Modelling of Solar Absorption Cooling System under Egypt Climate Using TRNSYS

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Abstract: - Solar energy has a great ability in cooling and air conditioning as the demand for cooling and air conditioning coincides with the availability of solar energy. In this study, the performance of a single stage LiBr/H_2O solar absorption cooling system was investigated under different a climate of Egypt. Four Egyptian cities with different climates were selected for the investigation. The selected cities are Al_Arish, Cairo, Assuit and Aswan. The thermal performance of the solar absorption cooling system was investigated in terms of the collector temperature rise, the rate of energy gained and the coefficient of the performance COP of the absorption machine. The results for Aswan give the better performance compare to the other selected cities. Where, the temperature rise of the collector, the rate of energy gained from and the COP of the absorption machine are 28.5 C, 97.4 kW, respectively. The effect of the collector area was studied on the exit fluid temperature from the solar collector for Cairo and Aswan. The maximum outlet temperature increases from 107.5 to 148.9 ºC with increasing the collector area from 40 to 180 m^2 for Cairo. While, the outlet temperature increases from 143.4 to 176.2 ºC with increasing the collector area from 40 to 180 m^2 for Aswan. This study was performed using the TRNSYS simulation program**.**

Key-Words: - absorption system, Solar cooling, parabolic trough collector, simulation, storage tank, TRNSYS

1 Introduction

In recent years, the trend in architecture for greater glazed surfaces, combined with greater comfort expectations have meant a dramatically increase in energy consumption for air-conditioning. In some country, this has already led to an electrical grid overload and break down. This risk and the need to reduce green house gases for electricity production make the introduction of cooling with renewable energy sources indispensable. At the end of last century it was still common view that solar cooling would only be profitable through photovoltaic driven compression cooling machines. However, optimized collectors, improved components and an enhanced system design have contributed to make solar thermal cooling a real technical alternative. It is now even able to compete financially with systems operating with conventional electricity sources. Using the solar energy directly for cooling and heating is a promising technology; a lot of research has been conducted for this purpose solar cooling has the advantage of both the supply of the sunshine and the need for cooling reaching maximum levels in the

