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Asselman et al.

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[54] **HOT-GAS RECIPROCATING ENGINE**

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[52] **U.S. Cl.** **60/524**

[51] **Int. Cl.** **F01k 27/00**

[58] **Field of Search** 60/517, 524

[56] **References Cited**

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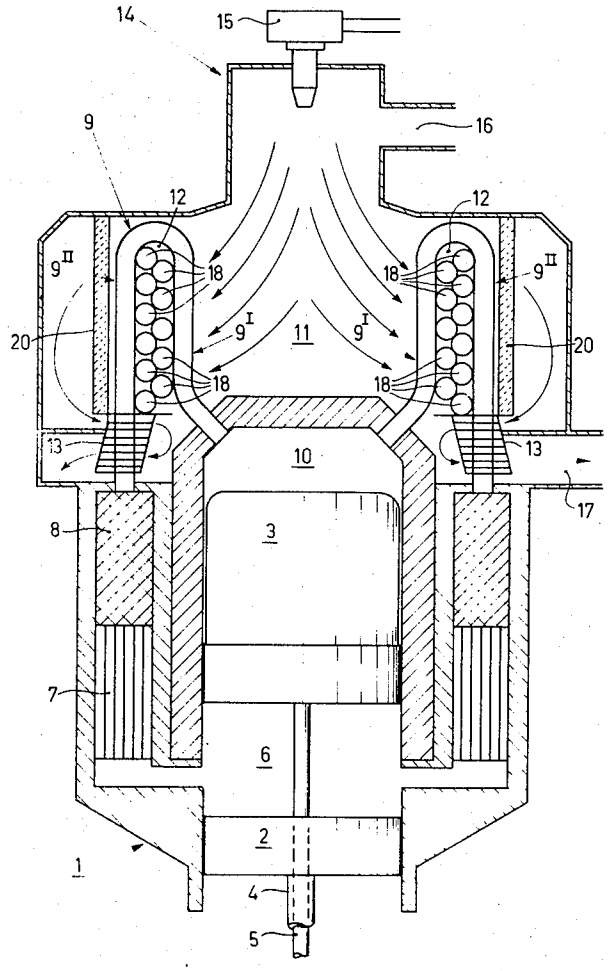
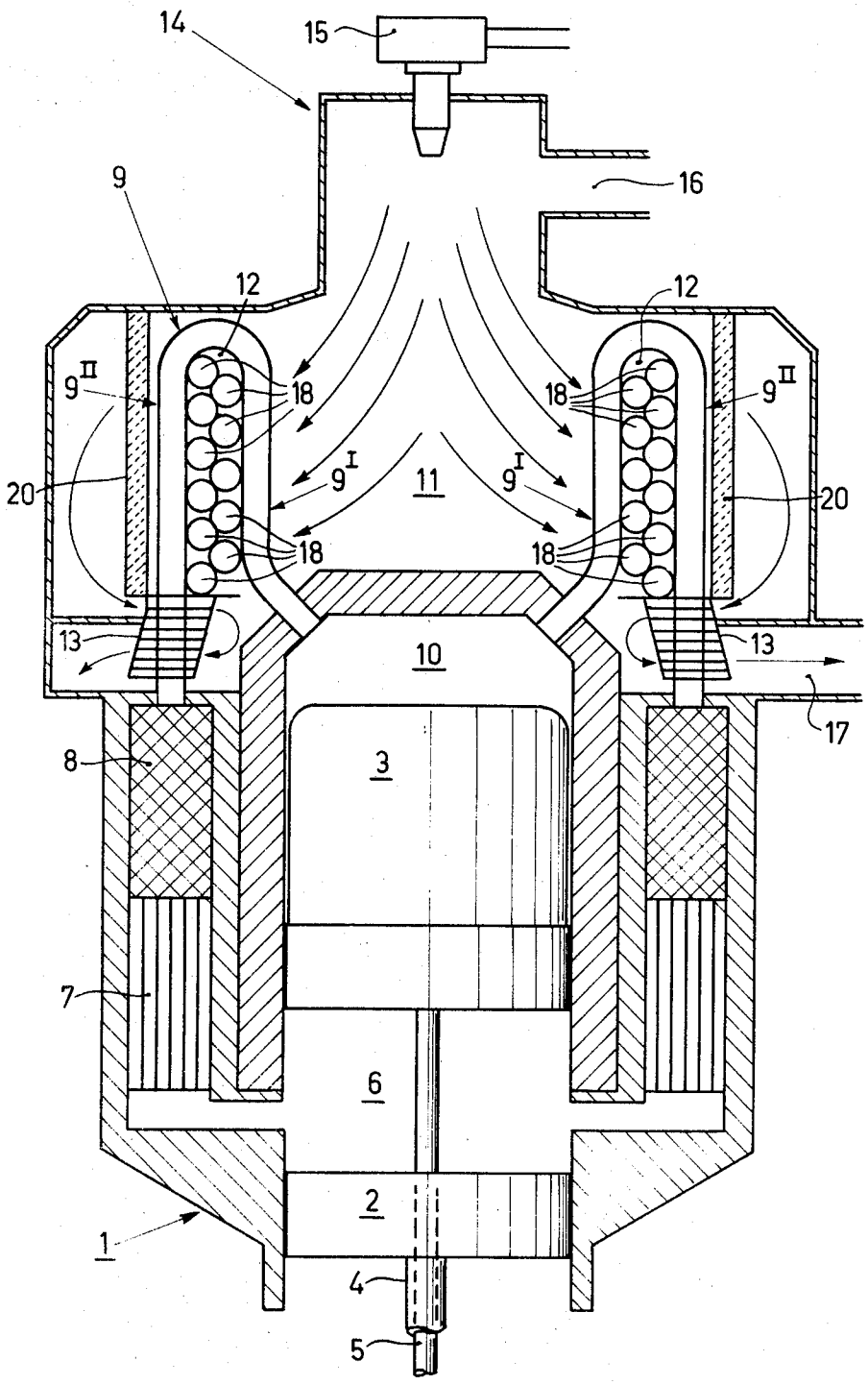
[57] **ABSTRACT**

