Integrated AHP – TOPSIS Approach for Optimization of Coolant with Nanoparticles in PVT-Based Hydrogen Production System

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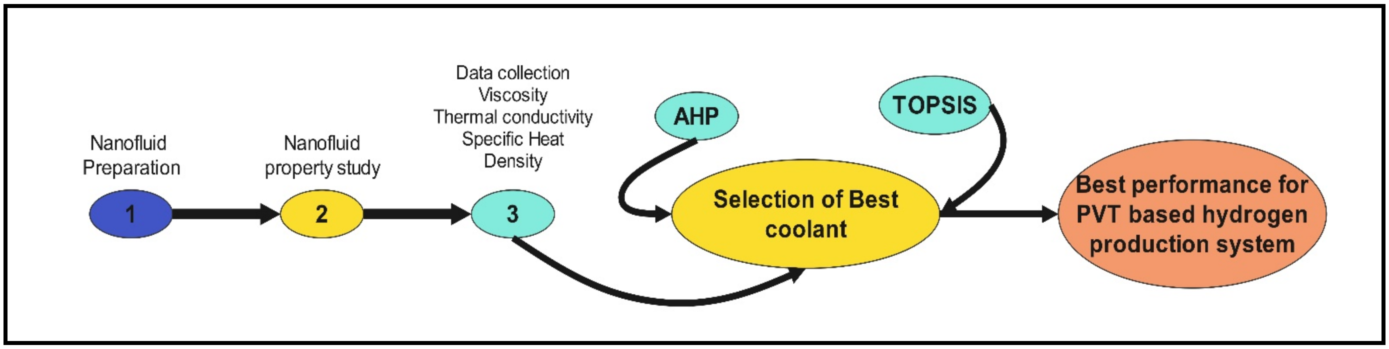

ABSTRACT: The production of hydrogen using photovoltaic–thermal (PVT) solar collectors with minimal environmental impact is a significant issue that necessitates a methodical approach. The selection of an appropriate nanofluid is essential in a thermal collector to optimize the performance of the photovoltaic-thermal (PVT) system and increase the rate of hydrogen production. This study analyzes several nanofluids in terms of viscosity, thermal conductivity, density, specific heat, pumping power, and fluid cost. This study discovered a nanofluid that may significantly enhance the rate of hydrogen generation. To achieve this objective, the analytical hierarchy process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods were used to identify the appropriate choice and assess the hydrogen production rate. First, the AHP technique was used to determine the required weights, followed by sorting the alternatives using the TOPSIS technique. The findings indicate that a hybrid nanofluid consisting of a 0.2% volume concentration of Al_2O_3–CuO in water exhibits the most favourable heat transfer characteristics and is considered the best option for improving heat transfer efficiency and boosting the rate of hydrogen generation.

Keywords: Photovoltaic – Thermal solar collector, Hydrogen yield rate, TOPSIS, AHP, Hybrid nanofluid

نهج متكامل لتحليل العملية الهرمية (AHP) – تقنية ترتيب التفضيلات بتشابهها مع الحل المثالي (TOPSIS) لتحسين المبرد مع الجسيمات النانوية في نظام إنتاج الهيدروجين القائم على الكهروضوئية–الحرارية (PVT)

