Organic Rankine Cycle Heat Recovery Equipment

Date added to ETL 2015 (updated 2018)

1. Definition of Technology

Organic Rankine Cycle (ORC) Heat Recovery Equipment covers products that are specifically designed to convert waste heat to electrical power by means of a closed thermodynamic power cycle that does not involve the internal combustion of fuel.

2. Technology Description

ORC Heat Recovery Equipment typically captures waste heat from exhaust stacks in manufacturing plants, or other waste heat from industrial processes, and uses it to generate electricity that is used on site.

The ECA scheme covers products that can capture low to medium grade waste heat through an Organic Rankine Cycle. In ORC units, the captured waste heat is used to heat a working fluid. Vapour is produced, which is used to mechanically drive an electricity generator by means of an expander (e.g. turbine or screw). The low pressure vapour is then condensed (rejecting its heat to a lower temperature heat sink) and pumped back to the higher pressure, to complete the cycle.

The waste heat may be captured directly, by means of an internal or external heat exchanger, or indirectly, by means of a secondary heat recovery system.

Heat rejection to the lower temperature ambient heat sink may be directly to the air using a heat exchanger, or via a secondary cooling medium (e.g. cooling water).

The ECA scheme covers three categories of product:

1. **Remote, secondary-cooling type**
   These products include a complete, closed circuit for the working fluid, contained within the unit. The condensing heat-exchanger is supplied with open connections for a secondary cooling circuit (e.g. cooling water), for connection on site.

2. **Integral cooling type**
   These products include a complete, closed circuit for the working fluid, contained within the unit. The condenser rejects its heat directly or indirectly to the air, via a heat exchanger (contained within the unit). The heat exchanger may use dry air cooling, evaporative or adiabatic cooling.

3. **Split-circuit type**
   ‘Split’ type products have separate heat collection and rejection units specifically designed to be connected together during installation by pipework to create the closed circuit for the working fluid, forming a single functional unit. The main assembly includes the heat capture heat-exchanger, expander and power generator. The second unit includes the condensing heat-exchanger, for rejection of heat to the air, using dry air cooling, evaporative or adiabatic cooling.

ORC Heat Recovery Equipment is available in a range of efficiencies. The ECA Scheme aims to encourage purchase of higher efficiency products, which can realise substantial reductions in carbon emissions when used to reduce the use of electricity from the mains supply.

Investments in ORC Heat Recovery Equipment can only qualify for Enhanced Capital Allowances if the specific product is named on the Energy Technology Product List. To be eligible for inclusion on the Energy Technology Product List, products shall meet the eligibility criteria as set out below.
ECA’s can only be claimed for equipment where the electricity will be used on site, and not where power is generated for sale to or via unspecified third parties.

3. Eligibility Criteria

To be eligible, products shall:

- Consist of a factory-built packaged unit or split system (comprising a main assembly and a matched heat-rejection unit, designed for connection together on site).
- Be designed to generate electricity or produce mechanical power in the ORC shaft from waste heat with a temperature of less than or equal to (<=) 350 °C.
- Be designed to provide three-phase electricity at 230/400 Volt a.c. at 50Hz.
- Be rated for continuous operation with an electrical power output not exceeding 1.5 MWe.
- Not incorporate any form of combustion equipment, including boost burners.
- Not use water, ammonia or any water based solution as a working fluid.
- Be designed for, and include fittings for, permanent installation.
- Be CE marked.

