$

Trapping efficiency $\eta_t = \frac{\text{Air mass retained}}{\text{Air mass delivered}}$

Air mass retained

$$m_a = \rho_{a,0} V_D \Lambda \eta_t$$

Scavenging ratio $\eta_{sc} = \frac{\text{Air mass retained}}{\text{Trapped charge mass}}$

$1 - \eta_{sc}$ is the fraction of previous cycle charge that remains

