

DescriptionTechnical Field

5 **[0001]** The present disclosure pertains to a gas engine piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures. The present disclosure also pertains to a gas engine comprising such piston. Further, the present disclosure also pertains to a gas engine operation method comprising such piston.

Technological Background

10 **[0002]** Growing awareness of the detrimental effects associated with conventional fossil fuel emissions have made natural gas (NG) an attractive alternative for internal combustion engines (ICEs), particular for its advantages, which include being environment friendly, clean burning, economical, and efficient.

15 **[0003]** Since hydrogen and natural gas have different combustion behaviours, the use of hydrogen gas as well as gas mixtures consisting of hydrocarbon and hydrogen gases are considered a viable option to further the cleanliness of gas engine cycles. However, operating gas engines with hydrogen or hydrogen/hydrocarbon gas mixtures also bears the risk of potentially detrimental effects inherent to hydrogen combustion in gas engines.

20 **[0004]** The gas engine piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures, the gas engine, and the gas engine operation method of the present disclosure solve one or more problems set forth above.

Summary of the Invention

25 **[0005]** Starting from the prior art, it is an objective to provide a simple, cost-effective, and reliably operating gas engine piston. It is also an objective to reliably prevent low-temperature cooling oil coking in gas engines combusting lean combustion gases comprising hydrogen.

30 **[0006]** This objective is solved by means of a gas engine piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures with the features of claim 1, a gas engine comprising such a piston with the features of claim 13, and with a gas engine operation method with the features of claim 14. Preferred embodiments are set forth in the present specification, the Figures as well as the dependent claims.

35 **[0007]** Accordingly, a gas engine piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures is provided. The gas engine piston comprises a piston body and at least one heat-insulating element having a higher heat-insulating property than the piston body.

40 **[0008]** Furthermore, a gas engine for hydrogen or hydrogen/hydrocarbon gas mixtures comprising such a gas engine piston is provided.

45 **[0009]** Process-wise, a gas engine operation method is provided, comprising such a gas engine piston, the method comprising the steps of operating the gas engine piston with hydrogen or a hydrogen/hydrocarbon gas mixture, and observing no high or low temperature cooling oil coking.

Brief Description of the Drawings

50 **[0010]** The present disclosure will be more readily appreciated by reference to the following detailed description when being considered in connection with the accompanying drawings in which:

55 Fig. 1 schematically shows a gas engine piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures according to a first embodiment;

Fig. 2 schematically shows the piston of Figure 1 according to a further development;

Fig. 3 schematically shows the piston of Figure 2 according to a further development;

Fig. 4 schematically shows the piston of Figure 3 according to a further development;

Fig. 5 schematically shows the piston of Figure 4 according to a further development;

Fig. 6 schematically shows a gas engine according to an embodiment of the present disclosure;

Fig. 7 schematically shows a flow chart of a gas engine operation method according to a first embodiment; and

Fig. 8 schematically shows a flow chart of a gas engine operation method according to another development.

Detailed Description of Preferred Embodiments

55 **[0011]** In the following, the invention will be explained in more detail with reference to the accompanying Figures. In the Figures, like elements are denoted by identical reference numerals and repeated description thereof may be omitted in order to avoid redundancies.

[0012] The present disclosure is generally directed towards a gas engine piston capable of combusting hydrogen or hydrogen/hydrocarbon blends as combustion gas. According to one example, the gas engine piston may be suitable for a combustion gas comprising only hydrogen as it is used in H₂-gas engines. According to another example, the piston may be suitable for a combustion gas comprising hydrogen/hydrocarbon mixture with a given hydrogen/hydrocarbon gas substitution ratio.

[0013] It was found that hydrogen and hydrogen/hydrocarbon gas blends can offer improved flame speeds, a wider flammability range, lower minimum ignition energy, and reduced emissions.

[0014] Being able to operate a gas engine at leaner mixture conditions not only reduces emissions but also is also associated with reduced heat releases and lower piston temperatures. However, low piston temperatures can cause low-temperature cooling oil coking to the detriment of engine performance.

[0015] In view thereof, improved gas engine pistons are needed to compensate for lower heat releases observed during the combustion of lean combustion gases comprising hydrogen.

[0016] Partial or full substitution of natural gas with hydrogen allows operating a combustion cycle at burn conditions that are leaner than the stoichiometric combustion of natural gas. Lean burn conditions are desirable, since higher air concentrations can lead to faster and more complete oxidation, thereby enhancing thermal and combustion efficiencies.

[0017] However, the inherently increased air concentration is leads to improved heat absorption, thereby lowering the piston's heat release and peak temperatures. It has been observed that at lean combustion conditions, piston temperatures can drop below a critical point, thereby causing low-temperature cooling oil coking which is detrimental to piston health and piston performance.

[0018] To avoid such low-temperature cooling oil coking, the gas engine piston according to the present disclosure comprises a heat-insulating element configured to retain combustion heat inside the gas engine piston to such an extent that a piston temperature does not fall below a critical cooling oil temperature.

[0019] Providing the thermal insulation in the shape via the heat-insulating element, insulating the piston, helps achieving a higher temperature with the result that coke in the piston is burnt and misfiring incidents are reduced.

[0020] In Figure 1, a gas engine piston 10 for combusting hydrogen or hydrogen/hydrocarbon gas mixtures in a gas engine 100 is schematically shown in a cross-sectional view. The gas engine piston 10 may be a piston of a gas engine of the reciprocating, internal combustion engine (ICE)-type used for combusting hydrogen gas only or a hydrogen/hydrocarbon gas mixture.

[0021] The gas engine piston 10 may be configured to combust lean hydrogen gas or lean hydrogen/hydrocarbon gas mixtures. In the context of the present disclosure, the term "lean" may refer to a combustion gas comprising hydrogen or a hydrogen/hydrocarbon mixture which is leaner than the stoichiometric mixture of natural gas.

[0022] The gas engine piston 10 comprises a piston body 12 and at least one heat-insulating element 14. The heat-insulating element 14 has a higher heat-insulating property than the piston body 12.

[0023] For example, the heat-insulating element may be configured such that no piston cooling 110 is required. This may be the case when only hydrogen is used in the combustion gas 120.

