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# Experimental Investigation of Various Cooling Techniques for Enhancing Solar Cells Efficiency

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**Abstract**.

This paper presents a field study for the effect of an active water cooling on the performance of photovoltaic system. Three systems each of 1 $m^2$ commercial mono-crystalline PV panels have been installed on the rooftop of the high institute of engineering in culture and science city at 6 October city in Cairo, Egypt (29.9N Latitude). Two of the systems are cooled using two different geometries of copper pipes(serpentine shape and a novelty structure rectangular helical shape) are attached in the backside of the PV module to allow water flowing below it using three different of flow rates (2,4 and 6 L/min) and compared with the uncooled panel. The results illustrate that arise in average electrical efficiency from 8.54% to 10.88% with performance improvement percentage 27.4% at 6 L/min flow rate. The average electrical efficiency increases from 8.54% to 10.17% for serpentine shape and 8.54% to 10.88% for rectangular helical shape at 6 L/min.

## 1. INTRODUCTION

In the context of greenhouse gas emissions and fossil resources depletion, solar energy is one of the most promising sources among renewable energy sources. Nowadays, electricity generation from solar energy is very attractive in Egypt due to the recent regulation laws about renewable energy usage. A Lot of work has been carried out on solar cells to obtain the maximum possible power[1]. Cooling can enhance the electrical generation of PV module performance. The heat rejected by PV cooling systems can be utilized for building heat, or in modern applications.

A brief review of some results is presented in this section. Bahaidarah et al[2], investigated experimentally and numerically by using EES software program the effect of cooling the module by mounting a heat exchanger (cooling panel) at the back surface of the PV module. Numerical model results are found to be in a good agreement with the measurements of the experimental results. An increasing in the PV module efficiency by 9% with active water cooling when the module temperature decreased significantly to about 20%.

Abdul Hai Alami et al [3], incorporated a layer of synthetic clay to the rear surface of PV module as a novel passive evaporative cooling technique to allow a thin film of cold water to evaporative through this layer. The results illustrate that this method will reduce the PV module temperature, maximum increase of output voltage about 19.4% and output power about 19.1%, this feasibility is more effective and environmentally friendly.

K.A. Moharram et al [4], a water cooling system is studied to improve the performance of PV module experimentally and theoretically. In order to calculate the time, it takes to cool down the temperature of the PV module, a mathematical model had been developed. The results show that the highest output energy can be achieved when PV module temperature reaches to max allowable temperature (MAT) of 45°C, more than this degree the PV module needs for cooling.

H.G. Teo et al [5], optimized the efficiency of PV/T system from 8-9 % to 12-14% by active cooling. The results achieved for a PV/T system experimentally and by conduct a simulation model. Incorporated a parallel array of ducts works as a heat exchanger device attached at the back surface of PV/T modules. The results show that decreasing the temperature of modules that will increase the efficiency linearly.

M. Rosa-Clot et al [6], An experimental study for a photovoltaic (PV) panel submerged in water. An increasing of electric power output is observed for shallow water. Experiments have been conducted for single crystalline silicon panels. Results demonstrate an increasing in efficiency. Operating problems are discussed and the advantages of using underwater solar panels are represented.

Azadeh Kordzadeh et al [7], investigated an experimental study to decrease the PV module temperature using water pump which, serves as the source of cooling water to the module. With an observation of results the PV module and the overall efficiency improved.

M. Abdolzadeh et al [8], investigated an improvement of the performance of a photovoltaic water pumping system. A spraying water over the photovoltaic cells is performed. The experimental results show that the power of PV module increased because of spraying water over the photovoltaic cells. This can optimize the system and subsystem efficiency and the pump flow rate when operating under different heights. Experiments of the short circuit current of the module in depend on module temperature. The results indicated that the water spray optimized the system performance.

L. Dorobanțu et al [9], demonstrated an decreasing of overheating for PV module by running water at the surface of the panel. The dirt deposit on the surface of the panel can be washed away by the free running water. The results presented 8.4% increase in the power output, without considering the quantity of used pump water for cooling.

