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STUDY AND SIMULATION OF THE INFLUENCE OF GUIDE VANE SHAPE ON THE SOLAR VORTEX ENGINE SYSTEM USING CFD

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ABSTRACT

This investigation affords a computational evaluation of a Hybrid Solar Vortex Engine (HSVE.PV) gadget, aiming to enhance airflow dynamics and improve machine efficiency thru changes to the manual vane geometry. Three vane configurations had been expected: a immediately vane at 20°, a curved vane, and a mixed right away-curved format. Using industrial Ansys Fluent 2024, the fashions were simulated under regular boundary conditions to investigate the effect on airflow pace and vortex formation within the chimney. The effects found out that the curved movement over the base case. The better vortex glide and stress distribution located in the third configuration suggest a large development in energy switch capability. The effects observed out that the curved Guide Vane accelerated airflow velocity moderately, whilst the blended layout completed the best average performance, with apeak outlet tempo of 1.737 m/s representing a 20% improvement over the base case. The more advantageous vortex waft and pressure distribution determined within the third configuration imply a large development in power transfer ability.

KEYWORDS

Vortex, Guide Vane, Solar Vortex Engine, Solar Updraft Power, Solar Chimney, CFD.

1. INTRODUCTION

There are many renewable energy sources, such as solar energy, wind energy, hydroelectric energy, and other renewable sources (Jehhef and Siba, 2018; Sebestyén, 2021). A significant technology in modern systems involves the use of sustainable energies and other energy sources which can improve efficiency depending on the location and timing this is achieved by fill the gap between the times when energy is harvested and when it is needed (Cheng, Kai and Zhu, 2023; Rtemi, El-Osta and Attaiep, 2023; Hadi, Alamili and Kadhum, 2025). Recent studies are moving towards improving the use of renewable energy to the maximum extent, but despite some developments in energy systems, the use and efficiency are generally low (Odeh and Behnia, 2009; Nada, El-Nagar and Hussein, 2018).

The following paragraphs focus on the importance of solar and wind energy because the research depends on them. The use of solar energy is of great importance in reducing global warming, which receives 3.8 million watts of annual incident sun energy (Abed and ghaydh, 2024), and it was discovered that the yearly solar radiation received in Iraq is between 4.5 and 5.5 kWh/m^2 (Ali, Jabbar and Al-Shaibani, 2025). Although there are some developments in energy systems, one such study presented the use of solar heat to replace the extracted steam to heat the feed water. The increased solar radiation can generate increased energy to meet the increasing demand for energy. In addition, this can eliminate the variability in energy production in individual solar energy systems (Morton, 2006; Simpson, Pearlstein and Glezer, 2012; Jamel, Abd Rahman and Shamsuddin, 2013; Pandey, Kumar and Samykano, 2022). Solar energy is highly variable across daily, seasonal, and weather conditions, resulting in poor alignment between production and consumption. Additionally, its conversion efficiency remains low. However, increased production and widespread adoption are expected to drive future cost reductions (Ahmed et al., 2022; Stevanović, Stevanović and Živković, 2022; Alaskaree, 2025). Fig.1 shows the general schematic of the hybrid solar chimneys (Ahmed et al., 2022).

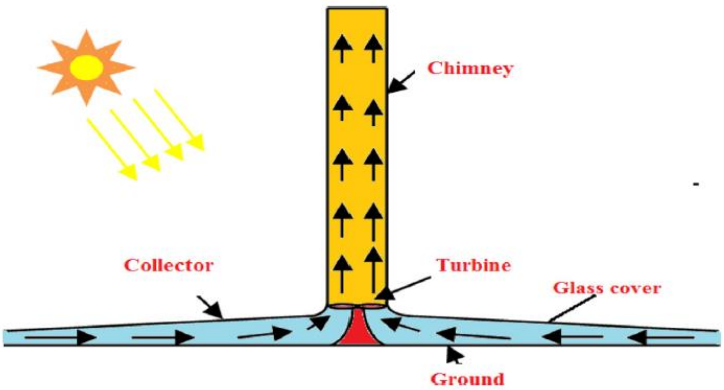


Fig.1. Hybrid solar chimney diagram (Ahmed et al., 2022).

(Al-Kayiem, Mustafa and Gilani, 2016) used CFD to analyze a solar vortex engine (VGE) and the effect of upper hole diameter on vortex strength. Increasing the diameter from 0.3 m to 0.9 m reduced tangential velocity and vortex intensity. Simulations showed 5.1% error compared to experimental data, confirming accuracy. Results highlight the critical role of top opening size in vortex performance and system efficiency. Fig.2 shows the general schematic of the solar vortex engine (Al-Kayiem, Mustafa and Gilani, 2016).

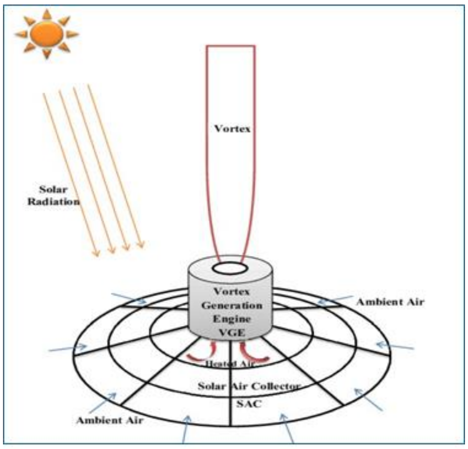


Fig. 2. Solar vortex engine diagram(Al-Kayiem, Mustafa and Gilani, 2016).

