SIMPLIFIED STUDY FOR THE PROPOSED APR1400 CONDENSER PERFORMANCE BASED ON EL-DABAA SITE, EGYPT, WITH RESPECT TO BNPP & SHIN KORI NPP.

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1. Introduction

Egypt lies in the northern corner of Africa. It is bounded by the international frontiers of the Mediterranean Sea in the North, the Red Sea in the East, Libya in the west and Sudan in the south. The total area of Egypt is 1.01 million Km2; geographically it is divided into four main divisions: The Nile Valley and Delta (approx. 33,000 Km^2). The western desert (approx. 681,000 Km2), the eastern desert (approx. 325,000 Km2), and Sinai peninsula (approx. 61,000 Km2). Egypt lies for the most part within the Temperate Zone, and the bio-climate varies from arid to extremely arid. The daily maximum temperatures in Egypt ranges from 18°C to 41°C and daily minimum temperature ranges from 5°C to 23°C.

The entire Egyptian Mediterranean coastal region, from Sallum in the west to Rafah in the east, shares essentially similar climate. The greater part of the annual rainfall is confined to a few rainstorms occurring in the mid-winter months. On the rainless days, the winter climate is mostly warm, sunny and frost free. During the transitional spring and autumn months, there are few days with light rain, marked seasonal changes in temperature and, to a lesser extent, changes in humidity and cloudiness. There is no rain during the summer [1].

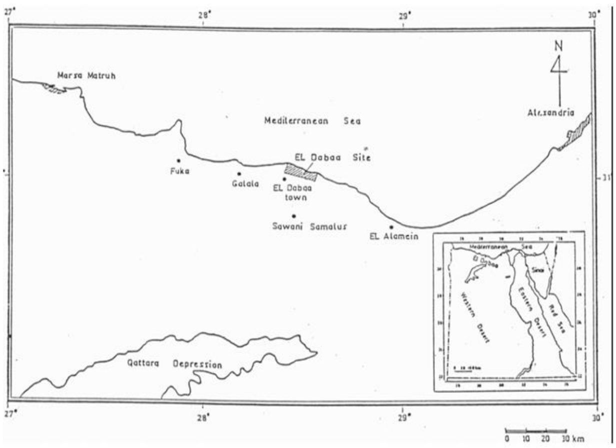

Fig.1 El-Dabaa site Location [2]

El-Dabaa Site, on the Mediterranean Sea coast, has been selected and qualified as a site for the first Egyptian nuclear power plant. The reasons which led the country to promote launching a nuclear power program were basically the following:

• Steadily increasing demand for energy and electricity, caused by population growth, urbanization, industrialization, and the desire and intention to improve the conditions and the standard of living of the people, Table I shows the Egyptian electricity production, Consumption and capacity [1].

• Inadequate and insufficient known national primary energy resources to supply on a medium- and long-term the increasing demand for energy and electricity; also limited potable water resources, which will require the addition of new sources of supply, in particular for remote areas.

• Perception of nuclear power as a convenient, economically competitive and viable source of energy which, if introduced in the country, would not only complement the traditional energy sources, but would also promote technological development and serve as an incentive for social and economic progress [2].

In this paper we will introduce APR-1400 as the most likely selected reactor type for 1st Egyptian Nuclear Power Plant. Then we will study the optimized APR-1400 condenser performance based on El-Dabaa site conditions.

1.1 Brief design description of the APR-1400

The Advanced Power Reactor 1400 (APR1400) is an evolutionary advanced light water reactor (ALWR) based on the Optimized Power Reactor 1000 (OPR1000), which is in operation in Korea. The APR1400 incorporates a variety of engineering improvements and operational experience to enhance safety, economics, and reliability. The advanced design features and improvements of the APR1400 design include a pilot operated safety relief valve (POSRV), a four-train safety injection system with direct vessel injection (DVI), a fluidic device (FD) in the safety injection tank, an in-containment refueling water storage tank (IRWST), an external reactor vessel cooling system, and an integrated head assembly (IHA). Development of the APR1400 started in 1992 and continued for ten years. The APR1400 design received design certification from the Korean nuclear regulatory body in May of 2002 [3].

The Nuclear Steam Supply System (NSSS) generates 4000 MWt, producing saturated steam. The NSSS

Table I: Egyptian electricity production, Consumption and capacity [1]

						Annual Average Growth Rate (%)	
Electricity Generation	1980	1990	2000	2005	2009	1980 to 2000	2000 to 2009
Total	18.94	39.43	70.34	111.69	142.69	6.78	8.18
Nuclear	-	-	-	-	-	-	-
Hydro	9.80	9.98	14.27	12.64	12.86	1.89	1.14
Geothermal	-	-	0.08	0.55	1.13	-	34.06
Thermal	9.14	29.45	55.99	98.49	128.69	9.49	9.69
Installed Capacity	1980	1990	2000	2005	2009	1980 to 2000	2000 to 2009
Total	4.87	11.73	17.02	21.14	24.44	6.46	4.10
Nuclear	-	-	-	-	-	-	-
Hydro	2.44	2.74	2.65	2.78	2.84	0.40	0.80
Geothermal	-	-	-	-	-	-	-
Thermal	2.42	8.98	14.36	18.17	21.29	9.31	4.48

contains two primary coolant loops, each of which has two reactor coolant pumps, a steam generator, a 42-inch ID hot leg pipe and two 30-inch ID cold leg pipes. In addition, the safety injection lines are connected directly to the Reactor Vessel. An electrically heated pressuriser is connected to one of the loops of the NSSS. The pressuriser has an increased volume (relative to previous design) to enhance transient response. Pressurized water is circulated by means of electric-motor-driven, single-stage, centrifugal reactor coolant pumps. Reactor coolant flows downward between the reactor vessel shell and the core support barrel, upward through the reactor core, through the hot leg piping, through the tube side of the vertical U-tube steam generators, and back to the reactor coolant pumps. The saturated steam produced in the steam generators is passed to the turbine [4].

It can be inferred that, the APR 1400 is a great opportunity that we recommend its exploitation by the Egyptian government for Nuclear Power Generation purposes. The reason that makes APR 1400 a great opportunity is the excellence it has over other nuclear reactors: higher thermal efficiency (36.25%), lower construction cost and shorter construction time. For this reason we studied the APR-1400 Condenser performance and its effects on the overall plant based on El-Dabaa site with respect to BNPP & SHIN KORI NPP. To execute our calculation we used the KEPCO International Nuclear Graduate School (KINGS) Numerical Probabilistic Analysis Simulator.

2. Condensate System

Condenser is the major component in the condensate system and one of the important auxiliary equipment in nuclear power plants. The thermal efficiency of the entire unit was depended on the condenser performance. The main factors affect the operation of the condenser performance are cooling water inlet temperature, cooling water flow rate, condenser thermal load, cooling tubes fouling, the amount of air leaking into the condenser, condenser cooling area. The cooling water inlet temperature and the condenser heat transfer area were depended entirely on the natural conditions and design value.

2.1 Condensate System (CD) Functions

The functions of the Condensate System (CD), as part of the steam closed cycle are:

- To receive and condense exhaust steam entering the condenser.
- To collect condensate drained to the hot well.
- To supply condensate to the Feed water System (FW).
- To purify condensate through the condensate polishing demineralizers of the Condensate Polishing System, upgrades its quality by chemical addition.
- To raises the condensate temperature through the low-pressure feed water heater train and removes the entrained oxygen and no condensable gases by deaeration. The condensate in the deaerator storage tanks supplies feed water to the suction of the feed water booster pumps and the start-up feed water pump.
- To provides gland seal water, turbine exhaust hood spray water and cooling media for various systems.

2.1.1 System Description

The Condensate System consists of the condenser, condensate pumps, low-pressure feed water heaters, deaerator, deaerator storage tanks, gland seal water

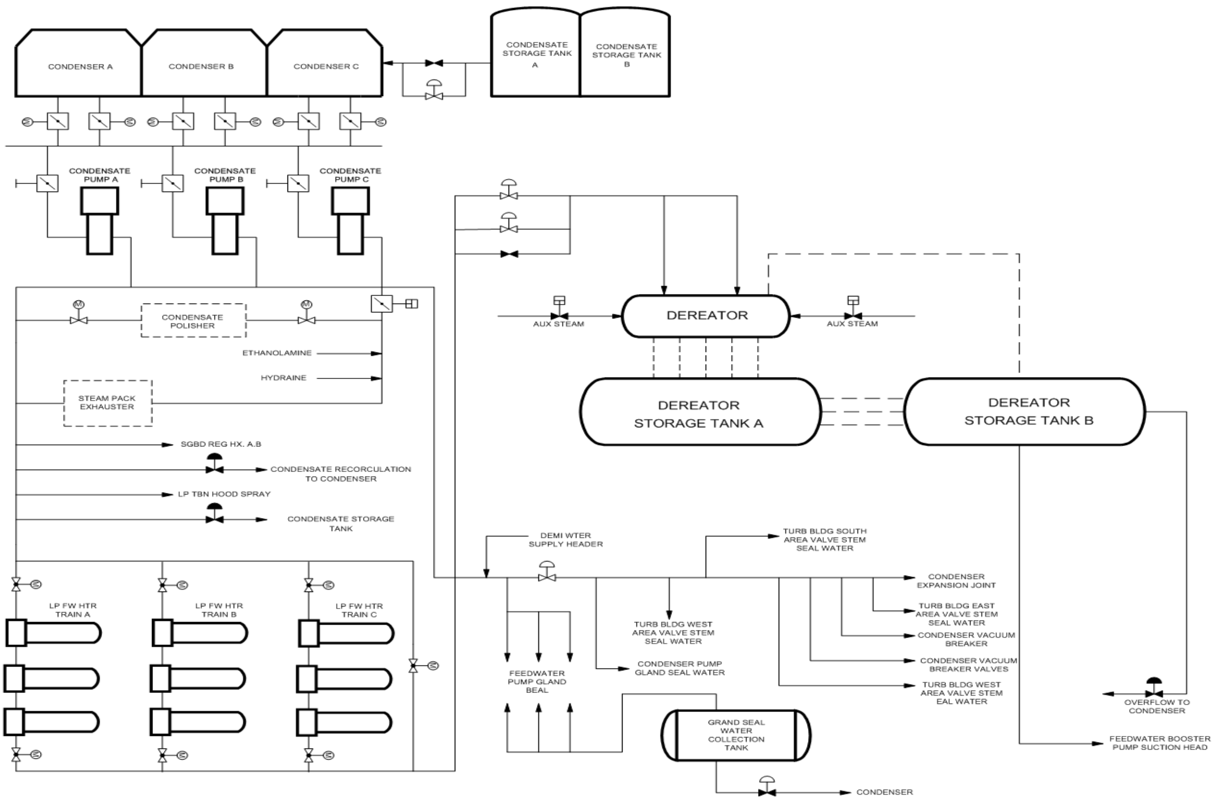

Fig. 2 the condensate System for APR-1400 [4]

collection tank, overboard pump, and associated piping, valves, instrumentation and controls. Three 50% capacity motor-driven condensate pumps (two operating and one standby) deliver condensate from the condenser hot well to in-line full flow condensate polisher with partial flow mode followed by, the steam packing exhauster, and three stages of low pressure feed water heaters to the deaerator. The two lowest pressure feed water heaters are installed in the main condenser necks. Three heaters are installed horizontally in the heater bay. Isolation valves are provided at the inlet and outlet of each of the three heater strings such that each LP heater string is isolated as a whole. Condensate is also provided to the steam generator blow down regenerative heat exchanger for cooling. Deaerator storage tank level is controlled by two pneumatic valves at the deaerator inlet which adjust condensate flow to the deaerator. During low load periods, one valve controls flow, at higher loads, one valve is open and the other valve controls flow.

Condenser hot well level is maintained by directing condensate flow to and from the condensate storage tank using makeup lines. Makeup from the condensate storage tank is directed to the condenser for vacuum deaeration. Dissolved oxygen in the makeup water is minimized by the nitrogen pressurization of the condensate storage tank. The configuration of the primary and secondary systems including the Condensate System is shown in Figure 2 [4].

2.2 Main Condenser

The main purposes of the condenser are to condense the exhaust steam from the turbine for reuse in the cycle and to maximize turbine efficiency by maintaining proper vacuum. As the operating pressure of the condenser is lowered (vacuum is increased), the enthalpy drop of the expanding steam in the turbine will also increase. This will increase the amount of available work from the turbine (electrical output). Figure 3 shows the isometric cross section of the Nuclear Power Plant condenser including the tube bundle, the feedwater heaters, inlet and outlet seawater pipes, and the steam extraction pipes inside the condenser neck.

2.2.1 Condenser operation

The main heat transfer mechanisms in a surface condenser are the condensing of saturated steam on the outside of the tubes and the heating of the circulating water inside the tubes. Thus for a given circulating water flow rate, the water inlet temperature to the condenser determines the operating pressure of the condenser. As this temperature is decreased, the condenser pressure will also decrease. As described above, this decrease in the pressure will increase the plant output and efficiency.

The non-condensable gases consist of mostly air that has leaked into the cycle. These gases must be vented from the condenser.

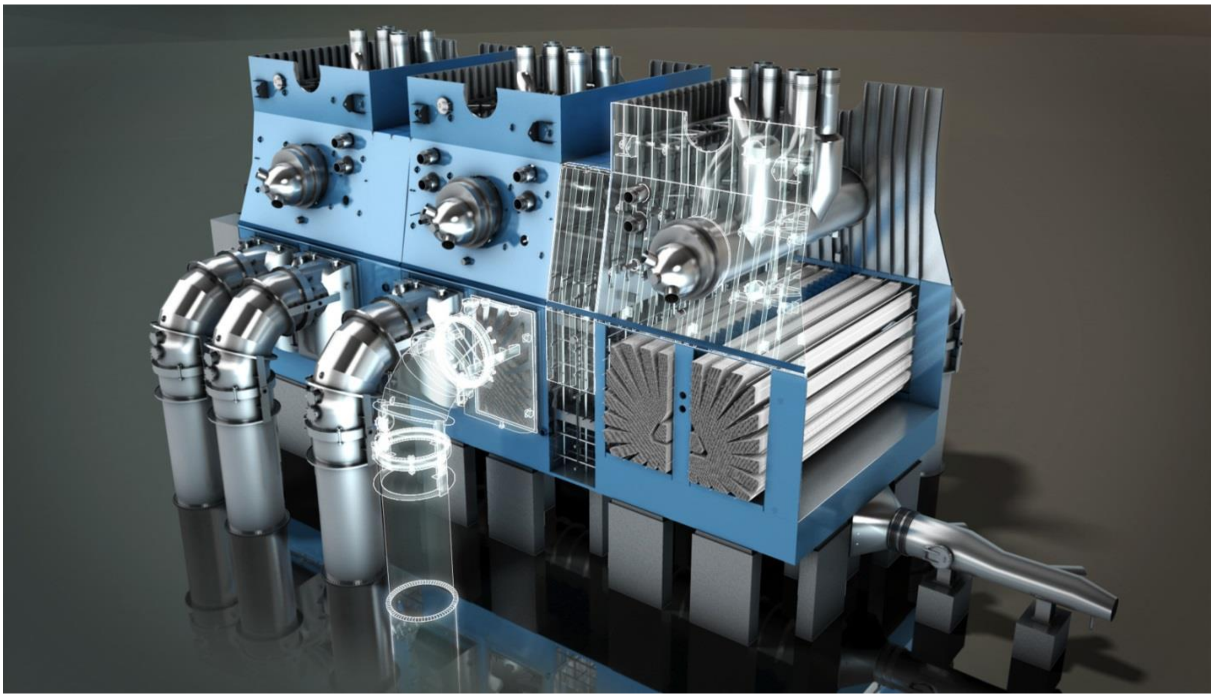

Fig. 3. The isometric cross section of the Nuclear Power Plant condenser [9].

Functions of the condenser:

- Is to create a vacuum by condensing steam.
- Removing dissolved non-condensable gases from the condensate.
- Conserving the condensate for reuse as the feed water supply to the steam generator.
- Providing a leak-tight barrier between the high grade condensate contained within the shell and the untreated cooling water.
- Providing a leak-tight barrier against air ingress, preventing excess back pressure on the turbine.
- Serving as a drain receptacle, receiving vapor and condensate from various other plant heat exchangers, steam dumps, and turbine bleed-offs.
- Receptacle for adding DM makeup.

3. KINGS NPA

Western Service Corporation (WSC) has developed simulation products for the power and process industry using a state-of-the –art simulation environment called 3KEYMASTER. This application is capable of simulating all aspects of the Thermal- Hydraulics systems, electrical distribution and logic and control systems. The 3KEYMASTER system runs on standard, commercial off-the-shelf computers under Microsoft Windows operating systems. The 3KEYMASTER system includes a full set of tools and libraries accessed through an ergonomically designed graphical user interface that allows for instantaneous dynamic visualization of the process being simulated as the system is being configured.

The 3KEYMASTER Executive and Environment has been used on over 50 simulators worldwide, including the KINGS NPA. The feature rich system provides a stable environment for full scope simulator development. The 3KEYMASTER includes an executive system, a simulator control system, an integrated simulation model developing system (i.e, Model Builders) and configuration management features for the simulator software.

4. Thermal-hydraulic parameters with respect to condenser performance

The suitable case to illustrate this section is to give an example of high temperature arid area like the gulf countries, especially that the APR-1400 currently under construction in United Arab Emirates. For the condenser, the water source of the (Ultimate Heat Sink) UHS is the Arabian Gulf and it is capable of providing sufficient cooling water for at least 30 days to permit plant safe shutdown and subsequent cooling under the worst environmental conditions as specified in the regulatory requirement [5].

Due to the once-through nature of the UHS cooling water and the overall size of the UHS, water evaporation is not a significant controlling parameter to be considered in the UHS design. A typical APR1400 NPP secondary side is designed for 36.5°C (normal condition) and 38.5°C (accident condition) of the UHS temperature of the Gulf. In fact, the plant is designed to be shut down when the UHS temperature exceeds 38.5°C, as specified in the Technical Specification [6].

The lowest pressure (and temperature) of the cycle is limited by the temperature of the cooling water supplied to the condenser. Condensation occurs when the temperature of the condenser cooling water is below the saturation temperature of the steam entering the condenser. In practice, the temperature difference between cooling water and steam is about 10°C to 15°C. For example, if the cooling water is at 20°C, the condenser temperature is about 35°C and corresponding saturation pressure is 0.006 MPa. The corresponding thermal efficiency of the cycle would be 32% (refer to Figure 4 [7]). If the cooling water is at 35°C, the condenser is at about 50°C and 0.013 MPa. The thermal efficiency of the cycle would be 30%. Increase of cooling seawater temperature by 15°C results in a 2 percentage-point loss of efficiency and about a 6% power loss. This means for a 1450 MWe power cycle in APR1400, as in the cases of the Shin-Kori site in Korea and a Barakah site, the power loss would be about 90 MWe [7].

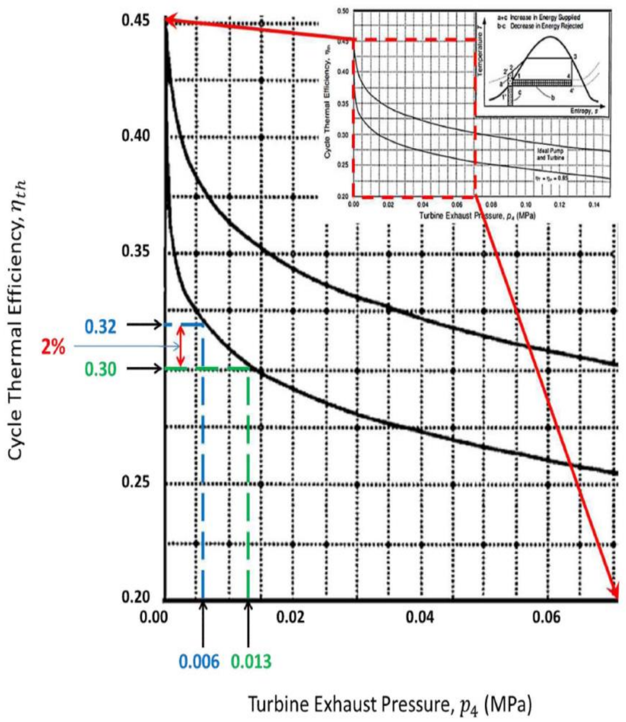

Fig. 4. Thermal Efficiency of Rankine Cycle for a Saturated Turbine Inlet State for Varying Turbine outlet Pressure. Turbine Inlet: 7.8 MPa Saturated Vapor [7].

The average seawater cooling temperature difference of 15°C higher will result theoretically in about a 2% drop of thermal efficiency in a simplified Rankine cycle of a PWR plant, equivalent to approximately a 90 MWe loss in a typical APR1400 power plant [7].

Also, Said M. A. Ibrahim in [8] conclude that, the output power and the thermal efficiency of the plant decrease by approximately 0.3929 and 0.16%, respectively, for 1°C increase in temperature of the condenser cooling water extracted from the environment. The impact of climate changes in condenser cooling water is an important design consideration when constructing PWR NPP.

5. Results and analysis

To optimize the required APR-1400 Condenser design based on El-Dabaa site, Egypt Conditions, we choose to compare between the two different APR-1400 Condensers (Barakah, UAE and Shin Kori, South Korea). But, the mean annual ambient temperature in the UAE is 28.0°C. The winter temperature regime is characterized by warm and sunny weather where daytime temperatures average 23.0°C, but the summer climate is characterized by high temperatures and high humidity. These summer air temperatures are often above 38.0°C, but during spells of high humidity the temperatures can be as high as 49.0°C. These temperatures can be even higher (over 50.0°C) in the northern part of the Gulf, making the region one of the hottest places on the globe. Humidity in coastal areas averages 50 to 60 percent, touching over 90 percent in summer and autumn transition months [7]. As Barakah, UAE is one of the hottest sites having a Nuclear Power Plant all over the world, so that a modification had been carried to the APR-1400 Condenser design to meet the requirements of performance and efficiency.

El-Dabaa site, Egypt seawater profile all over the year can be shown in figure 5, all the data was taken in the year 2011. From EL-Dabaa site seawater temperature profile we can find that, the maximum temperature is 29.57 °C and the minimum temperature is 16.14 °C. Then the input seawater temperature values which we will use in our study should to include the range between minimum and maximum temp. The input seawater temperature for Barakah and Shinkori APR-1400 Condencer model, based on El-Dabaa site, Egypt conditions are shown in Table II, taking into consideration that the APR-1400 thermal Power is 3987 MWth [4]

Table II: the input seawater temperature for Barakah and Shinkori APR-1400 Condencer model.

Month	Average Temperature °C
January	18.09
February	17.24
March	17.68
April	18.47
May	20.59
June	23.98
July	27.27
August	28.60
September	27.31
October	25.29
November	22.10
December	19.87
Minimum	16.15
Maximum	29.57

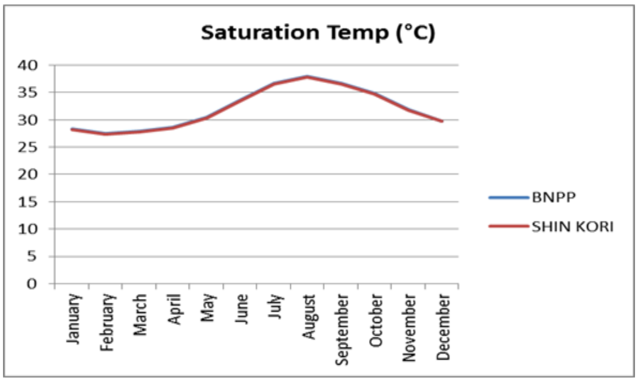

Fig. 6. Saturation Temperatures for Shinkori and Barakah APR-1400 condensers performances, based on El-Dabaa seawater temperature variation.

Based on EL-Dabaa site data, Figures 6, 7 shows the parameters: Saturation Temperatures and Cooling Water outlet temperatures respectively for Shinkori and Barakah APR-1400 condensers performances, which looks to be almost typically.

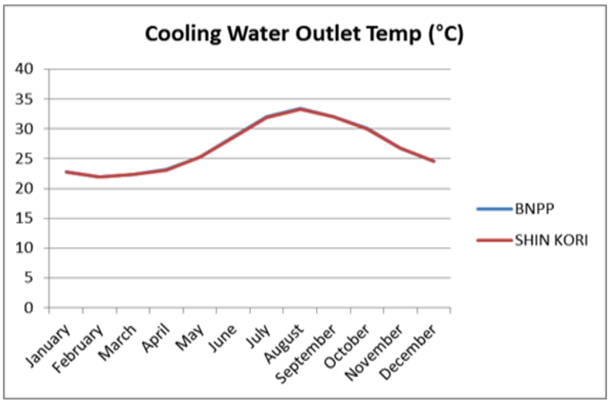

Fig. 7. Cooling Water outlet temperatures for Shinkori and Barakah APR-1400 condensers performances, based on El-Dabaa seawater temperature variation.

According to El-Dabaa site Conditions Figures 8, 9 represents the Shinkori and Barakah APR-1400 power variations and condensers pressure respectively.

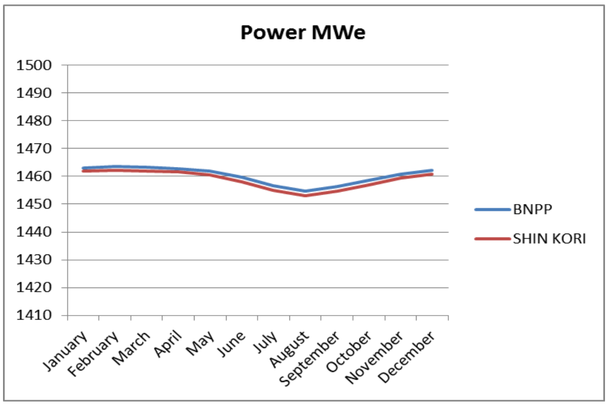

Fig. 8. Shinkori and Barakah APR-1400 power variations based on with El-Dabaa seawater temperature variation.

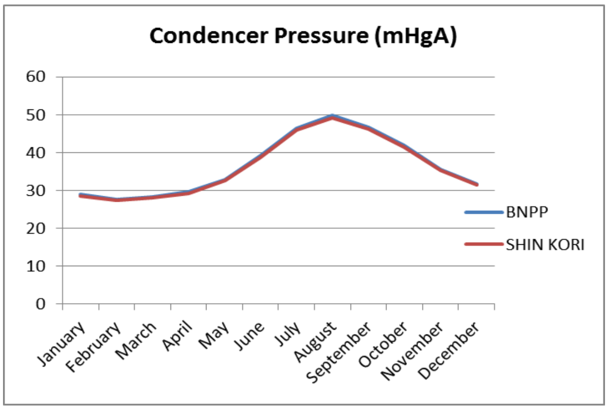

Fig. 9. Shinkori and Barakah APR-1400 condensers pressure based on El-Dabaa seawater temperature variation.

The overall efficiency of APR-1400 nuclear power plant variation all over the year for Shinkori and Barakah APR-1400 NPPs, according to El-Dabaa site seawater temperature exchange all over the year is represented in Figure 10.

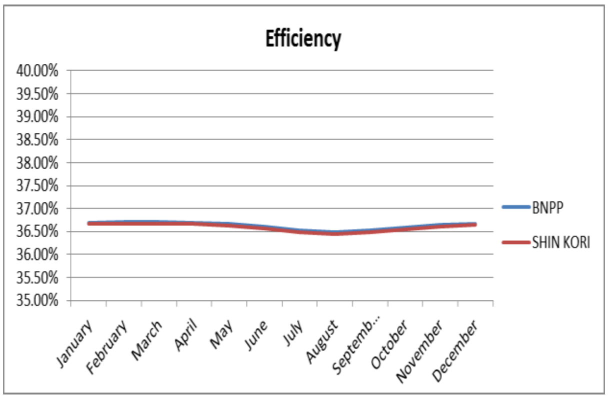

Fig. 10. Efficiency variation all over the year for Shinkori and Barakah APR-1400 NPPs, according to El-Dabaa site seawater temperature.

Table III, IV represent the output date for Shinkori and Barakah APR-1400 NPPs performances and the condensers parameters based on to El-Dabaa site seawater temperature, respectively.

6. Conclusion

As the climate conditions, especially the seawater temperatures (intake for the cooling system) having a direct effects on the condenser performance and the overall NPP Efficiency, we studied the seawater temperature change based on EL-Dabaa site conditions and it's feedback on the proposed APR-1400 condenser performance and the NPP efficiency.

All of the calculations and analysis had been executed by using KINGS NPA by applying EL-Dabaa seawater

Table III: Shinkori APR-1400 NPP performance and the condenser parameters based on to El-Dabaa site seawater temperature.

Month	El-Dabaa site, Ave Temp ℃	Power (MWe)	Condencer (mHgA)	Saturation temp (℃)	Cooling water outlet temp (℃)	APR-1400 Eff (%)
January	18.08	1461.88	28.634	28.123	22.728	36.67%
February	17.24	1462.3	27.391	27.362	21.881	36.68%
March	17.67	1462	28.036	27.761	22.32	36.67%
April	18.47	1461.67	29.223	28.475	23.117	36.66%
May	20.58	1460.5	32.62	30.384	25.238	36.63%
June	23.97	1458.11	38.845	33.476	28.631	36.57%
July	27.26	1454.88	45.982	36.529	31.937	36.49%
August	28.60	1453.09	49.28	37.8	33.289	36.45%
September	27.31	1454.62	46.139	36.591	31.99	36.48%
October	25.29	1456.88	41.561	34.69	29.95	36.54%
November	22.09	1459.5	35.274	31.76	26.751	36.61%
December	19.87	1460.92	31.417	29.728	24.517	36.64%
Minimum	16.1468	1463.2	25.867	26.386	20.784	36.70%
Maximum	29.5709	1451.85	51.423	38.59	34.207	36.41%

Table IV: Barakah APR-1400 NPP performance and the condenser parameters based on to El-Dabaa site seawater temperature.

Month	El-Dabaa site, Ave Temp ℃	Power (MWe)	Condencer (mHgA)	Saturation temp (℃)	Cooling water outlet temp (℃)	APR-1400 Eff (%)
January	18.09	1463.1	28.94	28.3	22.8	36.70%
February	17.24	1463.6	27.7	27.5	22	36.71%
March	17.68	1463.4	28.32	27.9	22.4	36.70%
April	18.47	1462.8	29.57	28.6	23.2	36.69%
May	20.59	1461.9	32.96	30.5	25.3	36.67%
June	23.98	1459.8	39.27	33.6	28.7	36.61%
July	27.27	1456.7	46.46	36.7	32	36.54%
August	28.60	1454.8	49.84	38	33.4	36.49%
September	27.31	1456.4	46.64	36.7	32.1	36.53%
October	25.29	1458.5	42.01	34.8	30.1	36.58%
November	22.10	1460.9	35.67	31.9	26.8	36.64%
December	19.87	1462.2	31.76	29.8	24.6	36.67%
Minimum	16.15	1463.7	26.24	26.6	20.9	36.71%
Maximum	29.57	1453.6	52.37	38.9	34.4	36.46%

temperature variations for the 2 types of APR-1400 Condensers (Shinkori, south Korea & Barakah, UAE), and the main findings were as follow:

For the APR-1400 condensers (Shinkori and Barakah) performance

- The average difference all over the year for saturation temperature, cooling water outlet temperature, and condenser pressure are 0.135℃, .05785 ℃, and 0.3948 mHgA respectively. This shows that the Barakah condenser performance is not significantly better than the shinkori condenser performance based on EL-Dabaa Conditions, especially if we considered the cost difference between the two condensers designs.

For APR-1400 NPPs (Shinkori and Barakah) net efficiency

- The average difference all over the year for the power productions and net efficiency are 1.4791 MWe and .00037 %, respectively. Which, shows that the Barakah condenser design is a bit better than the shinkori design based on EL-Dabaa Conditions, but not significant.

From our study we conclude that there is no big difference for APR-1400 condenser behaviour due to the climate change between EL-Dabaa site and Shinkori, hence for APR-1400 proposed in EL-Dabaa site we recommend Shinkori condenser.

ACKNOWLEDGEMENTS

This research was supported by the 2015 research fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

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