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Design, Fabrication and Testing of Solar Spiral Collector with Lenses considering induced vibrational effects

A Thesis Submitted to the Council of College of Engineering University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in mechanical Engineering

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

* وَالشَّمْسُ تَجْرِي لِمُسْتَقَرٍّ لَهَا ذَٰلِكَ تَقْدِيرُ الْعَزِيزِ الْعَلِيمِ *

صَدَقَ اللَّهُ العَظِيم

سورة يس – الآية (38)

Dedication

In the Name of ALLAH, the most Merciful, the most Compassionate.

The current study is dedicated to My great teacher and messenger, Mohammed (May Allah bless and grant lime).

*To My Family {**My Father, My Mother, My Brother and My Sisters**}*

***All-Sincere** and **Good People** where they are in the world.*

My Lovely Country Iraq.

Marwa Mohammed Raheem 2021

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Abstract

This study was divided into two parts. The first part deals with fabricating, testing and simulating of two scenarios of solar heating water system with spiral collector. The main part of the first scenario includes a traditional spiral solar collector with an area (0.5) m^2 while the second scenario includes the same spiral collector integrated with lens. Generally, each scenario consists from storage tank, pump and instrumentation of measurements. The main objective of the first part is to study and analyze the effect of using lens in enhancing the thermal performance of the spiral collector. In order to measure and analyze the thermal performance under the effect of different weather data, the experiments were carried out at the period between 1^{st} December to15^{th} February 2020 from 8:30 AM to 2:30 PM. The experimental results show that the maximum outlet temperature, useful energy, and the efficiency were recorded about 21 ^{o}C, 109W and 35 % respectively in the case of spiral collector without the lens. While, in the case of spiral with lens was found to be about 32 ^{o}C, 178W and 61 % respectively. As compared between the two scenario, the lens has enhanced the useful heat gain and efficiency of a spiral collector by 72.2 W and 28.4 % during three months. In parallel, the fluent under ANSYS simulation was used to simulate the behavior of the two scenarios of spiral collector. The simulation results show that a good a agreement with the experimental results.

On the other side, the second part of the study deals with fabrication and testing a vibration system to measure the natural frequency that take place on spiral pipe due to the effect of temperature and mass flow rate of water. The experimental results of vibration show that the increasing of water temperature and mass flow rate lead to an increase in the frequency and natural frequency due to the kinetic energy of the fluid.

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Latin Symbols

Symbol	Description	Unit
A_a	Aperture area	m^2
A_r	receiver area	m^2
A_t	lens focus area	m^2
C_p	Specific heat capacity under constant water	J/kg.k
C_r	concentration ratio	…….
D_o	outer diameter of tube	M
D_i	inner diameter of tube	M
F'	collector efficiency factor	…….
F_R	collector heat removal factor	…….
F_n	Natural frequency	Hz
h	heat transfer coefficient	$W/m^2.^oC$
h_{air}	heat transfer coefficient of air	W/m^2
h_f	heat transfer coefficient tube of fluid	$W/m^2.K$
I	Intensity of solar radiation	W/m^2

I_b	Hourly beam radiation	W/m^2
I_d	Hourly diffuse radiation	W/m^2
I_g	Hourly global radiation	W/m^2
I_T	Flux on tilted surface	W/m^2
I_t	intensity solar radiation with lens	W/m^2
I_{bn}	Beam radiation in the direction of the rays	W/m^2
K	thermal conductivity	W/m. ^oC
k	Element stiffness	N/m
L	length of absorber plate	M
m´	Mass flow rate of fluid through the collector	kg/s
m	Element mass	Kg
N_u	Nusselt number	…….
P_r	Prandtl number	…….
Q_{abs}	absorbed heat rate	W
Q_{conv}	convocation heat transfer	W
Q_{loss}	loss heat transfer rate	W
Q_{rad}	radiation heat transfer	W
Q_s	Solar energy	W
Q_u	Useful heat gain	W
R_b	Beam radiation	…….
R_d	Diffuse radiation	…….
R_r	Reflected radiation	…….
T_a	Air temperature	^oC
T_{am}	Ambient temperature	^oC
T_{in}	Inlet temperature	^oC
T_{out}	Outlet temperature	^oC
T_r	plate temperature	^oC
T_n	Period of oscillation	Sec
U_L	Overall loss coefficient	W/m^2
V_{air}	wind velocity of air	m/sec
W	pitch of tubes center to center distance	M

Greek Symbols

Symbol	Description	Unit
Α	Absorption coefficient of plate	…….
Β	Slope	…….
Δ	Declination angle	Degree
ε_r	receiver emittance	…….
η	Collector efficiency	%
η_{opt}	optical efficiency	%
Θ	Angle of incidence	Degree
Θ_z	Zenith angle	Degree
μ	dynamic viscosity	Kg/m. s
Ρ	density of air	Kg/m^3
P_r	Reflectivity	…….
σ	Stefan-Boltzmann constant [$5.67.10^{-8}$ $W/m^2.K^4$]	$W/m^2.K^4$
Τ	Transmission coefficient of glazing	…….
$(\tau\alpha)_{av}$	average value of transmissivity – absorptivity product for beam or diffuse radiation	…….
Φ	Latitude location of the plant	…….
∅	Effectiveness	…….
υ	kinematic viscosity	m^2/sec
ω	Hour angle	Degree
ω_n	Natural frequency	rad/sec

LIST of ABBREVIATIONS

Abbreviations	Explanation
CFD	Computational fluid dynamics
COSQC	central organization for standardization and quality control
ETC	Evacuated tube collector
ETSC	Evacuated tube solar collector
FPC	Flat plate collector
FPSC	Flat plate solar collector
HPSC	Heat pipe solar collector
PV	Photovoltaic
PVT	Hybrid solar collector photovoltaic thermal

PT	Thermal solar collector
SWHS	South Windsor high school
SDHW	Solar domestic hot water

Chapter One

INTRODUCTION

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INTRODUCTION

1.1 Solar collectors overview

The solar collectors are considered the main component in the solar heating systems. There are different types and designs of solar collectors: flat plate solar collector (FPSC) and evacuated tube solar collector (ETSC). FPSC type is a simple type and more commonly used in heating solar systems (Sözen et al., 2008) while the ETSC is a complex and more expensive but high efficiency. Improving the design of the flat plate solar collector depends on several indictors: thermal performance, cost, and ease of installation (Dagdougui et al., 2011).

Many researchers in the previous studies were worked in various aspects to improve the thermal performance and efficiency of flat plate solar collector. These aspects were included: design area and thermal properties evaluation (Cooper, 1981), (Agbo & Okoroigwe, 2007) and (Do Ango et al., 2013) whereas the thermal efficiency was tested under different parameters and conditions like the fluid input temperature, ambient temperature, solar radiation and other parameters of design such as diameter, length and number of absorber pipes. (Kang et al., 2006) showed that the thermal efficiency of flat plate collectors is affected by the number of riser tubes, mass flow rate, thermal conductivity and thickness of the absorber plate. While, (Chen et al., 2012) proved that efficiency is a function of flow rate. In addition, (Matrawy & Farkas, 1997) proved that the efficiency of parallel plate collectors is about 10% and 6 % more than the efficiency of serpentine tube and parallel tubes collectors respectively.

Also, (Wang et al., 2019) tested the thermal performance of serpentine flat plate collectors with different pipe spacing and pipe diameters. Two layers of phase change material with different temperatures of 70 °C and 15 °C were used in the space area of the upper half and lower half of the pipe to improve the freezing and high-temperature resistance performance of the collector. Furthermore, (Kanimozhi et al., 2019) showed that the using a porous medium with agitator gives more efficiency as 63.8% than without porous medium as 56.6% . (Krishnavel et al., 2014) analyzed the solar water heating systems with different types of concrete absorber using wire mesh with metal scraps to enhance the thermal conductivity of the concrete absorber. A study was conducted by (Pavlović et al., 2016) to predict the optical and thermal analysis of a parabolic dish concentrator with a spiral coil receiver. The optical analysis proved that ideal position of the absorber is at 2.1 m from the reflector in order to maximize the optical efficiency and to create a relatively uniform heat flux over the absorber. According to the results of thermal part, the energetic efficiency was approximately recorded 65% while, the exergetic efficiency was varied from (4 to 15) %. Similarly, (Pavlovic et al., 2018) compared between two shapes of collectors (spiral and conical) using a developed thermal model. The model includes the optical, thermal and energetic thermal under different temperatures and flow rates. (Digole et al., 2020) investigated experimental study on a spiral receiver at various mass flow rates of water with nine mirrors and seven heliostats to determine the outlet water temperature. The results of the experiments show that the outlet temperature varies with the number of heliostats and the mass flow rate, so that the maximum temperature of 92.4°C was reached for nine heliostats with a mass flow rate of 0.0016 Kg/sec at noon and an average temperature of 84.4°C for the whole day.

1.2 Vibration overview

Vibration is defined as a motion that repeats after an equal interval of time. In other words it is defined as a periodic motion acts on the body to do it a vibrate. Mechanical vibration is the study of oscillatory motions of a dynamic system. An oscillatory motion is a repeated motion with equal intervals of time. One method of classifying mechanical vibrations is based on degrees of freedom. The number of degrees of freedom for a system is the number of kinematically independent variables necessary to completely describe the motion of every particle in the system. Based on degrees of freedom, the mechanical vibrations classified as a single degree of freedom systems, two degrees of freedom systems, multi-degree of freedom systems and continuous systems or systems with infinite degrees of freedom (Krodkiewski, 2008). Furthermore, the other classifications of vibrations are (Free and forced vibrations, damped and un-damped vibrations). When the initial disturbance acts on the system and left it, the system vibrates on its own resulting in free vibrations (D. Liu et al., 2018). Free vibration takes when a system vibrates under the action of forces inherent in the system and when the external forces are absent; the frequency of free vibration of a system is called natural frequency which is a property of a dynamical system. On the contrary, the forced vibration takes place under the excitation of external forces (Z. Y. Liu et al., 2018). The forced vibration takes place at different forced frequencies or external frequencies. The damped vibration occurs when the energy is lost or dissipated during oscillations then the vibration is known as damped vibration while, un-damped vibration occurs when no energy is lost or dissipated during oscillations.

Another classification of vibration problems are; Linear, Non-linear, Random, Deterministic, Transient, Steady state, Longitudinal, Transverse and Torsional vibrations (Dukkipati RV., Alpha Science International;, n.d.).

Pipelines are used in various filed of industry such as: oil, gas, the petroleum and power and chemical plants. Therefore, the studying and analyzing the vibration in pipelines systems are very important to assess the pipe resistance as a result of the vibrations that occur in the system (Shemshadi et al., 2020). As reported in (Zhao & Sun, 2018) study, experimental test was investigated on a curved pipe conveying fluid to measure the critical velocity of flow and its effect on the natural frequency. (Aun et al., 2020) investigated an experimental study of induced vibration on characteristics of fluid flow and heat transfer. An orifice was installed in the pipe with heating the working fluid under different conditions and temperatures. The results of experimental test shows that using an orifice increases the pipe frequency parameters such as acceleration, velocity and displacement. In addition, these vibration fundamental parameters increase together with increasing Reynold number as well as water inlet temperatures. (Al-dulaimi, 2020) experimentally studied the effect dynamic behavior of a copper pipe conveying fluid at different fluid temperatures with three types of support (fixed - fixed, fixed - free and simply support - simply support). The experimental results obviously increase the frequency and amplitude of vibration with an increase in the temperature of the fluid.

1.3 Thesis outlines

This thesis is the result of a research work which is sponsored by the Diyala University-College of Engineering. The significance and objectives of this project are disclosed in the next section of this chapter. Additional information is discussed in the balance of this thesis to achieve its objectives. This thesis is divided into six technical chapters, each of which is devoted to the description of a specific part of the research activities as follows:

Chapter II describes the literature review of this thesis. The topics are divided into two main section. The first section surveys the definition of sun energy and solar collectors. Also, the description of solar collectors are described in details. While, the second section deals with the definition of vibrations and their types. Furthermore, the effect of support and temperature and mass flow rate on the systems are described.

Chapter III presents the mathematical methodology of vibration in system in index of natural frequency. In other side, the solar radiation including: beam, diffuse and reflected radiation are analyzed. The chapter also described the heat transfer in collector for example; useful heat collector, heat removal factor and efficiency of the solar collector.

Chapter IV deals with the materials and project description, which include research requirements and system description. The measurements, instrumentations and data acquisition are described in details. This chapter also includes experimental setup.

Chapter V presents the work conducted using ANSYS FLUENT which includes numerical solution procedure: the model geometry, meshing, the CFD model set up (General solver and Physical models) and Simulation of the model for the spiral solar collectors.

Chapter VI shows the simulation and experimental results. Comparisons between the results of the present study with studies available in literature are presented. Chapter VII concludes this thesis and provides suggestions for future studies in this field to improve and develop the analysis of natural frequency and the performance of the spiral solar collector with lens.

1.4 Problem statement

Oscillation account due to the difference in the fluid temperature with respect to the flat plate solar collector. Conventional flat plate solar collectors, which are in high demand, absorb the solar radiation to increase the water temperature. To increase the solar collector efficiency, lenses can be used to increase the collector efficiency by increasing the solar radiation falling onto the collector.

In view of this phenomenon, the principal research problem for this project is the performance of spiral solar collector supported with lens and influence natural frequency. The system design is based on conventional spiral collectors. In general, this research aims to study and identify the performance of the system, and compare it with the performance of the conventional system.

1.5 Objectives of the research

The main objective of this study is to fabricate two solar water heating systems: the first one with conventional spiral collector and the second one with the same collector supported with lens. In addition, the thermal performance of the systems is investigated in terms of performance coefficients and the efficiency. Furthermore, a comparison between the experimental and numerical results is made to evaluate the effect of lens on the performance spiral collector. In parallel, another system is fabricated to study the effect of fluid flow rate and temperature on the vibration in the spiral pipe.