Title: IMPROVEMENTS IN WASTE HEAT RECOVERY UNITS

Abstract: A waste heat recovery unit (10) comprises a duct (12) for hot gas. The duct (12) is divided into first, second and third adjacent and parallel channels (44, 46, 48) each with an inlet and an outlet. A heat exchanger is located in each of the first; and third channels (44, 48). The second channel (46) is located between the first and third channels (44, 48) and provides a bypass channel. A damper system (50) is operable to selectively open and close the inlets of the three channels (44, 46, 48). This provides a more compact waste heat recovery unit configuration which is more straightforward to manufacture and maintain.
before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
Improvements in Waste Heat Recovery Units

The present invention relates to waste heat recovery units (WHRUs).

Gas turbines are commonly used in oil and gas facilities; both onshore and offshore, to provide shaft power to drive compressors or other machinery, and for power generation. The gas turbine exhaust consists of a large quantity of hot gas, typically in the range of 480-500°C. Some oil/gas facilities typically also require heat for other parts of the process. Therefore heat can be recovered from the gas turbine exhaust by means of a waste heat recovery unit, which is a heat exchanger using heat from the exhaust gases to heat a stream of water, oil or other fluid.

A WHRU essentially consists of a heat exchanger with an array of tubing through which a stream of fluid to be heated is circulated. Exhaust gas from the gas turbine are passed around the exterior of the tubing thereby transferring heat to the fluid stream within the tubing.

It is desirable to reduce the size and weight of WHRUs, especially for offshore applications. This can be achieved by increasing the heat transfer coefficients, thus reducing the size and weight of the tube bank. It is also desirable to recover the maximum possible amount of heat to reduce the need to satisfy additional heat requirements by burning fossil fuels.

The present invention provides a waste heat recovery unit comprising a duct for hot gas, wherein the duct is divided...
into first, second and third adjacent and parallel channels each with an inlet and an outlet, a heat exchanger located in each of the first and third channels, the second channel being located between the first and third channels and providing a bypass channel, further comprising a damper system operable to selectively open and close the inlets of the first, second and third channels,

in this way, a more compact arrangement is provided which is easier to manufacture and maintain and requires a smaller space envelope.

Preferably, the damper system comprises a plurality of rotatable blades mounted to walls dividing the duct into the first, second and third channels, and connected to a common actuator.

Preferably, this actuator is operable to rotate the blades simultaneously and in opposite directions whereby the blades are rotated towards one another to close the inlet to the bypass channel and are rotated away from another to close the inlets to the heat exchanger channels.

Preferably, the cross section of each channel is substantially rectangular.

In one embodiment, each heat exchanger comprises an array of tubing for circulating fluid to be heated, the tubing supported by a support structure and extending across the respective heat exchanger channel, wherein a portion of the array extends through the support structure such that a plurality of tubing porthons are located outside the main
flow channel, the tubing portions arranged adjacent to and spaced from one another, and further comprising a plurality of baffles each located between adjacent tubing portions to at least partially fill the space in between them.

Preferably, the tubing comprises a portion of finned larger outer diameter extending across the duct and through the support structure, and a portion of smaller outer diameter located external to the support structure, such that a smaller spacing is provided between adjacent larger outer diameter tubing portions, and a larger spacing is provided between adjacent smaller outer diameter tubing portions, and wherein the baffles are provided in a larger spacing.

Each baffle may comprise a rigid plate within an outer insulating blanket. By way of example, the rigid plate may be formed of metal and the blanket of ceramic or body soluble fibres.

Preferably, the damper system comprises a plurality of rotatable blades, each blade comprising an upstream plate spaced from a downstream plate, and means to supply pressurised gas into the spacing between the upstream and downstream plates, wherein a plurality of apertures are formed in at least some of the downstream plates to allow leakage of pressurised gas.

In a second aspect, the present invention provides a heat exchanger for a waste heat recovery unit, comprising a duct defining a main flow channel for hot gas, an array of tubing supported by a support structure and extending across the duct for circulating fluid to be heated, wherein part of the
array extends through the support structure such that a plurality of tubing portions are located outside the main flow channel; adjacent to and spaced from one another, and further comprising a plurality of baffles each located between adjacent tubing portions so as to at least partially fill the spacing between them.