[0024] Likewise, the heat-insulating element 14 may be configured such that excess cooling provided by a conventional natural gas piston cooling 110 is compensated. This may be the case when hydrogen or a hydrogen/hydrocarbon mixture is combusted. In this case, a piston according to the present disclosure may easily be retrofitted to an engine 100 without necessitating changes to the piston cooling 110 to prevent low-temperature cooling oil coking by piston temperatures below a critical cooling oil temperature. In other words, a temperature may be achieved that is high enough to burn off coke, which may lead to reduced incidents of misfiring.

[0025] According to the embodiment shown in Figure 1, the piston body 12 may for example be made of a first material 16 and the heat-insulating element 14 may be of a second material 18 having a higher heat-insulating property than the first material 16.

[0026] In the context of the present disclosure, the heat-insulating property of a heat-insulating element 14 may be understood as the thermal resistance R of a heat-insulating element 14. The higher the thermal resistance, the lower the heat loss via the heat-insulating element 14, and the better the heat insulation performance of the heat-insulating element 14.

[0027] The thermal resistance R can be defined as the ratio of temperature difference observed on two faces of a heat-insulating element 14 to the rate of heat flow per unit area and can be expressed by the ratio between a thickness d and a thermal conductivity A of a heat-insulation element 14:

$$R = d/\lambda \quad (1)$$

[0028] Having a higher heat-insulating property than the piston body 12 may be in the affirmative, if the heat-insulation element 14 with a thickness d_{Element} has a higher thermal resistance R than the piston 12 having a piston body thickness d_{Piston} .

[0029] Alternatively, having a higher heat-insulating property than the piston body 12 may be in the affirmative, if the heat-insulation element 14 with a thickness d has a higher thermal resistance R than a piston segment of the same thickness. Accordingly, instead of a thermal resistance comparison, a thermal conductivity comparison may be utilized. For a given thickness, the lower the thermal conductivity of a heat-insulating element 14, the better the heat insulation performance of a heat-insulating element 14.

[0030] In summary, if the heat-insulating element 14 has a lower thermal conductivity λ than the piston body 12, the heat-insulating element 14 may be considered having a higher heat-insulating property than the piston body 12.

[0031] Measurements of thermal conductivity λ or thermal resistance R may be carried out in a standardized manner with laboratory methods such as defined for example in the UNE-EN ISO 8990: 1997 standard.

[0032] In cases when a thermal conductivity of a heat-insulating element 14 cannot be identified, the ratio of temperature difference observed on two faces of the heat-insulating element 14 to the rate of heat flow per unit area may be taken as a basis, following the definition of the thermal resistance R .

[0033] The heat-insulating element 14 and/or the heat-insulating property thereof may be based on a predetermined parameter 20. In other words, the heat-insulating element 14 and/or the heat-insulating property may be selected or dimensioned based on a predetermined parameter. The predetermined parameter 20 may refer to the intended work environment of the gas engine piston 10. For example, the predetermined parameter 20 may be based on a gas engine 100 specific parameter.

[0034] Further, the predetermined parameter 20 may be based on a cooling oil property and/or a cooling oil flow.

[0035] In the context of the present disclosure, the cooling oil property may be a thermophysical property of the cooling oil used, such as density, thermal conductivity, specific heat, and viscosity. Further, a cooling oil property may also include temperature limits of a cooling oil at a given temperature.

[0036] A predetermined parameter based on a cooling oil property may thus allow dimensioning the heat-insulating element 14 to match a specific cooling oil.

[0037] Likewise, a predetermined parameter 20 based on a cooling oil flow may be understood as a parameter taking into account heat transport phenomena of a cooling oil flow, in particular a cooling oil velocity, static, dynamic, and/or total pressures, as well as volumetric or mass flow of the cooling oil.

[0038] Preferably, a predetermined parameter based on a cooling oil flow may comprise a cooling performance of a cooling oil for a given scenario in the form of an approximation, calculation, and/or simulation.

[0039] By that, the heat-insulating device and/or the heat-insulating property thereof may be dimensioned to counteract a given temperature gradient or heat-flux inflicted by a cooling oil presence, or cooling oil flow at or in the vicinity of a gas engine piston.

[0040] If for example a cooling oil with a given critical low-temperature cooling oil coking point is used, the heat-insulating element 14 may be designed such that it provides a sufficient heat-insulation to avoid temperatures below the critical low-temperature cooling oil coking point. The latter may be achieved by means of simple experiments by adjusting the shape, position, and/or heat insulating properties of the heat-insulating element.

[0041] Alternatively, or additionally, the predetermined parameter 20 may be based on a combustion gas 120. Thereby, gas engine pistons 10 for dedicated combustion gases 120 may be provided, the gas engine piston 10 being suitable for operation with said combustion gas 120.

[0042] Further, the predetermined parameter 20 may be based on a combustion gas concentration 122, a hydrogen gas concentration 124, and/or a hydrogen/hydrocarbon gas substitution ratio 126. The term combustion gas concentration 122 may refer to the volumetric or molar concentration of a combustion gas such as hydrogen or a hydrogen/hydrocarbon gas mixture, preferably in vol.-%. Likewise, the term hydrogen gas concentration 124 may refer to the volumetric or molar concentration of hydrogen, preferably in vol.-%. The term hydrogen/hydrocarbon gas substitution ratio 126 may refer to a volumetric or molar ratio between the hydrogen and hydrocarbon gas. Further, pure natural gas may be used as a reference.

[0043] Thereby, observed heat losses during the combustion of lean hydrogen or lean hydrogen/hydrocarbon gas mixtures may be compensated by implementing a suitable heat-insulating element 14 configured such that no low-temperature cooling oil temperature coking occurs by achieving a temperature high enough to burn off coke.

[0044] Accordingly, pistons for a dedicated combustion gas concentration 122, hydrogen gas concentration 124, and/or hydrogen/hydrocarbon gas substitution ratio 126 may be provided such that they are configured to be operable at a given combustion gas concentration 122, a given hydrogen gas concentration 124, and/or a given hydrogen/hydrocarbon gas substitution ratio 126 without causing low-temperature cooling oil coking.