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الملخص: إنتاج الهيدروجين باستخدام مجمعات شمسية كهروضوئية–حرارية (PVT) مع تأثير بيئي ضئيل هو مسألة مهمة تتطلب نهجًا منهجيًا. اختيار سائل نانوي مناسب في المجمع الحراري ضروري لتحسين أداء نظام الكهروضوئية–الحرارية (PVT) وزيادة معدل إنتاج الهيدروجين. تحلل هذه الدراسة عدة سوائل نانوية من حيث اللزوجة، التوصيل الحراري، الكثافة، الحرارة النوعية، قوة الضخ، وتكلفة السائل. وقد اكتشفت هذه الدراسة سائل نانوي قد يعزز بشكل كبير معدل توليد الهيدروجين. لتحقيق هذا الهدف، تم استخدام أسلوب العملية التحليلية الهرمية (AHP) وتقنية ترتيب التفضيلات بتشابهها مع الحل المثالي (TOPSIS) لتحديد الخيار المناسب وتقييم معدل إنتاج الهيدروجين. أولاً، تم استخدام تقنية AHP لتحديد الأوزان المطلوبة، تلاها تصنيف البدائل باستخدام تقنية TOPSIS. تشير النتائج إلى أن سائل نانوي هجين يتكون من تركيز حجمي بنسبة 0.2% من Al_2O_3–CuO في الماء يعرض خصائص نقل حراري مواتية للغاية ويعتبر الخيار الأفضل لتحسين كفاءة نقل الحرارة وتعزيز معدل إنتاج الهيدروجين.

الكلمات المفتاحية: كهروضوئي؛ مجمع شمسي؛ هايدروجين؛ TOPSIS ؛ العملية الهرمية؛ سائل نانوي.

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1. INTRODUCTION

Green hydrogen refers to hydrogen generated through water electrolysis using renewable energy sources. The concept of green hydrogen is increasingly capturing the attention of researchers worldwide because of its cleanliness and environmental friendliness. According to Rystad Energy, the projected production of green hydrogen globally is expected to experience significant growth from 2023 to 2030. The forecast indicates that the annual production of green hydrogen has already reached 1118.2 thousand tons. The Photovoltaic–Thermal (PVT) solar collector-based hydrogen production system concurrently generates hydrogen, electrical energy, and heat energy. Consequently, the PVT-based hydrogen production system is garnering more attention from researchers. Various factors, such as solar radiation, wind speed, inclination angle, and thermophysical properties of heat transfer fluids, influence the hydrogen yield rate. Among these factors, the dispersion of nanoparticles is one of the simplest and most essential ways to alter the heat transfer properties of traditional fluids. While a fluid containing a single nanoparticle exhibits excellent heat transfer properties, scientists have further enhanced these properties by dispersing numerous nanoparticles throughout a traditional fluid.

Despite the notable focus on investigating heat transfer fluid selection to enhance the hydrogen yield rate, less attention has been paid to exploring other factors influencing heat transfer fluid selection. Therefore, this study employs the Multi-Criteria Decision-Making (MCDM) approach to determine the appropriate heat transfer fluid for a PVT-based hydrogen generation system.

An innovative hydrogen production system based on a combination of photovoltaic-thermal (PVT) and Thermoelectric Generator (TEG) was developed and analyzed by Behzadi et al. (Behzadi et al. 2019). The parameters of the system were also optimized using a multi-objective optimization-based genetic algorithm. The obtained results revealed that the proposed TEG-based PVT hydrogen production system yields more hydrogen than conventional systems. The optimum exergy efficiency and total cost rate of the system were determined to be 12.01% and 0.1762 $/h, respectively.

Behzadi et al. conducted a thermos economic analysis of a hybrid solar collector-based hydrogen production system (Behzadi et al. 2018). This study demonstrated that integrating a thermal collector with a photovoltaic (PV) module effectively reduces the temperature of the PV module. The results showed that the developed combined system achieved a product unit cost of 42.16 $/GJ and an overall exergy efficiency of 10.56%. Salari et al. developed a hydrogen production system with a PVT module, a thermoelectric generator (TEM), and a proton exchange membrane (PEM) fuel cell and analyzed its performance. This study indicates that the PVT–TEG–PEM-based hydrogen production system yields more hydrogen than other systems (Salari et al. 2022).

Babayan et al. developed a hydrogen production system using PVT and Phase Change Material (PCM) and investigated its performance. The research demonstrated that the PVT-based hydrogen production system, when not using PCM, produces 5.3% less hydrogen than other configurations, with a peak exergy efficiency of 15.17% (Babayan et al. 2019). Sangeetha et al. conducted an experimental study on a multiwalled carbon nanotube (MWCNT), Al_2O_3, and TiO2 nanofluid-cooled PVT-based hydrogen production system (Sangeetha et al. 2021). The findings indicated that the MWCNT-cooled PVT-based system achieved peak energy, exergy efficiency, and hydrogen yield rate.