(Al-Kayiem, Mustafa and Gilani, 2018) was developed a novel Solar Vortex Engine (SVE) combining an 8 m solar collector and a cylindrical vortex generator. Air entered through tangential slots, creating a rotational updraft. At 1040 W/m² solar irradiance and 35.6 °C ambient temperature, vortex air reached 48–49 °C with a tangential-to-axial velocity ratio of 7.5. Results confirm effective vortex formation. (Abbood and Abbas, 2018) investigated how different ground types sand, a sand-pebble mix, and black pebbles affect the performance of a solar chimney power plant in Kerbala, Iraq. Experimental tests showed that black pebbles provided the highest airflow temperatures and better thermal storage, especially during nighttime, leading to more efficient energy use.

The results show that choosing appropriate ground materials, such as black pebbles, can greatly improve a plant's performance during both day and night by enhancing heat absorption and storage. To further increase energy efficiency, (Hussein and Ahmed, 2018) investigated a new hybrid solar chimney design that uses solar photovoltaic (PV) panels as a glass roof. Their findings revealed that a tilt angle of 45° provided the best performance, with mechanical efficiency ranging between 8% and 13%. They also observed an average air temperature increase of about 2–3 °C on typical days. The experiments were carried out in Kirkuk, Iraq, during the summer, using various instruments to measure temperature, air velocity, and the electrical output of the solar panels.

During the summer, experiments were conducted in Kirkuk, Iraq, using various instruments to measure the electrical output of the solar panels, air velocity, and temperature. The results indicated that a tilt angle of 45° achieved the highest energy efficiency, with overall system efficiency ranging from 8% to 13%. On typical days, the air temperature inside the solar collector increased by approximately 2–3 °C.

(Kiwan and Salim, 2020) enhanced a conventional solar chimney by integrating PV panels and a water pool for panel cooling and freshwater generation. The modified system achieved a utilization factor of 4.37%, compared to 0.51% for the original. It generated 45.35% more electricity annually than a standalone PV system. Optimal performance occurred when submerged PV panels were placed closer to the chimney. The cost of freshwater was $1.60/m³, 46.3% lower than comparable systems highlighting improved economic and energy efficiency.

(Huang et al., 2020) investigated a hybrid sun chimney integrated with photovoltaic panels for air purification. Their outcomes showed that substituting 50–60% of the collector's glass cowl with PV modules decreases airflow by way of about 14%, whilst simultaneously producing enormous electric electricity. However, large-scale simulations indicated that big PV insurance ought to enhance airflow by way of up to 2.42 times, main to stepped forward air-cleansing overall performance, higher strength performance, and decreased land requirements. (Das and Chandramohan, 2020) carried out a solar vortex engine (SVE) that demonstrated vortex performance at a 0.3 m top hole diameter, reach a velocity of 1.4 m/s and 73.9s^{-1} vortex. With an inlet velocity of 0.7 m/s, the theoretical and actual output power were 3.5 W and 2.3 W, respectively. With higher solar radiation, the power increased by 269%, although the efficiency dropped to 7.8%.

(Al-Kayiem, Tukkee and Gilani, 2022) studied the effect of vortex generator (VG) design on solar vortex engine (SVE) performance through the application of 3-D CFD and experiments. Three VG arrangements were investigated, basic, cone and holed on backside structure. The cone ramped up the air's temperature and buoyancy, which inflated today. Case-1 (Base) realized 0.5% best static stress drop, and 5% in comparison to Case-2 and three respectively . The hollow in bottom had a negative impact on the scale-of-vortex.

(Boonloi, Sudsanguan and Jedsadaratanachai, 2024) the solar strength upstream tower became advanced by means of placing a vortex generator in the wind region to collect crosswinds and function at night. Testing the layout at wind speeds of two-8 m/s, depending on the peak of the generator in terms of the diameter of the tower, indicates the most Q when each factors are equal. The rectangular, cylindrical, and diffuser shapes led to 60%, 41%, and 48% increase in internal wind velocity, respectively, permitting commercial use due to improved system performance.

(Singh et al., 2024) Singh et al. (2024) used 3D numerical simulations to study how vortex location affects vortex formation and current recycling in a convergent-divergent solar tower. They found that when the flow was slow (0.13 m/s), inserting the vortex at the narrowest point of the throat reduced the center-to-center distance. Placement down the throat gave the greatest restriction ratio, 31%. The lowest effect in the hot zone occurred when the hot zone was placed under the throat.

(Nie et al., 2024) In Hohhot, China, Ni et al. (2024) evaluated a flow model to improve solar power tower modeling. Laminar, RNG, k-ω SST, and transition models were examined. In comparison to the RNG model, the transition model had the lowest error, reducing the relative error by 1.04% at 13:00 and 0.1% at 17:00.

(Rahimi-Larki et al., 2025) carried out a 3D CFD to assess sloped-collector solar chimneys (SCSC) under crosswind conditions. A slope angle of 20°–30° improves updraft, boosting power output by 10–35%. At 12 m/s crosswind, output drops by 55%, but adjusting the slope angle recovers 16%, achieving ~35 kW. (Das and VP, 2025) evaluated behavior and power potential using a 3D computational study of the Solar Vortex Engine (SVE) flow, which contain 8 air entry slots, and turbine position was 0.702 m from the base. The optimal flow parameters were 1.42 m/s velocity, 311.1 K temperature, and 1.58 Pa pressure.

One of the modern systems is a combination of a hybrid solar chimney and a solar vortex engine in a system called Hybrid Solar Vortex Engine PV (HSVE.PV) which cools the solar cells in addition to generating electricity through the engine installed in the chimney (Jaffar, Ismaeel and Shuraiji, 2022). Fig. 3 shows the design adopted in the HSVE.PV design. This system was developed by finding the ideal angle (20 degrees) after comparing a group of angles (Jaffar, Ismaeel and Shuraiji, 2023).

