

SUBSEA COOLER

Field of the invention

The present invention relates to compact cooler designs for subsea applications.

5 **Background**

Subsea coolers are well-known. Due to the environment in which they are used, several challenges not commonly encountered in non-subsea coolers must be addressed. Examples of subsea coolers, for cooling a well flow such as a hydrocarbon flow, are disclosed in for example the applicant's own published
10 application WO 2011008101 A1, which is hereby incorporated by reference in its whole, or in Norwegian patent NO 330761 B1. Other known subsea coolers are described in WO 2010110674 A2 and WO 2010110676 A2.

A common solution for subsea coolers is the use of passive coolers. In these solutions the fluid to be cooled, e.g. a well flow, is led through multiple pipes
15 arranged in a large common volume of cooling fluid, i.e. seawater. Large amounts of seawater pass through the common volume at a relatively slow rate due to natural convection, i.e. the seawater rises through the cooler since it is heated by the fluid to be cooled. Thus, it is difficult to regulate or control the cooling effect of passive coolers. Further, the design of passive coolers makes it difficult to obtain a compact
20 cooler due to restraints caused by the rate of heat transfer, the required distance between the cooling fluid pipes etc.

A potential solution to at least some of the disadvantages of a passive cooler solution is the use of active coolers having a "pipe-in-pipe" solution. In these coolers, a first pipe containing the fluid to be cooled is surrounded by a second pipe
25 (or an element having a channel through which the first pipe is arranged). The inner wall of the second pipe (or element channel) and the outer wall of the first pipe delimit a flow channel through which the cooling fluid is passed. In a "pipe-in-pipe" solution, the rate of the cooling fluid is controlled by a pump. The advantages of a
30 "pipe-in-pipe" solution are the increased temperature control (i.e. increased control of cooling effect) and, as a consequence of being an active cooler, the possibility of designing a more compact cooler.

However, the use of a "pipe-in-pipe" solution with seawater as the cooling fluid presents corrosion problems not present in passive coolers. First of all, it is difficult to protect the inner pipes against corrosion due to the restricted flow channels, and
35 secondly, corrosion may have detrimental effects since corrosion products may obstruct the flow channel.

Based on the prior art, there is a need for a compact subsea cooler providing increased temperature control.

The present invention provides a subsea cooler design which alleviates at least some of the disadvantages related to the use of “pipe-in-pipe” coolers subsea.

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Summary of the invention

The present invention provides a subsea cooler design which alleviates at least some of the disadvantages of the prior art coolers.

The invention is defined in the attached claims, and in the following:

10 In a main embodiment, the invention provides a subsea cooler comprising at least one pipe and a housing, wherein

- the pipe have an inlet and an outlet for a fluid to be cooled, and comprises straight sections connected by bend sections;
- 15 - the housing encloses at least a part of the pipe, and comprises an inner surface forming a flow channel extending along and surrounding the pipe; and
- the flow channel is fluidly connected to an inlet and an outlet for a cooling fluid and a pumping element for driving the cooling fluid
- 20 through the flow channel, wherein at least one sacrificial anode is positioned in the flow channel such that said sacrificial anode is in electrical contact with the pipe.

25 In the context of the present application, the term fluidly connected in relation to the flow channel is intended to mean a connection, such as a conduit, which ensures that cooling fluid is transferred from the inlet to the flow channel and from the flow channel to the outlet.

30 In another embodiment of the subsea cooler according to the invention, the flow channel is formed by at least a first inner surface and at least a second inner surface of the housing, and where the first inner surface extend along a straight section of the pipe, and the second inner surface extend along at least parts of a bend section, wherein a sacrificial anode is arranged at the second inner surface.

35 The second inner surface may form at least parts of a flow channel along, and surrounding, a bend section. The second inner surface may be provided at the outside of a bend to form at least parts of the flow channel around the bend. The

first and second inner surfaces may form a continuous flow channel for a fluid at the outside of the connected straight and bend sections of the pipe.

5 The second inner surface may also be described as being situated on the outside of a bend section. The term “outside of a bend section” is intended to mean that the second inner surface of the housing is situated at a distance to the bend section pipe and also being arranged at the outside of the bend of said bend section. At least parts of the second inner surface may advantageously be perpendicular to the first inner surface.

