Lab 1

Energy tracing = Energy Balance

⇓

Why

→ If we understand how energy is lost we can know how to improve the engine performance in terms of efficiency and power output.

It's simply the first law of thermodynamics:

$$\dot{Q} - \underset{\text{power}}{\dot{W}} = \frac{\sum n_p (\bar{h}^\circ_f + \Delta h)_p - \sum n_R (\bar{h}^\circ_f + \Delta h)_R}{\text{time}}$$

$$Q_{H.V} = \sum n_R (\bar{h}^\circ_f + \underbrace{\Delta h}_{\to 0})_R - \sum n_p (\bar{h}^\circ_f + \underbrace{\Delta h}_{\to 0})_p$$

$$\dot{m}_f \, Q_{H.V} = \frac{\sum n_R \bar{h}^\circ_{f_R} - \sum n_p \bar{h}^\circ_{f_p}}{\text{time}} = \dot{m}_{fuel} * Q_{H.V}$$

$$\dot{W} = T * \omega$$

$$\therefore -\dot{Q} - T\omega = -Q_{H.V}\,\dot{m}_{fuel} + \sum n_p \Delta h_p - \sum n_R \Delta h_R$$

$\div -1$

$$\dot{Q} + T\omega = Q_{H.V}\,\dot{m}_{fuel} + \underbrace{\sum n_R \Delta h_R}_{\to \text{zero}} - \frac{\sum n_p \Delta h_p}{\text{time}}$$

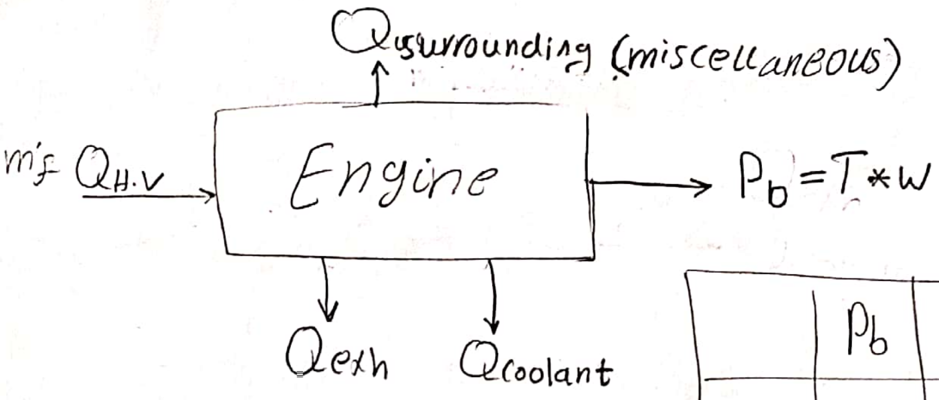
$$\dot{Q} + T\omega = Q_{H.V}\,\dot{m}_{fuel} - \frac{\sum n_p \Delta h_p}{\text{time}}$$

$$Q_{H.V} * \dot{m}_f = \frac{\sum n_p \Delta h_p}{\text{time}} + \dot{Q} + T\omega = \dot{Q}_{exh} + P_b + \dot{Q}$$

$\frac{\sum n_p \Delta h_p}{\text{time}} \Downarrow \dot{m}_{ex} * C_p (T_{ex} - T_{amb})$

$\dot{Q} \to$ Coolant

$\dot{Q} \to$ Surrounding

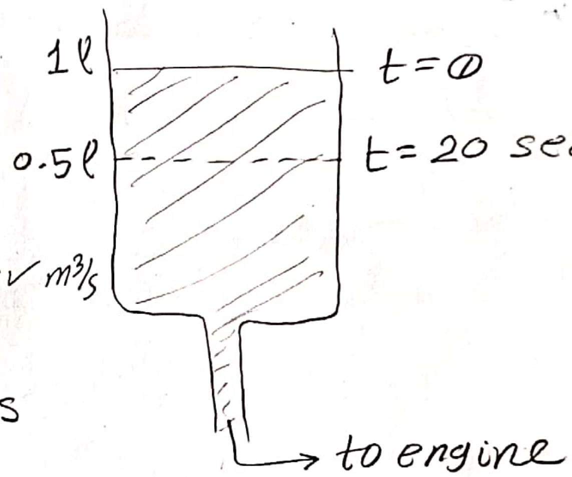


incomplet combustion
exhaust energy

	P_b	Q_{cool}	Q_{misc}	He_{ic}	$\dot{m}h_{ex}$
Diesel	34-38	16-35	2-5	1-2	22-35
SI	25-28	17-26	3-10	2-5	34-45

Fuel Power:

$\dot{m}_{fuel} * Q_{H.V} \Rightarrow$ Given



$$\dot{m}_{fuel} = \rho * \dot{V}_{fuel}$$

$$\dot{V}_{fuel} = \frac{V}{time} = \frac{(1-0.5)*10^{-3}}{20} = \checkmark \ m^3/s$$

$$\dot{m}_{fuel} = \rho * \dot{V}_{fuel} = \checkmark \ kg/s$$

Brake power: The engine power without the loss in power consumed in the gearbox, alternator differential, water pump and auxiliary components.

$$P_b = \underset{\downarrow\ N.m}{T} * \underset{\downarrow\ rad/sec}{W}$$

, Brake power = load (Ib) * N(rpm) * $\frac{0.746}{2800}$

Load → dynamometer ⇒ **Report** (one type of dynamometer)

2

Coolant losses: to reduce engine's temperature

$$Q_{coolant} = \dot{m}_c * C_p * (T_{c,o} - T_{c,i})$$

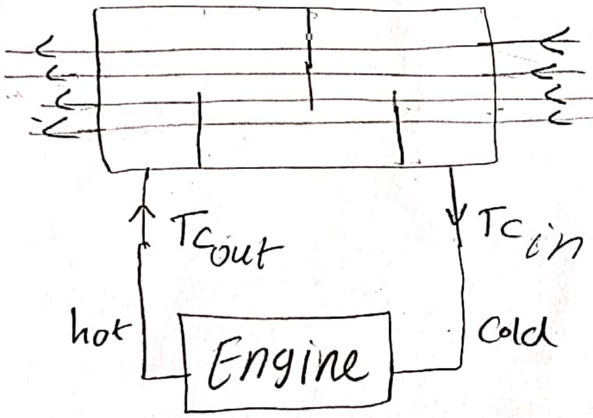
$\dot{m}_c \Rightarrow ?? \Rightarrow$ orifice $\Rightarrow \dot{m}_c = C_d A_o \rho_w \sqrt{\frac{2 g \Delta h \rho_w}{\rho_{merc}}}$

$$\dot{m}_c = 0.0533292 * \sqrt{\Delta h}$$

$\Delta h \rightarrow$ mm

Note: the engine must reach the steady state where the temperatures and speed is constant

Shell and tube heat exchanger



Exhaust losses:

$$Q_{exh} = \dot{m}_{exh} * C_{p_{ex}} * (T_{ex} - T_{amb})$$

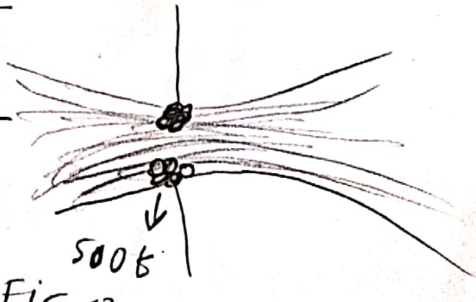
$C_{p_{ex}} \rightarrow \boxed{1.13\ kJ/kg.k}$