In this paper, we worked on improving the HSVE.PV system by changing the shape of the Guide Vane to increase the air force entering the system and thus increase the vortex force that will increase the electrical energy production and cooling of the solar cells. The first stage was to design a prototype using the commercial program Ansys Fluent 2024 and then verify the initial results by comparing them with the results of previous studies (Jaffar, Ismaeel and Shuraiji, 2023). The second stage was to propose and design three shapes of the Guide Vane, the first is straight at an angle of 20°, the second is curved based on the same angle, and the third is a combination of the first and second cases. The last stage is to review and analyze the results and then compare them with the previous study (Jaffar, Ismaeel and Shuraiji, 2023).

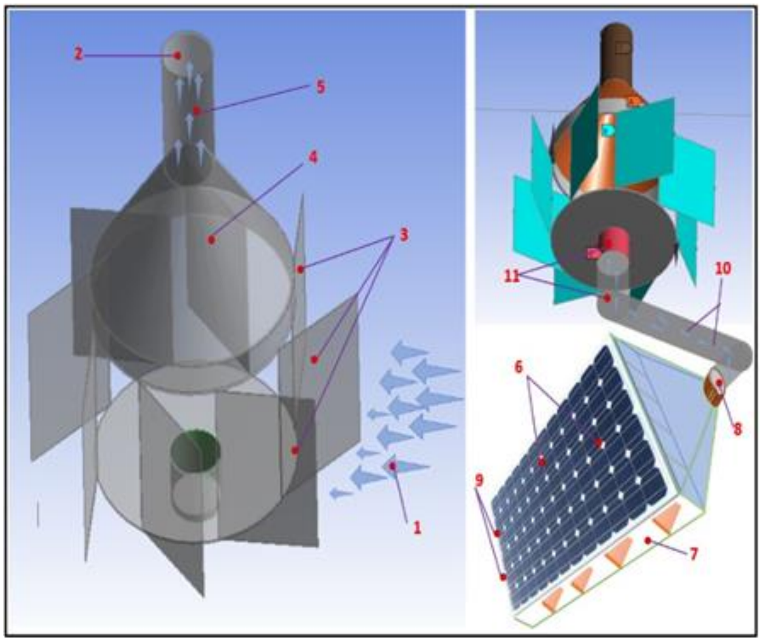


Fig.3. Schematic diagram of the Proposed Model (HSVE.PV), 1- air entry, 2-air out, 3-Guide Vane, 4- Glass Surface, 5- Chimney, 6- PV, 9/7- Air entry through the Inflow Guided Baffles, 10/8- Air flow through the tube, 11- air Intake Tube from PV (Jaffar, Ismaeel and Shuraiji, 2022).

2. MODEL GENERAL STRUCTURE (SVE) WITH SIMULATION PHASES ANALYSIS

The proposed model was designed based on research (Jaffar, Ismaeel and Shuraiji, 2023), which relied on the dimensions that were designed and other conditions that the research relied on, such as temperatures, radiation intensity, and physical properties of materials. The proposed design consists of four main parts: the chimney that sucks in air, the glass pane that allows sunlight to pass through, the Guide Vane that directs air inward, and the intake pipe that can be used for ventilation and cooling of the solar panels. The following Fig.4 shows these parts in addition to the base that supports and connects the Guide Vane, which is numbered with the suction tube.

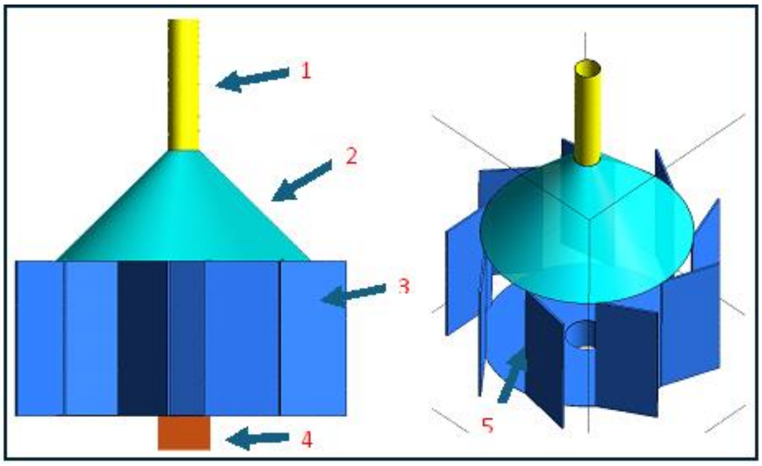


Fig.4. The prototype where, (1) refers to the chimney, (2) the glass universe, (3) the guide vane, (4) the suction pipe, and (5) the supporting base.

After the initial model was designed and the required simulation was conducted several times until the SVE-E model was approved, then the shape of the guide vane was changed to a curve and the simulation was conducted and then the first and second shapes were combined as shown in Fig.5, which shows the shapes that were compared.

