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A Review on Solar Liquid Flat Plate Collector

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Abstract:
A Flat Plate Collector is a heat exchanger that converts the radiant solar energy from the sun into heat energy using the well known greenhouse effect. It collects, or captures, solar energy and uses that energy to heat water in the home for bathing, washing and heating, and can even be used to heat outdoor swimming pools and hot tubs. For most residential and small commercial hot water applications, the *solar flat plate collector* tends to be more cost effective due to their simple design, low cost, and relatively easier installation compared to other forms of hot water heating systems. Also, solar flat plate collectors are more than capable of delivering the necessary quantity of hot water at the required temperature. In this paper we discussed about how to improve collector efficiency as well as how heat transfer take place during a heat transfer process. Theoretical results well matched with analytical results.

INTRODUCTION:
The flat-plate solar collectors are probably the most fundamental and most studied technology for solar-powered domestic hot water systems. The overall idea behind this technology is pretty simple. The Sun heats a dark flat surface, which collect as much energy as possible, and then the energy is transferred to water, air, or other fluid for further use.

Solar liquid collectors are potential candidates for enhanced heat transfer, but there are just a few studies focused on this topic. However, enhancement techniques can be applied to thermal solar collectors to produce more compact and efficient designs. This work presents the study of heat transfer enhancement in a tube-on-sheet solar panel with wire-coil inserts, using TRNSYS as the simulating tool. The numerical simulation methodology predicts the thermo-hydraulic flow behaviour of enhanced and standard tube-on-sheet solar collectors, evaluating the local losses, friction coefficients and Nusselt numbers as functions of the operating parameters. The standard and the enhanced collectors have been simulated under the same ambient, radiant and operating conditions. The standardized efficiency curves according to the standard UNE-EN 12975-2 are provided. The enhanced collector increases the thermal efficiency values by 4.5%.

A parametric study was performed to relate the fluid and flow characteristics with the heat transfer enhancement by wire-coil inserts. The simulations were performed for different working fluids (water and propylene glycol/water mixtures) in a mass flow rate range from 15 to 120 l/h m^2.

Based on finite volume method, the steady-state thermal performances of the flat-plate solar collector are studied by taking account of absorber plate thickness, collector tube spacing, collector tube length, collector tube diameter and insulating layer thickness. A physical model of gilled flat-plate solar collector is built, then the numerical simulation of the model is carried out and the numerical simulation results are compared and analyzed with experimental results. The results show that: Either increasing the absorber plate thickness or reducing the collector tube spacing can significantly improve the instantaneous efficiency of the collector. Setting the solar radiation intensity of 700 W/m2 and the environmental speed of 4 m/s, when the absorber plate thickness increases from 0.1 mm to 2.1 mm, the collector instantaneous efficiency increases from 46.57% to 64.03%.When the collector tube spacing decreases from 170 mm to 50 mm, the collector instantaneous efficiency increases from 52.81% to 66.01%. Reducing the collector tube length and increasing collector tube diameter are both conducive to improve the instantaneous efficiency of the collector. When the collector tube length decreases from 2800 mm to 1200 mm, the collector instantaneous efficiency increases from 57.50% to 60.12%.When the collector tube diameters increases from 8 mm to 20 mm, the collector instantaneous efficiency increases from 56.18% to 63.97%. When the thickness of insulating layer is 30 mm or more, increasing its thickness has no significant effect on improving the instantaneous efficiency of the collector. The research results are helpful to optimize the design parameters of the flat-plate solar collector.

A flat-plate solar collector can reach “stagnation” temperatures exceeding 170^0C particularly during power failures or periods when there is minimal energy demand. Excessive pressures may occur in a solar collector during stagnation conditions – a potentially danger for residents. In this work the authors propose experimental and numerical investigations of natural cooling of flat plate solar collectors to control their overheating under stagnation conditions. Experimental and numerical investigations have been conducted on a commercially available Enerworks Heat Safe (EHS) residential flat plate solar collector integrated with a back mounted air channel. Numerical investigations have been performed employing a three-dimensional finite-volume numerical model validated against experiments carried out by the authors. The validated numerical tool was applied to explore the dissipation of heat from the collector through natural convection and its dependence on collector geometrical parameters, tilt angle and operational conditions. It was found that a solar collector integrated with a well designed back mounted air cooling channel and a control valve at the outlet opening would be able to provide suitable heat transfer rates and keeps the maximum temperature of the absorber plate over a practical range of stagnation conditions. From the conducted investigations it has been evidenced that an optimal size of back-mounted collector air-channel can be found with suitable tilt angle, corresponding to which the overheating of collectors can be controlled passively under stagnation conditions.

