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## THE GRAZ CYCLE - 1500 °C MAX TEMPERATURE POTENTIAL H<sub>2</sub> - O<sub>2</sub> FIRED CO<sub>2</sub> CAPTURE WITH CH<sub>4</sub> - O<sub>2</sub> FIRING.

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### ABSTRACT

The GRAZ CYCLE a Hydrogen Oxygen fired double loop high temperature steam cycle, combining gas turbine philosophy with steam plant practice has been proposed and presented in several publications by H. JERICHA (1985, 1989, 1991, 1992). In scientific discussion with Japanese researches from CRIEPI and NEDO in the course of the Japanese government setting up the New Sunshine Project, for which the use of hydrogen gas turbine is intended, these fellow researches named our project THE GRAZ CYCLE thus acknowledging the contribution of former and present members of our institute, who had solved thermodynamic problems of cycle fluid properties and cycle heat balance calculation, and, are now at work on the problem, of the required intensive combustion chamber liner and blade cooling.

In this paper the potential of this cycle shall be investigated, regarding a maximum turbine inlet temperature of 1500 °C. Further improvements are presented which are due to the introduction of an intercooled steam compressor, with additional beneficial high pressure steam production, and a very high pressure ratio for the high temperature turbine as required by the limitations of the heat exchanger temperatures.

The second part of this paper is dedicated to the replacement of hydrogen fuel by artificial or fossil methane. The cycle fluid, now being no more pure steam, but a mixture of about 80% steam and 20% CO<sub>2</sub>, flowing in about quite the same process, but with the capability of CO<sub>2</sub> retention after the condensation of the steam part of the fluid in the low pressure condenser. As will be shown this is the most practical way of separating the two fluids, without the investment of costly additional heat exchanger surfaces, and without temperature differentials leading to power losses, but with recompression of the non condensable CO<sub>2</sub> gas.

### INTRODUCTION

A Solar plant derives Hydrogen and Oxygen from the splitting of Water, So that fuel and oxidising Reaction partner are obtained

simultaneously. To compare the Graz Cycle to an air breathing gas turbine cycle the exact design of an air separation plant would be required. This is beyond the scope of the paper, so only a rough estimation of the power requirement was made. Running the cycle with oxygen as the reactive agent, induces a penalty of about 4% in efficiency, in comparison to combusting in air, but offers the potential of including such a demonstration plant later on into a solar energy system, providing hydrogen and artificial methane as well as oxygen from the splitting of water and carbon dioxide. Recompression can be done by proper cooling in an isothermal turbocompressor, the power consumption of which certainly reduces output but does not deteriorate very much the excellent efficiency of the overall cycle

Thermodynamic cycle properties efficiency, output and turbo machinery dimensions for future possible pilot plants are given, regarding a range of output for which proper turbomachinery flow configuration could be obtained.

### HYDROGEN FIRING

The justification for the thermodynamic features of the GRAZ CYCLE has been extensively given in literature [13, 16, 17, 18, 19]. Here as the first part of our results, concerning the potential of the cycle, the improvement in raising the maximum temperature to 1500 °C is presented. Fig. 1 shows the cycle scheme fig. 2 the temperature specific entropy diagram and fig. 3 the temperature entropy diagram of the cycle, whereas the following figures show the heat transfer from the exhaust steam from the high temperature turbine and the evaporation of the high pressure steam, as well as the heat temperature diagram for the compressor - intercooler. As can be seen from these diagrams there are ample temperature differences provided and in fig. 2 and. 3 the main advantage of the cycle is clearly visible, that is heat input comes at very high temperature and heat rejection at the lowest possible temperature to the cooling water. The heat transfer in the heat exchanger ( high temperature steamcooler - high pressure steam evaporator ) is conducted with ample



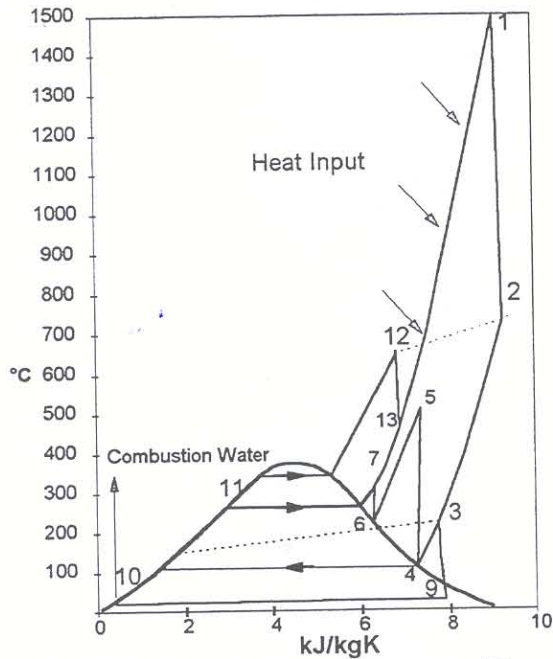


FIG. 2 Temperature - Specific Entropy - Diagram of the H<sub>2</sub>/O<sub>2</sub> Fired Graz Cycle