Amorhossein Fathi et al[10], investigated an experimental study of PV system with and without coolant system for the back surface of PV panels. This cooling system increased the electrical efficiency and improved preheated water at uniform surface temperature. A comparison conducted between two types of PV modules (single mono-crystalline and a poly-crystalline). The results show an optimization in electrical, thermal and overall efficiencies to 12.3%, 49.4% and 61.7% respectively. The system consists of PV, cooling water system and solar water heater.

M. Rajvikram et al[11], an experimental study for PV panel system with and without cooling techniques has been investigated. An annotated PCM (phase change material) with aluminum sheet studied as a one of new techniques to improve the efficiency of PV modules. Focus on 2 days measurements using two 5W panels under direct sun rays. The results show an improving in the conversion efficiency by an average of 24.4% with decreasing in module temperature about 10.35ºCand increasing by 2% in electrical efficiency. An infra-red camera used to observe the decreasing of temperature.

Three monocrystalline photovoltaicmodules are used in this study. The first PV cell is without cooling, while the two others with cooling with difference heat exchangers (serpentine, and rectangular helical shapes) as shown in figs (1)and (2) by using an active water-cooling system. Details of these setup design, materials, and measuring instruments used in this study as well as the methodology.

## 2. Experimental set-up

To investigate cooling effect on the monocrystalline Photovoltaicmodules performance, test set up is built on the rooftop of the high institute of engineering in culture and science city at 6 October city in Cairo, Egypt. This has been carried out during June2019 where, the data is collected daily at an interval of every thirty minutes, from 8 am until 4 pm.

During the operation, solar radiation is measured by using a digital solar power meter, which is put at the same level as the solar panels. Temperature measurements are important in these experiments so, the temperature of the lower surfaces is measured by using calibrated K type Thermocouple. There are sixteen thermocouples in each PV cell are attached to the back of the cell between the steel sheet and the cell in an array shown in fig (3).The output signal of the thermocouples transferred to DACs to store its data in the lap top. The PV current and PV voltage are collected during the operation of system to calculate the power output from the PV modules. All the experimental test rig components that used have been calibrated. Table (1) shows the installation conditions of the experimental setup. A

General view of the complete experimental set-up is shown in fig (4).

**Table .1** Installation condition of the experimental setup.

| Location | 6 October city, Cairo, Egypt |
|---|---|
| Latitude | 29.952654 |
| Longitude | 30.921919 |
| Tilt angle | 30° |
| Orientation | South |

**Fig. 1 .** A serpentine shape of copper tube.

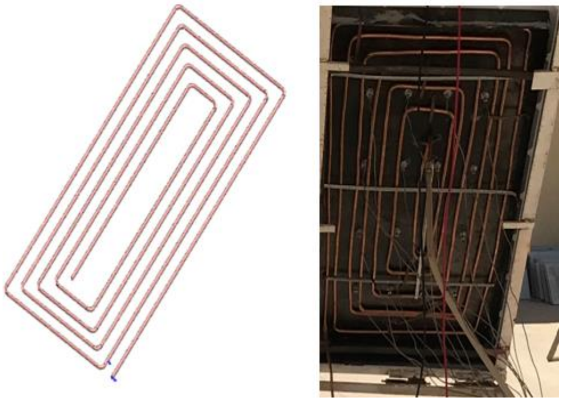

**Fig. 2 .** A rectangular helical shape of copper tube.

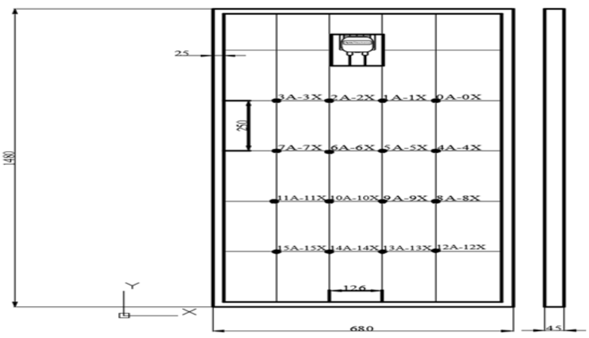

**Fig. 3 .**Thermocouples distribution at the back surface of the PV cell.

**Fig. 4.**Photograph of the experimental system.

## 2.1 Photovoltaic cooling system description

In the present study two identical systems are established using different heat exchanger at the back surface of the PV module. The experimental setup schematic drawing is shown in fig (5).Table (2) Represents the components of the system.

