MESIN KONVERSI ENERGI

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MOTOR BAKAR

MESIN!
ANUGERAH atau KUTUKAN?

Penemuan terbesar sejak roda?

- Membuat transportasi menjadi mudah!
- Membuat hidup jadi mudah!

ATAU MEMBUAT?

- Peningkatan polusi
- Peningkatan konsumsi bahan bakar fosil
- Meningkatnya kemacetan di jalan raya

KLASIFIKASI MESIN PEMBAKARAN DALAM

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KLASIFIKASI MESIN PEMBAKARAN DALAM

1. Aplikasi
2. Desain Mesin Dasar
3. Siklus Operasi
4. Siklus Kerja
5. Desain dan Lokasi Katup / Port
6. Bahan bakar
7. Persiapan Campuran
8. Pengapian
9. Stratifikasi Charge
10. Desain Ruang Pembakaran
11. Metode Pengendalian Beban
12. Pendinginan

KLASIFIKASI MESIN PEMBAKARAN DALAM

1. Applikasi

2. Otomotif : (i) Mobil
(ii) Truk/Bus
(iii) Kendaraan di luar Jalan raya
2. Locomotive
3. Pesawat ringan
4. Marine: (i) Outboard
(ii) Di dalam pesawat
(iii) Kapal
5. Pembangkit Listrik: (i) Portable (Domestik)
(ii) Tetap (Daya Puncak)
6. Pertanian: (i) Traktor
(ii) Perangkat pompa
7. Pemindahan Tanah: (i) Pembuang
(ii) Tippers
(iii) Peralatan Pertambangan
8. Penggunaan di Rumah:(i) Mesin Pemotong Rumput
(ii) Blower salju
(iii) Peralatan
9. Lainnya

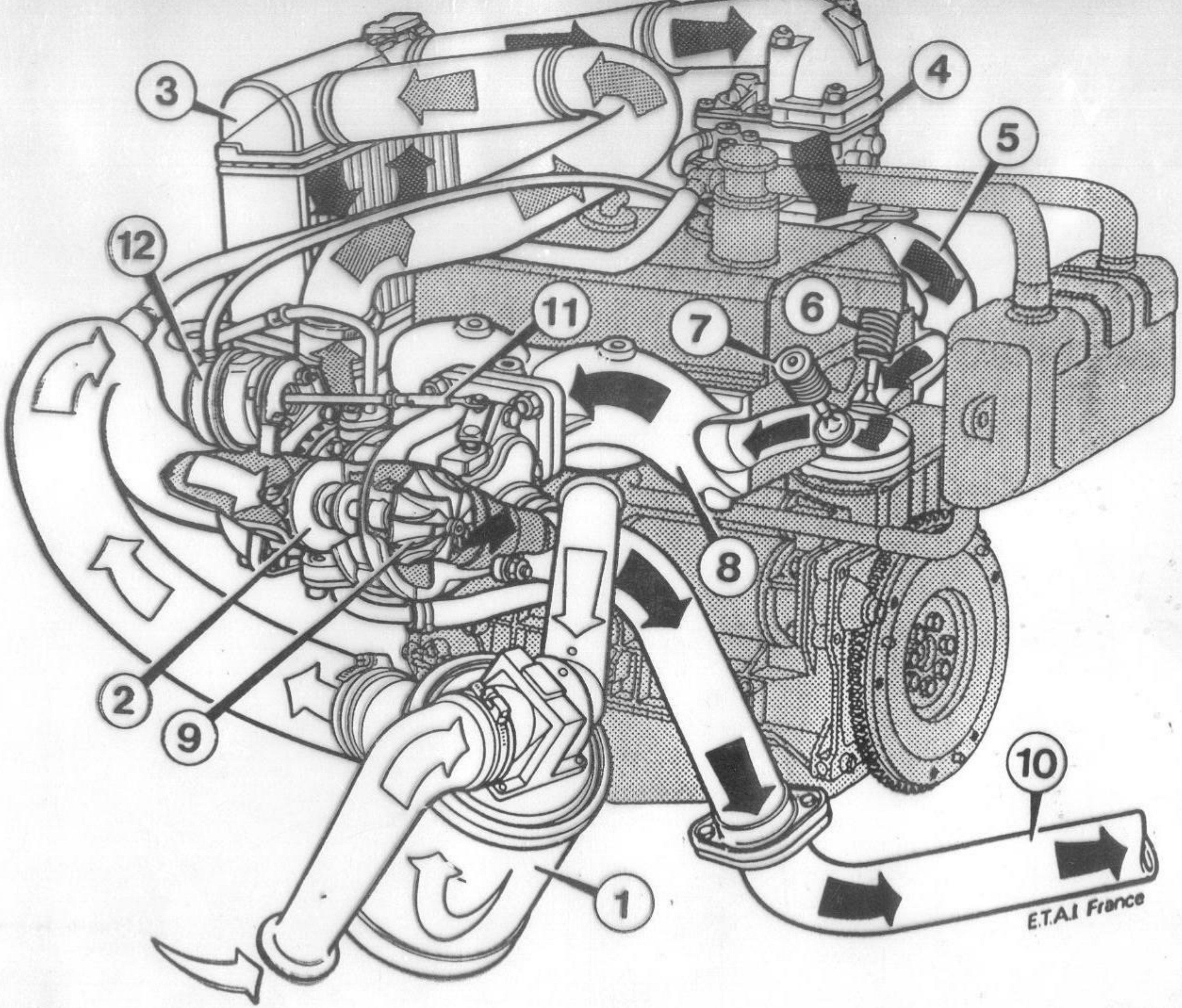


FIGURE 1-10
Turbocharged four-cylinder automotive spark-ignition engine. (*Courtesy Regie Nationale des Usines.*)

Mesin Diesel Otomotif

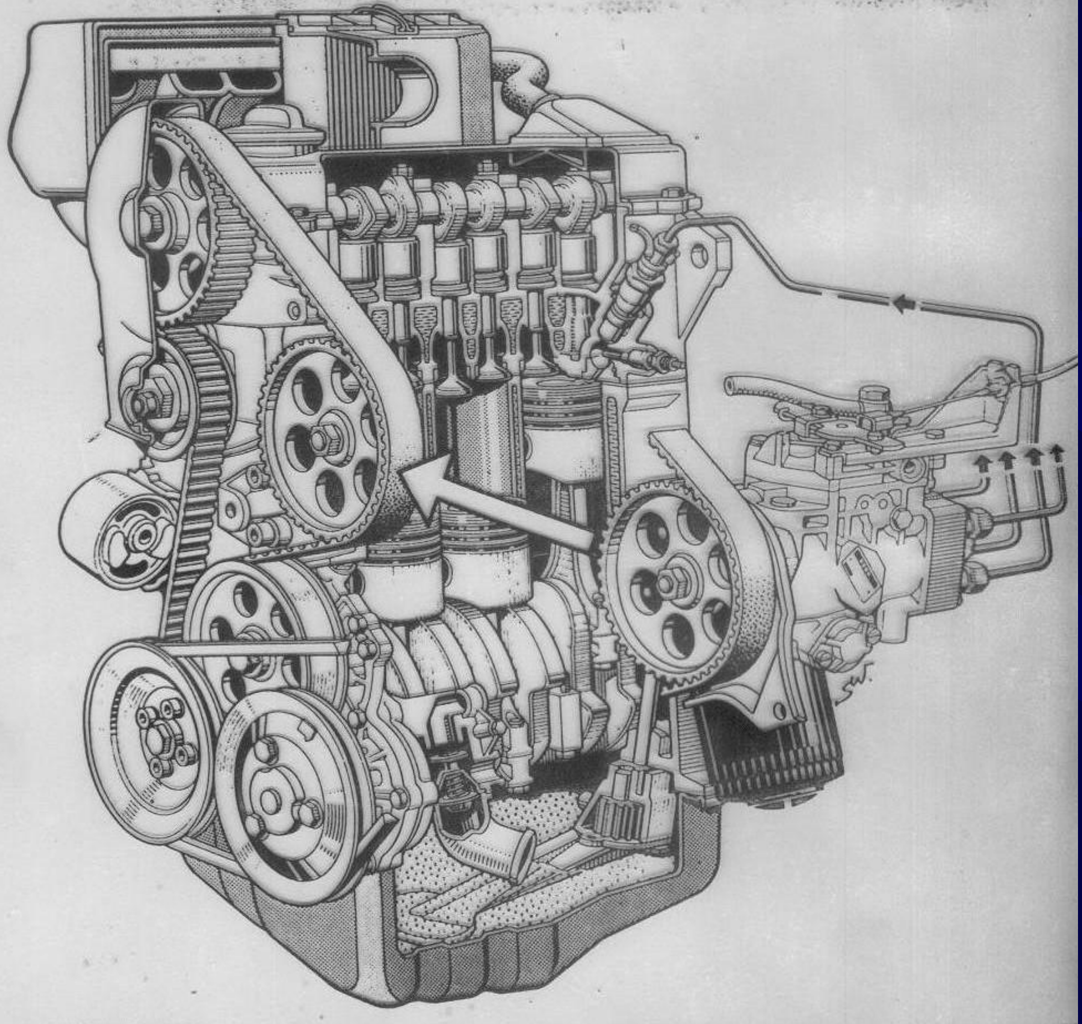


FIGURE 1-21
Four-cylinder naturally aspirated indirect-injection automobile Volkswagen diesel engine.[14]
placed volume 1.47 liters, bore 76.5 mm, stroke 80 mm, maximum power 37 kW at 5000 rev/min

Mesin Kapal Dengan Siklus 2 Langkah

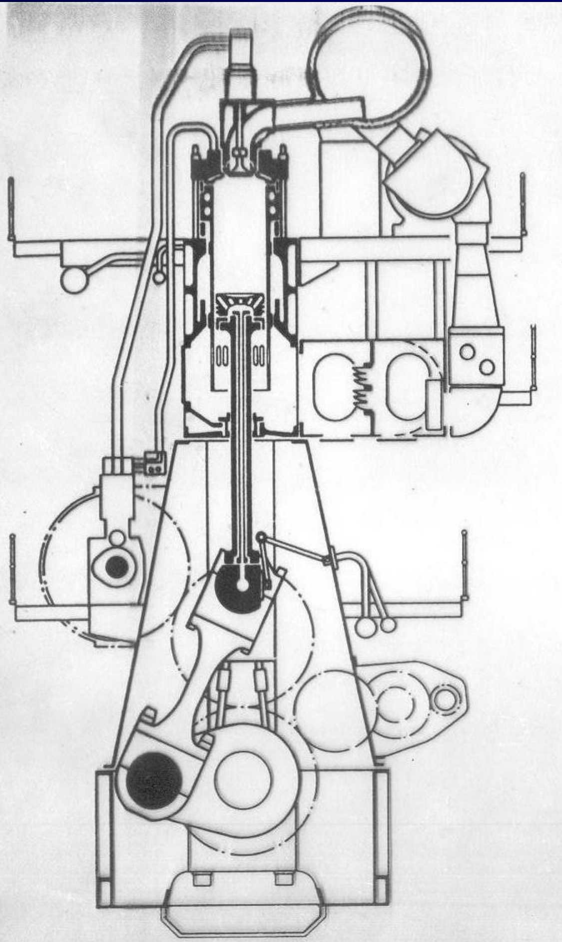


FIGURE 1-24
Large Sulzer two-stroke turbocharged marine diesel engine. Bore 840 mm, stroke 2900 mm, rated power 1.9 MW per cylinder at 78 rev/min, 4 to 12 cylinders. (*Courtesy Sulzer Brothers Ltd.*)

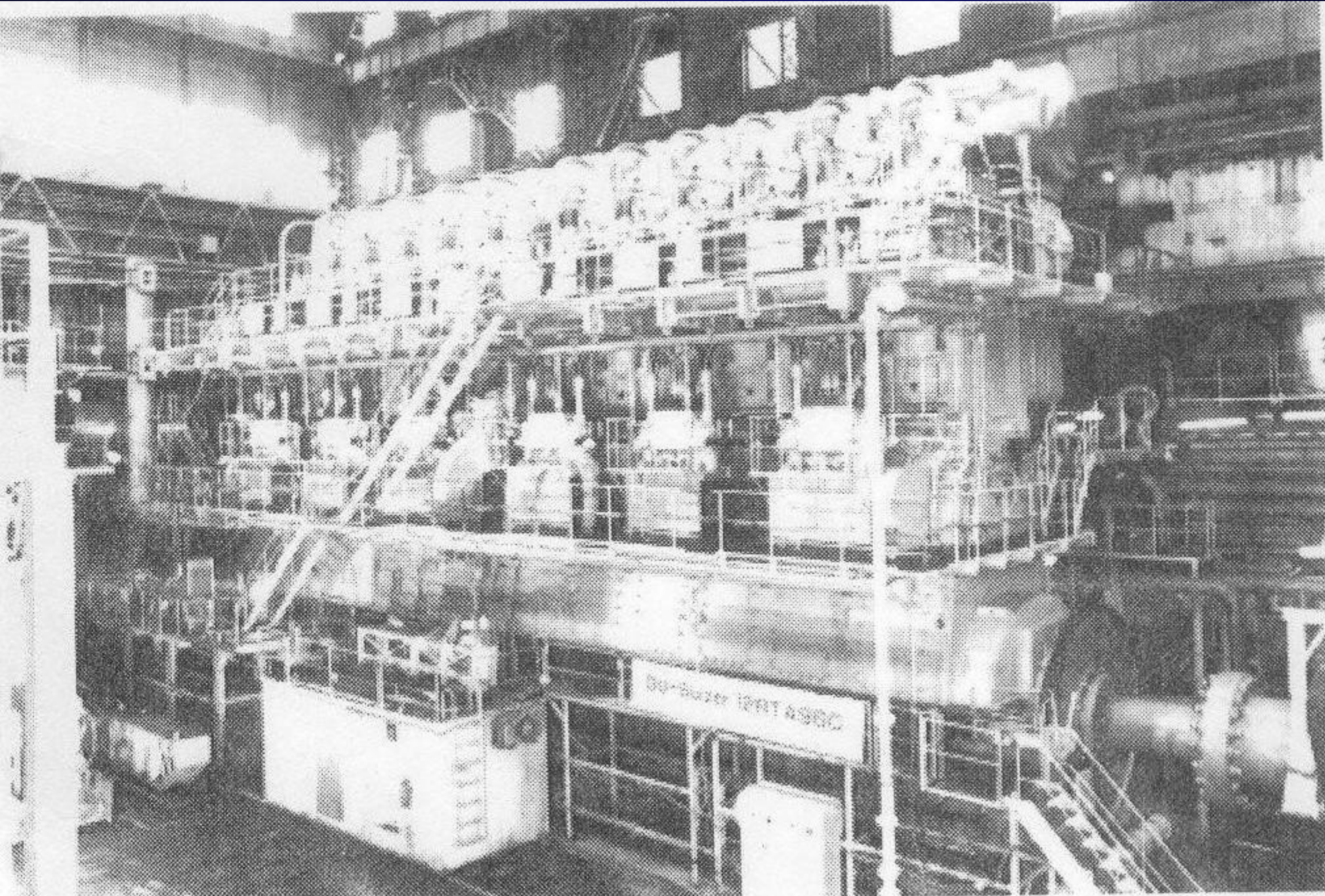


Figure 1.8 The world's most powerful diesel engine was tested by Diesel United in Japan in 1997. The 12-cylinder Sulzer RTA96C, destined for a containership, developed 65 880 kW at 100 rev/min

