Charge Stratification and Fuel/Air Ratio Effect on the Efficiency of (ICADE) I. C. Engine Cycle

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Abstract

The Isolated Combustion and Diluted Expansion (ICADE) internal combustion engine cycle combines the advantages of constant volume combustion of the Otto cycle with the high compression ratio of the Diesel cycle. This work studies the effect of isolated air mass (charge stratification) on the efficiency of the cycle; the analysis shows that the decrease of isolated air mass will increase the efficiency of the cycle and the large dilution air mass will quench all NO_x forming reactions and reduce unburned hydrocarbons. Furthermore, the effect of Fuel / Air ratio on the efficiency shows that the increase of Fuel / Air ratio will increase efficiency of the cycle.

Keywords: I.C. engine cycle, isolated combustion, diluted expansion, cycle efficiency.

1. Introduction

The study of air standard cycles to obtain the performance of internal combustion engine has a great importance in spite of the actual engine works at different conditions rather than the supposed conditions in air standard cycles [11].

The actual cycle experienced by an internal combustion engine is not, in the true sense a thermodynamic cycle. An ideal air-standard thermodynamic cycle occurs in a closed system of constant composition. This is not what actually happens in an IC engine, and for this reason air-standard analysis gives, at best, only approximations to actual condition and outputs. Major differences include: [1]

1. Real engines operate on an open cycle with changing composition. Not only does the inlet gas composition differ from what exit, but often the mass flow rate is not the same. During combustion, total mass remains about the same but molar quantity changes. Finally, there is a loss of mass during the cycle due to crevice flow and blow by past the pistons.

2. Air-standard analysis treats the fluid flow through the entire engine as air and approximates air as an ideal gas. In a real engine, inlet flow may be all air, or it may be mixed with up to 7% fuel, either gaseous or as liquid droplets, or both. During combustion, the composition is then changed to a gas mixture of mostly Co_2, H_2O and N_2, with lesser amounts of CO and hydrocarbon vapor.

3. There are heat losses during the cycle of a real engine which are neglected in air-standard analysis. Heat loss during combustion lowers actual peak temperature and pressure from what is protected. The actual power stroke, therefore starts at a lower pressure, and the work output during expansion is decreased.

4. Combustion requires a short but finite time to occur, and heat addition is not instantaneous at TDC, as approximated in an Otto cycle. A fast but finite flame speed is described in an engine. This results in a finite rate of pressure rise in the cylinders, a steady force increase on the piston face, and a smooth engine cycle. Because of the finite time required, combustion is started before TDC and ends after TDC, not at constant volume as in air-standard analysis. By starting combustion TDC, another loss in the combustion process of an actual engine occurs because combustion

efficiency is less than 100%. This happens because of the less than perfect mixing, local variations in temperature and air-fuel due to turbulence, flame quenching, etc. SI engines will generally have a combustion efficiency of about 95%, while CI combustion engines are generally about 98% efficient [8].

5. The blow down process requires a finite real time and a finite cycle time, and does not occur at constant volume as in air-standard analysis. For this reason, the exhaust valve must open 40^0 to 60^0 before BDC, and the output work at the latter end of expansion is lost [5].

6. The intake valve is not closed until after bottom-date center at the end of the intake stroke in an actual engine. Because of the flow restriction of the valve, air is still entering the cycle at BDC, and volumetric efficiency would be lower if the valve closed here. Because of this, however, actual compression does not start at BDC, but only after the inlet valve closes. With ignition then, occurring before top dead center, temperature and pressure rise before combustion is less than predicted by air-standard analysis [10].

7. Engine valves require a finite time to actuate. Ideally, valves would open and close instantaneously, but this is not possible when using a cam follower and this result in fast but finite valve actuation [7].

Because of these differences which real air-fuel cycles have from the ideal cycles, result from air-standard analysis will have errors and will deviate from actual conditions. Interestingly, however, the errors are not great, and property values of temperature and pressure are very representative of actual engine values. Tayler[3] shows that over a large range of operating variables the indicated thermal efficiency of an actual SI four-stroke cycle engine can be approximated by 85% of Otto thermal efficiency.

Three cycles have a great importance during the analysis of I.C. engine; they are:

1. Otto cycle (constant volume cycle)
2. Diesel cycle
3. Dual combustion cycle

Otto cycle represents the theoretical basis of spark ignition engine while the diesel cycle represents the theoretical basis of compression ignition engine. The modern high speed compression ignition engine works with dual combustion cycle.