The well-established correlation of Hollands et al. (1976), which is applicable to isothermal boundaries and Rayleigh numbers up to10^5, underestimates the convective heat loss across the air gap of flat plate solar collectors with tube-and-sheet type absorbers both in normal operation and at stagnation. Two reasons for this discrepancy were identified. (1) The Rayleigh number of the air gap above absorbers with highly selective coatings can be three times as high as the application limit. (2) The absorber is not isothermal during normal operation. Based on a literature study and theoretical considerations the application limit of the correlation was extended to Ra = $3*10^5$. By means of an analytically derived correction parameter, the correlation was adapted to non-isothermal boundary conditions.

For the cost- and efficiency optimization of flat-plate collectors an accurate analytical model was developed, based on the model of Duffie and Beckman (1991), enhanced by the new correlation for convective heat loss between absorber and cover plate. The model was validated against data of standardized collector tests. It is able to predict both the thermal efficiency and the stagnation temperature within the uncertainty limit of the standardized test method EN 12975-2 (CEN, 2006).

Solar energy is universally accepted as the most potential alternative power source due to its inexhaustible availability, diverse conversion technology and environmental friendly nature. Hybrid photovoltaic-thermal (PV/T) system is an optimized solar energy system that produces electricity and thermal energy simultaneously from the same physical profile. The basic problem of the hybrid collector is the removal and transfer of heat in an efficient way. In this article, PV/T system with a novel design of thermal collector excluding the absorber plate has been introduced to resolve the above mentioned problem.

A parallel plate thermal collector without absorber plate has been attached directly to the PV module backside by means of thermal paste only and the performance of the PV/T is evaluated numerically and validated by experimental data for different operating conditions. A 3D numerical analysis of the PV/T system has been performed using finite element method (FEM) based software COMSOL Multi-physics. The outdoor experimental investigation has been done under the typical climatic condition of Malaysia. Elevation head of water has been employed to ensure passive cooling of PV module.

The numerical simulation results are found in well agreement with those of experimental measurements. Thermal performance of PV/T without absorber plate is found almost as good as that with absorber plate.

The numerical and experimental values for maximum overall efficiency of the PV/T system was found 84.4% and 80%, respectively under the irradiation level at 1000 W/m2 with both inlet and ambient temperatures being 34^0C. The developed simulation model can be extended for other designs of thermal collector using different materials.

We report an experimental study investigating the thermal performance of a flat-plate solar collector using insert devices, over a Reynolds number range 200–8000 and a Prandtl number range 5–8, using water as the working fluid. A variety of conventional and novel insert configurations were considered which include, twisted-tape inserts, wire coil inserts and wire mesh insert. The results clearly indicate the enhancement of the Nusselt number by all insert devices. Comparison of the best inserts from different insert families show that in the laminar flow regime, the mesh insert performed the best whereas, the concentric coils achieved the highest Nusselt number augmentation in the turbulent regime, relative to the smooth pipe with no inserts. From the practical aspects, concentric coils were recommended as the best insert among those tested, which shows an overall Nusselt number enhancement of 110% in the low Reynolds number range and 460% in the high Reynolds number range. The impact of collector inclination of the performance of these insert devices was also investigated. The results show that the channel inclination does not have a significant impact on the Nusselt number enhancement[1].

This paper reports a numerical study of enhanced forced convection in a channel of solar water collector using multiple metal-foam blocks. Both Darcy–Brinkman–Forchheimer flow model and two-equation energy model based on local thermal non-equilibrium are used to characterize the thermo-flow fields inside the porous regions. Solution of the coupled governing equations for the porous/fluid composite system is obtained using a stream function-vorticity analysis. The results show that the recirculation caused by metal-foam block will significantly augment the heat transfer rate on heated surface. Besides, a useful correlated equation to predict Num is proposed and the validity of the LTE condition is examined.