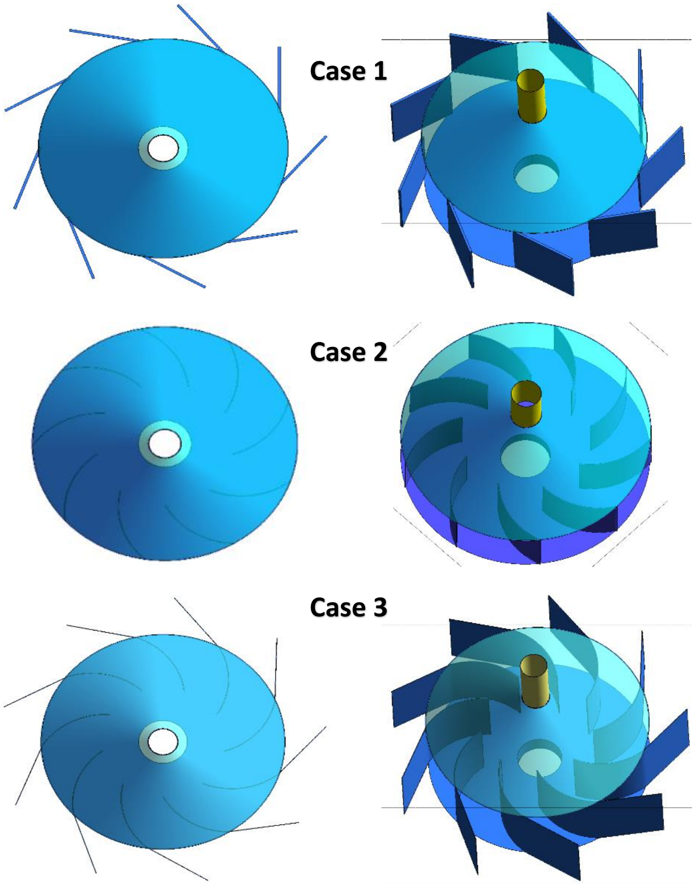


Fig.5. The three shapes being compared in guide vane

3. COMPUTATIONAL PROCEDURES FOR SIMULATION CASES

In this part, a mesh was created for each model and improved using the tools available in commercial program Ansys Fluent 2024 as shown in Fig.6, where Tetrahedrons were used to build the elements. Then, the elements to be worked on were named, namely air, aluminum, and glass, in order to enter the physical properties of the materials in the next stages. In addition to determining the air inlets and outlets shown in Fig.7, where the green color represents the external air velocity at 1 m/s, while in the intake pipe it is 0.1. Table 1 represents the results of the number of elements for each model and the number of nodes.

Table 1: Number of elements and nodes for each case

Model	Elements	Nodes
Case 1	1605770	303161
Case 2	1590573	299133
Case 3	1771099	335737

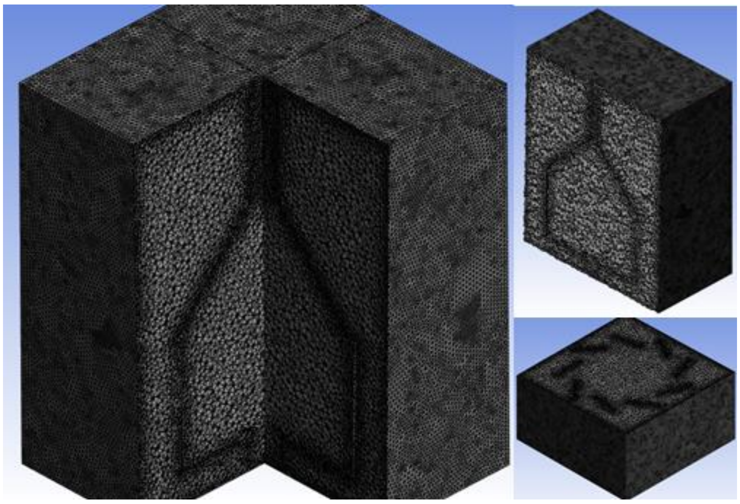


Fig.6. Generated mesh details

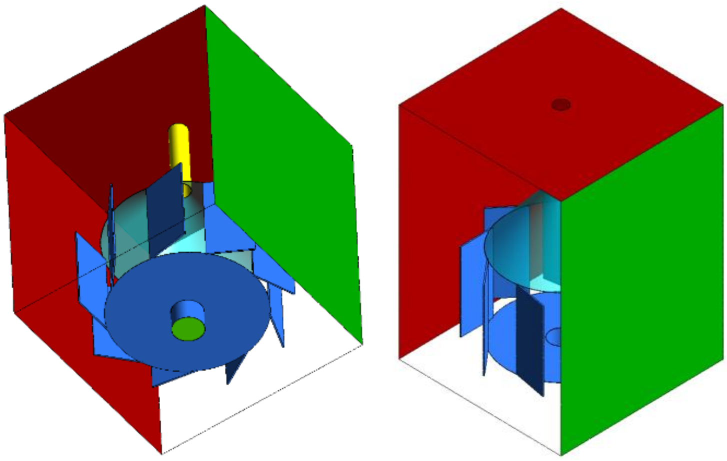


Fig.7. Air inlet and outlet location

4. MODEL VALIDATIONS

The proposed models were consistent with previous studies through the temperature distribution in the metal and glass parts. Through experimental procedures, it was shown that the metal surface has higher temperatures than the glass surfaces for different applications (Kaluba, Mohamad and Ferrer, 2020; Essa et al., 2022; Abdullah et al., 2023; Hussen et al., 2023; Elamy et al., 2024).

This is due to the fact that the thermal conductivity coefficient and the high absorption of solar radiation are greater in metals compared to glass. This proves that the proposed models have proven correct in the simulation. Simulations were conducted for all models, and they were consistent. The temperature distribution of the third model was shown, where the temperature of the metal surface was higher than the glass surface, as shown in Fig.8.