Otto cycle is distinguished among the three cycles that it has the highest thermal efficiency

when the three cycles work at the same compression ratio. Otto cycle efficiency is given by the equation [5]

$$h = 1 - \frac{1}{r_c^{g-1}} \qquad \qquad …(1)$$

while the efficiency of diesel cycle is given by the equation [5]

$$h = 1 - \frac{1}{r_c^{g-1}} \left(\frac{r^{g-1}}{g(r-1)} \right) \qquad …(2)$$

The engine works by Otto cycle is limited by certain compression ratio due to fuel octane number requirements [9], while diesel engine works at high compression, the ratio is nearly three times of Otto compression ratio. This makes it have the highest efficiency rather than when the engine works by Otto cycle. The heat addition at constant volume in Otto cycle makes it more efficient than the other cycle when they work at the same compression ratio, while the diesel cycle is distinguished by the ability of work at high compression ratio. From this the idea of Isolated Combustion and Diluted Expansion (ICADE) cycle was born. The (ICADE) cycle introduced by (Jone L. Loth & Eric Loth) (4) include the two advantages: heat addition at constant volume, and high compression ratio.

2. ICADE Cycle Description

A new stratified charge internal combustion engine named the "Isolated combustion and Diluted Expansion (ICADE)" engine is described here. It combines the advantage of constant volume combustion and compression ratio of the Diesel cycle. Unlike most designs using an isolated combustion camber, the ICADE cycle does not require any external mechanical controls. At about 30° crank angle before the piston reaches TDC, the cylinder is divided in two parts by an especially design dome mounted on top of the piston. Each part contains roughly the same mass of air. The first part on top of the dome constitutes the combustion chamber. Its compression ratio is designed for the octane number of the fuel at hand. The second part is the remaining cylinder volume above the piston. That part is further compressed to about half the volume of the combustion chamber. This higher compression ratio is what improves the efficiency. Fuel is injected directly into the isolated combustion chamber. A unique feature of this

configuration is that the volume in the isolated combustion chamber varies a little over 30° of crank angle. This allows even slow burning mixtures to burn at near constant volume, thereby producing high combustion pressurization. As soon as the combustion chamber pressure rises above that in the cylinder, a ball type check valve in the dome opens and the combustion products rush into the cylinder to mix with the compressed air. This dilution quenches all No_x forming reactions and provides excess O_2 to reduce unburned hydrocarbons. The dilution of the combustion products prier to expansion simulates a stratified charge engine. Such a stratified engine produces less power per unit of displacement volume. For temporary increased power production additional fuel can be burned by admitting very lean fuel/air mixture instead of pure air. The mixture must be lean enough that compression ignition is not possible. A schematic of the engine geometry is shown in Fig.(1). Depending on the ratio of dome height to piston stroke, the dome starts to isolate the combustion chamber at about 30° before TDC. Although the dome is actually a "leaky valve", the mass above the dome undergoes very little volume change or change or compression and therefore remains at near constant volume at about 30° of crank angle. Near constant volume combustion has several advantages.

1. Fuel injected in the combustion chamber can be ignored early without power loss associated with compression of the combustion product.
2. Fuel cannot leak into the cylinder because the pressure there is higher.
3. Even slow burning fuels have adequate time for combustion thereby producing significant combustion pressurization.
4. Only after combustion pressurization, will the ball be forced of its seat to allow rapid mixing of the combustion products with compressed air above the piston expansion.

No external mechanisms are needed to control the opening and closing of the ball valve. At the start of the compression stroke the inertia of the ball forces it into the piston. There it accelerates with the piston velocity to reach a maximum velocity at midpoint of the stoke.