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same season. The potential of the solar cooling system depends on two main concepts. The first is the solar collector technology, which includes the collector type such as the flat plate collector, the evacuated tube collector and the solar concentrators and include also the design parameter such as the collector area, dimensions and the martial used in manufacturing the collector. The second concept is the cooling machine which can be classified according to the energy supplied into two categories: thermal driven cooling system and electricity driven (photovoltaic) cooling system. The most common thermal driven cooling systems are the absorption and the adsorption cooling system. The solar assisted absorption system can serve both the heating and the cooling required for space, improving the system efficiency as compared to those producing either chilled or hot water alone [1]. Several researchers have studied and tested different solar assisted cooling systems, liquid absorption or solid adsorption systems, with successes [2-5]. However the use of liquid sorption for solar cooling induces two features: First, the liquid sorption cycle operates continuously, while solar energy is inherent transient during the day and vanishes during the night, so that large heat storage tank must be installed between the solar collector and the generator. Second, the solution is most often circulated by a pump working all the day long, this pump consumes electricity that must be supplied by photovoltaic cells or reliable electricity network. Le Lostec et al. have published the most comprehensive absorption chillier performance data set where the uncertainties of their measurements were reported. They provided data from 18 sets of operating conditions of ammonia/water absorption chillier with a nominal cooling capacity of 10 kW and later used these data to validate a model [7]. Extensive studies have been allocated for modelling, simulations and optimization of the solar cooling system [8-10]. Assilzadeh et al. study a solar-absorption system designed for a tropical climate in Malaysia using TRNSYS software [11]. Through a sensitivity analysis by varying the collector area and slope, the storage tank volume, and the pump flow rate, the optimal design of the system for Malaysia's climate was determined for continuous reliable operation of the system. Balghouthi et al. modelled an 11 kW solar adsorption system with 30 m^2 flat plate solar collectors and an 800 L water storage tank. The results showed that the system is suitable for Tunisia weather conditions [12]. Ortiz et al. used TRANSYS program to simulate a single effect, hot water fired absorption chillier [13]. The results showed that the hot water storage tank acted as a buffer and an energy reservoir to maintain the system stability due to irregular solar irradiation during the day. Florides et al. carried out a numerical model to evaluate the characteristics and the performance of single stage $LiBr/H_2O$ absorption chillier. Information on designing each component of the chillier are presented and examined [14]. Calise et al developed a transient simulation model of a Solar Heating and Cooling SHC system, with three different system configurations [15]. Single effect $LiBr/H_2O$ absorption chillier was coupled to evacuated-tube collectors, and a gas-fired boiler was included for auxiliary heating (only during the heating season). In the first configuration, the system was designed for maximum cooling load, and an electric chillier was added for auxiliary cooling. In the second configuration, the system was designed in such way to balance only a fraction of the maximum cooling load. In the third configuration, no electric chillier was included and the boiler was also used in the summer period to supplement the heat for the absorption chillier. The authors also developed a cost model to calculate operating and capital costs. An optimization method was applied to the system to determine the set of optimum variables resulting in energy efficiency maximization. The results showed that the system had the potential to improve energy efficiency, but the proposed system cost was unfavourable due to its high capital cost. Hang et al. assessed the economic and environmental prospects of a solar cooling system for a medium-sized benchmark office building in Los Angeles [16]. The system was modelled considered the use of evacuated tube solar collectors, hot water storage, single-effect $LiBr/H_2O$ absorption chillier, and a gas-fired heater for auxiliary heating. The system performance was optimized by variation of storage tank volume and collector area. They determined a trade-off between cost (equivalent uniform annual cost) and energetic/environmental performance (solar fraction and CO2 reduction). Marc et al present a dynamic modelling of a single-effect absorption chillier working with LiBr/H2O solution powered only by a solar collector field. The model was validated with experimental tests and proved good accuracy for predicting the outlet temperatures of the system components [17]. Lizarte et al. conducted an experimental test on single effect air cooled LiBr/H2O absorption chillier for residential use. The prototype has a nominal cooling capacity of 4.5 kW and it was driven by thermal energy generated from 42.2m^2 vacuum flat plate solar collector. The results showed that the prototype was able to supply an average of 3.35 kW of cooling

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over the period of 7.5 h with a mean daily coefficient of performance (COP) of 0.62 [18]. Chemisana et al. presented a comparison between two cooling systems for a specific three-floor building, with and without solar concentration. The first is a conventional system which consists of evacuated tube collectors feeding single-effect absorption chillier. On the other hand, a Fresnel reflective solar concentrating system is coupled to double-effect absorption chillier. The results showed an important reduction of the solar collectors' absorber area in the concentrating system compared with the standard solar thermal installation. However, the solar concentrating system requires a large aperture area. In addition, the rejected heat in the double-effect chillier is lower, implying that the investment and operation costs of the solar concentrating cooling system can be reduced significantly [19].

The objective of this study is to investigate dynamically the performance of the solar absorption cooling system under different Egyptian climate conditions. The model described in this paper single effect LiBr/h2O absorption chillier powered with hot synthetic oil heated with parabolic trough concentrator. The effect of the collector area on the thermal performance was also studied for Cairo and Aswan. The solar collector types used in this study is the Parabolic Trough Concentrator PTC connected with stratified storage tank. The dynamic performance in term of the temperature rise, the rate of energy gained and the coefficient of performance for the absorption chillier was investigated theoretically through the TRNSYS simulation program. Also, the effect of the cooling load and the collector aperture area on the operating period of the solar adsorption cooling system was investigated in this study.

2 Description of the System

The solar absorption cooling system in this investigation depends on coupling a single – stage LiBr/H_2O absorption cooling machine with Parabolic Trough Concentrator (PTC) solar collector. The solar collectors are used as a heat source for heating the heat transfer fluid HTF, which is synthetic oil. A stratified storage tank was used between the solar concentrator and the absorption machine for maintaining a constant energy input to the cooling machine. A single speed pump is used to flow the HTF from the solar collector to the stratified storage tank. Another constant speed pump delivers the heated oil from the storage tank to the single effect absorption chillier. The absorption chillier is connected with a cooling tower as shown in Fig. 1. The PTC was mounted with horizontally and rotates around single North-south axis. A single speed pump was used to push the HTF in the solar circuit. For maintaining the collector temperature rise higher 4 ºC an on/off differential controller was used. When the temperature rise of the solar collector is smaller than 4 ºC the controller send a signal to the pump to stop the fluid circulation. Anther on/off differential controller was used for the circuit of feeding hot energy to the absorption chillier through a single speed pump. When the outlet temperature of fluid flowing from the storage tank to the absorption chillier is higher than 110 C the controller send a signal to circulating pump to circulate the hot fluid to the absorption chillier. The modelling and simulation in this study are performed in the TRNSYS (version 17) environment, a widely used simulation program for energy systems [20].