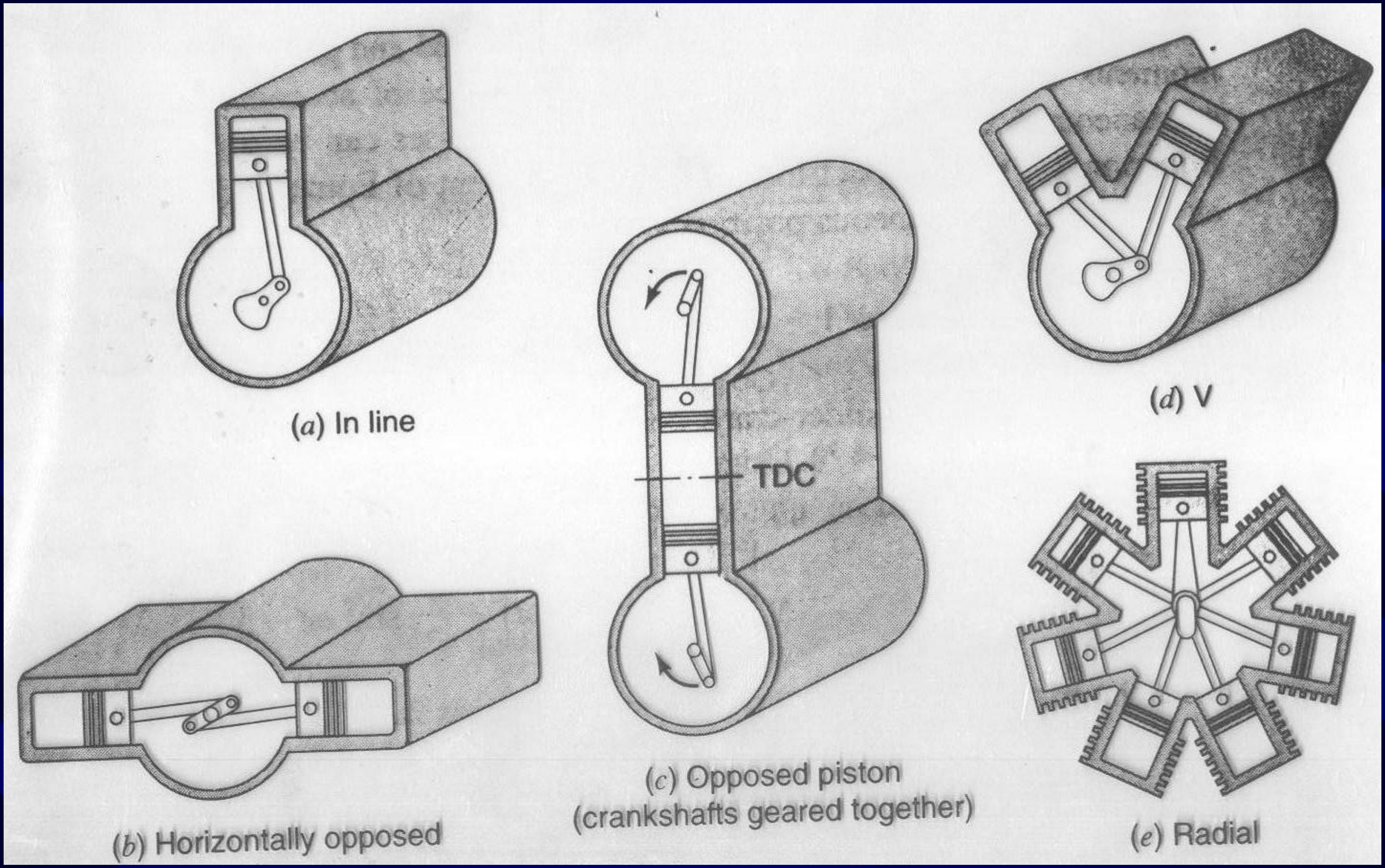
KLASIFIKASI MESIN PEMBAKARAN DALAM

2. Desain Mesin Dasar

1. Bolak-balik (a) Silinder tunggal
   (b) Multi Silinder (I) In-line
   (ii) V
   (iii) Radial
   (iv) Silinder berlawanan
   (v) Piston berlawanan

2. Rotary (a) Single Rotor
   (b) Multi-rotor

Tipe Mesin Gerak Bolak-balik



V Engine

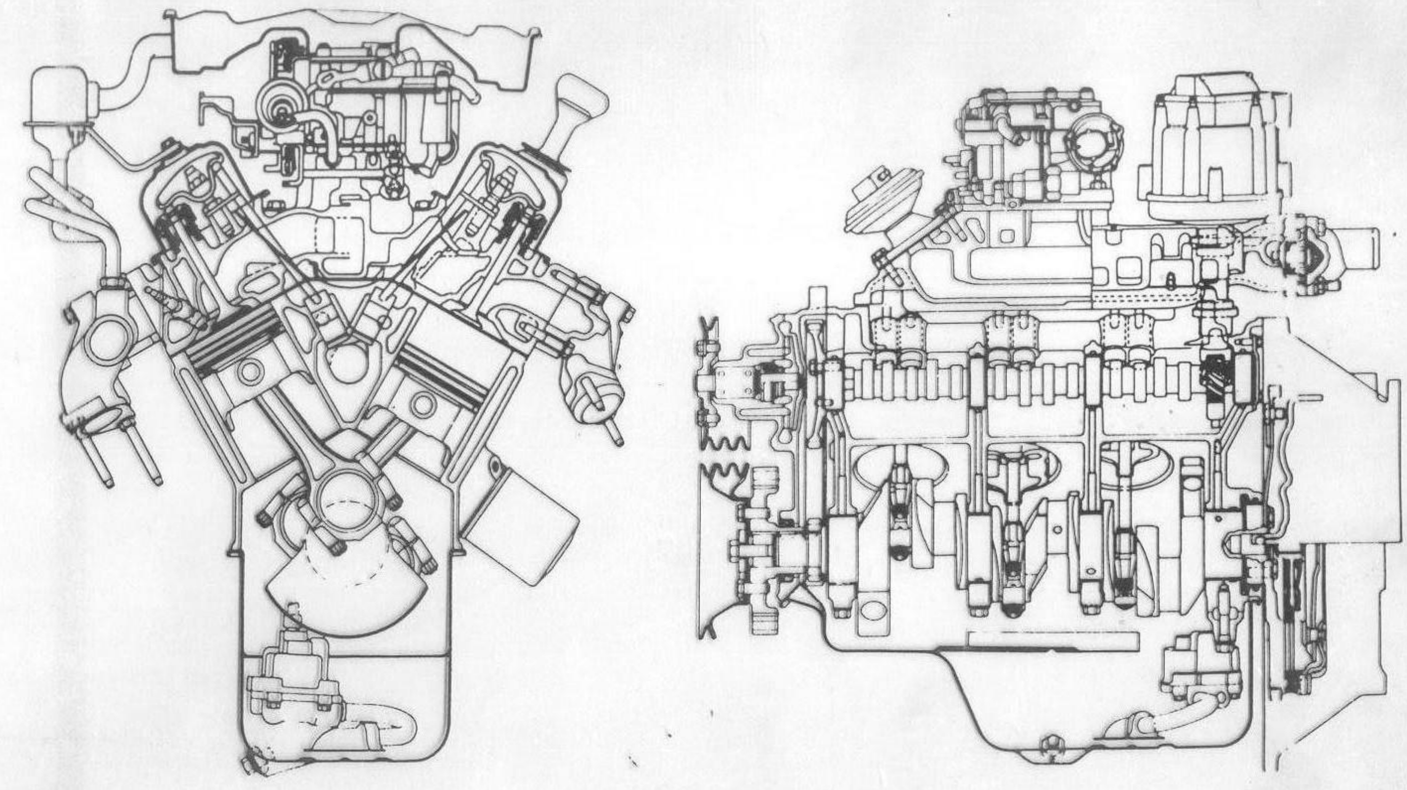
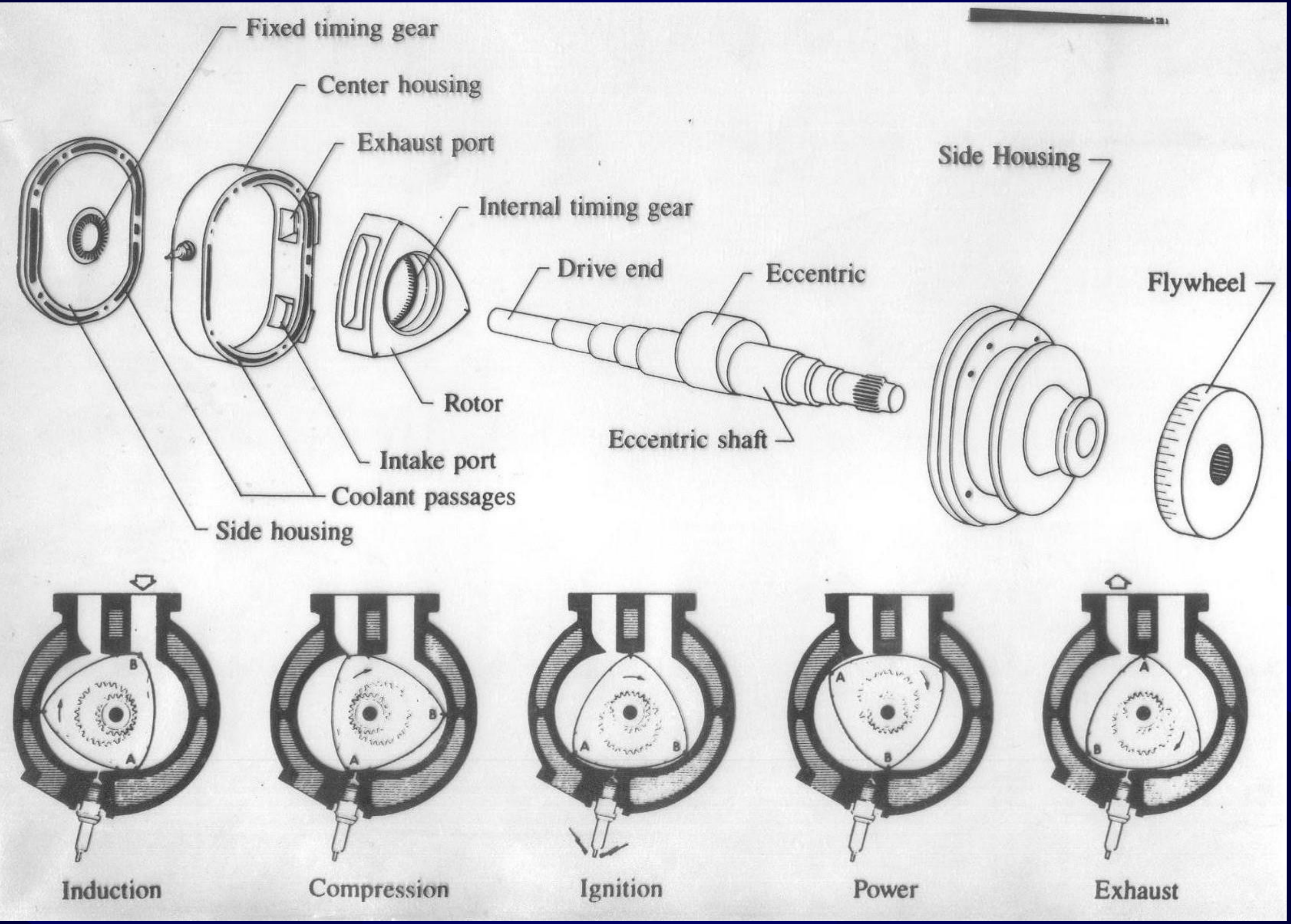


FIGURE 1-9
Cross-section drawings of General Motors 60 degree V-6 spark-ignition engine.[13] Displacement 2.8 liter, bore 89 mm, stroke 76 mm, compression ratio 8.5, maximum power 86 kW at 4800 rev/min

Mesin Wankel Rotary



Tipe-tipe Mesin Rotary

FIGURE 7.1a A turbocharged RX-7 rotary engine. (Photo courtesy of Mazda Motors of America.)

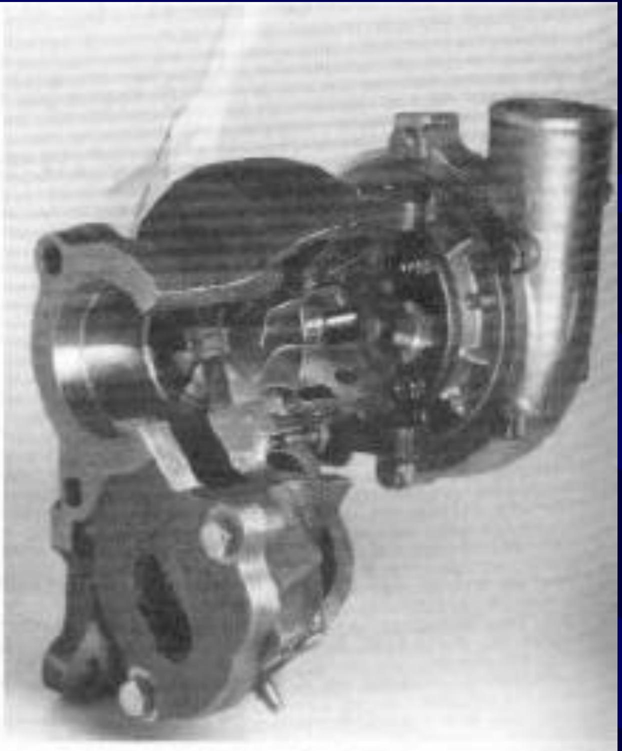
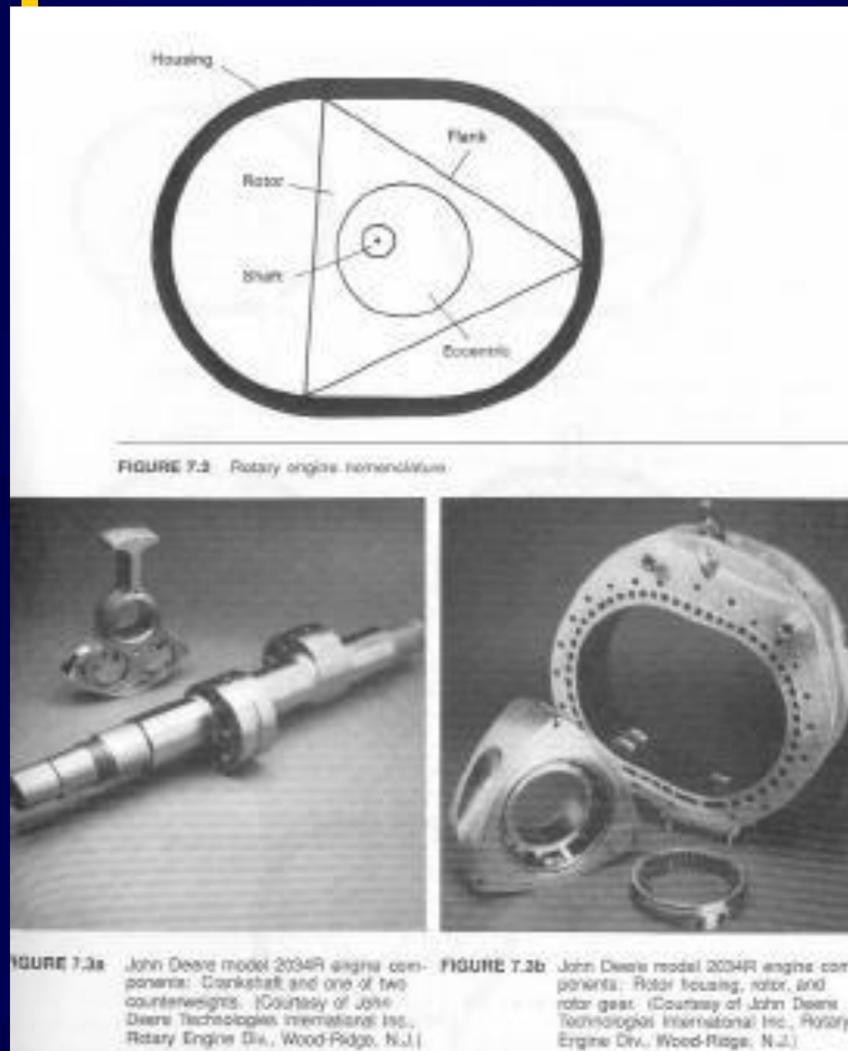


FIGURE 7.1b An RX-7 rotary engine turbocharger. (Photo courtesy of Mazda Motors of America.)