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In yet another embodiment of the subsea cooler according to the invention, the flow channel is formed by at least a first inner surface and at least a second inner surface of the housing, and where the first inner surface extend along a straight section of the pipe, and the second inner surface extend along at least parts of a bend section, 15 wherein a sacrificial anode is arranged at the first inner surface, preferably the anode is partly embedded in the first inner surface such that a substantially unobstructed flow channel is obtained.

20 In yet another embodiment of the subsea cooler according to the invention, each bend section of the pipe is in electrical contact with a sacrificial anode.

In yet another embodiment of the subsea cooler according to the invention, the at least one sacrificial anode is in electrical contact with the pipe via an electrical conductor, such as a wire.

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In yet another embodiment of the subsea cooler according to the invention, at least a part of at least one of the inner surfaces of the housing is made in a non-metallic material.

30 In yet another embodiment of the subsea cooler according to the invention, a further electrical conductor connects the at least one sacrificial anode to the pipe, such that a closed circuit is formed between the pipe and the anode.

35 In yet another embodiment of the subsea cooler according to the invention, the cross-sectional area of the flow channel is larger at the bend sections than at the straight sections, said cross-section in a plane perpendicular to a centerline of the pipe.

40 In yet another embodiment of the subsea cooler according to the invention, the flow channel comprises at least one cavity arranged such that, during use, corrosion products from the sacrificial anode may accumulate in said cavity by gravitation and/or by being pushed to said cavity by a cooling fluid flow.

In yet another embodiment of the subsea cooler according to the invention, the cavity is arranged below a bend section.

- 5 In yet another embodiment of the subsea cooler according to the invention, the straight sections of the pipe comprises multiple fins in the longitudinal direction of the corresponding straight section, preferably the height (h) of the fins is such that the fins are able to support the pipe against the first inner surface.
- 10 In yet another embodiment of the subsea cooler according to the invention, the subsea cooler comprises multiple parallel arranged pipes, wherein the outlets of the pipes are connected to a common outlet header pipe and the inlets of the pipes are connected to a common inlet header pipe.
- 15 In yet another embodiment of the subsea cooler according to the invention, the housing have multiple housing elements comprising at least a first housing element which include the first inner surface and at least a second housing element which include at least one of the second inner surfaces.
- 20 In yet another embodiment of the subsea cooler according to the invention, the first housing element comprises a block having multiple through-bores, each bore comprising a first inner surface.
- 25 Preferably, the second housing element is arranged to enclose multiple parallel bend sections.
- 30 In yet another embodiment of the subsea cooler according to the invention, the second housing element comprises at least one cavity arranged such that, during use, corrosion products from the sacrificial anode may accumulate in said cavity by gravitation.

Short description of the drawings

Fig. 1 shows a longitudinal and a transvers cross-section of a typical pipe-in-pipe arrangement.

- 35 Fig. 2 shows the transverse cross-sections of two alternative pipe-in-pipe arrangements.

Figs. 3a and 3b is a cross-sectional view of a subsea cooler according to the invention.

Figs. 4a-4d show different sectional views of the subsea cooler illustrated in figs. 3a and 3b.

Fig. 5 is a cross-sectional view of an alternative embodiment of a subsea cooler according to the invention.

5 Figs. 6a-6e show different sectional views of a subsea cooler according to the invention having an alternative housing solution.

Fig. 7 is a cross-sectional view of a flow channel comprising a cavity for corrosion products.

10 Fig. 8 is a transverse cross-sectional view of two alternatives of pipe-in-pipe solutions comprising longitudinal fins.

Description of some embodiments of the invention

15 The principle of pipe-in-pipe cooler solutions is shown in fig. 1, wherein a first pipe 1 is surrounded by a second pipe, or housing 4. A flow channel 8 is formed between an inner surface 7 of the housing and the first pipe. In use, a cooling fluid is transported through the flow channel 8, while a fluid to be cooled (e.g. a process fluid such as gas and/or oil) is transported through the first pipe 1. Commonly, the direction of the two separate fluid flows is opposite the other, i.e. the flows are counter-current. As shown in fig. 2, the design of the inner surface of the housing 4
20 may be varied to obtain different transverse cross-sections of the flow channel 8.