In a third aspect, the present invention provides a waste heat recovery unit comprising at least one duct for directing hot gas to a heat exchanger unit and at least one bypass duct to bypass hot gas around the heat exchanger unit, and a damper system comprising a plurality of rotatable blades, each blade comprising an upstream plate spaced from a downstream plate, and means to supply pressurised gas into the spacing between the upstream and downstream plates, wherein a plurality of apertures are hinged in at least some of the downstream plates to allow leakage of pressurised gas into the or each heat exchanger duct.

The invention will now be described in detail by way of example only and with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of a conventional waste heat recovery unit;

Figure 2 is a schematic illustration of a conventional WHRU with an integral bypass duct;

Figure 3 is a schematic illustration of a conventional WHRU with a separate bypass duct.
Figure 4 is a schematic perspective view of a central bypass configuration \( \text{WHRU} \) in accordance with the present invention;

Figure 5 is a cross section of Figure 4 along the line AA;

Figure 6 is an enlarged detail view of a baffle plate system for use with the present invention;

Figure 7 is a schematic illustration of a \( \text{WHRU} \) damper blade for use with the present invention.

A typical conventional \( \text{WHRU} \) configuration is shown schematically in Figure 1. The \( \text{WHRU} \) 10 comprises a duct 12 for carrying hot exhaust gases (indicated by arrows 1) from a gas turbine 14 to an array of heat exchanger tubing 16. For clarity, a single length of tubing 16 is shown, in practice, a plurality of such tubes are provided and may be referred to as a bundle or coil. As shown, the tubing 16 passes across the duct 12 multiple times with \( 180^\circ \) turns at each side. The tubing 16 is supported on each side, and sometimes at intermediate points, by tube sheets 18. The \( 180^\circ \) return bends 20 of the tubing 16 are located in header bones 22 on the exterior side of the tube\( \text{s} \) sheets 18, out of the main flow channel. The fluid to be heated is circulated through the tubing 16, usually in a counter current configuration, entering at the upper end of the \( \text{WHRU} \) 10 and exiting at the lower end as shown by the arrows F in Figure 1.
In oil and gas facilities utilising WHEDS, the required amount of heat can vary with plant requirements and feed stock changes over the lifespan of the equipment. In addition, the flow and temperature of the hot gas from the gas turbine may vary with ambient conditions and machine loading. Current practice is to design the WHRU for the worst case combination of gas turbine exhaust conditions and heat demand. However, this means that for most of the time surplus heat is available. Current systems control this by bypassing a portion of the gas turbine exhaust flow around the heat exchange tubing array.

One popular configuration uses an integral bypass arrangement as shown schematically in Figure 2. This arrangement consists of a bypass duct B in parallel with the duct 12 containing the heat exchanger tubing 16, creating two parallel streams for the exhaust gas. Each of the ducts 12, B is provided with a damper system D to selectively open and close the ducts. The damper systems are typically mechanically linked to each other so that as one opens the other closes. This enables the flow of hot gas to the tubing 16 to be controlled.

However, there are a number of disadvantages with this arrangement. It is necessary to have some space between the two parallel channels and this increases the overall space requirement for the unit. Indeed, in some conditions, as shown in Figure 3, the bypass duct B is entirely separate and is set at a much greater distance from the duct 12 including the WHRU tubing 15, to avoid leakage of heat from the bypass duct to the tubing 16. However, this further increases the space requirement for the whole unit, in
addition, the walls of the bypass duct B are typically made of steel and the weight of the unit is thus increased, which is disadvantageous in offshore applications. The isolation damper for the WHDU section of the duct 12 is large and this adds to the overall cost of the unit. The tubing of the WHRD is a single item of significant weight and this may even exceed crane capacity of the offshore facility.

Another solution is known as the “CTIBAS” design. This uses central bypass channel concentric with and surrounded by an annular heat exchange duct containing an annular array of tubing. This has some advantages over the system mentioned above in that there is no gap between the separate ducts for the heat exchange tubing and for the bypass flow and a large damper system is avoided.

However, this design also has major drawbacks. The tubes of the heat exchanger have to be bent into the annular configuration which adds to the cost of manufacture and creates integrity risks. The annular arrangement means that welds in the construction are not accessible and individual tubes cannot be removed for maintenance. In addition, the overall circular design does not take advantage of the corners of an available plot of space on a facility.