Komponen Mesin Wankel



Twin-rotor Wankel

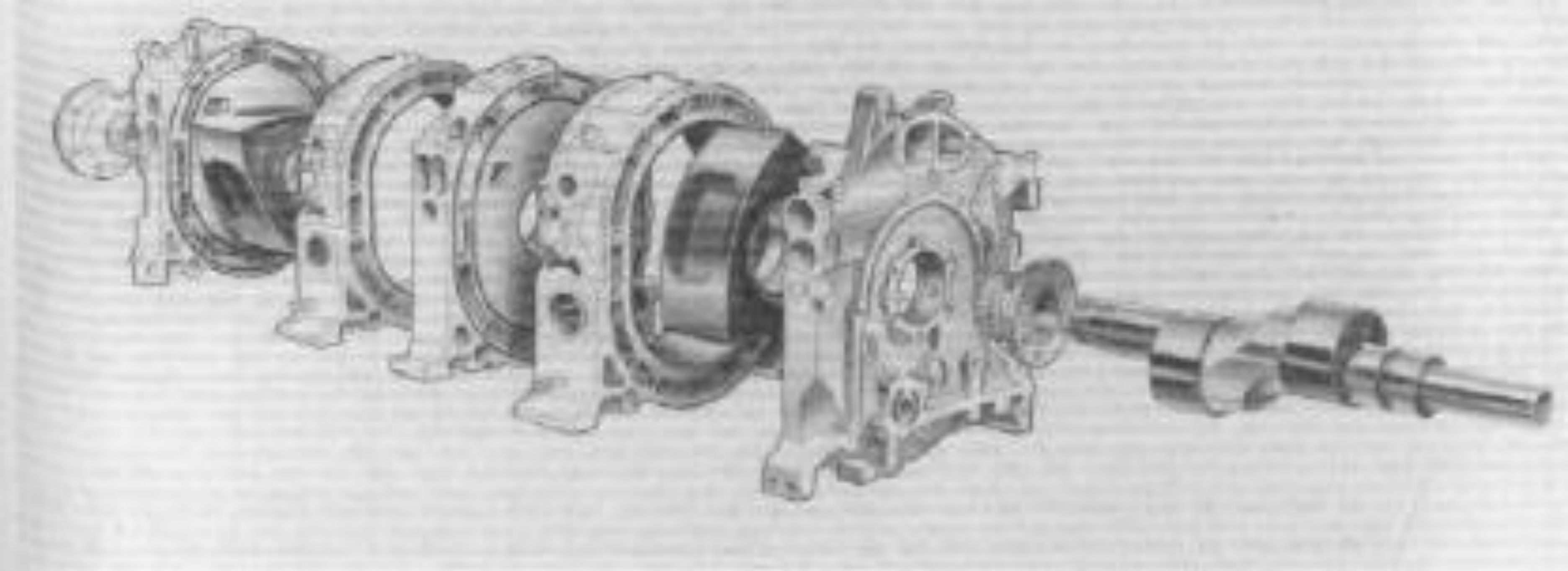


FIGURE 7.9 Exploded view of a twin-rotor rotary engine. (Courtesy of Mazda Motors of America.)

Apex Seals

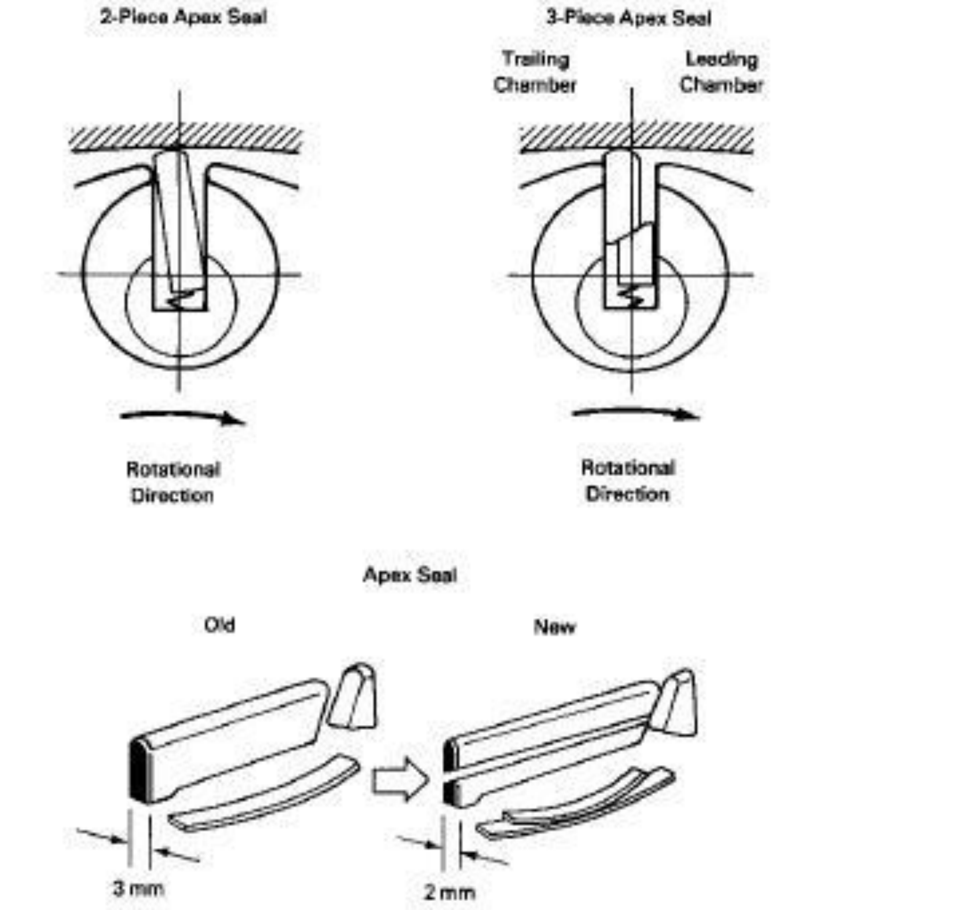


FIGURE 7.11 Design improvements in the apex seals of the Mazda RX-7 rotary engine. (Reprinted with permission. ©1987, Society of Automotive Engineers, Inc.) (See ref. 6.)

KLASIFIKASI MESIN PEMBAKARAN DALAM

3. Siklus Operasi

- Otto (Untuk SI Engine konvensional)
- Atkinson (Untuk Mesin SI Ekspansi Komplet)
- Miller (Untuk Mesin SI penutupan katup masuk awal atau lambat)
- Diesel (Untuk Mesin Diesel Ideal)
- Dual (Untuk Mesin Diesel Aktual)

TIPIKAL UKURAN DAN DAYA MESIN DIESEL

TABLE 12.2
Typical size and output of diesel engines

Bore (mm)	45	80	127	280	400	840
Stroke (mm)	37	80	120	300	460	2900
Displacement (liter/cylinder)	0.06	0.402	1.77	18.5	57.82	1607
Number of cylinders	1	4L*	8V†	6–9L	6–9L	4–12L
Output/cylinder(kW)	0.7	10	40	325	550	3380
Rated speed (rpm)	3600	4800	2100	1000	514–520	55–76
BMEP (atm)	4	7.5	13	22	22.2	16.6

*L designates in-line cylinder arrangement.

†Designates V-shaped cylinder arrangement.

EFISIENSI TERMAL TERBAIK UNTUK BERBAGAI TIPE POWER PLANT

TABLE 12.1
Best thermal efficiency estimates for various power plants

Power plant type	Efficiency (%)
Spark-ignited, port-injected, stoichiometric	31.5
Direct-injected, spark-ignited, stoichiometric	33
Direct-injected, spark-ignited, lean, early injection	34.5
Indirect-injected diesel	35.5
Direct-injected, spark-ignited, lean, late injection	38
Gas turbine	38
High-speed, direct-injected diesel	43
Heavy-duty, direct-injected diesel (HDDI)	46
Fuel cell	52
Turbocompounded, HDDI diesel	54

PERBANDINGAN TIGA MESIN PEMBAKARAN DALAM

Table 1-1 Comparison of Three Internal Combustion Engines

Characteristics	Model Airplane	Automotive	Marine
Bore (m)	0.0126	0.089	0.737
Stroke (m)	0.0131	0.080	1.016
Displacement per cylinder (m^3)	1.6×10^{-6}	4.98×10^{-3}	0.433
Power per cylinder (kW)	0.1	16.8	529
Engine speed (rpm)	11,400	2500	160
Mass per cylinder (kg)	0.12	34.3	3.56×10^4
Mean piston speed (m/s)	5.0	6.6	5.6
Bmep (bar)	3.2	8.0	4.5
Power/Volume (kW/m^3)	6.3×10^4	3.4×10^4	1.2×10^3
Mass/Volume (kg/m^3)	7.5×10^{-2}	8.2×10^{-2}	6.9×10^{-2}
Power/Mass (kW/kg)	8.4×10^5	4.1×10^5	1.7×10^4

KLASIFIKASI MESIN PEMBAKARAN DALAM

4. Siklus Kerja (Langkah)

1. Siklus 4 Langkah : (a) Natural aspirasi
   (b) Supercharger/Turbocharger
2. Siklus 2 Langkah : (a) Crankcase Scavenged
   (b) Uniflow Scavenged
   (i) Katup Inlet/Lubang buang
   (ii) Lubang Inlet/Katup buang
   (iii) Katup Inlet dan Katup buang
   Mungkin Natural aspirasi dg Turbocharger

Mesin SI 2 Langkah dan 4 langkah

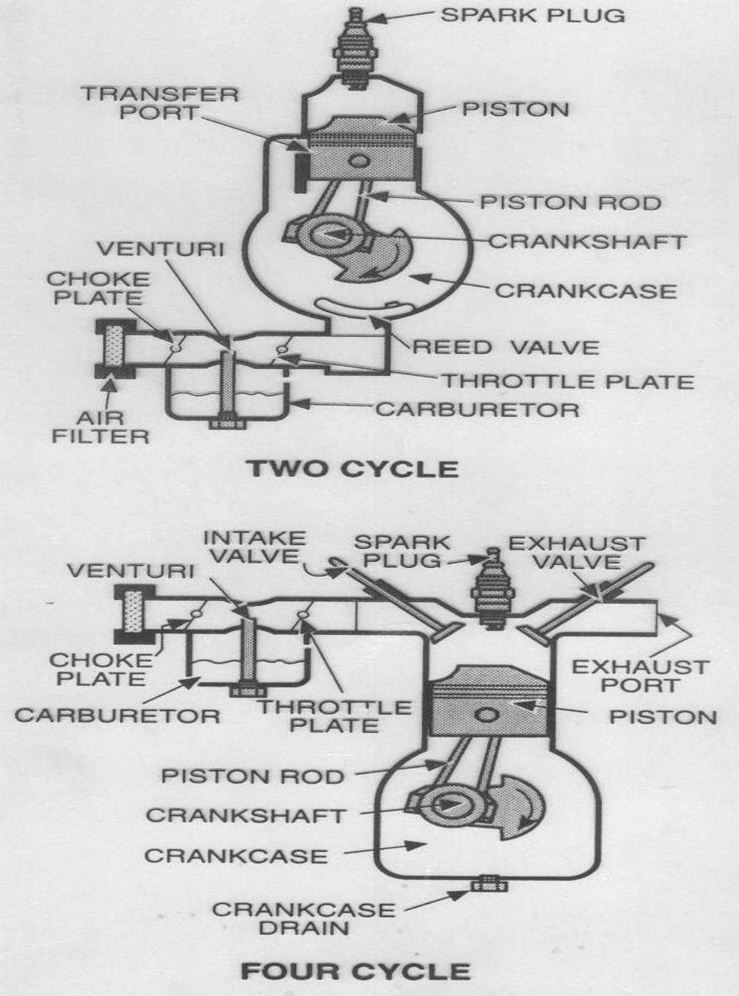


Figure 10.6 Charge preparation and the carbureted SI engine.

