Energy Convers. Mgmt Vol. 34, No. 9–11, pp. 1219–1227, 1993
Printed in Great Britain

0196-8904/93 $6.00 + 0.00
Pergamon Press Ltd

Oil enhancement Carbon Dioxide Oxygen Power Universal Supply (OCDOPUS project)

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ABSTRACT

Following the contributions of Hochstein (1940), Degtiarev (1967), Pechtl (1991), Yantovskii (1991), De Ruyck (1992), Van Steenderen (1992), Bolland et al (1992), Holt et all (1992) we have considered an internal combustion carbon dioxide power plant aimed at producing some flows needed for enhancement of oil recovery.

The power unit consists of air separation machine to produce oxygen for combustion and nitrogen for injection, combustion chamber, turbine, compressors, recuperator and cooling tower.

The unit consumes the oil gases as fuel and produces liquid CO_2, highly compressed nitrogen, process steam and power, if necessary.

No exhaust gases are released from the plant.

The outline of plant, the cycle on T-S diagram, the tables of state points and flowrates are presented along with efficiency calculation.

The plant seems to be of interest for offshore oil drilling platform.

INTRODUCTION

Oc-to-pus... Any cephaloid of the genus octopus, having eight arms provided with suckers,... a far reaching and powerful organization.

(New Webster Dictionary, College Edition)

But what's ocDopus? Something alike.

Having apperad in 1940 CO_2 cycles [1] attracted little attention. The main thermodynamic benefit of CO_2 in respect to H_2O, low condensation heat and ability to be pumped to high pressure in liquid state with good recuperation was offset by some toxicity, corrosion effects and low admissible cycle temperature around 600 ^oC as in ordinary boilers in case of external combustion.

Even after invention of internal combustion CO_2 cycles [2] when the temperature might be elevated, this cycle remained out of interest.

However greenhouse menace recently has given rise to the series of works [3-8] where combustion of fuel in a mixture of oxygen and flue gases (H_2O, CO_2 or both) was suggested. The unanimous conclusion of the listed papers stated that reasonable efficiency of 35-45% is possible in spite of power consumption to produce oxygen.

The main benefit of these cycles is cleanliness. They are really zero-emission cycles without exhaust gases. The only effluent is the flow of liquid CO_2 in a special pipeline to dispose it of.

The thermodynamic properties of internal combustion CO_2 cycles were appropriate but economics was questionable.

As a remedy to improve economics the use of CO_2 for enhancement of oil recovery (EOR) was proposed by M.Steinberg and many others. The benefit of the use of CO_2 for EOR is well documented. For example in the paper of United Nations Comission [9] one can see:

> ... the use of carbon dioxide is considered to be very promizing. Aqueous solutions with a concentration of 4-5% are also used. With one ton of carbon dioxide it is possible to recover as much as 20 tons of additional oil with an increase in the oil recovery factor of 5-15% and lower specific consumption of water... the practice is to inject carbon dioxide and water alternatively.

In the meantime opinions on the oil/CO_2 mass relation are much less optimistic: about 0,5 t of oil for 1 t of injected CO_2. It seems to be admissible in net-energy point of view. Large amount of laboratory tests has shown the benefit of CO_2 injection in respect to flue gas mixture. The possible oil extraction was increased from 54% to 96% by temperature 120 °C and pressure 400 bar when flue gases were replaced by CO_2 [10].

From other sources we know the use of comperessed nitrogen to back up the liquid CO_2 flow. The thermal EOR is also used, here a steam or hot water are the energy carriers. The combustion of deep oil in the injected oxygen is known.

In this respect we try to develop a new power supply unit enable to produce all the goods, needed for EOR : power, CO_2, nitrogen, oxygen, process steam and hot water in the OCDOPUS plant.

THE OCDOPUS OUTLINE

In a simplified manner all the flows from and to are presented on the Fig.1. Here just eight arms are evident. Certainly, some cooling water is needed too for a cooling. In case of a platform it is sea water.

The plant outline is presented on the Fig.2. The things of our project are restricted within dotted line boundary.

Air enters the separation unit 1, where it is splitted on the two flows, oxygen and nitrogen. It is depicted as a small square, but in effect a separation unit is a big facility, its mass is as much as for the whole power plant. The oxygen enters combustion chamber 2 along with recirculated CO_2 and flow of fuel gases. Combustion products (mainly CO_2) expand in the turbine 8, cooled down in the recuperator 3 and cooling tower 4. After the water separation in 5 the dry CO_2 is compressed from 7 up to 100 bar in a compressor 10, which might be either isothermal or adiabatic with additional recuperators (Degtiarev proposal [13]).

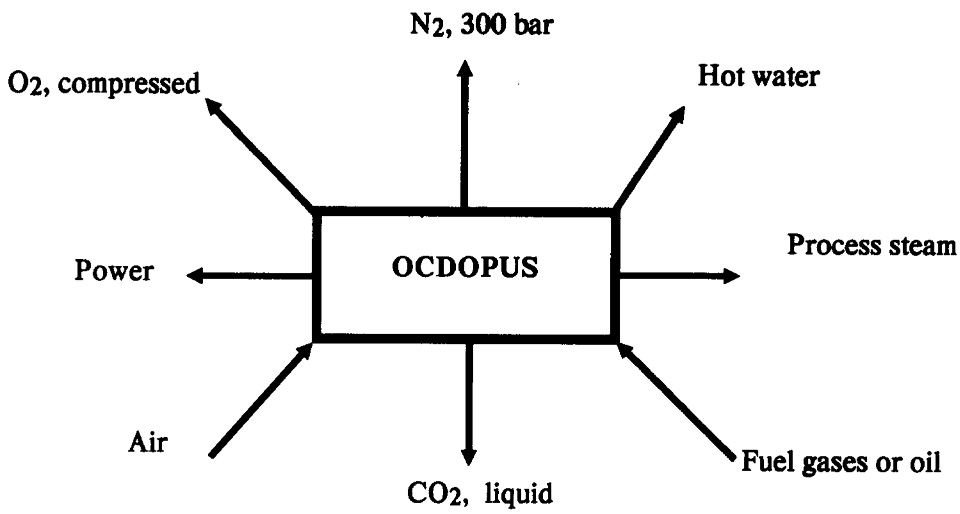

Fig.1. OCDOPUS production and consumption.

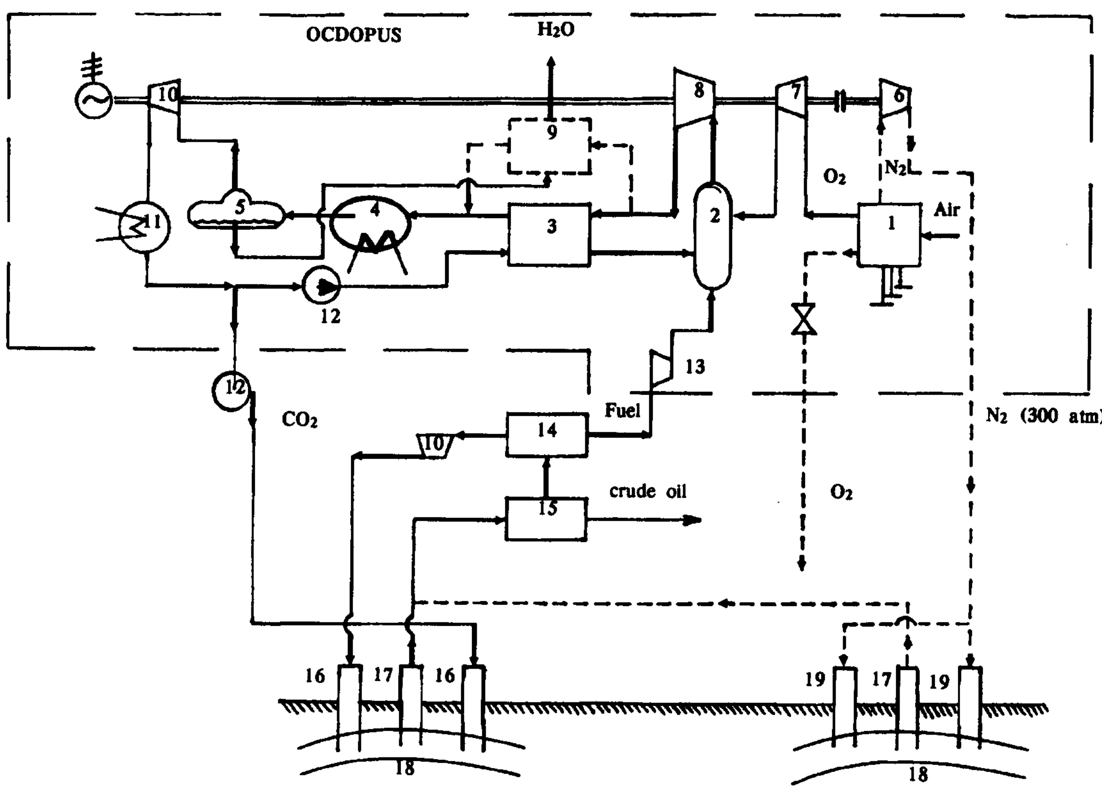

Fig.2.
1 - Unit for air separation; 2 - Combustion chamber; 3 - Recuperator; 4 - Cooling tower; 5 - Water separator; 6 - Nitrogen compressor; 7 - Oxigen compressor; 8 - Turbine; 9 - Steam production; 10 - CO_2 compressor; 11 - CO_2 condenser; 12 - CO_2 pump; 13 - Fuel gas compressor; 14 - CO_2/fuel gas separator; 15 - Oil/gases separator; 16 - CO_2 injection well; 17 - Productive well; 18 - Reservoir; 19 - Nitrogen injection.

The CO_2 condensation at 60 bar takes place in 11, then liqued CO_2 is pumped up to 100 bar and returned to recuperator 3.

Combustion born water might be heated in 9 if a process steam is needed. Combustion born CO_2 is released in liquid state and enters a pipeline to be injected in a well.

The nitrogen compressor 6 is attached to the shaft by a juncture, it might be switched on or off on site. When the total flowrate of nitrogen from separation unit is to be compressed and injected the net power to the grid equals zero.

NUMERICAL RESULTS

The cycles in T-S coordinates are presented on the Fig.3 and 4. Chemical composition of

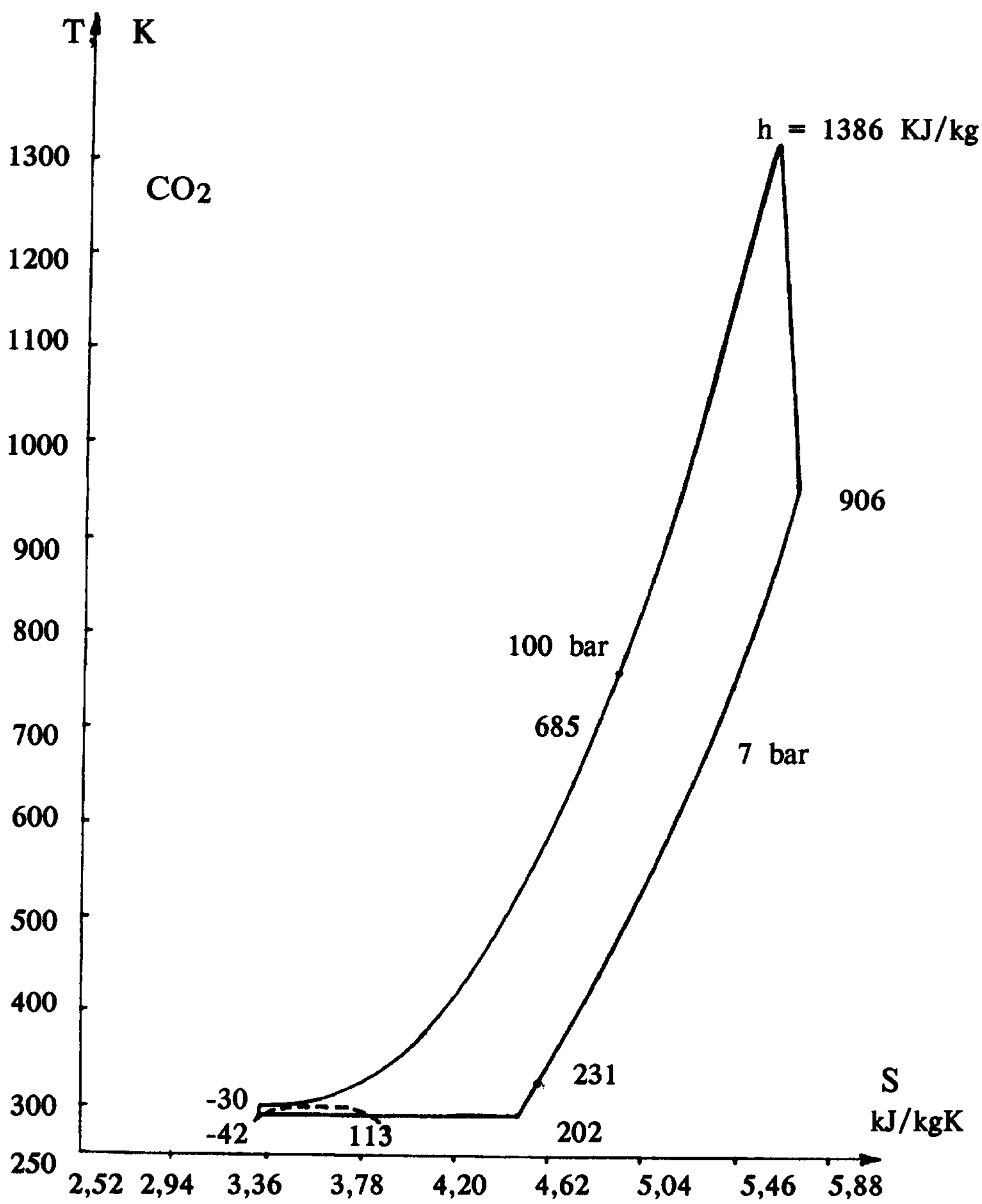

Fig.3. T-S diagram of the cycle with isothermal compression.

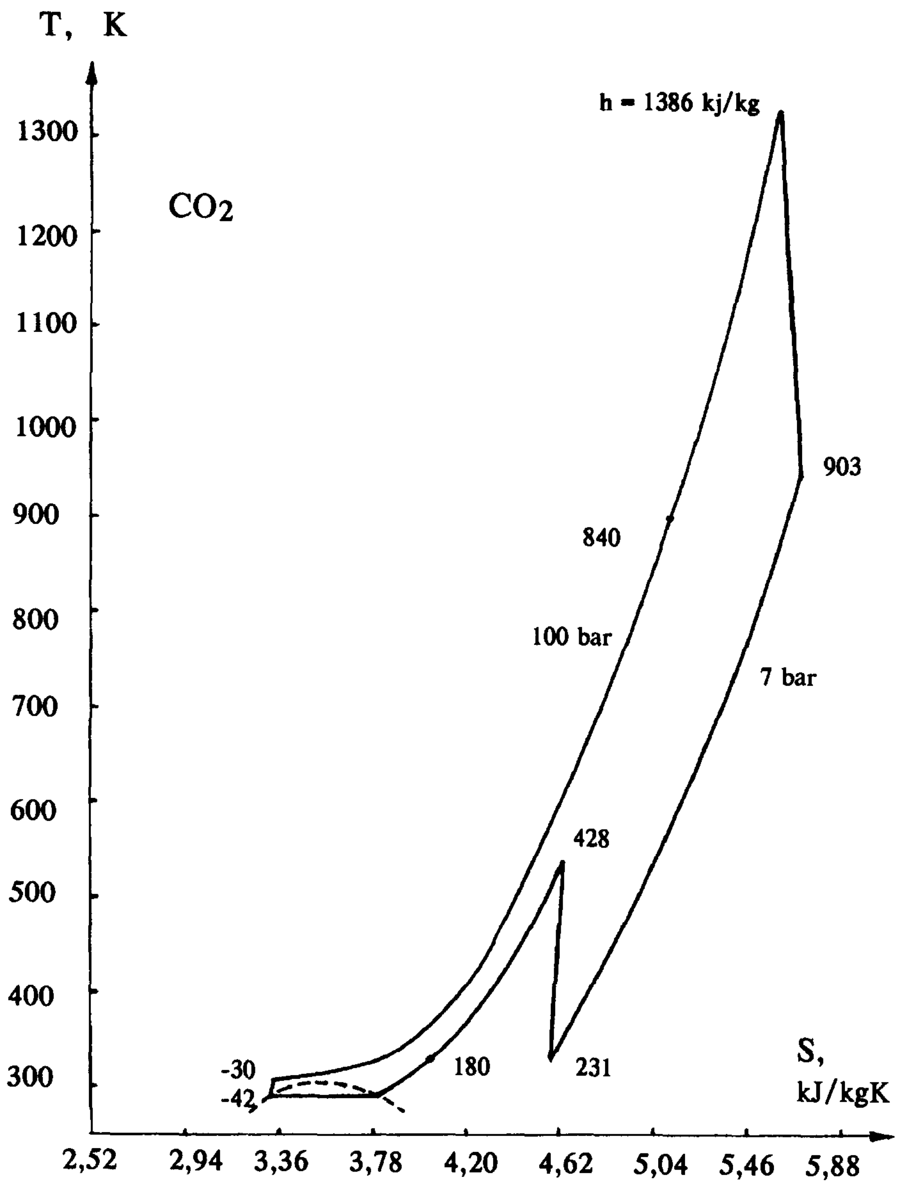

Fig.4. T-S diagram of the cycle with adiabatic compression and additional recuperators.

used fuel (oil gases) was assumed as C_6H_{14}. Reference equation of perfect combustion is:

$$1/6\ C_6H_{14} + 19/12\ O_2 \rightarrow CO_2 + 7/6\ H_2O + 50\ MJ/kg\ C_6H_{14}$$

The stoichometric coefficient equals 3.6.

The upper temperature of the cycle 1323 K (1050 °C) was selected in order to use ordinary gas turbines "of-the-shelf". We try to follow the same principle in the selection of other equipment. Rather high pressure 100 bar is needed in CO_2 cycles to explore the thermodynamic benefits of this working substance.

All the results are presented in the Table 1.

TABLE 1. The results of cycle calculations for net power 10 MW.

	Isothermal CO_2 compression		Adiabatic CO_2 compression	
	(Tables of [11])	(of [12])	(Tables of [11])	(of [12])
Max. temperature, K	1323	1300	1323	1300
Recuperator drop entrance/exit, K	174/25	147/25	42/25	36/25
Turbine work, kJ/kg	480	459	483	460
CO_2 compression	131.9	129.7	208.8	195.1
Fuel gas compression	8.5	10.0	9.24	8.7
Oxygen compression	42.8	39.5	33.2	31.0
Air separation	55.0	50.4	42.0	39.6
Combustion enthalpy rise	701.4	644.6	546.0	509.0
Total flowrate, kg/s	43.8	45.2	53.0	53.8
Cycle efficiency, %	34,0	35.5	35.0	36.0
Mass share in flowrate before/after combustion	Fuel 0.0141/0 O_2 0.0508/0 CO_2 0.9351/0.979 H_2O 0/0.021	0.013/0 0.0467/0 0.9403/0.9807 0/0.0193	0.0109/0 0.0392/0 0.95/0.984 0/0.016	0.010/0 0.037/0 0.953/0.985 0/0.0150
Some flows to consumer kg/s	CO_2 1.92 Steam 0.92 Nitrogen 7 300 bar zero power	1.80 0.87 7	1.81 0.85 7	1.71 0.81 7

An example of efficiency calculation, last columne.

$$\frac{460-195.1-8.7-31.0-39.6=0.36}{509} = 0.36$$

Turbine isoentropic efficiency was assumed as 0.85, it is a real figure for a cooling-free gas turbin blade.

We have considered the two kinds of CO_2 compressors 10, isothermal and adiabatic one with equal internal efficiency of 0.85. Certainly, the isothermal multistaged intercooled compressor consumes less power. However if we use following Degtiarev [13] the compression heat to increase the CO_2 temperature after pumping, the entrance temperature difference in the main recuperator will decrease. This let us decrease exergy losses and the total cycle efficiency is increased in spite of greater compressor work (ladyboot like cycle, Fig.4).

The bottom part of CO_2 processing is depicted on the diagram, see Fig.5. Solid line reflects adiabatic compression, unfortunately the upper part is missed. For isobaric cooling additional recuperators are used.

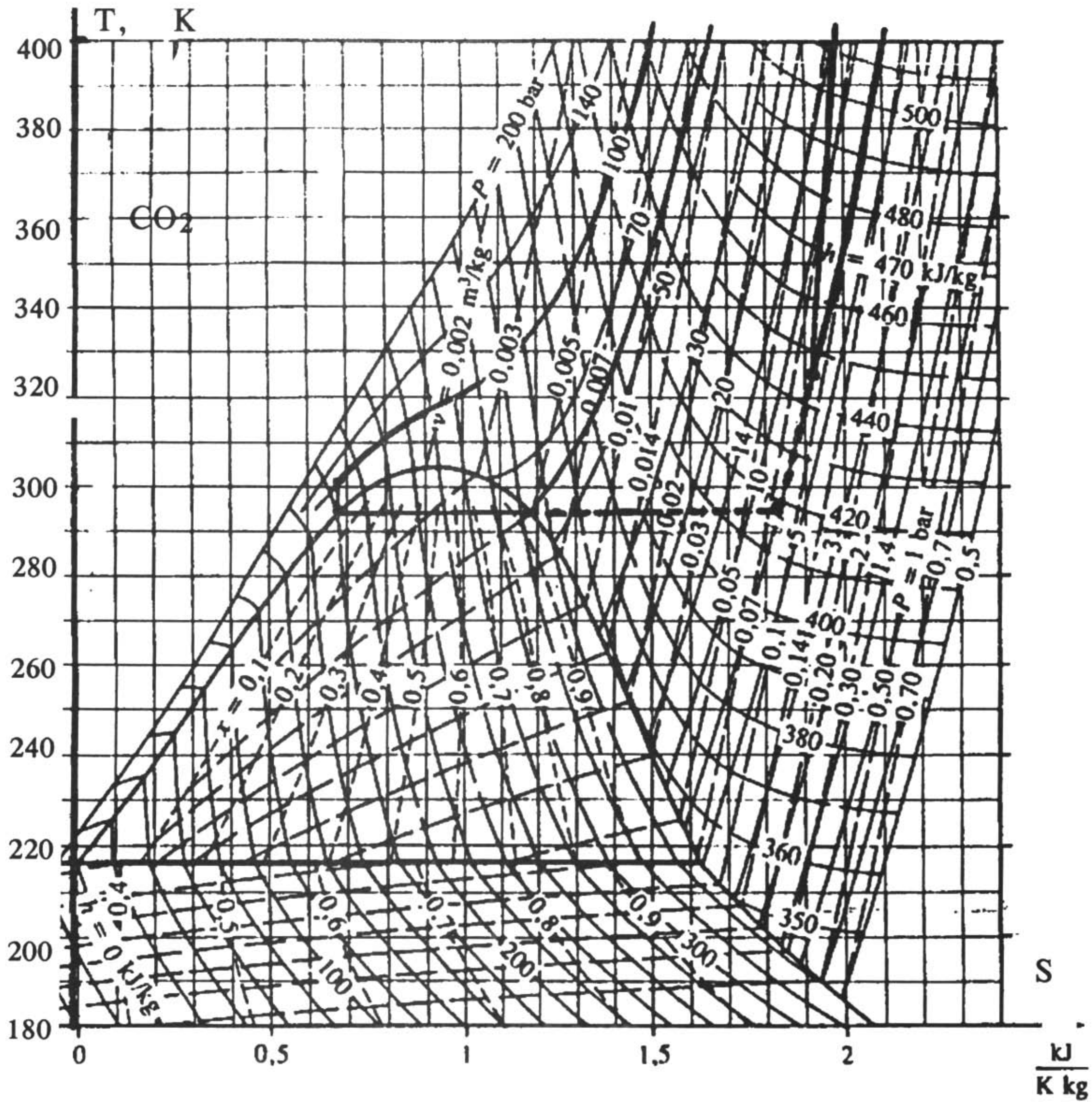

Fig.5. The bottom part of the both cycles. Dotted line for isothermal compression.

The dotted line reflects isothermal option. In effect the horisontal line concists of many "teeth", describing multystaged compressor. The enthalphy of CO_2 vapor at the end of compression is much less than at the start. Here the CO_2 behaviour differs from ideal gas.

The principal difficulty of internal combustion CO_2 cycles calculations is the lack of thermodynamic tables for the mixtures of CO_2 and steam. However in our special case the total content of steam is less than 2% of total flowrate, therefore our neglection of CO_2 and steam difference in properties seems to be admissible in this scouting study. In computer simulation all the mixture properties should be calculated simultaneously.

Even for pure CO_2 there exists a discrepancy in different tables. To illustrate the influence of this discrepancy on the results of calculation we present the comparison of the figures by the two best tables of Vargaftig [11] and Altunin [12]. The difference is evident, but admissible in a scouting study.

In some cases of the offshore use of OCDOPUS plant the mass of the unit is of primary importance.

The heaviest part of the plant is the main recuperator 3. In our case its mass equals 61.4 t, the transferred heat flow is 29.1 MW, the surface is 5990 m^2. We guess the total mass of power plant as 100 t and the same for air separation unit, therefore total OCDOPUS mass is around 200 t or 20 kg/kW. It is a common figure for heavy-duty plants. Certainly, more rigorous calculations are needed.

CONCLUSION

The preliminary study of OCDOPUS concept have shown it is worth of further efforts. The one design point, hitherto not optimized, promized efficiency around 35 % by the temperature before turbine 1050 °C, pressure interval 7-100 bar and turbin efficiency 85%.

No exhaust gases are released from the plant.

If a prediction of 10:1 oil recovery with respect to CO_2 injection is valid, the 1000 t of crude oil in a day might be extracted, if 0.5:1 it is 50 t only.

The daily fuel consumption (0.538 kg/s) of the 10 MW plant is just 50 t. Therefore relation of 0.5:1 is admissible in case of gaseous fuel and prohibitive in case of crude oil combustion.

ACKNOWLEDGEMENT

We thank our readers for looking through the paper in spite of our poor English.

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