The present invention provides an alternative configuration in order to address these issues. As shown in Figure 4 the WHRU 10 again comprises a duct 12 for the flow of hot exhaust gas from the gas turbine. At the inlet to the WHEU section the duct 12 may be of circular cross-section as shown, or rectangular or other convenient shape, but the
cross section of the WHPI itself is generally square or rectangular. Two dividing walls 40, 42 separate the duct 12 into three adjacent parallel channels 44, 46, 48 of generally rectangular or square cross section.

The outer channels 44, 48 each contain an array of heat exchange tubing although this is not shown in Figure 4 for clarity. This may be arranged in any conventional manner. It may include the baffle plate system described further below.

The central channel 46 does not include any heat exchange tubing and provides a bypass duct.

As shown in Figure 5, a damper system 50 controls the flow of exhaust gas and determines which ducts it will pass through. The damper system 50 typically comprises a pair of deeper blades 52, 54 which are rotatably mounted at the lower extremity of the dividing walls 40, 42.

Preferably, rotation of the danger blades 52, 54 is controlled by a common actuator so that the blades 52, 54 will rotate in unison but in opposite directions. Thus, to pass hot gas through the two heat exchanger arrays in the outer channels 44, 48 one damper blade 52 is rotated anticlockwise and the other damper blade 54 is rotated clockwise so that they move towards each other and together they close the entrance to the bypass channel 46.

In order to close the heat exchanger channels 44, 48 the actuator rotates the damper blade 52 clockwise and the other damper blade 54 anticlockwise in order to open the bypass channel 44 and close the heat exchanger channels 44, 48.
damper blades 52, 54 may also be positioned at an intermediate point so that some flow passes through the heat exchanger channel & 44, 48 and some through the bypass channel 46.

Thus, a WHRU including a bypass duct is provided in a compact arrangement which is more straightforward to manufacture and maintain and has a reduced space requirement than the previous configurations.

In the construction of a WHRU, whether of a conventional configuration or the central bypass configuration described above, the tubing 16 and tube sheets 18 require space to expand as they heat up in the flow of exhaust gas. Therefore, clearances must be left in the structure and it is not possible to completely seal all the gaps between the tubing 16 and the tube sheets 18. Consequently, some exhaust gases will escape through such gaps and bypass the main flow channel containing the majority of the array of tubing 16.

To compensate for the losses caused by such bypass flow, conventional systems may be made larger and heavier to maintain a desired heat transfer performance. However, this conflicts with the general desire to reduce size and weight of the WHRU.

In a further feature of the present invention a baffle system to restrict such bypass flow of hot gas may be provided, as shown in Figure 6, the portion 24% of the tubing 16 within the main flow channel of the duct 20 and between the tube sheets 18 has an enlarged outer diameter and increased surface area. Typically this is created by forming
a helical fin which is welded to the exterior of the tubing 16 to provide a larger surface area for heat transfer. In a conventional system, the parts of the tubing 16 which are within the header box 22 and are external to the tube sheets 18 and the main flow channel, include noma of the portion 24 with the fin, and also a reduced outer diameter portion 26, without the fin, for forming the return bends 20. Accordingly, a small cap 28 is left between adjacent parts of the larger diameter portion 24 of the tubing 16, where the fin is present. A larger gap 30 is left between adjacent parts of the smaller diameter portion 26 of the tubing 16, where no fin is present.

Furthermore, there is a gap 29 between the tube sheet 18 and the larger diameter portion 24 of the tubing 16 which includes the fin. This gap 22 is necessary for contraction and to allow for thermal expansion, but it creates a leakage path indicated by arrows L which can reduce the performance of the heat exchanger as hot gases bypass the main flow channel and the main body of the tubing 16. In addition, the tube sheet 18 is normally not integral with the wall of the duct 12 and there are further gaps 31 around the edges of the tube sheet 18, creating a further leakage path indicated by arrows L.