A 3D numerical model for flat-plate liquid solar collectors has been developed. This model is envisioned for predicting the efficiency curve of the collector, for which the different heat transfer mechanisms involved are simultaneously taken into account: solar radiation absorption, transmission and reflection; natural convection in the air cavity; heat conduction across the tube-absorber welded junction; mixed convection flow in the risers; and heat losses by convection and radiation to the ambient. To ensure the reliability of the model, the heat transfer results inside the risers and in the air cavity were contrasted with well-known experimental correlations available in the open literature.

The thermal efficiency obtained with this numerical model is successfully validated against own experimental data. This heat transfer model is intended for evaluating the impact of different operating conditions and design features on the overall performance of solar collectors, reducing costs in prototype construction and experimentation.

In the present paper we present an experimental analysis and a thermal and hydrodynamic modelling of a newly designed flat-plate solar collector characterized by its corrugated channel and by the high surface area directly in contact with the heat transport fluid. The thermal and hydrodynamic modelling of the collector has been performed by means of the Finite Element Method (FEM), validated with analytical results for a well-known fin-and-tube type solar collector. The thermodynamic efficiency of the collector is analyzed by means of its experimental heating curves. The yield of the new collector has been compared to a previously existing commercial collector of related geometry but with less area in direct contact with the heat transport fluid. The experimental results are seen to adequately fit the simulation predictions, and a methodology to use in order to compute the parameters characterizing the thermal behavior of the collector is introduced[2].

A prototype of glazed flat plate solar collector with roll-bond absorber is presented and its performance is experimentally characterized. Differently from common sheet-and-tube collectors, in the present prototype the channels for the liquid are integrated in the roll-bond absorber plate. Measurements of thermal efficiency are reported for two samples of the prototype, one with a black coating on the absorber and the other with a semi-selective coating. Efficiency test runs have been performed in both steady-state and quasi-dynamic conditions, according to the standard EN 12975-2 (EN 12975-2. Thermal solar systems and components e solar collectors part 2: test methods. Brussels: CEN; 2006). The efficiency measurements are compared with those taken for standard glazed flat plate collectors with sheet-and-tube absorber under the same test conditions. The experimental results show that the roll bond absorber can provide higher performance. Besides, the thermal efficiency can be further increased and this is shown by means of a numerical model. The model is experimentally validated for standard flat plate collectors with sheet-and-tube absorber and for roll-bond collectors.

The present work aims at investigating an innovative flat aluminum absorber for process heat and direct steam generation in small linear solar concentrating collectors. After defining its optimal width through a Monte Carlo ray-tracing analysis, this absorber has been manufactured with the bar-and-plate technology, including internal offset strip tabulators in the channel. This technology is cost-effective and extremely flexible, allowing to easily adapt the geometry of the absorber to different reflecting optics configurations. It has been mounted on an asymmetrical parabolic trough concentrator to form a solar collector with a concentration ratio of 42, which has been experimentally investigated. In particular, a new test procedure is presented, applied and validated to characterize the thermal performance of the collector during steam generation. The results show that a promising overall thermal efficiency of 64% at 0.160 K m^2 W^{-1} can be achieved with negligible pressure drop[3].

The present study aims to investigate exergy efficiency of a Flat-plate solar collector containingAl_2O_3–water nanofluid as base fluid. The effect of various parameters like mass flow rate of fluid, nano particle volume concentration, collector inlet fluid temperature, solar radiation, and ambient temperature on the collector exergy efficiency is investigated. Also, the procedure to determine optimum values of nano particle volume concentration, mass flow rate of fluid, and collector inlet fluid temperature for maximum exergy efficiency delivery has been developed by means of interior-point method for constrained optimization under the given conditions. According to the results, each of these parameters can differently affect the collector exergy by changing the value of the other parameters. The optimization results indicate that under the actual constraints, in both pure water and nano-fluid cases the optimized exergy efficiency is increased with increasing solar radiation value. By suspending $Al2O_3$ nanoparticles in the base fluid (water) the maximum collector exergy efficiency is increased about 1% and also the corresponding optimum values of mass flow rate of fluid and collector inlet fluid temperature are decreased about 68% and 2%, respectively.

