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EVALUATION OF THE FEASIBILITY OF SEAWATER DESALINATION USING THE AP1000 NUCLEAR REACTOR AS A ENERGY SOURCE

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1. Introduction

Cogeneration of heat and power or the combined heat and power (CHP) mode of operation of power plants has long been used in various industries around the world. The purpose of this method is to optimize energy flows and reduce energy losses, enabling the improvement of energy efficiency (fuel), energy security and reduction of industrial CO2 emissions [1], [2].

Based on this premise, nuclear cogeneration emerges as an excellent alternative to the use of nuclear energy. Nuclear cogeneration is the simultaneous production of electricity and heat or a heat-derived product from an NPP. There is currently a wide range of nuclear reactors available for cogeneration. In addition, future concepts of nuclear reactors, which incorporate cogeneration characteristics and compliance with stricter economic criteria, are being developed in several countries [1], [3]. The following table outlines current and future co-generating nuclear reactors.

Table 1 - Current and Future Cogenerator Reactors.

Plant	Country	Reactor Type	Reactor Thermal Power (MW_{th})	Cogeneration Product	Plant Status
Halden	Norway	BWR	25	Process steam	In operation
HTR-PM	China	pebble bed HTGR	2x250	Process steam or H_2	In construction
Gosgen	Switzerland	PWR	3002	Process steam	In operation
NGNP	EUA	HTGR prismatic	up to 625	Steam H_2	Preliminary
SMART	R. of Korea	PWR integral	330	Desalination and district heat	design certificate
GTHTR-300	Japan	HTGR prismatic	600	H_2, desalination and process heat	Pre-licensing

Source: IAEA (2019).

In the operation of a nuclear power plant, a refrigerant recovers the thermal energy released by fission in the reactor core, which is converted into heat in the form of steam or hot gas. A portion of the heat (about 30-50% depending on system design) is converted to electricity, and normally the rest is disposed of in the environment as waste. As an alternative to this waste, since this heat still retains the necessary energy pressure and temperature, which are acquired during the energy conversion process, it can be used for various applications, such as producing heating or cooling, an energy source for the desalination of water, as the MSF studied in this work, production of hydrogen, oil and synthetic fuel, adding potential benefits to nuclear plants operating in the energy markets [4].

The AP1000 nuclear reactor offers excellent advantages for the production of drinking water through the use of waste heat and its coupling with the MSF desalination plant. The MSF method for seawater desalination requires low energy requirements, making it ideal for cogeneration systems taking advantage of this waste heat. MSF is based on instantaneous evaporation, ie seawater is evaporated by reducing pressure as opposed to increasing temperature. The heat of condensation released in each stage increases the temperature of the incoming water in the next. MSF plants consist of a heat input and several distillation sections where it is released.

2. Methodology

The cogeneration of a nuclear plant will be done through a computational model that will be built using the Aspen Plus® chemical process simulator in the interaction of two different systems:

(i) the energy conversion cycle of the AP1000 nuclear reactor;

(ii) the seawater desalination process, using MSF technology coupled to the AP1000 reactor.

Aspen Plus® is a Chemical Process Simulation (CPS) software that will calculate the overall efficiency as well as estimate some operating parameters of fundamental components.

Chemical process simulation is able to do a more rigorous, detailed analysis and this increases confidence in the proposed process design [5]. Mathematical models are used to satisfy the intended objectives, such as the Peng-Robinson (PR) Model and the NRTL (Non-Random Two Liquid) Model. Having seen all this, the construction of the system flowchart proposed in this work in Aspen Plus® follows the following assumptions:

- simulated components are in steady state and operating with nominal parameters;
- changes in kinetic and gravitational energy are neglected;
- heat losses in process components, pipes and joints are also neglected;
- pressure drops in the pipes are not taken into account.

To calculate the overall efficiency of the proposed system, the mass, energy and exergy balances are performed according to the following expressions:

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \tag{1}$$

$$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \sum_{out} \dot{m}\left(h_{PT} - h_0 + h_f\right) - \sum_{in} \dot{m}\left(h_{PT} - h_0 + h_f\right) \tag{2}$$

$$\dot{Ex}_{\dot{Q}_{in}} - \dot{Ex}_{\dot{Q}_{out}} + \dot{Ex}_{\dot{W}_{in}} - \dot{Ex}_{\dot{W}_{out}} = \sum_{out} \dot{m}_{out} ex_{out} - \sum_{in} \dot{m}_{in} ex_{in} + \dot{Ex}_d \tag{3}$$

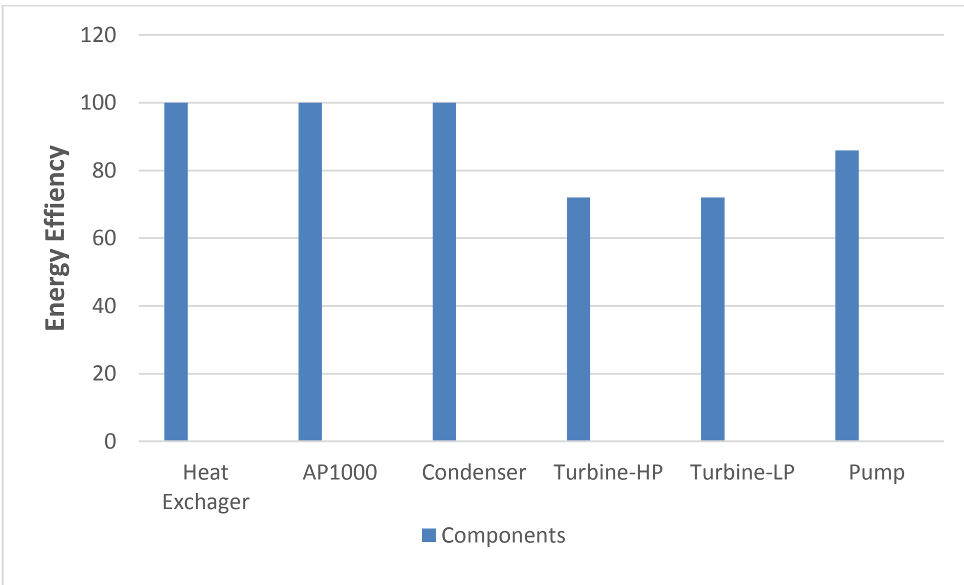
3. Results and Discussion

In the proposed work, the coupling between a seawater desalination plant and an AP1000 nuclear reactor was analyzed, through the Rankine cycle, taking advantage of the heat from the reactor that would be wasted under normal conditions. In the proposed work, the coupling between a seawater desalination plant and an AP1000 nuclear reactor was analyzed, through the Rankine cycle, taking advantage of the heat from the reactor that would be wasted under normal conditions. First, the two processes mentioned in the previous topic were analyzed separately, as the energy supplied to the desalination plant cannot compromise the functioning of the nuclear plant. Thus, a flowchart was built in the Aspen Plus software to assess the efficiency of the Rankine cycle, as well as the energy and exergy efficiency of the main components of the cycle. The efficiency found matches the value reported by [6]:

$$\eta_{Rankine} = \frac{\dot{W}_{cycle}}{\dot{Q}_i} = \frac{\dot{W}_{turbine} - \dot{W}_{pump}}{\dot{Q}_{AP1000}} = 30{,}25\% \quad (4)$$

The figure below compares the efficiencies of the components of the energy conversion cycle.

Comparison of the efficiencies of the components of the AP1000 reactor energy conversion cycle model.



Source: Author (a) (2021).

The energy extraction point, waste heat, that feeds the desalination plant was done in the low pressure turbine - LP of the Rankine cycle in the AP1000 reactor, at a value of 532 MW, and thus indicating nuclear cogeneration. This amount did not compromise the normal functioning of the AP1000 plant.

The residual heat from the extraction point, heat stream from the AP1000 reactor conversion model, provided a significant amount of desalinated water from the MSF plant. Approximately 52206.1 l/sec were obtained, corresponding to a mass flow of 20.5344 kg/s of sea water.

4. Conclusions

From the data and results presented, it was evidenced that nuclear cogeneration is promising and has a substantial efficiency, thus showing itself as an excellent alternative for safe and sustainable growth.

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