

Research Article

Thermodynamic Modeling and Performance Analysis of an Atkinson cycle under Efficient Power Density Condition

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Abstract

Thermodynamic analysis of an ideal air standard Atkinson cycle using Work Criteria Function (WCF) is presented in this paper. Three past known criteria in the context of Finite time thermodynamics or Entropy Generation Minimization i.e Power, Power density & efficient power are re-casted in terms of Work Criteria Function which is relatively a new approach to analyze the performance & maximize the power output of any heat engines. The formulation of this concept gives rise to new performance criteria i.e Efficient power density (EPD) which is defined as the efficient power divided by maximum volume of working fluid & its maximum value gives Maximum Efficient Power Density (MEPD). This theory has been implemented to calculate the Power output & efficiency of an Atkinson cycle. Finally a comparative study of different criteria has been made to draw the inference & thus result is obtained. The result obtained from this analysis showed that engine designed at MEPD condition have an advantage of smaller size, more efficient & requires lesser pressure ratio than those designed at MP, MPD & MEP conditions. This work has been carried out by incorporating relative air fuel ratio, fuel mass flow rate & residual fraction such that these parameters are the function of variable specific heat & it is observed that the efficiency increases with the increase of relative air fuel ratio & residual fraction. This result can be helpful in the thermodynamic modeling & design of practical Atkinson engine

Keywords: Atkinson cycle, Finite time thermodynamics, power density, efficient power, efficient power density, Work criteria Function (WCF), relative air fuel ratio, mass flow rate of fuel & residual gases.

1. Introduction

Atkinson cycle is a type of internal combustion engine which was named after its inventor a British Engineer James Atkinson in 1882 (Pulkrabek WW, 2004). FTT concept has been used as diagnostic tool in wide range of application & research areas in the fields of quantum thermodynamics [F. L. Curzon and B. Ahlborn, 1975]. It has been used to optimize & analyze the performance of real thermodynamic process, systems, engines & cycles. Leoff determined the thermal efficiency of a reversible Atkinson cycle at maximum work output. Ge et al studied the performance of endoreversible & irreversible Atkinson cycle. Wang & Hou compared the performance of air standard Atkinson cycle & Otto cycles (Wang P, Hou SS, 2005). Chen et al & Sahin et al evaluate the performance characteristics of reciprocating Diesel, Otto, Atkinson, Brayton, Carnot, dual & Miller cycles & made a comparative performance analysis & optimization of irreversible Atkinson cycle under maximum power density & maximum power conditions (Chen L, Lin J, Sun F, 1998).

From detailed study it is found that under MPD condition it is more advantageous in the point of view of engine size & thermal efficiency. Liu & Chen investigated the influence of variable heat capacities of the working fluid, heat leak losses, compression & expansion efficiencies & other parameters of Atkinson cycle & Joule Brayton cycle (Zheng T, Chen L, Sun F, et al, 2002). Recently it was found that temperature dependent specific heats gives better approximation to actual cycles than using constant temperature specific heats. (Sarkhi A, Akash B, Abu-Nada E, et al, 2008)

Maheshwari G & Patodi K analyzed the Atkinson cycle with variable specific heat of the working fluid under MEP conditions (Maheshwari G, Chaudhary S, Somani SK, 2009). They conclude that MEP conditions had an advantage of smaller size & are more efficient than those designed at MP & MPD conditions beside engines designed at MEP conditions require lesser pressure ratio than those designed at MPD conditions (Maheshwari G, Chaudhary S, Somani SK, 2007). The optimal design parameters have been derived analytically & the effect of irreversibilities on general & optimal performances was evaluated.

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Maximizing the efficient power gave a compromise between power & efficiency. The different performance criteria were employed to optimize the performance of Atkinson cycle using FTT concept & taking account endoreversible & internally irreversible conditions. The inclusion of the engine size in the evaluation of its performance is very important factor from an economical point of view. Huleihil.M formulate a more generalized approach combining the known criteria in literature (maximum power, maximum power density & maximum efficient power) are reviewed & recast in terms of Work Criteria Function (WCF)(Huleihil.M,2014). This WCF allows the definition of a new criterion, the efficient power density (EPD) which is defined as efficient power divided by maximum volume of working fluid & its maximum is Maximum efficient power density (MEPD).

$$WCF = \eta^a \cdot Q_h / V_{max}^b \tag{1}$$

In this equation a & b are integers to represent the criterion considered in the study. The study uses a=0, b=0 to give the expression of the heat input to the system & the power extracted by the engines is given when a=1 & b=0. The power density criterion is defined when a=1 & b=1. The efficient power criterion is defined when a=2 & b=0. The efficient power density is defined when a=2 & b=1.

