(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 November 2010 (18.11.2010)

PCT

(10) International Publication Number
WO 2010/131941 A1

(51) International Patent Classification:
F02C 3/34 (2006.01) *F02C 3/30* (2006.01)
F02C 3/20 (2006.01)

(21) International Application Number:
PCT/MY2010/000074

(22) International Filing Date:
12 May 2010 (12.05.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PI 20091937 13 May 2009 (13.05.2009) MY

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

— *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))*

(54) Title: GAS TURBINE ENGINE

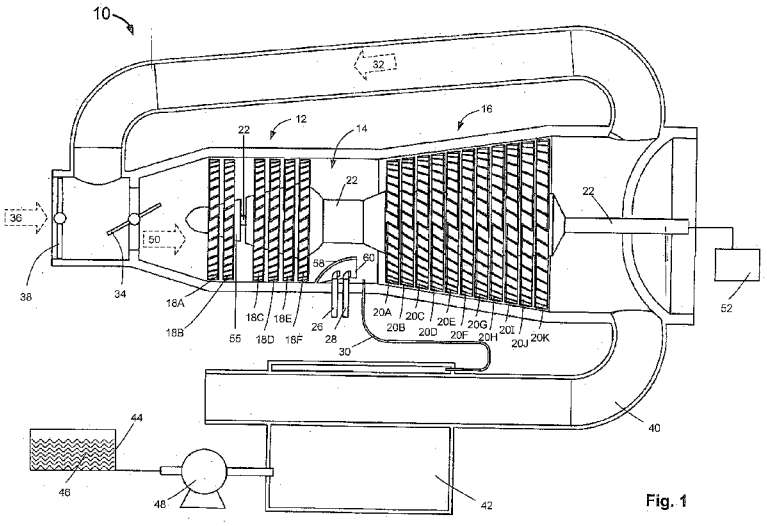

Fig. 1

(57) Abstract: A gas turbine engine having a compressor upstream of a combustion chamber and a turbine downstream of the combustion chamber, the compressor being coupled to the turbine by a shaft, the combustion chamber including a fuel injector, the gas turbine engine including an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of the fuel injector.

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GAS TURBINE ENGINE

The present invention relates to gas turbine engines.

Gas turbine engines are known wherein ambient air enters the front of a compressor having a series of compressor blades. The compressed air then enters a combustion chamber where fuel is injected and burnt and the exhaust gas then exits the engine via a turbine which generates power. The exhaust gas includes various pollutants, including carbon dioxide and NO_x. In order to reduce the carbon dioxide emissions the engine can be run "leaner", but this tends to increase the NO_x. A compromise therefore has to be made.

There is therefore a need for a gas turbine engine that produces less emissions.

Thus, according to the present invention there is provided a gas turbine engine having a compressor upstream of a combustion chamber and a turbine downstream of the combustion chamber,

the compressor being coupled to the turbine by a shaft, the combustion chamber including a fuel injector,

the gas turbine engine including an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of the fuel injector.

Advantageously, the oxidising agent injector can inject an oxidising agent having a lower proportion of nitrogen than ambient air, and as such less NO_x will be produced in the exhaust gas stream.

The invention will now be described, by way of example only, with reference to the accompanying drawing showing a schematic cross-section of a gas turbine engine according to the present invention.

With reference to the drawing there is shown a gas turbine engine 10 having a compressor 12, a combustion chamber 14 and a turbine 16. The compressor is a multi-stage axial flow compressor having six stages of compression defined by six sets of compressor blades

18A, 18B, 18C, 18D, 18E and 18F. Between adjacent sets of compressor blades there is a set of stator blades (not shown).

Compressor blade set 18A and 18B are selectively rotatably mounted on shaft 22. A clutch (shown schematically as item 55) can be engaged to selectively couple the compressor blade sets 18A and 18B to shaft 22, or can be disengaged to selectively decouple set of compressor blades 18A and 18B from shaft 22.

The turbine is an eleven-stage axial flow turbine having eleven sets of turbine blades 20A, 20B, 20C, 20D, 20E, 20F, 20G, 20H, 20I, 20J and 20K. Between adjacent sets of turbine blades are a set of stator blades (not shown).