a medium maximum pressure of 50 bar is supplied. This can be overcome by arranging power consuming and power producing machines of similar volume flow on one shaft, as it is the case with the steam compressors and the high pressure turbine, as well as with the upper part of the high temperature turbine and it is necessary to select a suitable high speed. In order to come up with reasonable blade dimensions it is necessary to build the hydrogen oxygen gas cycle in the power range of 190 MW for a future pilot plant, with the prerogative of having gears developed, which are able to transfer power in the range of 80 MW. These gears seem to be feasible since high speed shafts of air breathing gas turbines have been developed for larger gear load recently.

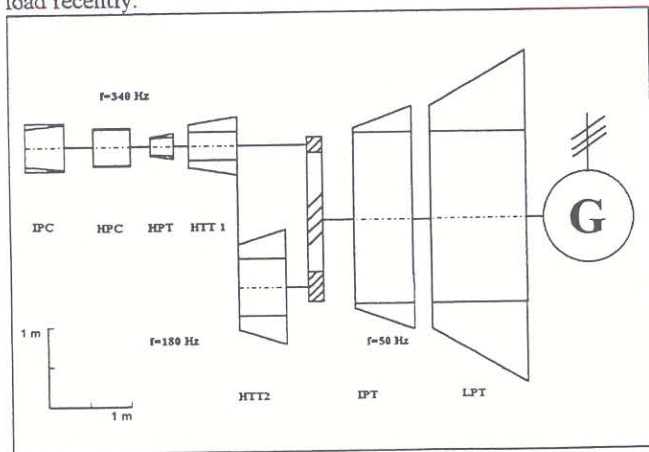


FIG. 4 Turbomachinery Dimensions for a pilot plant of 180 MW, (enlarged mass flow required for proper blade dimensions)

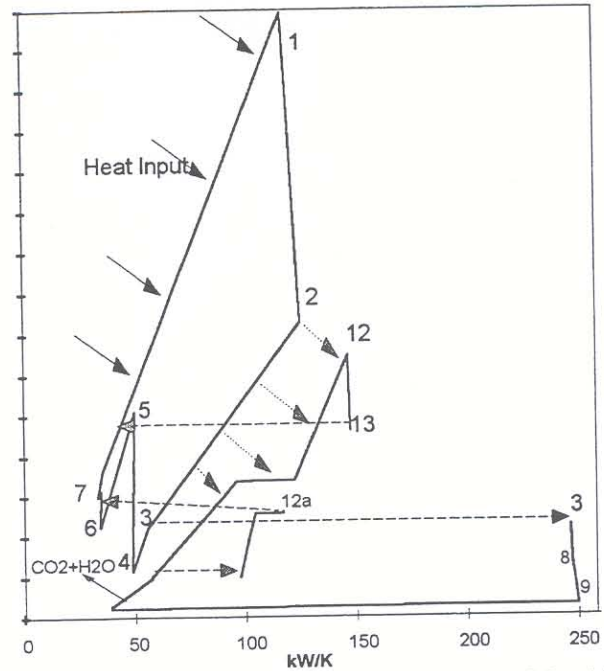


FIG. 3 Temperature - Entropy - Diagram of the H<sub>2</sub>/O<sub>2</sub> Fired Graz Cycle

#### METHANE FIRING

Using methane as fuel with oxygen the Graz cycle can be operated as well. As a further improvement the authors suggest a cycle of highest possible efficiency using a mixture of steam and CO<sub>2</sub> as working fluid [8]. The H<sub>2</sub>/O<sub>2</sub> fired configuration Promises efficiency of up to 59 % (based on HHV, equivalent to 65 % based on LHV in comparison to air breathing machines) in the hydrogen/oxygen fired version [11]. Its advantages are medium pressures, the possibility to effect the heat input at very high temperatures and to maintain the heat rejection at conventionally low condenser temperature. In both forms, in the hydrogen/oxygen fired version and in the fossil methane/oxygen fired version ([10], [13], [16]), the operation of this Graz Cycle is analogous to a very high temperature internally oxygen fired gas turbine.