Mesin Diesel 2 Langkah dan 4 Langkah

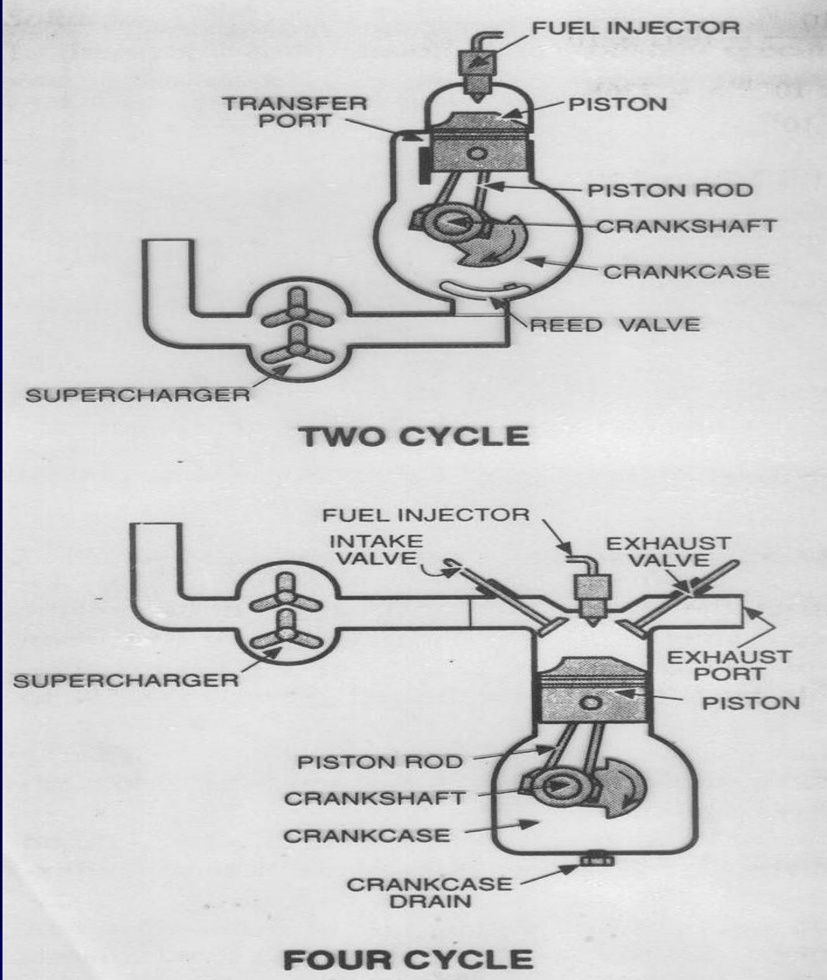
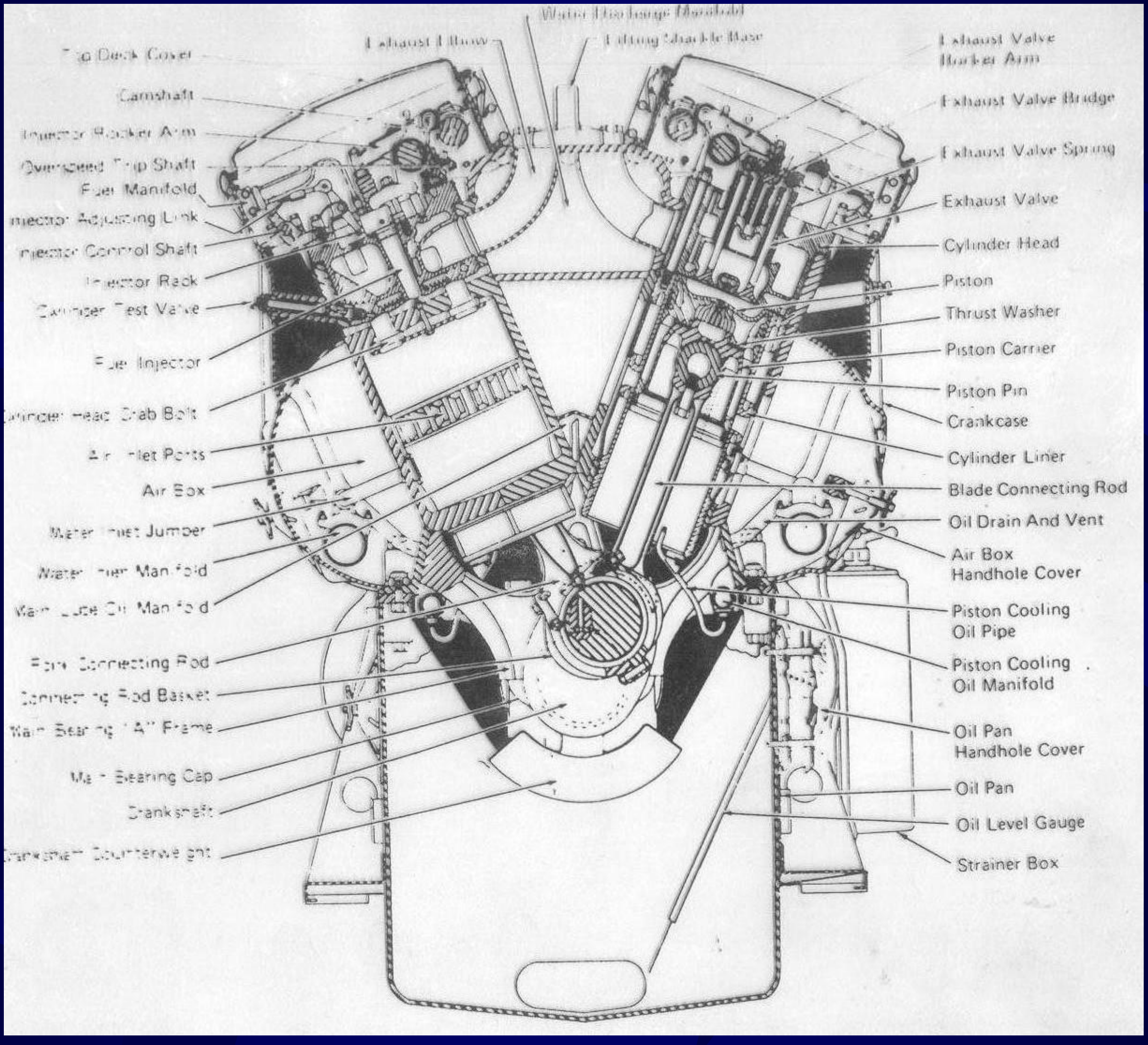


Figure 11.4 Charge preparation and the compression CI engine.

Mesin 2 Langkah



Tipe Supercharger

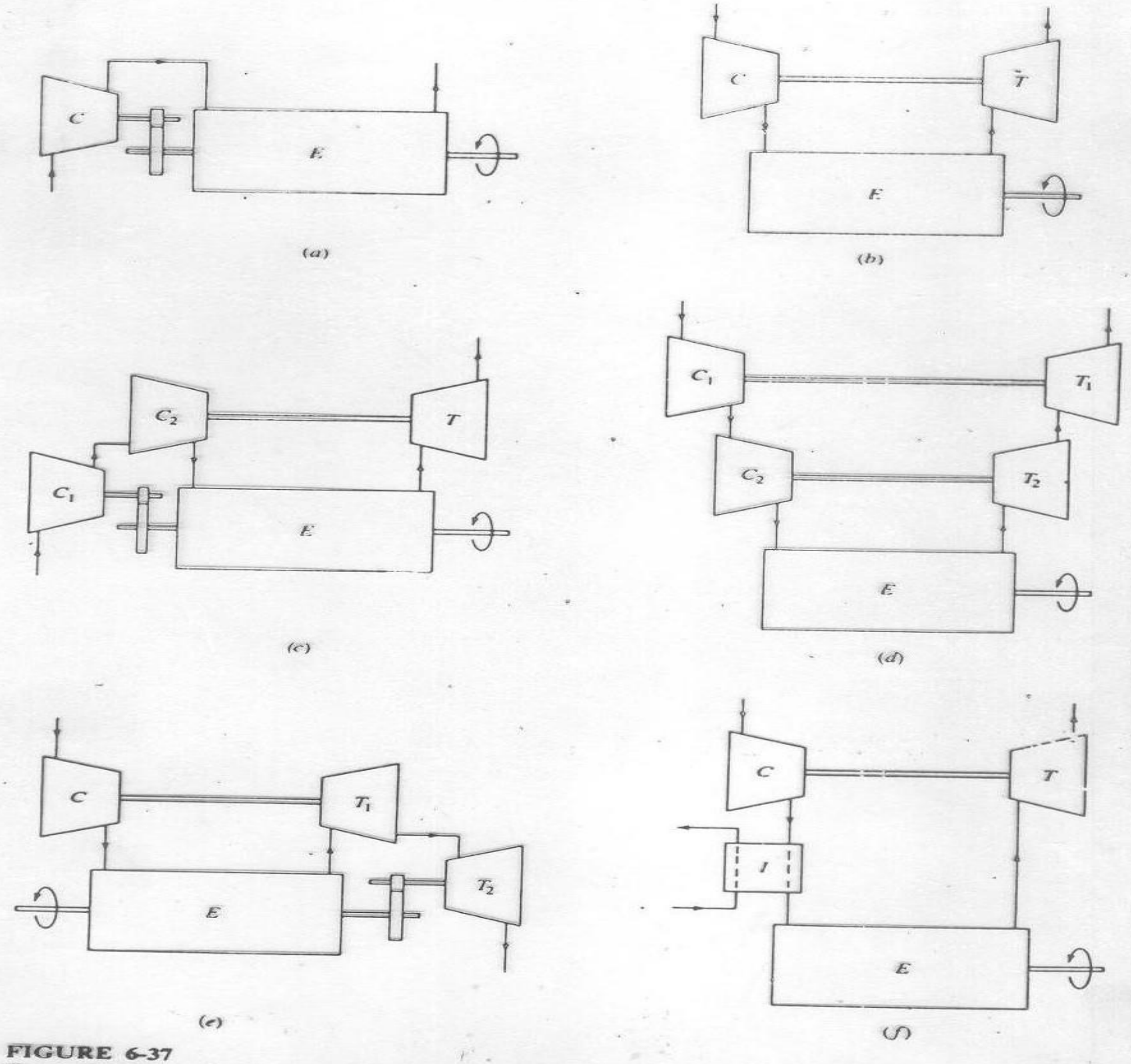


FIGURE 6-37
Supercharging and turbocharging configurations: (*a*) mechanical supercharging; (*b*) turbocharging; (*c*) engine-driven compressor and turbocharger; (*d*) two-stage turbocharging; (*e*) turbocharging with tı bocompounding; (*f*) turbocharger with intercooler. *C* Compressor, *E* Engine, *I* Inter-cooler, *T* Turbine.

KLASIFIKASI MESIN PEMBAKARAN DALAM

5. (a) Desain Katup/lubang

1. Poppet Valve
2. Rotary Valve
3. Reed Valve
4. Piston Controlled Porting

5. (b) Lokasi Katup

1. T-head
2. L-head
3. F-head
4. I-head: (i) Over head Valve (OHV)
   (ii) Over head Cam (OHC)

Poppet Valve

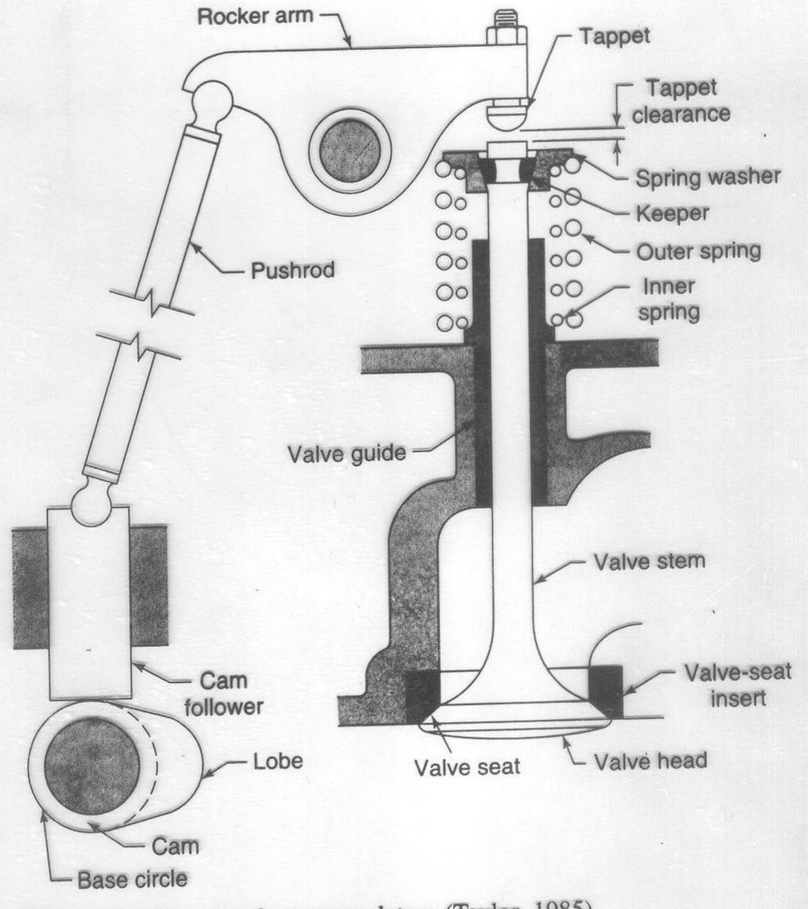
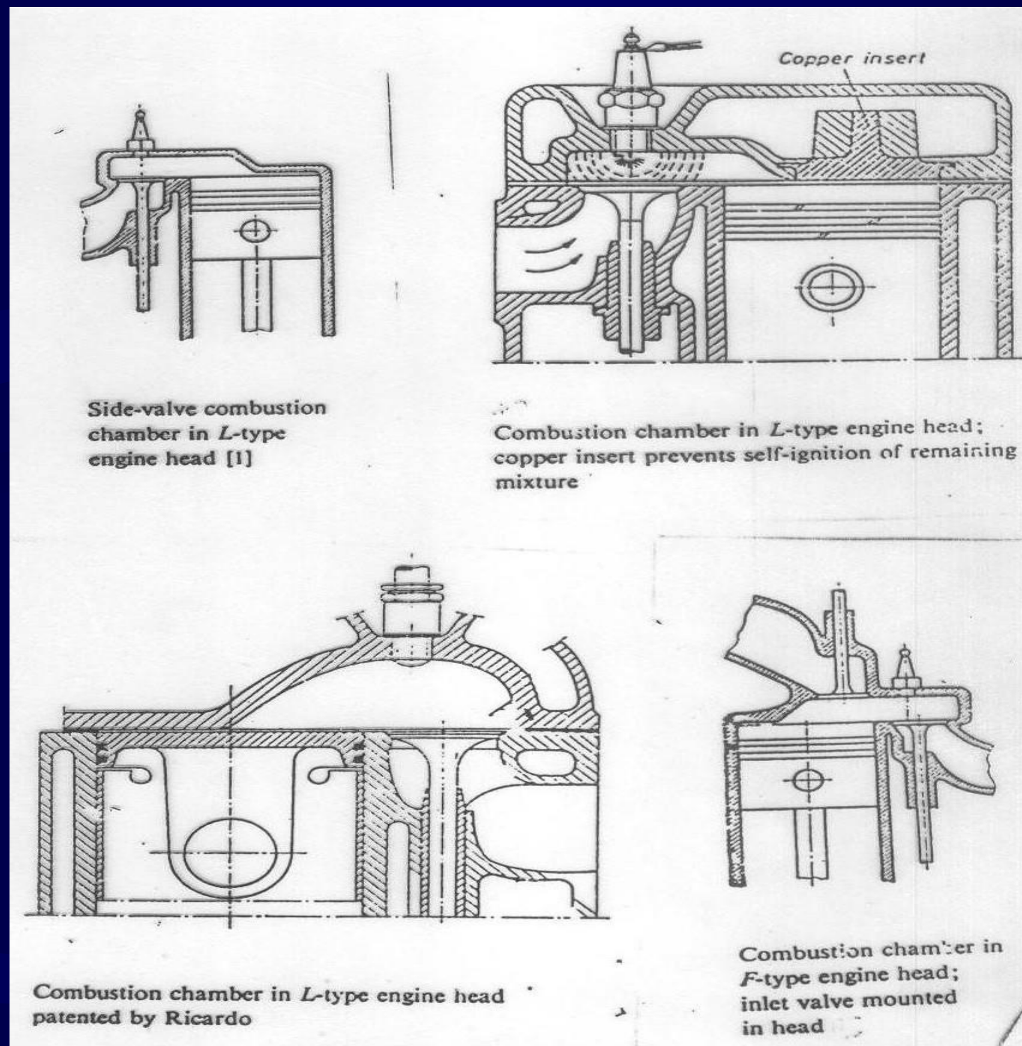


Figure 1-12 Poppet-valve nomenclature (Taylor, 1985).