The compressor is connected to the turbine via shaft 22. Between the compressor and the turbine is the combustion chamber 14. The combustion chamber also includes an oxidising agent injector, in this case an oxygen injector 26. The combustion chamber also includes a fuel injector 28 and a water injector 30.

The gas turbine engine includes a recirculation path 32 fluidly connecting the exit from the turbine with the compressor intake 50. In the recirculation path there is provided a valve, in this case a butterfly throttle valve 34.

An engine intake 36 that allows ambient air to enter the compressor. The intake 36 includes a valve, in this case a butterfly throttle valve 38.

An exhaust system 40 allows exhaust gas to exit from the engine. The exhaust system passes through a gas-to-water heat exchanger 42. A water reservoir 44 includes water 46 which is pressurised via pump 48 and then passes through the gas-to-water heat exchanger 42 to the water injector 30. Typically pump 48 will pressurize the water to 150 to 200 bar.

Operation of the gas turbine engine 10 is as follow:-

Normal Running

Under normal running conditions the butterfly valve 38 will be closed and the butterfly valve 34 will be at least partially open. Clutch 55 will be disengaged. Gas in the compressor intake 50 will pass to the right when viewing the figure through the compressor. The gas will pass blade sets 18A and 18B which will be "freewheeling" since the clutch 55 is disengaged. The gases will then continue to right when viewing the figure, being progressively compressed as it passes each subsequent compressor blade set. On exiting the compressor and entering the combustion chamber it will mix with oxygen being injected via the oxygen injector 26. As the gas/oxygen mixture passes further into the combustion chamber fuel is injected which burns due to the oxygen in the gas/oxygen mixture. Heat is therefore generated. As the heated gas passes further into the combustion chamber it will heat water injected from the water injectors 30 which will turn the water into steam. The steam and gas mixture will then pass through the turbine causing it to rotate shaft 22. An amount of power transferred to shaft 22 will drive the compressor, and the remaining power is free for use and will drive a power absorber 52. In this case, an electricity generator. As the gas exits the turbine, some of the gas will be diverted into the recirculation path 32 (typically 50-60%) and the remainder of the gas will be diverted into the exhaust system 40.

The gas diverted in through the circulation path will be conveyed to the compressor intake 50 after having passed the butterfly valve 34, and will pass through the engine again as described above.

That proportion of the gas entering the exhaust system 40 will then pass through the gas-to-water heat exchanger 42, wherein some of the heat of the exhaust gas will be transferred to the water. In this way the water 46 is preheated prior to being injected into the combustion chamber.

Engine Start-up

When the engine is cold, it can be advantageous to use ambient air to start the engine. Under these circumstances, the butterfly valve 38 is opened and the clutch 55 is engaged.

As all blade sets of the compressor are rotated ambient air will be sucked into the compressor intake 50. As will be appreciated, the ambient air includes an amount of oxygen and therefore the oxygen injector 26 may not be required to inject oxygen during start-up, or alternatively may only be required to inject a relatively small amount of oxygen during start-up.

Once the engine has been started and is up to its normal running temperature, then the butterfly valve 38 can be closed and the clutch 55 disengaged. Advantageously, by arranging a clutch 55 to engage the first two sets of compressor blades during start up, then sufficient pressure can be produced in the combustion chamber during this period. Once the engine is up to normal running temperature, the clutch can be disengaged, thereby reducing the energy requirement of the compressor 12.

In further embodiments, the clutch 55 may not be required and hence all compressor blades will rotate at the same speed. In further embodiments the pitch of the stator blade between adjacent sets of compressor rotor blades may be varied to vary the compression.

As described above, the oxygen injector injects oxygen. As will be appreciated, when the butterfly valve 38 is closed, no air is being fed into the gas stream and in particular, since air contains nitrogen, then no nitrogen is being fed into the gas stream. Consequently, when the oxygen is injected then no NO_x can be produced. The exhaust gas in exhaust system 40 therefore primarily contains water and carbon dioxide. The gas-to-water heat exchanger 42 will cool the exhaust gas and therefore significant amounts of water will condense and can therefore be removed from the exhaust gas, leaving an exhaust gas having large amounts of carbon dioxide.