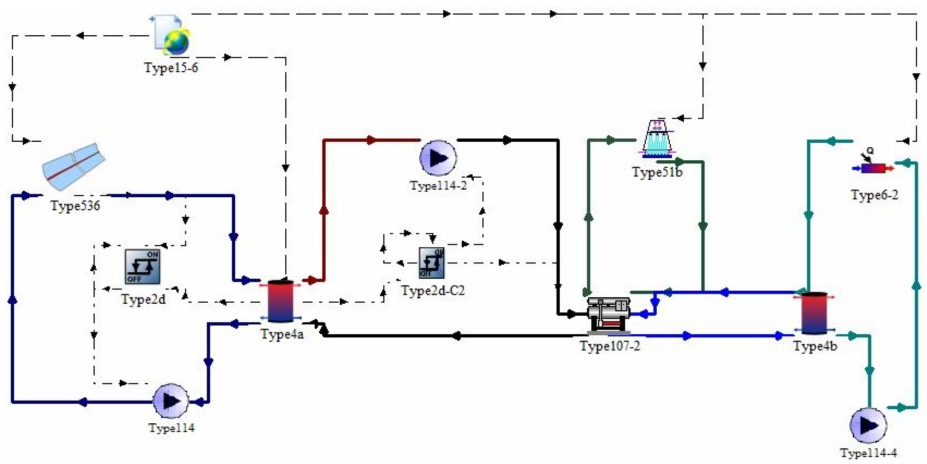

Fig. 1 layout of the TRNSYS simulation model for solar absorption cooling system with PTC

3 Modeling of the Cooling System

The previous described configuration of the solar absorption cooling system is modeled in TRNSYS simulation program. TRNSYS is a well-known software diffusely used for both commercial and academic purposes. The software includes a large library of built-in components, often validated by experimental data [20]. The components models are linked together to form the desired system.
The following assumptions have been taken into consideration while developing a model of the system:

1. Heat losses are only considered in the storage tank. i.e. Heat losses in the pipelines and heat exchangers are negligible.
2. The flow mixing between the bypass and the tank/burner flow is assumed adiabatic and perfectly mixed.
3. Thermal properties of oil are assumed to be constant.
4. The thermal storage tank is mounted in the vertical orientation to promote thermal stratification.

The solar cooling system model and its components are schematically shown in Fig 1. The main components of the solar absorption cooling system are described below.

1) Parabolic Trough Concentrating: Linear Parabolic Trough Concentrating Solar Collector models a type of solar concentrator that is used in high temperature applications. In this type the fluid passes through a long evacuated tube that runs along the north-south axis and is mounted horizontaly. In the solar cooling system, the solar collector model was used to collect the solar radiation and convert it to heat, then moving the heat to a Heat Transfer Fluid HTF and delivering it to a storage tank.

2) Stratified Storage Tank: Stratified thermal energy storage tank with uniform losses models the thermal performance of a storage tank. The storage tank is subject to thermal stratification. it is modelled by assuming that the tank consists of 25 fully-mixed equal volume segments.

3) Absorption Chillier: Single effect absorption chiller model the thermal performance of a single effect $LiBr/H_2O$ cooling chillier. The machine powered by hot water fluid and it can be powered with other hot fluids with changing the hot fluid properties.

4) Auxiliary heater: Auxiliary heater component is connected to the chiller loop of the absorption machine and simulate the cooling load where it work as a sensible heat load for the absorption cooling system.

5) Single speed pump: Single speed pump component is connected in series with the solar heating loop and the powering loop of the absorption chiller. The model sets the downstream flow rate based on its rated flow rate parameter and the current value of its control signal input.