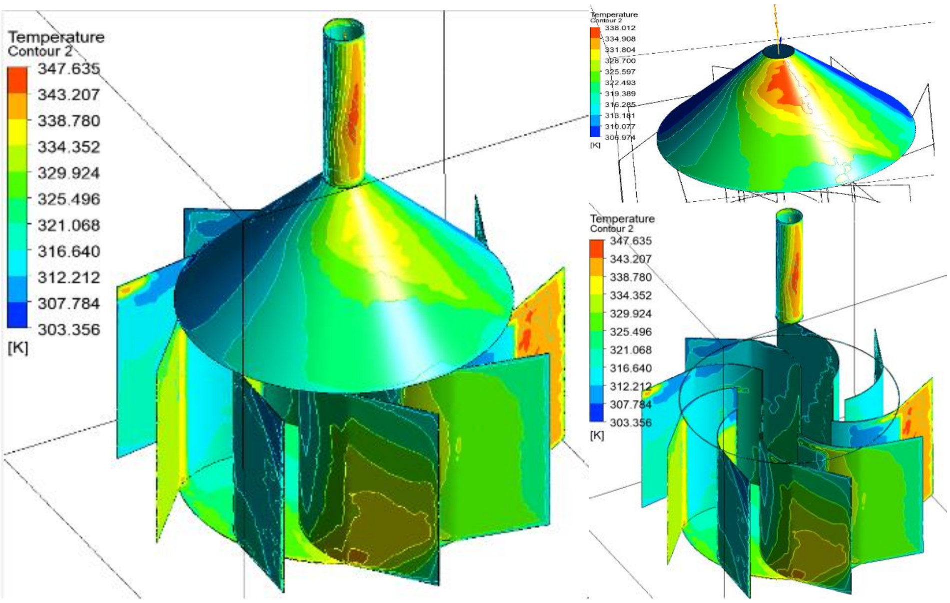


Fig.8. Temperatures distributions on surface to model 3

The pressure distribution of the three models was also simulated and was logical in distribution. The pressure distribution at the inlet was the largest possible and at the outlet it was smaller than that, therefore, the air current occurring due to the pressure difference. Also, the pressure distribution on the surfaces facing the inlet air stream is large due to the collision of the inlet air stream on the surface and raising the pressure in that area. The simulation results of the three models were consistent and the pressure distribution of the third model is shown in Fig.9.

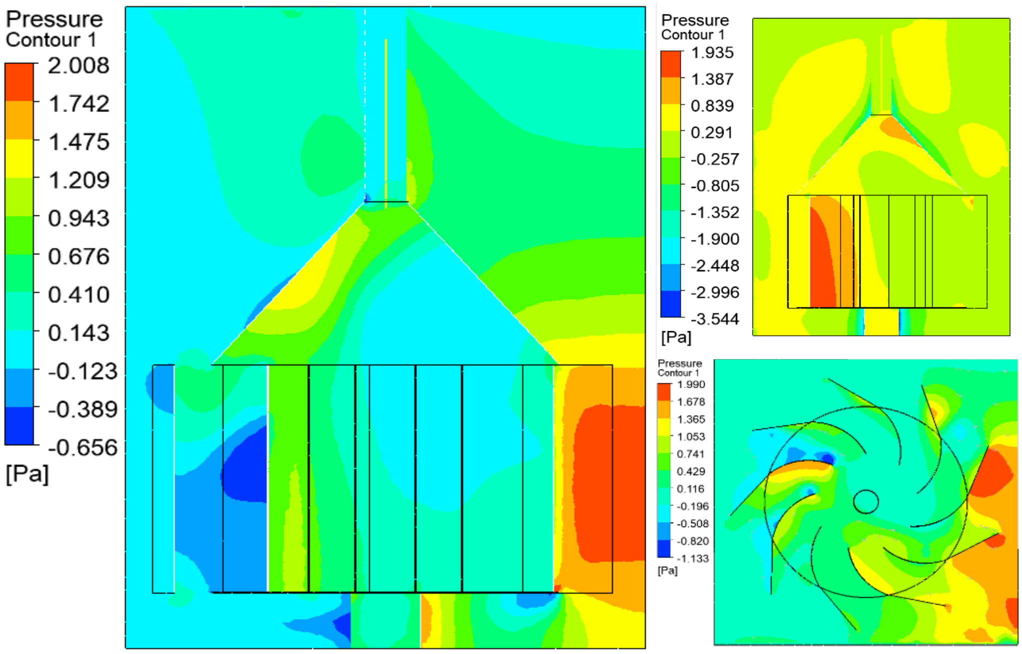


Fig.9. Temperatures distributions on surface to model 3

5. RESULTS AND DISCUSSIONS

After simulating the three proposed models, the results of the first model for temperature distribution were consistent with the results of the practical and theoretical literature, as the temperature of the metal surfaces was higher than the glass surfaces, and the pressure distribution over the inlet area and the surfaces facing the air stream entry was higher than in the rest of the model range. The outgoing air velocity was 1.019 m/s as shown in Fig.10. The simulation results of the second model regarding the temperature and pressure distribution were consistent, while the exit air velocity was 1.258 m/s as shown in Fig.10. The velocity distribution in the third proposed model is different as the outgoing air velocity increased to 1.672 m/s as shown in Fig.10.