A cross-section of a subsea cooler according to the invention is shown in fig. 3a. The cooler comprises a pipe 1 surrounded by a housing 4. The pipe comprises both straight sections 5 and bend sections 6. A flow channel 8 is formed between an inner surface 7,13 of the housing and the pipe. The pipe 1 includes an inlet 2 and an outlet 3 for a fluid to be cooled, e.g. a process fluid, and the flow channel comprises an inlet 9 and an outlet 10 for a cooling fluid, e.g. seawater. The inlet 9 of the flow channel is connected to a pumping element 20. In cooler solutions for subsea applications corrosion is a common problem, especially when the cooler fluid is seawater. In a cooler according to the invention, i.e. a pipe-in-pipe solution,
25 corrosion of the pipe is especially important to avoid since clogging of the flow channel may easily occur due to the restricted cross-sectional area of the flow channel 8. In this embodiment, to alleviate or solve this problem, sacrificial anodes 11 are arranged outside of each bend section 6, and connected to the pipe via an electrical conductor 12. In addition, sacrificial anodes are arranged near the inlet 2 and the outlet 3 of the pipe. A magnified view of a bend section 6 connected to a sacrificial anode 11 outside of said section is shown in fig. 3b. The anode is
30 connected to the pipe via an electrical conductor (e.g. a wire) and a clamp 23. The

electrical conductor may be any connection or contact allowing an electrical current to pass between the pipe 1 and the sacrificial anode. For instance if the pipe 1 at some point is in contact with the housing 4 (e.g. pipes having fins 15, fig. 8), the housing is made of a metal, and the anode 11 is in contact with the housing 4, a
5 separate connection between the anode and pipe is redundant since electrical current may pass from the pipe via the housing to the anode.

Sectional views of the cooler in fig. 3 are shown in fig. 4a-4d. A top section, a mid section and a bottom section is outlined in fig. 4a. The sectional views of figs. 4b-4d are shown in a horizontal plane perpendicular to the vertical plane of the cross-section in fig. 4a. The use of the terms vertical and horizontal are only for
10 illustrative purposes and does not imply any required direction for arranging the cooler during use. The cooler comprises multiple parallel pipes 1. The outlet 3 of each pipe is connected to a common outlet header pipe 16, and the inlet 2 of each pipe is connected to a common inlet header pipe 17. The flow channels 8 are fluidly
15 connected to the flow channel inlet 9 via a common inlet header 21, and to the flow channel outlet 10 via a common outlet header 22.

An alternative embodiment of a cooler according to the invention is shown in fig. 5. In this embodiment, the sacrificial anodes 11 are arranged along the straight sections 5 of the pipe 1, in addition to sacrificial anodes arranged near the inlet 2 and the outlet 3 of the pipe. When the anodes 11 are arranged in the flow channel 8
20 at the straight sections 5 it is preferred that the anodes are partly embedded in the inner surface 7 of the housing. By having the anodes partly embedded, preferably such that only one surface of the anode is exposed to the flow channel 8 (i.e. the surface is flush with the inner surface of the housing), the flow channel is not
25 substantially restricted by the anodes.

A further embodiment of a cooler according to the invention is shown in fig. 6a-e. A top section, a mid section, a bottom section and an A-A cross-section are outlined in fig. 6a. The sectional views of figs. 6b-6d are shown in a horizontal plane perpendicular to the vertical plane of the cross-section in fig. 6a. The use of the
30 terms vertical and horizontal are only for illustrative purposes and does not imply any required direction for arranging the cooler during use. In this cooler the housing is made up of multiple housing elements 18,24. The first housing element is a block 18 comprising multiple through-bores 19. The through-bores are for accommodating at least parts of the straight section of each pipe. A second housing element
35 comprises longitudinal boxes 24. The boxes cover multiple parallel bend sections 6, and form fluid tight connections with the block 18, thereby forming multiple flow channels 8 surrounding the pipes 1. In this embodiment, sacrificial anodes 11 are arranged at an inner surface of the boxes.

