Engine Friction and Lubrication

NAZARUDDIN SINAGA
Efficiency and Energy Conservation Laboratory

Mechanical Engineering Department
Diponegoro University

Engine Friction and Lubrication

Engine friction

- terminology
- Pumping loss
- Rubbing friction loss

Engine Friction: terminology

- Pumping work: W_p
  - Work per cycle to move the working fluid through the engine
- Rubbing friction work: W_{rf}
- Accessory work: W_a

Total Friction work: $W_{tf} = W_p + W_{rf} + W_a$

Normalized by cylinder displacement $\rightarrow$ MEP

- tfmep = pmep + rfmep + amep

Net output of engine

- bmep = imep(g) – tfmep

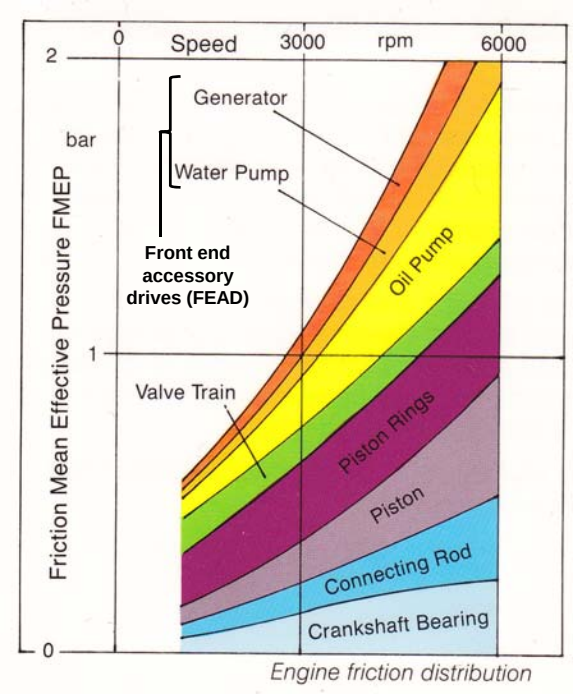
Mechanical efficiency

- η_m = bmep / imep(g)

Friction components

1. Crankshaft friction
   - Main bearings, front and rear bearing oil seals
2. Reciprocating friction
   - Connecting rod bearings, piston assembly
3. Valve train
   - Camshafts, cam followers, valve actuation mechanisms
4. Auxiliary components
   - Oil, water and fuel pumps, alternator
5. Pumping loss
   - Gas exchange system (air filter, intake, throttle, valves, exhaust pipes, after-treatment device, muffler)
   - Engine fluid flow* (coolant, oil)

***Have to be careful to avoid double-counting. The engine coolant and oil flow losses are provided for by the oil and water pump. The nature of the loss is a pumping loss though.**



Engine friction distribution

SI engine friction

(excluding pumping loss)

Source: FEV Brochure

Engine Friction

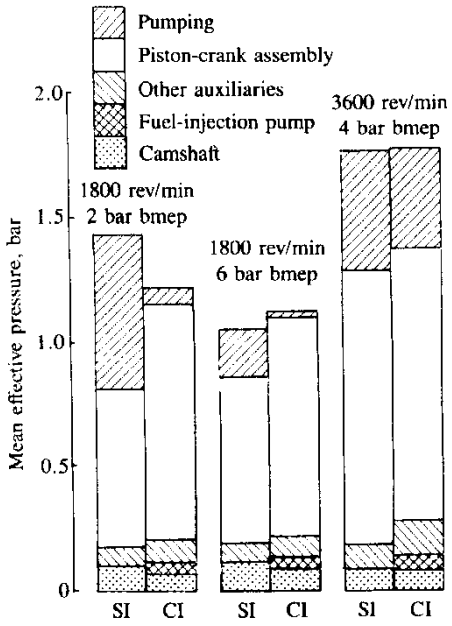


Fig. 13-1
Comparison of major categories of friction losess: fmep at different loads and speeds for 1.6 L four-cylinder overhead-cam automotive Spark Ignition (SI) and Compression-Ignition (CI) engines.