A hot-gas receiprocating engine including a heater housing of at least two rows of pipes which are arranged one behind the other in the flow path of combustion gases, transverse to the flow direction, the intermediate space being filled with a mass of a material which is readily heat-radiant during operation of the engine and through which the combustion gases can flow.

7 Claims, 1 Drawing Figure

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HOT-GAS RECIPROCATING ENGINE

BACKGROUND OF THE INVENTION

The invention relates to a hot-gas reciprocating engine, provided with a heater as a heat exchanger for exchanging heat between combustion gases and a working medium present in the engine. The heater comprises at least two rows of pipes which are consecutively arranged at a distance from each other, thus forming an intermediate space, in the flow path of the combustion gases. The rows of pipes extend in planes mainly transverse to the gas flow direction, with passages for the combustion gases being present between the pipes of each row.

A hot-gas reciprocating engine of this kind is known from Netherlands Patent Specification 73,669 and British Patent Specification 857,758. In the heater thermal energy is applied to the engine's working medium such as helium or hydrogen of the engine, with a flow of hot combustion gases along the heater pipes while giving off heat thereto.

In spite of the large temperature difference between the combustion gases (temperature 2,200° – 2,300°C) and the heater pipes (temperature approximately 700°C), the transfer of heat from these combustion gases to the heater pipe walls is comparatively poor. In order to achieve proper transfer of heat, a comparatively large pipe surface area is required, which implies pipes of comparatively large length. However, longer pipes give rise to larger flow losses of the working medium in the pipes in view of the larger flow resistances, with the result that the thermal efficiency and the power are adversely affected. Also the compression ratio of the engine is negatively influenced in that the dead volume increases as the pipe length increases which becomes significant particularly in a reduction of the power, and furthermore, longer pipes imply a larger construction volume of the engine.

The limited heat transfer from the combustion gases to the heater pipes impedes the realization of a higher specific power (hp-shaft power per litre cylinder volume) by way of an increase of the working medium pressure in the engine and/or of the number of revolutions.

SUMMARY OF THE NEW INVENTION

The present invention has for its object to provide a hot-gas engine of the kind set forth with an improved heat transfer between the combustion gases and the heater pipe walls to mitigate the above drawbacks. To achieve this object, the hot-gas reciprocating engine according to the invention is characterized in that the intermediate space is filled with a mass of a material which is readily heat-radiant during operation of the engine and through which the combustion gases can flow.

It is thus achieved that the heat transfer from the combustion gases to the heater pipes not only takes place by convection, but also by radiation. During the starting period of the engine, the temperature of the mass in the indermediate space is increased to a high value by the combustion gases flowing therethrough, the mass being maintained at this temperature during normal operation of the engine. The mass then acts as a heat radiator, with the result that the pipe wall parts facing the intermediate space are heated. The higher the emission coefficient of the mass at the radiation temperature, the higher the intensity of the heat radiation (radiation law of Stefan-Boltzmann).

The heat-radiant mass then also produces a better distribution of the thermal load over the pipe circumference of the row of pipes which is first passed by the combustion gases. This mass furthermore ensures improved mixing of the combustion gases, which results in more complete combustion.

In a preferred embodiment of the hot-gas reciprocating engine according to the invention, the heat-radiant mass is composed of spherical particles. This offers the advantage that the choice of the sphere diameter accurately defines the dimensions of the passage openings for the combustion gases and that these dimensions are the same everywhere. According to the invention, the spherical particles are preferably hollow. As a result, the weight and the heat capacity of the mass are low. The latter means that only a small amount of heat is required for heating the mass, with the result that the heating-up time is short.

In a further preferred embodiment of the invention, the heat-radiant mass is made of silicon carbide (SiC). At an operating temperature of the heat-radiant mass of about 1,700°C occurring in the hot-gas reciprocating engine, silicon carbide has a favourable, high emission coefficient of 0.8 (the ideal, theoretical maximum is **1** for so-termed black bodies). Moreover, silicon carbide offers the advantage of high heat-resistance and high thermal-shock resistance, so that no problems can arise, for example, if the flames of the burner of the hot-gas reciprocating engine are directed onto the heat-radiant mass in the cold state.

A further preferred embodiment of the invention is characterized in that in the flow path of the combustion gases, behind the pipe rows, a further mass of a material is arranged through which the combustion gases can flow and which radiates heat at least in the direction of the pipe rows, this further mass being arranged transverse to the flow direction.

It is thus achieved that the pipe wall parts of the last pipe row, viewed downstream for the combustion gases, which are remote from the intermediate space are also exposed to radiation. This additional heating furthermore enhances uniform thermal loading over the circumference of the pipes constituting the last row.

The invention will be described in detail hereinafter with reference to the drawing which is a diagrammatic representation of one embodiment of the hot-gas reciprocating engine and which is not to scale.

BRIEF DESCRIPTION OF THE DRAWING AND THE PREFERRED EMBODIMENT

The figure in the drawing is a longitudinal sectional view of a hot-gas reciprocating engine with a heater which is composed of two rows of pipes, the rows being concentrically arranged about a space for combustion gases.

The reference numeral **1** denotes a cylinder in which a piston **2** and a displacer **3** are movable with a phase difference. The piston and the displacer are connected to a drive system not shown by way of a piston rod **4** and a displacer rod **5**, respectively. Present between piston **2** and displacer **3** is a compression space **6** which is in open communication, via a cooler **7**, a regenerator **8** and a heater **9**, with an expansion space **10** above the displacer.

The heater **9** consists of a number of bent pipes which are arranged in a ring about a space **11** for combustion gases and which communicate at one end with regenerator **8** and which open into expansion space **10** at the other end. The arrangement is such that an inner pipe row 9^I and an outer pipe row 9^{II} are concentric with an annular intermediate space **12** being present between said rows. Present between the pipes of each row are gaps which serve as passages for combustion gases. The pipes of outer row 9^{II} are provided on their lower ends with fins **13** so as to increase the heat-transfer surface at this area.

The hot-gas reciprocating engine furthermore comprises a burner unit **14,** comprising a burner **15** and an inlet **16** for combustion air, and an outlet **17** for combustion gases.

The annular intermediate space **12** is filled with hollow spheres or spherical elements **18** of silicon carbide. Identical, accurately defined passage openings for combustion gases are present between the contact points of the spheres. The spheres are stacked such that they constitute an apparently closed wall for the pipe rows. Arranged about the outer pipe row 9^{II} is a cylindrical sleeve **20** which is made of a porous ceramic material, silicon carbide is the present case.

During operation of the hot-gas engine, the hot combustion gases (temperature, for example, 2,200°C) originating from the burner unit **14** flow along the pipe of the inner row 9^I while giving off heat thereto. The combustion gas temperature then decreases to, for example, 1,700°C. The combustion gases subsequently flow through the passage openings between the hollow silicon carbide spheres **18,** again while giving off heat thereto. Because the transfer of heat between the combustion gases and the hollow spheres is high, the mean temperature of the spheres will not be substantially lower than 1,700°C. After the combustion gases have passed the outer pipe row 9^{II} while giving off heat thereto, their temperature can amount to some 1,100°C. Subsequently, the combustion gases flow through the porous sleeve **20** while giving off heat thereto, after which, after having given off further heat to the fins **13,** they leave the hot-gas engine via outlet **17.**

The silicon carbide spheres at a temperature of about 1,700°C constitute excellent heat radiators whose radiation is incident on the pipe wall parts of the two pipe rows facing intermediate space **12,** these parts thus being additionally heated. The pipe wall parts of the outer pipe row 9^{II} which are outwards directed are exposed to the radiation of the porous sleeve **20** so they are also additionally heated. As a result, heat of the combustion gases is transferred to the heater pipes not only by convection but also by radiation.

As a result of the improved heat transfer with a higher thermal loading of the heater pipes which is uniformly distributed over the pipe circumference, the length of these pipes may be shorter, which results in lower flow losses of working medium in the pipes, smaller dead volume of the pipes, and smaller construction volume of the engine.

The improved heat transfer furthermore offers better possibilities as regards increasing the specific engine power, for example, by increasing the medium pressure in the engine because more heat must and can then be transferred to the larger working medium mass flow in the pipes.

Even though the drawing shows a heater which is composed of two concentrically arranged rows of straight, mutually parallel pipes, the invention is obviously also applicable to many other heater configurations. For example, the pipes of a row may be curved, the pipes of a row may enclose an angle with the pipes of another row, and the planes through the pipe rows may have all sorts of shapes and may enclose an angle with respect to each other.

What is claimed is:

1. In a hot-gas reciprocating engine including a heater as a heat exchanger for exchanging heat between combustion gases and a working medium present in the engine, the improvement in combination therewith wherein said heater comprises at least two inner and outer rows of pipes, the rows of pipes being spaced apart in the direction of the gas flow thus forming an intermediate space between the rows, with passages for the combustion gases present between the pipes of each row, said heater further comprising within said intermediate space a mass of hollow spherical elements which elements are readily heat-radiant during operation of the engine and between which the combustion gases can flow.

2. Apparatus according to claim **1** wherein said mass comprises silicon carbide (SiC).

3. Apparatus according to claim **1** further comprising a further mass adjacent to and downstream of said outer row of pipes, said further mass being porous for permitting a flow therethrough of said combustion gas and being heat-radiant for radiating heat to the adjacent outer row of pipes.

4. In a hot-gas engine including a heater which has a housing defining a central zone and an outlet radially spaced from said zone, the engine operable with a burner providing hot combustion gases which flow from said zone to said outlet, the improvement in combination therewith comprising heater tubes formed as concentric inner and outer rows generally surrounding said zone, the rows spaced apart to define between them an annular space, a mass comprising a plurality of readily heat-radiant elements situated in said annular space, with space defined between said elements through which said combustion gas can flow.

5. Apparatus according to claim **4** wherein said mass comprises hollow spherical elements.

6. Apparatus according to claim **4** further comprising a further mass adjacent to and downstream of said outer row of pipes, said further mass being porous for permitting a flow therethrough of said combustion gas and being heat-radiant for radiating heat to the adjacent outer row of pipes.

7. Apparatus according to claim **3** wherein said further mass comprises a sleeve porous to the flow of said combustion gas.

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