Performance criteria

Eligible products shall meet or exceed the minimum adjusted net efficiency set out in Table 1, according to the maximum temperature of waste heat that the product is designed to capture:

Table 1 - Adjusted net efficiency thresholds for ORC Heat Recovery Equipment

<table>
<thead>
<tr>
<th>Maximum design waste heat temperature (°C)</th>
<th>&lt;= 125°C</th>
<th>&gt; 125°C and &lt;= 250°C</th>
<th>&gt; 250°C and &lt;= 350°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Category</strong></td>
<td><strong>Minimum adjusted net efficiency, ( \eta )</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Remote, secondary-cooling type</td>
<td>&gt;= 7.0%</td>
<td>&gt;= 12.5%</td>
<td>&gt;= 17.5%</td>
</tr>
<tr>
<td>2. Integral cooling type</td>
<td>&gt;= 4.6%</td>
<td>&gt;= 7.4%</td>
<td>&gt;= 15.6%</td>
</tr>
<tr>
<td>3. Split-circuit type</td>
<td>&gt;= 4.6%</td>
<td>&gt;= 7.4%</td>
<td>&gt;= 15.6%</td>
</tr>
</tbody>
</table>

“<=” means “less than or equal to”
“>=” means “greater than or equal to”
“>” means “greater than”
Where:

\[
Net \text{ Efficiency}, \eta = \frac{\text{Electrical output (kW)} - \text{Electrical input (kW)}}{\text{Thermal Input (kW)}}
\]

And adjusted net efficiency \( \bar{\eta} \) is defined in Table A below.

The electrical input applies to 100% of the electrical consumption of the product, including any pumps and fans contained within it. However, for remote, secondary-cooling type (category 1) products, the energy use of pumps and fans associated with the secondary cooling circuit should not be included as electrical input, and are not included in the net efficiency calculation.

For the avoidance of doubt, test data should be presented to one decimal place. As an example, a remote, secondary-cooling type product designed to capture waste heat with a temperature of 125°C, with an adjusted net efficiency of 6.9%, would be deemed to be a fail.

**Required test procedures**

The required minimum performance shall be determined using Methods A or B, as set out in Tables A and B below.

Products can either be tested in an accredited laboratory, or performance may be determined from measurements made during field trials or acceptance tests, provided that the measurements have been made by, or witnessed by, an accredited laboratory or contractor that is accredited to make those measurements. The product’s adjusted net efficiency shall be calculated by an independent body that is competent to verify the measurement data.
Under this test method, product performance shall be demonstrated by calculating the net efficiency (as defined above), from measurements of thermal input, electrical output and electrical input, in the application and at the rated capacity, for which it is designed. The reference test conditions, which depend on the maximum temperature of waste heat that the product is designed to capture, are set out in Table 2 below.

### Table 2 - Reference test conditions

<table>
<thead>
<tr>
<th>Maximum design waste heat temperature (°C)</th>
<th>&lt;= 125°C</th>
<th>&gt; 125°C and &lt;= 250°C</th>
<th>&gt; 250°C and &lt;= 350°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference test conditions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1$ - inlet temperature of the captured waste heat source</td>
<td>125 °C</td>
<td>250 °C</td>
<td>350 °C</td>
</tr>
<tr>
<td>$T_2$ - inlet temperature of the heat rejection sink</td>
<td>Remote, secondary cooling type products (inlet temperature of the secondary coolant)</td>
<td>30 °C</td>
<td>30 °C</td>
</tr>
<tr>
<td></td>
<td>Integral cooling type products (air on temperature, dry bulb)</td>
<td>20 °C</td>
<td>20 °C</td>
</tr>
<tr>
<td></td>
<td>Split-circuit type products (air on temperature, dry bulb)</td>
<td>20 °C</td>
<td>20 °C</td>
</tr>
</tbody>
</table>

At the reference conditions, the adjusted net efficiency, $\bar{\eta}$, is equal to the net efficiency $\eta$, as defined above.

Where the application does not make it feasible for tests to be carried out at the conditions above, then alternative inlet temperatures $T_1$ and $T_2$ can be used. In such cases, the adjusted net efficiency, $\bar{\eta}$, should be calculated as defined in Table 3 below.