From there on the piston slows down but the ball continues at constant velocity and thus floats away from the piston to seal off the dome outlet. This occurs just before the dome type isolation valves closes. As the air in the cylinder is further compressed, the resulting pressure differential maintains the check valve in the closed piston. Not until the pressure above the ball exceeds the cylinder pressure by 35 psi will the ball unseat itself and allow the combustion products to rush into the cylinder and mix with the air. The resulting dilution and temperature reduction terminates any No4 forming reactions and reduces the heat losses to the cylinder walls during expansion. To further reduce heat loss the combustion chamber could be insulated as direct fuel injection is used and the walls there need not support any piston skirt force.
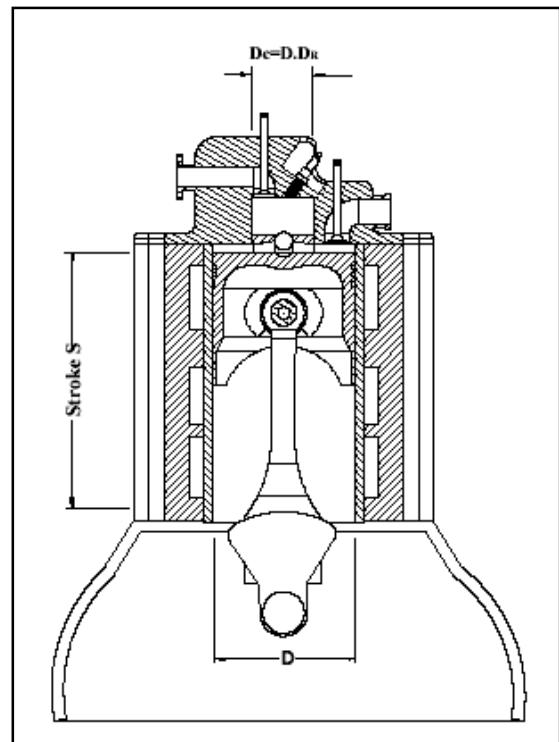

Fig.1. ICADE Engine Layout.

The advantages of the ICADE cycle over the Otto cycle are [4]:

1. The cylinder compression ratio r_p is higher than the combustion chamber compression ratio r_c. Thus the average compression ratio is higher than for the Otto cycle, which explains the higher ICADE cycle efficiency.
2. The ICADE cycle has the combustion products quench from T_{i4} down to T_{i6} immediately after combustion to halt the formation of No_x. This is unlike the Otto cycle where the temperature drops slowly and No_x formation can continue during piston expansion.
3. The ICADE engine can be lighter for the same volume V1 because the maximum cylinder pressure Pi6 is lower than P3 in the Otto cycle.

However for the same power rating the structure weight will be about the same.

4. If the isolation valve closure could be modulated or the combustion chamber volume be reduced at part power operation, then the need for an engine throttle valve and associated efficiency loss would be eliminated. The reduced mixture temperature Ti6 would further lower cycle wall heat losses. But for the configuration shown in Fig.(1) these schemes are not possible as the valve opens and closes automatically under the action of inertia and pressure.

The disadvantages of the ICADE cycle over the Otto cycle are:

1. Required direct combustion chamber fuel injection. But this can be done slowly during about 30° of crank angle.

2. Additional mechanical complexity such as a combustion chamber isolation valve, like a dome on the piston with ball type check valve, is needed.

3. Although for a given engine volume V1 the ICADE cycle engine weight is lower and the efficiency is higher than for the Otto cycle, the power output per unit volume is reduced. For example if the ICADE cycle combustion camber volume Vc is half of the Otto cycle volume V2 , then the fuel burned per cycle is half and the engine power output is reduced accordingly.

3. Analysis of the ICADE Cycle

Making a comparative analysis between the ICADE and the Otto cycle, it is found both cycles are operated at identical conditions such as   [Fuel – Air ratio , combustion compression ratio (r_c) intake conditions (V_1 , P_1 ,T_1 and intake mass m)]. The ICADE cycles differ in that the air remaining in the cylinder] mp = m-m$_c$]is compressed further by the cylinder compression ratio (r_p) with limitation P$_{i5}$ < P$_{i4}$ as shown in Fig. (2) which shows the pressure as a function of crank angle for both Otto and ICADE cycles .

Both cycles have the same maximum temperature ratio;

$$\left[TR = \frac{T_3}{T_1} = \frac{T_{i4}}{T_{i1}} \right]$$

At TDC after combustion the ball type check valve opens and the combustion products mix with the lower air inside the cylinder.

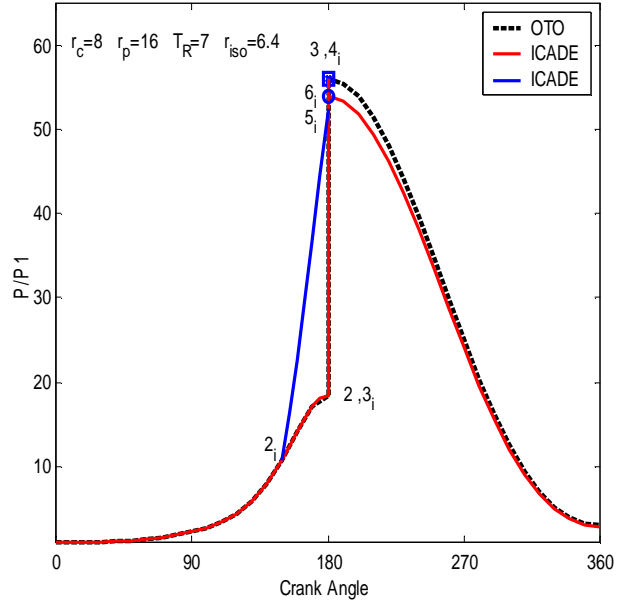$$m_R = \frac{m_P}{m} = \ 1 - \frac{m_c}{m}$$

Fig.2. Pressure as A Function of Crank Angle for Both Otto and ICADE Cycle.

