**The Effect of Material Preference on Engine Performance in Otto Cycle Engine**

***Nilay AKDENİZ ACAR1,\*, Emre ARABACI2,***

*1Alaplı Vocational School of H. Education, Dept. of Machinery and Metal Tech., Zonguldak Bülent Ecevit Uni., Zonguldak, Türkiye*

*2Faculty of Technology, Department of Automotive Engineering, Pamukkale University, Denizli, Türkiye*

|  |
| --- |
|  **Abstract**Internal combustion engines are used in the automotive industry, construction, agriculture and energy sectors. These internal combustion engines have been in development for over 150 years. However, the thermodynamic cycles of internal combustion engines are among the main topics of thermodynamics textbooks. In this study, Otto cycle, which is the thermodynamic equivalent of spark ignition engines, has been analyzed from a different perspective. For the Otto cycle, the performance evaluation was made by using the melting points of various materials as the maximum temperature value. Thus, the effect of material selection on specific net work and mean effective pressure for an Otto cycle engine was investigated. It has also been shown that the optimum compression ratio of the engine can be determined depending on the material selection. It is foreseen that the results obtained in this study are guiding especially for engine designers. |
| Keywords: Otto cycle engine, Engine material, Performance |

1. **Introduction**

Performance analysis using thermodynamic cycles for internal combustion engines that we have been using for more than 150 years is very instructive in terms of determining the design parameters. Engines in use today are classified as compression-ignition or spark-ignition, and both are widely used. It is possible to find many studies on the thermodynamic cycles of these engines in the literature. It is possible to list some of the works as follows. Gonca et al. [1] examined different cycles comparatively in their study. Chen et al. [2] examined the effect of specific heat changes on performance in the irreversible Otto cycle in their study. Yuan et al. [3] optimized the thermodynamic cycles for two finite dimensional reservoirs in their study. Ge et al. [4] investigated the optimal piston movement configuration in an otto cycle engine according to the maximum ecological function. Ozdemir et al. [5] examined the effect of average piston speed and residual gas ratio on performance for the irreversible otto cycle.

In this study, the effect of material selection on engine performance in Otto cycle engines was investigated theoretically. As it is known, Otto-cycle engines are engines in which the heat input is constant. As a general thermodynamic approach, thermal efficiency is presented only as a function of compression ratio. However, with the compression ratio, the in-cylinder pressure and temperature also increase. In addition, the maximum in-cylinder temperature varies according to the compression ratio as well as the input heat. In addition to these conditions described, a performance evaluation was made by limiting the maximum temperature of the cycle. Specific net work and mean effective pressure parameters were used for performance evaluation.

1. **Materials and Methods**

In this study, a model was created on the air standard Otto cycle (Figure 1). Thermodynamic relations are created for this model [6-8]. Irreversibility is ignored in the model. The following equations are used for thermal efficiency and specific net work.

|  |  |
| --- | --- |
| $$η\_{th}=\frac{w\_{net}}{q\_{in}}=\frac{q\_{in}-\left|q\_{out}\right|}{q\_{in}}=1-\frac{1}{ε^{k-1}}$$ | (1) |
| $$w\_{net}=q\_{in}-\left|q\_{out}\right|=c\_{v}\left(T\_{3}-T\_{2}-T\_{4}+T\_{1}\right)$$ | (2) |
| $$T\_{4}=\frac{T\_{3}}{ε^{k-1}}=\frac{T\_{1}T\_{3}}{T\_{2}}$$ | (3) |

Figure 1 shows the P-v and T-s diagrams for the Otto cycle.

****

**Figure 1**. P-v and T-s diagram for Otto cycle

The following equations are used for specific net work optimization:

|  |  |
| --- | --- |
| $$\frac{dw\_{net}}{dT\_{2s}}=c\_{v}\left(-1+\frac{T\_{1}T\_{3}}{T\_{2}^{2}}\right)=0$$ | (4) |
| $$T\_{2,opt}=\sqrt{T\_{1}T\_{3}}=T\_{4,opt}$$ | (5) |
| $$ε\_{opt}=\sqrt[k-1]{\frac{T\_{3}}{T\_{1}}}=\sqrt[k-1]{τ}$$ | (6) |
| $$w\_{net,max}=c\_{v}T\_{1}\left(\sqrt{τ}-1\right)^{2}$$ | (7) |

The following equations are used for the mean effective pressure optimization:

|  |  |
| --- | --- |
| $$\frac{dp\_{me}}{dT\_{2}}=\left(k-1\right)\left(T\_{1}T\_{3}-T\_{2}^{2}\right)\left(\frac{T\_{2}}{T\_{1}}\right)^{\frac{1}{k-1}}-T\_{1}\left[\left(k-2\right)T\_{3}+T\_{2}\right]-T\_{2}\left(T\_{3}-kT\_{2}\right)=0$$ | (8) |
| $$\frac{dp\_{me}}{dε}=ε\left(k-1\right)\left(τ+ε^{2k-2}\right)-\left(k-2\right)τ-\left(τ+1\right)ε^{k-1}+kε^{2k-2}=0$$ | (9) |