Air consists of 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.03% carbon dioxide and 0.01% other gases by volume. Preferably, relatively pure oxygen is used in the present invention, i.e. a gas having 99% by volume of oxygen. When nitrogen is removed from air, the oxygen content comprises 95% by volume of the resultant gas. Advantageously, such a gas can be used in the present invention since it contains no nitrogen and hence the exhaust gases will not contain NO_x. Whilst using a gas free of nitrogen minimises the

NO_x emissions, nevertheless significant improvements in emissions can be made when the gas contains at least 80% by volume of oxygen or at least 90% by volume of oxygen.

As mentioned above, the fuel injector is positioned within the combustion chamber. In further embodiments the oxygen injector could be positioned in the compressor intake 50, i.e. upstream of the compressor. In further embodiments the oxygen injector could be positioned in the compressor itself, in particular the oxygen injector could be positioned between adjacent pairs of rotor blades.

The relative position of various components in the exhaust gas stream is significant. Thus, the fuel injector 28 is positioned downstream of the oxygen injector 26. The water injector 30 is positioned downstream from the oxygen injector 26. The water injector 30 is positioned downstream from the fuel injector 28.

In further embodiments it is possible to move the water injector 30 to the left when viewing the figure, i.e. to move the water injector upstream, or to the right when viewing the figure, i.e. to move the water injector downstream. Thus, by varying the position of water injector relative to the fuel injector, the efficiency of a gas turbine engine can be improved over a range of operating conditions.

The butterfly throttle 34 is used to control the amount of residual gas going into the turbine. The amount of residual gas needs to be controlled in order to:-

a) control the charge temperature entering the combustion chamber, the optimum temperature being that temperature where auto-ignition of the fuel occurs and
b) to maintain optimal gas flow velocity going into the combustion chamber.

As mentioned above, the power absorber 52 is an electricity generator. In further embodiments the power absorber could be any type of power absorber, including a vehicle.

As mentioned above, the water being injected is pre-heated via the exhaust gas. Alternatively, or additionally, the water could be pre-heated by any other heat source, in

particular the heat source could be engine coolant used to cool the gas turbine engine. The coolant may be pressurized to above atmospheric pressure to increase its boiling temperature and hence its specific heat capacity, for example the coolant could be pressurized to 3 bar or more. Alternatively or additionally, lubricating oil that has been circulating within the engine to cool the bearings etc may be used to heat the water 46.

Alternatively, or additionally, the water 46 may be heated by external heat sources, such as sunlight or geothermal energy.

As shown in the figure a shield 58 shields the oxygen injector 26 and fuel injector 28 from gas stream produced by the compressor. The shield is open at a downstream end 60. The shield allows stabilisation of the flame.

It will also be noted that the oxygen injector and fuel injector are both circumferentially aligned. Furthermore the oxygen injector is circumferentially aligned with the water injector 30. Furthermore the fuel injector 28 is circumferentially aligned with the water injector 30. Circumferentially aligning the water injector with the fuel injector allows injected water to cool any components immediately downstream of the flame, thereby preventing hot spots within the engine.

As shown in the figure, there is a single oxygen injector 26, a single fuel injector 28, a single water injector 30, and a single shield 58. In further embodiments there may be a plurality of oxygen injectors, fuel injectors, water injectors and shields spaced circumferentially around the combustion chamber.

As mentioned above, the valve 34 is a butterfly valve. In further embodiments alternative valves could be used. In particular an iris valve could be used. Where an iris valve is used, it could be positioned between adjacent sets of rotor blades, in particular it could be positioned between blade set 18B and 18C.

As mentioned above, the recirculation path feeds recirculated gas to the front of the compressor. In further embodiments the recirculated gas could be fed into the compressor between two adjacent blade sets. In particular the recirculated gas could be fed into the

compressor between blade set 18B and 18C. Under these circumstances blade sets 18A and 18B would only compress ambient air on start up. No recirculating gases would pass blade sets 18A and 18B.

The fuel used may be a fluid fuel, for example a liquid or a gas. The fuel may have long chain carbon molecules, for example molecules having eight or more carbon atoms. The carbon atoms within the molecules may be in a straight chain, or alternatively the carbon atoms may be branched. Preferably the fuel is derived from plant material.