2. Thermodynamic Modeling

The PV & TS diagram of air standard Atkinson cycle is shown in figure 1. All four processes are reversible. process 1-2 is an adiabatic (isentropic) compression; process 2-3 is a heat addition at constant volume; process 3-4 is adiabatic expansion process; process 4-1 heat rejection at constant pressure. In actual practical cycles the specific heats of working fluid are variable & these variations will have great influence on the performance of cycle (Ebrahimi R, 2011). The variable specific heat model incorporates residual fraction mass flow rate of fuel & air, relative air fuel ratio.

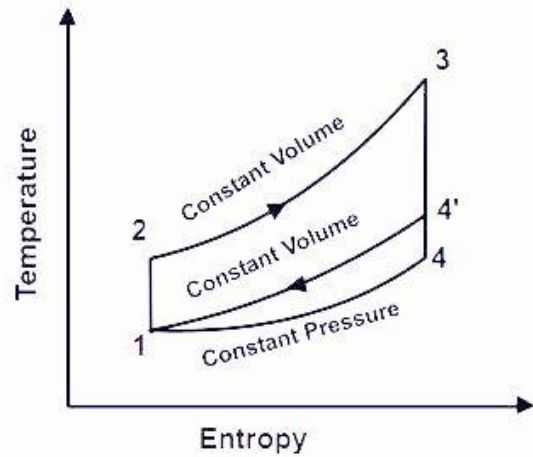
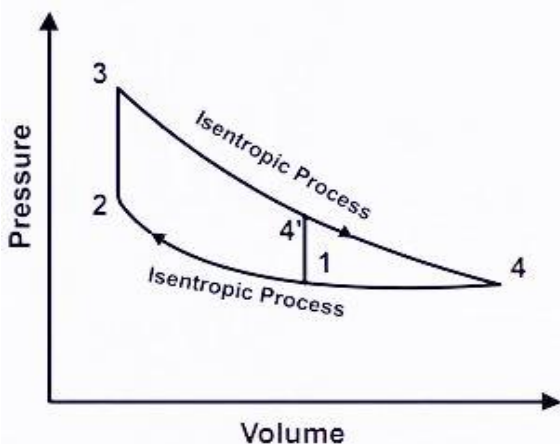


Figure 1: P-V and T-S diagram of air standard Atkinson cycle

The relation between the mass flow rate of the fuel (m_f), mass flow rate of air (m_a), mass flow rate of mixture (m_x), mass flow rate of residual gas (m_r), relative air fuel ratio (λ) & residual fraction (X_r) are given below in Equation (1)-(11). (Ebrahimi R, 2013). The subscripts f, a, x, r represents fuel, air, mixture, residue respectively. The variations of specific heats with respect to above parameters can be expressed as,

$$C = \frac{(m_a c_a + m_f c_f + m_r c_r)}{(m_a + m_f + m_r)} \tag{1}$$

$$X_r = \frac{m_r}{(m_a + m_f + m_r)} \tag{2}$$

$$1 - X_r = \frac{m_a + m_f}{(m_a + m_f + m_r)} \tag{3}$$

$$\lambda = \frac{(m_a / m_f)_{actual}}{(m_a / m_f)_{ideal}} \tag{4}$$

$$z = \frac{(1 - x_r)}{\{1 + \lambda (m_a / m_f)_{ideal}\}} = \frac{m_f}{(m_a + m_f + m_r)} \tag{5}$$

$$z \lambda \left(\frac{m_a}{m_f}\right)_{ideal} = \frac{m_a}{(m_a + m_f + m_r)} = \frac{\text{mass of air}}{\text{total mass of mixture}} \tag{6}$$