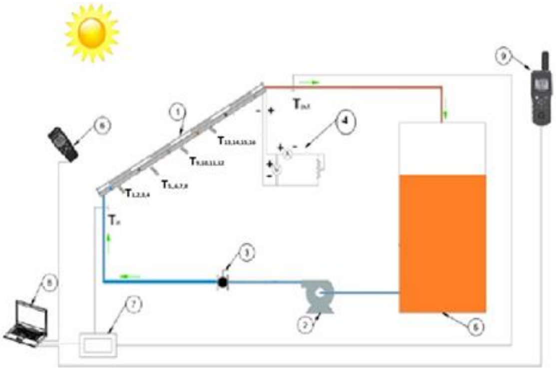

**Fig. 5.** Schematic drawing of the experimental setup PV cooling system.

**Table .2** system components.

| Component number | Component type |
|---|---|
| 1 | PV test module with cooling pipes |
| 2 | Ac pump |
| 3 | 1/2" Throttling valve |
| 4 | Digital millimeters |
| 5 | 170 liters tank |
| 6 | Digital solar power meter |
| 7 | 16 Bit data acquisition |
| 8 | Lap top |
| 9 | Environmental meter |

## 2.2 Methods of calculations

After plotting the characteristic curve at each time and knowing the values of optimum voltage and current, the following equations are used to analyze the characteristics and performance of the three photovoltaic cells.

- $P_{in} = I_t * A$ (1)
- $P_{pv} = Voltage * Current$ (2)
- $P_{max} = V_{opt} * I_{opt}$ (3)
- $\eta_c = {P_{max}}/{P_{in}}$ (4)
- $\mathrm{P_{increase}} = \frac{\mathrm{P_{cooled}} - \mathrm{P_{ref}}}{\mathrm{P_{ref}}} * 100\%$ (5)
- $Performance\ improvement\ (\%) = \frac{\eta_{PV/T} - \eta_{PV}}{\eta_{PV}} * 100$ (6)

## 3. Results and discussions

The present measurements were carried out through of June 2019 and three different volume flow rates 2,4, and 6 L/min. When the flow rate was 2 L/min and the total solar radiation is **700.88** W/m$^2$, the average output power from the first PV/T system (serpentine shape) during the day is**61.93** W with **10.02** % higher than PV module (without cooling), which records **56.28** W and the average output power from the second PV/T system (rectangular helical shape) during the day is **64.93**W with **15.36**% higher than PV module. The average value of electricity generation efficiencies of first PV/T, second PV/T and PV systems during the daytime are found to be **9.01** %, **9.44** %, and**8.25** % respectively. Fig (6) represents the variation of the output power from PV/T systems and PV module during the daytime at 2 L/min,fig(7) represents the variation of electrical efficiencies of the PV/T systems and PV module during the daytime at 2 L/min and fig (8) represents the variation of the performance improvement percentage in the electrical efficiency of the PV systems during the daytimeat2 L/min.

