



# SURFACE VEHICLE INFORMATION REPORT

J3173™

OCT2025

Issued 2020-02  
Revised 2025-10

Superseding J3173 FEB2020

## Waste Heat Recovery System Thermal Management

### RATIONALE

Five-Year Review.

#### 1. SCOPE

Waste heat recovery (WHR) systems are used in vehicles and machines powered by internal combustion (IC) engines to capture unused and therefore wasted heat and utilize it. This reduces fuel consumption and emissions by improving efficiency. This information report is a survey of the waste heat recovery methods that include the use of heat exchangers.

#### 2. REFERENCES

##### 2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

##### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (U.S. and Canada only) or +1 724-776-4970 (outside U.S. and Canada), [www.sae.org](http://www.sae.org).

SAE J1004 Glossary of Engine Cooling System Terms

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2025 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

**TO PLACE A DOCUMENT ORDER:** Tel: 877-606-7323 (inside USA and Canada)  
Tel: +1 724-776-4970 (outside USA)  
Fax: 724-776-0790  
Email: [CustomerService@sae.org](mailto:CustomerService@sae.org)  
<http://www.sae.org>

SAE WEB ADDRESS:

Full document details: SAE J3173\_202510

For more information on this standard, visit [https://www.sae.org/standards/content/J3173\\_202510/](https://www.sae.org/standards/content/J3173_202510/)

Documents

Standard, visit Sharing Hub

### 3. INTRODUCTION

Waste heat recovery (WHR) systems can be used in vehicles and machines powered by internal combustion (IC) engines to increase overall system efficiency by recouping usable energy from engine waste thermal energy and consequently reduce fuel consumption and emissions. This information report is a survey of the waste heat recovery methods that include thermal management systems with emphasis on those using an Organic Rankine Cycle (ORC) for energy recovery. Different WHR systems can be found in passenger cars and light trucks, medium- and heavy-duty trucks, and other vehicles and equipment powered by internal combustion engines. Waste thermal energy is turned into a usable form of energy by either direct recovery in the form of thermal energy or by converting thermal energy into either mechanical or electrical energy. Direct waste heat recovery typically recovers heat and utilizes this heat to warm up engine coolant or thermal fluid to aid in warming the passenger cabin or powertrain components. Energy recovery by converting thermal energy into mechanical energy usually utilizes ORC or Stirling cycle systems. Thermoelectric generators (TEG) recover waste thermal energy and convert it directly into electrical energy, while ORC and Stirling cycle engines do so indirectly by converting the recovered thermal energy to mechanical and then to electric energy using generators. This report will focus on recovering thermal energy and converting it into mechanical power by using ORC. These ORC systems typically include a working fluid circulating through an evaporator/boiler, where exhaust heat is used to convert the working fluid from a liquid to a high-pressure gas. The high-pressure gas powers a turbine that produces mechanical energy. The fluid is then routed to a condenser to bring it back to a liquid state to repeat the cycle. This information report describes the systems available for use now and those being considered with emphasis on the heat exchangers and thermal management of the process.

### 4. THE THERMODYNAMICS OF EXHAUST GAS WASTE HEAT RECOVERY

There is historical evidence of the introduction of various systems to the internal combustion engine to improve its power and efficiency. Massive resources have been expended for this research. One of the most commonly incorporated systems that improved engine performance and efficiency is the turbocharger. This exhaust gas waste heat recovery system provides a typical boost pressure of 55 to 85 kPa (8 to 12 psi) for gasoline engines and 100 to 275 kPa (15 to 40 psi) for diesel engines, which can improve fuel efficiency by 5 to 10%. The drawback of the system is at low engine speed, where the engine is unable to get boost from the turbocharger during initial acceleration. This phenomenon is called turbo lag. A lack of mass flow rate and pressure at the inlet of the turbocharger causes this effect. Additionally, the temperature of the exhaust gas has adverse effects on the turbo effect, especially at high-speed operations where it heats the turbocharger and spins beyond its limit so that it requires a bypass. Therefore, understanding the duty cycle of the automotive engine is very critical when designing any waste heat recovery system. Stationary engines are usually run at a constant speed and load. Therefore, designing waste heat recovery systems for constant speed engines is less complicated than variable speed engines, such as automotive applications. To illustrate the importance of various parameters, an example of a turbocharger is given in Figure 1. Figure 1 graphs Mollier diagrams of enthalpy ( $h$ ) versus entropy ( $s$ ) for compression and expansion stages of a typical turbocharger.

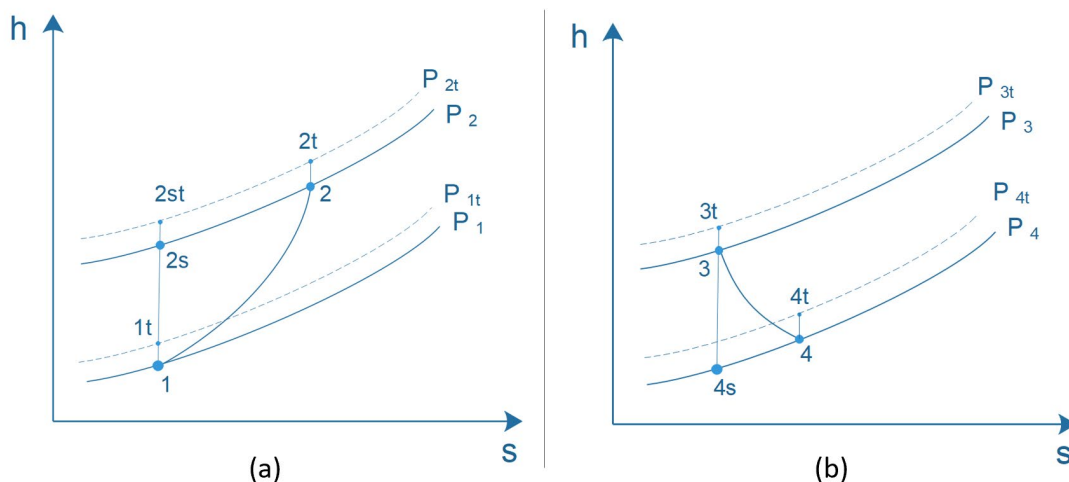


**Figure 1 -  $h$ - $s$  diagram: (a) compressor, (b) turbine**

Here, total temperature ( $T_t$ ) is calculated using wall temperature ( $T_w$ ) and dynamic temperature ( $T_D$ ) using the following equations:

$$T_t = T_w + T_D \quad (\text{Eq. 1})$$

$$T_D = \frac{U^2}{2c_p} \quad (\text{Eq. 2})$$

where:

$U$  = velocity of flowing medium

$c_p$  = specific heat capacity at constant pressure

Also, total pressure ( $P_t$ ) is calculated using the isentropic gas equation:

$$P_t = P_s \left( \frac{T_t}{T_s} \right)^{\frac{k}{k-1}} \quad (\text{Eq. 3})$$

where:

$P_s$  = static pressure

$k$  = heat capacity ratio;  $c_p/c_v$

$c_v$  = gas specific heat capacity at constant volume

$T_s$  = compressor inlet temperature

Now, the turbine efficiency at the turbine inlet and outlet is obtained by applying thermodynamic equations to the isentropic process and is given by:

$$\eta_T = \frac{1 - \frac{T_{4t}}{T_{3t}}}{1 - \left( \frac{P_{4s}}{P_{3t}} \right)^{\left( \frac{k-1}{k} \right)_g}} \quad (\text{Eq. 4})$$