$$\left\{ \frac{m_a}{(m_a + m_f + m_r)} \right\} = \frac{(1 - x_r) \lambda (m_a / m_f)_{ideal}}{\{1 + \lambda (m_a / m_f)_{ideal}\}} \tag{7}$$

$$\left\{ \frac{m_f}{(m_a + m_f + m_r)} \right\} = \frac{(1 - x_r)}{\{1 + \lambda (m_a / m_f)_{ideal}\}} \tag{8}$$

$$\left\{ \frac{m_r}{(m_a + m_f + m_r)} \right\} = \frac{(x_r) \{1 + \lambda (m_a / m_f)_{ideal}\}}{\{1 + \lambda (m_a / m_f)_{ideal}\}} \tag{9}$$

$$C_{vx} = \frac{[(1 - x_r) \{ \lambda \left(\frac{m_a}{m_f}\right)_{ideal} c_{va} + c_{vf} \} + x_r c_{vr} \{1 + \lambda \left(\frac{m_a}{m_f}\right)_{ideal}\}]}{\{1 + \lambda \left(\frac{m_a}{m_f}\right)_{ideal}\}} \tag{10}$$

$$C_{px} = \frac{[(1 - x_r) \{ \lambda (m_a / m_f)_{ideal} c_{pa} + c_{pf} \} + x_r c_{pr} \{1 + \lambda (m_a / m_f)_{ideal}\}]}{\{1 + \lambda \left(\frac{m_a}{m_f}\right)_{ideal}\}} \tag{11}$$

The heat supplied or heat addition in the isochoric process may be written as

$$Q_s = m_x C_{vx} (T_3 - T_2) \tag{12}$$

From eqⁿ (20), (21) & (22)

Mass flow rate of air fuel mixture is given as

$$\frac{T_4}{T_1} = \left(\frac{\tau}{\theta}\right)^{1/\gamma} \tag{23}$$

$$m_x = \frac{mf \{1 + \lambda \left(\frac{ma}{mf}\right)_{ideal}\}}{(1 - x_r)} \tag{13}$$

Using Equation (20) - (23) we get Net Work done

The heat rejected during isobaric heat rejection process is given as

$$= \left[\frac{mf}{(1 - x_r)}\right] [T_1] \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} [\tau - \theta] - \left[\frac{mf}{(1 - x_r)}\right] [T_1] \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \left[\left(\frac{\tau}{\theta}\right)^{1/\gamma} - 1 \right]$$

$$Q_r = m_x C_{px} (T_4 - T_1) \tag{14}$$

From eqⁿ (10), (11), (12), (13) & (14) we get following equations,

$$= \left[\frac{mf}{(1 - x_r)} T_1\right] \left\{ \left[(1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right] [\tau - \theta] - \left[(1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right] \left[\left(\frac{\tau}{\theta}\right)^{1/\gamma} - 1 \right] \right\} \tag{24}$$

$$Q_s = m_f \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\frac{(T_3 - T_2)}{(1 - x_r)} \right] \tag{15}$$

$$Q_r = m_f \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\frac{(T_4 - T_1)}{(1 - x_r)} \right] \tag{16}$$

Let us assume:

$$K_1 = \left[\frac{mf}{(1 - x_r)}\right] [T_1] \tag{25}$$

2.1 Power output & MP output

The power output (W) of the cycle can be written as:

$$W = Q_s - Q_r \tag{17}$$

Substituting the value of Q_s & Q_r from Equation (15) and (16) it can be written as,

$$K_2 = [(1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} \right\}] \tag{26}$$

$$K_3 = [X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\}] \tag{27}$$

$$K_4 = [(1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\}] \tag{28}$$

$$K_5 = [X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\}] \tag{29}$$

$$K_6 = [K_2 + K_3] \tag{30}$$

$$K_7 = [K_4 + K_5] \tag{31}$$

$$K_8 = [K_6 / K_7] \tag{32}$$

$$= m_f \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\frac{T_3 - T_2}{1 - x_r} \right] - m_f \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\frac{T_4 - T_1}{1 - x_r} \right]$$

$$= \left[\frac{mf}{(1 - x_r)}\right] \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} [T_3 - T_2] - \left[\frac{mf}{(1 - x_r)}\right] \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} [T_4 - T_1] \tag{18}$$