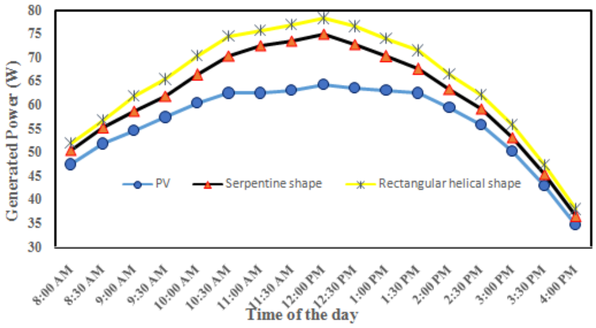

**Fig. 6.**Generated Power by PV/T systems and PV module at 2 L/min

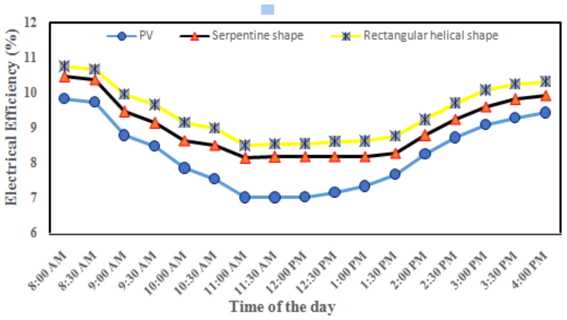

**Fig. 7.** Comparison of photovoltaic efficiencies of the PV/T and PV modules during the daytime at 2 L/min.

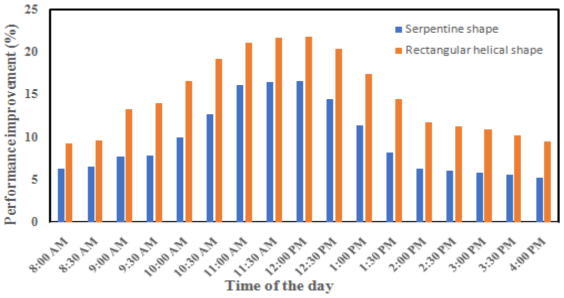

**Fig. 8.** Performance improvement in the electrical efficiency for PV/T systems due to water-cooling at 2 L/min.

When the flow rate was 4 L/min, and the total solar radiation is **679.94** W/m$^2$, the average output power from the first PV/T system (serpentine shape) during the day is **64.12**W with **15.19** % higher than PV system (without cooling), which records **55.67** W and the average output power from the second PV/T system (rectangular helical shape) during the day is **67.57**W with **21.38** % higher than PV system. The average value of electricity generation efficiencies of first PV/T, second PV/T and PV systems during the daytime are found to be **9.68** %, **10.21** %, and **8.33** % respectively. Fig (9) represents the variation of the output power from PV/T systems and PV module during the daytime at 4 L/min, fig (10) represents the variation of electrical efficiencies of the PV/T systems and PV module during the daytime at 4 L/min and fig(11) represents the variation of the performance improvement percentage in the electrical efficiency of the PV systems during the daytime at 4 L/m.

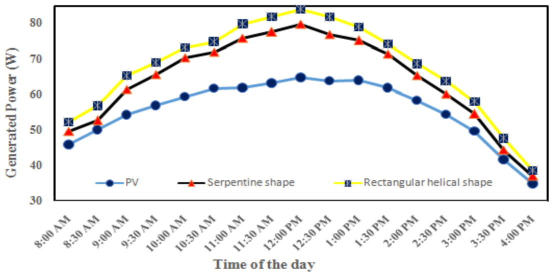

**Fig. 9.** Generated Power by PV/T systems and PV module at 4 L/min

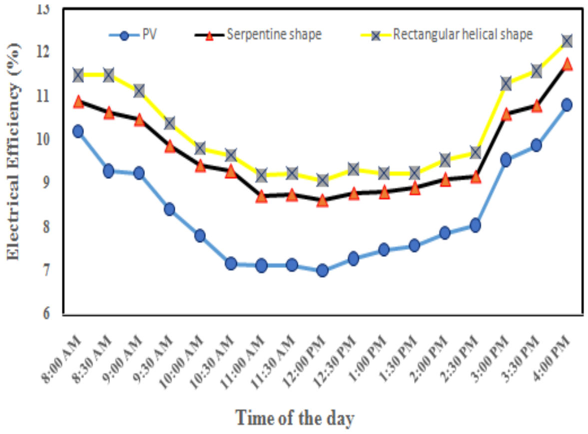

**Fig. 10.**Comparison of photovoltaic efficiencies of the PV/T and PV modules during the daytime at 4 L/min

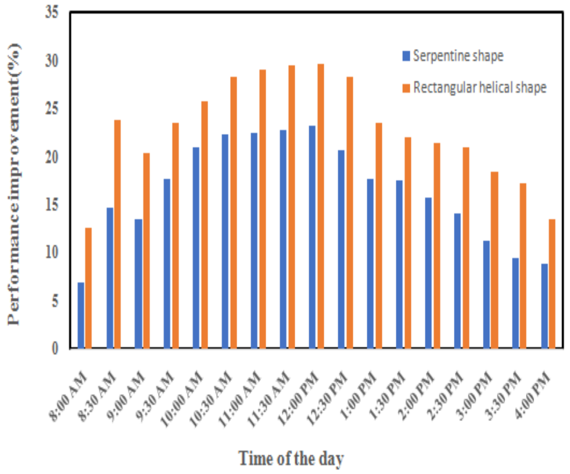

**Fig. 11 .** Performance improvement in the electrical efficiency for PV/T systems due to water-cooling at 4 L/min.

When the flow rate was 6 L/min, and the total solar radiation is **670.58** W/m$^2$, the average output power from the first PV/T system (serpentine shape) during the day is **66.85**W with **20.19** % higher than PV system, which records **55.62** W and the average output power from the second PV/T system (rectangular helical shape) during the day is **71.45**W with **28.46** % higher than PV system. The average value of electricity generation efficiencies of first PV/T, second PV/T and PV systems during the daytime are found to be **10.17** %, **10.88** %, and **8.54** % respectively.