Station 1:- Otto Cycle ICADE Cycle

With volume V_1 , at the start of the compression stroke, with crank angle $q = 0$ degrees to combustion chamber at compression ratio (rc).

$$m = \frac{P_1 V_1}{RT_{1i}} \qquad\qquad …(3)$$

$$r_C = \frac{V_1}{V_2} \qquad \text{(Otto cycle)} \qquad …(4)$$

$$r_C = \left(\frac{V_1}{V_{3i}} \right) \times (1 - mr) \qquad \text{(ICADE cycle)} \qquad …(5)$$

Station 2:- (Otto Cycle Only)

At $q = 180$ degrees   with volume V_2

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1} \right)^{\frac{g}{g-1}} = \left[(r_C)^{g-1} \right]^{\frac{g}{g-1}} \qquad …(6)$$

Station 2i :- [ICADE Cycle Only]

At $q = 150$ degrees. Compression ratio at point of isolation is;

$$r_{iso} = \frac{V_1}{V_{iso}} \qquad \qquad \ldots(7)$$

$$\frac{P_{i2}}{P_1} = \left(\frac{T_{i2}}{T_1}\right)^{\frac{g}{g-1}} = \left[(r_{iso})^{g-1}\right]^{\frac{g}{g-1}} \qquad \ldots(8)$$

Station 3i :- [ICADE Cycle Only]

With volume v_{i3} at $q = 180$ deg *rees*

$$\frac{P_{i3}}{P_1} = \left(\frac{T_{i3}}{T_1}\right)^{\frac{g}{g-1}} = \left[(r_C)^{g-1}\right]^{\frac{g}{g-1}} \qquad \ldots(9)$$

Note that

$$T_{i\,3} = T_2$$

$$P_{i\,3} = P_2$$

But with mass mc instead of m and volume v_c .

Station 3:- [Otto Cycle Only]

At $q = 180$ degrees with mass = m

$$V_3 = V_2$$

combustion at constant volume with temperature ratio $TR = \dfrac{T_3}{T_1}$ which depended on Fuel/ Air ratio.

$$\frac{P_3}{P_2} = \frac{T_3}{T_2} = (TR) \quad \left(\frac{T_1}{T_2}\right) = (TR)\left(\frac{1}{r_c}\right)^{g-1} \qquad \ldots(10)$$

Station 4i :- [ICADE Cycle Only]

At $q = 180$ degrees with mass = mc

$$V_{4\,i} = V_{3\,i}$$

combustion at constant volume with temperature ratio;

$$\left(TR = \frac{T_{i\,4}}{T_i}\right)$$

$$T_{i\,4} = T_3 \qquad \qquad \ldots(11)$$

$$\frac{P_{i4}}{P_{i3}} = \frac{T_{i4}}{T_{i3}} (TR).\left(\frac{T_1}{T_{i3}}\right) = (TR)\left(\frac{1}{r_c}\right)^{g-1} \qquad \ldots(12)$$

$$\frac{P_{i4}}{P_{i3}} = \frac{P_3}{P_2} \qquad \qquad \ldots(13)$$

but

$$P_{i3} = P_2$$

$$P_{i\,4} = P_3 \qquad \qquad \ldots(14)$$

Station 5i :- [ICADE Cycle]

At $q = 180$ degrees, Icade cycle isolated cylinder clearance volume V_P .

$$\frac{V_P}{V_1} = \frac{mr}{r_P} \qquad \qquad \ldots(15)$$

$$\frac{V_C}{V_1} = \frac{(1-mr)}{r_c} \qquad \qquad \ldots(16)$$

$$\frac{T_{5i}}{T_1} = (r_p)^{g-1} \qquad \qquad \ldots(17)$$

$$\frac{P_{5i}}{P_1} = \left(\frac{T_{5i}}{T_1}\right)^{\frac{g-1}{g}} = \left[(r_p)^{g-1}\right]^{\frac{g-1}{g}} \qquad \ldots(18)$$

Station 6i :- [ICADE Cycle]

At $q = 180$ digrees, at this point the piston is still at TDC and the ball type check valve is open which allows the high pressure combustion products at p_{i4} to mix with the air in the cylinder at pressure P_{5i} .