Multiplying & dividing by T₁ in eqⁿ (18)

$$= \left[\frac{mf}{(1 - x_r)}\right] [T_1] \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{va} + C_{vf} \right\} + X_r C_{vr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\left(\frac{T_3}{T_1}\right) - \left(\frac{T_2}{T_1}\right) \right] - \left[\frac{mf}{(1 - x_r)}\right] [T_1] \left\{ (1 - X_r) \left\{ \lambda \left(\frac{ma}{mf}\right)_{ideal} C_{pa} + C_{pf} \right\} + X_r C_{pr} \left\{ 1 + \lambda \left(\frac{ma}{mf}\right)_{ideal} \right\} \right\} \left[\left(\frac{T_4}{T_1}\right) - \left(\frac{T_1}{T_1}\right) \right] \tag{19}$$

$$\tau = \left(\frac{T_3}{T_1}\right) \tag{20}$$

& Isentropic temp. ratio (θ)

$$\theta = \left(\frac{T_2}{T_1}\right) \tag{21}$$

The total change in entropy change in cycle must be zero, therefore

$$T_2 T_4^\gamma = T_3 T_1^\gamma \tag{22}$$

$$Q_s = [K_1] [(K_2) + (K_3)] [\tau - \theta]$$

$$Q_s = [K_1] [K_6] [\tau - \theta] \tag{33}$$

$$Q_r = [K_1] [(K_4) + (K_5)] \left[\left(\frac{\tau}{\theta}\right)^{1/\gamma} - 1 \right]$$

$$Q_r = [K_1] [K_7] \left[\left(\frac{\tau}{\theta}\right)^{1/\gamma} - 1 \right] \tag{34}$$

From Equation (17), (33) and (34) it can be written as:

$$W = [K_1] \left\{ [K_6] [\tau - \theta] - [K_7] \left[\left(\frac{\tau}{\theta}\right)^{1/\gamma} - 1 \right] \right\} \tag{35}$$

For a given τ taking the derivative of W with respect to θ & setting it equal to zero $\left[\frac{dW}{d\theta} = 0\right]$ will give the optimum value of θ as θ_{mp}. Substituting the value of θ_{mp} in Equation (35) $[\theta \approx \theta_{mp}]$ will give the MP output (W_{mp}) as:

$$W_{mp} = [K_1] \left\{ [K_6] [\tau - \theta_{mp}] - [K_7] \left[\left(\frac{\tau}{\theta_{mp}}\right)^{1/\gamma} - 1 \right] \right\} \tag{36}$$

The efficiency(η) of cycle can be expressed as:

$$\text{Efficiency}(\eta) = \frac{\text{Net work done}}{\text{Heat supplied}} = \frac{W}{Q_s}$$

$$\eta_{mp}(\tau) = 1 - \left[\left(\frac{\tau}{\theta} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_7}{(\tau - \theta) \cdot K_6} \right] \tag{37}$$

On using Equation (33)&(36) we get efficiency at the MP condition as function of τ :

$$\eta_{mp}(\tau) = 1 - \left[\left(\frac{\tau}{\theta_{mp}(\tau)} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_7}{(\tau - \theta_{mp}(\tau)) \cdot K_6} \right]$$

$$\eta_{mp}(\tau) = 1 - \left[\left(\frac{\tau}{\theta_{mp}(\tau)} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mp}(\tau))} \right] \tag{38}$$

2.2 Power density & MPD condition

The power density (W_{pd}) of the cycle is defined as the ratio of the output power (W) to the maximum specific volume (v_4).

Power Density is termed as,

$$W_{pd} = \frac{W}{v_4} \tag{39}$$

$$\text{For closed cycle } v_4 = \left(\frac{\tau}{\theta} \right)^{1/\gamma} \times v_1 \tag{40}$$

Combining equation (35) & (40)

$$W_{pd} = \left[\frac{mf}{(1-xr)} \right] \left[\frac{T_1}{\left(\frac{\tau}{\theta} \right)^{1/\gamma}} \right] \left[\frac{1}{v_1} \{ [K_6][\tau - \theta] - [K_7] \left[\left(\frac{\tau}{\theta} \right)^{1/\gamma} - 1 \right] \} \right] \tag{41}$$

