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Orignal Article

CSP Integrated Solar Combined Cycle Simulation

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KEYWORDS

CSP Solar
HTFs
LCOE
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ABSTRACT

This research highlights the simulation of CSP integrated solar combined cycle 50kW capacity coupled with two heating transfer fluids (HTFs) in Riyadh, Saudi Arabia. The case study also reported unprecedented results of which is the most viable system among two cases with the help of comparative analysis between two salts. Financial parameters in case of selected site helped to create the holistic financial model as well. This study shows the prospects of gas turbine integration with CSP to achieve higher energy output and lower Levelized cost of energy LCOE.

1. Introduction

Over the last decade the price of solar power has gone down dramatically [1-3]. The cost of solar resources has decreased on the face of it; however, it still poses challenges to lower its unit price than other traditional conventional means of generating electricity. Thus, the government support is must-have requirement in terms of incentives and subsidies which has become inevitable. Renewable energy standards and tax credits are essential to promote its advantages [4-6]. Considering the significance of renewables, one technology is better positioned with integration of natural gas and that is concentrating solar power (CSP) which is type of system that utilizes the solar energy with make use of heliostats, parabolic through collector systems. Although, there are four major CSP technologies (1) linear Fresnel (2) parabolic trough (3) dish/engine (4) power tower. The fourth one has been dealt in this research. Concentrating solar power technology leads to the power generation by converging the solar irradiation or beam of light to concentrate it at a point of moving working fluid cycle [7-9]. In this paper, the combined natural gas power plant is integrated with concentrated solar heliostat tower solar system which is utilizing two salts 60% NaNO3 40% KNO3 and 46.5% LiF 11.5% NaF 42% KF to discern the efficacy of whole system. The research stretches over the designing and selecting the site, heliostat field, receiver, and tower parameters along some technical key aspects like inflation rate, debt amount, purchase of land, discount rate. After designing the primary factors, technical and financial feasibility is observed for a specific site while simulating for results with the help of SAM which refers to system advisory model created by NREL National renewable energy laboratory.

2. Research Methodology

In this paper, a combined natural gas power plant is integrated with a concentrated solar heliostat tower solar system. This system utilizes two types of salts: 60% NaNO3 and 40% KNO3, as well as 46.5% LiF, 11.5% NaF, and 42% KF to determine the efficacy of the entire system. The methodology adopted for designing and simulating the location is software comparative based. Computer models are being generated for CSP integrated solar combined cycle 50 kw capacity.

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3. Result and discussion

Using - Salt 60% NaNO3 40% KNO3:

The research could be generated on the basis of the comparative analysis by using different salts but we have primarily used two salts for the system design of CSP integrated with gas turbines. A mixture of 60% sodium nitrate and 40% potassium nitrate is being used for the study of ISCC mainly focused for households or remote islands power generation.

Table.1. Weather and location details

Header Data from weather file		Annual Average Calculated from Weather File Data	
City	Riyadh	Global horizontal	6.29 kWh/m^2/day
State	Riyadh	Direct normal beam	6.46 kWh/m^2/day
Country	KSA	Diffuse horizontal	1.99 kWh/m^2/day
Time zone	GMT 3	Average temperature	26.1 C
Elevation	618 m	Average wind speed	3.8 m/s
Data source	NSRD8		
Latitude	24.674 N		
Longitude	46.719 E		
Station id	Omar		

Table.2. Heliostat framework designing & Field coordinated selection [10-12]

Heliostat Properties		Heliostat Operation	
Heliostat width	12.2 m	Heliostat stow/deploy angle	8 deg
Heliostat height	12.2 m	Wind stow speed	15 m/s
Ratio of reflective area to profile	0.97	Heliostat startup energy	0.025 kWe-hr
Single heliostat area	144.375 m^2	Heliostat tracking power	0.055 kWe
Image error (slope, single-axis)	1.53 mrad	Design-point DNI	950 w/m^2
Reflected image conical error	4.32749 mrad		
Number of heliostat facets - X	2		
Number of heliostat facets - Y	8		
Heliostat focusing method	Ideal		
Heliostat canting method	On-axis		
Solar Field Layout Constrains		**Land Area**	
Max. heliostat distance to tower height ratio	8.5	Non-solar field land area	0 acres
Min. heliostat distance to tower height ratio	0.75	Solar field land area multiplier	1
Tower height	120.231 m	Base land area	296.71 acres
Maximum distance from tower	1021.96 m	Total land area	297 acres
Minimum distance from tower	90.173 m	Total heliostat reflective area	28,009 m^2