As this process is adiabatic and at constant volume, the internal energy does not change and the final mixture temperature as given by:

$$\frac{T_{6i}}{T_1} = (1-mr)\frac{T_{4i}}{T_1} + (mr)\frac{T_{5i}}{T_1} \qquad \ldots(19)$$

$$V_{6i} = Vp + V_C = V_1\left[\frac{mr}{r_p} + \frac{(1-mr)}{r_c}\right] \qquad \ldots(20)$$

From the equation of state:

$$\frac{P_{6i}}{P_1} = \frac{V_1}{T_1} * \frac{T_{i6}}{V_{i6}} = \frac{\left(\dfrac{T_{i6}}{T_1}\right)}{\dfrac{mr}{r_p} + \dfrac{1-mr}{r_c}} \qquad \ldots(21)$$

Station 4 :- [Otto Cycle]

At $q = 360$ digrees, the Final expansion of the Otto cycle ends up at $V_4 = V_1$, with temperature T_4

$$\frac{P_4}{P_3} = \left(\frac{1}{r_c}\right)^g \qquad \ldots(22)$$

$$\frac{P_4}{P_1} = \frac{P_3}{P_1}\left(\frac{1}{r_c}\right)^r \qquad \ldots(23)$$

$$\frac{T_4}{T_1} = \frac{T_3}{T_1}\left[\left(\frac{1}{r_c}\right)^g\right]^{\frac{g-1}{g}} \qquad \ldots(24)$$

$$\frac{T_4}{T_1} = TR\left[\left(\frac{1}{r_c}\right)^g\right]^{\frac{g-1}{g}} \qquad \ldots(25)$$

Station 7i :- [ICADE Cycle]

The final expansion of the ICADE cycle ends up at $V_{7i} = V_1$ with temperature T_{7i}

$$\frac{T_{7i}}{T_1} = \frac{T_{6i}}{T_1}\left(\frac{V_{6i}}{V_{7i}}\right)^{g-1} = \frac{T_{6i}}{T_1}\left(\frac{mr}{r_p} + \frac{1-mr}{r_c}\right)^{g-1} \qquad \ldots(26)$$

For the ICADE cycle:
The expansion work

$$= mc_v\left(T_{i6} - T_{i7}\right) \qquad \ldots(27)$$

The compression work

$$= m_p c_V\left(T_{5i} - T_{1i}\right) + m_c C_v\left(T_{3i} - T_{1i}\right) \qquad \ldots(28)$$

The heat supplied

$$= m_c c_v\left(T_{4i} - T_{3i}\right) \qquad \ldots(29)$$

$$h_{i_{th}} = \frac{\left[mc_v\left(T_{6i} - T_{7i}\right)\right] - \left[m_p c_v\left(T_{5i} - T_{1i}\right) + m_c c_v\left(T_{3i} - T_{1i}\right)\right]}{m_c \quad C_V\left(T_{4i} - T_{3i}\right)} \qquad \ldots(30)$$

$$h_{ith} = \frac{\left(T_{6i} - T_{7i}\right) - \frac{m_p}{m}\left(T_{5i} - T_{1i}\right) - \frac{m_c}{m}\left(T_{3i} - T_{1i}\right)}{\frac{m_c}{m}\left(T_{4i} - T_{3i}\right)} \qquad \ldots(31)$$

By substituting the temperatures from the above equations this expression is reduce to:

$$h_{ith} ICADE = 1 - \frac{B}{r_c^{(g-1)}} \qquad \ldots(32)$$

Where B is given by :

$$B = \frac{\left[mr + \frac{r_P}{r_c}\left(1 - mr\right)\right]^{g-1}\left[\frac{\left(1 - mr\right)TR}{\left(r_p\right)^{g-1}} + mr\right] - 1}{\frac{\left(1 - mr\right) \quad TR}{r_c^{g-1}} + mr \quad - 1} \qquad \ldots(33)$$