CLAIMS

1. A gas turbine engine having a compressor upstream of a combustion chamber and a turbine downstream of the combustion chamber,

the compressor being coupled to the turbine by a shaft, the combustion chamber including a fuel injector,

the gas turbine engine including an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of the fuel injector.

2. A gas turbine engine as defined in claim 1 in which the oxidising agent injector is downstream of the compressor.

3. A gas turbine engine as defined in claim 2 in which the oxidising agent injector is positioned in the combustion chamber.

4. A gas turbine engine as defined in claim 1 in which the oxidising agent injector is upstream of the compressor.

5. A gas turbine engine as defined in claim 1 which the compressor includes a first set of compressor blades upstream of a second set of compressor blades and said oxidising agent injector is positioned downstream from the first set of compressor blades and upstream from the second set of compressor blades.

6. A gas turbine engine as defined in any preceding claim including a water injector positioned downstream of the fuel injector.

7. A gas turbine engine as defined in claim 6 in which the water injector is positioned upstream of the turbine.

8. A gas turbine engine as defined in claim 6 or 7 wherein water is preheated above an ambient temperature before being injected.

9. A gas turbine engine as defined in claim 8, including an exhaust gas path having a heat exchanger wherein the exhaust gas heats the water to be injected.

10. A gas turbine engine as defined in claim 8 including a heat exchanger to allow engine coolant to heat water to be injected.

11. A gas turbine engine as defined in any of claims 6 to 10 in which water is pressurised above a combustion chamber pressure before being injected.

12. A gas turbine engine as defined in any preceding claim including a recirculation path for recirculating gas exiting from the turbine into the compressor.

13. A gas turbine engine as defined in claim 12 including a recirculation gas valve positioned in the recirculation path for controlling the amount of recirculated gas entering the compressor.

14. A gas turbine engine as defined in any preceding claim including an intake for allowing ambient air into the compressor.

15. A gas turbine engine as defined in claim 14 including an ambient air valve for controlling the amount of ambient air entering the compressor.

16. A gas turbine engine as defined in any preceding claim including a first set of compressor blades upstream of a second set of compressor blades, said first set being selectively decoupleable from said second set.

17. A gas turbine engine as defined in claim 16 when dependent upon claim 12 wherein said recirculation path recirculates gas downstream of the first set of compressor blades and upstream of the second set of compressor blades.

18. A gas turbine engine as defined in claim 16 or 17 when dependent upon claim 15 wherein said ambient air valve is positioned between the first set of compressor blades and the second set of compressor blades.

19. A gas turbine engine as defined in claim 18 wherein said ambient air valve is an iris valve.

20. A method of operating a gas turbine engine as defined in any preceding claim, wherein the oxidising agent is a gas having a higher oxygen content than air.

21. A method as defined in claim 20 in which the oxidising agent includes at least 80% by volume of oxygen, more preferably at least 90% by volume of oxygen, more preferably at least 95% by volume of oxygen.

