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HERA

AN HTR FOR USE IN A REFINERY

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The tremendous increase in crude oil prices promoted numerous studies the purpose of which was to reduce energy and particularly oil consumption. In this field, two French groups, CEA (Commissariat à l'Energie Atomique) and CFR (Compagnie Française de Raffinage) decided to examine together the substitution of conventional heat sources by nuclear generated heat, as a means of energy input to the refining operation (the fuel consumption of a refinery is about 6 % of the crude oil treated).

1 - GENERAL FEATURES

The typical refinery needs 3 forms of energy :

1 - Driving energy which is generally provided by electricity but also by steam expansion through a turbine. It is used to run pumps and compressors.

2 - Heat which is used to carry out fractionnation of crude oil and chemical conversions such as cracking and desulfurisation. This heat may be provided by direct combustion or distributed as steam.

3 - Steam used as a process fluid to reduce partial pressures during fractionnation or to participate in chemical reactions.

These needs must satisfy some criteria :

a - The heat necessary must be provided at a sufficient temperature level which is given in table 1 for the basic refining processes

Refining Process	Temperature level (°C)
Atmospheric distillation	360
Vacuum distillation	400
Gas-oil desulfurisation	330
Catalytic reforming	540
Steam reforming	800 à 900

Note 1 - Steam reforming is normally considered as a petrochemical process which leads to hydrogen, ethylene, ammonia, methanol.

Note 2 - Catalytic cracking of gas oil and vacuum distillates is self sufficient in energy since coke deposited on the catalyst is burnt off continuously.

TABLE 1 - TEMPERATURE LEVELS FOR BASIC REFINING PROCESSES

b - The energy supply must be permanent and reliable, this is because a refinery must operate throughout the year without any complete shut down. The various process units will undergo periodic shut downs to enable planned maintenance to be carried out. The power plant consists of several boilers and turboalternators which ensure a permanent supply of electricity and steam. The process plants have their own individual furnaces to supply high temperature level process heat requirements.

Nuclear reactors produce primary energy as heat ; the aim of this project is to supply the heat available from the reactor to the process plants. The standard nuclear power generation reactors (BWR and PWR) produce electricity from low temperature steam (280 to 300°C). This temperature level is insufficient for the purpose of the project and the High Temperature Reactor (HTR) must therefore be considered.

The temperature (750°C) of the primary cooling loop at the outlet of the HTR reactor core allows the heating of the main refining processes. It therefore seems practical to consider the industrial application of such reactors during the 1980's since some of them are already in operation (Fort St Vrain - U.S.A.) or in the construction phase (Schmehausen - Germany).

2 - MAIN CHOICES

1 - One reactor - For a large refinery (23 millions MTPY) the size of the reactor will be in the range of 1000 to 1500 MW. It is not economically attractive to use two small reactors or a spare reactor. In order to fulfil the requirements of permanency and reliability, we have forseen the following arrangements :

a - For siting convenience, one part of the refinery remains independent of the HTR.

b - The furnaces of the process plants which are replaced by exchangers are kept ready for operation.

c - The boilers of the actual power plant are kept in operation at minimum capacity in order to ensure their total availability in case of a nuclear power deficiency.

2 - Secondary cooling loop - The core of the HTR is cooled by a primary helium cooling loop. For nuclear safety reasons , a secondary loop at higher pressure is used to carry the heat to the process plants : Helium has been chosen because of its thermodynamic properties as a heat transmission medium. The maximum temperature of the loop has been limited to 637°C. This temperature allows the use of austenitic stainless steel. The pressure has been fixed at 61 bar max. (it has now emerged from the study that a higher pressure which would reduce the energy circulation requirements would be preferable).

3 - Heat distribution - The process plants of the refinery have been distributed in two groups.

The high temperature level group which includes only the catalytic reformers and the low temperature level group which comprises the other plants such as crude oil distillations, gas oil desulfurisers and subsidiary fractionnating requirements.

The high temperature helium of the secundary loop heats first of all the exchangers of the first group, then, at a temperature of about 535°C, the other exchangers of the second group.

4 - Steam and electricity production - The HTR is used as a heat producer and it generates steam instead of the existing boilers, to supply the existing turboalternators. This steam is produced in a steam generator placed in the secundary helium loop. The steam pressure has been fixed at 76 bars. A new turboalternator has been installed in the HTR area to produce the necessary power for the HTR and the secondary helium circulation.

3 - PLANT DESCRIPTION

The plant associates a High Temperature Reactor with a helium secondary circuit which produces :

a - steam from steam generators (SG). A part of this steam provides electric power from a turbin generator designed for the needs of the plant, the other part being distributed in the refinery at different pressures for industrial purposes.

b - heat for oil process heat exchangers. The attached flow diagram and data sheet give the main characteristics of the plant.

The 1080 Mw core of the HTGR consists of prismatic fuel element blocks in 210 columns and 8 layers. The active core is 6.34 m high and 5.98 m in diameter giving a power density of 6.07 Mw/m3. The PCRV 25.42 m high and 28.20 m in diameter is of standard pod design and contains 4 intermediate heat exchangers (IHE), two steam generators (SG) and two 100 % core auxiliary heat exchangers. A prestressed concrete containment with a liner surrounds the reactor. A downstream primary helium flow of 560 kg/s at 55 bars cools the core (inlet temperature 356°C, outlet temperature 725°C). The temperatures achieved are consistent with current technology of HTGR. The heat is transfered to a 60 bars helium secondary circuit by four stainless steel straight tubes IHE located in pods. The primary helium, which has a lower pressure, flows outside of the tubes (inlet temperature 725°C, outlet temperature 350°C) and is circulated by four variable speed motor driven blowers of 3.8 Mw each (pressure drop 0.9 bar).

In order to obtain the same working conditions for the IHE, all the hot or cold helium ducts have a common point which is a collector under the PCRV. The 641 kg/s helium secondary flow is heated from 310°C to 637°C by the four IHE of 272 Mw each which are directly connected to cold and hot collectors.

From these collectors, the secondary helium circuit divides in two parallel branches supplying process heat exchangers and steam generators :

- Process branch : A 330 kg/s helium flow is taken from the hot collector to heat the oil exchangers located at a distance of about 600 m of the reactor. The returned cold helium at 308°C is circulated by three variable speed motor driven axial blowers of 16.2 Mw each (5.48 bar pressure drop). The hot and cold helium in the secondary loop circulates in large 1.50 m diameter piping. In order to minimize pipe expansion problems, the piping system is based on the concept of an internally insulated carbon steel pipe with stainless steel liner.

- Steam generator branch : a 311 kg/s helium flow is taken from the hot collector at 637°C to heat the two SG. of 291 Mw each located in pods. The outlet helium flow at 276°C is circulated by two variable speed motor driven circulators of 7.75 Mw each (2 bars pressure drop) and returned to the cold collector at 311°C. The 16 m high and 4 m diameter SG. are once through helical type with down hill boiling.

A 768 t/h steam flow is generated at 76 bar and 484°C. A 638 t/h fraction of this flow is partially expanded in a turbine generator set and produces 104 Mwe for the needs of the plant. The remaining 130 t/h of live steam and two bleeds from the turbine are connected to the steam network of the refinery at a distance of about 1200 m from the reactor and provide respectively : 130 t/h at 66 bar and 470°C, 202 t/h at 36 bar and 400°C and 97 t/h at 13 bar and 290°C. This production of nuclear steam is added to this of the existing conventional steam generators working at one third of their capacity in order to ensure quick action relief of steam if necessary.

4 - ECONOMIC ASPECTS

The installation of a nuclear plant providing process heat, steam and electricity to a part of a refinery involves expenses and income. Expenses are of three types : investments, nuclear fuel and operation. Income is essentially constituted by spared fuel burned to heat the process exchangers and to produce steam, and production of electricity.

The following assumptions are made on the load of the plant : for the two first years, the equivalent full load time is respectively 3000 and 5000 hours per year. After the second year, the nuclear reactor has an availability of 87.5 % and the reactor refinery complex has a load factor of 75 %.

The spared fuel is 507,000 tons per year. Computed expenses and income in constant francs actualized with a 10 % rate over a life time of 30 years, and refering to the actualized spared fuel (4.727 Mt), give the following results :

	Expenses or income actualized MF	Expenses or income actualized in F per t of spared fuel F/t	Percentage
<u>Expenses</u>			
Investments	3075	650	82.5
Nuclear fuel	447	95	12.0
Operation	375	79	10.0
<u>Income</u>			
Electricity	- 169	- 36	- 4.5
Total	3728 MF	788 F/t	100 %

The cost of the investments is high : 2500 MF at 1/1/77. With a spared crude oil of 500 000 t/year, this leads to a prime cost of about 800 F/t. This is approximately twice the present time cost.

5 - CONCLUSION

The studies made have shown that it was technically possible to use a High Temperature Reactor to provide a large part of the energy (process heat, steam, electricity) consumed in a refinery.

Nevertheless, economic calculations have lead to a prime cost of spared crude oil twice the existing price. A more simple design of the plant with steam generators heated directly by primary helium circuit and an increase of the helium pressure in order to reduce the blower's power could decrease this price of 10 to 15 %. In addition, if it was possible to extend the power of the reactor from 1000 to 2000 Mw, the investment cost per kw should be divided by a 1.4 factor. Consequently, it appears that the installation of an HTGR reactor in a refinery is not economical with respect to the cost of the crude oil of the present day.

The safety problems have not been completely studied and are of two types :

- Risk of contamination to personnel or refinery products, which are solved by stop valves on each penetration through the containment and by testing the activity of public utility products ;

- Risk of oil product bursting in the vicinity of the reactor, possibly inducing shock waves ; burning ; earthquakes ; or missile projection. In such circumstances, one must be able to shut down the reactor and to remove the residual heat. In fact, in this plant, the minimum distance of 500 m between the reactor and the storages of fuel products is an important factor for safety.