This paper presents a novel flat plate solar water heater (SWH) using micro heat pipe array (MHPA) sprayed solar selective coating and arranged closely as the absorber of collector. The collector has the advantage of resistance to freezing, high heat transfer ability, relatively low heat loss, elimination of welding, and prevention of leakage. The experiments were conducted first to investigate the thermal performance of the novel collector. The test results for the collector's instantaneous efficiency show that the slope and intercept of the instantaneous efficiency curve are 5.6 and 0.85 respectively. Then, the thermal performance monitoring analysis of the forced circulation SWH with 2 m2 novel collector under different weather conditions were carried out using trial installations in Beijing, China. The test data were analyzed from the aspects of water temperature, effective heat gain, and thermal efficiency. The test results show that the daily effective heat gains on the three typical days in different seasons are 13.43MJ/m^2, 11.05MJ/m^2, and 7.42MJ/m^2 respectively, corresponding to the solar irradiation of 18.9MJ/m^2, 17.2MJ/m^2, and 14.7MJ/m^2. The daily average thermal efficiencies are 71.05%, 64.25%, and 50.49%, respectively. These experimental results provide basis and reference for practical application of the novel SWH[4].

Based on the heat transfer characteristics of absorber plate and the heat transfer effectiveness-number of heat transfer unit method of heat exchanger, a new theoretical method of analyzing the thermal performance of heat pipe flat plate solar collector with cross flow heat exchanger has been put forward and validated by comparisons with the experimental and numerical results in pre-existing literature. The proposed theoretical method can be used to analyze and discuss the influence of relevant parameters on the thermal performance of heat pipe flat plate solar collector.

An experimental study was conducted to investigate fluid temperature fields inside a flat-plate solar collector tube. The results show the highest fluid temperature at the upper end of the tube which decreased gradually to the lowest value at the bottom end of the tube, whereas, the temperature field in the horizontal plane is symmetric about the centerline. The vertical temperature gradients vary with the axial distance. The local fluid temperature increased nonlinearly along the collector length and its magnitude decreased with an increase in the Reynolds number. The local Rayleigh number increased with the axial distance and at a given location, its magnitude increased with a decrease in the Reynolds number, whereas, the local Nusselt number trends in flat-plate collector tube are in general similar to that in the conventional laminar channel flows. The local fluid temperature increased with an increase in the incident heat flux at a given collector orientation but decreased for the inclined collectors. The results show that over the given Reynolds number range, the fluid in a flat-plate collector tube is stably stratified over most of the fluid cross-sectional domain and the convective currents are suppressed and restricted to a thin layer adjacent to the lower tube wall.
The results from the present study provide the physical explanation for the heat transfer enhancement by insert devices. That is, the insert devices disrupt the stably stratified layer and induce mixing which enhances the heat transfer.

This research study presents an investigation on the behavior of a Pulsating Heat Pipe Flat-Plate Solar Collector (PHPFPSC) by artificial neural network method and an optimization of the parameters of the collector by genetic algorithm. In this study, several experiments were performed to study the effects of various evaporator lengths, filling ratios, inclination angles, solar radiation, and input chilled water temperature between 9:00 A.M. to 5:00 P.M., and the output temperature of the water tank, which was the output of the system, was also measured. According to the input and output information, multilayer perceptron neural network was trained and used to predict the behavior of the system. A two-layer neural network with a unipolar sigmoid activation function and a 6-20-1 structure was obtained as the network with the highest performance. The trained network was validated with experimental data and used to evaluate the objective function to maximize the thermal efficiency of the system.

Also, a continuous genetic algorithm was developed to optimize the system efficiency. An initial population size of 700 and a mutation rate of 4 % were obtained as the best values. Furthermore, at the evaporator length of 1.08, filling ratio of 56.94 %, and inclination angle of 25.01, the maximum thermal efficiency of the system was 61.4 %[5].

The effect of the input water temperature of the water tank on the optimal values of optimization variables was examined. The results indicated that an increase in the temperature of the input water of the water tank leads to a decrease in the thermal efficiency of the system. A comparison of the results of this study with previous research indicates that the use of heat pipes in solar collectors can increase the efficiency of solar collectors up to 4 %. According to the results, the use of neural networks, as an input–output model, is a proper way to predict the complicated behavior of these systems. Also, genetic algorithm is an efficient method for solving non-linear optimization problems.