22. A method as defined in claim 20 in which the oxidising agent is substantially free of nitrogen.

23. A method as defined in any one of claims 20 to 22, further including the step of injecting water.

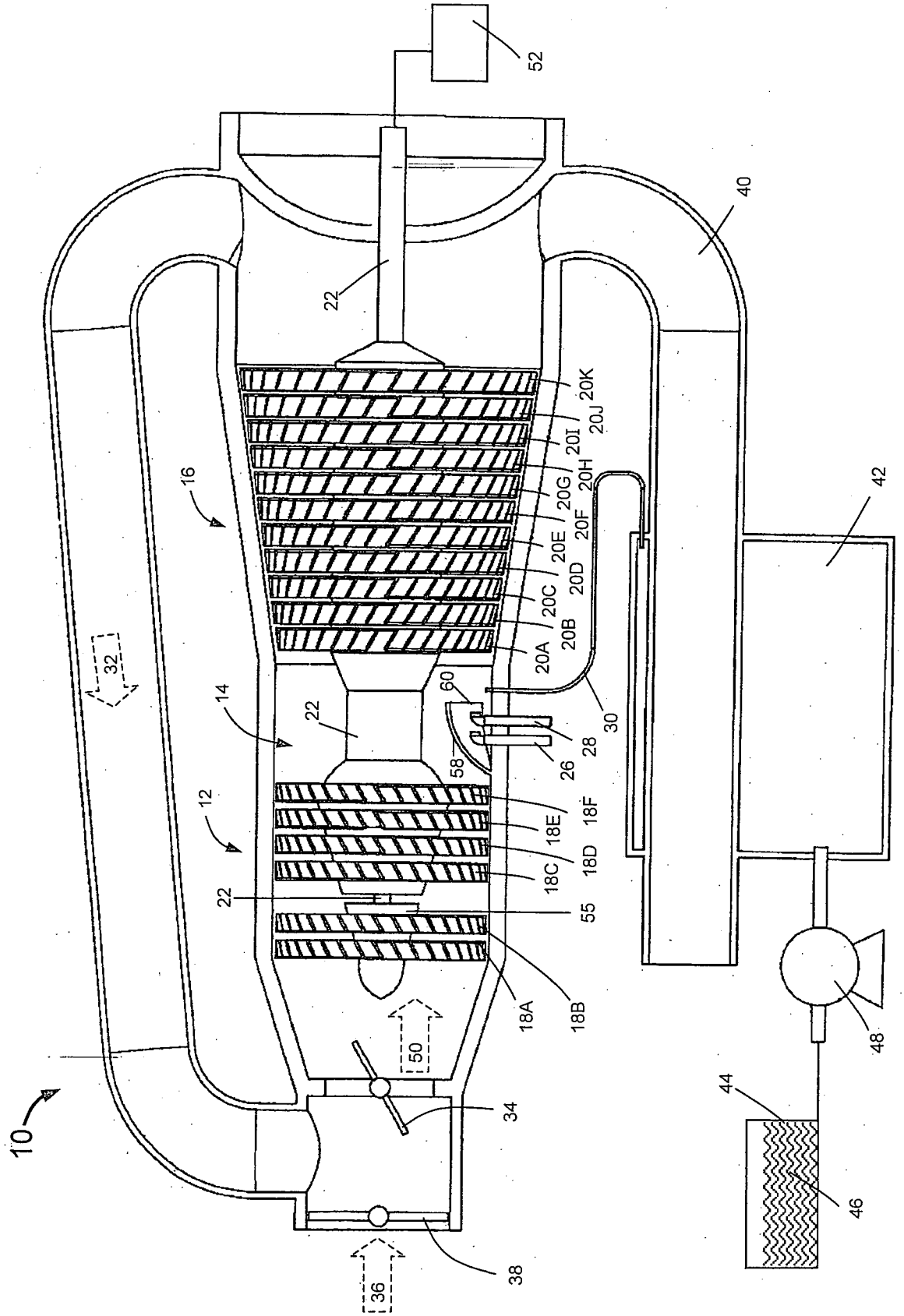
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Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2010/000074

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

F02C 3/34 (2006.01) *F02C 3/20* (2006.01) *F02C 3/30* (2006.01)

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)
see below under the Electronic databases consulted

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Google patents : keywords: gas turbine, two stage compressor, injection, iris valve and similar terms

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Supplementary Box

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 6637183 B2 (VITERI et al.) 28 October 2003	
X	Figure 5 and accompanying description	1, 4, 12-15 20-22
Y	Figure 5 and accompanying description	6-11, 16, 18, 19
	US 6112511 A (MYERS) 5 September 2000	
Y	Figures 1, 2, column 3, line 49-column 4, line 32	6-11
	US 2003/0182944 A1 (HOFFMAN et al.) 2 October 2003	
Y	Figure 3 and paragraph [0082]	16, 18, 19
	US 3316717 A (CASTLE et al.) 02 May 1967	
Y	Figure and column 2, line 66- column 3, line 2	19

[X] Further documents are listed in the continuation of Box C [X] 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

"&" document member of the same patent family

Date of the actual completion of the international search
29 September 2010

Date of mailing of the international search report
08 OCT 2010

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2010/000074

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0220896 A1 (VARATHARAJAN et al.) 27 September 2007 Figure 1, page 2 paragraphs [0020]-[0021]	1-3, 14, 20-22
X	WO 1998/051912 A1 (CONDON et al.) 19 November 1998 The whole document	1-3, 12, 14, 15, 20, 23
A	US 6148602 A (DEMETRI) 21 November 2000 The whole document	1-11, 20-23

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2010/000074

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 6.4(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 the Supplemental Box

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 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.