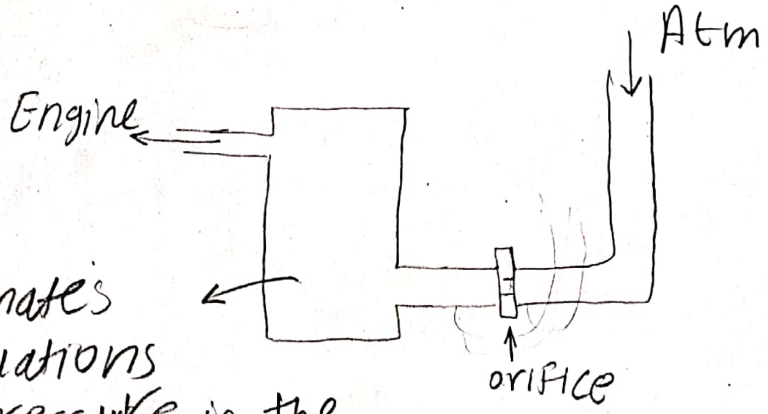
$\dot{m}_{exh} = \dot{m}_{air} + \dot{m}_{fuel} \Rightarrow$ Mass conservation

$$\dot{m}_{air} = \rho_{air} * C_d * A_o * \sqrt{\frac{2 g \cdot h_w * \rho_w}{\rho_{air}}}$$

$\rightarrow$ air orifice

$$\boxed{\rho_{air} = 1.23\ kg/m^3}$$





eliminates fluctuations in pressure in the engine side to obtain constant readings from the manometer

Surrounding losses

$$Q_{surr} = \dot{m}_f Q_{H.V} - P_b - Q_{exh} - Q_{coolant}$$

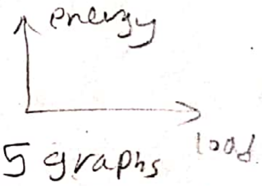
to the oil

radiation from cylinder block

Friction

* at given load Calculate percentage of each type of losses to the fuel power * comment

Required
* dynamometer
* Fill the table
*



5 graphs $\dot{m}_f Q_{H.V}, P_b, Q_{cool}, Q_{exh}$
Q_{surr}
*Graph 6. all energies

No	Speed	Load	h_{cw}	$T_{c,i}$	$T_{c,o}$	$h_{w\text{-}air}$	T_{ex}	V_{fuel}	time
1	1000 RPM	0	Const			Const			
2		5	Const			Const			
3		10	Const			Const			
4		15	Const			Const			
5		20	Const			Const			

Constant speed

No throttle valve

ICE Laboratory

Energy Balance

Objective

To know what is the benefit of Engine Energy Balance and how we made engine test and knowing its performance.

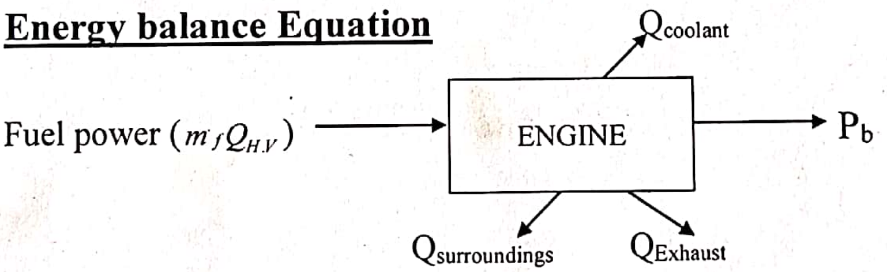
Discussion

- Why do we need to do Engine Energy Balance?
- How can we test the engine performance?
- What are the tools that used in testing the engine?

Engine Energy Balance

There are many reasons to perform an energy balance study on an engine. **The knowledge of how the energy is lost will help in finding means to improve the performance of the engine in terms of efficiency and power output**. This seems to be the main reason behind most energy studies performed on engines. By improving the efficiency of the engine, the result is a higher percentage of the fuel's energy getting converted into power output. This is noticed as improved performance. Although the goal of understanding engine operation to improve efficiency is common, there are many different reasons an energy balance study helps to reach this goal. Energy balances studies help characterize the impact a change has on the overall system. Once the impact is identified by the energy balance, one can attempt to either maximize or oppose its use due to the benefits and drawbacks. These changes include variations in fuel, physical changes to engine design, or adjustments of engine settings.