Atmospheric Attenuation		Mirror washing	
Polynomial coefficient 0	0.006789	Water usage per wash	0.70 L/m^2,aper.
Polynomial coefficient 1	0.1046 1/m^2	Washes per year	63
Polynomial coefficient 2	-0.017 1/m^2		
Polynomial coefficient 3	0.002845 1/m^2		
Average attenuation loss	5.8 %		

Table 1&2 shows the input parameters used for the designing of the Heliostat field with width and height of 12.2m. And the 'Heliostat stow' is an important parameter in power generation cycle and it describes the angle of heliostat in which it is deployed and the wind stow seep taken is 8m/s which is its average value for the location site selected i.e Riyadh Saudi.

DNI is the direct normal irradiance received normal to the sun over the whole surface area of the heliostat and this comes out to be 950 W/m2 for the Riyadh based site. So, to make the system design feasible and economical for any concentrating solar power technology we have to select those sites for analysis which receives maximum DNI (Direct Normal Irradiance) in W/m2 from the solar and this could be affected by atmospheric conditions. Studies revealed that on the clear and sunny days, atmospheric conditions can reduce direct beam radiation by 10% and incase of thick, cloudy days it could resist direct beam conditions by 100%. In other words, Studies have shown that on clear and sunny days, atmospheric conditions can reduce direct beam radiation by 10%, and on thick, cloudy days, it can completely block direct beam radiation.

Table.3. shows the no. of heliostat panels selected for the system capacity of 50KW which is 194 with the help of heliostat modelling calculations, and it is optimized automatically by the solar geometry field facility, resulting a feasible system design for ISCC. This also facilitates us by measuring the Tower and receiver parameters according to the power generation capacity of the plant such as the tower height, receiver height and the diameter of the tower.

Fig.1. at the bottom of the page tells us about the optimum efficiency of receiver heat transfer fluid HTF pump which is the default value for any system design irrespective of its capacity. Also, we have adjusted the receiver thermal power generated with the help of heliostats and the tower.

Table.3. Describe the no. of heliostat panels selected for the system capacity of 50KW [13]

Minimum receiver turndown fraction	0.25
Maximum receiver operation fraction	1.2
Receiver startup delay time	0.2 hr
Receiver startup delay energy fraction	0.25
Receiver HTF pump efficiency	0.850
Maximum flow rate to receiver	2.00895 kg/s
Receiver design thermal power	0.1 MWt

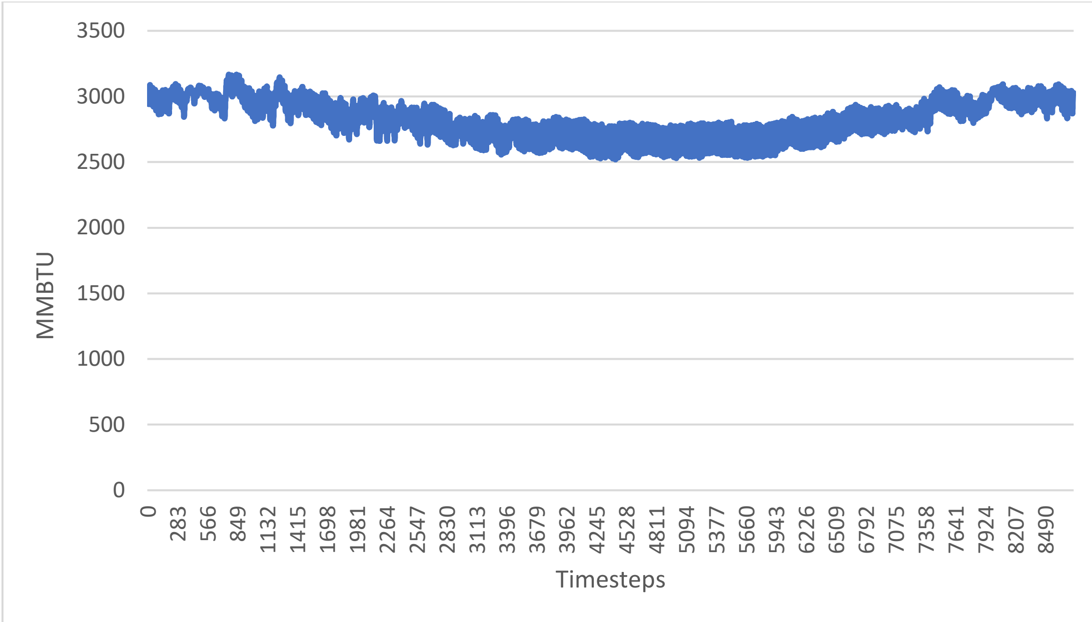

Figure.1. Cycle natural gas used during timestep

Fig.2. shows the relationship between the timesteps and the MMBTU. Timesteps is an incremental change of time in which the data is being analyzed and during that period the boundary conditions and the variables are held constant. To analyze data at microscopic level, it is recommended to take small timesteps for system design. Whereas the MMBTU stands for the metric million British thermal unit and it is the amount of energy required to raise the temperature of one pond of water by one Fahrenheit but it is being used as a measure of natural gas in our case. Furthermore, this graph explains us about the cycle natural gas generation with the increment in time i.e. timesteps and this remains approximately constant which shows a constant behavior of gas turbine working.

Fig.3. signifies the relationship between the Annual Power generation of the cycle and the timesteps. Annual power generation is about 48,0378 KWt in the year 1 of the cycle which is very close to the max capacity generation of the plant that is due to some heat and miscellaneous losses.

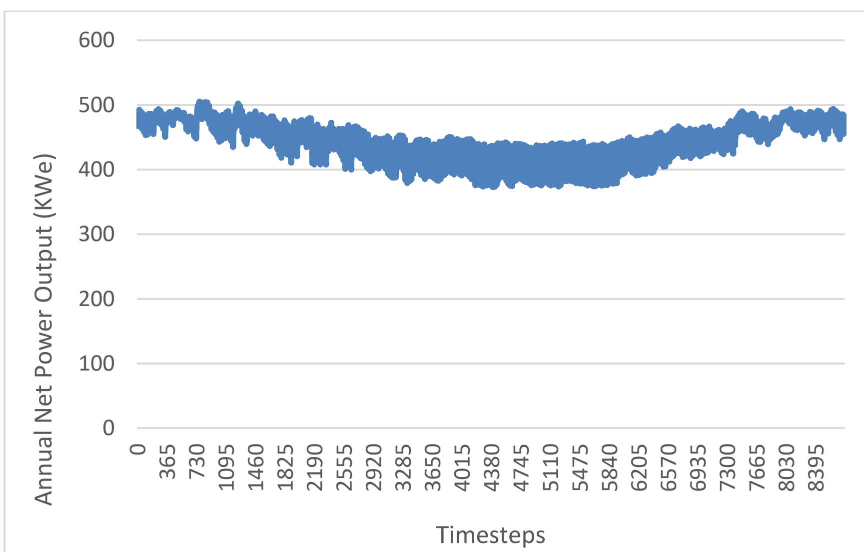

Figure.3. Cycle Net Power Output

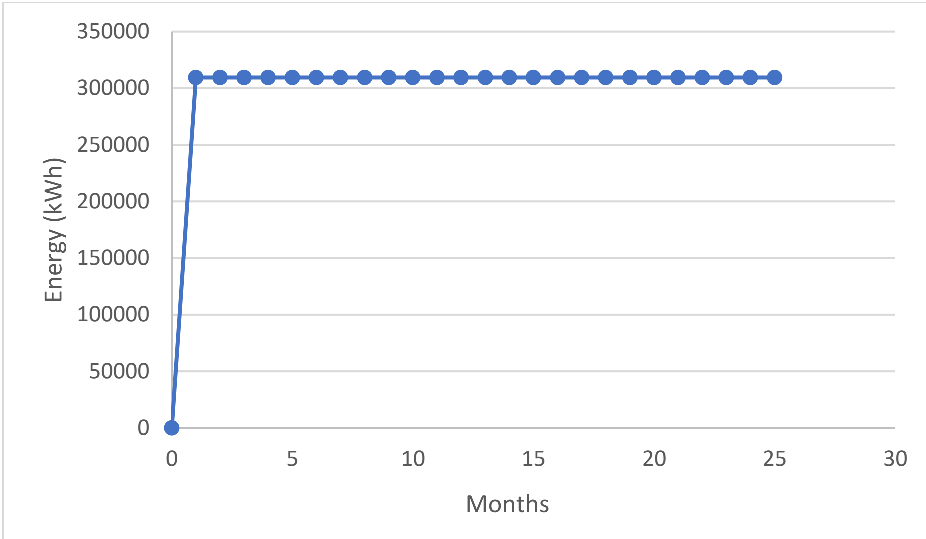

Figure.4. Energy (kWh)

Fig.4. represents a relationship between the energy production in KWh and months and it's a straight line that explains that the energy production remains constant with the increment in time. The graph goes linear and then it becomes straight means in the first 2 months the plant capacity is being raised to its maximum value which is 309,440 KWh and then it generates the constant energy with Degradation Value of 0%. Degradation Value is the time in which the plant takes power when it is not operating so this value is considered to be 0% because CSP systems give very negligible degradation value at whole.

Fig.5-6. represents the Line chart for system cycle power generation over a period of time and it depends on the weather conditions, the site chosen for analysis as well as on the system losses and HTF used in the tower but on average it is showing a maximum power generation thus explains about the feasibility of the project.

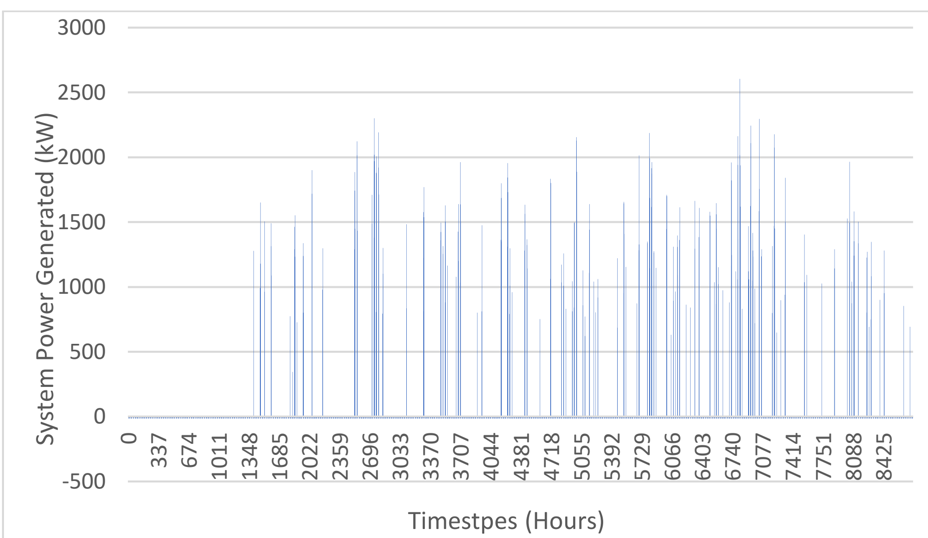

Figure.5. System generated power (kW)

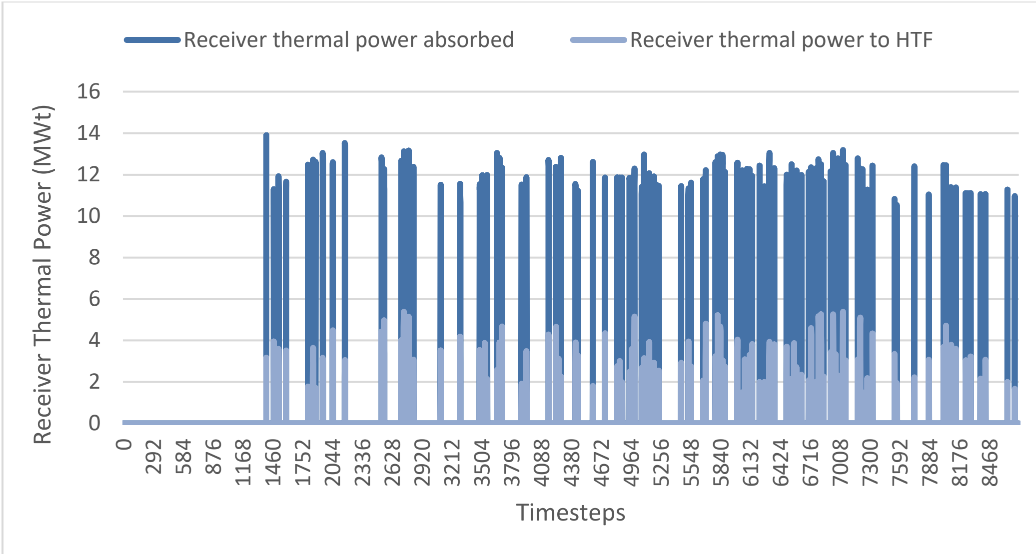

Figure.6. Receiver thermal power (MWt)

<u>Using - Salt 46.5% LiF 11.5% NaF 42% KF:</u>

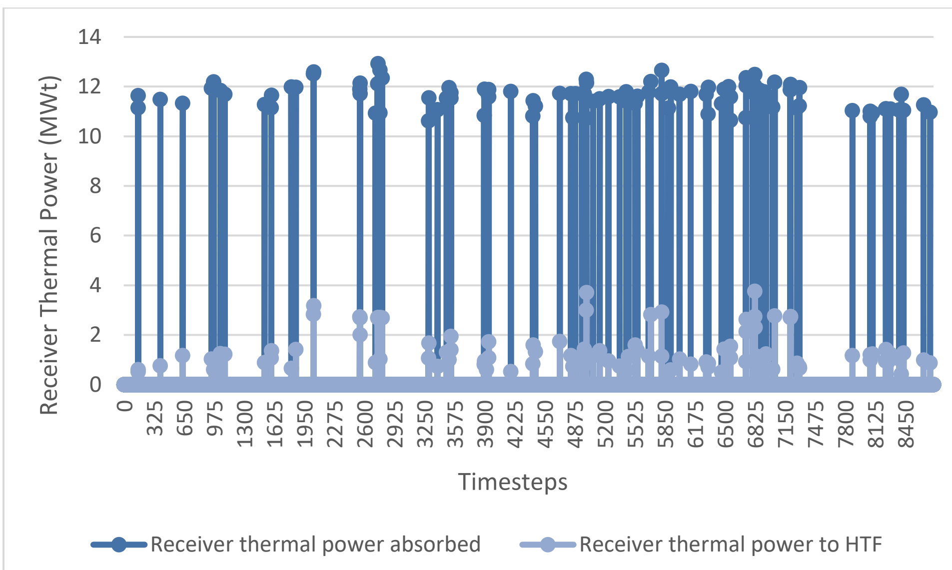

Figure.7. Receiver Thermal power

Fig.7. represents the relationship between the receiver thermal power extracted from the solar (Dark Blue line) and the receiver thermal power absorbed (Light Blue line). Receiver thermal power is always larger because this is the energy directly extracted from solar power than the power which it actually transfers to the heat transfer fluids (HTF's).