[0045] According to the illustration shown in Figure 1, the piston 12 may comprise a top land 24. The heat-insulating element 14 may comprise a coating 22 applied to the piston body 12. In the Figures, the coating 22 is shown schematically by means of the cut-out section. In the shown embodiment, heat-insulating element 14 may be provided on the top land 24 of the piston 12. The heat-insulating element 14 may extend partially or fully across the entire surface of the top land 24.

[0046] In Figure 2, a further development of the gas engine piston 10 shown in Figure 1 is illustrated schematically. The same principles, explanations, and definitions provided in the context of Figure 1 may also apply to Figure 2. The

embodiment shown in Figure 2 differs from the embodiment shown in Figure 1 in that the piston 12 may further comprise a fire land 26, wherein the heat-insulating element 14 may be provided on the top land 24 and/or on the fire land 26.

[0047] According to the shown illustration, the heat-insulating element 14 may be provided in the form of a coating 22 provided on both the top land 24 and on the fire land 26. The heat-insulating element 14 may extend partially or fully across the entire surfaces of the top land 24 and/or the fire land 26. Likewise, the gas engine piston 10 of Figure 1 may also comprise a fire land 26, yet without the heat-insulating element 14 provided thereon.

[0048] According to another embodiment not shown in Figure 2, the heat-insulating element 14 may be provided only on the fire land 26. Accordingly, the heat-insulating element 14 may be provided in the form of a coating 22 which is provided on the fire land 26. The heat-insulating element 14 may extend partially or fully across the entire surface of the fire land 26. The fire land 26 may also be considered the first land.

[0049] In Figure 3, a further development of the gas engine piston 10 shown in Figures 1 and 2 is illustrated schematically. The same principles, explanations, and definitions provided in the context of Figures 1 and 2 may also apply to Figure 3. The embodiment shown in Figure 3 differs from the embodiment shown in Figure 2 in that the piston 12 may further comprise a piston skirt 28, at least one piston ring groove 40 configured to accommodate a piston ring 30, and at least one second land 32 between the piston skirt 28 and the piston groove 40, wherein the heat-insulating element 14 is provided on the top land 24, the fire land 26 and the second land 32.

[0050] According to the shown illustration, the heat-insulating element 14 may be provided in the form of a coating 22 which is provided on the top land 24, the fire land 26, and the second land 32. The heat-insulating element 14 may extend partially or fully across the entire surfaces of the top land 24, the fire land 26 and/or the second land 32. Naturally, the gas engine pistons 10 of Figures 1 and 2 may also comprise a second land 32, yet without the heat-insulating element 14 provided thereon.

[0051] According to another embodiment not shown in Figure 3, the heat-insulating element 14 may be provided only on the second land 32. Accordingly, the heat-insulating element 14 may be provided in the form of a coating 22 which is provided on the second land 32. The heat-insulating element 14 may extend partially or fully across the entire surface of the second land 32.

[0052] In Figure 4, a further development of the gas engine piston 10 shown in Figures 1-3 is illustrated schematically. The same principles, explanations, and definitions provided in the context of Figures 1 to 3 may also apply to Figure 4. The embodiment shown in Figure 4 differs from the embodiment shown in Figure 3 in that the gas engine piston 10 may further comprise a second ring groove 34 configured to accommodate a second ring 36, and a third land 38, wherein the second land 32 is provided between the top ring groove 40 and the second ring groove 34 and the piston skirt 28, wherein the heat-insulating element 14 is provided on the top land 24, the fire land 26, the second land 32, and the third land 38.

[0053] In Figure 5, a further development of the gas engine piston 10 shown in Figure 4 is illustrated schematically. The same principles, explanations, and definitions provided in the context of Figure 4 apply. The embodiment shown in Figure 5 differs from the embodiment shown in Figure 4 in that the heat-insulating element 14 may be provided on the top land 24, the fire land 26, the second land 32, the third land 38, and the piston skirt 28.

[0054] The heat-insulating element 14 of Figures 4 and 5 may extend partially or fully across the entire surfaces of the top land 24, the fire land 26, the second land 32, and/or the piston skirt 28, respectively. Likewise, the gas engine piston 10 of Figures 1-4 may also comprise a piston skirt 28, yet without the heat-insulating element 14 provided thereon.

[0055] According to further developments not shown in Figures 4 and 5, the heat-insulating element 14 may also be provided only on the third land 38, and/or the piston skirt 28. Accordingly, the heat-insulating element 14 may be provided in the form of a coating 22 which is provided on the third land 38 and/or the piston skirt 28. The heat-insulating element 14 may extend partially or fully across the entire surface of the third land 38 and/or the piston skirt 28.

[0056] In Figure 6, a first embodiment of a gas engine 100 is shown schematically. The gas engine 100 may be configured to be operable with hydrogen as combustion gas, representing a H₂-gas engine. Alternatively, the gas engine 100 may be configured to be operable with a hydrogen/hydrocarbon gas mixture. Additionally, the gas engine 100 may be configured to be operable with a lean hydrogen or hydrogen/hydrocarbon gas mixture as combustion gas. The gas engine 100 comprises at least one gas engine piston 10 according to the present disclosure. Further, the gas engine 100 may comprise a system for piston cooling 110. The piston cooling 110 may be variably adjustable, switched on, or off, and may also be fully omitted. In applications where the combustion gas comprises only hydrogen, the piston cooling 110 may be switched off or may be fully omitted.

[0057] In Figure 7, a gas engine operation method is shown in a flow chart. The method steps may be conducted with a gas engine piston 10 according to the present disclosure and comprise the steps of operating S10 the gas engine piston 10 with hydrogen and/or hydrocarbon gas and observing S20 no high or low temperature cooling oil coking. Preferably, the step of operating S 10 the gas engine piston 10 may comprise operating the gas engine with a lean combustion gas comprising hydrogen or a hydrogen/hydrocarbon mixture.

[0058] In Figure 8, a further development of the gas engine operation method of Figure 7 is shown. The embodiment shown in Figure 8 differs from the embodiment shown in Figure 7 in that the method may further comprise a step of

substituting S02, at least partially, hydrocarbon gas with air and hydrogen gas, and/or a step of deactivating S04 piston cooling 110. The step of deactivating S04 piston cooling 110 may refer to cases when only or mostly hydrogen is present in the combustion gas. Preferably, the step of substituting S02, at least partially, hydrocarbon gas with air and hydrogen gas, may comprise substituting hydrocarbon gas until a lean combustion gas is obtained, having a flammability limit lower than a flammability limit of natural gas.