Frances et al. developed a hydrogen generation system consisting of photovoltaic panels, a photoelectrochemical water-splitting reactor, and a fuel cell system. They observed overall energy and exergy efficiencies reaching 19% and 12%, respectively (Frances et al. 2020). Chandrasekar et al. analyzed a setup with PVT and semi-lengthened wavy fins, PVT and longitudinal fins, and a PV module-based electrolyzer unit (Chandrasekar et al. 2022). Hydrogen yield rates were obtained for different configurations, with Wavy-finned PVT, longitudinal-finned PVT, plain PVT, and plain PV producing approximately 13.5, 12.1, 9.5, and 7.8 ml/min, respectively.

Li et al. examined the hydrogen production rate of a water-based PVT system and electrolyzer unit and showed significant improvements in the photochemical reaction and hydrogen yield rate compared with other systems, achieving an optimal hydrogen production rate of 18.49%. (Li et al. 2022) The study concluded that PVT with an electrolyzer unit is preferable over the PV module-based unit in terms of electricity efficiency and hydrogen production rate.

Multi-criteria decision-making (MCDM) stands out as a prominent approach to decision-making, aiming to identify the most suitable choice by considering multiple factors throughout the selection process. Various researchers have employed several MCDM strategies in diverse thermal and solar applications to predict the linear and nonlinear behaviours of systems.

In a study by Sivalingam et al. the additive ratio assessment (ARAS) approach, combined with the combinative distance-based assessment (CODAS) MCDM methodologies, was used to predict the performance of vehicle radiators with varying volumes of Multi-Walled Carbon Nanotubes (MWCNT) under varied operating circumstances. (Sivalingam et al. 2022) The experimental results demonstrated a significant 18.39% increase in the "Nu" value when the inlet temperature was set at 70 °C, the MWCNT nanomaterials were present at a concentration of 0.6%, and the mass flow rate was 90 g/s. Ghasempour et al. conducted a review summarizing the findings from several MCDM methods used by different researchers to choose optimal sites and techniques for solar power plants (Ghasempour et al. 2019). In a separate study, Siksnelyte-Butkiene et al. reviewed studies using various MCDM strategies to determine the most appropriate renewable energy technology for household usage, assessing the advantages and disadvantages of the Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Compromise Ranking and Interactive Trade-Offs (CRITIC), and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) procedures (Siksnelyte-Butkiene et al. 2020).

Simsek et al. categorized numerous publications in various journals dealing with energy project sustainability and multi-criteria analysis, using factors like article focus, author motivation, and overall contribution (Simsek et al. 2018). Podder et al. employed the Non-dominated Sorting Genetic Algorithm (NSGA-II) and TOPSIS technique to enhance the effectiveness of a water-based PVT solar collector and absorber (Podder et al. 2021). They discovered that the highest thermal and electrical efficiency reached 82.55% and 10.45%, respectively, at a mass flow rate of 0.02 kg/s, an inlet temperature of 32°C, and an inclination angle of 38.88°. Sharma et al. optimized the parameters of a V-down baffled PVT system using a hybrid Taguchi-TOPSIS MCDM technique, finding optimal values for the relative angle of attack (α/90), relative distinct width (gw/Hb), and relative separate position (Dd/Lv) of 0.666, a, and 0.67, respectively (Sharma et al. 2022).

Yilmaz et al. prioritized the heat transfer fluid in a parabolic trough solar collector using the Analytic Hierarchy Process (AHP) - Vlsekriterijumsko Kompromisno Rangiranje (VIKOR) Technique (Yilmaz et al. 2023). The findings revealed that water and molten salt were rated first among the various heat transfer fluids. In a study by Zindani et al., the performance of seven concentrated solar power plants using vegetable oils was assessed using the TOmada de Decisao Interativa Multicriterio (TODIM) method, with results indicating that sunflower oil performed the best, whereas palm oil performed the worst (Zindani et al. 2022).