☒ No protest accompanied the payment of additional search fees.

Supplemental Box II
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No: B

Databases : WPI, EPODOC

(i) GAS_TURBINE OR (BRAYTON W CYCLE) OR F02C with keywords: INJECT, WATER, OXYGEN? and similar terms

(ii) GAS_TURBINE OR (BRAYTON W CYCLE) OR F02C with keywords: INJECT, OXYGEN?, COMPRESSOR? and similar terms

(iii) F02C3/34 with keywords: INJECT, WATER, OXYGEN? and similar terms

(iv) GAS_TURBINE OR (BRAYTON W CYCLE) OR F02C with keywords: OXYGEN?, COMPRESSOR? and similar terms

Databases : English Fulltext Search (TXTE) in EPOQUE

(v) GAS_TURBINE OR (BRAYTON W CYCLE) with keywords: INJECT, OXYGEN?, COMPRESS+, TWO, STAGE+ and similar terms

(vi) GAS_TURBINE OR (BRAYTON W CYCLE) with keywords: COMPRESS+, TWO, STAGE+, ENGAG+ and similar terms

(vii) GAS_TURBINE OR (BRAYTON W CYCLE) with keywords: COMPRESS+, COUPL+ and similar terms

(viii) GAS_TURBINE OR (BRAYTON W CYCLE) with keywords: SEMI, CLOSE?, CYCLE? and similar terms

Supplemental Box
(To be used when the space in any of Boxes I to IV is not sufficient)

Continuation of Box No: III

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

In assessing whether there is more than one invention claimed, I have given consideration to those features which can be considered to potentially distinguish the claimed combination of features from the prior art. Where different claims have different distinguishing features they define different inventions.

This International Searching Authority has found that there are different inventions as follows:

- Claims 1-4, 20-23 are directed to a gas turbine engine having a compressor. It is considered that an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of a fuel injector in comprises a first distinguishing feature.

- Claims 5, 16-19 are directed to a gas turbine engine. It is considered that an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of a fuel injector and the compressor including a first set of compressor blades upstream of a second set of compressor blades and the positioning of an oxidising agent injector between theses sets of blades comprises a second distinguishing feature.

- Claims 6-11 are directed to a gas turbine engine. It is considered that an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of a fuel injector and a water injector positioned downstream of the fuel injector comprises a third distinguishing feature.

- Claims 12-15 are directed to a gas turbine engine. It is considered that an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of a fuel injector and a recirculation path for recirculating gas exiting from the turbine in to the compressor comprises a fourth distinguishing feature.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

The only feature common to all of the claims is an oxidising agent injector for injecting an oxidising agent into a gas stream upstream of a fuel injector. However, this feature is not novel in the light of the prior art document:

US 6637183 B2 (VITERI et al.) 28 October 2003. See figures 2, 3 and column 11, line 12-37. It is seen that gaseous oxygen is introduced through the duct (150) upstream of fuel injection (32) into the working fluid path.

This means that the common feature can not constitute a special technical feature within the meaning of PCT Rule 13.2, second sentence, since it makes no contribution over the prior art.

Because the common feature does not satisfy the requirement for being a special technical feature it follows that it cannot provide the necessary technical relationship between the identified inventions. Therefore the claims do not satisfy the requirement of unity of invention *a posteriori*.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/MY2010/000074

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	6637183	AU	76823/01	CA	2409700	US	2002100271
		US	6622470	US	2002023423	US	2002096660
		US	6824710	US	2004065088	US	6910335
		US	2005236602	WO	0190548		
US	6112511	WO	0011323				
US	2003182944	AU	2003234581	US	2008304954	WO	03100233
US	3316717	NONE					
US	2007220896	AU	2007200639	CN	101042071	JP	2007255424
		KR	20070096869	US	7650744		
WO	9851912	AU	71993/98				
US	6148602	NONE					

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX