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EDITOR: PROF MTE KAHN

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Editor's Synopsis

This Proceedings includes the papers presented at the 3rd Energy and Human Habitat Conference which took place between 28-29 November, 2022, in Cape Town, South Africa as a face to face event at the Castle of Good Hope.

The Conference was organized by the African and International Use of Energy platform consisting of academics from the Cape Peninsula University of Technology, the University of the Western Cape, University of South Africa, and University of Stellenbosch. The organizing committee, advisory board and review board, as well as the editors are grateful to the delegates who had submitted and presented papers.

The conference papers included experimental as well as overview studies applicable to Energy and the application or enhancement of human habitat. Although the conference was open for inclusion of studies from an energy policy and energy economics perspective, almost all the papers received in this call were of a more technical nature.

The conference received papers via its online submission platform and responded by related email. Reviews were double blind with two reviewers per paper and a third editorial review for decision to include the paper in the proceedings. Several paper abstracts were received but was not of sufficient quality to meet initial review requirements and some were also outside the scope of the conference. The conference received over 48 abstracts and received 38 papers as submissions. Only 21 papers were accepted and graded for inclusion in this Proceedings after peer review and these included only highly positive reviews with minimal corrective work.. The rejection ratio of papers was 44% rejection.The highest single institution papers accepted for publication was 28%, hence meeting the South African DHET requirement.

The authors were required to avail themselves for a face to face presentation with session chairs at the conference venue.

Prof MTE Kahn

Energy Institute, Cape Peninsula University of Technology

28 November 2022

Opening Remarks

Dr Marco Adonis, HOD , DEECE, CPUT

3rd Energy and Human habitat Conference

28 & 29 November 2022, Castle of Good Hope, Cape Town, South Africa

Distinguished Participants, Colleagues, Ladies and Gentlemen,

Good Morning.

I am very honoured to deliver opening remarks on behalf of the Department of Electrical Electronic and Computer Engineering of the Cape Peninsula University of Technology, at this esteemed Conference.

I would like to welcome all participants for their keen interest and enormous efforts to make this meeting possible.

At the outset, I would like to thank co-organizers of this event. My special thanks goes to Professor Mohamed Tariq Kahn, Director of the Energy Institute, and Convenor of this Conference. Prof Kahn have been at the helm of the energy conferences since 2012 and have done a first for us in organising this event at the Castle of Good Hope. A Special Thanks to the Organising Committee, and the Review Committee, the Session Chairs and the many students and staff that were involved in making this event happen here today. For two years the conference continued as a digital event, and this is the fist face to face event since 2019.

I think you, the delegates here, will be more experienced and knowledgeable than myself on the theme of Energy and Human Habitat . So my remarks will be very short. I just would like to highlight the huge potential of Energy Technology in the achievement of SDGs , which are an important international achievement for the 2030 goals and beyond.

More than 700 million people on the African continent still do not have access to modern, productive energy sources, and many of them continue to use antiquated, ineffective traditional energy sources. The difficulty is still in successfully and sustainably getting this solution to the most remote off-grid areas, even though the answers already exist.

Energy poverty is still a problem, and many homes haven't been able to connect to the electricity despite significant attempts to expand the grid to several towns, produce more megawatts, and offer various "low cost" energy products and services for the "poor". Microgrids and effective use of modern technological advances hold the key to bridge the gap with Human Habitat and electrification. Grid extension alone does not provide energy access as long as the end-use energy dilemma is not resolved.

In addition to this, since the Paris Agreement went into force in 2016, reducing greenhouse gas emissions has become another important mission for all. Our nation is embarking on the Just Transition in the Energy sector to address concerns with job losses and re-skilling that could be associated with such a change from fossil fuels to renewables. This is why Conferences like these are important. To create networks of researchers that can share their views and ideas in order to create better understanding and co-operation.

I would like to thank all the presenters, facilitators, and participants, for making the time to be here. Thank you

3rd Energy and Human Habitat Conference 2022

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The conference disseminates original research and new developments which are published in this conference proceedings. The conference covers the following disciplines in the field of energy:
Energy and Society,
Smart Energy
Renewable Energy
Blockchain and smart contracts in energy
Smart Grids, Microgrids and Minigrids
EV and Electric Transportation
Energy Storage and Power Electronics
Energy Efficiency
Energy Economics
Energy Development

Publications produced for the conference

The following publications ensure that the research reports given during the conference are disseminated widely

Conference Proceedings

The conference proceedings contain full papers which are subjected to a blind peer review process.

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The target audience for the proceedings are specialists in the field.

Editorial and the Review Process

Our review board consists of international and national experts in specialist fields covered in the conferences. They are from different academic institutions, and from industry. Authors are invited to submit an abstract prior to submission of a paper. The abstracts of proposed conference papers are sent for evaluation, and only accepted abstracts would lead to the invitation to submit a full paper which is then reviewed by no less than two reviewers. A third editorial review is done before the papers are accepted for publication in the proceedings.

The Chairman and/ or Conference Administrator informs each main author of the outcome of the evaluation timeously, inviting the successful author(s) to submit a print-ready manuscript in accordance with possible comments and the instructions and guidelines provided in the conference paper template.
The author submits his paper via the electronic paper submission and review process, indicating the original paper number.

Upon receipt of the manuscript the paper is sent for review to at least two members of the editorial panel who specialise in the disciplines covered in the paper. Reviewer members of the editorial panel, review the paper by answering specific questions, indicating if the paper meets specific set criteria. A separate section allows for comments on the quality of the paper addressed separately to the editors and to the authors. These comments often also indicate what needs to be done to improve the quality of the paper. The reviewer has the option to attach an annotated copy of the manuscript which is returned to the authors with the review reports.

Once sufficient reviews have been received, the Conference Chair and/or Administrator informs the author(s) of the outcome of the evaluation, which is either that the paper is rejected or accepted for publication in the proceedings, or the author may be invited to improve the paper in line with recommendations from the editorial panel and then resubmitted.

The papers are checked and corrected for typographical errors and adherence to the template provided, which satisfies also the requirements of the digital repository styleguide. Only papers which have been accepted by the editor(s) are published in the conference proceedings.

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Originality - Novel and interesting, warranting publication. The paper contains original research and /or new developments
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Introduction: It clearly states the objective and the problem being investigated
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Result: The analysis and/or model is clearly presented, in a logical sequence and discussed sufficiently.
The paper is technically sound.
Conclusion: Claims are supported by the results and are reasonable, sound and justifiable
Reference: References are complete, adequate and appropriate
Figures and tables: All necessary and acceptable, suitable for a quality publication?
Units formulas and abbreviations conform to accepted standards

AIUE Proceedings of the 3rd Energy and Human Habitat Conference 2022

SIMULATION BASED HEAT ENHANCEMENT FOR CONCENTRATED SOLAR POWER

Author Deen Ismail Ebrahim[a], Dr. Fareed Ismail[b], Dr. Saleh Khamlich[c], Dr. Ouassini Nemraoui[d]

Abstract:

Conventional CSP systems experience laminar flow through the heat collection pipe. By introducing physical changes to this pipe turbulent flow could be created to enhance heat absorption.

Various models to create turbulent flow are discussed of which three designs were considered for simulated turbulent flow in CSP applications. The designs are based on helical coil insert, pin protrusions and dimple insert. Various parameters were set such as heat flux and fluid speed to achieve turbulent simulation.

The helical coil insert was found to best suited for heat enhancement. The results indicate the helical coil enhancement can increase the overall efficient of a CSP by 20% -30%, based on the thermal performance of 1,2-1,3. This indicates negligible pressure drop for an increase in heat transfer.

The efficiency depends on the radiation's uniformity on the receiver, an insight gained from the study is that the less uniform the radiation, the more efficient the helical coil will perform. Another advantage the coil has; is that it reduces the thermal stress by the fluid wall domain. This is all due to the 3-dimensional vortex generated by the helical coil.

The study recommends experimenting with variations in the parameters of the helical coil insert. Turbulent flow in the heat collection pipe has an advantage of extracting more heat generated by sun therefore having the possibility of increasing the efficiency of CSP systems.

Keywords:
CSP, Heat enhancement, renewable energy, vortex generator, solar collector,CFD

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I. INTRODUCTION

The world is currently facing an energy crisis, which has been further illuminated by the current COVID-19 pandemic. Energy provides the means for humans to meet their essential needs. Yet, fossil fuel generated energy which is still being used has negative environmental and health effects. [1], [2]

It is essential that renewable energy solutions be found. Countries that have a high level of solar radiation are excellent for solar thermal heating applications.

Concentrated Solar Power (CSP) Technology has the unique advantage of achieving higher intensity of energy in a small amount of surface area. This advantage makes it possible for small scale energy plants, with adequate system efficiency.[3]

The most mature CSP Technology is the parabolic trough collector in Fig. 1. Researchers undertook a study on the recent advances of CSP's and indicated the need to investigate new techniques for performance enhancement of the system. [4]

Turbulators, increase the turbulence within the receiver, which increases the heat transfer capacity. This is done by directing the energy more to the working fluid which reduces energy lost to environment.[4]

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Fig. 1 Parabolic Trough Collector [4]

Four different types of turbulators were simulated to find the effect it will have on parabolic trough CSP systems.

II. OBJECTIVES

The four turbulators considered will be helical coil, pin, dimple and fin insert. The simulation focuses on the practical application of these heat enhancement methods. To evaluate which heat enhancement performs better the following objectives must be met:

i. Design suitable turbulators for CSP application.
ii. Simulate heat enhancement based concepts on Fluent a component of ANSYS, a multi-physics engineering simulation software.
iii. Compile and evaluate the heat transfer results.

III. TURBULATORS

Turbulators or Heat transfer enhancement techniques improve the heat transfer rate by two passive methods. They either increase the contact area or increase turbulence.

Table 1 briefly summarizes the working fluid behaviour of 4 turbulator design methods.

Table 1 Summary of heat enhancement methods

Concept[2]	Brief explanation
Helical insert	Generates swirl through a spiral flow motion. [4], [5]
Pin inserts	Separates flow at pin causing mixing after.[6], [7]
Dimple insert	Similar to pin but more aerodynamic shape.[8], [9]
Fin insert	Forcefully alternates flow to mix in different direction.[10], [11]

The concept developed are constraint by minimal are alteration to ensure minimal pressure drop.

Each concept will follow strict volume and added along the complete length of the receiver, which can be seen in Fig. 2, 3, 4, 5. Obtaining which enhancement will be best for CSP application.

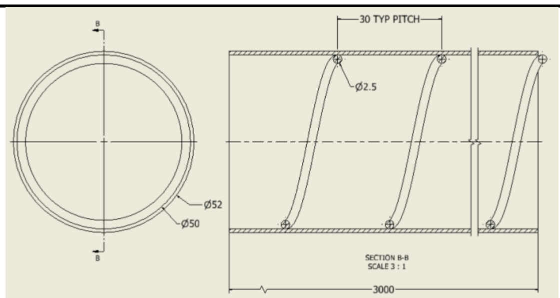

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Fig. 2 Helical Coil insert

Fig. 2 depicts the helical coil insert, which is based on a standard spring being inserted into the pipe. The standard spring size is 5 mm diameter and 30 mm pitch.

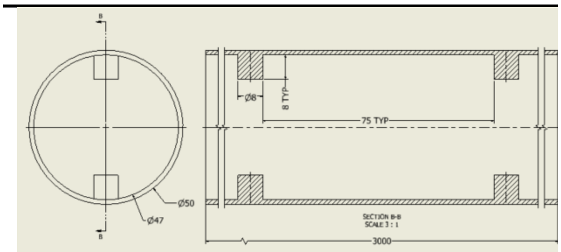

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Fig. 3 Pin Protrusion

The pin protrusion depicted in Fig. 3, is a cylinder with diameter of 8 mm and 8 mm long. The pin protrusion occurs every 75 mm throughout the receiver's length.

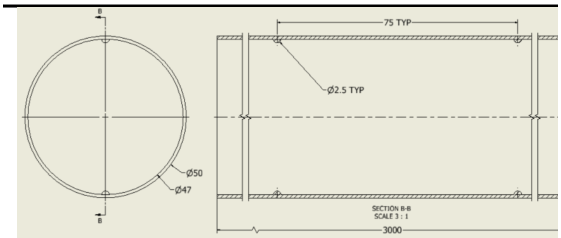

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Fig. 4 Dimple insert

Fig. 4 illustrates the dimple insert which is a half a sphere with diameter of 2.5 mm. The dimple insert occurs every 75 mm throughout the receiver's length.

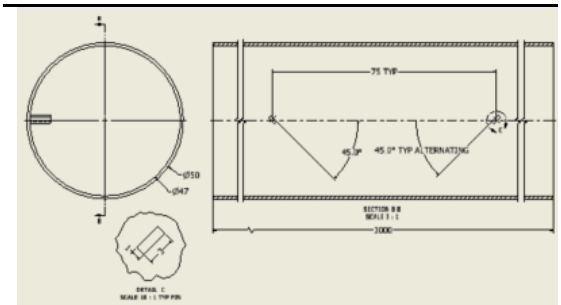

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Fig. 5 Fin insert

The fin inserts given in Fig. 5 is a rectangle,1 mm x 3mm, extruded 8 mm high. The fins alternate by 45° and -45° every 75 mm throughout the length of receiver.

Each concept is based on a 3 m long pipe, with a 50 mm outer diameter and 47 mm inside diameter. The selection of sizes was based on local steel pipe suppliers. The other local sizes did not match up well to the standard spring sizes.

IV. NUMERICAL METHOD

ANSYS software was utilised to perform a numerical simulation of the four concepts. The software utilises continuity, momentum and energy governing equations are used to describe the flow and heat transfer based on the assumptions in following section.[12].

The method utilized in this simulations study is broken down into assumptions, models, boundary conditions, mesh generation, scheme and validation.

i. Assumptions

The numerical simulation is established on the following assumptions:

- Only the fluid domain will be simulated, Therefore the wall thickness and material of pipe is negligible.
- Flow is steady, 3-dimensional & turbulent.
- Pressure based system.
- No heat generation/radiation, only heat flux on walls of the pipe.
- Gravity & buoyancy is negligible.
- Fully developed inlet velocity.
- 5% turbulent intensity inlet velocity.
- Air considered as working fluid.

The heat flux will be investigated for both partially and fully induced on the pipe wall. This give insight into how these enhancements will perform practically.

ii. Model

Model portion is broken up into two portions the turbulence model and the model selected to solve the governing equations.

Turbulent flow causes fluctuations in velocity which results in fluctuations in within the momentum and energy equations. Thus, the governing equations are modified to account for these fluctuations. The approach divides all quantities into sum of timemean quantity and fluctuating quantity. The steady state modified continuity, momentum and energy are given in equation 1, 2, 3, 4, 5.

$$\frac{\partial(p\bar{u})}{\partial x}+\frac{\partial(p\bar{v})}{\partial y}+\frac{\partial(p\bar{w})}{\partial z}=0 \qquad \text{Eq(1)}$$

$$\frac{\partial(p\bar{u})}{\partial t}+\frac{\partial(p\bar{u}\bar{u})}{\partial x}+\frac{\partial(p\bar{v}\bar{u})}{\partial y}+\frac{\partial(p\bar{w}\bar{u})}{\partial y}= -\frac{\partial\bar{P}}{\partial x}+(\mu_t+\mu)\left(\frac{\partial^2\bar{u}}{\partial x^2}+\frac{\partial^2\bar{u}}{\partial y^2}+\frac{\partial^2\bar{u}}{\partial z^2}\right) \qquad \text{Eq(2)}$$

$$\frac{\partial(p\bar{v})}{\partial t}+\frac{\partial(p\bar{u}\bar{v})}{\partial x}+\frac{\partial(p\bar{v}\bar{v})}{\partial y}+\frac{\partial(p\bar{w}\bar{v})}{\partial y}= -\frac{\partial\bar{P}}{\partial y}+(\mu_t+\mu)\left(\frac{\partial^2\bar{v}}{\partial x^2}+\frac{\partial^2\bar{v}}{\partial y^2}+\frac{\partial^2\bar{v}}{\partial z^2}\right) \qquad \text{Eq(3)}$$

$$\frac{\partial(p\bar{u})}{\partial t}+\frac{\partial(p\bar{u}\bar{w})}{\partial x}+\frac{\partial(p\bar{v}\bar{w})}{\partial y}+\frac{\partial(p\bar{w}\bar{w})}{\partial y}= -\frac{\partial\bar{P}}{\partial z}+(\mu_t+\mu)\left(\frac{\partial^2\bar{w}}{\partial x^2}+\frac{\partial^2\bar{w}}{\partial y^2}+\frac{\partial^2\bar{w}}{\partial z^2}\right) \qquad \text{Eq(4)}$$

$$\frac{\partial(pc_p\bar{T})}{\partial t}+\frac{\partial(p\bar{u}c_p\bar{T})}{\partial t}+\frac{\partial(p\bar{v}c_p\bar{T})}{\partial t}+\frac{\partial(p\bar{w}c_p\bar{T})}{\partial t}=k\left(\frac{\partial^2\bar{T}}{\partial x^2}+\frac{\partial^2\bar{T}}{\partial y^2}+\frac{\partial^2\bar{u}}{\partial z^2}\right)+\frac{\partial}{\partial x}\left(\frac{\partial\bar{T}}{\partial x}\frac{c_p\mu_t}{\sigma_t}\right) \qquad \text{Eq(5)}$$

Where $\bar{u},\bar{v},\bar{w}$ is velocity fluctuations. Also, $\bar{P}$, $\bar{T}$ are time-average pressure and temperature flow parameters. The subscript t for both μ_t,σ_t flow terms are turbulent viscosity and a constant developed by relating eddy-viscosity and turbulent diffusivity. c_p is the specific heat at constant pressure.

The k-ε turbulent model can be used to calculate the turbulent constants developed. The model is perfectly suited because it is robust, accurate and widely used model. [13]

This consist of two model equations, one for turbulent kinetic energy, k, derived from exact equation. The other for dissipation rate, ε, which is obtained by physical reasoning and mathematically derived.

Within these equations are defined terms which represent the fluctuations caused by turbulent flow. In Table 2, the adjustable experimental determined constants are given.

Table 2 k-ε experimental constants[14]

Constants expressed by symbols[7]	Physical representation	Value
$C_{1\varepsilon}$	Rate of production for dissipation.	1.44
$C_{2\varepsilon}$	Rate of destruction for dissipation.	1.92
C_{μ}	Turbulent-eddy viscosity	0.09
σ_{ε}	Transport of dissipation by diffusion.	1.3
σ_{k}	Transport of turbulent kinetic energy by diffusion	1

The modified governing equation, including the turbulence models, require boundary conditions to set constraints to boundary value problem.

i. Boundary conditions

Fig. 6 illustrates the BC's position on the fluid domain for all simulations. The boundary conditions consist of a wall, inlet and outlet.

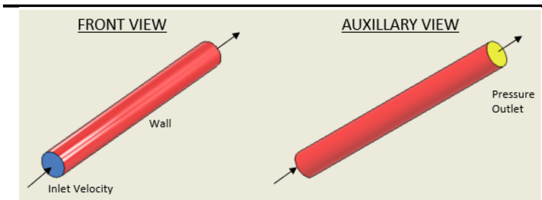

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Fig. 6 Boundary Condition Illustration

Plain pipe, dimple, fin and pin simulations utilised symmetry boundary condition by reducing it to a quarter circle pipe. Thus, improving the performance of those simulations, it can be seen in Fig. 7 on the meshing models.

The inlet boundary conditions location is indicated in blue on Fig. 6. As depicted on the image the flow is perpendicular to the inlets face, Table 3 gives all constraints set for inlet boundary condition.

Table 3 Inlet boundary condition

Inlet[9]	**Detail**
Velocity Magnitude	Re =20 000 – 100 000
Initial gauge pressure [Pa]	100
Turbulence intensity [%]	5
Temperature [K]	300

The outlet boundary condition is located in yellow on Fig.6. In Table 4 all constraints are given for outlet boundary condition. The flow is perpendicular to the outlets face.

Table 4 Outlet boundary condition

Outlet[10]	**Detail**
Gauge pressure [Pa]	0
Turbulence intensity [%]	5
Temperature [K]	300

The wall boundary condition is located in red in Fig. 6. This condition differs only when considering the full and partial heat flux.

For the partial heat flux case, the wall will be split into two to represent the partial flux. Thus, one wall will have a flux and the other will not.

The wall boundary condition constraints with a heat flux is given in Table 5. The other condition would be the same only without a heat flux.

Table 5 Wall boundary condition

Wall[11]	**Detail**
Wall motion	Stationary
Shear condition	No slip
Wall roughness	Height 0 [mm] Constant 0.5
Heat flux [W/m^2]	2032 & 0 for the partial case.
Turbulence intensity [%]	5
Temperature [K]	300

i. Mesh generation

Meshing refers to an overall computational domain broken up into elements. Each element contains the discretised governing equation. Fluent provides two method for meshing the domain. Global overall meshing scheme for whole body and local more controlled to specific features.

The plain pipe, dimple and fin models all have the same global mesh curvature size function. This function captures the curve pipe surface best. The pin and coil models utilised adaptive size function because the other methods mesh quality was insufficient.

Local meshing such as edge sizing and inflation was used for all models. To refine mesh by complex geometry and account for turbulence. Only multi-zoned method was used for the plain model to include the uniformity of the cross section.

All enhancement utilised instead patch independent method because the cross section would change. The coil insert had the most complexity in terms of geometry. Thus, a polyhedral mesh was used instead of default tetrahedral shape. The polyhedral performs better for gradient calculations and requires less elements, which is ideal considering the complexity of the oil insert. Fig. 7 demonstrates a section view of each mesh strategy.

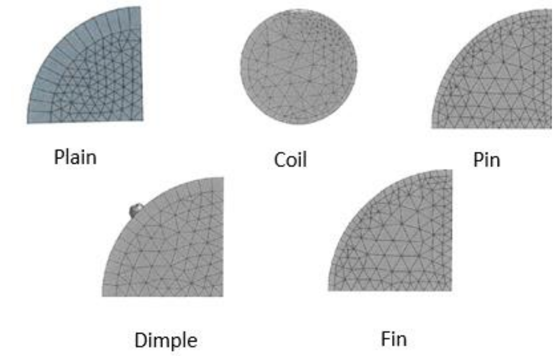

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Fig. 7 Meshing Strategy

i. Scheme

The scheme selected was the simple algorithm based on the convergence and accuracy needed. The algorithm is based on pressure -velocity coupling which convergences to a solution by guessing initial flow parameters. A flow chart of the algorithm is given in Fig. 8.

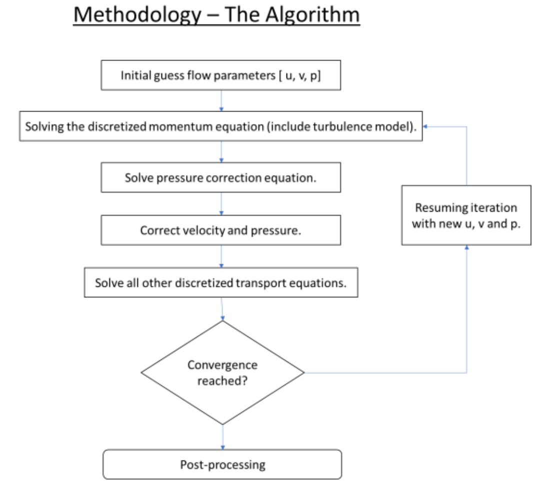

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Fig. 8 Methodology - The algorithm

Spatial discretisation is a method utilised for solving partial differentiation with a specific scheme related to space within the governing equations. The method selected for discretization is Green-gauss node based. This will be beneficial due to its accuracy in measuring irregular shapes.[15]

Presto's pressure scheme was also selected on Fluent for its accuracy in high Reynolds numbers and swirl. Similarly, second order upwind approximations were selected for accuracy.[10], [16]

ii. Validation

The quality of the mesh is validated in two ways. A grid independent study and the actual shape of the elements.

The grid independent study varies the number of nodes in a simulation only to evaluate the change in the output of simulation.

The results of the grid independent study based on the frictional factor indicates less than 5% error with variations in the number of nodes from 7500 to 90000.

The quality of the shape of the element determines quality of information captured. The aspect ratio of the shape gives insight into the quality. Every mesh was built with large aspect ratio to ensure good shape quality.

V. Results and Discussion

Thermal performance factor gives an indication of the improvement of heat enhancement against the energy required to move the liquid through the pipe. This factor applies perfectly with the application of CSP receiver and will be used to evaluate the best enhancement The equation below represents the thermal performance.

$$\eta = \frac{Nu/Nu_{plainpipe}}{f/f_{plainpipe}} \qquad \text{Eq(6)}$$

The equation indicates the ratio of heat transfer enhancement and friction between the enhancement and the plain pipe. The thermal performance for all concepts with full heat flux is given in Fig. 9.