The fluid used for the 2nd case analysis is a solution of 46.5% lithium fluoride, 11.5% sodium fluoride and 42% potassium fluoride. An abrupt behavior in the receiver thermal power transferred to HTF under the same parameters chosen for the case analysis 1 when HTF 2 is selected. This intermittent behavior in power cycle generation as shown in figure 10 at the end of the combined cycle of ISCC shows that the chosen fluid for 2nd case analysis is not an ideal choice for the chosen site

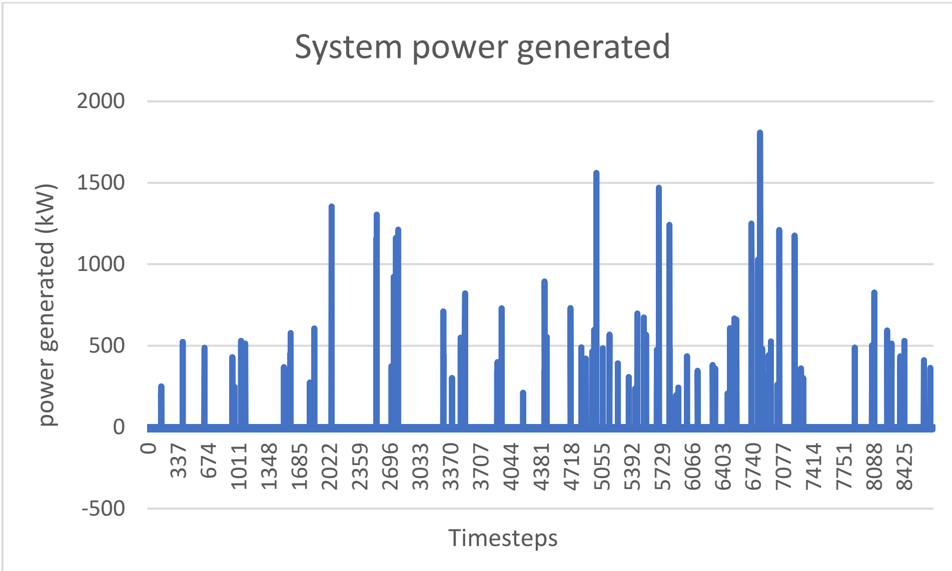

Figure.8. System Power Generated

Combined results are represented in fig.9-10 to discern the most suitable system to consider of CSP integrated solar combined cycle. Results manifested that system one has higher energy output in terms of kWh and lower LCOE and thus proved to be efficient and pertinent to be selected in case of Riyadh, Saudi Arabia.

