A Study of Flat Slate Solar Water Collector Taking into Account the Absorption and Emission within a Glass Cover Layer(ガラス内の吸収・放射を考慮した太陽熱平板温水器に関する研究)

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論 文 内 容 要 旨

The present dissertation deals with a study of a flat-plate solar water collector taking into account the absorption and emission within a glass cover. In deed, the glass cover represents the most important part of the solar collector system. Accurate prediction of thermal radiation in solar collector glass-cover is of a great importance to achieve rigorous models that can be used to simulate the real behavior of a solar collector. The optical constants of a clear glass material used commonly as a cover for a solar collector, from the ultra-violet to the near infrared, have been investigated. The simulation of the glass cover has been carried out considering it as a participating media subjected to solar and thermal radiation. However, the CPU time consumed has been found to be prohibitively long with non gray calculation. Therefore, semi gray models have been proposed to carry out the simulation with less time consuming. The new approach has been used to simulate the solar collector with two kinds of glass cover, normal and low-iron, assuming them as non gray medias. A simple program with accurate value of the real and imaginary parts of the complex refractive index of the glass materials (clear and low-iron) has been constructed in order to simulate the thermal behavior of a solar heating system (collector combined with a storage tank) in different locations in Japan. Finally, the whole system has been simulated in the south of Algeria (Adrar) in order to evaluate its performance in such hot and dry area.

Chapter 1 General Introduction

A rapid view of the importance of solar energy and its application for several goals has been presented. An introduction to solar hot water using different kinds of collectors has been done. A rapid view of a flat-plate solar collector and concentrating systems for different application has been also presented. A brief description of a solar heating system has been introduced. The importance of the glass material used commonly as a cover for a solar collector has been reported. The influence of the composition and color on the optical constant of the glass material which affects the thermal radiation and the temperature distribution with a glass layer has been also discussed. Some experimental methods for determining the optical constants of a bulk material have been discussed. The classical approaches of flat plate solar collector using both iterative solution and HWWB method have been reported. Finally the motivation and the objectives of the present study were pointed out.

Chapter 2: Determination of the Optical Constants of a Clear Glass Material

In Chapter 2, a simple method for calculating the optical constants of a glass material in the solar and near infrared ranges by the measurement of the reflectance at near zero incidence and the transmittance at normal incidence has been described. The back surface of the sample was roughened to prevent multiple reflections in transparent region below 5 μm. When the back surface is roughened the back interface reflectivity is almost eliminated. However, even though the back surface is scratched, small scattering light remains inside the glass and is being added to the first interface reflectivity. Therefore, when the back surface of the sample is roughened and blackened the reflectivity measured is lower than that obtained without the black color. The real and imaginary parts of the complex refractive index have been derived from the measurements of the reflectivity at near zero incidence and the transmittance at normal incidence and are plotted in Figure 1.1. The values obtained in the present chapter are in good agreement with those reported by Rubin.

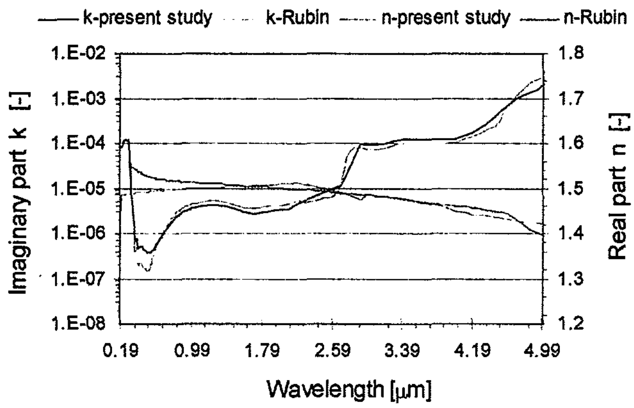

Figure 1.1 Optical constants of a clear glass material from 0.19 to 5 μm

Chapter 3: Simulation of Solar Water Collector Glass Cover Subjected to Solar and Thermal Irradiations

In Chapter 3, the combined non-gray radiative and conductive heat transfer in solar collector glass cover has been presented using the radiation element method by ray emission model. The glass material is analyzed as a non-gray plane-parallel medium subjected to solar and thermal irradiation in one dimensional case. Both collimated and diffuse incident irradiation are applied at the boundary surfaces using the spectral solar model proposed by Bird and Riordan. Figure 3.1 shows the analysis model of solar collector subjected to solar and thermal irradiation.

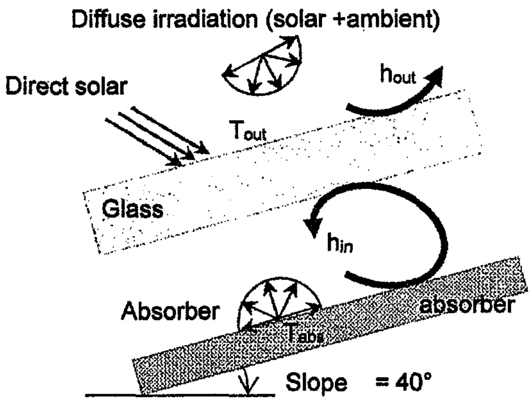

Figure 3.1 Analysis model of solar collector subjected to solar and thermal irradiations.

The optical constants of a clear glass, 160 values of n and k (NG160b), obtained in Chapter two combined with the values of n and k reported by Rubin in the infrared range of the spectrum, have been used. Three other models SG1, SG2 and NG10b have been proposed for rapid simulation and compared with NG160b. The effects of double glazing and the thickness of the glass cover have been also investigated. Figure 3.2 shows the ratio of the CPU times and the relative deviations of the heat fluxes amounts calculated for SG1, SG2 and NG10b from the reference model NG160b. We introduce the parameter R_a defined as a ratio of the CPU time consumed by the considered model to the CPU time consumed by the reference model (NG160b). In the case of semi-gray models SG1 and SG2 the CPU times are reduced to 5% and 6% of the reference computation and the relative deviations of the heat fluxes within a glass layer compared to the reference model NG100b are 8 % and 11 %, respectively.

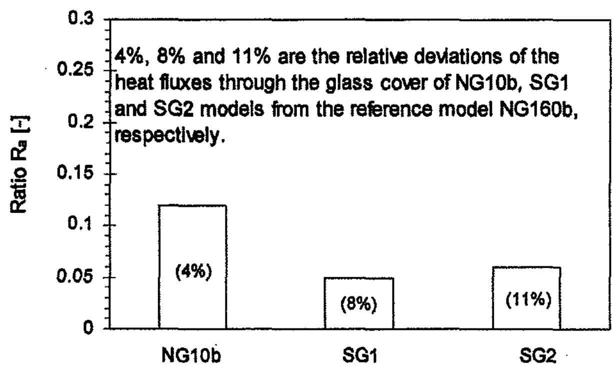

Figure 3.2 R_a defined as a ration of the CPU time consumed by the considered models to the CPU time consumed by the reference one (NG160b), and the relative deviations of the heat fluxes of the three defined models from the NG160 b.

Chapter 4: Simulation of Solar Water Collector System Taking into account the Absorption and Emission within a Glass Cover

Chapter 4 deals with a new theoretical approach of solar flat plate collector considering the glass cover as an absorbing and emitting media. Two kinds of glass materials, clear and low iron, have been studied. The optical constants of a clear and low iron glass materials proposed by Rubin have been used. The computational time for predicting the thermal behavior of solar collector were found to be prohibitively long for the non-gray calculation using 160 values of *n* and *k* for both glasses. Therefore suitable semi-gray models have been proposed for rapid calculation.

The new approach has been compared with the classical one. Figure 4.1 presents the instantaneous efficiencies of the solar collector with both clear and low iron glass covers. It has been shown previously that the efficiency curve was found to be not linear in shape, due to the non linearity of the radiative heat losses from the collector. The result shows that the solar collector with low iron glass has a higher efficiency, because the amount of the steady heat flux traveling through the glass cover is higher in case of low iron glass.

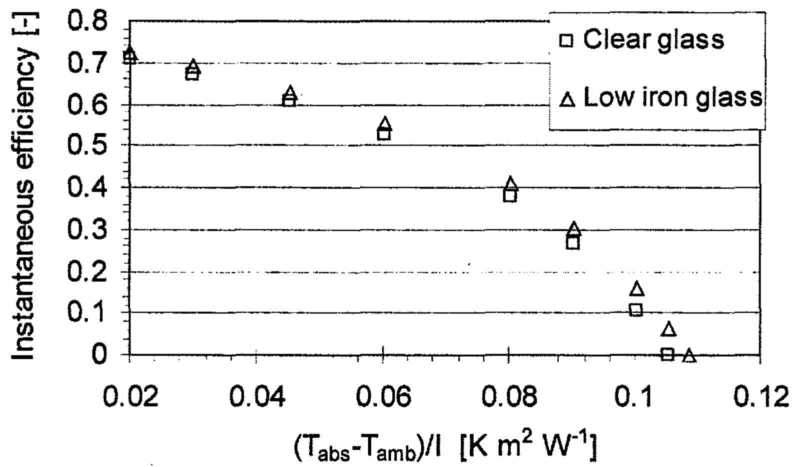

Figure 4.1 Instantaneous efficiencies of the solar collector using clear and low iron glass cover versus $(T_{abs}-T_{amb})/I$

Chapter 5: Thermal Performance of Solar Heating System under Japanese and Algerian Climates

In Chapter 5 a simplified code for simulating the thermal behavior of a solar heating system with flat plate collector used in Japan and horizontal storage tank has been presented. The single low iron glass flat plate solar collector provided by THERMO DYNAMICS LTD (G series) which consists on the absorber with arrangement of parallel riser fins connected to top and bottom headers has been considered. A simple numerical program has been constructed to predict the thermal behavior of the system. The program has been validated using the test result, according to the ASHRAE Standard, provided by the supplier. The simulation of the solar heating system has been carried out for five sites in Japan using the measured data of solar irradiation, ambient temperature and wind speed provided by Japan Meteorological Agency. The effect of parameters such us kind of glass cover material, mass flow, inlet fluid temperature and type of absorber surface, on the performance of the system has been examined. The same system has been simulated under Algerian Climate. Figure 5.1 shows the efficiency curves obtained both with test result and simulation program. The calculated result is in good agreement with the experimented one. In our belief, the present code predicts well the thermal behavior of the G32 solar collector system.