Fuel energy accounting for SI engine

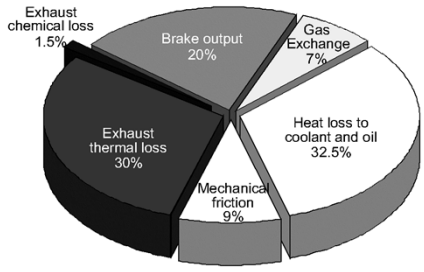


Figure 1. Typical engine losses at part load

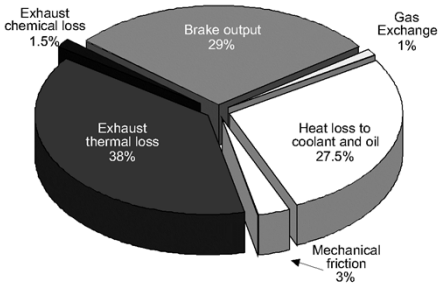


Figure 2. Typical engine losses at full load

SAE Paper 2000-01-2902

Pumping loss

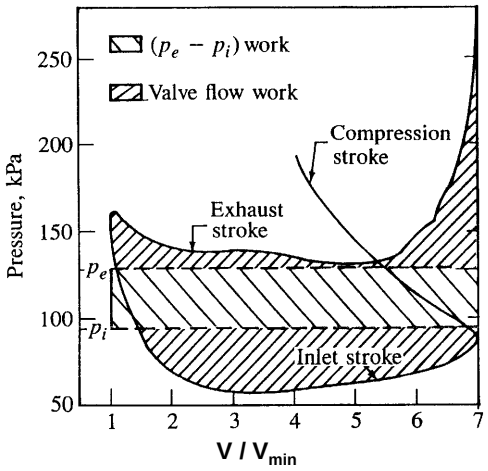
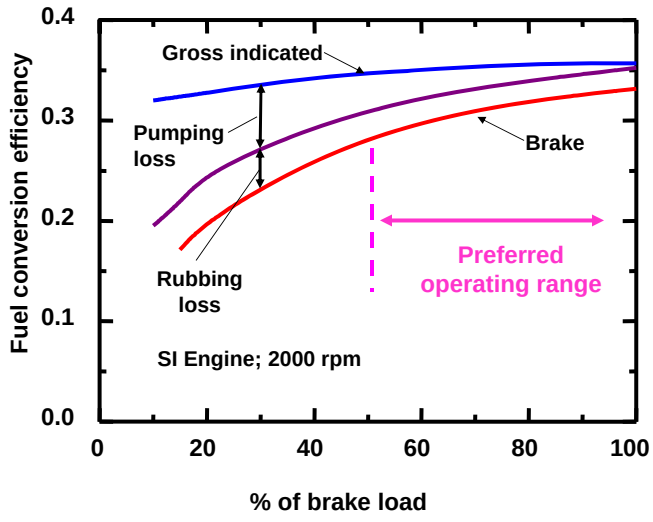
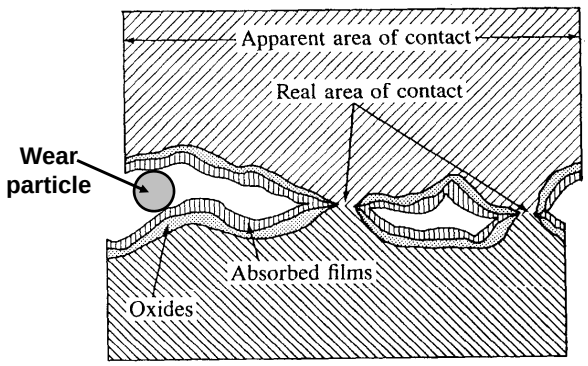


Fig. 13-15 Puming loop diagram for SI engine under firing conditions, showing throttling work $V_d(p_e-p_i)$, and valve flow work

SI Engine losses



Sliding friction mechanism



Energy dissipation processes:

- **Detaching chemical binding between surfaces**
- **Breakage of mechanical interference (wear)**

Bearing Lubrication

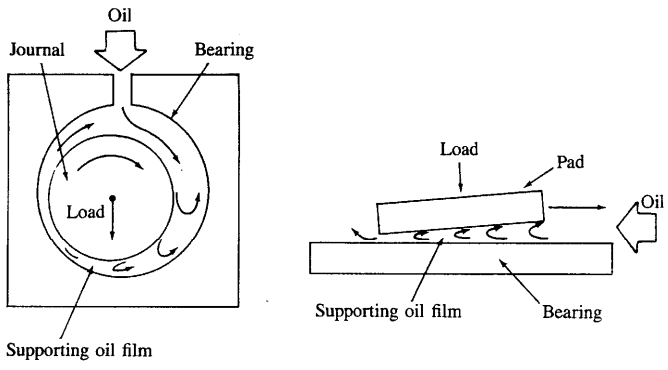
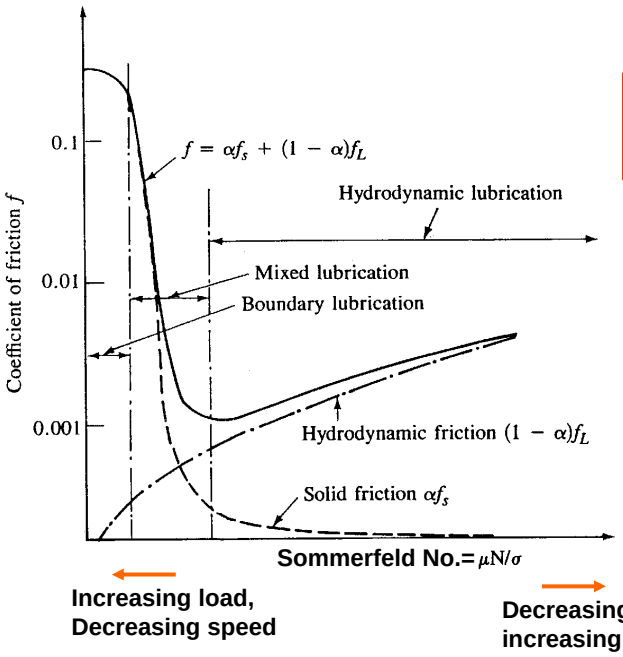


FIGURE 13-2
Schematic of a lubricated journal and a slider bearing.

Stribeck Diagram for journal bearing



μ = lubricant viscosity
N = shaft rotation speed
σ = loading force / area

Fig 13.3

Motoring break-down analysis

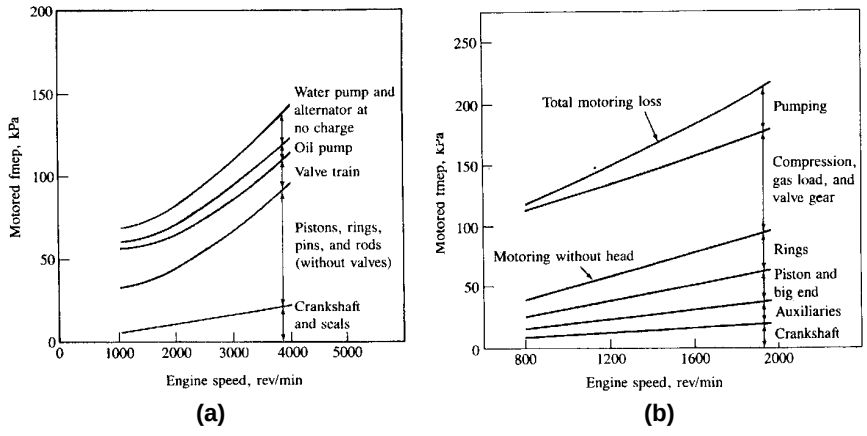
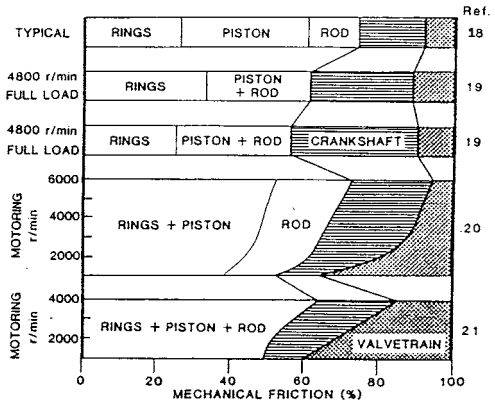


Fig. 13-14
Motored fmep versus engine speed for engine breakdown tests.
(a) Four-cylinder SI engine.
(b) Average results for several four- and six-cylinder DI diesel engines

Breakdown of engine mechanical friction



F.A. Martin, "Friction in Internal Combustion Engines," I.Mech.E. Paper C67/85, Combustion Engines – Friction and Wear, pp.1-17,1985.

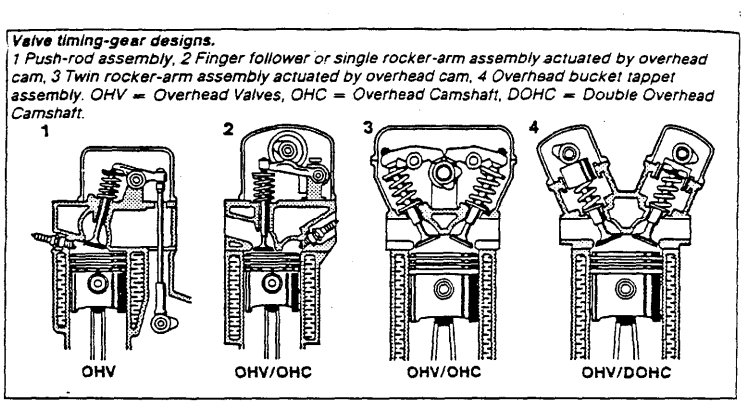
T. Hisatomi and H. Iida, "Nissan Motor Company's New 2.0 L. Four-cylinder Gasoline Engine," SAE Trans. Vol. 91, pp. 369-383, 1982; 1st engine.

2nd engine.

M. Hoshi, "Reducing Friction Losses in Automobile Engines," Tribology International, Vol. 17, pp 185-189, Aug. 1984.

J.T. Kovach, E.A. Tsakiris, and L.T. Wong, "Engine Friction Reduction for Improved Fuel Economy," SAE Trans. Vol. 91, pp. 1-13, 1982

Valve train friction



From Bosch Handbook

Valve train friction depends on:

- **Total contact areas**
- **Stress on contact areas**
  - ➢**Spring and inertia loads**

Low friction valve train

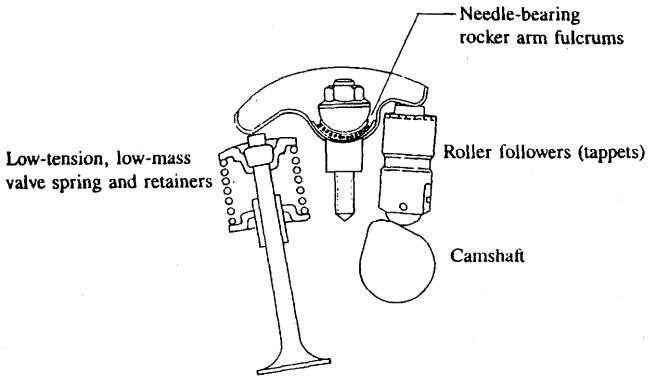
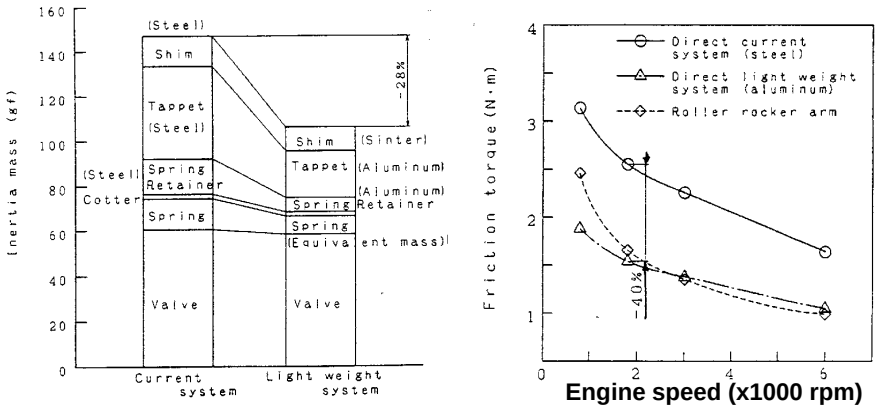


FIGURE 13-25
Low friction valve train.[22]

Valve train friction reduction



"Friction loss reduction by new lighter valve train system,"
JSAE Review 18 (1977), Fukuoka, Hara, Mori, and Ohtsubo

Piston ring pack

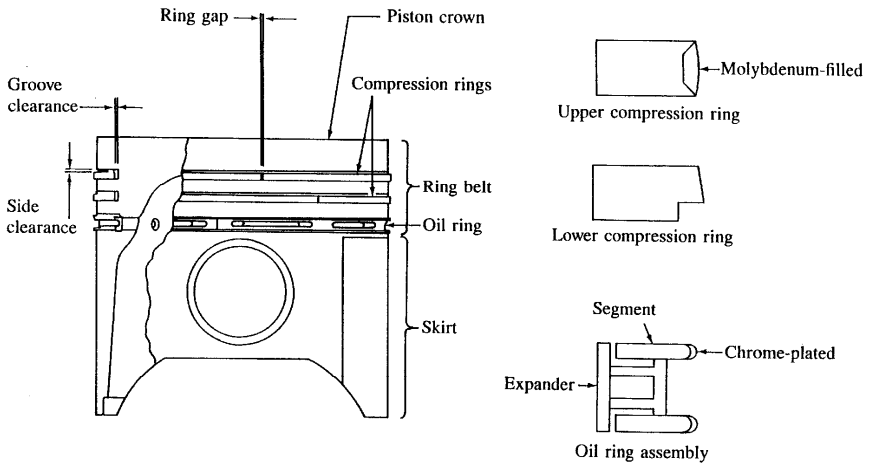


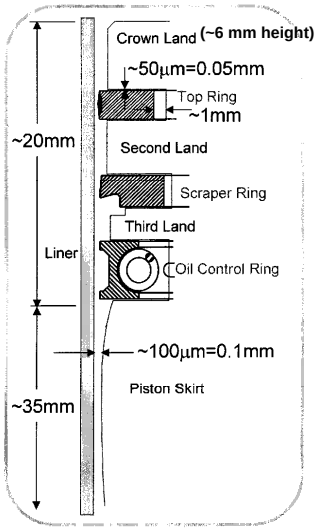
FIGURE 13-17
Construction and nomenclature of typical piston and ring assembly.[10]

Piston ring-pack dimensions

Vertical Motion:
- Stroke ~ 100mm
- Mean Piston Speed ~ 10m/s ~ 20 mph
- Peak Piston Acceleration ~ 10,000m/s² ~ 1000 g

Lateral Motion:
- Displacement ~ 100μm
- Velocity ~ 10-100 mm/s

Cylinder Liner:
- Liner Roughness ~ 0.1 μm
- Bore Distortion ~ 100 μm ~ 0.1mm



Ring Pack:
- Ring free shape deviation ~ 1 mm
- Ring face shape deviation ~ 10 μm
- Oil film thickness ~ 1 μm
- Ring height 1.2-1.5 mm
- Ring gap ~ 0.2 mm

Piston Skirt:
- Skirt shape deviation ~ 100 μm
- Ovality ~ 100 μm
- Tooling marks/waviness ~ 5 μm depth, ~ 1/25 slope
- Rougness ~ 0.01μm
- Thermal deformation ~ 100 μm
- Mechanical deformation ~ 100 μm

Massachusetts Institute of Technology — Sloan Automotive Laboratory

Source: MIT Sloan Automotive Laboratory.

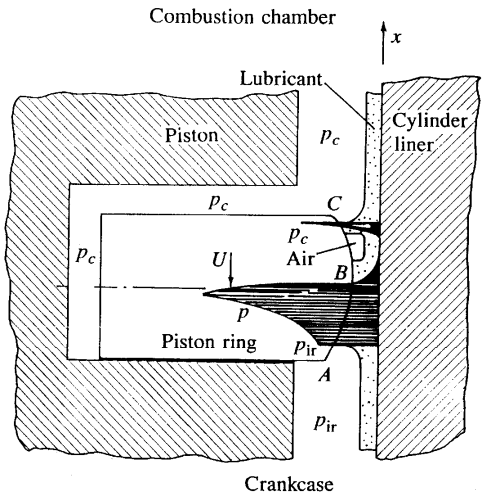
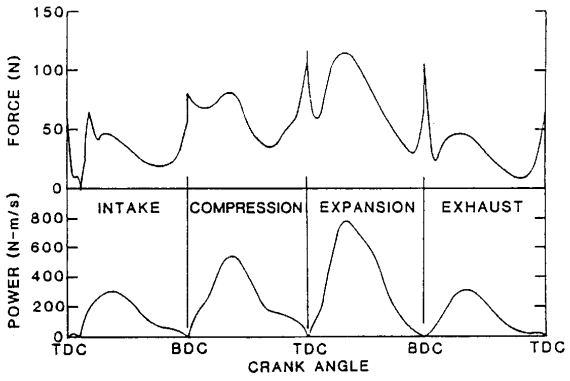


FIGURE 13-18
Schematic of pressure distribution in the lubricating oil film and around a compression ring during expansion stroke. Pressure profile in the oil film indicated by horizontal shading.[3]

Hydrodynamic lubrication of the piston ring

Friction force and associated power loss



Piston slap

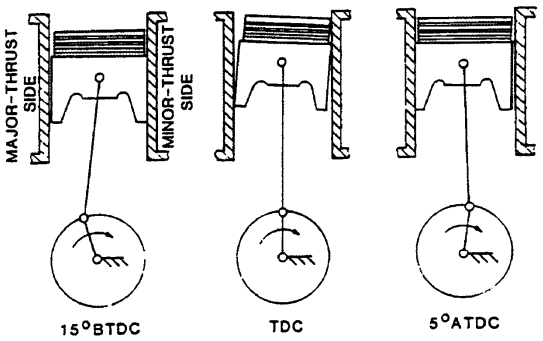


FIGURE 17
Piston motion near TDC firing with piston-pin Offset toward major-thrust side. (by 1-2% of bore)

Change timing (earlier) of transition so that the cylinder pressure at transition is lower – less force to accelerate piston

Transition is a "roll over" so that slap is less severe

Also the "slap" force is lower

Bore distortion

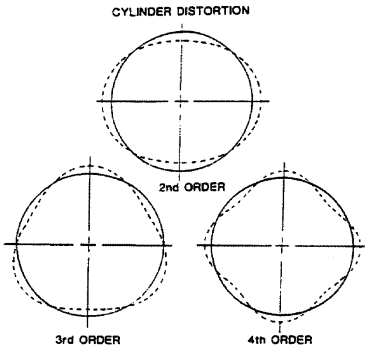


FIGURE 11
Three orders of bore distortion.

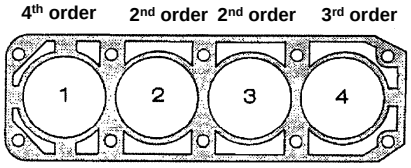
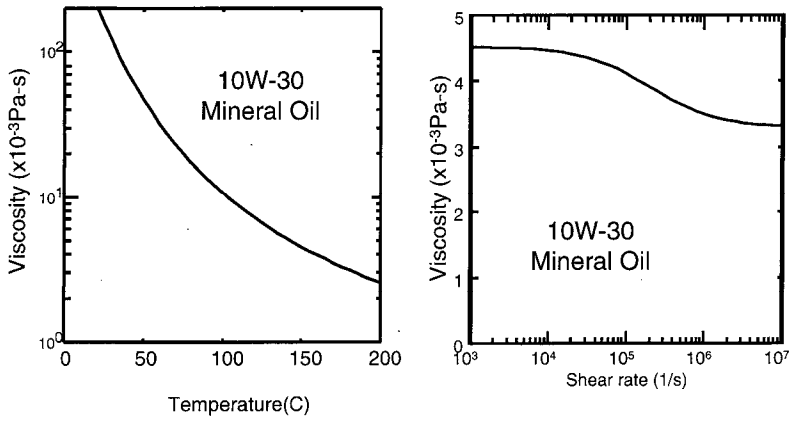


FIGURE 12
Top deck of hypothetical engine.

Lubricants

- Viscosity is a strong function of temperature
- Multi-grade oils (introduced in the 1950's)
  - Temperature sensitive polymers to stabilize viscosity at high temperatures
    - Cold: polymers coiled and inactive
    - Hot: polymers uncoiled and tangle-up: suppress high temperature thinning
- Stress sensitivity: viscosity is a function of strain rate

Viscosity

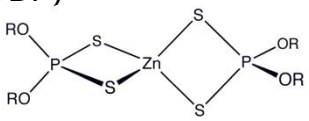


(From Linna et.al, SAE Paper 972892)

10W30 refers to upper viscosity limit equal to single grade SAE 10 at 0 deg F (-18C) and lower viscosity limit equal to SAE single grade 30 at 100 C.

Additive to lubricant

- VI Improvers
  - To improve viscosity at high temperature
- High temperature stability
- Acid neutralization
- Detergents and dispersants
  - To keep partial oxidation products and PM in suspension and to prevent lacquer formation
- Anti-wear additives
  - E.g. Zinc dialkyldithiophospate (ZDDP)
  - Formation of anti-wear film



(R = alkyl)

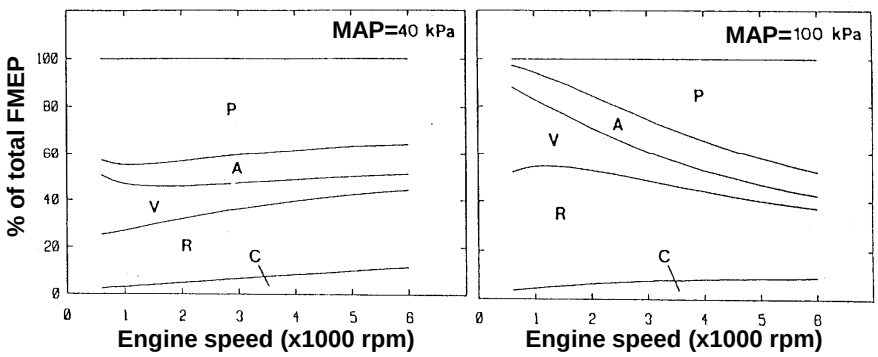
Modeling of engine friction

- Overall engine friction model:
  - tfmep (bar) = fn (rpm, V_d, ν, B, S, ….)
  - See text, Ch. 13, section 5; SAE Paper 900223, …
    - For engine speed N:
      - tfmep = a + bN + cN^2
- Detailed model:
  - see text Ch. 13, section 6; SAE Paper 890936

$$\text{tfmep} = \sum(\text{fmep})_{\text{components}}$$

With detailed modeling of component friction as a function of rpm, load, …

FMEP distribution



Distribution of FMEP for a 2.0L I-4 engine; B/S = 1.0, SOHC-rocker arm, flat follower, 9.0 compression ratio

C = crankshaft and seals
R = reciprocating components
V = valve train components
A = Auxiliary components
P = Pumping loss

SAE 890836

REFERENCES

1. **Wai Cheng.** *Internal Combustion Engines*. Massachusetts Institute of Technology: MIT Open Course Ware.
2. **Heywood, J.** *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York, 1988.
3. **Pulkrabek, W.C.** *Engineering Fundamentals of the Internal Combustion Engine*, Prentice Hall, Upper Saddle River, New Jersey, 2003.
4. **Colin R. Ferguson and Allan T. Kirkpatrick**. *Internal Combustion Engines: Applied Thermal Sciences*, 2nd Edition,, John Wiley and Sons, New York, 2000.
5. **Gupta, H. N**. *Fundamentals of Internal Combustion Engines*, PHI Learning Private Limited, New Delhi, 2009.
6. **Priangkoso, Tabah and N. Sinaga**. *Review of Fuel Consumption Mechanistic Models to be Applied on the Smart Driving Simulator Program*, Proceedings, 2nd National Science and Technology Seminar, Faculty of Engineering, Wahid Hasyim University, Semarang, June 2011.
7. **Mrihardjono, Juli and N. Sinaga**. *Driving Cycle Tests of Honda City Passenger Cars Fueled by Premium Gasoline*, Journal of Gema Teknologi, Volume 16, No. 3, October 2011, ISSN: 0852 0232.
8. **Sinaga, Nazaruddin and Tabah Priangkoso**. *Review of Empirical Models of Vehicle Fuel Consumption*, Journal of Momentum, Vol. 7, No. 1, April 2011.
9. **Sinaga, Nazaruddin**. *Energy-Saving Tests of Passenger Cars to Support the Smart Driving Program in Indonesia*, Proceedings, 10th National Seminar on Mechanical Engineering (SNTTM X), Mechanical Engineering Department, Faculty of Engineering, Brawijaya University, Malang, November 2011.
10. **Sinaga, Nazaruddin, T. Priangkoso, D. Widayana, and K. Abdurrohman**. *Experimental Study on the Effect of Driving Parameters on Fuel Consumption of 1500-2000 CC Passenger Cars*, Proceedings, 10th National Seminar on Mechanical Engineering (SNTTM X), Mechanical Engineering Department, Faculty of Engineering, Brawijaya University, Malang, November 2011.
11. **Sinaga, Nazaruddin**. *Smart Driving: Fuel Saving, Emission Quality Enhancement and Accident Reduction*, Paper presented in the Seminar of Astra-Undip, Mechanical Engineering Department, Diponegoro University, November 2012.
12. **Sinaga, Nazaruddin, and Mulyono**. *Experimental Study on the Impact of Pertamax and Pertamax-Plus Fuels on the Exhaust Emissions of Motorcycles*, Proceedings, National Seminar of Research and Community Service Institution, Politeknik Negeri Semarang, 2013, ISBN: 978-979-3514-66-6, Pages 168-172.
13. **Sinaga, Nazaruddin and S. J. Purnomo**. *Relationship of Throttle Position, Engine Rotation and Gear Position on Fuel Consumption of Passenger Cars*, Eksergi, Energy Engineering Journal, State Polytechnic Semarang, Vol. 9 No. 1, January 2013.
14. **Sinaga, Nazaruddin**. *Smart Driving Training to Reduce Greenhouse Gas Emissions and Transportation Costs of Land Transportation*, Proceeding, 12th National Seminar on Mechanical Engineering (SNTTM XII), Faculty of Engineering, University of Lampung, October 2013.

15. **Sinaga, Nazaruddin, S. J. Purnomo, and A. Dewangga**. *Development of Efficient Fuel Consumption Equation Models for EFI Gasoline Fuel Passenger Cars*, Proceeding, 10th National Seminar on Mechanical Engineering (SNTTM XII), Faculty of Engineering, University of Lampung, October 2013.
16. **Sinaga, Nazaruddin, and Y. N. Rohmat**. *Comparison of the Performance of LPG and Gasoline Motorcycles*, Proceedings, National Seminar on Green Industry Technology, Center for Industrial Pollution Prevention Technology (BBTPPI) Semarang, Ministry of Industry, Semarang May 21, 2014.
17. **Syachrullah, L.I, dan N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network*, Proceedings, 2nd National Seminar on Development of Research and Technology in Industry, Faculty of Engineering, Gajah Mada University Yogyakarta, June 2014.
18. **Paridawati and N. Sinaga**. *Reducing Fuel Consumption of an Injection System Motorcycle Using Artificial Neural Network Optimization Method with Back-Propagation Algorithm*, Proceedings, 2nd National Seminar on Development of Research and Technology in Industry, Faculty of Engineering, Gajah Mada University Yogyakarta, June 2014.
19. **M. Rifal and N. Sinaga**. *Impact of Methanol-Gasoline Blend on Fuel Consumption and Exhaust Emission of an SI Engine*, Proceedings, The 3rd International Conference on Advanced Materials Science and Technology (ICAMST 2015), Semarang State University, April 2015.
20. **Sinaga, Nazaruddin, and Mulyono**. *Experimental Study on the Motorcycle Performance with Variation of Gasoline Types*, Journal of Eksergi, Vol. 11, No. 1, ISSN: 0216-8685, Pages 1- 6, January 2015.
21. **Syachrullah, L.I, and N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network*, American Journal of Engineering and Applied Science, Vol. 8 Issue 2, pp. 236-250, ISSN: 1941-7039, February 26, 2016.
22. **Rojak, Amirur and N. Sinaga**. *Analysis of Air and Fuel Consumption on Passenger Cars Fuel with LGV*, Journal of Politeknosains, Vol. XV, No. 1, ISSN: 1829-6181, March 2016.
23. **Khudhoibi and N. Sinaga**. *Effect of Engine Remap on LGV-Fueled Car Operations*, Journal of Momentum, Islamic University of Wachid Hasyim, Vol. 12, No. 1, ISSN: 0216-7395, April 2016.
24. **Rifal, Mohamad and N. Sinaga**. *Impact of Methanol-Gasoline Fuel Blend on Fuel Consumption and Exhaust Emission of SI Engine*, AIP Conf. Proc. 1725, 020070-1–020070-6; Published by AIP Publishing, 978-0-7354-1372-6, March 2016.
25. **Sinaga, Nazaruddin and D. Alcita**. *Comparison of Fuel Consumption on EFI Car Fueled with Gasoline and Methanol-Gasoline M15*, Eksergi, Energy Engineering Journal, State Polytechnic Semarang, Polines, Vol. 12 No. 3, September 2016.
26. **Nazaruddin Sinaga**. *Preliminary Design of a Simple LPG Converter Kit for Small Scale Gasoline Engines*, Journal of Eksergi, Journal of Energy Engineering Polines, Vol. 13, No. 1, January 2017.

27. **Nazaruddin Sinaga and M. Rifal**. *Effect of Methanol-Gasoline Fuel Composition on Torque and Power of a 1200 CC EFI Passenger Car*, Journal of Rotation Vol. 19, No. 3, July 2017.
28. **Rifal, Mohamad and N. Sinaga**. Experimental Study of Methanol – Gasoline Ratio on Fuel Consumption, Exhaust Emission, Engine Torque and Power, Gorontalo Journal of Infrastructure and Science Engineering, Vol 1 (1), April 2018, pp. 47-54.
29. **Nugroho, A., Sinaga, N., Haryanto, I**. *Performance of a Compression Ignition Engine Four Strokes Four Cylinders on Dual Fuel (Diesel-LPG)*, Proceeding, The 17th International Conference on Ion Sources, Vol. 2014, 2018, 21 September 2018, AIP Publishing.
30. **Nazaruddin Sinaga, B. Yunianto, Syaiful, and W.H. Mitra Kusuma**. *Effect of Addition of 1,2 Propylene Glycol Composition on Power and Torque of an EFI Passenger Car Fueled with Methanol-Gasoline M15*, Proceeding of International Conference on Advance of Mechanical Engineering Research and Application (ICOMERA 2018), Malang, October 2018.
31. **Ahmad Faoji, Syaiful Laila, Nazaruddin Sinaga**. *Consumption and Smoke Emission of Direct Injection Diesel Engine Fueled by Diesel and Jatropha Oil Blend with Cold EGR System*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, January 21, 2019.
32. **Johan Firmansyah, Syaiful Laila, Nazaruddin Sinaga**. *Effect of Water Content in Methanol on the Performance and Smoke Emissions of Direct Injection Diesel Engines Fueled by Diesel Fuel and Jatropha Oil Blends with EGR System*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, January 21, 2019.
33. **Sinaga, Nazaruddin, M. Mel, D.A Purba, Syaiful, and Paridawati**. *Comparative Study of the Performance and Economic Value of a Small Engine Fueled with B20 and B20-LPG as an Effort to Reduce the Operating Cost of Diesel Engines in Remote Areas*, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.
34. **Sinaga, Nazaruddin, B. Yunianto, D.A Purba, Syaiful and A. Nugroho**. *Design and Manufacture of a Low-Cost Data Acquisition Based Measurement System for Dual Fuel Engine Researches*, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.
35. **Y Prayogi, Syaiful**, **and N Sinaga**. *Performance and Exhaust Gas Emission of Gasoline Engine Fueled by Gasoline, Acetone and Wet Methanol Blends*, International Conference on Technology and Vocational Teacher (ICTVT-2018), IOP Conf. Series: Materials Science and Engineering 535 (2019) 012013 doi:10.1088/1757-899X/535/1/012013