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MAIN CHARACTERISTICS

PRIMARY CIRCUIT

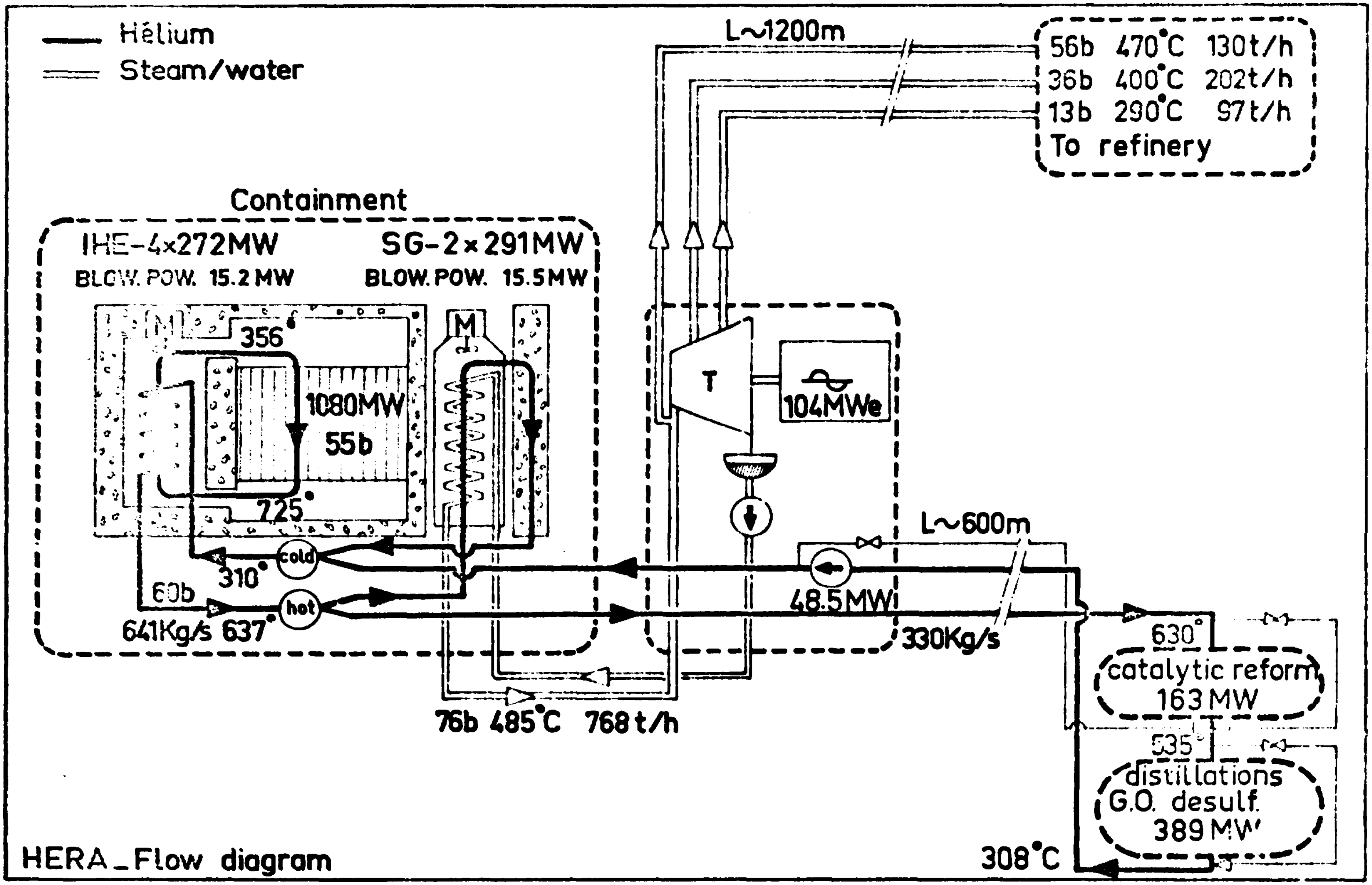
Reactor power	Mw	1080
Helium mass flow	kg/s	560
Helium pressure	bar	55
Helium inlet/outlet reactor temperature	°C	356/725
Pressure drop	bar	0.9
Blowing power	Mw	15.2

SECONDARY CIRCUIT

Heat transfered to the four IHE	Mw	1087.7
Helium mass flow	Kg/s	641
Helium pressure	bar	60
Helium inlet/outlet IHE temperature	°C	310/637
Process branch :		
Heat transfered to process heat exchangers	Mw	551.5
Helium mass flow	Kg/s	330
Helium inlet/outlet process HE temperature	°C	630/308
Pressure drop	bar	5.48
Blowing power	Mw	48.5
Steam generator branch :		
Heat transfered to the two SG.	Mw	583
Helium mass flow	kg/s	311
Helium inlet/outlet SG temperature	°C	637/276
Helium pressure drop	bar	2
Blowing power	Mw	15.5

STEAM/WATER CIRCUIT

Steam outlet SG.	Mass flow	t/h	768
	Pressure	bar	76
	Temperature	°C	484
Electric power		Mw	104
Steam to refinery	at 66 bar	t/h	130
	at 36 bar	t/h	202
	at 13 bar	t/h	97



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