[0059] It will be obvious for a person skilled in the art that these embodiments and items only depict examples of a plurality of possibilities. Hence, the embodiments shown here should not be understood to form a limitation of these features and configurations. Any possible combination and configuration of the described features can be chosen according to the scope of the invention.

[0060] This is in particular the case with respect to the following optional features which may be combined with some or all developments, items and all features mentioned before in any technically feasible combination. As an example, one piston may comprise more separate heat-insulating elements. A gas engine piston may be a component of a gas engine operable with a combustion gas comprising hydrogen or consisting of hydrogen. Further, the gas engine piston, or the gas engine, may be operable with a combustion gas of different hydrogen/hydrocarbon gas substitution ratios.

[0061] In the context of the present disclosure, the term hydrogen may refer to diatomic, homonuclear hydrogen, H₂. Likewise, the term hydrocarbon gas may refer to one or more heteronuclear hydrocarbon gases, C_nH_m.

[0062] A piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures in a gas engine may be provided, the piston comprising a piston body on at least one heat-insulating element having a higher heat insulation property than the piston body. By means of the heat insulating element, low temperature cooling oil coking may be prevented at lean burn conditions, in particular at burn conditions at flammability ranges below that of natural gas. By providing the heat-insulating element, transient heat fluxes from the combustion chamber through the piston may be reduced. In other words, the heat-insulating element is configured to promote retaining heat inside the combustion chamber.

[0063] Thereby, low-temperature cooling oil coking may be prevented or mitigated and associated detrimental effects on the gas engine piston can be avoided. In other words, a temperature may be achieved that is high enough to burn off coke, which may lead to reduced incidents of misfiring. Hence, the gas engine piston can be operated at lean combustion conditions, which may result in a higher thermal efficiency and less emissions.

[0064] According to a preferred development, the piston body may be made of a first material and the heat-insulating element may be made of a second material having a higher heat-insulating property than the first material. The first material usually comprises metal, preferably a steel alloy. The second material may be any material having a higher heat-insulating property than the first material, for example a reduced thermal conductivity. The latter may be attributed to a different material or to a material having a different configuration or shape, for example a porosity or a cavity. Thereby, the heat transfer through the piston may be reduced effectively.

[0065] According to a preferred development, the heat-insulating element and/or the heat insulating property thereof may be based on a predetermined parameter. Thereby, the heat-insulation performance of the heat-insulating element or the heat-insulating property of the element may be correlated to an external parameter. Thereby, a variety of different pistons may be produced suitable for such a parameter. The predetermined parameter may be based on empirically obtained data. Thereby, standardization of pistons comprising at least one heat-insulating element may be achieved, which reduces production costs, warehousing efforts, and maintenance.

[0066] According to a further development, the predetermined parameter may be based on a piston cooling system. For example, a piston cooling system designed for operation with natural gas. In such a case, providing a piston having a heat-insulating element based on the cooling system allows safe operation without necessitating a change in piston cooling. Likewise, a piston can be provided for a cooling system that is absent or switched off.

[0067] According to a further embodiment, the predetermined parameter may be based on a cooling oil property and/or a cooling oil flow. In the context of the present disclosure, cooling oil may be an oil taken from an oil sump of a gas engine, for example taken from an area below a crankshaft to which the piston cylinder is mounted. The cooling oil flow may be a flow of cooling oil fed to the gas engine piston via the cooling oil supply, for example to a piston bottom surface.

[0068] By providing a predetermined parameter based on a cooling oil property and/or a cooling oil flow, standardization of pistons may be achieved more easily. Thereby, a piston can be provided for an existing cooling system which is operated with a specific cooling oil and/or a specific cooling flow. By providing a piston having a heat-insulating element based on a predetermined parameter based on a cooling oil property and/or a cooling oil flow, the piston may readily be integrated into an engine having a compatible cooling system.

[0069] According to a further development, the predetermined parameter may be based on a combustion gas. Thereby, pistons for dedicated combustion gases may be provided which are known to be operable with a given combustion gas without causing low-temperature cooling oil coking.

[0070] According to a further development, the predetermined parameter may be based on a combustion gas concentration, a hydrogen concentration, and/or a hydrogen/hydrocarbon gas substitution ratio. The term combustion gas concentration may refer to a leanness of a combustion gas mixture. The term hydrogen gas concentration may refer to a volumetric or molar concentration of hydrogen in a volume of gas. The term hydrogen/hydrocarbon gas substitution

ration may refer to a volumetric or molar ratio between the hydrogen and hydrocarbon gas. Further, pure natural gas may be used as a reference.

5 [0071] Thereby, the thermal effects of combusting hydrogen may be implemented into a specific piston, for example in relation to a reference case where only natural gas is combusted. Accordingly, pistons for a dedicated combustion gas concentration, hydrogen gas concentration, and/or hydrogen/hydrocarbon gas substitution ratio may be provided such that they are known to be operable at a given combustion gas concentration, hydrogen gas concentration, and/or hydrogen/hydrocarbon gas substitution ratio without causing low-temperature cooling oil coking.

10 [0072] According to a further development, the heat-insulation element may comprise a coating applied to the piston body. Thereby, a safe and durable application of the heat-insulation element on the piston may be achieved. Thereby, operation safety of a piston according to the present disclosure may be achieved.

[0073] According to a further development, the piston body may comprise a top land, wherein the heat-insulating element is provided on the top land. The top land, adjacent to the combustion chamber, constitutes the piston surface with the highest heat influx. Hence, providing the heat-insulating element on the top land allows to effectively reduce the heat flux entering the piston. Thereby, low-temperature cooling oil coking may be prevented effectively.

15 [0074] According to a further development, the piston body may further comprise a fire land, wherein the heat-insulating element is provided on the top land and/or the fire land. The fire land surrounds the top land adjacent to and protruding away from the main combustion chamber. However, the fire land is still in fluid communication with the combustion chamber and is exposed to a high heat influx. Hence, providing the heat-insulating element on the fire land allows to effectively reduce the heat flux entering the piston. Thereby, low-temperature cooling oil coking may be prevented effectively.