The literature review presented above clearly illustrates the widespread use of nanoparticle-dispersed heat transfer fluids in various photovoltaic-Thermal (PVT) solar collector applications. The importance of selecting a suitable nanofluid as a heat transfer medium is underscored by considering various thermophysical parameters. The key thermophysical parameters that influence performance include thermal conductivity, viscosity, specific heat, and density. While numerous researchers have undertaken both experimental and numerical investigations, only a limited number have employed Multi-Criteria Decision Making (MCDM) approaches to select the optimal heat transfer fluid for enhancing PVT-based hydrogen generation systems.

Therefore, the principal objective of this research is to identify the most effective nanoparticle-based heat transfer fluid for a PVT-based hydrogen production system. This will be achieved through the application of the Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods, with the overarching aim of optimizing both the Photovoltaic (PV) module efficiency and the hydrogen output rate.

2. METHODOLOGY

2.1 AHP and TOPSIS Technique

The effectiveness of a Photovoltaic-Thermal (PVT)-based hydrogen generation system depends on several factors, and Multi-Criteria Decision Making (MCDM) techniques are employed to enhance the efficiency of the PVT system. Various MCDM methods, such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Multi-Attribute Utility Theory (MAUT), Multi-Objective Decision Making (MODM), Elimination and Choice Translating Reality ELECTRE, VIKOR (VIsekriterijumsko KOmpromisno Rangiranje), and decision support systems, are available. However, the TOPSIS technique has disadvantages, including high sensitivity to normalization, a strong dependency on alternatives, and a restricted amount of numerical data. It is a straightforward and widely employed technique in several applications.

The required nanofluids were prepared using a two-step synthesis method. In the first step, nanoparticles were prepared using mechanical or chemical methods. The prepared nanoparticles were mixed with the base coolants by sonication and stirring in the second step. The properties of the prepared nanoparticle-based coolants were studied using experimental test rigs. The test was performed continuously three times, and the average values were considered for further calculation in this work.

AHP, a mathematical technique of MCDM proposed by Saaty, establishes a hierarchical framework for addressing complex problems (Aragonés-Beltrán et al. 2014). In this study, the AHP method was applied to calculate the relative importance of each criterion for selecting the best heat transfer fluid. The TOPSIS method, developed by Hwang and Yoon in 1981, has been widely used to select optimal parameters in various applications (Yoon and Hwang 1995). In this study, different heat transfer fluids are ranked using the TOPSIS approach. The essential stages of the AHP-TOPSIS method are shown in Fig. 1 summarized below.

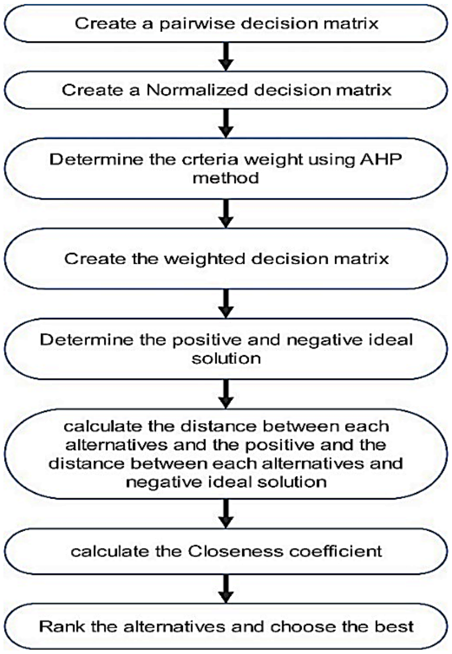

Figure. 1. Steps involved in the AHP – TOPSIS method

Step 1: In this phase, a pair-wise decision matrix is constructed using Saaty's relative importance scale and presented as

$$X=\begin{pmatrix} 1 & X_{12} & X_{13} & \ldots. X_{1n} \\ X_{21} & 1 & X_{23} & \ldots. X_{2n} \\ . & . & 1 & . \\ . & . & . & . \\ X_{m1} & X_{m2} & X_{m3} & \ldots.1 \end{pmatrix} \quad \begin{array}{l} X_{ii}=1 \\ X_{ji}=\dfrac{1}{X_{ij}} \quad X_{ij}\neq 0 \end{array} \tag{1}$$