Energy balance Equation



$$\dot{m}_f Q_{H.V} = P_b + Q_{coolant} + Q_{Exhaust} + Q_{surrounding}$$

Where

$\dot{m}_f$ Is mass flow rate of the fuel (Kg/s)

$Q_{H.V}$ Is the heating value of the fuel (KJ/Kg)

P_b Is the Brake Power of the engine (KW)

$Q_{coolant}$ Is the heat loss to the coolant (KW)

$Q_{Exhaust}$ Is the heat loss from the exhaust (KW)

$Q_{surrounding}$ Is a loss to surroundings that cannot be calculated (friction, oil, radiation)

Now we will take each term and explain how to measure it

Fuel Power

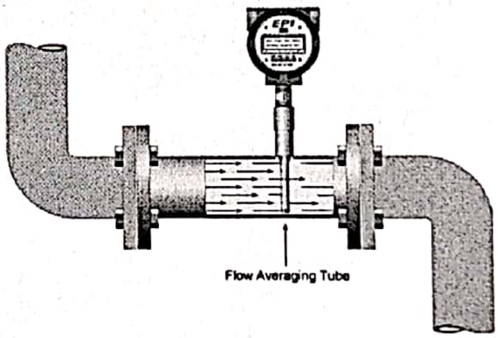
This is the Power which we take from the Fuel. This power is resulted from the chemical reaction of fuel which gives us the heat and explosion we need. We calculate it from the product of mass flow rate multiplied by the Heating value of the fuel .

$$\text{Fuel Power} = \dot{m}_f * Q_{H.V}$$

$Q_{H.V}$ (diesel) = **43.1** Mj/Kg
Density of diesel fuel = **830** Kg/m^3

How to measure Fuel Power

Fuel flow rates ($\dot{m}_f$) were measured with flow meters or else **by measuring the volume of fuel consumed and the specific time of consumption.**



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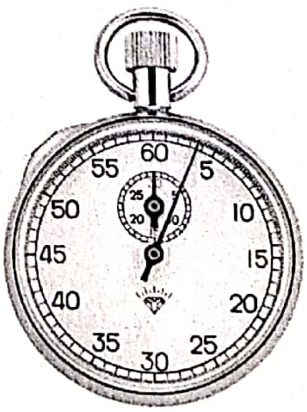


Brake Power (P_b)

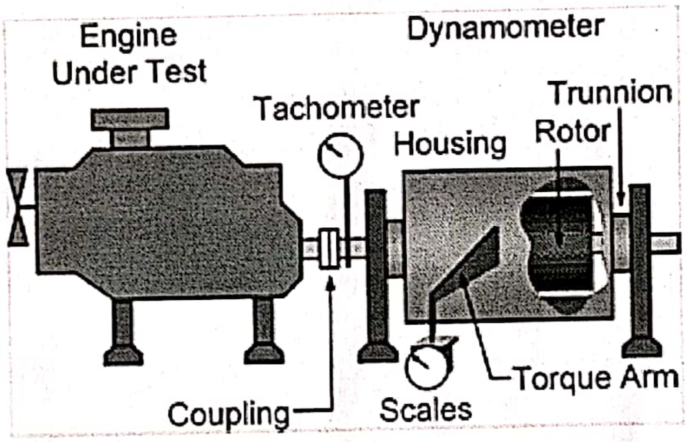
Brake power is the measure of an engine's power without the loss in power caused by the gearbox, alternator, differential, water pump, and other auxiliary components. We get it from the product of the torque multiplied by the RPM of the Engine

$$\text{Brake Power} = \tau_b \times \omega$$

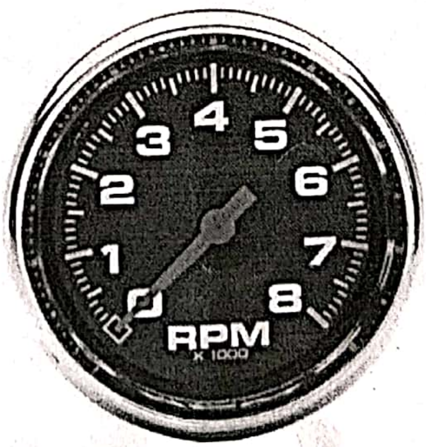
BP(KW) = load(lb) * N(rpm) * 0.746 / 2800

How to measure Brake Power

In order to measure **the brake Torque (τ_b)** of the engines **dynamometers** were used. Hydraulic brake dynamometers were used in most cases examined, however, it should be noted that other dynamometers such as water brake, fan brake, prony brake, eddy current, direct current, or electric motor/generator.



We can measure **engine speed (ω)** by using **tachometers**



Coolant Losses ($Q_{Coolant}$)

This is the heat loss to the coolant. We may name it losses but actually we need to do it to reduce the temperature of the engine. To measure the energy transferred through conduction of engine components, the losses to the coolant, are calculated by:

$$\text{Coolant Losses} = m_c \times c_p \times \left(T_{c,o} - T_{c,i}\right)$$

$$m_c = 0.0533292 * \text{sqrt}(h)$$

Where

m_c is the coolant mass flow rate (Kg/s)

c_p is the specific heat at constant pressure (for water = 4.186 KJ/Kg.k)

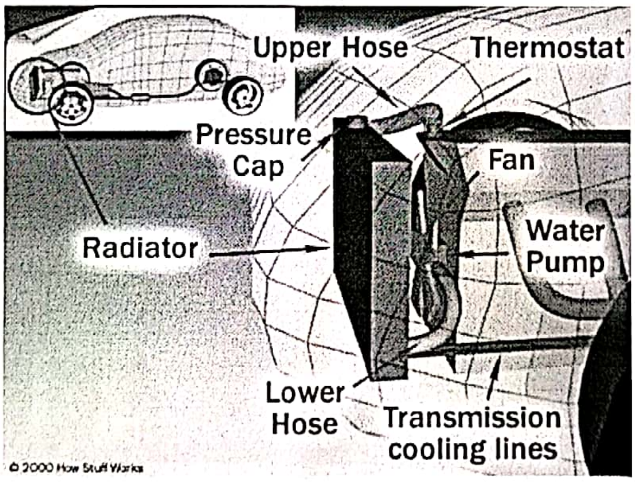
$T_{c,o}$ is outlet coolant temperature

$T_{c,i}$ is inlet coolant temperature

h is manometer reading in (mm)

How to measure Coolant Losses (Q_C)

Heat loss to the engine coolant was usually measured by finding the difference in **coolant temperature at the engine's inlet and outlet.**



Exhaust Losses ($Q_{Exhaust}$)

It is the heat that is released from the exhaust system which contains heat that can be used in any other process in the car. The losses through the exhaust were determined by measuring the air and fuel flow rates, and determining the exhaust gas temperature

$$\text{Exhaust Losses} = m_e \times c_{p_{ex}} \times (T_{ex} - T_{amb})$$

$$m_e = m_{air} + m_{fuel}$$

$$m_{air} = \rho_{air} \times C_d \times A_o \times \text{sqrt}(2 \times g \times h_w \times \rho_w / \rho_{air})$$

Where

m_e is the Exhaust mass flow rate

$C_{p\,ex}$ is the specific heat at constant pressure (if not given assume it = 1.13 KJ/Kg.k)

T_{ex} is exhaust temperature

T_{amb} is ambient temperature

C_d is coefficient of discharge (0.658)

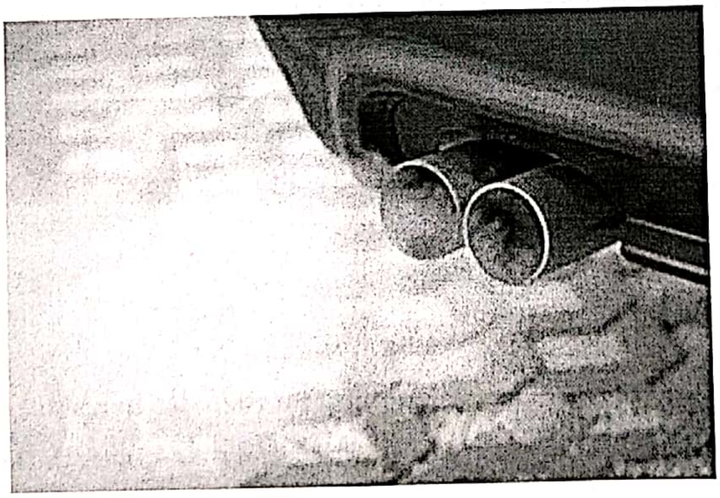
ρ_{air} assume 1.23 kg/m^3

A_o is area of orifice (value is 0.001353 m^2)

How to measure Exhaust Losses (Q_E)

For measuring losses to the exhaust, finding the mass flow rate of the exhaust by direct measurement or from adding **the air and fuel flow rates** into the engine, then maximum heat can be found from cooling the exhaust to ambient temperature.

Air flow rates were measured with either some kind of flow meter or by a pressure change (manometer) in a flow element.



Losses to surrounding ($Q_{surrounding}$)

This term we can not measure it but we can calculate it from the difference of the fuel power and the other losses. This type of losses may go to the oil or friction or by radiation from the cylinder block or anything we cannot calculate easily

Energy balance for the Engine

We will make a variable load test for the engine. All sensors are connected to the engine and all indicators are working.

Procedure:

1. Start the engine
2. Open the throttle valve until the speed reach 1000 rpm
3. Wait while the engine is running until you reach steady state
4. Read all the data shown in the table from the indicators
5. Repeat the same procedures with load varying between (0, 5, 10, 15, and 20)lb

NO.	Speed (RPM)	Load W (lb)	h_{cw}	$T_{c,i}$	$T_{c,o}$	h_{w_air}	T_{ex}	V_{fuel}	time
1									
2									
3									
4									
5									

Requirements

1. **Fill the table and calculate all types of losses**
2. **Draw relationship between the types of Energy and Load on the engine (Load on X-axis ,, Energy on Y-axis)**
   a. **Each energy vs load in a separate graph (5 grpahs)**
   b. **All energies on 1 graph vs load**
3. **Calculate the percentage of each type of losses to the fuel power at a given load (say 10 lb)**
4. **Report about one type of dynamometer.**

	FUEL ENERGY				DYNO.		COOLING LOSSES					EXHAUST LOSSES					
N (RPM)	Vol.	time	m_f*	F.P	W	B.P	h	m_{cw}*	Tin	Tout	Q_{cool}	h	m_{air}*	m_{ex}*	Tex	$Q_{exh.}$	Q_{surr}