Lokasi Katup



Side-valve combustion chamber in *L*-type engine head [1]

Combustion chamber in *L*-type engine head; copper insert prevents self-ignition of remaining mixture

Combustion chamber in *L*-type engine head patented by Ricardo

Combustion chamber in *F*-type engine head; inlet valve mounted in head

Profil Waktu Katup

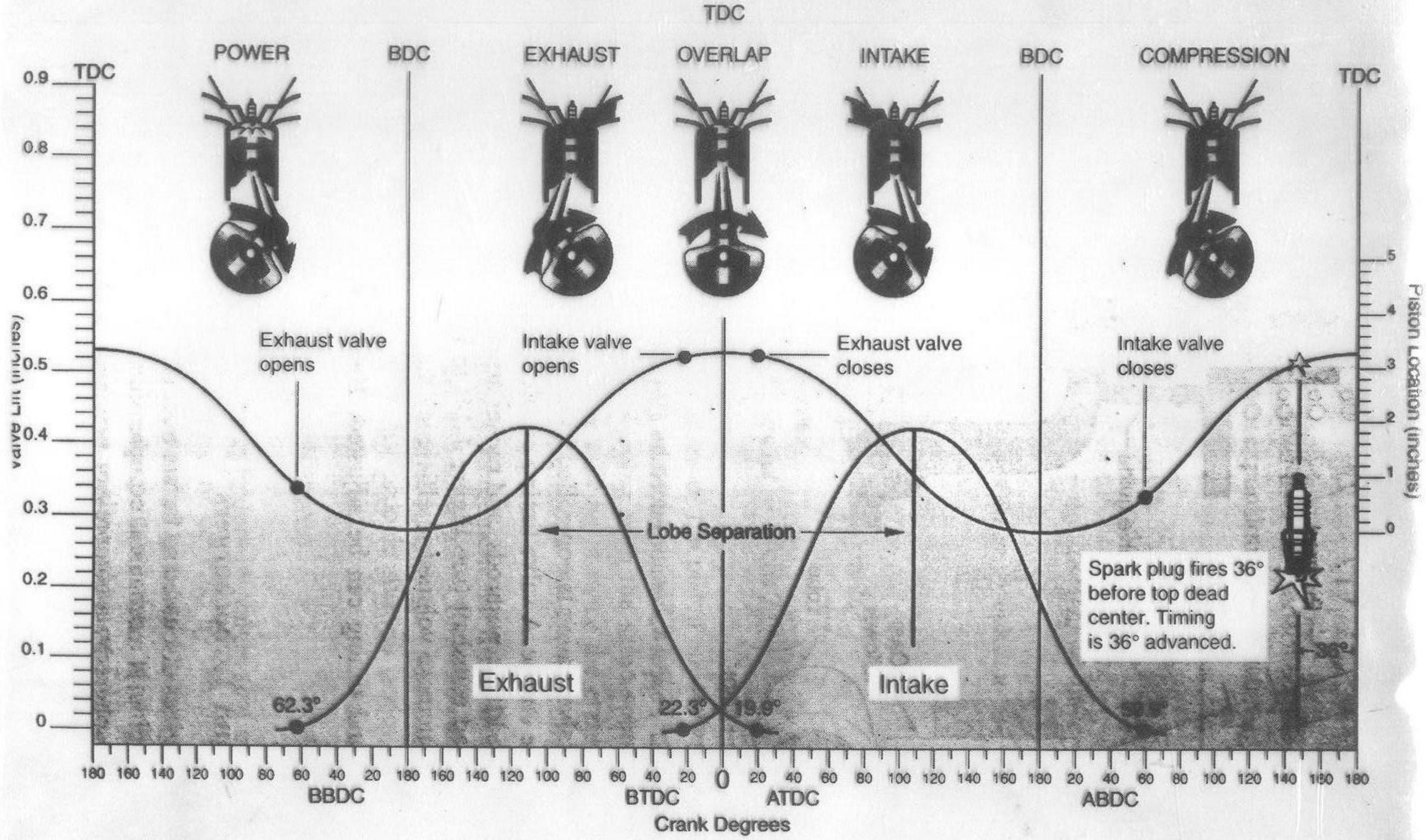


Figure 1-13 Valve timing profile. (Courtesy of Competition Cams, Inc.)

KLASIFIKASI MESIN PEMBAKARAN DALAM

6. Bahan bakar

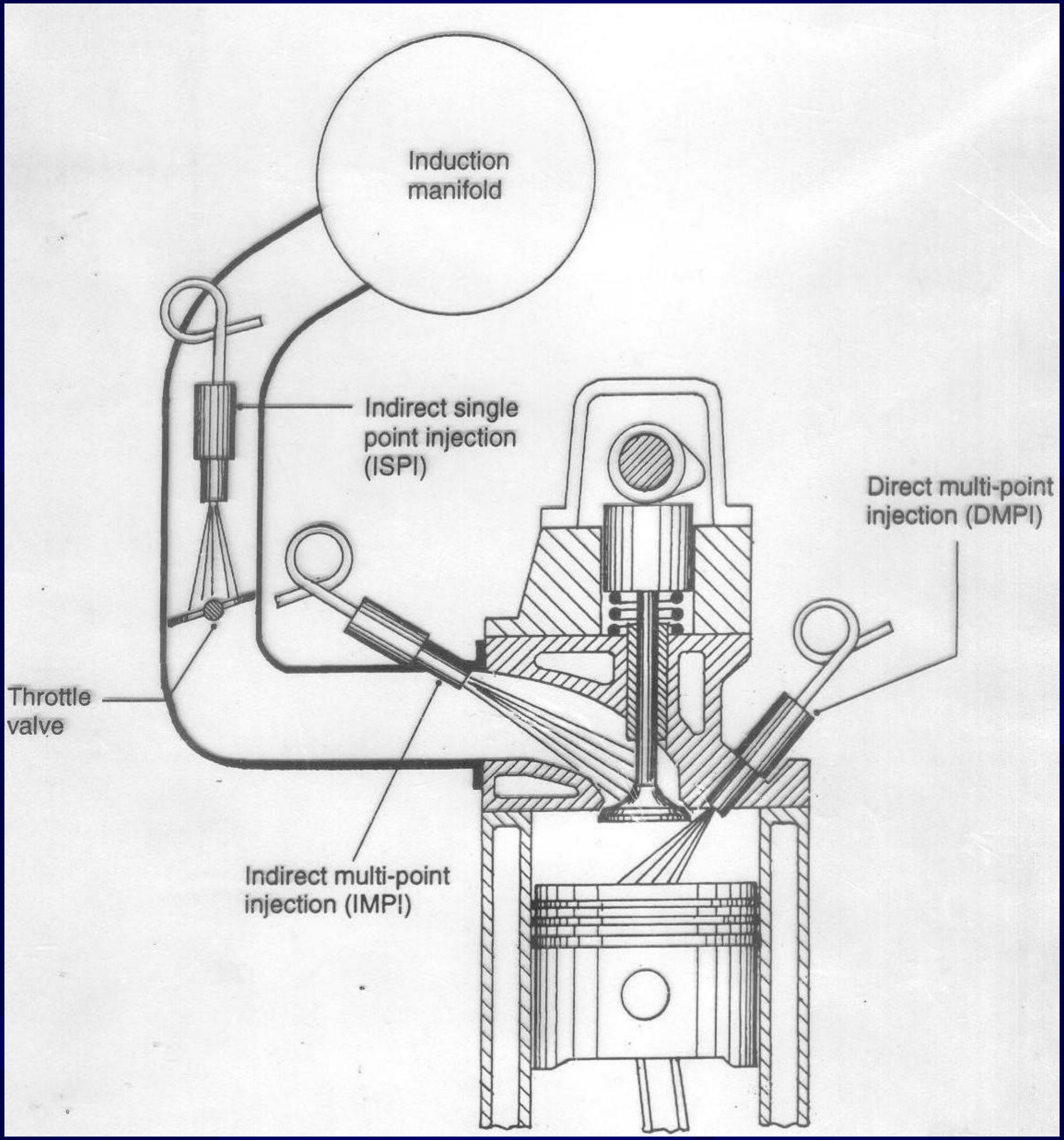
1. Konvensional:
   - (a) Turunan minyak mentah
     - (i) Petrol/bensin
     - (ii) Diesel
   - (b) Sumber lain :
     - (i) Batu bara
     - (ii) Kayu (termasuk bio-mass)
     - (iii) Pasir Tar
     - (iv) Serpihan
2. Alternatif:
   - (a) Berasal dari minyak bumi
     - (i) CNG
     - (ii) LPG
   - (b) Berasal dari Bio-mass
     - (i) Alkohol (methyl dan ethyl)
     - (ii) Minyak tumbuhan
     - (iii) Produser gas dan biogas
     - (iv) Hydrogen
3. Blending
4. Bahan bakar ganda

KLASIFIKASI MESIN PEMBAKARAN DALAM

7. Persiapan campuran

1. Karburetor
2. Fuel Injection
   - (i) Diesel
   - (ii) Gasoline
     - (a) Manifold
     - (b) Port
     - (c) Cylinder

Gasoline Fuel Injection



KLASIFIKASI MESIN PEMBAKARAN DALAM

8. Penyalaan

1. Spark Ignition/ dg percikan pada busi
   - (a) Konventional
     - (i) Battery
     - (ii) Magnet
   - (b) Metode lain
2. Compression Ignition/ dg tekanan

KLASIFIKASI MESIN PEMBAKARAN DALAM

9. Charge Stratifikasi

1. Secara homogen (Juga Pre-mixed charge)
2. Stratified Charge (i) Dg Karburetor

   (ii) Dg Injeksi bahan bakar

Charge Stratification

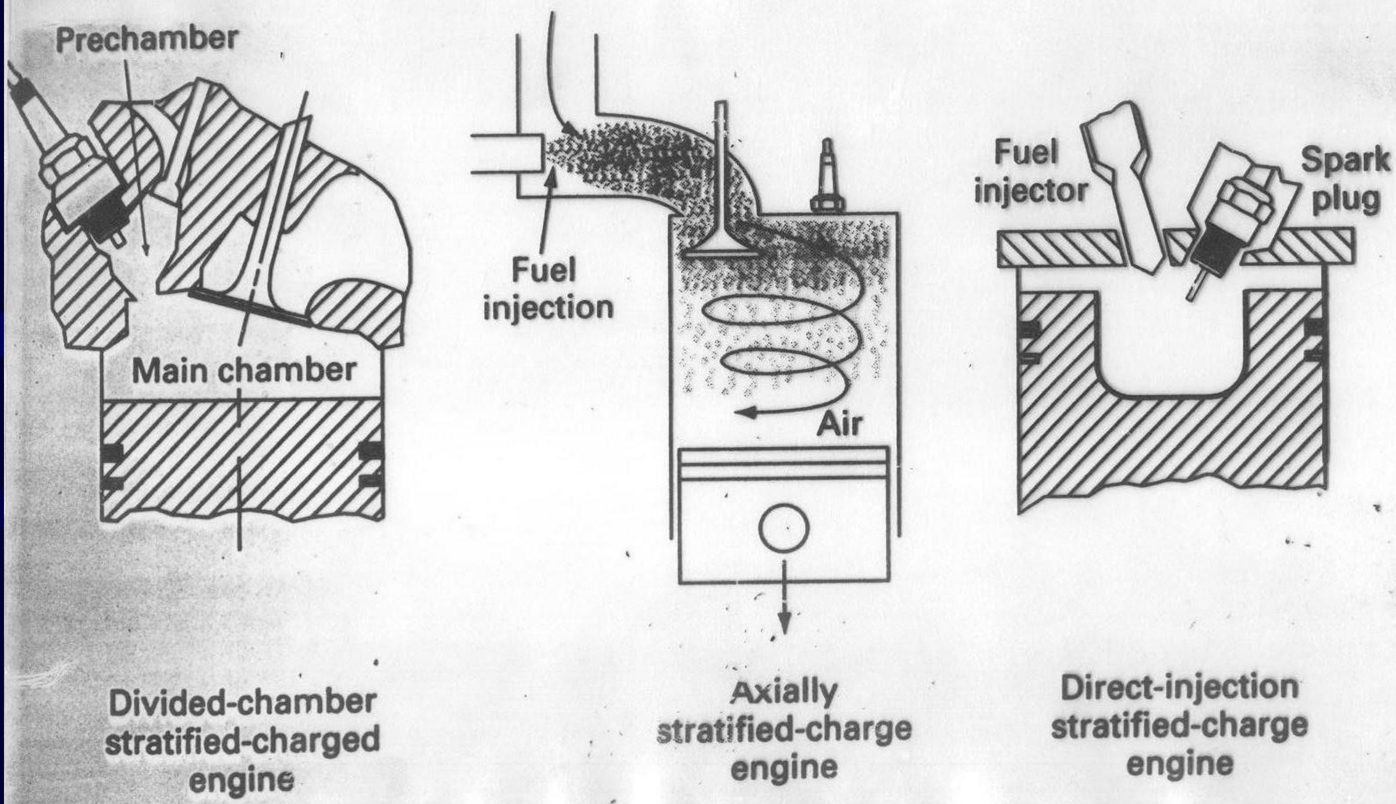


FIGURE 7.20
Types of spark-ignited-stratified charge engines [Amann, by courtesy of General Motors Corp.]

KLASIFIKASI MESIN PEMBAKARAN DALAM

10. Desain Ruang Bakar

1. Ruang bakar terbuka : (i) Tipe Disc
   (ii) Wedge
   (iii) Hemispherical
   (iv) Bowl-in-piston
   (v) Desain yg lain
2. Ruang bakar terpisah: (Utk CI) (i) Swirl chamber
   (ii) Pre-chamber
   (Utk SI) (i) CVCC (compound vortex controlled combustion)
   (ii) Desain yg lain

Desain Ruang Bakar

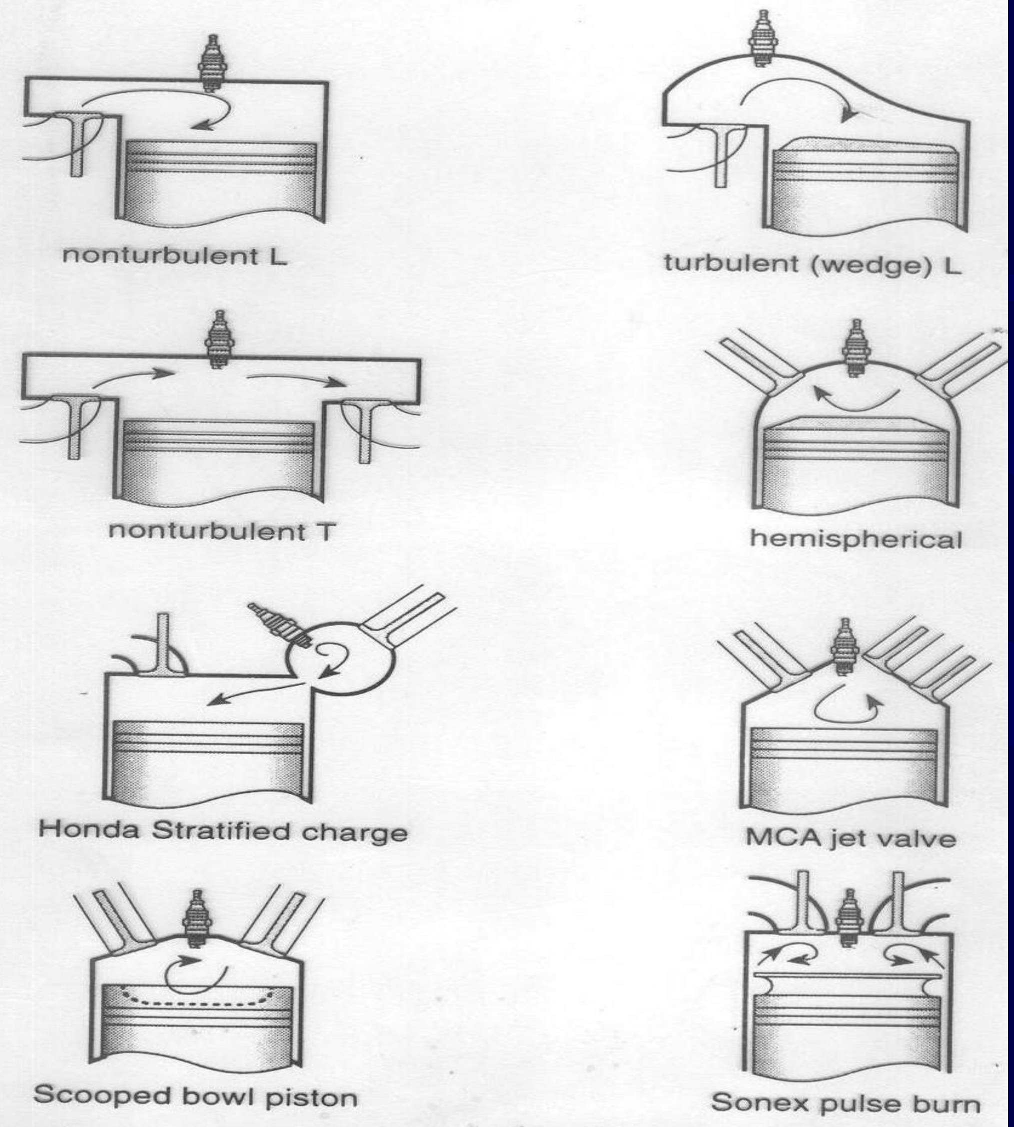


Figure 10.11 Various SI combustion chamber designs.