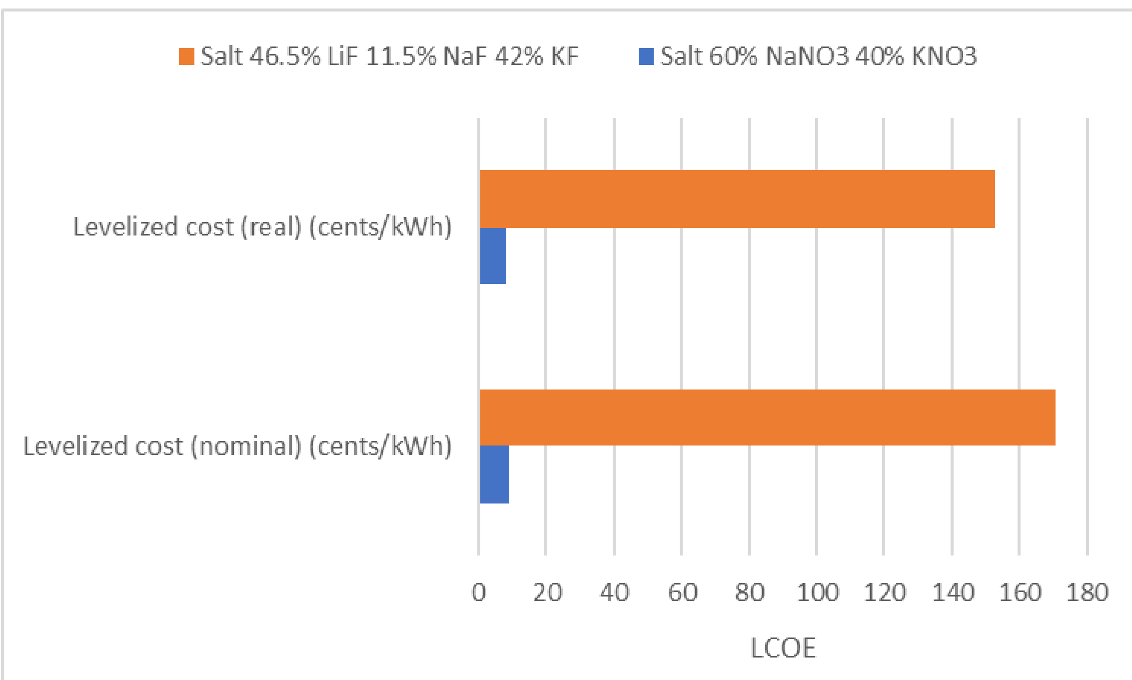

Figure.9. Both Fluids' Leviliezed Cost

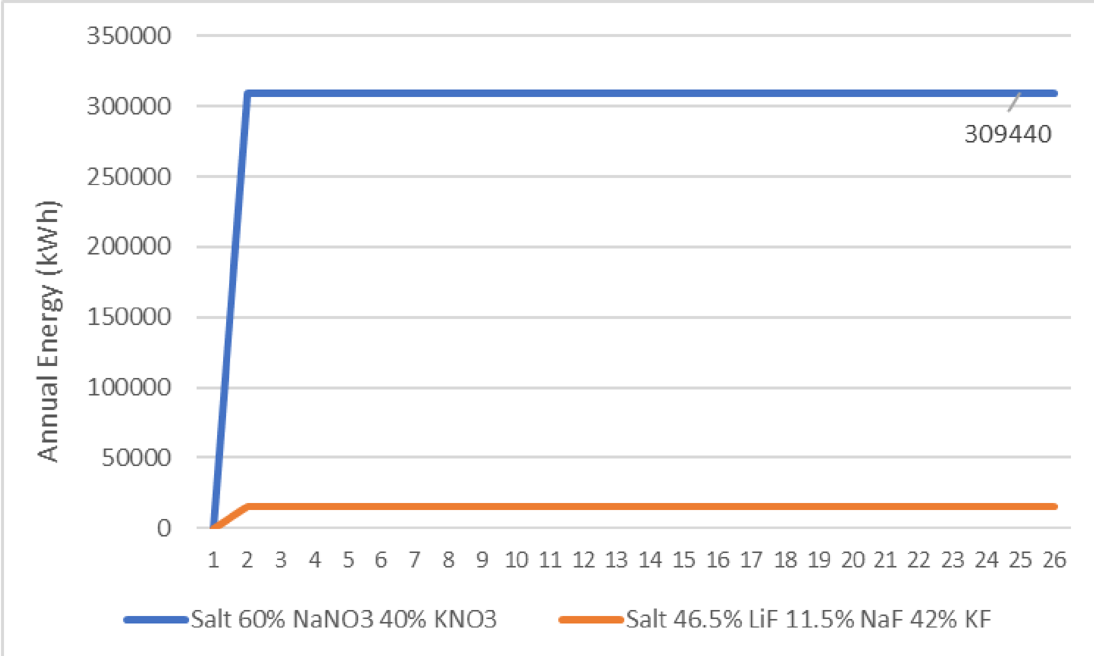

Figure.10. Both Fluids' Annual Energy

4. Conclusion

This research reported the substantial analysis of CSP integrated solar combined cycle with total capacity of 50kW. Tower receiver CSP technology is taken to account to observe the most appropriate system out of two in case of Riyadh, Saudi Arabia considering meteorological wind and solar data on SAM. SAM is assessment tool which inputs the technical, financial and climatological parameters for the appraisal of most efficient system and was used to do the comparative analysis. Financial model has also been formulated which take values like debt interest, inflation and discount rates, system and land cost as input to find the LCOE, IRR, NPV of either system. Results were inconspicuous and unprecedented which observed the viability with case-1 refers to Salt 60% $NaNO_3$ 40% KNO_3 as opposed to the second case-2 which refers to Salt 46.5% LiF 11.5% NaF 42% KF after observing the LCOE and Net power output by systems.

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