7 Thermodynamic Cycle Applications

The concept of a cyclic thermodynamic process was introduced in section 1.4, and the Carnot cycle was seen to represent a basic method of continuous heat-work conversion. Certain other cycles with equal or lower efficiency are found to have more acceptable overall features, and these cycles are used for comparative purposes in assessing the performance of real heat engines and heat pumps commonly used in engineering.

7.1 Ideal Cycles as Performance Criteria

Reversible processes can be fitted together in various ways to construct reversible cycles, in which the net work transfer is given by the area enclosed by the $p$-$v$ loop, and the net heat transfer by the area enclosed by the $T$-$s$ loop (figure 7.1). Clockwise traces of these loops represent positive net work and net heat respectively. The fundamental thermodynamic cycle is the Carnot cycle (section 3.7) obtained by linking two isothermal and two isentropic processes alternately. This gives a maximum level of thermal efficiency between the two working temperatures (sections 3.7 and 3.8) but a work ratio (section 3.6) too low for practical purposes.

The analysis of the Carnot cycle, given from energy considerations alone in chapter 3, can now be simplified using the expressions derived in chapters 3 and 5, and collated in appendix A, as follows

<table>
<thead>
<tr>
<th>Process</th>
<th>$q$</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-2) Isentropic compression</td>
<td>0</td>
<td>$c_v (T_1 - T_2)^*$</td>
</tr>
<tr>
<td>(2-3) Isothermal expansion</td>
<td>$RT_2 \ln v_3/v_2$</td>
<td>$RT_2 \ln v_3/v_2$</td>
</tr>
<tr>
<td>(3-4) Isentropic expansion</td>
<td>0</td>
<td>$c_v (T_3 - T_4)$</td>
</tr>
<tr>
<td>(4-1) Isothermal compression</td>
<td>$RT_1 \ln v_1/v_4^*$</td>
<td>$RT_1 \ln v_1/v_4^*$</td>
</tr>
</tbody>
</table>

*Negative flow direction.

E. M. Goodger, *Principles of Engineering Thermodynamics*  
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For the s.f. case, \( c_v \) is replaced by \( c_p \).

Thus

\[
\eta_{\text{Carnot}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{1}{2} \frac{q_4}{q_3} = 1 - \frac{RT_1 \ln \frac{v_4}{v_1}}{RT_2 \ln \frac{v_3}{v_2}}
\]

\[
= 1 - \frac{T_1 \ln \frac{v_4}{v_1}}{T_2 \ln \frac{v_3}{v_2}}
\]

For the isentropes

\[
T_2/T_1 = v_1/v_2 = T_3/T_4 = v_4/v_3
\]

Thus

\[
v_1/v_2 = v_4/v_3, \text{ and } v_4/v_1 = v_3/v_2
\]

Hence

\[
\eta_{\text{Carnot}} = 1 - T_1/T_2, \text{ as derived in section 3.8}
\]