### Table 3 - Adjusted net efficiency for alternative inlet temperatures

<table>
<thead>
<tr>
<th>Maximum design waste heat temperature (°C)</th>
<th>&lt;= 125°C</th>
<th>&gt; 125°C and &lt;= 250°C</th>
<th>&gt; 250°C and &lt;= 350°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1 (allowable range)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;= 125°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 125°C and &lt;= 250°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 250°C and &lt;= 350°C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Remote, secondary-cooling type products

Adjusted net efficiency, $\eta = \left(\frac{125 - 30}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 125}\right)$

Integral cooling and split circuit type products

Adjusted net efficiency, $\eta = \left(\frac{125 - 20}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 125}\right)$

Note: $T_1$ and $T_2$ above are defined in Table 2 and expressed in degrees Celsius.

The adjusted efficiency, $\eta$, shall meet or exceed the associated minimum adjusted net efficiency threshold defined in Table 1.

For example, a category 1 ORC product designed for a maximum waste heat temperature of 200ºC, with a net efficiency of 10.8% ($T_1 = 200ºC$ and $T_2 = 30ºC$), will have an adjusted net efficiency of 12.6%, and therefore deemed eligible.

The assessment of thermal input shall be done in accordance with the procedures set out in:

- **EN 305:1997** “Heat exchangers - Definitions of performance of heat exchangers and the general test procedure for establishing performance of all heat exchangers”; or
- **EN 306:1997** “Heat exchangers - Methods of measuring the parameters necessary for establishing the performance”; or
- **EN 308:1997** “Heat exchangers - Test procedures for establishing the performance of air to air and flue gas heat recovery devices”.

The assessment of electrical output and electrical input shall be done in accordance with the relevant procedures set out in:

- **BS ISO 8528-6:2005** “Reciprocating internal combustion engine driven alternating current generating sets - Test methods”.

<table>
<thead>
<tr>
<th>Remote, secondary-cooling type products Adjusted net efficiency, $\eta$</th>
<th>$\eta\left(\frac{250 - 30}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 250}\right)$</th>
<th>$\eta\left(\frac{350 - 30}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 350}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integral cooling and split circuit type products Adjusted net efficiency, $\eta$</td>
<td>$\eta\left(\frac{250 - 20}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 250}\right)$</td>
<td>$\eta\left(\frac{350 - 20}{T_1 - T_2}\right) \left(\frac{273.15 + T_1}{273.15 + 350}\right)$</td>
</tr>
</tbody>
</table>
Under this test method, product performance shall be demonstrated by calculating net efficiency (as defined above), from design calculations. The accuracy of these calculations shall be confirmed by interpolation and extrapolation of measurements obtained from tests (carried out according to Method A above) of at least two units of the same basic design as the product, i.e.:

- Use the same working fluid as the product
- Use the same thermodynamic cycle
- Have the same expander type - i.e. manufacturer, method of expansion (e.g. reciprocating, turbine, or screw)
- Use the same heat exchanger types - for both waste heat capture and heat rejection to the ambient heat sink; and any other recuperative heat exchangers
- Use the same method of rejecting heat to the ambient heat sink - i.e. water-cooled; or dry or evaporative air-cooled.

The product shall have a rated maximum electrical output of no more than 20% greater or smaller than one of the tested products.

The test report shall include (or be accompanied by):

a) Details of the methodology and calculations used to determine product performance
b) A copy of the published performance data for the product
c) Manufacturer’s design data for the product
d) The following data for the tests carried out according to Method A and for the design conditions of the product:
   i. Details of the composition, specific heat capacity, inlet and outlet temperatures, and flow-rates of:
      • The captured waste heat source
      • The low-temperature heat sink
   ii. Electricity output and input
   iii. Calculated net efficiency and adjusted net efficiency
e) Details of main components of the tested units and (where these are not identical to the product) calculations demonstrating that their performance can be used to validate that of the product, including:
   i. Heat exchangers
   ii. Expander
   iii. Alternator

4. Scope of Claim
Expenditure on the provision of plant and machinery can include not only the actual costs of
buying the equipment, but other direct costs such as the transport of the equipment to site, and the direct costs of installation. Clarity on the eligibility of direct costs is available from HMRC.