20 [0075] According to a further development, the piston may further comprise a piston skirt, at least one piston ring groove configured to accommodate a piston ring, and at least a second land between the piston skirt and the piston ring groove, wherein the heat-insulating element is provided on the top land, the fire land, the second land, and/or the piston skirt. Thereby, the heat flux entering the piston can be reduced further, allowing to prevent low-temperature cooling oil coking.

25 [0076] According to a further development, the at least one piston ring groove may be a top ring groove configured to accommodate a top ring, wherein the piston may further comprise a second ring groove configured to accommodate a second ring, and a third land, wherein the second land is provided between the top ring groove and the second ring groove and the piston skirt, wherein the heat-insulating element is provided on the top land, the fire land, the second land, the third land, and/or the piston skirt. Thereby, the heat flux entering the piston can be reduced further, allowing to prevent low-temperature cooling oil coking.

30 [0077] A gas engine for hydrogen or hydrogen/hydrocarbon gas mixtures may be provided, comprising at least one piston according to the present disclosure. Thereby, lean gas mixtures comprising hydrogen may be combusted with a low likelihood of low-temperature cooling oil coking. Thereby, detrimental cooling oil coking effects on the gas engine may be avoided.

35 [0078] According to a preferred embodiment of the gas engine, the gas engine is an H₂-gas engine comprising a piston according to the present disclosure. Thereby, no piston cooling is needed. Instead, piston cooling may be switched off or may be omitted.

40 [0079] According to an alternative embodiment, a conventional gas engine for natural gas may be provided, comprising a conventional natural gas piston cooling system and a piston according to the present disclosure. Due to the heat-insulating element, the piston may be operated with a hydrogen/hydrocarbon gas mixture and cooled in a similar way a conventional natural gas combustion would be cooled. Further, such gas engine may be operated even at a lower leanness compared to natural gas combustion. In this case, the heat-insulating element may be configured to compensate for the observed or expected losses in heat release. Thereby, a conventional natural gas engine may be retrofitted with a piston according to the present disclosure and operated with a leaner combustion gas (hydrogen/hydrocarbon blend) without the necessity of changing the piston cooling system.

45 [0080] According to a development, the gas engine may comprise a piston cooling in the form of a cooling system for a gas engine piston. The cooling system may comprise a cooling oil supply configured to feed a cooling oil flow to the gas engine piston, and a control device configured to control the cooling oil. Thereby, a simple, cost-effective, and reliable piston cooling system may be provided. Preferably, the cooling oil system may be configured such that it can be switched off in a case when the combustion gas comprises only or predominantly hydrogen gas.

50 [0081] A gas engine operation method is provided, comprising a piston according to the present disclosure, the method comprising the steps of operating the piston with hydrogen and/or hydrocarbon gas, and a step of observing no low-temperature cooling oil coking. Referring to the method, the same principles, explanations, and definitions provided in the context of the gas engine piston and the gas engine apply.

55 [0082] According to a development of the gas engine operation method, the method may further comprise a step of substituting, at least partially, hydrocarbon gas with air and hydrogen gas, and/or a step of deactivating piston cooling. Thereby, a simple, cost-effective, and reliable gas engine operation method may be provided. Further, low-temperature

cooling oil coking incidents in gas engines using hydrocarbon-hydrogen mixtures as combustion gas may be prevented effectively.

Industrial Applicability

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- [0083]** With reference to the Figures, a gas engine piston, a gas engine, and an operation method for a gas engine are applicable in any suitable combustion engine, for example internal combustion engines ICEs for gaseous fuels and in particular an ICE operating with combustion gases comprising hydrocarbon-hydrogen gas blends.
- 10 **[0084]** In practice, a gas engine piston, a gas engine and/or any combination of these various assemblies and components may be manufactured, bought, or sold to retrofit or replace a gas engine, or a gas engine already in the field in an aftermarket context, or alternatively may be manufactured, bought, sold, or otherwise obtained in an OEM (original equipment manufacturer) context.
- [0085]** As alluded to previously herein, the aforementioned developments may provide a simple, cost-effective and reliably operating cooling system for a gas engine piston.
- 15 **[0086]** Referring to Figure 1, there is a development shown disclosing a piston for combusting hydrogen or hydrogen/hydrocarbon gas mixtures in a gas engine, the piston comprising a piston body on at least one heat-insulating element having a higher heat insulation property than the piston body. One skilled in the art will expect various developments of the present disclosure will have an improved simplicity, necessitating less maintenance and less complex adjustment technologies for gas engine pistons.
- 20 **[0087]** The same advantages apply to the remaining figures, in particular to the gas engine comprising such a piston, and to the gas engine operation method.
- [0088]** The present description is for illustrative purposes only and should not be construed to narrow the breadth of the present disclosure in any way. Thus, those skilled in the art will appreciate that various modifications might be made to the presently disclosed developments without departing from the full and fair scope and spirit of the present disclosure.
- 25 Other aspects, features and advantages will be apparent upon an examination of the attached drawings and appended claims. As used herein, the articles "a" and "an" are intended to include one or more items and may be used interchangeably with "one or more." Where only one item is intended, the term "one" or similar language is used. Also, as used herein, the terms "has," "have," "having," "include", "includes", "including", or the like are intended to be open-ended terms. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.
- 30 **[0089]** All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.
- [0090]** Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein.
- 35 **[0091]** Certain steps of any method may be omitted, performed in an order that is different than what has been specifically mentioned or in some cases performed simultaneously or in sub-steps. Furthermore, variations or modifications to certain aspects or features of various developments may be made to create further developments and features and aspects of various developments may be added to or substituted for other features or aspects of other developments in order to provide still further developments.
- 40 **[0092]** Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.
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Claims

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1. A gas engine piston (10) for combusting hydrogen or hydrogen/hydrocarbon gas mixtures, the piston (10) comprising a piston body (12) and at least one heat-insulating element (14) having a higher heat-insulating property than the piston body (12).
 2. The gas engine piston (10) according to claim 1, wherein the piston body (12) comprises a first material (16) and the heat-insulating element (14) comprises a second material (18) having a higher heat-insulating property than the first material (16).
 3. The gas engine piston (10) according to any of the previous claims, wherein the heat-insulating element (14) and/or
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the heat-insulating property thereof is based on a predetermined parameter (20).