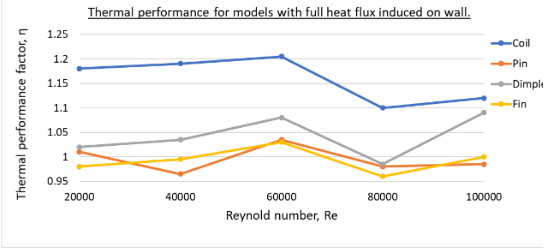

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Fig. 9 Thermal performance for model with full heat flux

It can be clearly seen in the graphics that the helical coil insert far outperforms the other models. The helical coil generates a 3-dimensional vortex which maximises the mixing within the pipe. More specifically, a phenomenon of maximum mixing occurs at 60000 Reynolds, where the maximum thermal performance occurs for the coil.

The dimple enhancement follows with the pin and fin thermal performance being very similar.

The partial heat flux case which evaluates the practical non-uniform is shown in Fig. 10.

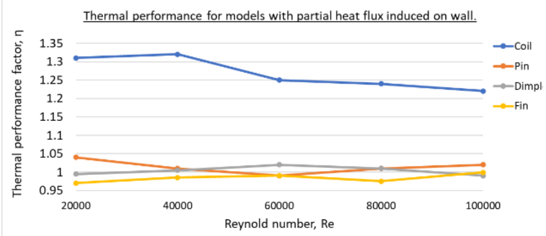

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Fig. 10 Thermal performance for model with partial heat flux

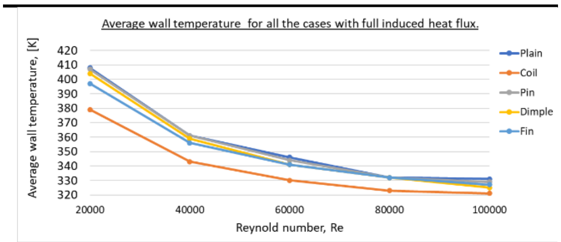
Once again, the coil exceeds all other enhancement methods, even improving its previous performance for a full heat flux.

All other enhancements had minimal thermal performance advantage when the wall is partial heated.

The thermal performance of the helical coil outperforms each of the other enhancements by 15% for a full heat flux, but when the radiation is not uniform this is increased to 25%.

The coil is perfect for practical CSP application. Base on the thermal performance findings, the coil enhancement can increase the overall efficiency by 20 -30% depending on the uniformity of the radiation.

The fluid wall temperature for all enhancements with full heat flux is given in Fig. 11. This indicates the amount of thermal stress experienced by the model. The less thermal stress, the better for deformation prevention and the life cycle receiver.

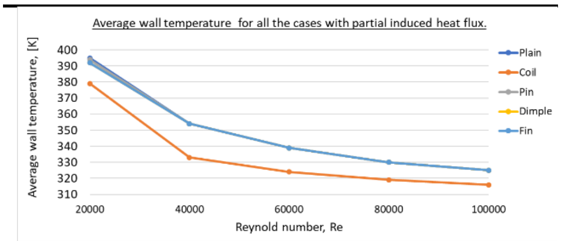


16

Fig. 11 Average wall temperature for all cases with full induced heat flux

The coil experiences the least thermal stress compared to other models. The helical coil passively distributes the heat evenly because of the 3-dimensional vortex developed.

Once more, the partial heat flux case is evaluated for practical application purposes in Fig. 12.



17

Fig. 12 Average wall temperature for all the cases with partial induced heat flux

All enhancements except the coil have minimal effect on the average wall temperature when a partial heat flux is induced.

The coil insert induced swirl and a 3-dimensioal vortex which reduced the fluid wall temperature drastically. Due to the bulk of the heat being distributed in the centre of the pipe.

VI. CONCLUSIONS AND RECOMMENDATION

The pin, coil, dimple, and fin concepts were developed based on heat enhancement method research.

The results indicate the helical coil enhancement can increase the overall efficient of a CSP by 20% -30%, depending on radiations uniformity. Which drastically outperforms the other heat enhancement methods simulated.

Another advantage which outperforms the other heat enhancements, is the 7% reduction in thermal stress experienced by the coils' fluid domain. This is all due to the vortex generated by the helical coil.

The findings indicate the helical coil enhancement has application within the solar collector of a CSP. Furthermore, a recommendation to investigate variations in the helical coil parameters can possibly lead to further efficiency increases.

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