In this matrix, 'm' is the number of rows, 'n' is the number of columns, 'X_{ij}' represents the significance of the i^{th} element relative to the j^{th} element.

Step 2: Each element in the pairwise comparison matrix must be normalized using the formula shown below.

$$Y_{ij}=\frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}} \tag{2}$$

Step 3: The consistency of the selected pairwise matrix can be checked by calculating the criterion weight, consistency index and consistency ratio by using the following equations.

Weighted normalized pairwise matrix can be prepared by

$$W=\left[\sum_{j=1}^{n}\frac{Y_{ij}}{n}\right]_{n\times 1} \tag{3}$$

where i = 1,2,3 …… n and j = 1,2,3 …… n

The following formula may be used to calculate the consistency index (CI) and consistency ratio (CR).

$$CR=\frac{CI}{RI}=\left[\frac{\lambda_{\max}-n}{n-1}\right]\times\frac{1}{RI} \tag{4}$$

Where 'n' is the number of criteria, 'RI' is the Random Index depends on the number of criteria and λ_{max} is the maximum Eigan value and can be found as

$$\lambda_{\max}=\left[\frac{Addition\ of\ weighted\ sum\ value}{Criteria\ weight}\right] \tag{5}$$

The same weights may be used for further computations if the resulting CR is less than 0.1. If not, the preceding procedures should be repeated until consistency is achieved.

Step 4: The normalized decision matrix (n_{ij}) and weighted normalized decision matrix (v_{ij}) may be obtained by using the following formulas.

$$n_{ij}=\frac{X_{ij}}{\sqrt{\sum X_{ij}^{\ 2}}} \tag{6}$$

Where, 'i' is the number of alternatives (i = 1, 2,….m) and 'j' is the number of criteria (j = 1,2,….n)

$$v_{ij}=w_j\times n_{ij} \tag{7}$$

Step 5: The positive ideal and negative ideal solutions can be calculated as

$$\begin{aligned} S^{+}&=\left\{v_1^{*},v_2^{*},\ldots\ldots,v_j^{*}\right\} \\ &=\left\{\left(\max(v_{ij})\square i\in I'\right),\left(\min(v_{ij})\square i\in I''\right)\right\} \end{aligned} \tag{8}$$

$$\begin{aligned} S^{-}&=\left\{v_1^{*},v_2^{*},\ldots\ldots,v_j^{*}\right\} \\ &=\left\{\left(\min(v_{ij})\square i\in I'\right),\left(\max(v_{ij})\square i\in I''\right)\right\} \end{aligned} \tag{9}$$

Step 6: The distance from the positive ideal (Di+) and negative ideal (Di-)solution can be calculated by using the following formula.

$$D_i^{+}=\sqrt{\sum_{j=1}^{n}\left(V_{ij}-V_j^{+}\right)^2} \tag{10}$$

$$D_i^{-}=\sqrt{\sum_{j=1}^{n}\left(V_{ij}-V_j^{-}\right)^2}$$

(11)

Step 7: Applying the following formula, the relative closeness to the ideal solution can be determined.

$$RC=\frac{D_i^{-}}{D_i^{+}+D_i^{-}} \tag{12}$$

Step 8: Finally, alternatives are ranked, and the best ones are identified based on the relative closest values.