In the second part of the present work the capabilities of the Graz Cycle in using methane of fossil or of artificial origin are discussed. Firing methane with oxygen and using steam as a cooling medium results in similar combustion chamber design problems as mentioned in previous articles describing the hydrogen/oxygen fired cycle ([16], [17], [18], [19]). Cooling of burners, combustion chamber liner and high temperature turbine blades is effected by pure steam, a measure which together with the maximum combustion temperature selected, defines the ratio of carbon dioxide and steam in the high temperature cycle loop. So the use of a mixture of about 20 % carbon dioxide and 80 % steam as the working fluid offers the possibility of regaining CO<sub>2</sub> from this working fluid simply by extracting it after the condenser, so that CO<sub>2</sub> after recompression is available for further use. CO<sub>2</sub> is also regained at atmospheric pressure from the feed water heater, where heat is transferred to the feed water from condensation of the steam part of the expanded gas mixture bled from the low pressure turbine. See Fig 5.

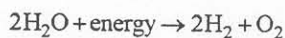
The reactivity of carbon and hydrogen towards oxygen being much higher than that to nitrogen will prevent formation of nitrogen oxide even if some nitrogen were present in a fossil natural fuel gas. Due to the absence of nitrogen in the cooling medium and the extraction of the noncondensable gases together with the CO<sub>2</sub> combustion products and due to the closed scheme of the steam-CO<sub>2</sub> mixture cycle there will be no environmental load by toxic and CO<sub>2</sub> emissions and the retained carbon dioxide can be made available for future integrated solar energy systems.

The purpose of this paper is also to investigate the possibility of building such a CH<sub>4</sub>/O<sub>2</sub> fired Graz Cycle pilot plant. At first the thermodynamics of the cycle are discussed and the optimised thermodynamic parameters are presented. Also the design of turbomachinery is presented in terms of a feasibility study, which has been discussed with important gas turbine manufacturers. So for a typical pilot plant of 50 MW and 100 MW turbomachinery dimensions are shown. To secure the feasibility of the main components several detailed studies have already been conducted. Important results have been obtained in continuation of the work presented at 1991 CIMAC conference in Florence [17]. A cold flow study of a combustion chamber was undertaken for firing conditions of hydrogen with oxygen with steam cooling, which is now being adapted for the very similar purpose of burning CH<sub>4</sub> and oxygen.

The high temperature turbine uses extensive cooling by high temperature steam in novel configurations as a means to cope with the very high gas temperature of the cycle fluid. These especially effective means of cooling are researched at our institute at the moment and first results are presented here.

## FUEL SYSTEM

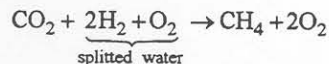
Solar radiation power is most effective in the southern belt of deserts near the equator. Solar power can be gained by thermal plants, by photovoltaic or even by biological systems. Electricity generated could effect the splitting of water by means of electrolyzers or splitting of water could be effected directly by biological systems. So for the solar production of hydrogen the chemical reaction equation reads, regarding the molecules produced:



These gases could be transported by pipelines or in liquid state. The liquification of hydrogen has the disadvantage that it has to be effected at very low temperatures and the transport is hampered by the fact that liquified hydrogen still has a relatively large specific volume which makes transport tanks bulky and requires extreme thick insulation. So it would be worth-while to deliberate more conventional methods of energy transport. One established procedure is the transport of liquified natural gas which is transported in very large quantities in the pacific area especially supplying Japanese power stations.

So it might be reasonable to deliberate the production of artificial fuels at the sites of solar power stations. By using CO<sub>2</sub> - which could be transported back there from the centers of consumptions - artificial fuels like methanol or artificial

methane could be created. The following reaction equation does hold:



The artificial fuel CH<sub>4</sub> thus produced could be transported via pipeline or via overseas transport in liquified state as liquid artificial gas (LAG) to consumers in highly populated areas. Whether it would be economic to transport oxygen as well has still to be investigated, but doing so would relieve the atmosphere completely from taking part in this cycle of reactions. At the centers of consumption the above mentioned Graz Cycle plants could be run, which would operate at an extremely high efficiency compared to conventional plants and which would offer the possibility to retain the carbon dioxide as demonstrated above. After compressing and liquifying the CO<sub>2</sub> combustion product it could be transported back to the sites of solar hydrogen generation and/or ensuing production of artificial fuels, thus closing the transport cycle of such an integrated solar hydrogen energy system.

In that manner thermal power stations could be created which would operate without emitting gases to the atmosphere, without aspiring of air or oxygen and solely with some input and output of water.

In the present situation with the prevalent use of fossil fuels the pilot plant scheme presented would fulfill the task of retaining CO<sub>2</sub>, oxygen would have to be gained by separating air. Assuming a fuel supply of LNG the cold of fuel would greatly facilitate the air separation. In an integrated air separation fuel vaporisation plant a cold source could contribute to cool the compressed air so that only a minimum of power input would be required to produce oxygen. Part of that cold could also be used to liquify carbon dioxide for later return to the solar plants as mentioned above.

## CYCLE THERMODYNAMICS

The cycle scheme of the Graz Cycle fired with methane and oxygen is represented in fig. 5. The construction of the Graz Cycle as a double loop cycle (see temperature-specific entropy-diagram in fig. 6) is motivated as follows:

By Carnot's law it is necessary for a highly efficient cycle to effect the heat input at highest possible temperature and to reject the heat at lowest possible temperature. Highest temperature is selected in the range of modern gas turbines between 1300<sup>o</sup> and 1500<sup>o</sup> C, but for reasons of turbine design according to gas turbine philosophy it is necessary to keep the highest pressure limited. For an industrial machine at these temperatures it does not seem possible at present day technology to run a combustion chamber at pressures much higher than 50 bar. The same holds true for the casing of the following high temperature gas turbine.



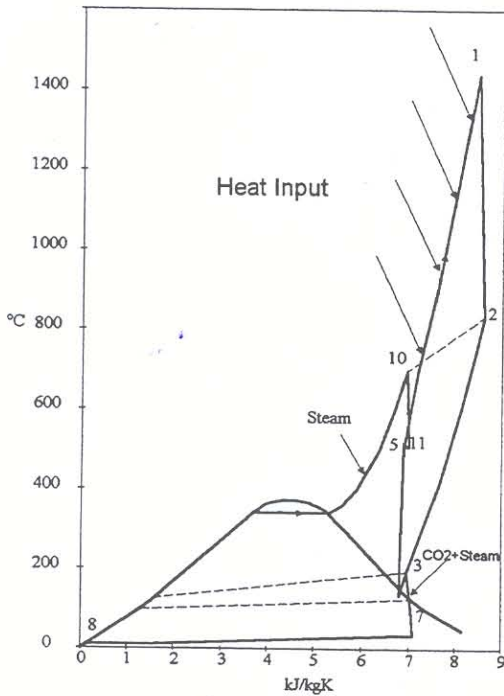


FIG. 6 Temperature - Specific Entropy - Diagram of the  $\text{CH}_4/\text{O}_2$  Fired Graz Cycle

Expanding the gas flow in the lower loop to a pressure of 0.06 bar the separation of water and carbon dioxide can be effected. The new element of the carbon dioxide separator in form of a condenser with additional counteracting cooling flows is quite near in design to conventional condenser practice. Here we cool the non condensable gases as much as possible in separated tube arrangements in order to keep the  $\text{CO}_2$  compressor power as low as possible. So the recompression of carbon dioxide even from the low pressure of 0.05 to atmosphere (a pressure ratio of 20) needs relatively low compression power in comparison to the overall heat and power balance (see table 1), using several intermediate stages of cooling as is the general practice in isothermal compressors. Some part of the combustion water also goes with the carbon dioxide and is separated continuously in the intercoolers of this carbon dioxide compressor. Part of the gas mixture is extracted from the low pressure turbine to heat the feed water. A pressure of about 1 bar is selected so that after condensation of the water content  $\text{CO}_2$  is made available at ambient pressure and is fed to the  $\text{CO}_2$  retention line.

So the mass of carbon dioxide of the condenser and of the preheater are equal to the carbon dioxide of the combustion and are then presented at atmospheric pressure and ambient temperature for further use (e.g. for deep sea storage as proposed by [20]). The excess water of the combustion is retrieved from the cycle partly after the preheater, partly in the isothermal compressor and the rest after recompression after the condenser. So the mass flow of the lower loop is determined by the mass of combustion carbon dioxide which has to be completely separated.

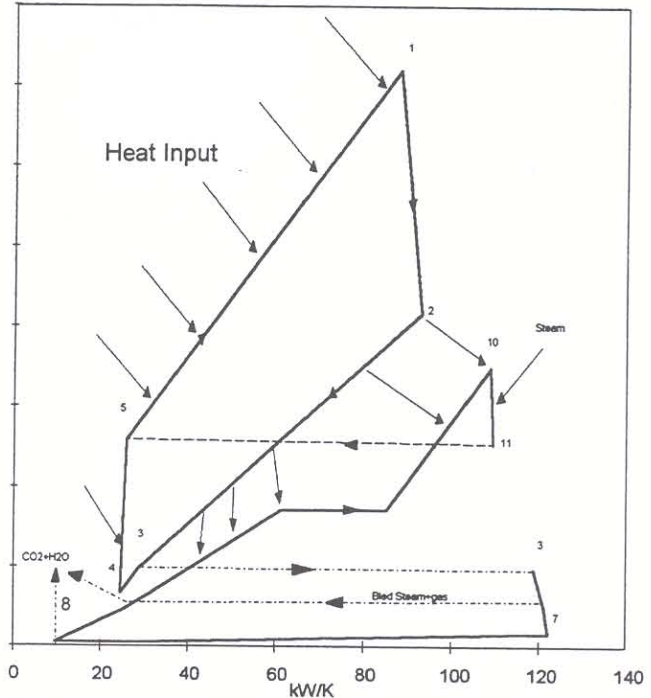


FIG. 7 Temperature - Entropy - Diagram of the  $\text{CH}_4/\text{O}_2$  Fired Graz Cycle

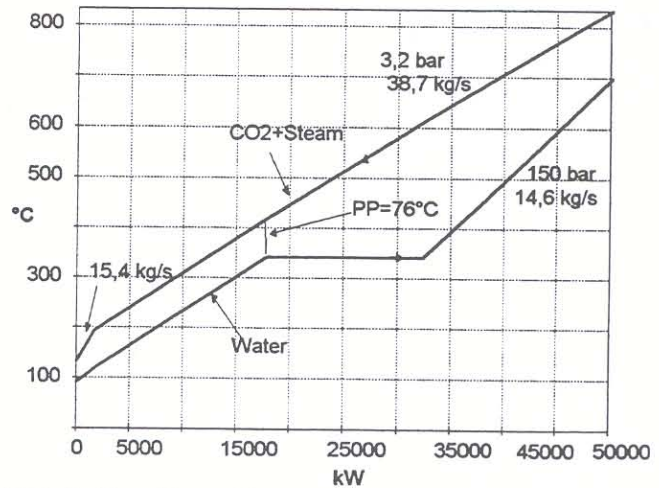


FIG. 8 Heat Flow - Temperature - Diagram of the  $\text{CH}_4/\text{O}_2$  Fired Graz Cycle

After the condenser the working fluid is pure water, which is compressed to 150 bar by the feed water pump. After heating, evaporation and superheating according to fig. 6, steam is expanded in the high pressure turbine to a pressure of 50 bar. This steam is mixed together with the gas mixture delivered by the compressor in the combustion chamber, thus cooling the combustion chamber liner and burners.

The cycle function can be better demonstrated by using a temperature-entropy (specific entropy times mass flow) -diagram (fig. 7).

The reader asked to observe the high temperature gas turbine loop and the low temperature steam plant loop, the heat transfer in the generation of high pressure steam, and also the mass transfer connections in the formation of the double loop cycle. Please note that entropy increases with heat transfer over finite temperature differences and the entropy span increases accordingly. In comparison the heat transfer is shown in a heat flow-temperature-diagram (fig. 8) which clearly shows the temperature differences and the pinch point as a function of heat flow. Ample temperature differences are provided which serve to keep the required heat exchangers surfaces within economic limits.

TABLE. 2 Power Balance of the CH<sub>4</sub>/O<sub>2</sub> Fired Graz Cycle

Turbomachinery	Power [kW]
High Temperature Turbine HTT	51016
High Pressure Turbine HPT	5470
Low Pressure Turbine LPT	10589
Compressor	-10425
<b>Power Output</b>	<b>56650</b>
Electrical Power Output	55635
-CO <sub>2</sub> Compressor	-931
-Feed Pump	-341
<b>Net Electrical Power Output</b>	<b>54363</b>
Heat Input (HHV)	95662
<b>Thermal Efficiency (HHV) evaluated to LHV</b>	<b>56.8 % 63.1 %</b>

It can be said therefore, that the cycle proposed makes definite use of established engineering practice in gas turbine and steam turbine design, tries to minimise the necessary heat exchanger surfaces and effects the separation of carbon dioxide and water in an effective manner also by well proven isothermal compressor design. According to the heat power balance (table 1) the efficiency of the cycle is about 56.8 % based on HHV (equivalent to 63.1 % based on LHV in comparison to an air breathing machine), making it a most efficient and promising means of retaining CO<sub>2</sub> from the atmosphere.

### PLANT CONFIGURATION

The following fig. 9 and table 3 show the dimensions for the turbomachinery of the pilot plant in question, one for 50 MW output, the other for over 100 MW output. For such a pilot plant the limitations of gears have to be considered which are assumed to be of a maximum transfer power of 50 MW. So a 100 MW pilot plant could be built with high speed turbines according to fig 9. For very large power stations the gears could be replaced by direct drive or some part of the high temperature expansion could be effected at generator speed, other parts as the high temperature recompression and the high pressure turbine could also be effected at higher speeds, balancing power consuming and power producing turbomachinery on each shaft.

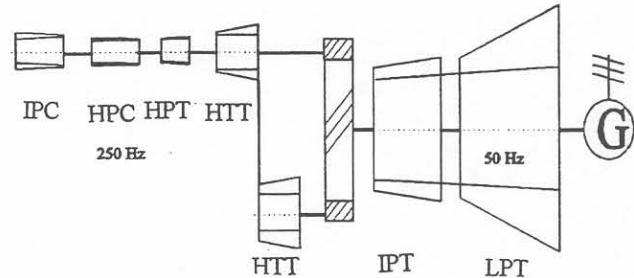
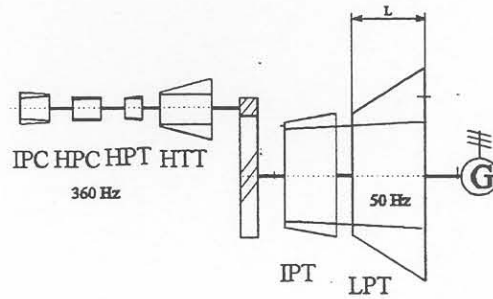


FIG. 9 Turbomachinery Dimensions for a Pilot Plant of 50 MW and 100 MW

TABLE. 3 Turbomachinery Dimensions for a Pilot Plant of 50 MW and 100 MW, Diameters  $d_1$  and  $d_2$  Turbine inlet and outlet, blade length  $l_1$   $l_2$ , Axial length L, Number of stages z, Frequency f

#### 50 MW pilot plant

	$d_1$ [m]	$d_2$ [m]	$l_1$ [m]	$l_2$ [m]	L [m]	Z st	f[Hz]
LPT	1.06	1.567	0.121	0.52	0.7	8	50
IPT	0.94	1.08	0.094	0.135	0.52	7	50
HTT	0.32	0.454	0.021	0.154	0.5	6	360
HPT	0.19	0.222	0.011	0.019	0.17	6	360
HPC	0.211	0.211	0.027	0.010	0.28	15	360
IPC	0.257	0.257	0.058	0.018	0.29	9	360

#### 100 MW pilot plant

	$d_1$ [m]	$d_2$ [m]	$l_1$ [m]	$l_2$ [m]	L [m]	Z st	f[Hz]
LPT	1.49	2.216	0.171	0.735	0.99	8	50
IPT	1.33	1.53	0.133	0.191	0.74	7	50
HTT	0.45	0.642	0.030	0.218	0.5	6	250
HPT	0.269	0.314	0.161	0.028	0.24	6	250
HPC	0.298	0.298	0.037	0.015	0.39	15	250
IPC	0.363	0.363	0.082	0.025	0.41	9	250

### COMBUSTION CHAMBER

One of the most critical parts in the design of such a high temperature cycle is the combustion chamber burning CH<sub>4</sub> and oxygen. A cold flow study of a combustion chamber was done using air, helium and nitrogen to match Reynolds number and flow conditions according to the high temperature combustion chamber. The flow scheme for such a combustion chamber was presented recently ([17]) using additional cooling flows

introduced by axial jets supplying the liner with cold steam near the wall. Four different liners had been tested and the flow conditions visualized. Swirler flow, return flow and cooling flow had been studied under varying velocities, mass flows and injection angles [21]. These experimental investigations indicated that flow conditions in combustion chambers for such high temperature cycles follow standard design principles but special care has to be taken in the design of the recirculation area and the axial cooling jets. This is topic of ongoing investigations.

### HIGH TEMPERATURE TURBINE COOLING

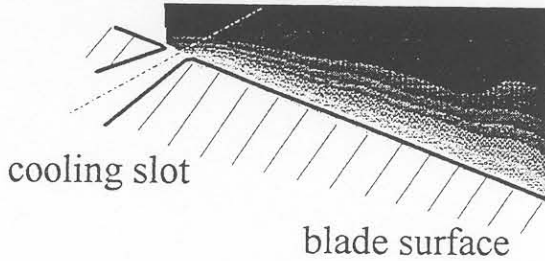


Fig. 10: Result of an interferometric investigation of cooling air films on turbine blades using supersonic film cooling. Light gray indicates higher air density corresponding to lower temperature air film on blade surface.

It has to be born in mind that a mixture of 20 % carbon dioxide and 80 % steam has a distinctly higher specific heat in comparison to a mixture of air and combustion gases as they are expanded in a conventional gas turbine. Since the temperature limits are about the same the expansion in the proposed turbine takes place at the higher heat drop and therefore requires a higher number of stages. The same is true for the number of stages to be cooled. As can be seen from the plant configuration (table 3), the high temperature turbine requires about six stages, where at least four stages have to be cooled. This means cooling has to be supplied for about 8 blade rows additional to the combustion chamber and transition piece cooling requirements. On the other hand due to the high density of the gas expanded the flow areas are relatively low and the same is true for blade span and blade length. The authors therefore have deliberated new and very intensive methods of cooling by means of steam into a gas turbine expanding a gas-steam mixture. Designing the high pressure turbine for extraction and using steam at a very high pressure for blade injection cooling enables supercritical conditions at the slot exit. In this area supersonic effects take place thus bending the injected cooling steam towards the blade surface even at areas of higher blade curvature. Experiments performed recently ([22]) indicate a high dynamic range of possible pressure ratios (up to 4:1 were observed) for the input of the cooling steam (see fig. 10) in continuous close contact to the blade surface.

### CONCLUSION

CH<sub>4</sub>/O<sub>2</sub> firing of the Graz Cycle has been proposed. The feasibility study concerning the components of a pilot plant in

the range of 50 to 100 MW has been presented. Using newly developed designs for burners, combustion chamber cooling and blade cooling within the frame of gas turbine design philosophy the feasibility of such a plant can be secured. Such a pilot plant would have the advantage to be used under present conditions for CO<sub>2</sub> retention, thus contributing greatly to the goal of CO<sub>2</sub> emission reduction to which all governments of industrial states submitted themselves. Otherwise it could be used without any alterations as part of an international world-wide solar energy system as proposed by the Japanese government in its WE-NET Research program [23]: Artificial fuels should be produced by solar plants, transported into the centers of consumption and the CO<sub>2</sub> retained in the power plants supplied back to these solar plants. Our plant proposed would guarantee an extremely high efficiency of use of hydrogen, artificial methane or methanol without exhausting any gases to the atmosphere and being able to close the cycle of energy production and energy consumption in a most effective manner.

### ACKNOWLEDGEMENTS

The thermodynamic cycle has been designed with the software IPSE of SIMTECH Thermodynamic Simulations. We are grateful for their support in developing the thermodynamic description of the CO<sub>2</sub>/steam mixture and of additional calculating modules. The authors are also grateful to the Austrian Science Foundation (FWF) for its financial support of this work.

### REFERENCES

- [1] Pechtl, P.A., 1990, "Zur Beurteilung von CO<sub>2</sub>-Emissionsminderungsmaßnahmen aus kalorischen Kraftwerken", ÖIAZ, 135. Jhrg., Heft 12
- [2] Boras, G.S., Smelser, S.C., 1991, "An Engineering and Economic Evaluation of CO<sub>2</sub> Removal from Fossil Fuel Fired Power Plants", Energy, Vol. 16, No. 11/12
- [3] Nakayama, S., et al., 1992, "Pulverised Coal Combustion in O<sub>2</sub>/CO<sub>2</sub> Mixtures in a Power Plant for CO<sub>2</sub> Recovery", Proceedings, First Internat. Conference on CO<sub>2</sub> Removal, Pergamon Press, Amsterdam
- [4] Rice, I.G., 1993, "Steam Injected Gas Turbine Analysis Part III - Steam Regenerated Heat"m ASME IGTI Conference, Cincinnati, OH
- [5] Schütz, M., et al., 1992, "Study an CO<sub>2</sub> Recovery from an IGCC Plant", Proceedings, First Internat. Conference on CO<sub>2</sub> Removal, Pergamon Press, Amsterdam
- [6] Hendriks, C.H., Blok, K., 1992, "CO<sub>2</sub> Recovery Using a Dual Gas Turbine IGCC Plant", Proceedings, First Internat. Conference on CO<sub>2</sub> Removal, Pergamon Press, Amsterdam
- [7] Mathieu, P., De Ruyck, J., 1993, "CO<sub>2</sub> Capture in

- [7] Mathieu, P., De Ruyck, J., 1993, "CO<sub>2</sub> Capture in CC and IGCC Power Plants Using a CO<sub>2</sub> Gas Turbine", ASME Cogen Turbo Power VII, Bournemouth, UK
- [8] Jericha, H., 1994, "Kohlenwasserstoff/Sauerstoff gefeuerte Wärmekraftanlage mit Kohlendioxidrückhaltung", Austrian Patent Application
- [9] Jericha, H., 1983, "A New Combined Gas Steam Cycle Promising up to 60 % Thermal Efficiency", Paper T10.1, Cimac, Paris
- [10] Jericha, H., 1985, "Efficient Steam Cycles with Internal Combustion of Hydrogen and Stoichiometric Oxygen for Turbines and Piston Engines", Cimac, Oslo
- [11] Fesharaki, M., 1993, "Kreisprozeßrechnungen neuer Schaltungen für Kombikraftwerke", Diploma Thesis, Graz University of Technology
- [12] Jericha, H., Wilplinger, H., Perz, E., 1987, "A Novel High Efficiency Steam Cycle", ASME Cogen Turbo I, Montreux
- [13] Jericha, H., 1987, "Efficient Steam Cycle With Internal Combustion of Hydrogen and Stoichiometric Oxygen for Turbines and Piston Engines", Int. Journal of Hydrogen Energy, Vol. 12, No. 5
- [14] Perz, E., Gasteiger, G., Steinrück, P., Mader, O., Jericha, H., 1988, "Design of a 50 MW Pilot Plant for a High Efficiency Steam Cycle", ASME Paper 88-GT-154
- [15] Perz, E., 1988, "Hochtemperatur-Dampfprozeß, Ausführbarkeitsstudie und Entwicklung einer 50 MW - Pilotanlage", Ph. D. Thesis, Graz University of Technology
- [16] Jericha, H., Ratzesberger, R., 1989, "A Novel Thermal Peak Power Plant", ASME Cogen Turbo III, Nizza
- [17] Jericha, H., Starzer, O., 1991, "Steam cooled hydrogen/oxygen combustion chamber for the hightemperature-steamcycle", CIMAC 17, G20
- [18] Jericha, H., Starzer, O., Pirker, H.P., 1992, "H<sub>2</sub>/O<sub>2</sub> Dampferzeugung in Kraftwerken - Dampfkreisläufe zur thermodynamisch optimalen Energieverwertung von solarem Wasserstoff", VDI Report. 912
- [19] Jericha, H., Pirker, H.P., Starzer, O., Dötl, R., 1994, "Further Development of the Hydrogen/Oxygen Steam Process (Combustion Chamber and High Temperature Turbine)", International Joint Power Generation Conference of ASME, Phoenix, USA
- [20] Seifritz, W., 1994, "Technical Communication: The Temporal Decoupling of Energy Production From Fossil Fuels and the Emission of Carbon Dioxide Into the Atmosphere", Int. J. Hydrogen Energy, Vol. 19, No. 11
- [21] Starzer, O., 1992, "Qualitative Untersuchung der Strömung in einer Gasturbinenbrennkammer mit Hilfe eines strömungsmechanisch ähnlichen Modells", DLR Report
- [22] H.Jericha, J.Woiseschläger, W.Sanz, F.Gollner, "Experimental investigation of a new type of film injection cooling using supersonic jets", to be published
- [23] CRIEPI - Central Research Institute of Electric Power Industries, Mitsubishi Heavy Industries, Ltd., "Concept of WE-NET and introduction of H<sub>2</sub>/O<sub>2</sub> turbine to be developed under New Sunshine Program in Japan", 1994