6) Cooling Tower: Cooling tower component, in this component a hot water stream is in direct contact with an air stream and cooled as a result of sensible heat transfer due to temperature differences with the air and mass transfer resulting from evaporation to the air. The air and water streams are configured in counter flow arrangements. Ambient air is drawn upward through the falling water. The cooling tower is composed of four tower cells that are in parallel and share a common sump. Water loss from the tower cells is replaced with make-up water to the sump.

4 The Results

Several runs were carried out using the simulation TRNSYS program on the proposed system under different metrological date of the selected areas of Egypt. The solar absorption cooling system using the parabolic trough collector as a heat collecting device, so that the beam radiation and the ambient temperature are most important meteorological date required for the comparison between performances of the system at the four selected zones of Egypt. Fig. 2 shows the ambient temperature of the heat transfer fluid and the horizontal beam radiation falling per unit area in Al-Arish, Cairo, Assuit and Aswan during three days in July. From the figure, we can observe that the ambient temperature is always higher for Aswan. It is recorded a temperature of about 46 ºC in the 3^{rd} day. While, the solar noon ambient temperature for Cairo and El-Arish were the lowest and it is recorded 34 ºC. The beam radiation for Aswan and Assuit are the higher compare to Cairo and they recorded maximum beam radiation of about 950 W/m^2 at solar noon temperature. While the horizontal beam radiation in

Cairo recorded a value of about 785 W/m^2 in the 2nd day. From the figure, we can deduce higher ambient temperatures for Aswan than Al-Arish. The difference in the ambient temperature ranges from 8 to 11 ºC. There is also an increase in the beam radiation for Aswan, Assuit and Al Arish relative to Cairo. These increases range from 113 to 214 W/m^2.

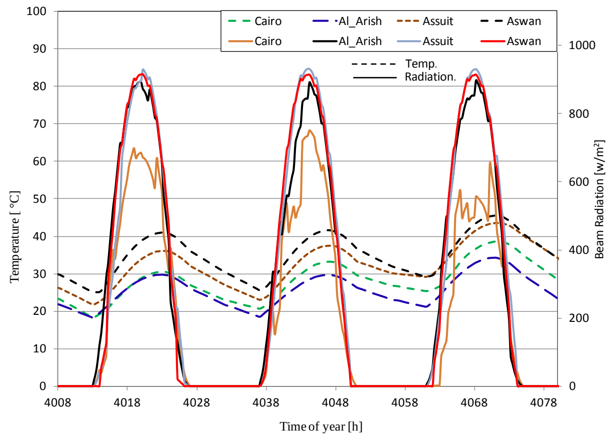

Fig.2 The ambient temperature and beam radiation during 3 days for the selected four Cities in Egypt

The temperature rise for the PTC is an important parameter for the comparison between the performances of the system at the different selected zones. Fig. 3 shows the temperature rise for the solar collectors the used in the solar cooling system at the selected four cities. From the figure, it can be observed that the PTC gives a high temperature rise of about 28.8 ºC for Aswan and that can be attributed to the higher ambient temperatures and the smaller losses from the collector. While the temperature rises of the Assuit, Cairo and the Al-Arish are 27.6 ºC, 21.9 ºC and 24.8 ºC, respectively.

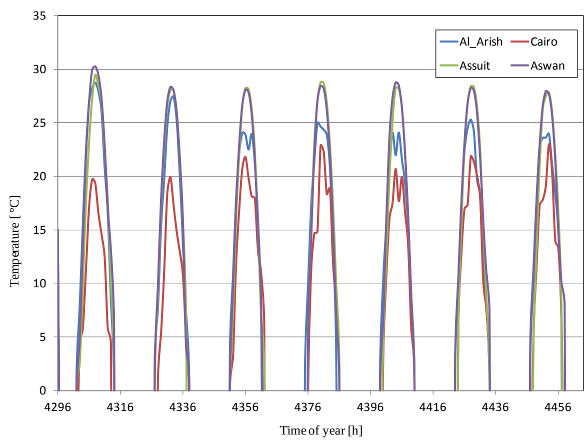

Fig. 3 The collector temperature rise for the selected four cities in Egypt

A comparison between the rates of energy gained from the solar collector at the selected zones is illustrated in Fig. 4. The rate of energy gained for the PTC is the highest Aswan and Assuit. The values of the rate of energy gained by the PTC collector are 99.4, 98.9, 72.5and 86.5 kW for Aswan, Assuit, Cairo and Al-Arish, respectively. That means an increase in the rate of energy gained by the collector for Aswan by about 12.9 kW more than that gained in Cairo.