When the sacrificial anodes 11 (i.e. galvanic anodes) are corroded, a corrosion product is formed (e.g. Al_2O_3 , ZnO or $\text{Mg}(\text{OH})_2$). The corrosion products are commonly not water soluble and may pose a potential clogging problem in the flow channel 8. To avoid clogging due to these corrosion products, the cooler may advantageously comprise cavities 14 in the flow channel 8. The cavities 14 are arranged such that at least some of the corrosion products, if/when they separate from the sacrificial anode 11, are accumulated in the cavities 14 due to gravity. A cross-sectional view of a bend section 6 comprising a cavity 14 in the surrounding housing element 4, or flow channel 8, is shown in fig. 7. A significant part of the corrosion products formed at the sacrificial anode 11 will accumulate in the cavity 14 due to gravity. Such a cavity 14 will also be beneficial when the sacrificial anode 11 is arranged along a straight section 5 of the pipe 1. Corrosion products will then be pushed or led in the direction of the flow, and finally accumulate in the cavity 14 in a similar manner as when the sacrificial anode 11 is outside the bend section 6. The design of the cavity may also include an element which reduces turbulence in the cavity. Such element may for instance be a lip at the edge of the cavity.

In pipe-in-pipe coolers, the inner pipe 1 must be supported to keep its position in the flow channel 8. A solution for obtaining such support is to provide the straight sections 5 of the pipe(s) with fins 15, see fig. 8. The fins 15 extend in the longitudinal direction of the pipe, and have a height (h) such that the fins 15 are able to support the pipe 1 against an inner surface of the outer pipe (or housing 4). A further advantage of fins is an increased heat transfer area.

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Claims

- 5 1. A subsea cooler comprising at least one pipe (1) and a housing (4), wherein
- the pipe have an inlet (2) and an outlet (3) for a fluid to be cooled, and comprises straight sections (5) connected by bend sections (6);
 - 10 - the housing (4) encloses at least a part of the pipe, and comprises an inner surface forming a flow channel (8) extending along and surrounding the pipe; and
 - 15 - the flow channel (8) is fluidly connected to an inlet (9) and an outlet (10) for a cooling fluid and a pumping element for driving the cooling fluid through the flow channel (8), wherein at least one sacrificial anode (11) is positioned in the flow channel (8) such that said sacrificial anode is in electrical contact with the pipe (1).
- 20 2. A subsea cooler according to claim 1, wherein the flow channel (8) is formed by at least a first inner surface (7) and at least a second inner surface (13) of the housing (4), and where the first inner surface (7) extend along a straight section (5) of the pipe, and the second inner surface (13) (extend along at least parts of a bend section) is situated on the outside of a bend section, wherein a sacrificial anode (11) is arranged at the second inner surface (13).
- 25 3. A subsea cooler according to claim 1 or 2, wherein the flow channel (8) is formed by at least a first inner surface (7) and at least a second inner surface (13) of the housing (4), and where the first inner surface (7) extend along a straight section (5) of the pipe, and the second inner surface (13) (extend along at least parts of a bend section) is situated on the outside of a bend section, wherein a sacrificial anode (11) is arranged at the first inner surface (7), preferably the anode is partly embedded in the first inner surface (7) such that a substantially unobstructed flow channel (8) is obtained.
- 30 4. A subsea cooler according to any of the preceding claims, wherein each bend section (6) of the pipe is in electrical contact with a sacrificial anode.
- 35 5. A subsea cooler according to any of the preceding claims, wherein the at least one sacrificial anode (11) is in electrical contact with the pipe via an electrical conductor (12).
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6. A subsea cooler according to claim 5, wherein a further electrical conductor connects the at least one sacrificial anode to the pipe, such that a closed circuit is formed between the pipe and the anode.

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7. A subsea cooler according to any of the preceding claims, wherein the flow channel (8) comprises at least one cavity (14) arranged such that, during use, corrosion products from the sacrificial anode may accumulate in said cavity by gravitation and/or by being pushed to said cavity by a cooling fluid flow.

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8. A subsea cooler according to claim 9, wherein the cavity (14) is arranged below a bend section.

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9. A subsea cooler according to any of the preceding claims, wherein the straight sections of the pipe comprises multiple fins (15) in the longitudinal direction of the corresponding straight section, preferably the height (h) of the fins is such that the fins are able to support the pipe against the first inner surface.

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