In the present invention baffle plates 32 are located in the larger gaps 10 between the smaller diameter port 26 of the tubing 6 in the header box 22. Each baffle plate 32 consists of a rigid inner plate 24, for example a metal plate approximately 3mm in thickness, which is encased in an insulating outer blanket 36, for example a ceramic fibre blanket approximately 25mm thick. The baffle plates 32 block
the larger gaps 30 so that the bypass flow of exhaust gas which has entered the header hex 22 via gap 29 and .31, can then only flow past the exterior of the larger diameter finned portion 24 of the tubing 16. Thus, although some bypass flow still occurs, this can be utilised for heat transfer into the fluid within the tubing 16 because it contacts the fin providing the larger surface area.

In this way the heat transfer performance of the WHRU 10 can be maintained despite the bypass flow and without increasing the size and weight of the unit. The baffle plates may be incorporated in a WHRU of conventional design or the central bypass configuration described above.

A further issue which arises with WHRUs which include a bypass channel is that in order to run the gas turbine, a small flow of heat transfer medium must be maintained through the array of fairing 1t even if substantially all of the exhaust flow is passed through the bypass duct. This is because there may be some leakage of heat back to the heat exchange tubing from the outlet of the bypass flow channel, or heat leakage through the damper system. This heat leakage is indicated by arrows h in Figure 2.

One existing solution is to have an entirely separate bypass duct widely spaced from the duct 12 containing the heat exchange tubing as in Figure 5. However, this solution requires more space for the entire unit, adds weight and creates the need for an additional stack emission point.

Another known solution is to form the damper blades from two parallel plates with a spacing between them. pressurised air
is supplied into the spacing, which can exit at edges of the blade. Thus, an area of increases pressure is provided at the damper, which is a higher pressure that the flow of exhaust gas and serves to further seal the entrance to the WHRU.

However, this is not effective in preventing heat leakage occurring at the downstream end from the bypass duct outlet back to the heat exchanger outlet.

In Figure 7, a damper blade 60 for addressing this problem is illustrated. The damper blade 60 comprised a pair of spaced parallel plates 62, 64. In use, these are arranged with the plate 62 upstream and the plate 64 downstream. Thus, when the damper is closed, exhaust gases will impinge on the upstream plate 62. A series of apertures 66 is provided in the downstream plate 64. This deliberately allows the pressurized seal air supplied to the interior spacing between the plates 62, 64 to leak out of the downstream plate 64 and into the flow channel of the WHRU.

In this way, the sealing effect is enhanced and the temperature of the heat exchange tubing 16 is kept below acceptable limits, even when there is no flow of heat transfer fluid in the tubing 16. This has the advantage of enabling the operator to start or continue to run the gas turbine even if the system which circulates the heat transfer fluid through the tubing 16 is out of service.

This arrangement of perforated damper plates may be incorporated in any conventional WHEU design, or used in
conjunction with either or both the baffle plate system and
the central bypass configuration as described above.

Thus, the present invention provides an improved waste heat
recovery unit which is more efficient than conventional
systems. The skilled person will appreciate that various
edifications may be made to the precise details described
above whilst not departing from the scope of the invention
as set out in the following claims.
Claims

1. A waste heat recovery unit comprising a duct for hot gas, wherein the duct is divided into first, second and third adjacent and parallel channels, each with an inlet and outlet, a heat exchanger is located in each of the first and third channels, and the second channel is located between the first and third channels and provides a bypass channel, and further comprising a damper system operable to selectively open and close the inlets of the first, second and third channels.

2. A waste heat recovery unit as claimed in claim 1, wherein the damper system comprises a plurality of rotatable blades mounted to walls dividing the duct into the first, second and third channels, and connected to a common actuator.

3. A waste heat recovery unit as claimed in claim 2, wherein the actuator is operable to rotate the blades simultaneously and in opposite directions, whereby the blades are rotated towards one another to close the inlet to the bypass channel and are rotated away from one another to close the inlets to the heat exchanger channels.

4. A waste heat recovery unit as claimed in any of claims 1-3, wherein the cross-section of each channel is substantially rectangular.

5. A waste heat recovery unit as claimed in any preceding claim, wherein each heat exchanger comprises an array of tubing for circulating fluid to be heated, the tubing
supported by a support structure and extending across the respective heat exchanger channel, wherein a portion of the array extends through the support structure such that a plurality of tubing portions are located outside the main flow channel, the tubing portions arranged adjacent to and spaced from one another, and further comprising a plurality of baffles each located between adjacent tubing portions to at least partially fill the spacing therebetween.

