<u>Step 1:</u> Calculating the Displacement Volume Rate (V_D)

For an internal combustion engine, the total volume swept by the piston per unit time is the displacement volume rate. This parameter depends on the engine's physical geometry, operational speed, and stroke cycle configuration.

For a **4-stroke engine**, a power stroke occurs once every two revolutions of the crankshaft per cylinder. The formula for the displacement volume rate ($\dot{V}_D$) is expressed as:

$$V_D = \left[\frac{\pi D^2}{4}\right] L \left[\frac{c \cdot a\left(\frac{n}{60}\right) \cdot 2}{s}\right]$$

Where:

- D = Bore diameter = 410 mm = 0.410 m
- L = Stroke length = 460mm = 0.460 m
- n = Engine speed = 810rpm
- s = Number of strokes = 4
- c = Number of cylinders = 1 (assumed baseline unless specified)

Substituting these values into the displacement rate equation:

$$V_D = \left[\frac{\pi(0.410\, m)^2}{4}\right](0.460\, m)\left[\frac{1 \cdot 1\left(\frac{810\, rpm}{60}\right) \cdot 2}{4}\right] = 0.40994\, \frac{m^3}{s}$$

<u>Step 2:</u> Determining the Clearance Ratio (c)

The clearance ratio (c) represents the ratio of the clearance volume (or clearance volume rate, V_C) to the displacement volume (or displacement volume rate, V_D). It is a key parameter that defines the geometric limitations of the cylinder combustion chamber.

$$c = \frac{V_C}{V_D} = \frac{0.06632\, \frac{m^3}{s}}{0.40994\, \frac{m^3}{s}} = 0.1618$$

This means the volume remaining in the cylinder when the piston is at Top Dead Center (TDC) is approximately 16.18% of the volume swept by the piston during its stroke from TDC to Bottom Dead Center (BDC).

<u>Step 3:</u> Deriving the Compression Ratio (r_k)

The compression ratio (**r_k**) is the ratio of the maximum cylinder volume (when the piston is at BDC) to the minimum cylinder volume (when the piston is at TDC). Mathematically, it is defined as:

$$r_k = \frac{V_C + V_D}{V_C} = \frac{c+1}{c} = \frac{0.1618 + 1}{0.1618} = 7.1805$$

The engine compresses the trapped air-fuel mixture to roughly $\frac{1}{7}$ of its original volume before ignition.

Step 4: Computing the Otto Cycle Thermal Efficiency (e_{OL})

For an ideal Otto cycle (representing gasoline engines), thermal efficiency is entirely a function of the compression ratio (r_k) and the specific heat ratio of the working fluid (k). Assuming a standard air-standard value of k = 1.4 for fresh air:

$$e_{OL} = \left(1 - \frac{1}{r_k^{\,k-1}}\right) x\, 100\%$$

Substituting r_k = 7.1805 and k = 1.4:

$$e_{OL} = 54.55\%$$

While the calculated thermal efficiency is **54.55%**, this is an *ideal air-standard limit*. In a physical 4-stroke gasoline engine, actual thermal efficiency is closer to **25% - 35\%**. This dramatic drop is due to real-world irreversibilities:

- Heat loss through the cylinder walls and cooling jackets.
- Incomplete combustion of the fuel.
- Pumping losses (energy spent drawing in air and pushing out exhaust).
- Mechanical friction of the pistons, bearings, and valvetrain.