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Interface Data with Hydrogen Processes

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Interface Data with Hydrogen Processes

Executive summary

For the long term objective of massive production of Hydrogen, a series of steps have to be followed. The first is to define a process for the Hydrogen generation. Then a suitable energy source has to be found. After that the evaluation of the feasibility of the coupling between the energy source and the Hydrogen generation process must be proved in terms of balance of plant, with both thermal as well as electrical energy supply compliance.The nuclear source is one of the type He-cooled VHTR (Very High Temperature Reactor) nuclear reactors, the only one among the innovative reactors of GEN IV capable of reaching the temperature requirements (He temperature of 950ºC at the reactor outlet) of the sulphuric acid splitting process of the I-S Cycle.

The design under which the coupling has been developed is the self-sustaining concept. This concept assumes that the power island is able to produce as much electricity as the total demand of the plant, including the primary circuit compressor, the secondary circuit compressor and all the machinery of the chemical plant. This means that the plant's net electricity balance is zero. This concept would enable the plant to work as an island, disconnected from the local network.

The scope of this document is to provide boundary conditions of selected reference concepts of VHTR plants coupled with a hydrogen production unit.

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LIST OF ACRONYMS AND ABBREVIATIONS

GA	General Atomics
GEN IV	GENeration IV
HP	High Pressure
HPC	High Pressure Compressor
HPT	High Pressure Turbine
HX	Heat Exchanger
IHX	Intermediate Heat Exchanger
I-S	Iodine-Sulphur
LMTD	Logarithmic mean temperature difference
LP	Low Pressure
LPC	Low Pressure Compressor
LPT	Low Pressure Turbine
PCHE	Printed Circuit Heat Exchanger
PT	Power Turbine
S&T	Shell and tubes
S_I	Sulphur Iodine
VHTR	Very High Temperature Reactor

1. INTRODUCTION

For the long term objective of massive production of Hydrogen, a series of steps have to be followed. The first is to define a process for the Hydrogen generation. Then a suitable energy source has to be found. After that the evaluation of the feasibility of the coupling between the energy source and the Hydrogen generation process must be proved in terms of balance of plant, with both thermal as well as electrical energy supply compliance.

The nuclear source is one of the type He-cooled VHTR (Very High Temperature Reactor) nuclear reactors, the only one among the innovative reactors of GEN IV capable of reaching the temperature requirements (He temperature of 950ºC at the reactor outlet) of the sulphuric acid splitting process of the I-S Cycle.

The design under which the coupling has been developed is the self-sustaining concept. This concept assumes that the power island is able to produce as much electricity as the total demand of the plant, including the primary circuit compressor, the secondary circuit compressor and all the machinery of the chemical plant. This means that the plant's net electricity balance is zero. This concept would enable the plant to work as an island, disconnected from the local network.

For the future industrialisation of the process and its coupling to the nuclear source, a first scale-up has been performed in order to have a first idea of the main issues and concerns of the dimensions and sizes of the real plant components.

2. SCOPE

The Project Reactor for Process Heat, Hydrogen and Electricity Generation (RAPHAEL) is a 6th Framework Program project which addresses the feasibility and performance issues of the Modular Very High Temperature Reactor. This innovative system is not only meant to provide competitive and safe electricity generation, but also to generate industrial process heat, in particular for hydrogen production.

Within the RAPHAEL project, the System Integration subproject aims at providing preliminary feasibility assessment of concepts of VHTR plants coupled with hydrogen production processes.

The scope of this document is to provide boundary conditions of selected reference concepts of VHTR plants coupled with a hydrogen production unit.

3. HYDROGEN PRODUCTION CYCLE

The hydrogen generation process selected is the I-S (Iodine-Sulphur) Cycle. A schematic description of the thermochemical cycle is included below.

The S_I process can be split in three different sections:

1) A Bunsen section where the two acids are generated:

The G.A. proposal has been taken which is supposed to convert:

$SO_2 + 16\ H_20 + 9\ I_2 \Rightarrow (H_2SO_4 + 4\ H_20) + ((2\ HI + 10\ H_20 + 8\ I_2)$

in two immiscible aqueous phases.

G.A. apparatus can be described as follow (all reactors around 120°C and 2 bars pressure):

Water, sulfur dioxide and iodine are mixed in a first reactor. The liquid demixes into 2 phases with some SO2 remaining solubilized in both phases. The H2SO4 product is then put in another reactor (H2SO4 booster, see Figure 3.1) where it reacts with a small amount of iodine to do another small Bunsen reaction, eliminating the sulfur dioxide and decreasing the water content. The HIx product is simply degassed with oxygen to remove the sulfur dioxide.

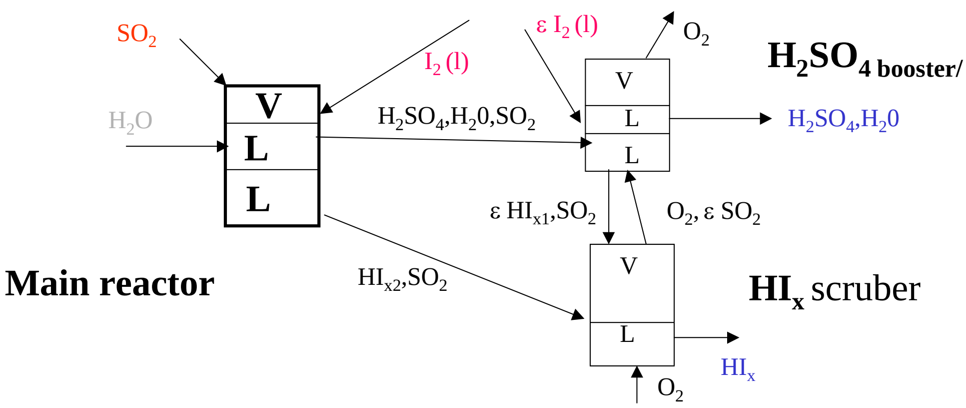

Figure 3-1 Bunsen Section Scheme

2) H2SO4 decomposition step (oxygen generation):

This is done in three steps:

- a partial distillation of sulphuric acid in a multi-stage evaporator, as done usually in the sulphuric acid industry nowadays (flash1, flash2,flasdh3)

- a decomposition of H2SO4 in SO3 and H2O (reactor R1)

- a decomposition of SO3 in SO2 and O2 in reactor R2.

The remaining SO3 is recombined with water to from again sulphuric acid in flash 2 and flash3 of the distillation step.

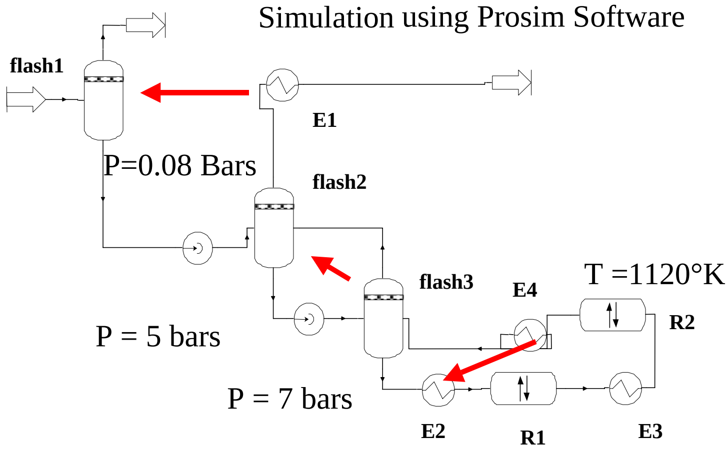

Figure 3-2 Sulphuric Acid Decomposition Scheme

3) HI decomposition (hydrogen generation step):

The product of the Bunsen section is a mixture of 2 HI, 10 H2O, 8 I2. Hydrogen is produced through a reactive distillation of HI in a column (C1). For energy optimization, a flash is put at the exit of the column to enable some water remaining with hydrogen, to liquefy at high temperature. The energy need for the boiler is provided by a water heat pump which brings the heat available at the condenser of the column and at the flash at the desired temperature.

The last flash 2 is used to purify the hydrogen at the exit.

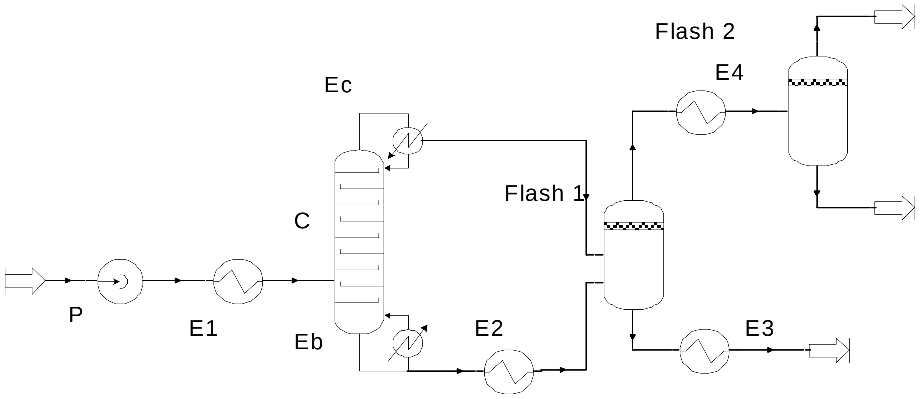

Figure 3-3 HI Decomposition Scheme

The heat released by E2 and E3 can be partially recovered by E1. The amount of heat recovered depends on the temperature difference assumed between the primary and the secondary circuit which in turn depends on the size of the heat exchangers. We assumed minimum temperature differences between primary and secondary sides of the heat exchangers of 10°C and 20°C. The heat recovered can then be deduced from the Q -T diagrams of E1 and E2+E3+E4. We find that, if the temperature difference is 10°C, then the net heat request is 107kW, and if the temperature difference is 20°C, it is 186 kW.

Based on the proposed flow sheets and models, we can give a first efficiency for the whole S_I cycle. The best estimate of the efficiency with today's knowledge and a temperature difference of 10°C for the heat recovery between E1 and E2, E3 is then 286/(343+420)=0.37. If the temperature difference is 20°C, the efficiency becomes 286/(422+420)=0.34.

All the heat balances, especially the heat request from the VHTR, are given in Reference [1].

4. THERMOCHEMICAL – VHTR COUPLING SCHEME. SYSTEM DESCRIPTION

4.1 INTRODUCTION

In this section the coupling scheme between Very High Temperature Reactor (VHTR) and the (I-S) Thermochemical Cycle and an estimation about the daily hydrogen production is studied.

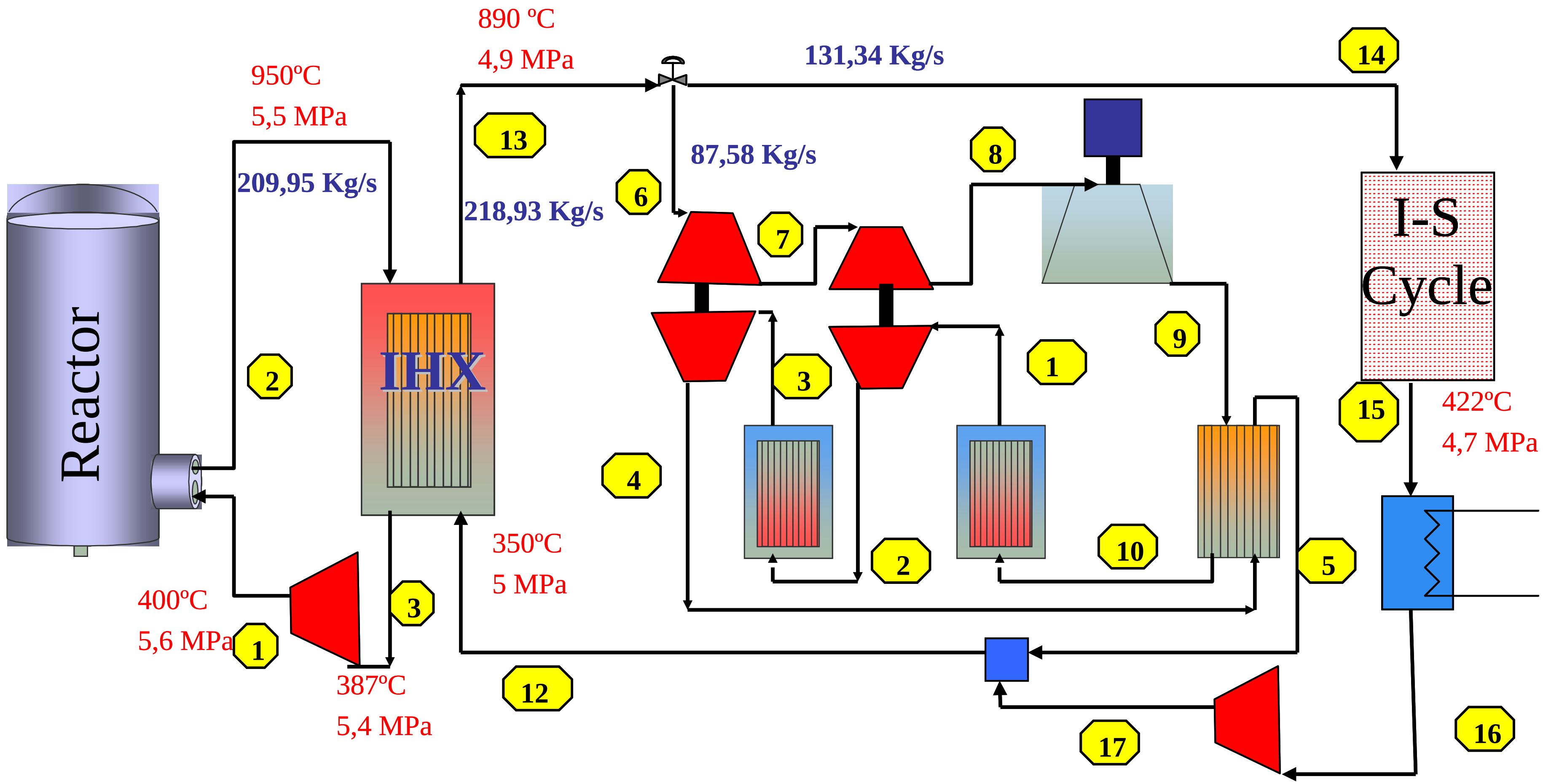

Figure 4-1 Coupling Scheme

4.2 COUPLING DESCRIPTION

The coupling system between a Very High Temperature Reactor (VHTR) and the H_2 (I-S) production plant is formed by two circuits: the primary circuit is composed by the Nuclear Reactor, an Intermediate Heat Exchanger (IHX) and a compressor; while the secondary circuit is formed by the power-generating cycle (Brayton cycle) and the various components that make up the I-S cycle. Both circuits use Helium as the circulating fluid and are coupled to each other through the intermediate heat exchanger (IHX), transmitting the heat from the reactor to the secondary circuit.

The choice for the Brayton cycle as part of the secondary circuit is based on the self-sustainability concept. Together with the production of hydrogen, it is necessary to produce as much electricity as the total plant demand (nuclear + chemical) Brayton cycle is considered due to the high efficiencies in generating electricity.

The selected coupling scheme is a flexible scheme that allows the electrical power rate and hydrogen production to be altered as a function of the amount of helium bypassed to the gas turbine or to the I-S hydrogen production cycle. The bypassing of the helium flow is done by means of a three-way valve that regulates the amount of helium required for each of these uses.

The cycle is calculated with the condition that the plant is self-sustaining, that is, the electricity production in the power turbine be the same as the electricity used by the plant auxiliary consumers (consumption of the I-S cycle, consumption of the primary and secondary compressors).

The auxiliary consumptions of the I-S cycle and the electric demand of the secondary compressor depend on the amount of helium flow for the production of H_2, since the auxiliary consumptions of the I-S cycle are produced as a function of the moles of H_2 produced. The energy consumed by the compressor of the primary circuit is independent of the amount of helium bypassed to the I-S cycle, and its consumption is constant since the amount of primary helium flow in the primary loop does not change.

All the cycle consumptions are shown on the following table:

Table 4-1 Electricity Consumers

I-S Cycle Consumption	
Heat Pump HI section	(113 kJ/mole H_2) 72.8 MWe
H_2SO_4 section and HI section Pumps	(17 kJ/mole H_2) 9.5 MWe
Primary Loop Consumption	
Primary compressor	14 MWe
Secondary Loop Consumption	
Secondary compressor	13.8 MWe

Electricity is produced by means of a Brayton power cycle with cooling, regeneration and intercooling. Its performance is close to 50% if all the helium flow is to be dedicated to the production of electricity.

Characteristics of Helium:

Helium is a gas whose main characteristic is its high specific heat (Cp). Its value of 5.19 kJ/kg.K, with a thermal conductivity of 0.15 W/mºC, is much greater than the Cp of other gases used in power cycles, such as CO_2 (Cp of 0.84 kJ/kg.K) or air (Cp of 1 kJ/kg.K). Its high specific heat value makes helium an ideal gas for use in power cycles.

A negative characteristic of helium is its low density, which is 7 times lower than that of air. This means the dimensions of the turbine are greater than if a different type of gas was used because its specific volumes are very high and the risk of leaks due to having a lower density than air are also very high.

4.2.1 Primary Circuit

The primary circuit is formed by the reactor and the primary compressor that pumps the helium through the reactor and compensates for the pressure drop in the circuit. The intermediate heat exchanger (IHX) is an important component in the circuit and is common to the secondary circuit, and it serves to transfer heat from the primary circuit to the secondary circuit.

4.2.1.1 Reactor

The reactor is a helium-cooled Very High Temperature Reactor (VHTR), whose characteristics have been provided by Reference [2]. Its most important parameters are the following:

Table 4-2 VHTR Main Parameters

VHTR Parameters	
Inlet temperature (ºC)	400
Outlet temperature (ºC)	950
Inlet pressure (MPa)	5.6
Outlet pressure (MPa)	5,5
Mass Flow (kg/s)	209.95
Power (MWt)	600

4.2.1.2 Intermediate Heat Exchanger (IHX)

The Intermediate Heat Exchanger has a plate configuration and is used to transfer the heat from the reactor to the secondary circuit. This heat is used to produce electric power in the power turbine and to produce hydrogen in the I-S thermochemical cycle.

The parameters of the primary circuit of the exchanger are as follows:

Table 4-3 IHX Characteristics In The Primary Circuit

IHX Primary Loop [2]	
T_{inlet} (ºC)	950
P_{inlet} (MPa)	5.5
T_{out} (ºC)	387
P_{out} (MPa)	5.4
Primary Mass Flow (kg/s)	209.95

4.2.1.3 Primary Compressor

The compressor of the primary circuit is designed to pump the helium to cool the reactor core. It also provides the necessary pressure to make up for the pressure drops in the reactor and in the IHX, which amount to 0.2 MPa [2].

The characteristics of the compressor are as follows:

Table 4-4 Primary Compressor Parameters

T_{inlet} (ºC)	387
P_{inlet} (MPa)	5.4
T_{outlet} (ºC)	400
P_{outlet} (MPa)	5.6
Isentropic Efficiency (%)	80 [3]
Mechanic Efficiency (%)	95
Pressure Ratio	1.037
Primary Mass Flow (kg/s)	209.95
Power (MWe)	14

4.2.2 Secondary Circuit

The secondary circuit is composed by three sections set out in parallel with each other. The first branch is the power cycle, which generates the electricity needed to supply all the auxiliary consumptions of the chemical and nuclear plants, the second cycle is the thermochemical cycle (I-S) for hydrogen production and the third is a safety loop.

The helium from the IHX is divided and part of it is bypassed to the Brayton cycle, while the rest is piped to the various exchangers of the I-S cycle to produce H_2.

4.2.2.1 Intermediate Heat Exchanger (IHX)

The function of the IHX is to transfer the heat power supplied by the reactor to the secondary cycle and use this power for the production of electricity and hydrogen. A plate heat exchanger is used. Its characteristics have been provided by Reference [2].

The diagram of the IHX is as follows:

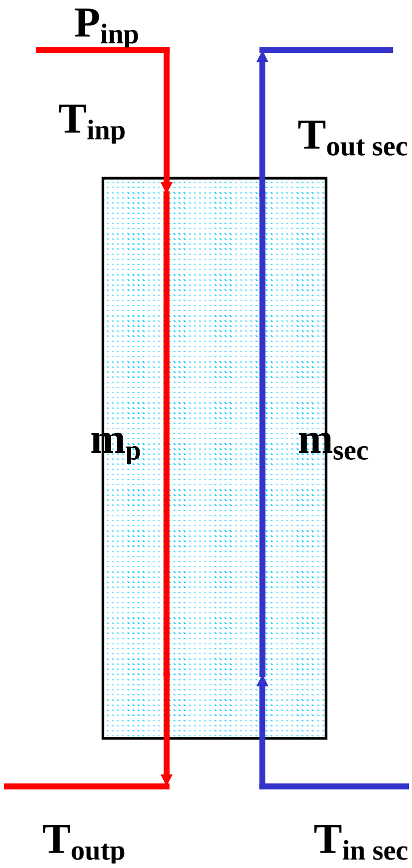

Figure 4-2 IHX Scheme

The data of the IHX provided by RAPHAEL project [2] are shown in Table 4-5:

Table 4-5 IHX Main Parameters

Efficiency	90%
(Tinp) inlet temperature IHX primary	950ºC
(Pinp) inlet pressure IHX primary	5.5 MPa
Mass flow IHX primary	209.95 kg/s
(Tinp) inlet temperature IHX secondary	350ºC
(Pinsec) inlet pressure IHX secondary	5 MPa
Mass flow IHX secondary	218.89 kg/s
Primary/secondary drop pressure	0.1 MPa

The data in Table 4-5 are used as a basis to calculate the rest of the IHX parameters. These calculations are shown in Section 5.2.1.

4.2.2.2 Flow Splitting

Under normal operation the helium flow from the IHX is divided into two currents: one is expanded in the Brayton cycle turbine while the other is used for hydrogen production in the I-S cycle.

The flow splitting is performed by means of a three-way valve that operates in critical pressure and temperature conditions (890ºC and 4.9 MPa).

The amount of flow piped for electrical production in the Brayton cycle turbine must be calculated so that the electricity production is the same as the electrical demand from all the auxiliary components in the plant.

The flow of helium piped to the power turbine is calculated by establishing a system of equations that is solved with an iterative method.

4.2.2.3 I-S Thermochemical Cycle

The I-S thermochemical cycle for the production of hydrogen was described during the 70s and later studied and developed by General Atomic Co.

The cycle is formed by two endothermic reactions that require heat at high and very high temperatures and by a low temperature exothermic reaction that serves to close the cycle.

R1: 9 I2 + SO2 + 16 H2O → (2HI + 10H2O + 8I2) + (H2SO4 + 4H2O) (120°C)

R2: 2 HI → H2 + I2 (220/330°C)

R3: H2SO4 → SO2 + H2O + ½ O2 (850°C)

The first reaction, called Bunsen reaction, proceeds exothermically in the liquid phase and produces two immiscible aqueous acid phases whose compositions are indicated by the use of brackets: aqueous sulphuric acid and a mixture of hydrogen iodine, iodine and water, identified as HIx. These acids are concentrated and the excess of water and iodine is recycled in R1 (For component designation, see flowsheet schematics in chapter 3). HI and H_2SO_4 are then decomposed according to reactions R2 and R3. Reaction R2 is the HI decomposition step with some endothermic heat from the reaction. Reaction R3 is the major endothermic reaction. It releases water, oxygen and sulphur dioxide and takes place in the vapor phase in a catalytic reactor at about 900°C. With the exception of hydrogen and oxygen, the products of the two last reactions are recycled as reactants in the Bunsen reaction.

A total of 2169 kJ/mole H2 are needed to produce 1 mole of hydrogen. Out of this total, 1665 kJ/moleH2 are supplied by internal heat recovery from various components (exchangers and reactors) of the I-S cycle, so the VHTR must provide 504 kJ/moleH2 (422 kJ/moleH2 for the decomposition of the H2SO4 and 82 kJ/moleH2 for the decomposition of HI).

The heat for the decomposition of the H2SO4 is supplied through two heat exchangers (E3 and E2 of H2SO4 section) and two reactors (R1 and R2 of H2SO4 section). These components exchange the heat from the helium with the flow current in the H2SO4 section.

In the section for the decomposition of HI, the VHTR provides heat only in a single exchanger (E1 HI section), since the rest of the heat that is needed for the decomposition of the HI is drawn from the heat recovered from exchangers E2, E3 and E4 of section 3 [1].

The diagram of the various components of the I-S cycle is as follows:

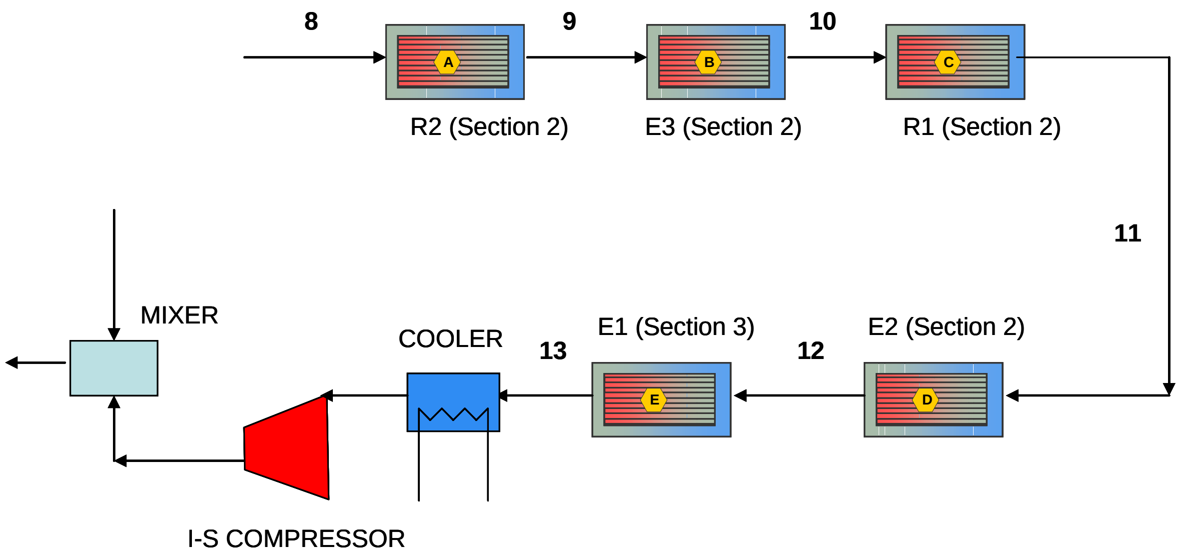

Figure 4-3 Schematic of the Secondary Circuit - IS cycle Heat Exchangers

The following figure shows how heat is transferred from the helium as it flows through the various exchangers of the I-S cycle.

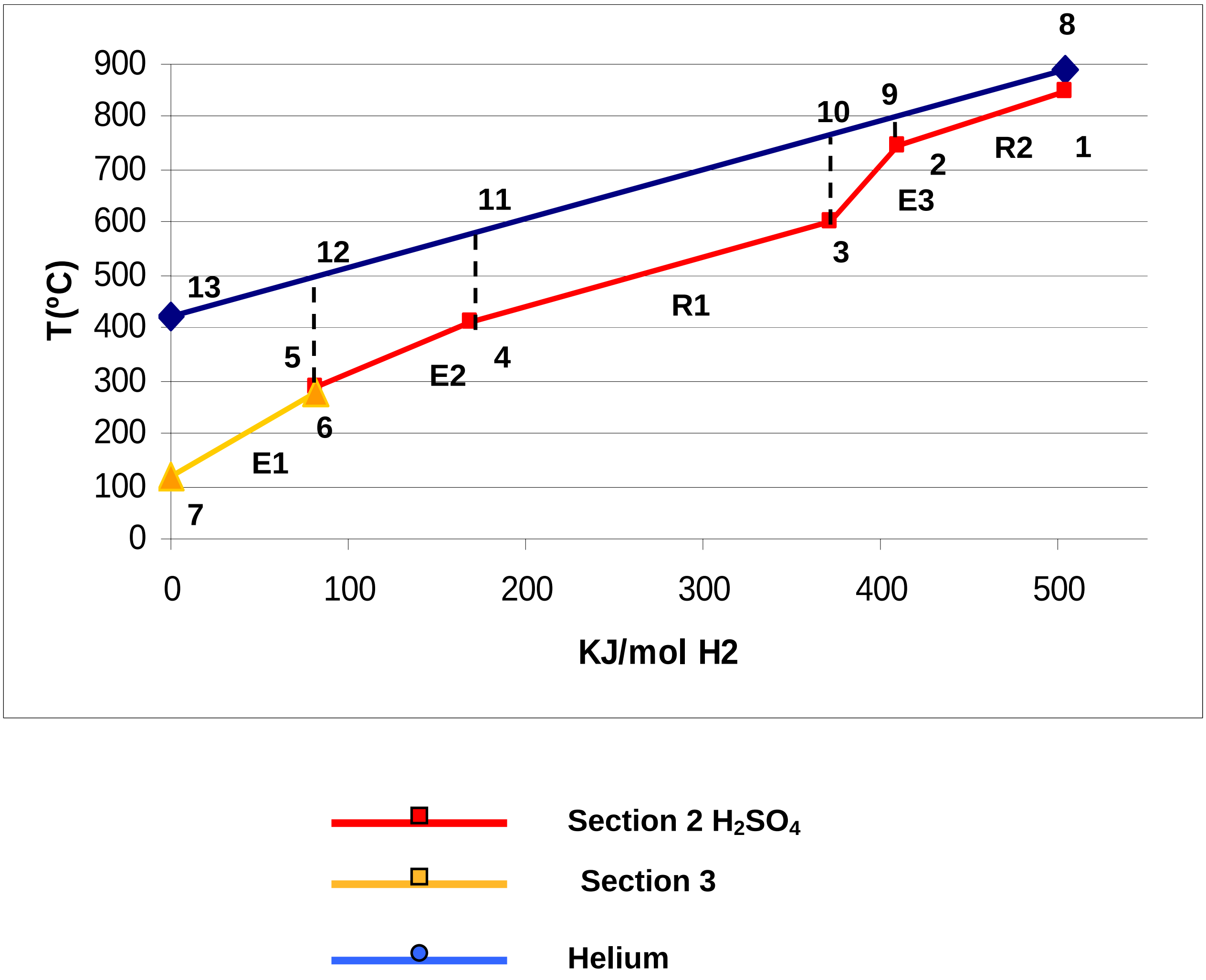

Figure 4-4 Temperature Profile through the Secondary Circuit - IS Cycle Heat Exchangers

The temperatures at the various points are shown in the following table:

Table 4-6 Inlet/Outlet Temperatures in the Heat Exchanger

Input data from I-S [1]	
Point	**I-S ºC**
1	847
2	747
3	602
4	412
5	287
6	276
7	120
Helium temperatures	
8	890
9	801
10	766
11	578
12	496
13	422

The helium flows through the three heat exchangers and the two reactors within the I-S cycle that require heat from the VHTR to produce H_2.