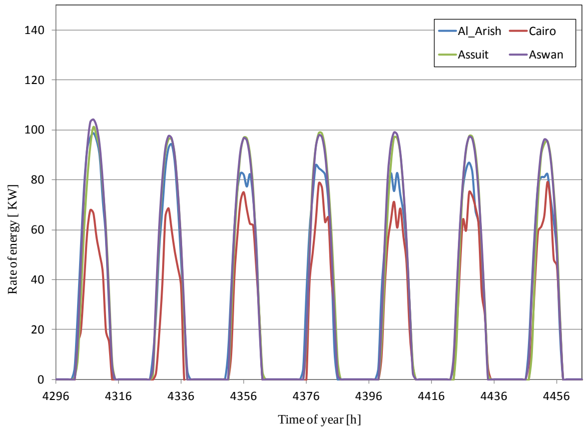

Fig. 4 The rate of thermal energy gained from the solar concentrator for the selected cities.

There is an effect on the coefficient of performance COP for the absorption system due to the operating of the solar absorption system in a different climate of Egypt. The COP for the absorption chiller is defined as the chilled water energy divided by the hot fluid energy plus the auxiliary electric energy provided for operating the pumpers and the controllers of the chiller. Fig. 5 shows the variation of the COP of the absorption chiller during one day in July for the selected four cities. The rated COP of the absorption chiller installed in the system is 0.578. The chiller work at COP less than the rated according to the energy input and the chiller water energy get by the chiller. The chillier works with a COP close to its rated and it decrease with time as shown in Fig. 5. The variation of the COP for Aswan ranges from 0.57 to 0.54. While, for Al-Arish city the COP ranges from 0.57 to 0.48.
Fig. 6 represents the variation of the rate of energy delivered from the parabolic trough collector to the storage tank and the rate of the energy exit from the storage tank and delivered to the absorption chiller during four days in July for Cairo. We can observe a constant energy consumed by the absorption chiller in spite of the variation of the inlet fluid temperature to the chiller. That leads to the version in the outlet fluid temperature exit from the chiller going to the storage tank.

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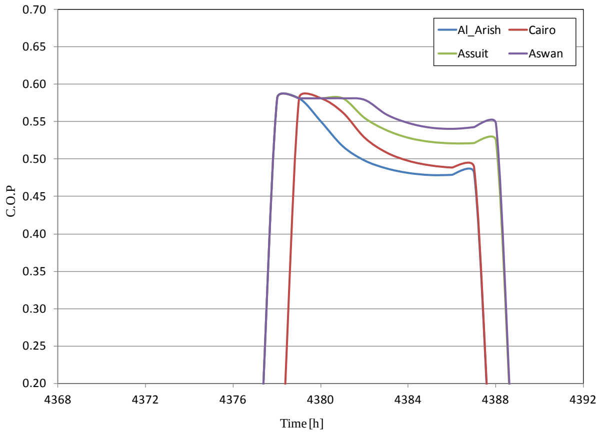

Fig. 5 The coefficient of performance COP of the absorption machine for the selected four cities.

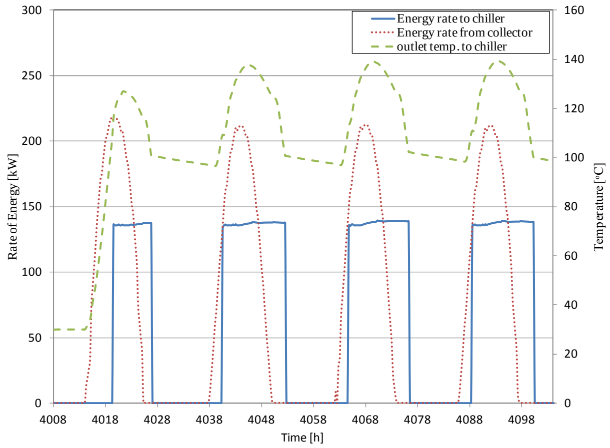

Fig. 6 The rate of energy delivered to the tank and the absorption chiller during four days in June for Cairo