For a given τ , taking the derivative with respect to θ and setting it equal to zero ($\frac{dW_{pd}}{d\theta} = 0$) will give the optimum value of θ as θ_{mpd} . Substituting the value of θ_{mpd} in Equation (41) [$\theta \approx \theta_{mpd}$] it can be written θ_{mpd} , W_{mpd} and η_{mpd} as:

$$W_{mpd} = [K_1] \left[\frac{1}{\left(\frac{\tau}{\theta_{mpd}} \right)^{1/\gamma}} \right] \left[\frac{1}{v_1} \{ [K_6][\tau - \theta_{mpd}] - [K_7] \left[\left(\frac{\tau}{\theta_{mpd}} \right)^{1/\gamma} - 1 \right] \} \right] \tag{42}$$

$$\eta_{mpd}(\tau) = 1 - \left[\left(\frac{\tau}{\theta_{mpd}(\tau)} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mpd}(\tau))} \right] \tag{43}$$

2.3 Efficient power & MEP

The efficient power of the cycle is defined as the product of power (W) & efficiency (η).

Defining efficient power as,

$$W_{ep} = W \times \eta \tag{44}$$

Substituting the value of W & η from Equation (35) & (37) we get,

$$W_{ep} = [K_1] \{ [K_6][\tau - \theta] - [K_7] \left[\left(\frac{\tau}{\theta} \right)^{1/\gamma} - 1 \right] \} \cdot \left\{ 1 - \left[\left(\frac{\tau}{\theta} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta)} \right] \right\} \tag{45}$$

For a given τ , taking the derivative with respect to θ and setting it equal to zero ($\frac{dW_{ep}}{d\theta} = 0$) will give the optimum value of θ as θ_{mep} . Substituting the value of θ_{mep} in Equation (45) [$\theta \approx \theta_{mep}$] it can be written W_{mep} & η_{mep} as:

For maximum efficient power,

$$\frac{dW_{ep}}{d\theta} = 0 \tag{46}$$

The value of θ_{mep} can be calculated by iteration method by substituting different value of τ .

$$W_{mep} = [K_1] \{ [K_6][\tau - \theta_{mep}] - [K_7] \left[\left(\frac{\tau}{\theta_{mep}} \right)^{1/\gamma} - 1 \right] \} \cdot \left\{ 1 - \left[\left(\frac{\tau}{\theta_{mep}} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mep})} \right] \right\} \tag{47}$$

$$\eta_{mep} = 1 - \left[\left(\frac{\tau}{\theta_{mep}(\tau)} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mep}(\tau))} \right] \tag{48}$$

2.4 Efficient power density & MEPD

Efficient power density (EPD) which is defined as the efficient power divided by maximum volume of working fluid:

For efficient power density,

$$W_{epd} = \frac{W_{ep}}{v_4} \tag{49}$$

From equation (41) & (52)

$$W_{epd} = [K_1] \left[\frac{1}{\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma}} \right] \left[\frac{1}{v_1} \{ [K_6][\tau - \theta_{mepd}] - [K_7] \left[\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma} - 1 \right] \} \cdot \left\{ 1 - \left[\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mepd})} \right] \right\} \right] \tag{50}$$

For a given τ , taking the derivative with respect to θ and setting it equal to zero ($\frac{dW_{epd}}{d\theta} = 0$) will give the optimum value of θ as θ_{mepd} . Substituting the value of θ_{mepd} in Equation (50) [$\theta \approx \theta_{mepd}$] it can be written W_{mepd} & η_{mepd} as

The value of θ_{mepd} can be calculated by iteration method by substituting different value of τ .

For maximum efficient power density,

$$\frac{dW_{epd}}{d\theta} = 0 \tag{51}$$

$$W_{mepd} = [K_1] \left[\frac{1}{\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma}} \right] \left[\frac{1}{v_1} \{ [K_6][\tau - \theta_{mepd}] - [K_7] \left[\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma} - 1 \right] \} \cdot \left\{ 1 - \left[\left(\frac{\tau}{\theta_{mepd}} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mepd})} \right] \right\} \right] \tag{52}$$

$$\eta_{mepd} = 1 - \left[\left(\frac{\tau}{\theta_{mepd}(\tau)} \right)^{1/\gamma} - 1 \right] \cdot \left[\frac{K_8}{(\tau - \theta_{mepd}(\tau))} \right] \tag{53}$$