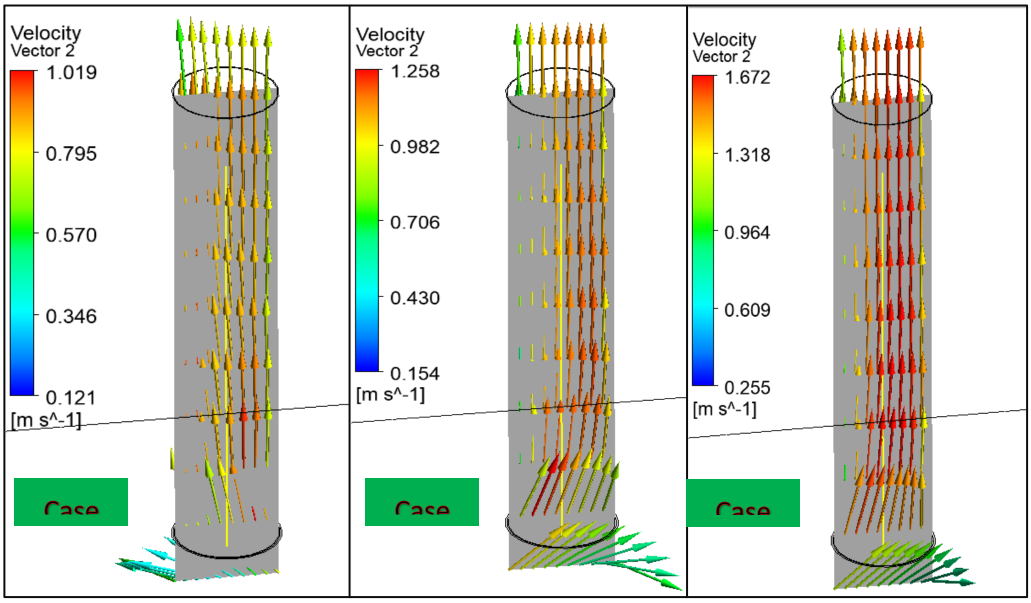
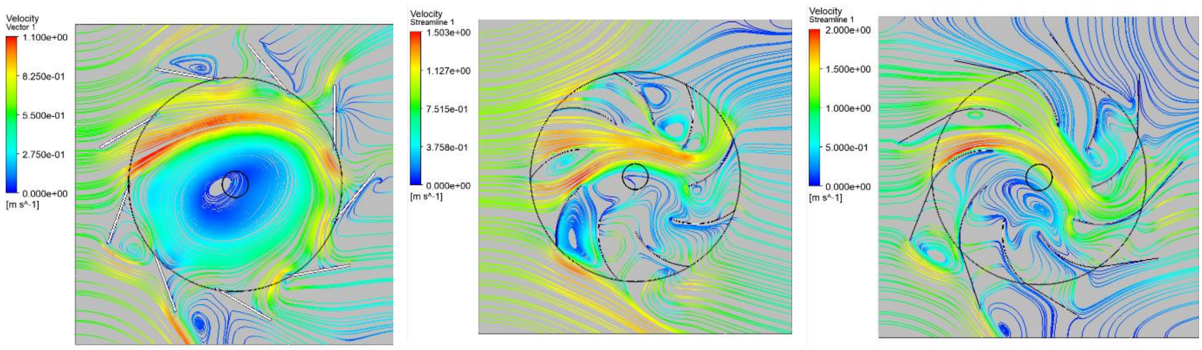


Fig.10 Velocity vectors for three cases

The results showed that the outgoing air velocity increased when the geometric shape of the moving surfaces of the three models was changed. Also, the generated vortex was different. The generated vortex of the first model was wrapped around the cone, and the repelling regions were characterized by sharp distribution, and the static regions were characterized by large static vortex, as shown in Fig.11.a. The results for the second model were that the exit velocity of the air stream increased slightly, and the generated vortices were farther away from the cone and the velocity curves followed a specific trend that tended to extend from the entrance area to the exit. The repelling areas were less severe and the static vortices were smaller as in Fig.11.b. The results of the third model showed that the exit speed of the air current increased more, and the generated vortex tended to flow more, extending from the entrance to the exit, and the static vortices moved away from the cone. Also, the repelling areas were characterized by greater smoothness, as in Fig.11.c.



(a) Case I **(b) Case II** **(c) Case III**

Fig.11. Velocity vectors for three cases top view, (a) case I, (b) case II, and (c) case III.

Fig.12 shows the exit velocity vortices of the third model from a different angle to generate an airflow velocity of 1.737 m/s. The results show that the third model is the recommended model because it generates the highest possible airflow velocity under the simulated conditions.

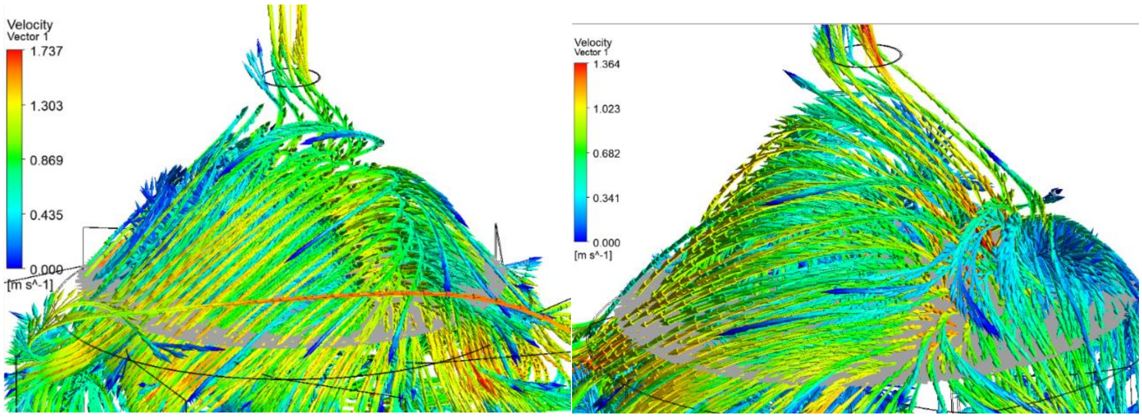


Fig.12. Velocity vectors for model 3 side view

6. CONCLUSIONS

To evaluate the effect of different vane geometries on the air velocity and thermal performance of hybrid solar vortex engine photovoltaic (HSVE.PV), this study performed a comprehensive computational fluid dynamics (CFD) investigation. Three arrangements were considered, with a wing with a pitch of 20°, a curved blade and a hybrid straight-curved blade. Each model was simulated under identical boundary conditions using the program ANSYS Fluent 2024, and the results were validated by comparison with previous experimental and numerical benchmarks.

Blade geometry influences airflow, vortices, and system performance, as indicated by the results. The hybrid layout achieved a top outlet pace of 1.737 m/s, which is 20% better than the bottom case. This is probably because it can maintain stable vortex systems and decrease losses. In addition, temperature and pressure distributions detected that the modified geometry take more functional energy conversion and improved internal flow stability. This study focuses on how important air flow which designing vortex-assisted solar chimney systems.