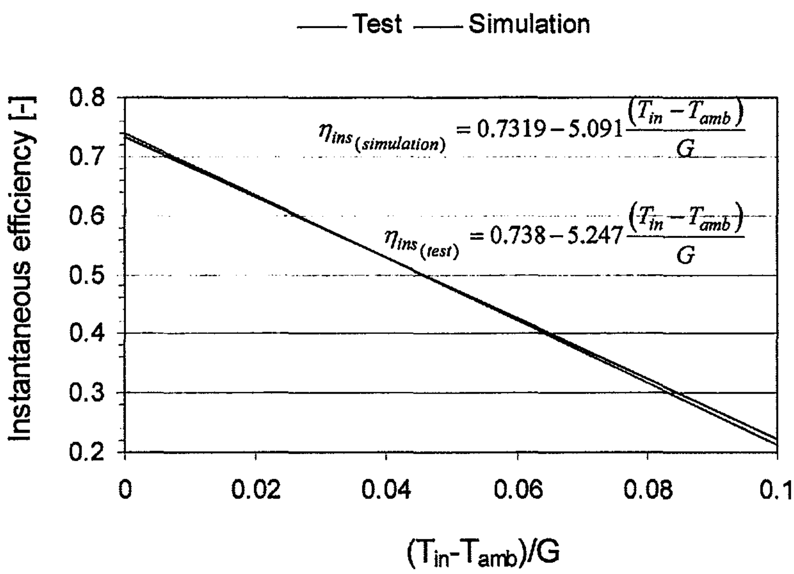

Figure 5.1 Efficiency curves based on the indoor test and the simulation result of the solar collector G32 model.

論文審査結果の要旨

太陽熱温水器において重要な役割を担う半透明ガラス平板の厳密なふく射モデルの提案は、多くの伝熱現象の解明に重要である。本研究では厳密なふく射モデルを提案し、太陽熱温水器に使用されるガラスの光学定数を可視光および近赤外光領域で解析している。また、ガラス平板複素屈折率に起因する吸収・放射を考慮した非灰色計算を行っている。本論文は以上の研究成果をまとめたもので、全編6章よりなる。

第1章は序論であり、本研究の背景および目的について述べている。

第2章では､反射率と透過率の測定によるガラスの簡易光学定数導出法について述べている。5μm以下の透過領域において光の多重反射を回避するためにガラス裏面を拡散面としている。裏面がすりガラス状であるにも関わらず、ガラス内には拡散光が残存しており、裏面が黒色拡散面のときには反射率は低く測定される。複素屈折率の実部と虚部は反射率と透過率の測定により求められる。この導出法は透明ガラスの光学定数に関する高精度データベース構築に大きく寄与する。

第3章では、温水器内ガラス平板の非灰色ふく射伝熱と熱伝導を考慮した複合伝熱解析法を光線放射モデルによるふく射要素法を用いて提案している。ガラスを平行平板とし、一次元非灰色ふく射伝熱解析を行っている。透明ガラスの光学定数には第2章で得られた値を用い、比較のために三種類の異なるモデルを参照としている。ガラス平板の厚さと二重ガラスの影響について解析を行い、考察を述べている。この解析法は太陽熱温水器の伝熱性能の高精度評価を行う研究に大きな進展を与える。

第4章では、ガラス平板を吸収・放射物質として考慮した太陽熱平板温水器の新たな理論的考察を述べている。透明ガラス、低鉄質ガラスの二種のガラスについて考察を行っている。太陽熱温水器の伝熱性能を評価するための非灰色モデルでは計算時間に長時間を要するため、セミグレイモデルを提案している。これはガラス内の吸収・放射を考慮した太陽熱平板温水器に関する理論的考察に大きく寄与するものである。

第5章では、貯水槽を考慮した温水器システムの性能を模擬する計算コードを提案している。吸収体を含むTHERMO DYNAMICS 社による単体低鉄分含有ガラスの温水器を考慮している。システムの伝熱性能を評価するために簡略化された計算プログラムを構築している。このプログラムは種々の天候条件下での温水器の性能を評価する上で有用であり、重要な成果である。

第6章は本論文で得られた成果をまとめた総括である。

以上要するに本論文は、ガラス平板を備えた太陽熱温水器の性能を定量的に評価しており、伝熱工学の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。