3. Results and Discussions

The derived expressions are used & plotted in order to compare the performance of the Atkinson cycle with variable specific heat of the working fluid. The following constants & range of parameters are selected $\gamma = 1.4$, $\tau = 1-20$, $\lambda = 0.9-1.2$, $C_{va}=0.717\text{kJ/kgK}$, $C_{vf}=1.638\text{kJ/kgK}$, $C_{vr}=0.8268\text{kJ/kgK}$, $C_{pa}=1.004\text{kJ/kgK}$, $C_{pf}=1.711\text{kJ/kgK}$, $C_{pr}=1.133\text{kJ/kgK}$, $K_1=0.6623$, $K_2=11.1587$, $K_3=1.3228$, $K_4=15.0939$, $K_5=1.8128$, $K_6=12.4765$, $K_7=16.9067$, $K_8=1.36$, $X_r=5\%$ -20% $m_f=0.0015-0.003\text{kg/s}$, $T_1=298\text{K}$, $(m_a/m_f)_s=15.1$ [33]

Max^m.power theory:

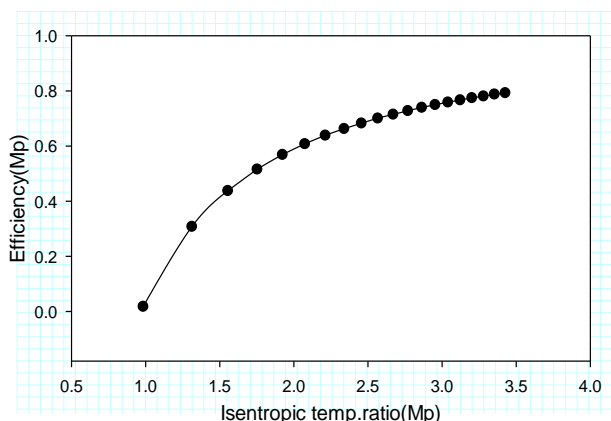


Figure 2 Variations of efficiency(η) with respect to Isentropic Temp. ratio Mp(θ_{mp})

Max^m. power density theory:

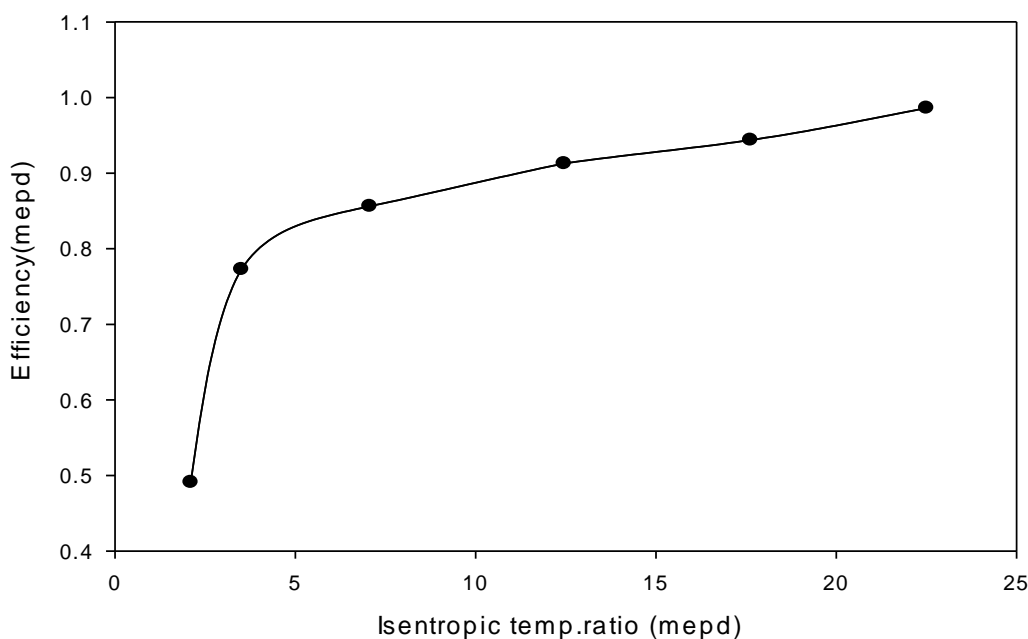


Figure 5 Variations of efficiency (η) with respect to Isentropic Temp. ratio Mepd (θ_{mepd})