The cycle efficiency improvement is shown in Fig. (3) as a function of the added piston compression after isolation as given by (r_p / r_c). The ICADE cycle reduces to the Otto cycle for the case when (m_p) goes to zero, or if the mass (m_p) has no extra compression or $r_p = r_c$ in either case coefficient B is reduced to 1.
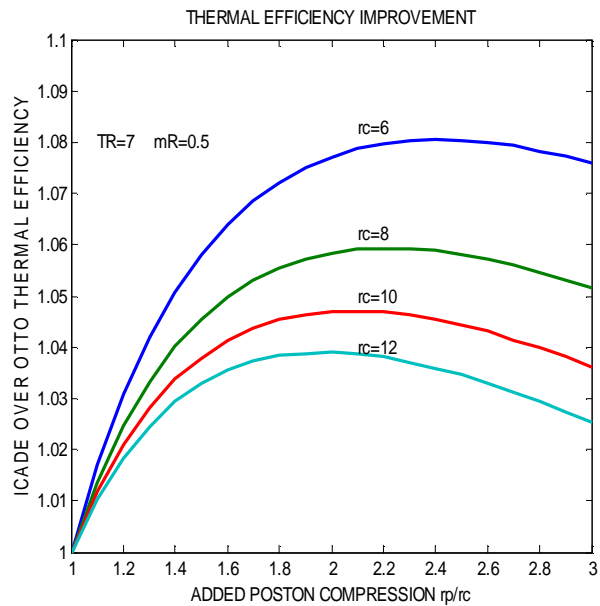

Fig.3. Comparison of ICADE and Otto Cycle Efficiency.

4. Discussion of Results
4.1. Isolated Air Mass (Charge Stratification) Effect

Both cycles are based on the same intake mass m, P, T, and combustion compression ratio r_c .

m_c is the mass isolated in the combustion chamber which compressed by r_c and mixed with fuel to ignite.

When we reduces m_c, m_p will increase , thus m_r will increase; this means the amount of mass compressed by r_p will increase and the cycle efficiency will approach to diesel cycle efficiency, but this will decrease the power generation from an engine.

The effect of isolated air mass is shown in Fig. (4), the ICADE cycle efficiency increases with the decrease of isolated air mass[increases of m_r]; the improvement over the Otto cycle efficiency is about 10% when (mr = 0.6) An increase of mr means that the stratification portion of the mass m_p will increase; this will quench all No_x forming reactions and provide excess O_2 to reduce unburned hydrocarbons.

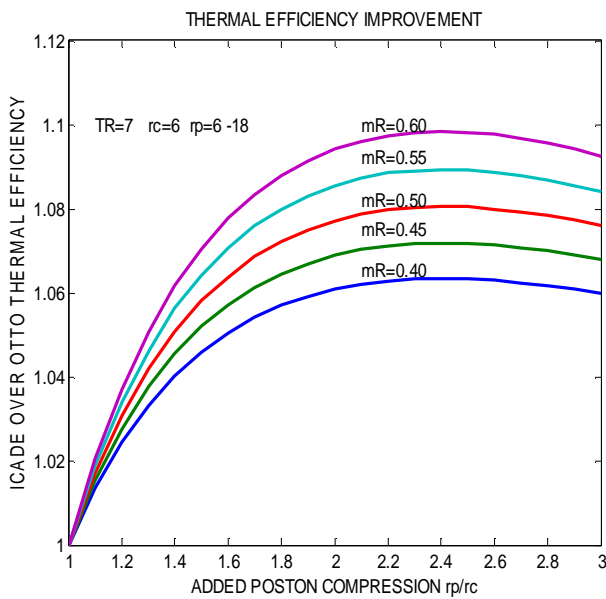More decreases in isolated air mass are not practical because of power losses.

We can notice that the increasing of efficiency of cycle with the increasing mr and TR.
In fact to obtain the best performance it is advised to work at high F/ A and high mr but according to the power requirement limitation.

The use of greater mr means the existence of great amount of air outside combustion chamber, so reducing the unburned hydrocarbons.