Desain Ruang Bakar

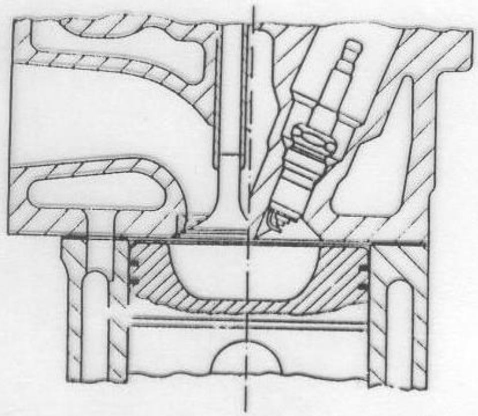


Fig. 14- Combustion space of the AVL HCLB-engine

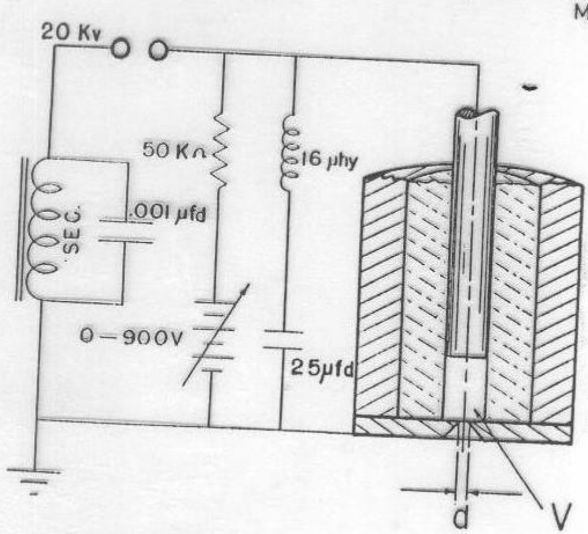


Fig. 16- Schematic of a plasma jet igniter, d≃ 1 mm, V ≃ 10 mm³

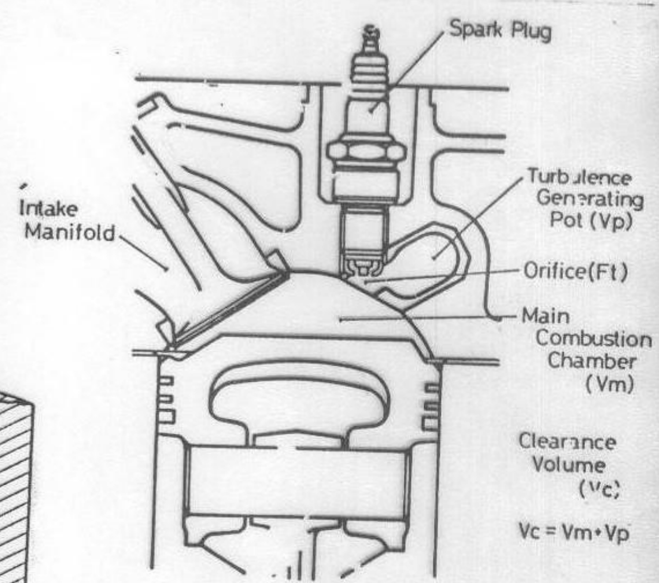


Fig. 15 - Configuration of the main combustion chamber and the TGP

Desain Ruang Bakar

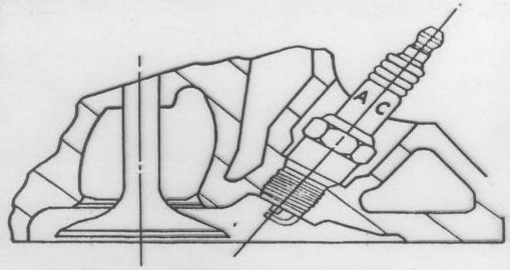


Fig. 9 – General Motors 2.8 L V-6 combustion chamber ( )

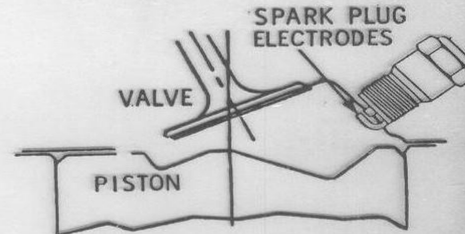


Fig. 9A – Experimental modified wedge chamber ( )

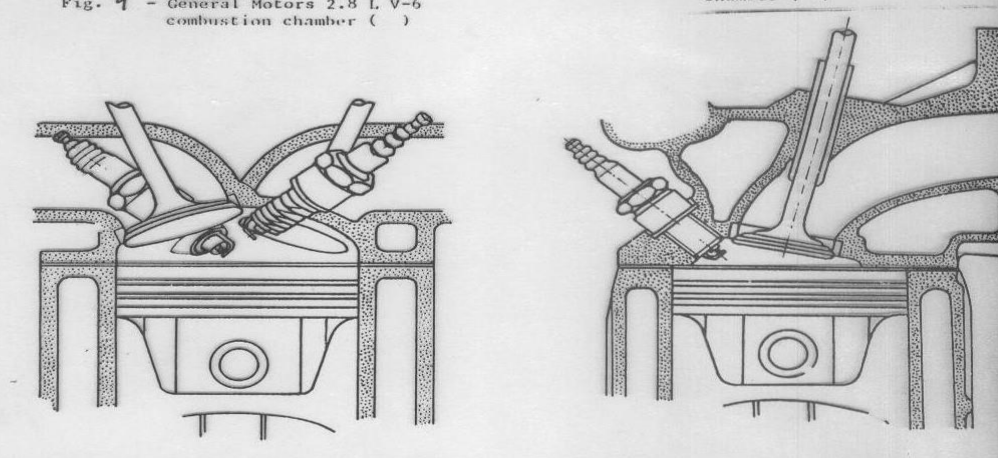


Fig. 10 Configuration o e combustion chambe of the test engines

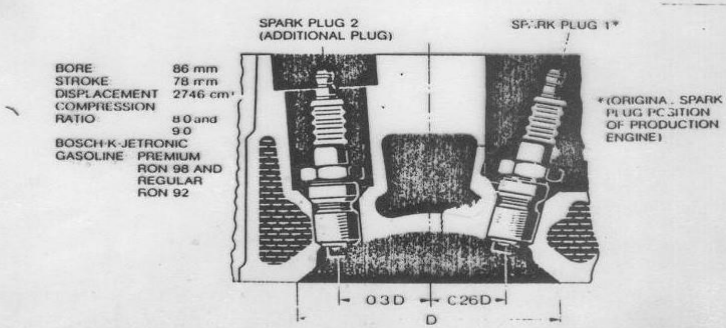


Fig. 11 Combustion chamber of a 6-cylinder engine with dual ignition system

Desain Ruang Bakar

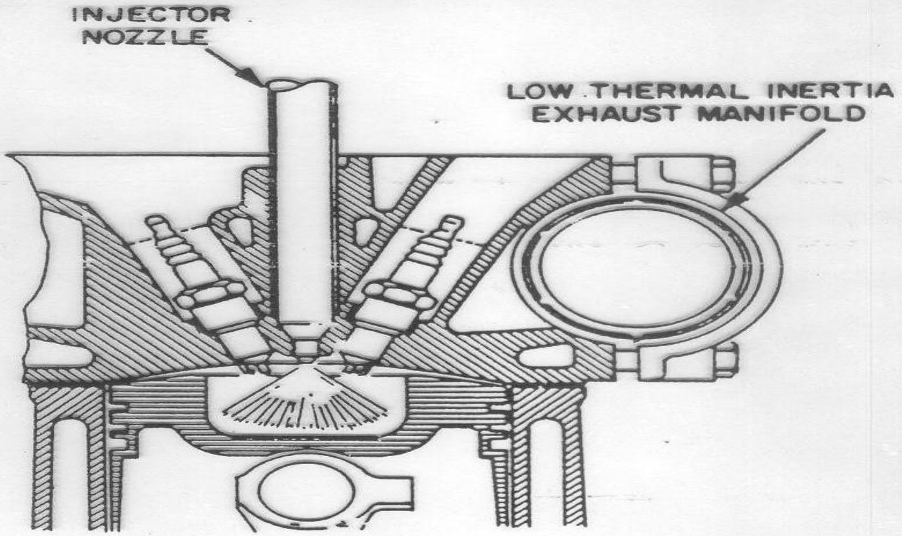


Fig. 11 - Combustion chamber of Ford PROCO engine

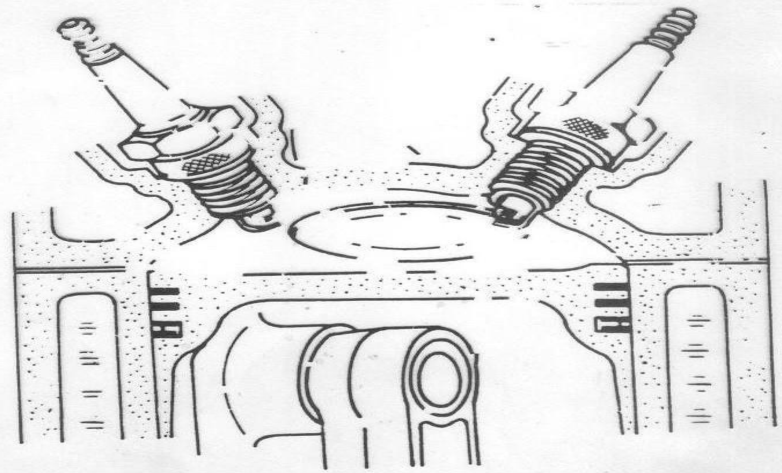


Fig. 12 - Configuration of dual spark plugs

Desain Ruang Bakar

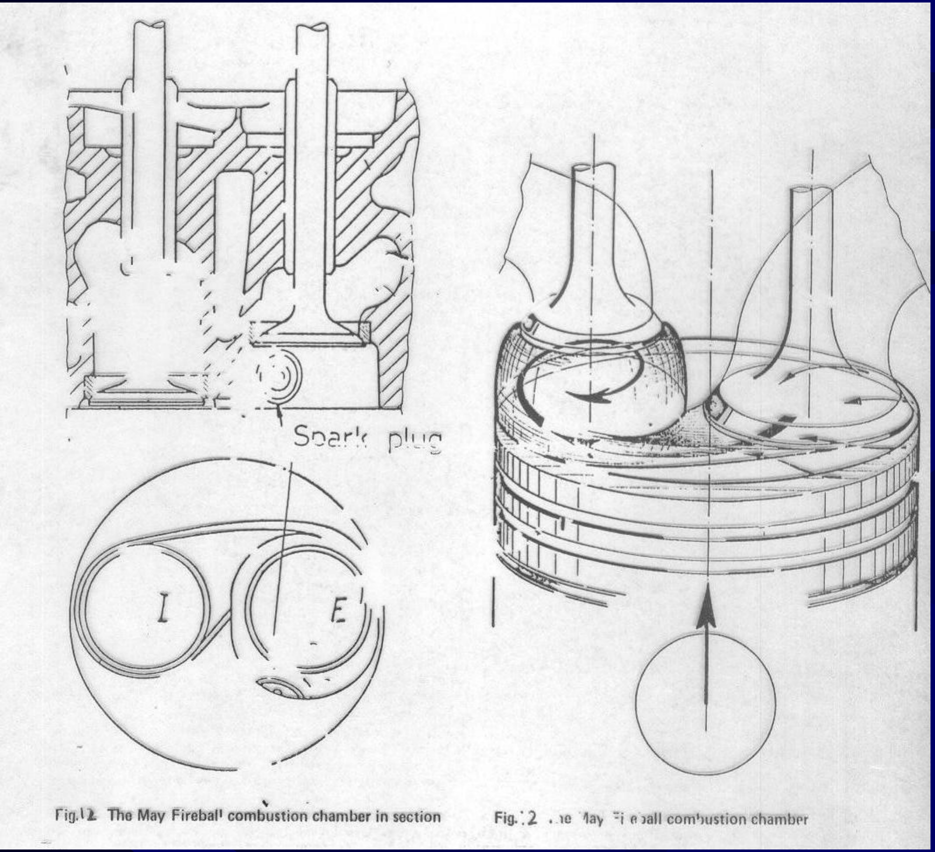


Fig. 12 The May Fireball combustion chamber in section

Fig. 2 The May Fireball combustion chamber

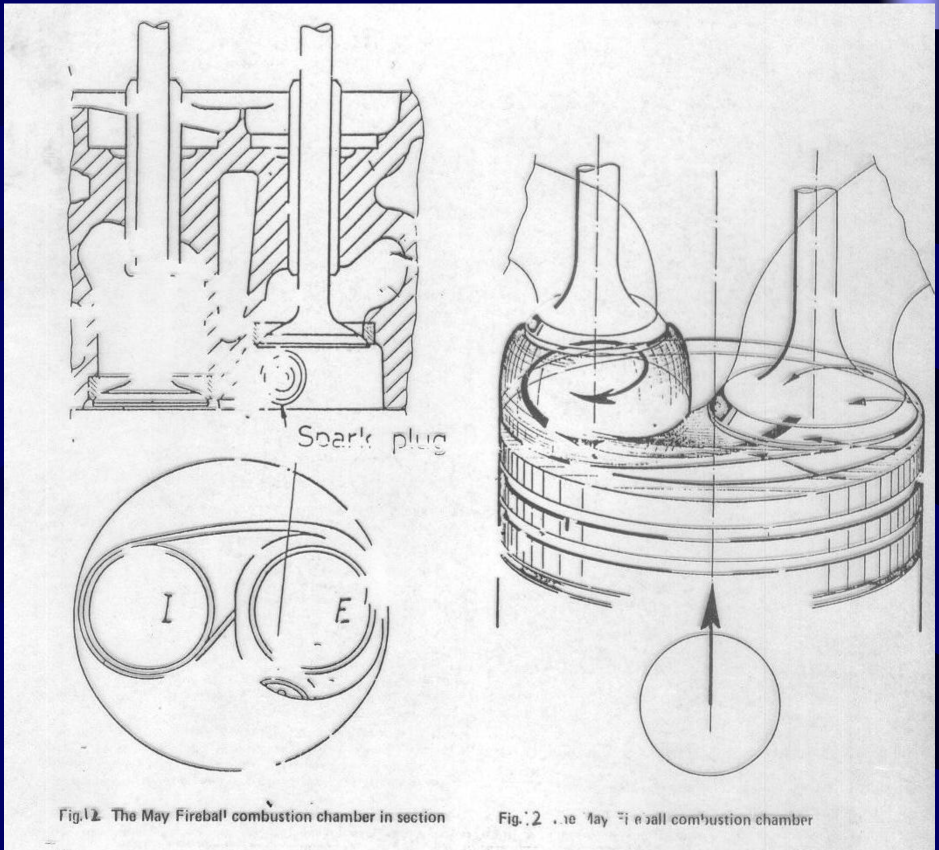


Fig. 12 The May Fireball combustion chamber in section

Fig. 2 The May Fireball combustion chamber

KLASIFIKASI MESIN PEMBAKARAN DALAM

11. Metode Kontrol Beban

1. **Throttling: (Untuk menjaga campurab tetap konstan) Juga disebut Charge Kontrol**

   Digunakan pada Mesin S.I. Karburetor

2. **Kontrol Bahan bakar (Untuk memvariasikan campuran sesuai kondisi beban)**

   Digunakan pada Mesin C.I. (Diesel)

3. **Kombinasi**

   Digunakan pada Fuel-injected Mesin S.I.