In addition to increasing airflow velocity, the third model that has been suggested also helps to improve PV surface cooling and possibly boost electrical generation efficiency. The development of more efficient renewable energy technologies will benefit from these insights, especially in areas with high solar irradiance.

Future studies need to incorporate brief simulations, strength and performance analyses, and huge-scale experimental validations underneath varying wind and heat masses to higher examine sensible applicability.

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7. REFERENCES

Abbood, M.H. and Abbas, M.R. (2018) 'Experimental study for ground type effect on solar chimney power plant', Kufa Journal of Engineering, 9(2), pp. 103–113. Available at: https://doi.org/http://dx.doi.org/10.30572/2018/kje/090208.

Abdullah, A.S. et al. (2023) 'Utilizing a single slope solar still with copper heating coil, external condenser, phase change material, along with internal and external reflectors—experimental study', Journal of Energy Storage, 63, p. 106899. Available at: https://doi.org/https://doi.org/10.1016/j.est.2023.106899.

Abed, R.H. and ghaydh, N.A. (2024) 'INVESTIGATION OF HYBRID PHOTOVOLTAIC/THERMAL SOLAR SYSTEM PERFORMANCE UNDER IRAQ'S CLIMATE CONDITIONS.', Kufa Journal of Engineering, 15(1). Available at: https://doi.org/https://doi.org/10.30572/2018/KJE/150101.

Ahmed, O.K. et al. (2022) 'Hybrid solar chimneys: A comprehensive review', Energy Reports, 8, pp. 438–460. Available at: https://doi.org/https://doi.org/10.1016/j.egyr.2021.12.007.

Alaskaree, E. (2025) 'OPTIMIZING HEAT TRANSFER IN INNOVATIVE SOLAR WATER HEATERS USING RECYCLED MATERIALS: ENHANCING EFFICIENCY AND SUSTAINABILITY', Kufa Journal of Engineering, 16(2), pp. 58–80. Available at: https://doi.org/https://doi.org/10.30572/2018/KJE/160204.

Ali, S.W.M., Jabbar, H.H. and Al-Shaibani, A.K. (2025) 'TECHNICAL AND ECONOMIC ANALYSIS OF RETROFITTING CONCENTRATED SOLAR COLLECTOR TO GENERATE THE THERMAL ENERGY REQUIRED FOR THE CRUDE OIL PRODUCTS

DISTILLATION PROCESS', Kufa Journal of Engineering, 16(2), pp. 197–214. Available at: https://doi.org/https://doi.org/10.30572/2018/KJE/160212.

Al-Kayiem, H.H., Mustafa, A.T. and Gilani, S.I.U. (2016) 'Vortex field simulation and analysis of a solar updraft power engine', WIT Transactions on Ecology and the Environment, 205, pp. 193–202. Available at: https://doi.org/10.2495/EQ160181.

Al-Kayiem, H.H., Mustafa, A.T. and Gilani, S.I.U. (2018) 'Solar vortex engine: Experimental modelling and evaluation', Renewable energy, 121, pp. 389–399. Available at: https://doi.org/https://doi.org/10.1016/j.renene.2018.01.051.

Al-Kayiem, H.H., Tukkee, A.M. and Gilani, S.I.U. (2022) 'Assessment of the design influence of the vortex generator on the performance of the solar vortex engine', Energy Conversion and Management: X, 16, p. 100283. Available at: https://doi.org/https://doi.org/10.1016/j.ecmx.2022.100283.

Boonloi, A., Sudsanguan, A. and Jedsadaratanachai, W. (2024) 'Crosswind and Vortex Usages for Electricity Production Enhancement of Solar Updraft Tower', Modelling and Simulation in Engineering, 2024(1), p. 4970781. Available at: https://doi.org/https://doi.org/10.1155/2024/4970781.

Cheng, Z., Kai, Z. and Zhu, S. (2023) 'Does green finance regulation improve renewable energy utilization? Evidence from energy consumption efficiency', Renewable Energy, 208, pp. 63–75. Available at: https://doi.org/https://doi.org/10.1016/j.renene.2023.03.083.

Das, P. and Chandramohan, V.P. (2020) 'Estimation of flow parameters and power potential of solar vortex engine (SVE) by varying its geometrical configurations: A numerical study', Energy Conversion and Management, 223, p. 113272. Available at: https://doi.org/https://doi.org/10.1016/j.enconman.2020.113272.

Das, P. and VP, C. (2025) 'Performance evaluation of solar vortex engine and optimization of number of air entry slots and turbine location', Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 47(1), pp. 2916–2932. Available at: https://doi.org/https://doi.org/10.1080/15567036.2020.1845879.

Elamy, M.I. et al. (2024) 'Enhancing spherical solar still thermal performance with built-in baffles, reflectors, and nanoparticle phase change material', Solar Energy, 284, p. 113060. Available at: https://doi.org/https://doi.org/10.1016/j.solener.2024.113060.

Essa, F.A. et al. (2022) 'Augmenting the performance of pyramid distiller via conical absorbing surface, reflectors, condenser, and thermal storing material', Journal of Energy Storage, 55, p. 105597. Available at: https://doi.org/https://doi.org/10.1016/j.est.2022.105597.

Hadi, A.-R.S., Alamili, A. and Kadhum, A.A. (2025) 'ROBUST SLIDING-MODE-BASED LEARNING FOR MAXIMUM POWER POINT TRACKING PHOTOVOLTAICS SYSTEM', Kufa Journal of Engineering, 16(2), pp. 249–262. Available at: https://doi.org/https://doi.org/10.30572/2018/KJE/160215.