6. A waste heat recovery unit as claimed in claim 5, wherein the tubing comprises a portion of larger outer diameter extending across the duct and through the support structure, and a portion of smaller outer diameter located external to the support structure, such that a smaller spacing is provided between adjacent larger diameter tubing portions, and a larger spacing is provided between adjacent smaller outer diameter tubing portions, and wherein the baffles are provided in the larger spacings.

7. A waste heat recovery unit as claimed in claim 5 or claim 6, wherein each baffle comprises a rigid plate within an outer insulating blanket.

8. A waste heat recovery unit as claimed in claim 5, wherein the rigid plate is formed of metal and the blanket is formed of ceramic fibres.

9. A waste heat recovery unit as claimed in any preceding claim, wherein the damper system comprises a plurality of rotatable blades, each blade comprising an upstream plate spaced from a downstream plate, and means to supply pressurised gas into the spacing between the upstream and
downstream plates, wherein a plurality of apertures are formed in at least some of the downstream plates to allow leakage of pressurised gas,

10, a heat exchanger for a waste heat recovery unit, comprising a duct defining a main flow channel for hot gas, an array of tubing supported by a support structure and extending across the duct for circulating fluid to be heated, wherein part of the array extends through the support structure such that a plurality of tubing portions are located outside the main flow channel adjacent to and spaced from one another, and further comprising a plurality of baffles each located between adjacent tubing portions so as to at least partially fill the spacing between them.

15, A heat exchanger as claimed in claim 10, wherein the tubing comprises a portion of larger outer diameter extending aortas the duct and through the support structure, and a portion of smaller outer diameter located external to the support structure, such that a smaller spacing is provided between adjacent larger outer diameter tubing portions, and a larger spacing is provided between adjacent smaller outer diameter tubing portions, and wherein the baffles are provided in the larger spacings,

12, A heat exchanger as claimed in claim 10 or claim 11, wherein each baffle comprises a rigid plate within an outer insulating blanket -

13. A heat exchanger as claimed in claim 12, wherein the rigid plate is formed of metal and the blanket is formed of ceramic fibres.
14. A waste heat recovery unit comprising at least one duct for directing hot gas to a heat exchanger unit and at least one bypass duct to bypass hot gas around the heat exchanger unit, and a damper system comprising a plurality of rotatable blades, each blade comprising an upstream plate spaced from a downstream plate, and means to supply pressurized gas into the opening between the upstream and downstream plates, wherein a plurality of apertures are formed in at least some of the downstream plates to allow leakage of pressurized gas into the or each heat exchanger duct.

15. A waste heat recovery unit: as claimed in claim 14, further comprising a heat exchanger as claimed in any of claims 10-13.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D21/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F28D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>DE 201 06 186 Ul (CAROLA POETZSCHER GMBH &amp; CO KG [DE]) 5 July 2001 (2001-07-05) figure 2</td>
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<td>Wo 2007/084011 AI (KANFA TEC AS [NO]; KASPERSEN TERJE [NO]; KLØSTER PAAL [NO]; SOERENSEN) 26 July 2007 (2007-07-26) figure 1</td>
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[ further documents are listed in the continuation of Box C.]

[ see patent family annex.]

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"S" document member of the same patent family

Date of the actual completion of the international search
11 November 2014

Date of mailing of the international search report
19/11/2014

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
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Fax: (+31-70) 340-3016

Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)
C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  □ Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2.  □ Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3.  □ Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 64(a).

Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1.  □ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2.  □ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3.  □ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4.  □ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest  □ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

□ The additional search fees were accompanied by the applicant’s protest but the applicable protest fee was not paid within the time limit specified in the invitation.

X No protest accompanied the payment of additional search fees.
This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9

   The first subject relates to a waste heat recovery unit with a particular layout for 2 heat exchange channels and one by-pass channel.

2. claims: 10-13

   The second subject relates to a heat exchanger with an array of tubes and a support structure, a plurality of tubing portions being located outside the main flow channel, the heat exchanger being provided with a plurality of baffles located between these tubing portions to fill at least partially the gaps.

3. claims: 14, 15

   The third subject relates to a waste heat recovery unit comprising a particular damper system to allow leakage of pressurized gas in the heat exchange duct.
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