The R2 reactor (SO_3 splitting of the H_2SO_4 section) is the reactor whose temperature difference between the hot side (helium) and cold side is lower. The temperature gradient at the inlet of the exchanger is 43ºC, while the temperature at the outlet is of 54ºC. The difference in minimum recommended temperatures for this type of exchanger is of 45-50ºC. The average temperature logarithmic difference (LMTD) in R2 is of 48ºC, so the exchanger is within these limits. These temperature gradients are large enough for the heat exchange to be optimum.

The rest of the exchangers do not present any problem as regards the temperature gradient because they are very high and the heat exchange is done adequately.

The outlet temperature of helium from exchanger E1 (point 13) is of 422ºC. This temperature could be reduced, thus increasing the heat transferred to the I-S cycle and increasing the production of hydrogen.

The outlet temperature of helium from heat exchanger E1 (point 13) depends on the pinch between points 9 and 2. If the temperature at point 13 is reduced, the pinch between these two points is also reduced, making the R2 exchanger increase in size because the heat exchanging surface of the heat exchanger would increase considerably. These temperatures are also constrained because of the maximum primary loop He temperature of 950ºC. [2]

The heat transferred by the VHTR in each exchanger is as follows:

Table 4-7 Heat Transferred from the VHTR to the IS Cycle

Heat Exchanger	Heat kJ/mole H_2	Heat (MW)
R2	95	60.153
E3	38	24.061
R1	202	127.904
E2	87	55.087
E1	82	51.921
TOTAL	**504**	**319.126**

The 319 MW supplied to the I-S cycle for H_2 production produce 633.19 moles/s, equivalent to a daily production of **110 tonnes of H_2.**

4.2.2.4 Mixing of Helium Flows

After the helium flows through the various exchangers of the I-S cycle, it exits at 422ºC. This temperature is much greater than the inlet temperature to the IHX, so the helium must be cooled by means of a cooler (helium-water).

This cooler reduces the temperature of helium from 422ºC to 329ºC. In the cooler, 63 MWt of energy are removed. This heat can be used for other industrial processes such as power generation by means of Rankine cycle, steam generation for the petrochemical industry, paper industry, desalination, district heating, etc. Even in the case that some of the internal heat recovery would not be physically feasible, the helium could provide with the corresponding heat input. The cooler removes more or less heat as a function of the amount of helium destined for hydrogen production, so that the mixture of the m_{Tur} current plus $m_{I\text{-}S}$ generates an inlet temperature to the IHX of 350ºC.

The flow through the five heat exchangers of the I-S cycle and through the cooler causes a 0.203 MPa pressure drop in the helium. This pressure drop is the difference between the pressure supplied by the compressor, increasing the pressure from

4.697 MPa to 5 MPa, which is the pressure needed at the inlet of the IHX. When the helium pressure increases, the compressor causes a 15.2ºC temperature increase which has to be taken into consideration to adjust the temperature at the outlet of the cooler and obtain a temperature of 350ºC after the helium flow from the power generation cycle has been mixed.

The mixture of the helium from the I-S cycle and the helium from the power cycle is done in a mixer, where no heat loss to the outside is considered.

4.2.2.5 Power Generation. Brayton Power Cycle

Power is generated from a closed Brayton power cycle with regeneration and intercooling. The Brayton cycle is formed by the following stages:

a) Compression

The first stage of the cycle is the compression of helium. This compression is, in turn, divided into two stages: a high-pressure stage and a low-pressure stage, separated by the helium cooling in the intercooler (points 3-4).

Compression is done by means of two rotating turbo compressors that are moved by their respective turbine stages. It is therefore the turbine itself that provides the energy for the cycle compression.

The temperature of a gas is always increased whenever it is compressed. This increase depends on the adiabatic coefficient of the gas and on the compression ratio. The compression is therefore achieved in two stages with inter-cooling, since the increase in the number of stages means that the process approaches to an isothermal process and the compression effort is reduced.

b) Regeneration

As helium exits the power turbine at a high temperature, this heat is used to heat up the helium before entering the IHX so that a higher outlet temperature is reached to notably increase performance.

Regeneration is performed in a regenerator. This is a counterflow heat exchanger that exchanges heat from the outlet helium of the LP section of the turbine (points 9-10) to the HP compressor outlet helium (point 4).

c) Heat supply (IHX).

The heat supply to the cycle is done in the IHX (points 22-6). Here, the temperature of helium from the regenerator is increased up to 890ºC, which is the maximum temperature of the cycle.

d) Expansion.

Once the gas is heated up, it enters the turbine and expands to generate energy. It first flows through the High Pressure Turbine (HPT), which moves the High Pressure Compressor (HPC) (points 6-7) and then flows through the Low Pressure Turbine (LPT) that moves the Low Pressure Compressor (LPC) (points 7-8). Finally, it is expanded in the power turbine, which moves the alternator and generates electrical power (points 8-9).

e) Cooling.

A heat sink is needed in the power cycle to be able to complete it. In the Brayton cycle, the heat sink is the precooler, where outlet helium from the regenerator is cooled to the minimum temperature of the cycle (30ºC). The heat removed from the precooler and intercooler can be used as cogeneration for other industrial processes.