Fig (12) represents the variation of the output power from PV/T systems and PV during the daytime at 6 L/min, fig (13) represents the variation of electrical efficiencies of the PV/T systems and PV module during the daytime at 6 L/min and fig (14) represents the variation of the performance improvement percentage in the electrical efficiency of the PV systems during the daytime at 6 L/min.

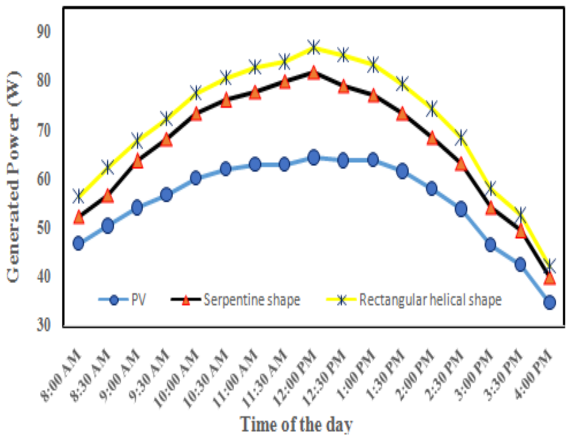

**Fig. 12 .** Generated Power by PV/T systems and PV module at 6 L/min.

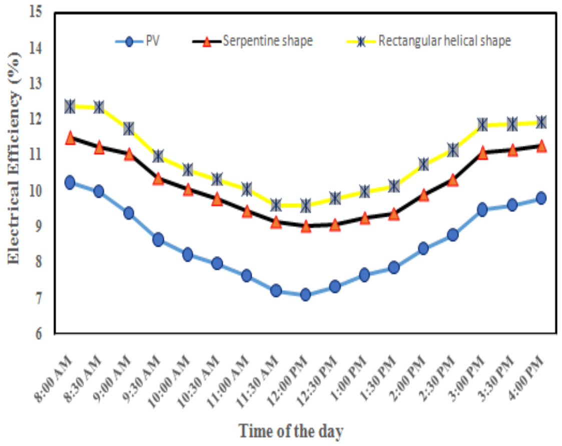

**Fig. 13 .** Comparison of photovoltaic efficiencies of the PV/T and PV modules during the daytime at 6 L/min.

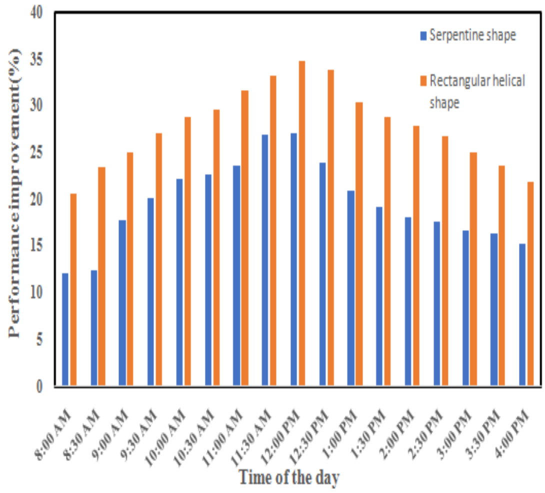

**Fig. 14.**Performance improvement in the electrical efficiency for PV/T systems due to water-cooling at 6 L/min

From figs (6),(9) and (12), we can notice that, the variation of the electricity generation in these figures has similar trend of solar radiation and the maximum values of electricity-generated rates from PV and PV/T systems occur at time between 12:00 and 12:30 pm. The results show that PV/T systems can produce more electricity than PV module because the output power of the PV/T systems increases with the decrease of the module surface temperature.