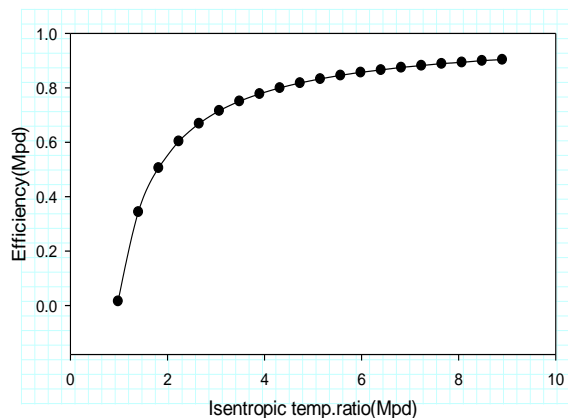


Figure 3 Variations of efficiency(η) with respect to Isentropic Temp. ratio Mpd(θ_{mpd})

Max^m. efficient power theory:

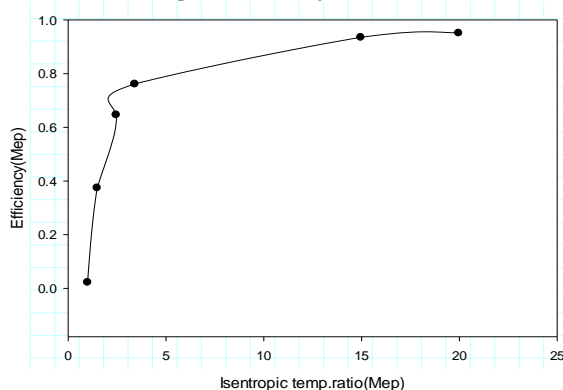


Figure 4 Variations of efficiency(η) with respect to Isentropic Temp. ratio Mep(θ_{mep})

Max^m. efficient power density:

Comparative analysis

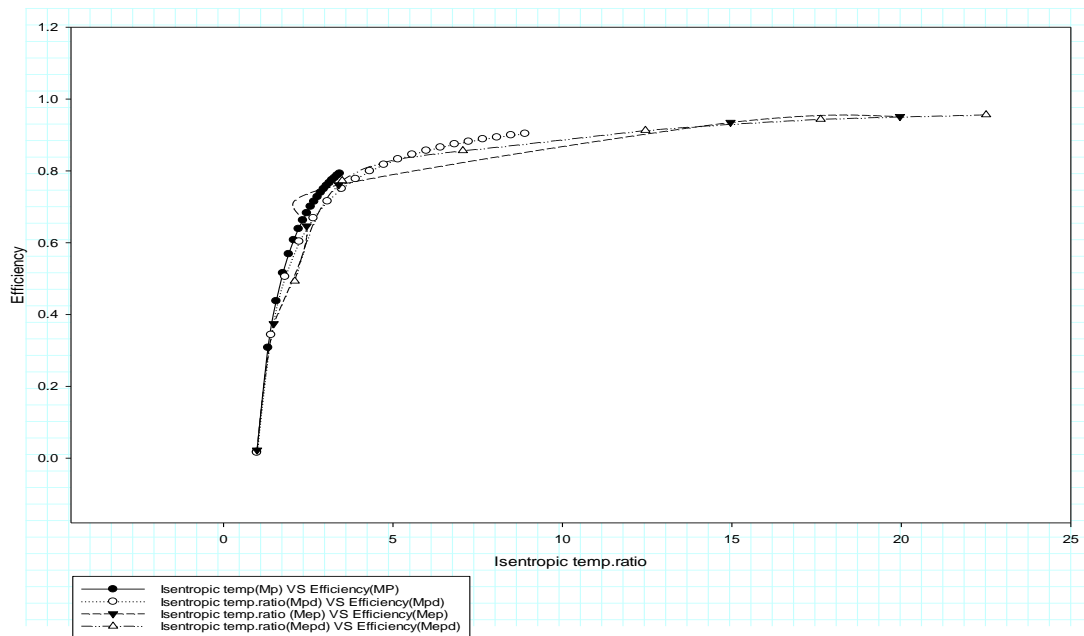


Figure 6 Variations of various efficiencies (η) with respect to Isentropic Temp. ratio (θ)