18) A newly designed solar collector named dual-function solar collector is proposed. The dual-function solar collector integrated with building can perform in two different modes: working as a passive space heating collector in cold sunny days such as in winter, or working as a facade water heating collector in hot days such as in summer. An experimental study has been carried out to investigate the performance of the novel system in space heating mode, whilst, the dynamic numerical model has been established and validated. The experimental and numerical results show that during the period of the measurement from 9:00 to 17:00, the mean indoor temperature was up to 24.7°C while the mean ambient temperature was only 4.8°C, and a temperature stratification was present in the room. Moreover, a numerical study on the effect of optical property of coatings has been carried out[6].

The flat-plate solar collector is an important component in solar-thermal systems, and its heat transfer optimization is of great significance in terms of the efficiency of energy utilization. However, most existing flat-plate collectors adopt metallic absorber plates with uniform thickness, which often works against energy conservation. In this paper, to achieve the optimal heat transfer performance, we optimized the thickness distribution of the absorber with the constraint of fixed total material volume employing entransy theory. We first established the correspondence between the collector efficiency and the loss of entransy, and then proposed the constrained extreme-value problem and deduced the optimization criterion, namely a uniform temperature gradient, employing a variational method. Finally, on the basis of the optimization criterion, we carried out numerical simulations, with the results showing remarkable optimization effects. When irradiation, the ambient temperature and the wind speed are 800 W/m^2, 300 K and 3 m/s, respectively, the collector efficiency is enhanced by 8.8% through optimization, which is equivalent to a copper saving of 30%. We also applied the thickness distribution optimized for wind speed of 3 m/s in heat transfer analysis with different wind speed conditions, and the collector efficiency was remarkably better than that for an absorber with uniform thickness[7].

An experimental study is conducted on the heat transfer in the reservoir of a solar water-heater flat-plate solar collector to obtain its temperature distribution. A total of 29 temperature sensors are placed inside the reservoir, and 2 sensors in the water inlet and outlet passages. The effect of the inlet and outlet positions on the temperature distribution inside the reservoir is studied to obtain the best location for the maximum temperature range. When the inlet position is II and the outlet position the reservoir exhibits the best performance because of the high temperature range and areas inside it.

This paper presents the heating performance and energy distribution of a system with the combination of ground-source heat pump and solar collector or a solar-assisted ground-source heat pump system (SAGSHPS) by calculation and experiment. The results show that the average absolute error is less than 0.6℃ and the relative error is less than 5% under the pulse load when the analytical solution to the 2-D solid cylindrical source model is used for the SAGSHPS. The coefficient of performance (COP) of the SAGSHPS is 2.95—4.70. The average fluid temperature in the borehole heat exchanger can increase by 3℃ with the assistance of solar collector, which will improve the COP of the heat pump by approximately 10% from the experimental data. The energy contributions to the total heating load of soil, electricity and solar are 56.30%, 36.87% and 6.83%, respectively[7].

22) The technical feasibility of an innovative solar collector is studied in this paper. A phase change material (paraffin) is used in the solar collector to store solar energy. This type of system combines both collection and storage of thermal energy into a single unit. The major advantages of the phase change stores are their large heat storage capacity and isothermal behavior during the melting and solidifying processes. A negative aspect of paraffin is its low thermal conductivity which increases the melting and solidifying time for paraffin energy storage. In this paper, new aluminum foams infiltrated with paraffin are presented. It presents a two dimensional model describing the melting and solidifying processes of paraffin while accounting for both phase change heat transfer and natural convection. Apparent heat capacity method was used to simulate the melting and solidifying processes of paraffin. The simulation results show that the motion of the hot liquid paraffin plays an important role in increasing the heat transfer between paraffin and top surface of solar collector. The shape profile of the pure paraffin solid-liquid interface is determined by the synergistic relationship between its temperature and velocity field[8].

Though aluminum foams impregnated with paraffin will limit motion of the hot liquid paraffin, the heat transfer ability is greatly improved. The distributions of the temperature in the paraffin with aluminum foams are more homogeneous compared with that of the paraffin without aluminum foams. Thus, use of aluminum foams infused with paraffin improves heat transfer and enhances paraffin’s melting and solidifying rates.