3. RESULT AND DISCUSSIONS

3.1 Results of the AHP Technique

Identifying a suitable heat transfer fluid in a PVT-based hydrogen production system is essential for young academics and entrepreneurs interested in the field of green hydrogen. For this purpose, six thermophysical features (criteria) and 10 heat transfer fluids (alternatives) are considered on the basis of the existing literature. The basic hierarchical structure of the AHP technique is illustrated in Fig. 2. This study considers the following criteria: viscosity of the fluid (C1), thermal conductivity of the fluid (C2), density of the fluid (C3), specific heat of the fluid (C4), pumping power necessary to circulate the fluid in a PVT solar collector (C5), and fluid cost (C6). As shown in Fig. 1, 10 alternative fluids, such as water (A1), Al_2O_3/water nanofluid (Φ – 0.05%) (A2), Al_2O_3/water nanofluid (Φ – 0.1%) (A3), Al_2O_3/water nanofluid (Φ – 0.2%) (A4), CuO/water nanofluid (Φ – 0.05%) (A5), CuO/water nanofluid (Φ – 0.1%) (A6), CuO/water nanofluid (Φ – 0.2%) (A7), Al_2O_3 - CuO/water nanofluid (Φ – 0.05%) (A8), Al_2O_3 - CuO/water nanofluid (Φ – 0.1%) (A9), and Al_2O_3–CuO/water nanofluid (Φ – 0.2%) (A10), are considered.

After preparing the hierarchical structure of the AHP process, a pairwise comparison matrix was prepared based on Saaty's 1-9 scale and is presented in Table 1.

The weight of each criterion was calculated by normalizing each element in the pairwise comparison matrix using Equation 2. The normalized pairwise comparison matrix is presented in Table 2. The weights of each criterion can be calculated using Equation 3 and are shown in Table 3. Equations 4 and 5 are used to calculate the constancy index and consistency ratio, and the obtained values are presented in Table 4. Finally, the calculated consistency ratio is below 0.1. Therefore, the calculated consistency ratio suggests a reasonable level of consistency, making the criteria appropriate.

3.2 Results of the TOPSIS Technique

This study uses the TOPSIS technique to select a suitable heat transfer fluid on the basis of its thermophysical characteristics. The goal is to improve the performance of PVT solar collectors and increase the hydrogen production rate. The TOPSIS analysis utilizes the criterion weights derived from the AHP results, which are 0.238, 0.466, 0.1, 0.113, 0.055, and 0.028 for C1, C2, C3, C4, C5, and C6, respectively. Before performing TOPSIS analysis, the decision matrix must be normalized, and a weighted normalized matrix must be computed using equations 6 and 7. The obtained normalized decision matrix and weighted normalized decision matrix are given in Tables 5 and 6, respectively. The ideal positive and negative ideal solutions are calculated using equations 10 and 11, respectively. In addition, the relative closeness to the ideal solution was calculated using Equation 12. The minimum relative closeness value is considered to be the worst heat transfer fluid, and the maximum closeness value is considered to be the best heat transfer fluid. The obtained ideal positive and negative solutions, relative closeness, and rank details are shown in Fig. 3.

As shown in Fig. 3, the Al_2O_3–CuO/water nanofluid with a volume concentration of 0.2% was ranked first and determined to be the most effective heat transfer fluid for maximizing electrical energy and hydrogen production rate. By introducing additional nanoparticles with distinct thermal characteristics into the base fluid, the Brownian motion of particles within the fluid was significantly intensified. Consequently, this enhanced motion facilitates the transfer of heat from one location to another, resulting in greater heat extraction from the PV module. As a result, electrical power production is increased, and a greater amount of water is separated into oxygen and hydrogen. This leads to an enhanced rate of hydrogen production when using a nanofluid consisting of Al_2O_3–CuO and water with a volume concentration of 0.2%.

Table 1. Pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5	C6
C1	1	0.333	3	5	3	9
C2	3	1	5	7	9	9
C3	0.333	0.2	1	0.333	3	5
C4	0.2	0.143	3	1	3	3
C5	0.333	0.111	0.333	0.333	1	3
C6	0.111	0.111	0.2	0.333	0.333	1

Table 2. Normalized pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5	C6
C1	0.201	0.175	0.239	0.357	0.155	0.3
C2	0.603	0.527	0.399	0.5	0.466	0.3
C3	0.067	0.105	0.08	0.024	0.155	0.167
C4	0.04	0.075	0.239	0.071	0.155	0.1
C5	0.067	0.058	0.027	0.024	0.052	0.1
C6	0.022	0.058	0.016	0.024	0.017	0.033

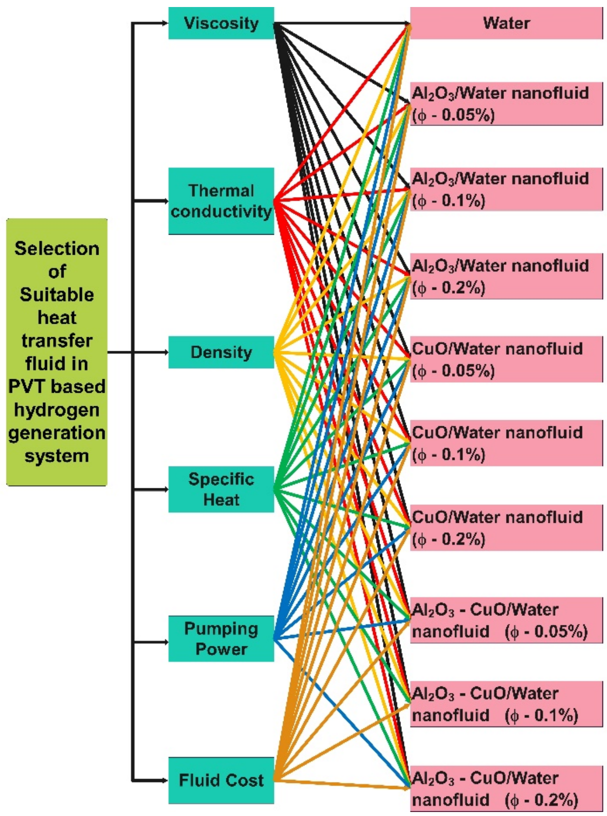

Figure. 2. Hierarchical structure of the AHP technique

Table 3. Details of the criteria weight.

Criteria	C1	C2	C3	C4	C5	C6
Weight	0.238	0.466	0.1	0.113	0.055	0.028

Table 4. Details of the consistency index and the consistency ratio.

λ_{max}	Consistency Index	Consistency Ratio	Random Index
6.612	0.122	0.098	1.24

Table 5. Normalized Decision matrix.

S. No	Heat Transfer Fluid	Nanoparticle vol. concentration	Viscosity (mPa - S)	Thermal conductivity (W/mK)	Density (kg/m3)	Sp. Heat (J/kgK)	Pumping power (W)	Cost (INR/Liter)
1	Water	0	0.296	0.312	0.314	0.317	0.249	0.138
2	Al_2O_3-Water	0.05	0.307	0.302	0.315	0.318	0.269	0.161
3	Al_2O_3-Water	0.1	0.313	0.304	0.315	0.317	0.299	0.215
4	Al_2O_3-Water	0.2	0.319	0.313	0.316	0.316	0.342	0.238
5	CuO-Water	0.05	0.31	0.313	0.315	0.317	0.284	0.307
6	CuO-Water	0.1	0.32	0.317	0.317	0.316	0.314	0.33
7	CuO-Water	0.2	0.324	0.322	0.318	0.315	0.347	0.346
8	Al_2O_3 +CuO - Water	0.05	0.315	0.322	0.316	0.317	0.332	0.399
9	Al_2O_3 +CuO - Water	0.1	0.325	0.326	0.317	0.316	0.327	0.422
10	Al_2O_3 + CuO-Water	0.2	0.333	0.33	0.318	0.314	0.38	0.438

Table 6. Weighted Normalized Decision matrix.