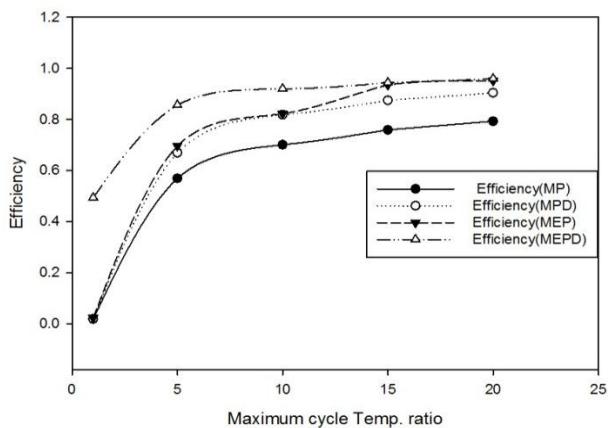


Figure 7 Variations of various efficiencies (η) with respect to Max^m. cycle Temp. ratio (τ)

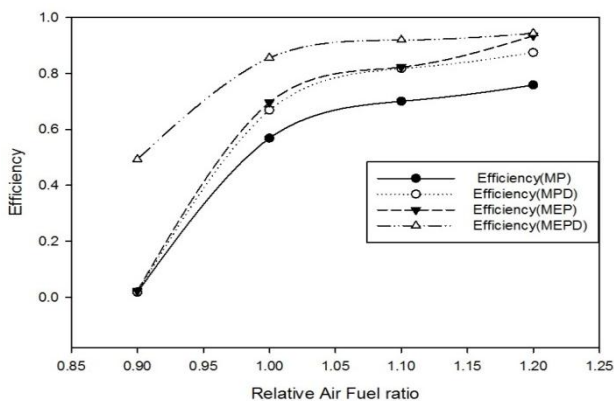


Figure 8 Variations of various efficiencies (η) with respect to Relative air fuel ratio(λ)

Comarpritive study

The Variations of efficiency of the Atkinson cycle with respect to the isentropic temperature ratio is shown in figure.2,3,4and5The comparative study can be analyzed from figure 6.It is inferred that the efficiency increases with increase in isentropic temperature ratio(θ),i.e ($\eta_{mepd} > \eta_{mep} > \eta_{mpd} > \eta_{mp}$). The Variations of efficiency of the cycle with respect to the maximum cycle temperature ratio (τ) is shown in figure 7 It is investigated that with the increase of maximum cycle temperature ratio (τ) efficiency increases &is maximum value yields for maximum value of (τ).If we analyze graph carefully it can be observed that increasing the value of τ the gap between efficiency reduces drastically & particularly in case of η_{mep} & η_{mepd} is almost same for maximum limit of τ , it can be examined efficiency increases with increase in Relative air fuel ratio(λ) from figure 8.It is found that the relative air fuel ratio, the fuel mass flow rate & the residual gases effects the performance of the engine in terms of power output & efficiency & thus they are important parameters during the design of the engine and can't be neglected.

Conclusion

A new criterion i.e MEPD criterion which has been introduced for analyzing the performance of an air standard Atkinson cycle with considerations of variable specific heats of working fluid incorporating the effect of relative air fuel ratio, the fuel mass flow rate & the residual gas is investigated.

The conclusion drawn from the above results are as follows:

- The increase in relative air fuel ratio increases the maximum power output & the maximum thermal efficiency.
- The maximum power output, the maximum thermal efficiency, the working range of cycle, the power output for maximum thermal efficiency & the thermal efficiency at maximum power output increases as the fuel mass flow rate increases.
- The engines designed at MEPD conditions are much more efficient than all other conditions, which reduces investment cost & has high pressure ratio which is required to run engine efficiently.
- The analysis helps us to understand the strong effects of relative air fuel ratio, fuel mass flow rate & residual gases on the performance of an Atkinson cycle.

The results obtained in this paper will help for designing & improvement of the practical internal combustion engine in the future.

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