Fig. (7) shows the improvement of cycle efficiency over Otto efficiency at (mr = 0.6, TR= 8) compared to the efficiency at (mr = 0.5, TR= 7). The use of (mr= 0.6, TR= 8) means the highest efficiency, the greatest power and little unburned hydrocarbons, but this will be accompanied with the increase of heat transfer to the cylinder wall in expansion stroke because of the raising of T_{6i} value.
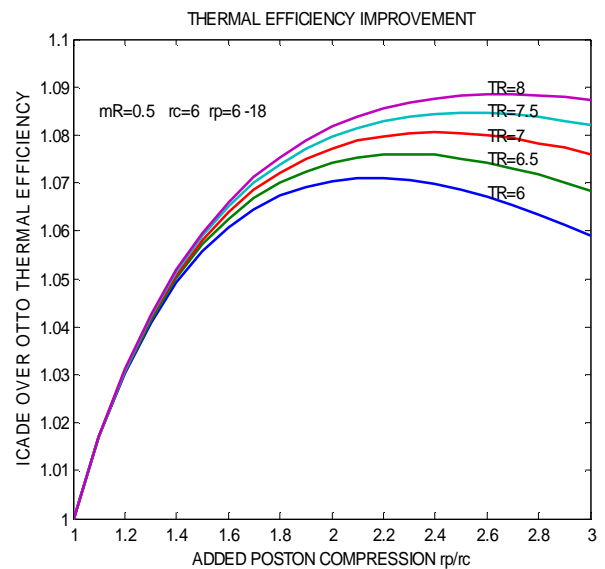

Fig.4. Effect of Charge Stratification on ICADE Efficiency Improvement.

Fig.5. Effect of FUEL/ Air Ratio on ICADE Efficiency Improvement.

4.2. Fuel/ Air Ratio Effect

At an increase F/A ratio inside the combustion chamber, this will lead to the increase of release energy, and so increase the maximum temperature inside the combustion TR

The effect of $\dfrac{F}{A}$ ratio on the efficiency of (ICADE) cycle is shown in Fig. (5).

We notice the efficiency increase with TR increasing so as the improvement over the Otto cycles thermal efficiency reaches 9% at TR = 8, with the increasing of power generation at the cycle.

But on the other hand the increasing of F/ A ratio will lead to the increasing of unburned hydrocarbons.

Fig.(6) show the improvement of efficiency over the efficiency of Otto cycle at different F/ A values and different values of mr .
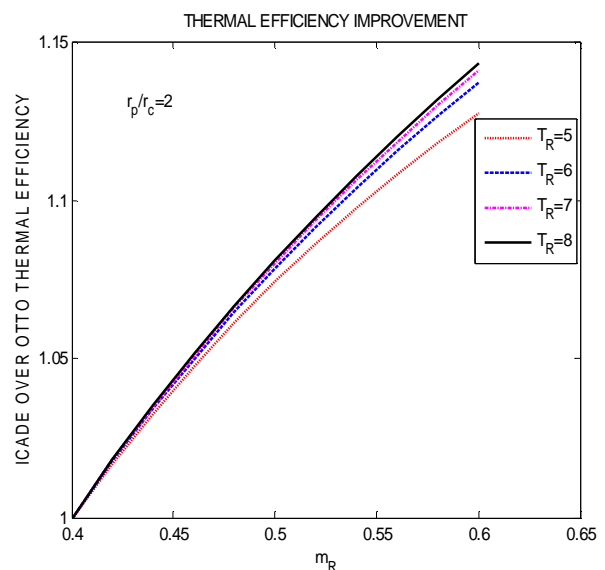
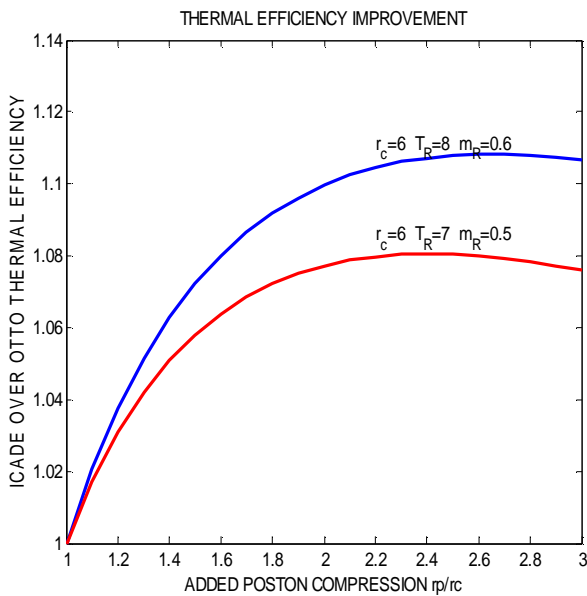**Fig.6. Combined Effect of Charge Stratification and Fuel/Air Ratio.**