S. No	Heat Transfer Fluid	Nanoparticle vol. concentration	Viscosity (mPa - S)	Thermal conductivity (W/mK)	Density (kg/m3)	Sp. Heat (J/kgK)	Pumping power (W)	Cost (INR/Liter)
1	Al_2O_3-Water	0	0.067	0.151	0.027	0.041	0.012	0.003
2	Al_2O_3-Water	0.05	0.07	0.146	0.027	0.041	0.013	0.004
3	Al_2O_3-Water	0.1	0.071	0.147	0.027	0.041	0.014	0.005
4	CuO-Water	0.2	0.072	0.151	0.027	0.041	0.016	0.006
5	CuO-Water	0.05	0.07	0.151	0.027	0.041	0.014	0.008
6	CuO-Water	0.1	0.073	0.153	0.028	0.041	0.015	0.008
7	Al_2O_3 +CuO - Water	0.2	0.074	0.156	0.028	0.041	0.017	0.009
8	Al_2O_3 +CuO - Water	0.05	0.072	0.156	0.027	0.041	0.016	0.01
9	Al_2O_3 + CuO-Water	0.1	0.074	0.157	0.028	0.041	0.016	0.011
10	Al_2O_3-Water	0.2	0.076	0.159	0.028	0.041	0.018	0.011

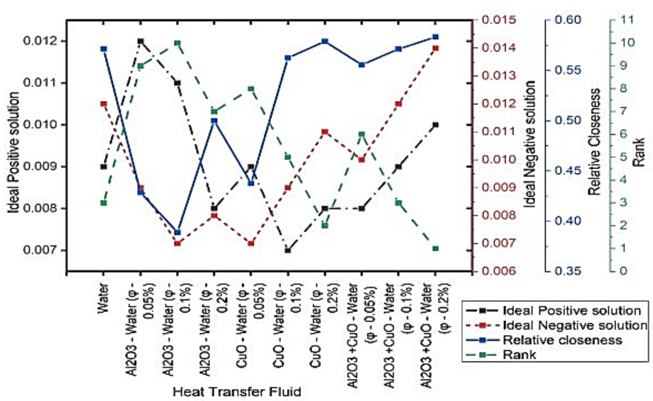

Figure 3. Details of ideal positive and negative solutions, relative closeness, and rank

4. CONCLUSIONS

Choosing the appropriate coolants containing either single or multiple nanoparticles for use in a PVT solar collector is an essential challenge to obtain the best possible electrical efficiency and hydrogen production rate. In this work, AHP and TOPSIS techniques are used to choose the optimal coolant for maximizing heat extraction from the Photovoltaic (PV) module. Six criteria (Viscosity, thermal conductivity, density, specific heat, pumping power and cost of fluid) were used to evaluate the heat transfer fluids (water, Al_2O_3/water (φ - 0.05%), Al_2O_3/water (φ - 0.1%), Al_2O_3water (φ - 0.2%), CuO/water (φ - 0.05%), CuO/water (φ - 0.1%), CuO/water (φ - 0.2%), Al_2O_3 - CuO/water (φ - 0.05%), Al_2O_3 - CuO/water (φ - 0.1%), Al_2O_3 - CuO/water (φ - 0.2%)). The following conclusions were drawn:

1. The necessary criterion weights for the TOPSIS methodology were established using the Analytic Hierarchy Process (AHP) method. The criteria weights were 0.238, 0.466, 0.1, 0.113, 0.055, and 0.028 for viscosity (C1), Thermal conductivity (C2), density (C3), Specific heat (C4), pumping power (C5), and fluid cost (C6), respectively.
2. The TOPSIS technique was used to choose the optimal coolant. The rankings for the different coolants are as follows: the Al_2O_3–CuO/ water hybrid nanofluid with a volume concentration of 0.2% ranked first, followed by the CuO/water hybrid nanofluid with a volume concentration of 0.2% in second place, and the Al_2O_3–CuO /water hybrid nanofluid with a volume concentration of 0.2% in third place.
3. Hence, the findings of this study might assist aspiring researchers in conducting many investigations using a PVT-based hydrogen generation system.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this article.

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