The effect of the collector area on the solar collector outlet temperature is presented in Fig. 7 and Fig. 8 for Cairo and Aswan, respectively. Fig. 7 shows the variation of the PTC outlet fluid temperature at different collector area for Cairo climate. From the figure, we can observe a small value of the outlet temperature during the first day. Where the sum of the energy collected during the first day is consumed in raising the fluid temperature of the storage tank to an appropriated degree (110 ºC), where the initial temperature of the storage tank was set at 45 ºC. for smaller collector area (less than 80 m^2), the first day pass in heating the fluid of the storage tank from 30 to 105 ºC without operating the absorption chiller. While Fig.8 shows the variation of the collector outlet temperature at different collector area for Aswan climate. From the figure, we can observe a higher collector outlet temperature compare to the system installed in Cairo. The outlet temperature reaches a value of about 178.2 ºC which corresponding to a value of about 148.7 C for Cairo.

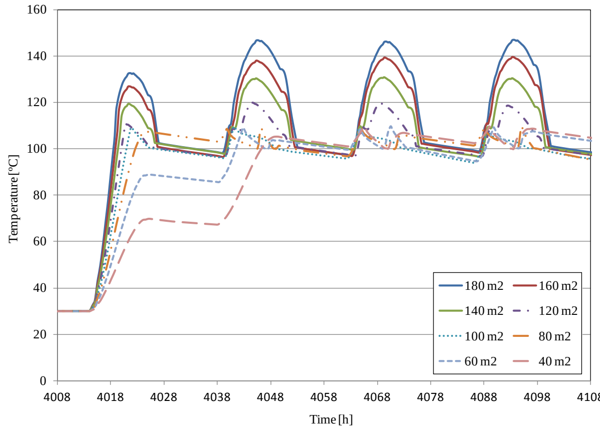

Fig. 7 The exit fluid temperature from the PTC at different collector area for Cairo.

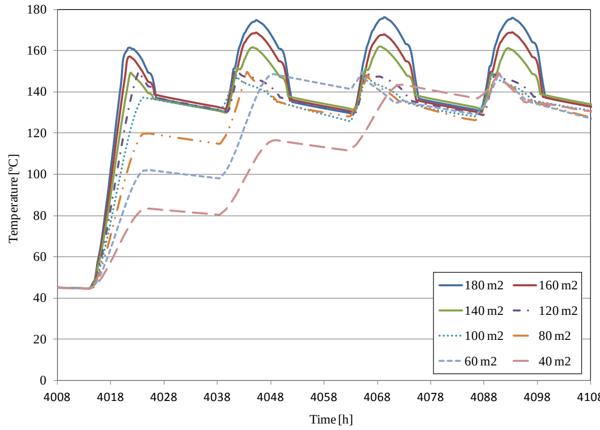

Fig. 8 The exit fluid temperature from the PTC at different collector area for Aswan.

4 Conclusion

The impact of the climatic condition on a solar absorption cooling system was investigated in this study by simulation the thermal performance of such a system using the TRNSYS simulation program under different zones in Egypt with different climatic conditions.

From the previous results, we can conclude that the collector temperature rise for Aswan is the higher compare to the other cities, where the temperature rises of the Aswan, Assuit, Cairo and the Al-Arish are 28.5 ºC, 27.6 ºC, 21.9 ºC and 24.8 ºC, respectively. Consequently the rate of the energy gained from the collector is highest for Aswan. The rate of energy gained calculated from the simulation program are 99.4, 98.9, 72.5and 86.5 kW for Aswan, Assuit, Cairo and Al-Arish, respectively. The COP of the absorption chiller was affected by the zone climate, where it has a higher value for Aswan and Assuit, range from 0.57 to 0.54, and was

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reduced to lower value, range from 0.75 to 0.48, for Cairo and Al-Arish. The effect of the collector is on the collector outlet temperature was also investigated for Cairo and Aswan. A reduction in the solar concentrator outlet temperature by about 17 % was achieved under the Cairo climate relative to Aswan City.

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