4. The gas engine piston (10) according to claim 3, wherein the predetermined parameter (20) is based on a piston cooling system (110).
5. The gas engine piston (10) according to any of claims 3 to 4, wherein the predetermined parameter (20) is based on a cooling oil property and/or a cooling oil flow.
6. The gas engine piston (10) according to any of the previous claims 3-5, wherein the predetermined parameter (20) is based on a combustion gas (120).
7. The gas engine piston (10) according to any of the previous claims 3-6, wherein the predetermined parameter (20) is based on a combustion gas concentration (122), a hydrogen gas concentration (124), and/or a hydrogen/hydrocarbon gas substitution ratio (126).
8. The gas engine piston (10) according to any of the previous claims, wherein the heat-insulating element (14) comprises a coating (22) applied to the piston body (12).
9. The gas engine piston (10) according to any of the previous claims, wherein the piston body (12) comprises a top land (24), wherein the heat-insulating element (14) is provided on the top land (24).
10. The gas engine piston (10) according to claim 9, further comprising a fire land (26), wherein the heat-insulating element (14) is provided on the top land (24) and/or on the fire land (26).
11. The gas engine piston (10) according to claim 10, further comprising a piston skirt (28), at least one piston ring groove (40) configured to accommodate a piston ring (30), and at least a second land (32) between the piston skirt (28) and the piston ring groove (40), wherein the heat-insulating element (14) is provided on the top land (24), the fire land (26), the second land (32), and/or the piston skirt (28).
12. The gas engine piston (10) according to claim 11, wherein the at least one piston ring groove (26) is a top ring groove configured to accommodate a top ring (30), further comprising a second ring groove (34) configured to accommodate a second ring (36), and a third land (38), wherein the second land (32) is provided between the top ring groove (40) and the second ring groove (34), wherein the third land (38) is provided between the second ring groove (34) and the piston skirt (28), wherein the heat-insulating element (14) is provided on the top land (24), the fire land (26), the second land (32), the third land (38), and/or the piston skirt (28).
13. A gas engine (100) for hydrogen or hydrogen/hydrocarbon gas mixtures, comprising at least one gas engine piston (10) according to the previous claims 1-12.
14. A gas engine operation method, comprising a gas engine piston (10) according to any of the previous claims 1-12, the method comprising the steps of
 - operating (S10) the gas engine piston (10) with hydrogen or a hydrogen/hydrocarbon gas mixture; and
 - observing (S20) no low temperature cooling oil coking.
15. The gas engine operation method according to claim 14, further comprising a step of substituting (S02), at least partially, hydrocarbon gas with air and hydrogen gas, and/or a step of deactivating (S04) piston cooling (110).

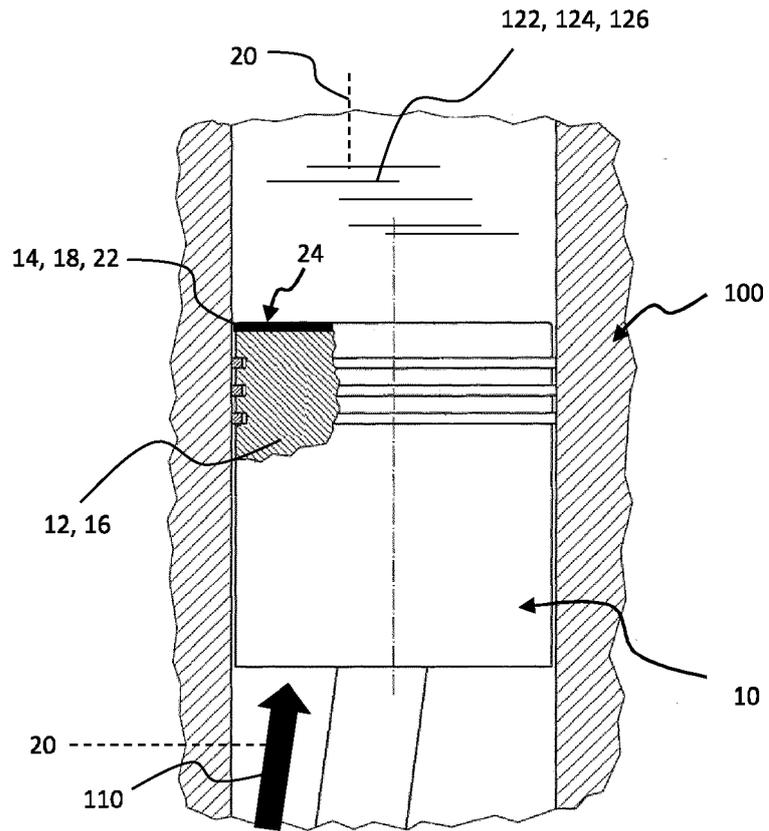


Fig. 1

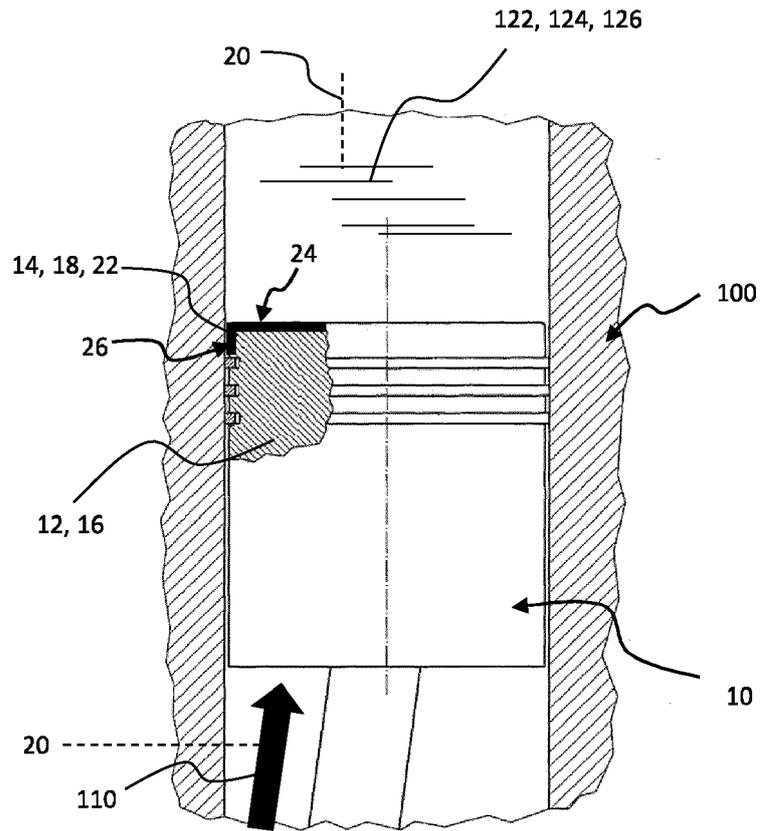


Fig. 2

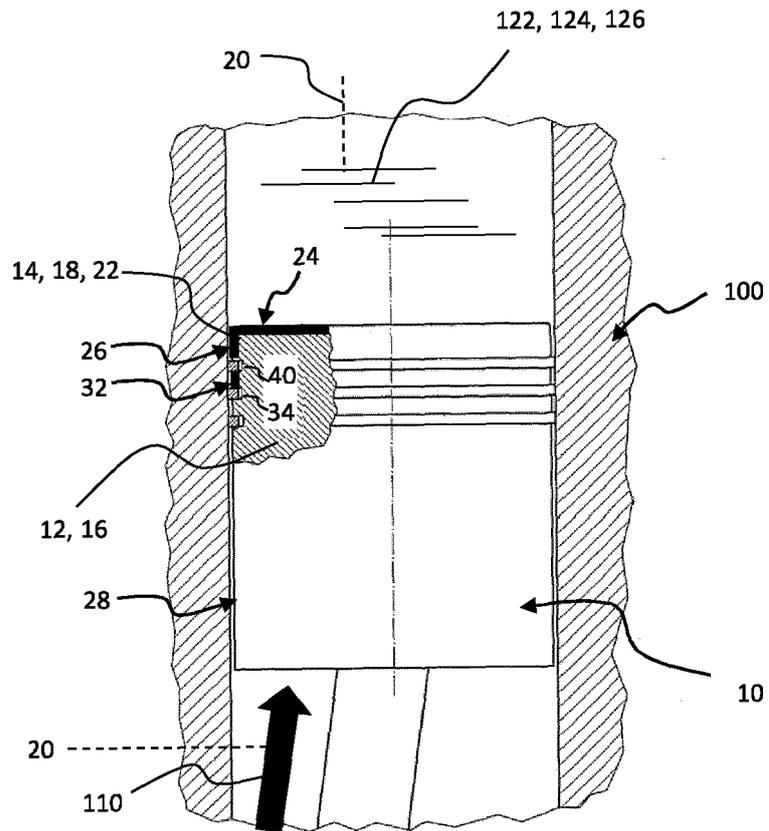


Fig. 3

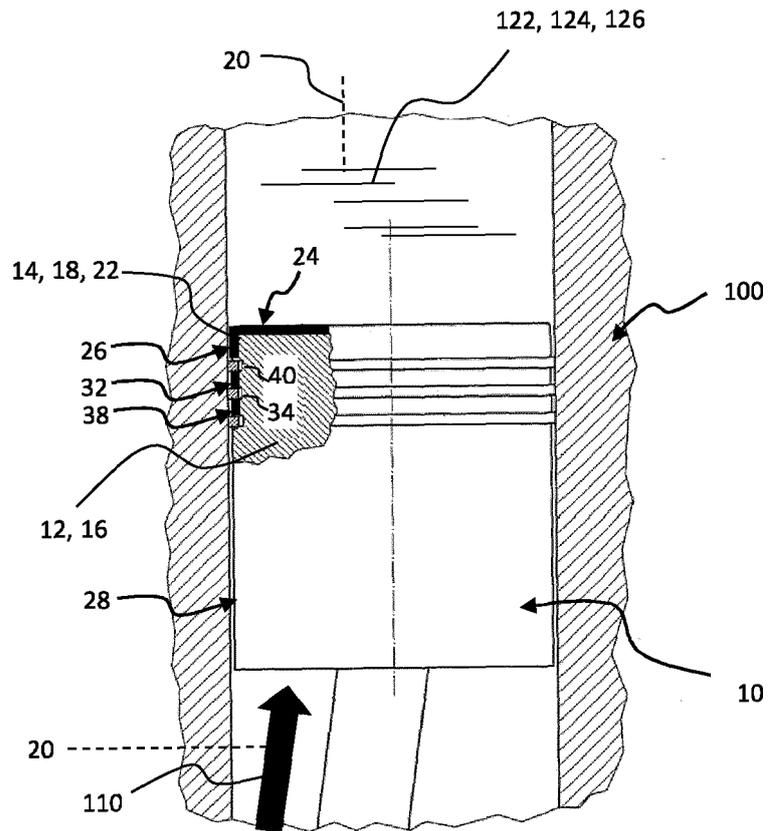


Fig. 4

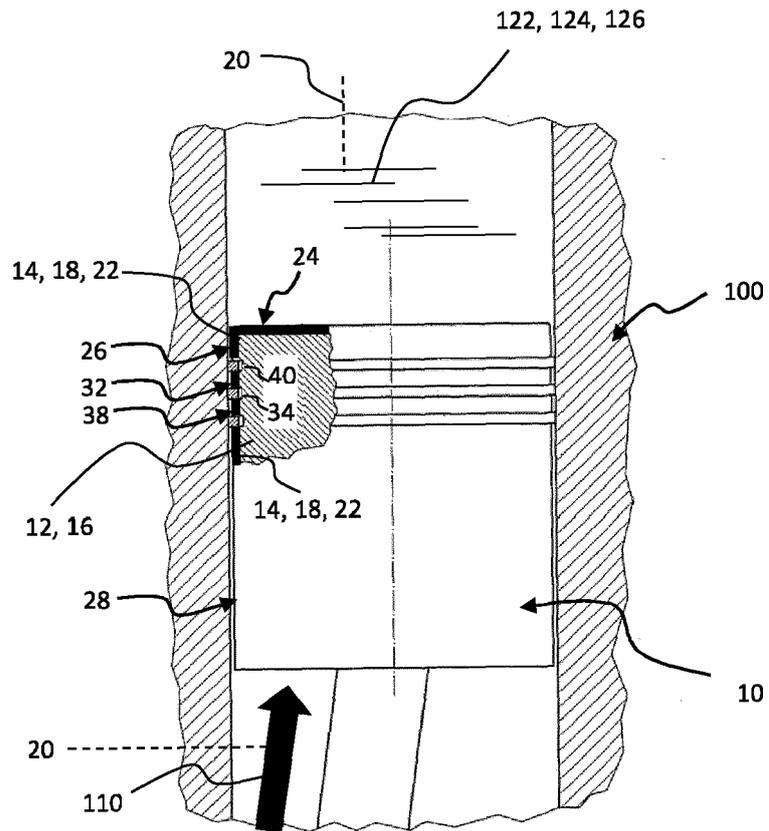


Fig. 5

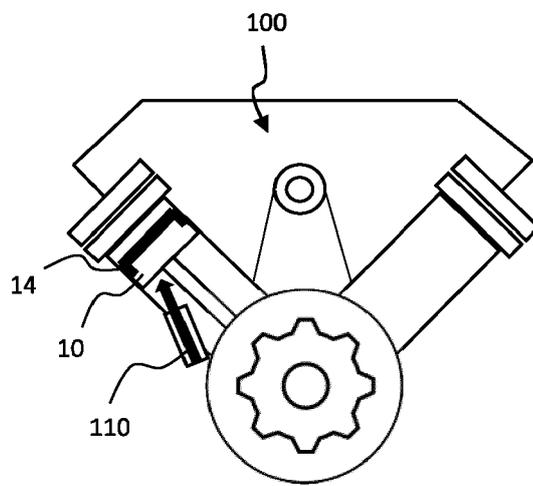


Fig. 6

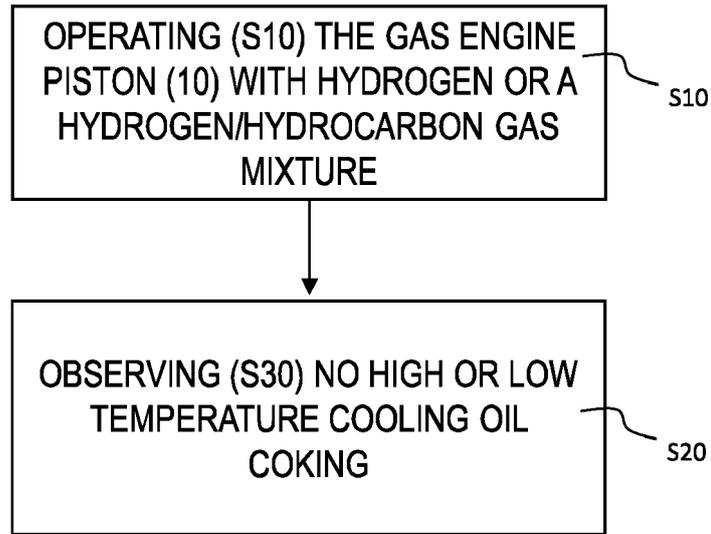


Fig. 7

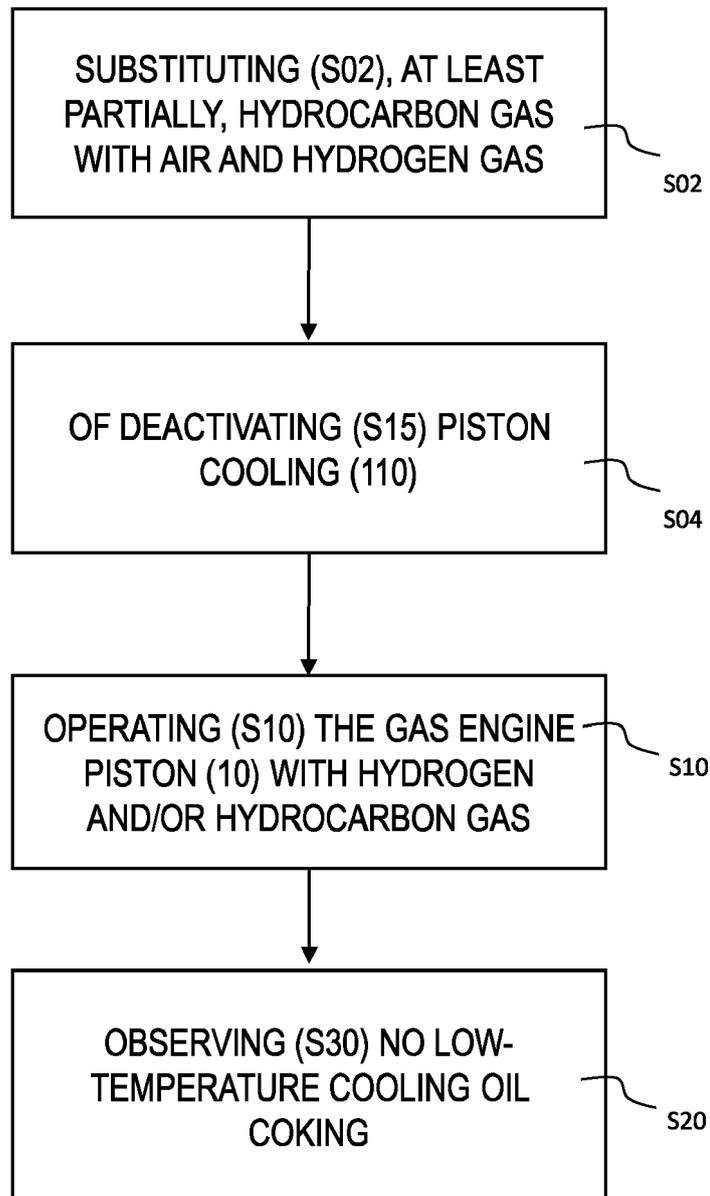


Fig. 8



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Application Number
EP 23 17 1006

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			F02F
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		22 September 2023	Matray, J
CATEGORY OF CITED DOCUMENTS			
<p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p>		<p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>	

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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