Based on a typical single pass flat plate solar air collector (FPSAC) model, the collector thermodynamic characteristic matching property between the air-side heat transfer and total heat losses is analyzed in terms of unified air-side heat transfer coefficient Ub-f and total heat loss coefficient UL. Then the limit design principle of FPSACs is discussed in order to obtain high collector efficiency intercepts.

The results show that, both lower and upper limit values of UL exist for obtaining an expected efficiency intercept (η0) which is lower than the maximum realizable intercept ((η_0)max) with specific collector components. The case of maximum realizable intercept (η_0)max can be obtained by the minimum realizable total heat loss coefficient (UL)min and a high convective heat transfer coefficient Ub-f (Ub-f = 200 W/(m2⍰K) is argued to be good collector air-side thermal performance and is considered in the present study), resulting in a minimum thermodynamic characteristic coefficient ζmin. And the maximum realizable intercepts for different component combination cases of FPSACs are obtained by numerical calculation. Besides, for FPSACs with specific airflow channels, the cases of minimum realizable (UL)min represent the limit design.

Based on the thermo-electric analogy (the so-called thermal entransy analysis), the unified airside convective heat transfer coefficient for different sorts of flat plate solar air collectors (FPSACs) is identified in terms of collector aperture area. In addition, the collector thermodynamic characteristic matching coefficient is defined to depict the matching property of collector thermal performance between the collector airside heat transfer and the total heat losses. It is found that the airside convective heat transfer coefficient can be experimentally determined by collector thermal performance test method to compare the airside thermal performances of FPSACs with different types of airflow structures. Moreover, the smaller the collector thermodynamic characteristic matching coefficient is, the better the thermodynamic perfect degree of a FPSAC is. The minimum limit value of the collector thermodynamic matching coefficient is close to zero but it cannot vanish in practical engineering. Parameter sensitivity analysis on the total entransy dissipation and the entransy increment of a general FPSAC is also undertaken. The results indicate that the effective way of decreasing total entransy dissipation and enhancing the useful entransy increment is improving the efficiency intercept of the FPSAC. This is equivalent to the cognition result of thermal analysis. However, the evaluation indices identified by the thermal entransy analysis cannot be extracted by singular thermal analysis[9].

In this study, thermal performance of double- and triple-pass solar air heater with longitudinal fins is mathematically evaluated. The effects of parameters, viz. mass flow rate, solar intensity and inlet temperature upon outlet temperature, thermal efficiency and increments in efficiency, power consumption are presented. The analytical solution for the mathematical model involving energy balance equations of different components of solar air heater is obtained using a MATLAB 8.1. Triple-pass solar air heater with fins exhibits better thermal performance, whereas double-pass solar air heater with fins is economically viable within the opted conditions.
The results of the analytical models are in good agreement with experimental findings of earlier researchers.

A method to determine the critical Rayleigh number Ra_{cr} for the closed air layer of the light-absorbing heat-exchange panel–transparent cover system of flat-plate solar thermal collectors is proposed based on the solution of a modified correlation equation suggested by Hollands et al. [3]. This method can be used to determine the thermal-engineering optimal thickness of the layer considered within the 20–60° range of its tilt to the horizon[10].

The influences on the absorption rate with different slope of incident light and aspect ratio are presented. The results show that the effect of aspect ratio on the absorption rate is larger, while the slope of incident light is relatively smaller. The results of the present work imply that the rational aspect ratio is 1. According to this conclusion, the optical path of sinusoidal_corrugated solar air collector with aspect ratio 0.5, 1 and 1.5 is simulated respectively by TRACEPRO software using. The conclusion is also verified by the simulations[11].

Conclusion

1) The numerical simulation methodology implemented in TRNSYS predicts the thermo hydraulic flow behaviour of enhanced and standard tube-on-sheet solar collectors, evaluating local losses, friction coefficient and Nusselt number as a function of the Reynolds number. This methodology allows the accomplishing of parametric studies to quantify the heat transfer enhancement introduced using insert devices in solar collectors.

2) From the experimental results it was concluded that the inlet and outlet openings of the air channel with width of 4 or 6 cm and with channel gap of 3 cm would be the optimal values for the collector under study. Moreover outlet opening size of the air channel has more pronounced effect on the temperature distribution than the inlet opening size and should be selected carefully while designing the integral stagnation control system at the outlet opening for the passive cooling of the collector under stagnation conditions.

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