Using the equations presented here, the maximum specific net work and maximum mean effective pressure can be determined. Here, the cycle maximum temperature is used as a performance limiter. The melting point of the engine building material selected as the cycle maximum temperature was used. Alumina (2345K), Titanium (1943K), Carbon-Steel (1813K), Cast Iron (1477K) were used as possible engine materials for this study [9]. For this reason, the range of 1250K-2500K was used as the maximum temperature in the calculations. In addition, a range of 2-25 is used for the compression ratio. In addition, it is assumed that $T\_{1}=300 K$, $P\_{1}=100 kPa$, $cv=0.718 kJ/kgK$, $k=1.4$.

1. **Results and Discussion**

Figure 2 shows the variation of the thermal efficiency depending on the compression ratio. Here all the lines overlap. Because thermal efficiency is only a function of compression ratio. As can be seen, the higher the compression ratio, the higher the thermal efficiency.



**Figure 2**. Variation of thermal efficiency with compression ratio

Figure 3 shows the variation of the specific net work and the mean effective pressure depending on the compression ratio. As can be seen, as the maximum temperature increases, the specific net work and mean effective pressure increase. However, both the specific net work and the mean effective pressure are maximum for only one compression ratio.



**Figure 3**. Variation of specific net work and mean effective pressure with compression ratio

Figure 4 shows the variation of the specific net work and the mean effective pressure with respect to the maximum temperature. In addition, the graphs show the variation of geometric compression ratio depending on the maximum temperature. Compression ratio values in cases where the specific net work and mean effective pressure are maximum were evaluated. In addition, the materials used for this paper are also labeled on the graphics. As can be seen, when materials with higher melting points are preferred, the engine can be operated at higher compression ratios.



**Figure 4**. Variation of specific net work and mean effective pressure with maximum temperature

Figure 5 shows the variation of specific net work and average effective pressure with respect to $T\_{2}/T\_{4}$. Here, $T\_{2}/T\_{4}$ temperature required for maximum specific net work and mean effective pressure is an important parameter. According to Eq. 5, it is stated that $T\_{2}=T\_{4}$ should be in order for the specific net work to be maximum. This is also shown in Figure 5. For the maximum value of the mean effective pressure, as the $T\_{3}$ temperature is increased, the $T\_{2}/T\_{4}$ temperature should also be increased. However, even when the maximum pressure is doubled, the $T\_{2}/T\_{4}$ value increases by 25%.



**Figure 5**. Variation of specific net work and mean effective pressure with respect to $T\_{2}/T\_{4}$

1. **Conclusion**

In this study, the effect of material selection on specific net work and mean effective pressure for an Otto cycle engine was investigated. It has also been shown that the optimum compression ratio of the engine can be determined depending on the material selection. It is foreseen that the results obtained in this study are guiding especially for engine designers.

**Acknowledgment**

No financial support was received from any institution or organization for this study.

**References**

1. Gonca, G. (2016). Comparative performance analyses of irreversible OMCE (Otto Miller cycle engine)-DiMCE (Diesel miller cycle engine)-DMCE (Dual Miller cycle engine). *Energy*, *109*, 152-159.
2. Ge, Y., Chen, L., & Qin, X. (2018). Effect of specific heat variations on irreversible Otto cycle performance. *International Journal of Heat and Mass Transfer*, *122*, 403-409.
3. Yuan, H., Ma, Y. H., & Sun, C. P. (2022). Optimizing thermodynamic cycles with two finite-sized reservoirs. *Physical Review E*, *105*(2), L022101.
4. Ge, Y., Chen, L., & Feng, H. (2022). Optimal piston motion configuration for irreversible Otto cycle heat engine with maximum ecological function objective. *Energy Reports*, *8*, 2875-2887.
5. Özdemir, A. O., Kılıç, B., Arabacı, E., & Orman, R. Ç. (2018). Effect of mean piston speed and residual gas fraction on performance of a four-stroke irreversible Otto cycle engine. *Scientific Journal of Mehmet Akif Ersoy University*, *1*(1), 6-12.
6. Kanoğlu, M., Çengel, Y. A., & Cimbala, J. M. (2020). *Fundamentals and applications of renewable energy*. McGraw-Hill Education.
7. Babu, V. (2019). *Fundamentals of Engineering Thermodynamics*. CRC Press.
8. Borgnakke, C. (2022). *Fundamentals of thermodynamics*. John Wiley & Sons.
9. Palaci, Y., & Gonca, G. (2020). The effects of different engine material properties on the performance of a diesel engine at maximum combustion temperatures. *Thermal Science*, *24*(1 Part A), 183-191.