KLASIFIKASI MESIN PEMBAKARAN DALAM

12. Pendinginan

1. Pendingin udara langsung
2. Pendingin udara tidak langsung (Pendingin cairan)
3. Pembuangan panas yg rendah (Mesin Semi-adiabatic).

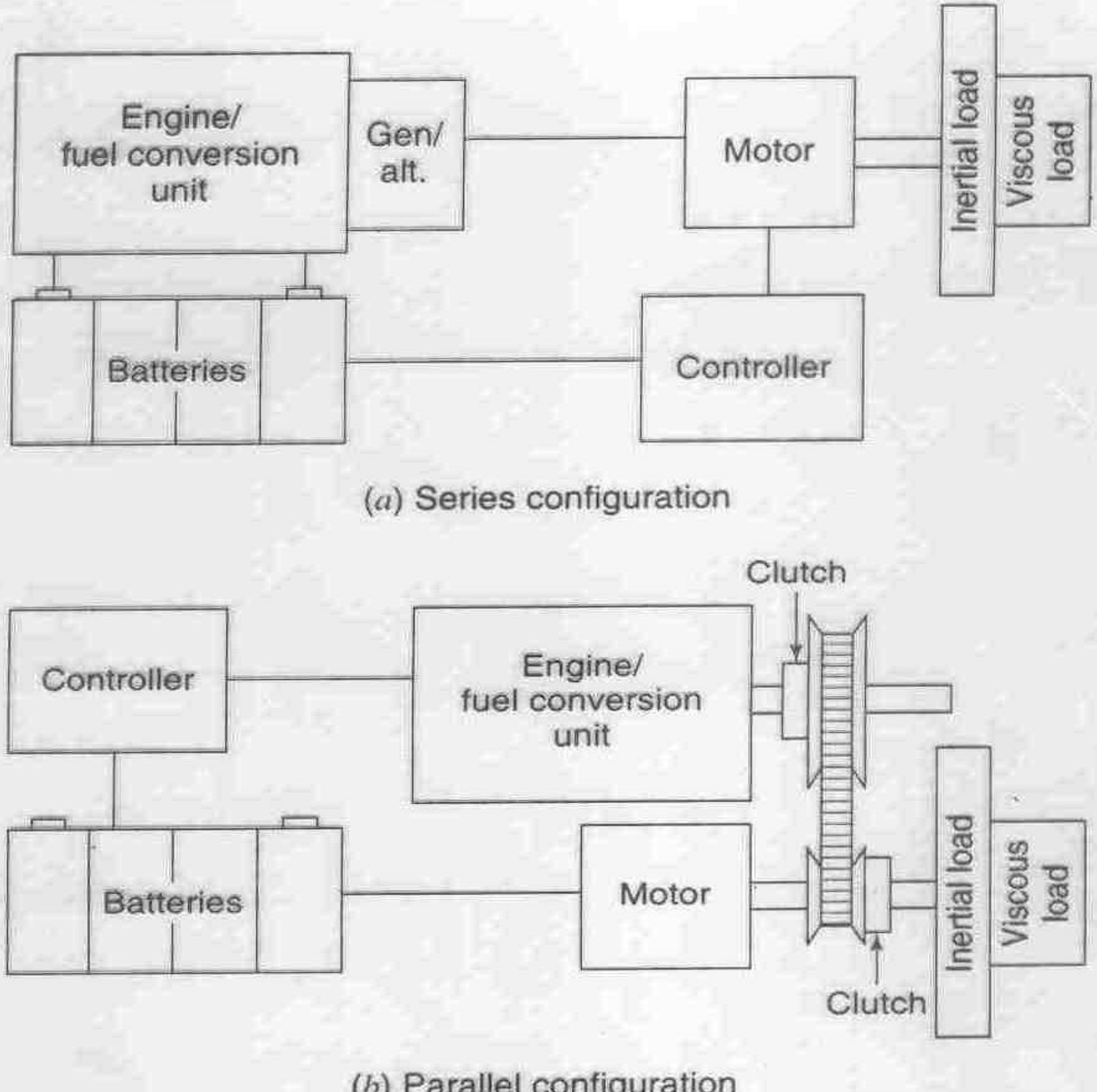
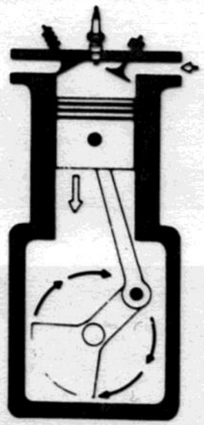


Figure 1-25 Hybrid electric vehicle powertrain configurations.

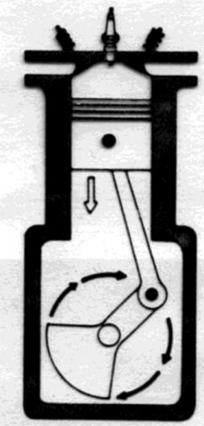
SIKLUS UDARA STANDAR MESIN PEMBAKARAN DALAM

Siklus Otto

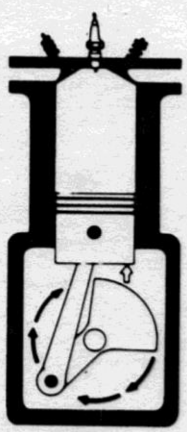
Siklus Otto 4 Langkah



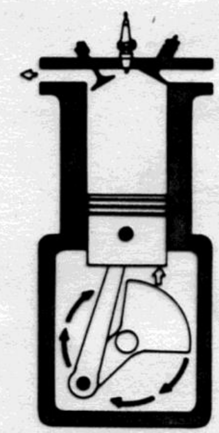
Piston moves down on intake stroke and fuel.



Piston is exploded down the cylinder on power stroke.

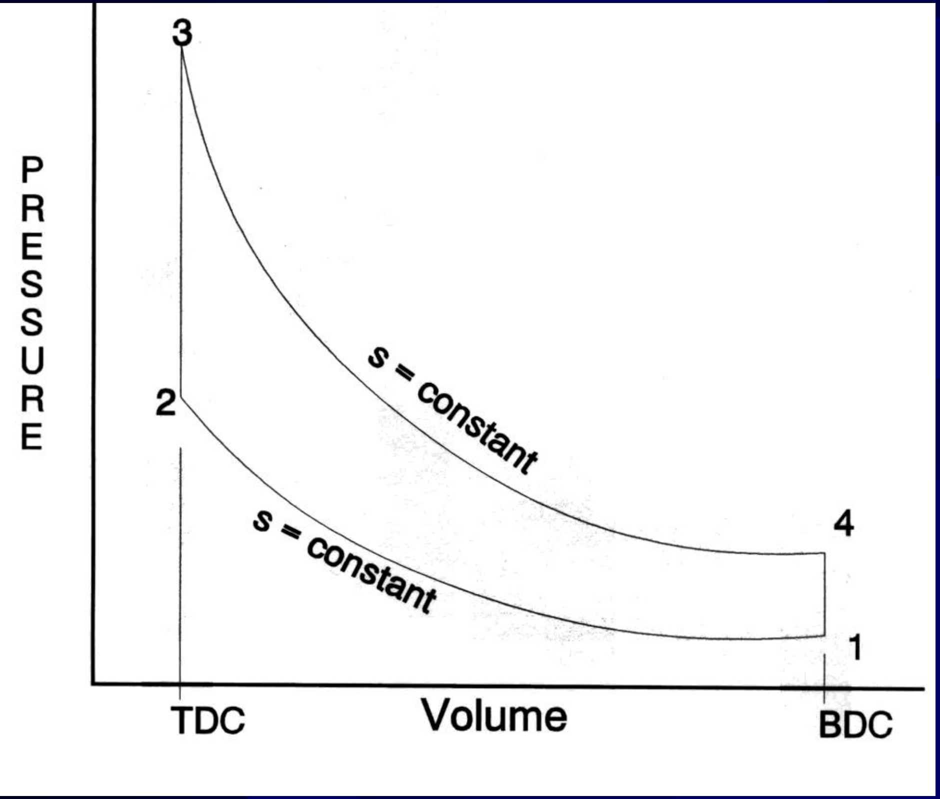


Piston moves up on compression stroke and fuel.

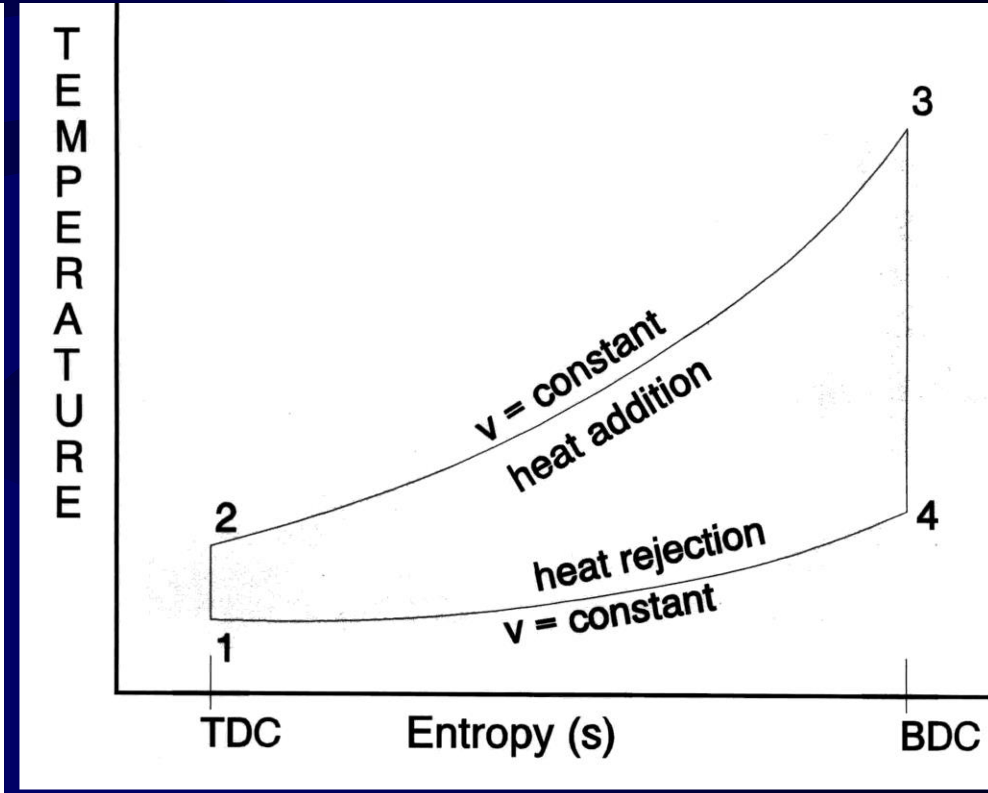


Burned gases are pushed out on exhaust stroke.

Siklus Otto P-V & T-s Diagrams



Pressure-Volume



Temperature-Entropy

Siklus Otto

- *Efisiensi Thermal:*

$$\eta_{th} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

  – Utk proses pemasukan dan pembuangan panas pd volume konstan;

$$Q_{in} = m\,C_v\,\Delta T \qquad\qquad Q_{\mathrm{Rej}} = m\,C_v\,\Delta T$$

  – Asumsi panas spesifik konstan:

$$\eta_{th} = 1 - \frac{m\,C_v(T_4 - T_1)}{m\,C_v(T_3 - T_2)} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

Siklus Otto

- Proses kompresi dan ekspansi isentropis:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \frac{T_3}{T_4}$$

- Dengan : $\gamma = C_p/C_v$

$$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$

maka

$$\eta_{th} = 1 - \frac{m\,C_v(T_4 - T_1)}{m\,C_v(T_3 - T_2)} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2}$$

Siklus Otto

Perbandingan kompresi (r_v) adalah perbandingan volume, dan sama dengan perbandingan ekspansi pada mesin siklus Otto.