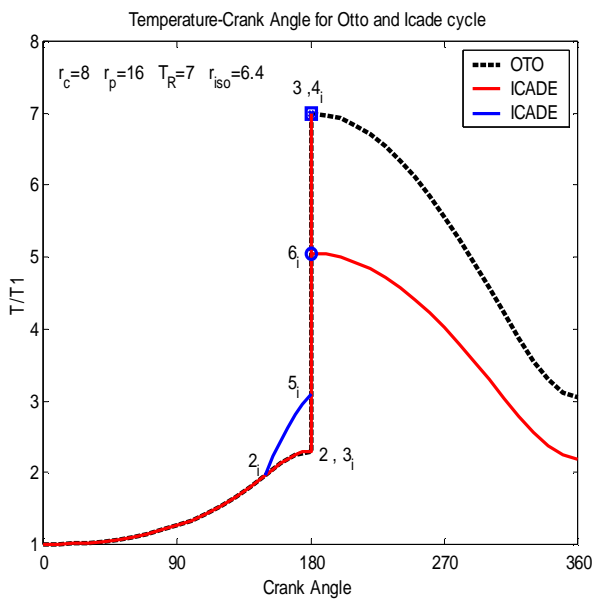**Fig.7. Comparison of ICADE Efficiency at Different Values of TR and m_R.**

Fig.8. Temperature as Function of Crank Angle for Both ICADE and Otto Cycles

5. Conclusions

1- Conversion to the ICADE cycle benefits the efficiency of spark ignition engines because the compression ratio is doubled and combustion pressurization is improved, even with slowly burning fuels.

2- It will be able to improve the cycle efficiency through the control of F/A and the amount of isolated air.

3- With the decreasing of the isolated air in combustion chamber, the efficiency of cycle will increase but power generation will decrease with the decreasing of isolated air amount.

4- During the increase F/A which means the highest maximum temperature of the cycle TR, the cycle efficiency will increase.

5- The combustion product dilution provides the excess air needed to minimize emissions of unburned hydrocarbons and reduce NOx formation.

6- Detonation is not expected to be too harmful as only the relatively small piston dome is subjected to the shock wave. Also the combustion product compression by the piston will be small [5].

Nomenclature

B	coefficient defined in text
C_v	specific heat at constant volume (kJ/kg.K)
D	piston diameter (m)
D_c	combustion chamber diameter (m)
D_R	combustion chamber to piston diameter ratio
m	total cylinder intake air mass (kg)
m_c	isolated combustion chamber mass (kg)
m_p	isolated cylinder air mass (kg)
m_r	charge stratification, mr = mp/m
P( )	Otto cycle pressure at station ( ) (Pa)
P_1	inlet reference pressure = P_{i1} (Pa)
P_i( )	ICADE cycle pressure at station ( ) (Pa)
s	piston stroke (m)
r_c	max. combustion chamber compression ratio
r_{iso}	compression ratio at point of isolation
r_p	cylinder compression ratio
T( )	Otto cycle temperature at station ( ) (K)
T_i( )	ICADE cycle temperature at station ( ) (K)
T_1	inlet reference temperature = Ti1 (K)
TR	maximum cycle temperature divided by T_1
V_1	maximum intake volume with piston at BDC (m^3)
V_c	combustion chamber volume (m^3)

V_d piston displacemen volume (m^3)

V_p cylinder clearance volume , piston at TDC (m^3)

$V()$ volume with piston at station ( ) (m^3)

γ specific heat ratio

$\acute{\eta}_{th}$ thermal efficiency

θ compression crank angle starting at BDC

ρ cutoff ratio

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تأثير الشحنة المطبقة ونسبة الوقود / الهواء على كفاءة دورة محرك الاحتراق الداخلي (ICADE)

حيدر عبد ضهد

مركز التدريب والمعامل/ الجامعة التكنولوجية

الخلاصة

دورة محرك الاحتراق الداخلي ذات الاحتراق المعزول والتمدد المخفف (ICADE) تجمع بين مميزات الاحتراق بثبوت الحجم في دورة اوتو مع نسبة الانضغاط العالية في دورة ديزل ، يدرس هذا البحث تأثير كتلة الهواء المعزول (الشحنة المطبقة) على كفاءة الدورة وقد تبين من خلال التحليل بان تقليل كتلة الهواء المعزول يودي إلى زيادة كفاءة الدورة ، كما ان زيادة كمية الهواء المخفف سيؤدي إلى تخميد تكون اكاسيد الناتروجين NO_x وكذلك الهايدرو كاربونات الغير محترقة ، كما تم دارسة تأثير نسبة الوقود / الهواء على كفاءة الدورة حيث تبين بان زيادة نسبة الوقود م الهواء سيؤدي إلى زيادة كفاءة الدورة.