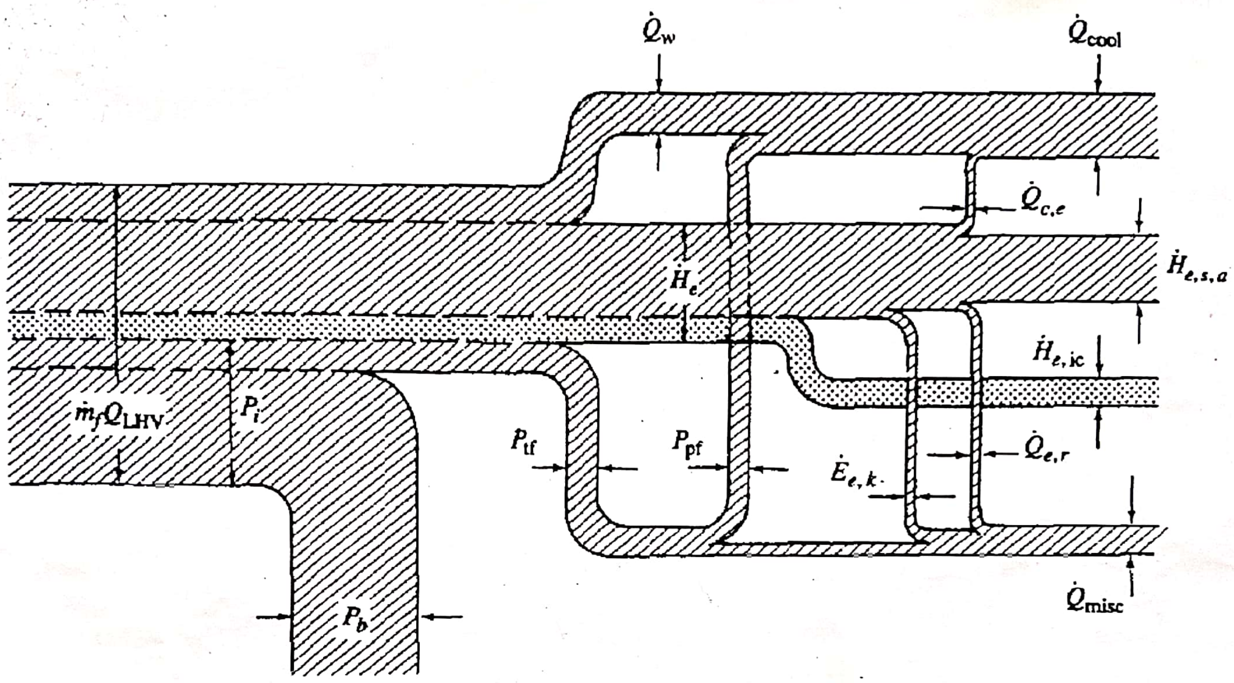


FIGURE 12-3
Energy flow diagram for IC engine. $(\dot{m}_f Q_{LHV})$ = fuel flow rate × lower heating value, $\dot{Q}_w$ = heat-transfer rate to combustion chamber wall, $\dot{H}_e$ = exhaust gas enthalpy flux, P_b = brake power, P_{tf} = total friction power, P_i = indicated power, P_{pf} = piston friction power, $\dot{Q}_{cool}$ = heat-rejection rate to coolant, $\dot{Q}_{c,e}$ = heat-transfer rate to coolant in exhaust ports, $\dot{H}_{e,s,a}$ = exhaust sensible enthalpy flux entering atmosphere, $\dot{H}_{e,ic}$ = exhaust chemical enthalpy flux due to incomplete combustion, $\dot{Q}_{e,r}$ = heat flux radiated from exhaust system, $\dot{E}_{e,k}$ = exhaust kinetic energy flux, $\dot{Q}_{misc}$ = sum of remaining energy fluxes and transfers.

Clean Combust research & other lab → Bengt Johansson

ARAMCO

Energ tracing in ICE

Req: 5 Graphs

BP, $\dot{Q}_{cool}$, Q_{exh}, Q_{surr}, I/P

at load X

$\dot{Q}_{cool}$ %

Q_{exh} %

Q_{surr} %

No	Speed	load lb	$h_{c,w}$ (cm)	$T_{c,i}$	$T_{c,o}$	h_{wair} (cm)	Tex	V_{fuel}	time
1	1000 rpm	0	7.8	33	34	1.2	45	50 mlt	1.50
2		5	7.8	37	39	1.2	65	50	1.35
3		10	7.8	41	43	1.2	70	50	1.05
4									
5									

$\dot{m}_f$

Heywood Fundamental of engine

Friction