The electrical and thermal powers in the various power cycle components are as follows:

Table 4-8 Thermal and Electrical Demand of Power Generation Section

Component	W(MWe)
LP Compressor	65.74
HP Compressor	65.74
Power turbine	110
Component	**Q(MWt)**
Precooler	69.54
Intercooler	65.17
Regenerator	81.556

4.3 VERIFICATION OF THE SELF-SUSTAINING CONCEPT

As set out throughout the document, the purpose of the plant is to produce hydrogen and provide electrical power to all the electrical consumers of the various components in the plant. For this purpose, after calculating the helium flows for the production of electricity and hydrogen there will be a verification that the energy produced by the power turbine equals the power consumed by the primary and secondary compressors, the heat pump of the I-S cycle and the hydraulic pumps of the I-S cycle.

Table 4-9 Verification of Self-Sustaining Concept

Electric Production	
Power Turbine (MWe)	+110.156
Primary compressor (MWe)	-14
Secondary compressor (MWe)	-13.826
Heat Pump (MWe)	-71.55
I-S Pump (MWe)	-10.76
TOTAL	0

4.4 SAFETY SYSTEM UPON MALFUNCTION EVENTS

The safety system upon malfunction events is used to remove the thermal power of the secondary circuit upon three types of malfunction:

- Malfunction in the turbine
- Malfunction in the I-S cycle
- Malfunction in both systems simultaneously

Malfunction in the turbine

Whenever there is a malfunction in the turbine and the generator is uncoupled from the network, the turbine is stopped and the helium flow from the turbine to the Heat extractor through the three way valve.

Malfunction in the I-S cycle

Whenever there is a malfunction in the hydrogen production cycle (I-S cycle) and hydrogen production is stopped, the helium that provides the thermal input to the I-S cycle is bypassed to the other two branches of the secondary cycle. Part of the helium flow is redirected to the power turbine and part to the Heat Extractor. Once this energy is dissipated, the helium is mixed with the helium from the power turbine, and it enters the IHX again to absorb the energy from the reactor.

The main function of the Heat Extractor is to cool down the helium flow in case of accident or partial or total shutdown for maintenance/inspection, and provide the reactor with helium at the designed temperature so that the reactor can maintain an almost steady-state operation (absorption of temperature oscillations to prevent reactor scram)

Malfunction in the turbine and I-S cycle

Whenever there is a malfunction in the turbine and in the I-S hydrogen production cycle simultaneously, all the helium of the secondary circuit is channeled to the safety system to remove all the heat transmitted in the IHX with the heat exchanger of this system.

The heat exchanger of the safety system can be a water pool containing tube bundles for the helium to be cooled. The cooling water evaporates and is recovered by means of condensation.

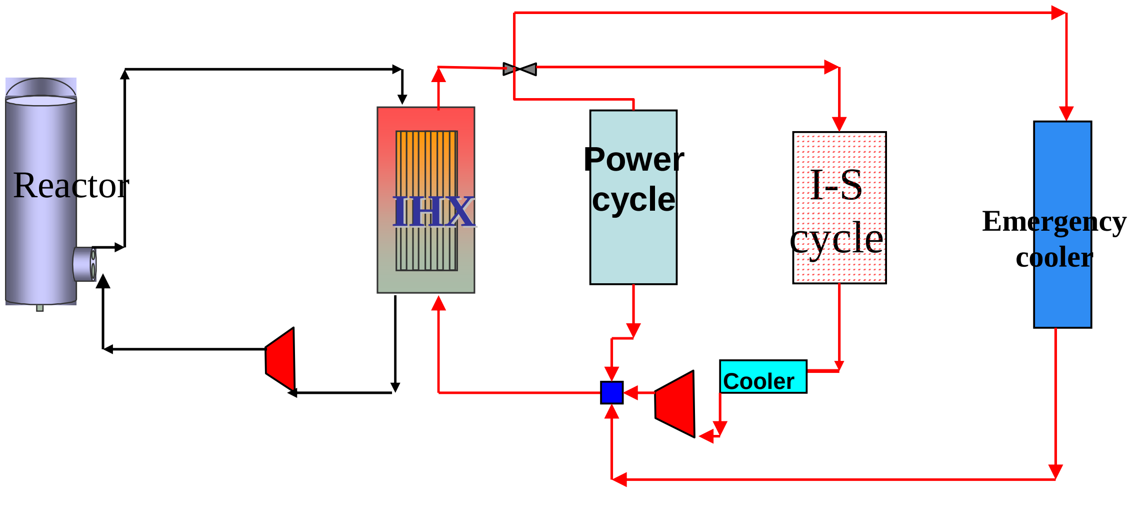

Figure 4-5 Global Coupling Scheme with Safety Loop

5. CONCLUSIONS

The coupling between the I-S Cycle and the VHTR nuclear reactor has been performed successfully. It has proved that the nuclear reactor is able to provide with thermal energy for the chemical processes requirements, while at the same time is able to produce, via a Brayton cycle, as much electricity as the whole coupling scheme requires.

The amount of hydrogen produced, **110 tons/day**, represents a very high value for a 600 MW nuclear reactor taking into account the electricity production demanded, **110 MWe**. It must not be forgotten that some hypotheses and simplifications have been used for the calculation. The evaluation here is a general balance of plant, which will require in the future a deeper study in order to take into account the plant layout and the effect of the scale-up on some components. Also in the future the possibility to consider modularization on the chemical plant shall be checked.

6. REFERENCES

[1] J.M Borgard, O. Boundouin: 'D5: S-I Cycle Data and Flow-Sheet'. FP6 Hythec project

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