These results will reflect on the electrical efficiency as shown in figs (7), (10) and (13) which represents the variation of electrical efficiencies of the PV/T systems and PV module during the daytime at different flow rates. It can be noticed that, the PV/T systems has higher efficiency than PV module due to cooling. On the other hand, figs (8), (11) and (14) represents the variation of the performance improvement percentage in the electrical efficiency of the PV systems during the daytime at different volume flow rates.

From these figures, it can be noticed that, the maximum performance improvement occurred during the peak operating hours of the day from 11.00 am to 2.00 pm because of the low temperature of the PV/T systems due to cooling compared with the PV module where, its temperature is high because of high solar radiation. At 2 L/min water flow rate, the maximum performance improvement in the first PV/T system (serpentine shape)is **16.66** % at 12:00 pm where, the values of the electric efficiency of the first PV/T system and PV module are 8.19 % and 7.02%, respectively and the maximum performance improvement in the second PV/T system (rectangular helical shape)is **21.79** % at 12:00 pm where, the values of the electric efficiency of the second PV/T system and PV module are 8.55 % and 7.02 %, respectively.

While, at 4 L/min water flow rate, the maximum performance improvement in the first PV/T system (serpentine shape)is **23.14** % at 12:00 pm where, the values of the electric efficiency of the first PV/T system and PV module are 8.62 % and 7 %, respectively and the maximum performance improvement in the second PV/T system (rectangular helical shape)is **29.57** % at 12:00 pm where, the values of the electric efficiency of the second PV/T system and PV module are 9.07 % and 7%, respectively. While, at 6 L/min water flow rate, the maximum performance improvement in the first PV/T system (serpentine shape)is **27.18** % at 12:00 pm where, the values of the electric efficiency of the first PV/T system and PV module are 9.03 % and 7.1 %, respectively and the maximum performance improvement in the second PV/T system (rectangular helical shape)is **34.92** % at 12:00 pm where, the values of the electric efficiency of the second PV/T system and PV module are 9.58 % and 7.1%, respectively.

## 4. Conclusions

This study investigated experimentally the effect of active water cooling on the PV module for improving the electrical performance is examined under real outdoor conditions of 6 October city - Cairo-Egypt. The main conclusions from the obtained results in this study are as follow:

1. It is found that, without active water-cooling, the temperature of the PV module is higher during daytime and solar cells could only achieve around **8%** electrical efficiency. On the other hand, when the PV module is operated with active water-cooling condition, the temperature dropped significantly, leading to an increase in the electrical efficiency of solar cells as much as **10.17%** in the first PV/T system (serpentine shape) and**10.88%** in the second PV/T system (rectangular helical shape) when the flow rate was 6 L/m.
2. It is observed that, water flow rate is effective on the increasing the electrical efficiency where, the maximum performance enhancement occurs at 6 L/m water volume flow rate.
    - When the flow rate was 2 L/min, the performance improvement in the electrical efficiency in the first PV/T system (serpentine shape) and in the second PV/T system (rectangular helical shape) are **9.21%** and **14.42%** respectively.
    - When the flow rate was 4 L/min, the performance improvement in the electrical efficiency in the first PV/T system (serpentine shape) and in the second PV/T system (rectangular helical shape) are **16.20%** and **22.56%** respectively.
    - When the flow rate was 6 L/min, the performance improvement in the electrical efficiency in the first PV/T system (serpentine shape) and in the second PV/T system (rectangular helical shape) are **19.08%** and **27.4%** respectively.

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## Nomenclature

| | |
|---|---|
| $(A)$ | Module surface area$(m^2)$ |
| $(I_{opt})$ | Optimum module current (Amps) |
| $(I_{Sc})$ | Short circuit current (Amps) |
| $(\mathrm{P_{cooled}})$ | Cooled module output power (W) |
| $(P_{in})$ | Incident solar radiation on the cell (W) |
| $(P_{max})$ | Maximum module output power (W) |
| $(P_{pv})$ | Module output power (W) |
| $(\mathrm{P_{ref}})$ | Reference module output power (W) |
| $(V_{oc})$ | Open circuit voltage (Volt) |
| $(V_{opt})$ | Optimum module voltage (Volt) |
| $(\eta_c)$ | Module electric efficiency (%) |