Huang, M.-H. et al. (2020) 'Experimental and numerical studies for applying hybrid solar chimney and photovoltaic system to the solar-assisted air cleaning system', Applied energy, 269, p. 115150. Available at: https://doi.org/https://doi.org/10.1016/j.apenergy.2020.115150.

Hussein, A.S. and Ahmed, O.K. (2018) 'Assessment of the performance for a hybrid PV/solar chimney', International Journal of Engineering & Technology, 7(4.37), pp. 114–120. Available at: https://doi.org/https://doi.org/10.1016/j.apenergy.2020.115150.

Hussen, H.M. et al. (2023) 'An experimental comparison study between four different designs of solar stills', Case Studies in Thermal Engineering, 44, p. 102841. Available at: https://doi.org/https://doi.org/10.1016/j.csite.2023.102841.

Jaffar, H.A., Ismaeel, A.A. and Shuraiji, A.L. (2022) 'Review of hybrid photovoltaic-air updraft solar application: present and proposed state models'. Available at: https://doi.org/https://doi.org/10.5109/6625729.

Jaffar, H.A., Ismaeel, A.A. and Shuraiji, A.L. (2023) 'Performance Evaluation of Solar Vortex Updraft Air Generator under the Effect of Various Vanes Angles Operation Conditions', Applied Solar Energy, 59(5), pp. 647–664. Available at: https://doi.org/https://doi.org/10.30684/ETJ.V39I9.2145.

Jamel, M.S., Abd Rahman, A. and Shamsuddin, A.H. (2013) 'Advances in the integration of solar thermal energy with conventional and non-conventional power plants', Renewable and Sustainable Energy Reviews, 20, pp. 71–81. Available at: https://doi.org/https://doi.org/10.1016/j.rser.2012.10.027.

Jehhef, K. and Siba, M. (2018) 'MIXED CONVECTION HEAT TRANSFER IN TRUNCATED CONE ENCLOSURE AS SOLAR CONTAINER WITH INTERNAL CENTERED TRIANGLE OBSTACLE', Kufa Journal of Engineering, 9(4), pp. 286–307. Available at: https://doi.org/http://dx.doi.org/10.30572/2018/kje/090420.

Kaluba, V.S., Mohamad, K. and Ferrer, P. (2020) 'Experimental and simulated performance of hot mirror coatings in a parabolic trough receiver', Applied Energy, 257, p. 114020. Available at: https://doi.org/https://doi.org/10.1016/j.apenergy.2019.114020.

Kiwan, S. and Salim, I. (2020) 'A hybrid solar chimney/photovoltaic thermal system for direct electric power production and water distillation', Sustainable Energy Technologies and Assessments, 38, p. 100680. Available at: https://doi.org/https://doi.org/10.1016/j.seta.2020.100680.

Morton, O. (2006) 'Solar energy: A new day dawning?: Silicon Valley sunrise.', Nature, 443(7107). Available at: https://doi.org/10.1038/443019a.

Nada, S.A., El-Nagar, D.H. and Hussein, H.M.S. (2018) 'Improving the thermal regulation and efficiency enhancement of PCM-Integrated PV modules using nano particles', Energy conversion and management, 166, pp. 735–743. Available at: https://doi.org/https://doi.org/10.1016/j.enconman.2018.04.035.

Nie, J. et al. (2024) 'Influence of different flow models on numerical simulation of solar updraft tower', Applied Thermal Engineering, 257, p. 124221. Available at: https://doi.org/https://doi.org/10.1016/j.applthermaleng.2024.124221.

Odeh, S. and Behnia, M. (2009) 'Improving photovoltaic module efficiency using water cooling', Heat Transfer Engineering, 30(6), pp. 499–505. Available at: https://doi.org/https://doi.org/10.1080/01457630802529214.

Pandey, A.K., Kumar, R. and Samykano, M. (2022) 'Solar energy: direct and indirect methods to harvest usable energy', in Dye-Sensitized Solar Cells. Elsevier, pp. 1–24. Available at: https://doi.org/https://doi.org/10.1016/B978-0-12-818206-2.00007-4.

Rahimi-Larki, M. et al. (2025) 'Performance investigation of a sloped collector solar chimney system exposed to the ambient crosswind', Energy, p. 134732. Available at: https://doi.org/https://doi.org/10.1016/j.energy.2025.134732.

Rtemi, L.A., El-Osta, W. and Attaiep, A. (2023) 'Hybrid system modeling for renewable energy sources', Journal of Solar Energy and Sustainable Development, 12(1). Available at: https://doi.org/https://orcid.org/0000-0003-3573-2546.

Sebestyén, V. (2021) 'Renewable and Sustainable Energy Reviews: Environmental impact networks of renewable energy power plants', Renewable and Sustainable Energy Reviews, 151, p. 111626. Available at: https://doi.org/https://doi.org/10.1016/j.rser.2021.111626.

Simpson, Ms.W., Pearlstein, A.J. and Glezer, A. (2012) 'Power generation from concentrated solar-heated air using buoyancy-induced vortices', in Energy Sustainability. American Society of Mechanical Engineers, pp. 585–593. Available at: https://doi.org/https://doi.org/10.1115/ES2012-91437.

Singh, J. et al. (2024) 'Study of vortex dynamics in a solar tower vortex generator', Energy Conversion and Management, 316, p. 118824. Available at: https://doi.org/https://doi.org/10.1016/j.enconman.2024.118824.

Stevanović, Simo, Stevanović, Snežana and Živković, R. (2022) 'Advantages and disadvantages of solar energy production and use', Journal of Agricultural, Food and Environmental Sciences, JAFES, 76(4), pp. 65–70. Available at: https://doi.org/https://doi.org/10.55302/jafes22764065s.