- Perbandingan kompresi

$$r_v = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

Perbandingan kompresi didefinisikan sebagai:

$$r_v = \frac{\text{Volume total}}{\text{Volume sisa}} = \frac{v_s + v_{cc}}{v_{cc}} \qquad r_v = \frac{v_s}{v_{cc}} + 1$$

Siklus Otto

- Dengan substitusi,

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{1-\gamma} = (r_v)^{1-\gamma}$$

Sehingga efisiensi termal siklus Otto udara standar menjadi:

$$\eta_{th} = 1 - (r_v)^{1-\gamma} = 1 - \frac{1}{(r_v)^{\gamma-1}}$$

Siklus Otto

- Ringkasan

$$\eta_{th} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$ dimana $$Q = m\,C_v\,\Delta T$$

$$\eta_{th} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$ dan $$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$ maka $$\eta_{th} = 1 - \frac{T_1}{T_2}$$

Proses isentropis $$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{1-\gamma} = (r_v)^{1-\gamma}$$

$$\eta_{th} = 1 - (r_v)^{1-\gamma} = 1 - \frac{1}{(r_v)^{\gamma-1}}$$

Siklus Otto

- Pemasukan panas(Q) dicapai melalui pembakaran bahan bakar
  - Q = Lower Heat Value (LHV) kJ/kg

$$Q_{in}/_{\mathrm{cycle}} = m_a \frac{F}{A} Q_{fuel}$$

juga

$$Q_{in} = m\, C_v\, \Delta T$$

Contoh

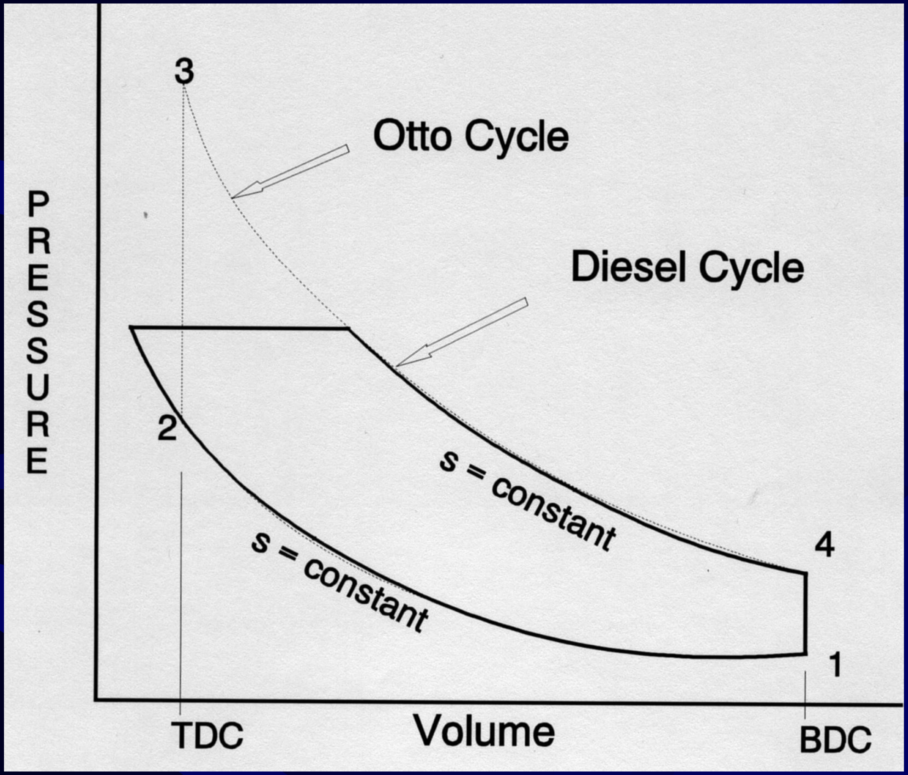
Siklus Otto Perkiraan P & T

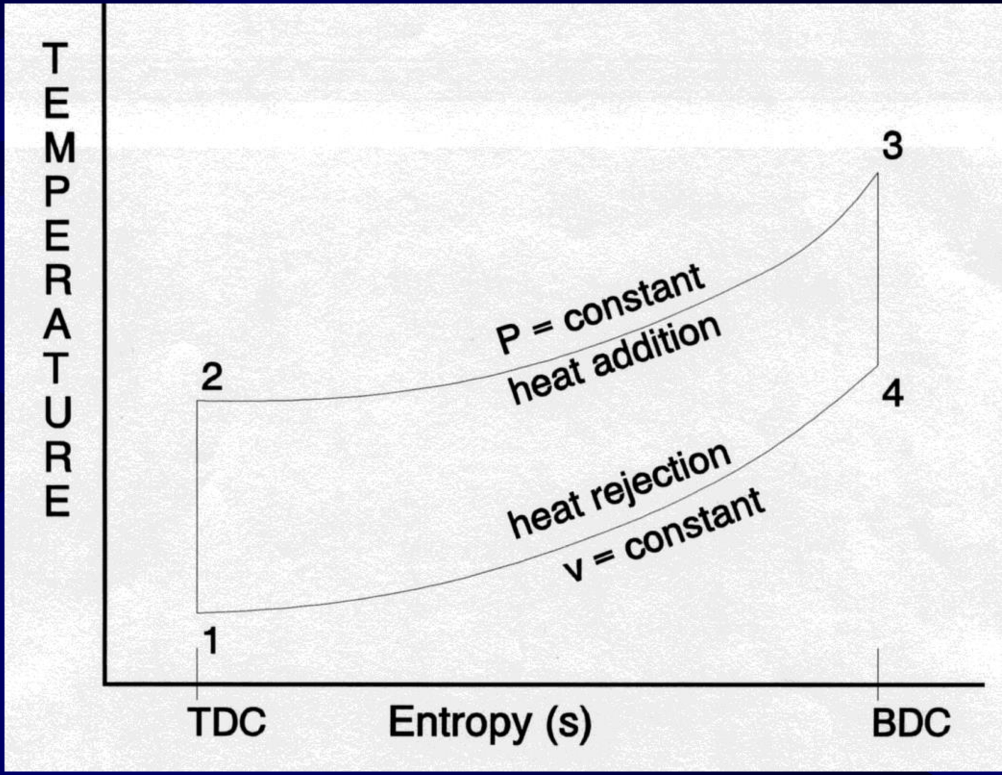
- Tentukan tekanan dan temperatur masing-masing titik proses pada siklus Otto ideal jika diketahui.

Perbandingan kompresi	=	9.5:1
Temperatur T_1	=	$25^oC = 298^oK$
Tekanan P_1	=	100 kPa

Siklus Diesel

Siklus Diesel P-V & T-s Diagram





Siklus Diesel

- *Efisiensi Termal (Diesel):*

$$\eta_{th} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Untuk proses pemasukan panas pada tekanan konstan;

$$Q = m\, C_p\, \Delta T$$

Untuk proses pengeluaran panas pada volume konstan;

$$Q = m\, C_v\, \Delta T$$

Asumsi panas spesifik konstan:

$$\eta_{th} = 1 - \frac{m\, C_v (T_4 - T_1)}{m\, C_p (T_3 - T_2)} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{\gamma\, T_2\left(\frac{T_3}{T_2} - 1\right)}$$

dimana: $\gamma = C_p/C_v$

Siklus Diesel

- Untuk proses kompresi dan ekspansi isentropis:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \qquad \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \frac{T_3}{T_4}$$

- Dimana, pada Mesin Diesel

$$V_1 = V_4 \qquad \frac{V_1}{V_2} \neq \frac{V_4}{V_3}$$

- Perbandingan kompresi (r_v) adalah perbandingan volume, pada mesin diesel, sama dengan hasil perkalian ekspansi pada tekanan konstan dan ekspansi dari cut-off.

Siklus Diesel

- Perbandingan kompresi

$$r_{v_c} = \frac{V_1}{V_2} \neq \frac{V_4}{V_3} \qquad r_{v_c} = r_{cp} \bullet r_e = \frac{V_2}{V_3} \bullet \frac{V_3}{v_4}$$

- Dengan substitusi,

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{1-\gamma} = (r_v)^{1-\gamma}$$

$$\eta_{th} = 1 - \frac{1}{(r_v)^{\gamma-1}}\left[\frac{(r_{cp})^{\gamma} - 1}{\gamma(r_{cp} - 1)}\right]$$

Siklus Diesel

- Hubungan kritis dalam proses mencakup

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{1-\gamma} = (r_v)^{1-\gamma}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = (r_v)^{\gamma}$$

$$Q = m\,C_p\,\Delta T$$

$$\frac{Q}{cycle} = m_a \frac{F}{A} Q_{fuel}$$

$$Q = m\,C_v\,\Delta T$$

$$\eta_{th} = 1 - \frac{1}{(r_v)^{\gamma-1}}\left[\frac{(r_{cp})^{\gamma} - 1}{\gamma(r_{cp} - 1)}\right]$$

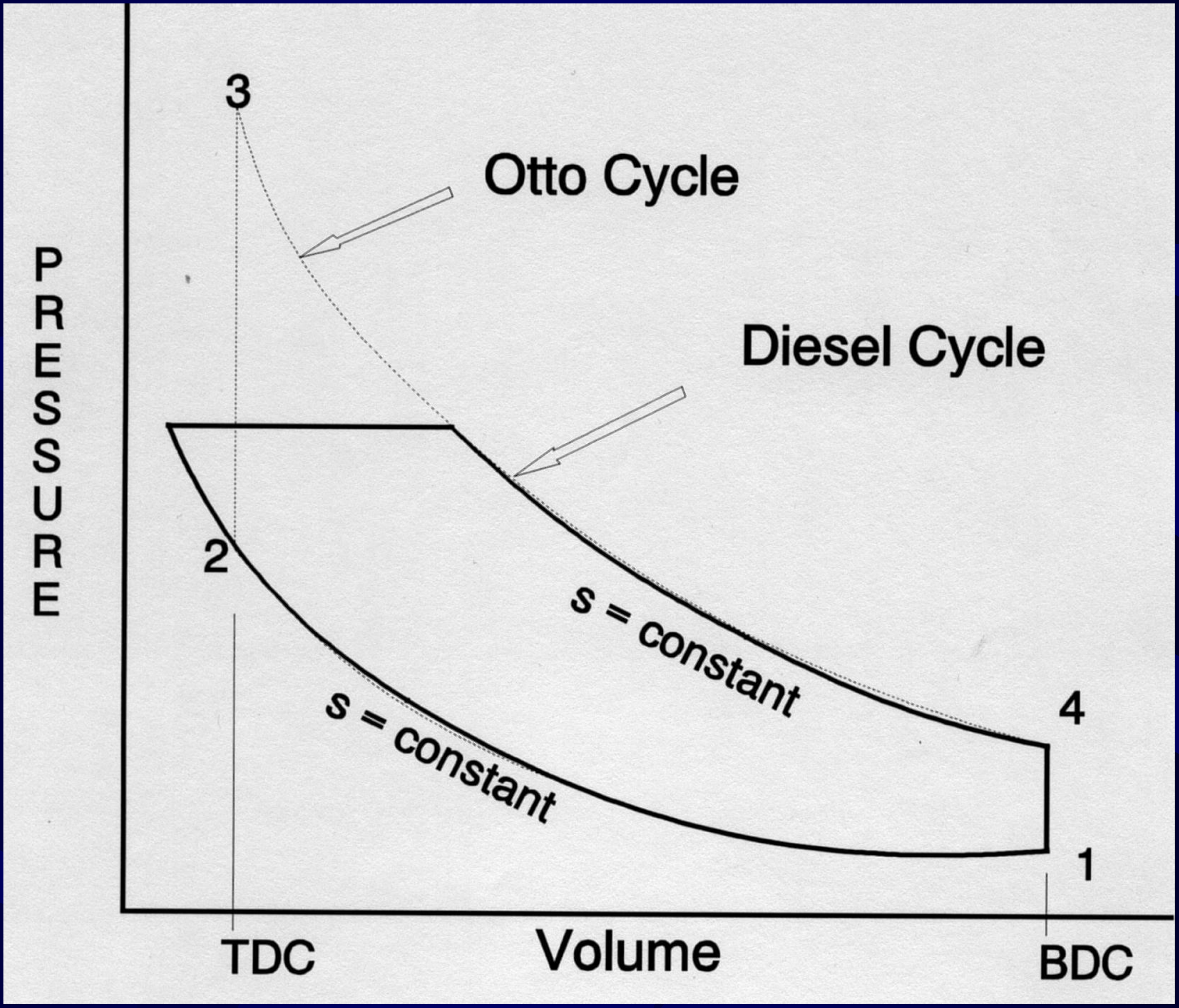
Contoh

Siklus Diesel Prediksi P & T

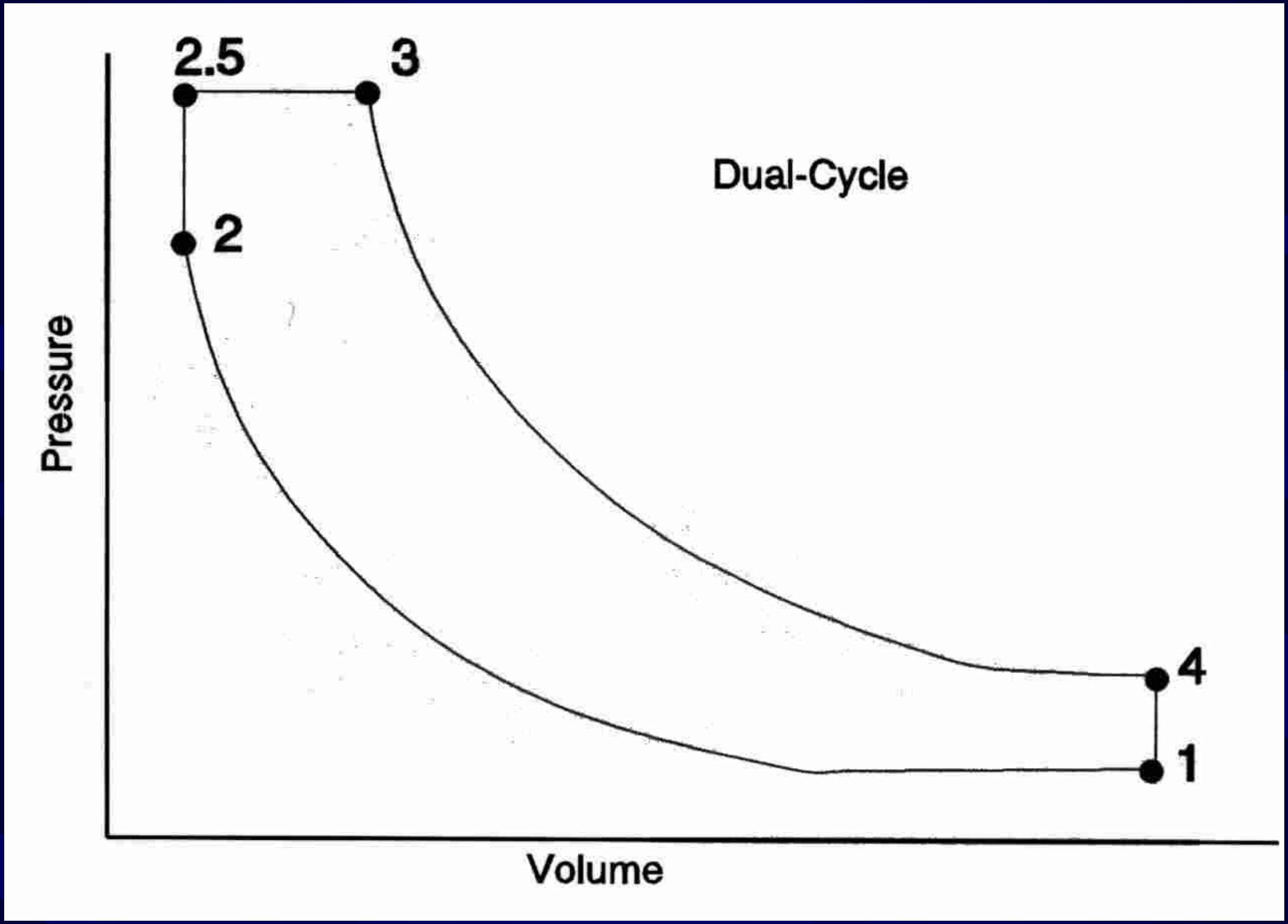
- Tentukan tekanan dan temperature masing-masing titik proses pada Siklus Diesel, jika diketahui.

Perbandingan kompresi	=	20 : 1
Temperatur T_1	=	$25^oC = 298^oK$
Tekanan P_1	=	100 kPa

Perbandingan Siklus Otto & Diesel



Dual Cycle P-V Diagram:



Efisiensi Dual Cycle

- Efisiensi Termal Dual Cycle

$$Q_{in} = m\,C_v\,(T_{2.5} - T_2) + m\,C_p\,(T_3 - T_{2.5})$$

$$Q_{Rej} = m\,C_v\left(T_4 - T_1\right)$$

$$\eta = 1 - \left(\frac{1}{CR}\right)^{(\gamma - 1)}\left[\frac{\alpha\,\beta^{\gamma} - 1}{(\alpha - 1) + \gamma\alpha(\beta - 1)}\right]$$

Dengan: $\gamma = C_p/C_v$

$$\alpha = \frac{P_3}{P_2} \qquad \beta = \frac{V_3}{V_{2.5}}$$

TERIMA KASIH