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REALIZATION AND NUMERICAL ANALYSIS UNDER COMSOL MULTIPHYSICS OF A RECYCLABLE SOLAR COLLECTOR MADE FROM SODA CANS

M. El Badaoui   A. Touzani

Applied Thermodynamics and Solid Combustibles (ATSC), Mohammedia School of Engineers (EMI), Rabat, Morocco
meryemelbadaoui@research.emi.ac.ma, atouzanikia@gmail.com

Abstract- This article aims to present the CanSol solar air collector project by recycling soda cans, while presenting the material used, the elaborate process, the calculation of the thermal efficiency of the solar collector, then a presentation of the experimentation region, plus a modeling under COMSOL Multiphysics, additionally an economic and environmental approach was established. The results obtained in this article are as follows, starting with a modeling under COMSOL Multiphysics were validated by the experimental results of the outlet temperature, furthermore, the outlet temperature and the efficiency were tested during the first seven days in November 2020 which were satisfactory results between 31.1 °C and 35.1 °C compared to the autumn season in Khouribga, Morocco noted an average temperature of 25 °C, plus an efficiency bounded by 40.85% and 70.01%. Finally, a low economic bill during the winter season, also a CO_2 emission reduced comparing to coal and electricity.

Keywords: Solar Air Collector, Soda Cans, Outlet Temperature, Efficiency, COMSOL Multiphysics, CO_2 Emissions.

1. INTRODUCTION

In order to protect the fossil energy and minimizing the greenhouse gas emissions. Morocco like other countries, collaborates to protect the environment and the fossil energy by hosting in 2016 in Marrakech the 22nd edition of the conference of the parties for climate change "COP22", besides, it owns one of the largest solar parks in the world, following that Morocco has a solar energy potential with an irradiation of about 5 kWh/m^2/day [1-3]. And it aims to reduce its CO_2 emissions by encouraging youth researchers for developing green projects. One of industrials, we find Afrique, by implanting "1000 Fikra" project, or "1000 ideas" is a project encouraging Moroccan re-searchers to develop and concretize their innovative green projects through incubation and monitoring.

Currently, the solar collector became widely used for heating water, dry agricultural products and heating air [4, 5], plus these collectors has many advantages such as: low cost, simple design and used for low and moderate temperatures applications [6]. Assuming that each Moroccan drinks at least, one can of soda per year, then knowing that one can produce 170 g of CO_2 [7], which lead 36 million cans as waste and 6120 tons of CO_2 per year that harms the environment.

Our project CanSol is part of it by recycling cans as raw materials to produce a solar air collector while preserving the environment and taking advantage of the abundant heat in Morocco.

2. MATERIALS AND METHODS

2.1. Materials

In order to establish our solar collector, we need some materials, which is presented in Table 1.

Table 1. Materials

Elements	Quantity
Cans	100
High temperature silicone	2 cans
High temperature painting	4 cans
Drill	1
Thermal insulation "extruded polystyrene"	1.5 m^2
Plexiglass	1.5 m^2
Aluminum Sheet	1.5 m^2

2.2. Process

In order to manufacture a recycled solar air heater collector. In the Figure 1, we will present the process of production.

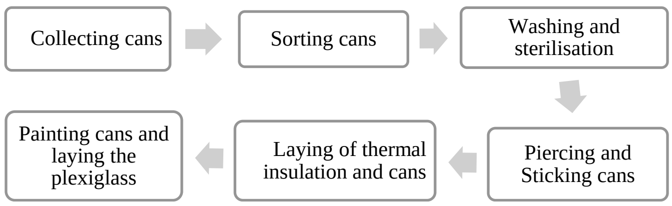


Figure 1. Process of production of solar air heater collector

Starting with a collection of cans from restaurants, cafes and hotels then, we sort these cans according to their conditions and their lengths then, we move on to the treatment phase of these cans through washing them with hot water "T=100 °C". Thus, the addition of acetic acid "CH_3COOH" for 5 minutes and left to sit for other 5 minutes, so that they are ready for use. After this phase, the cans of the two sides are drilled, then glued with a silicone at high temperature "1200 °C", and painted with a paint at high temperature "1100 °C". To absorb the maximum heat, the color chosen is black due to its high absorption coefficient compared to other colors [8], and this is presented in the Table 2.

Table 2. Absorption coefficient according to color

Color	White	Red	Dark green	Navy blue	Dark
Absorption coefficient	0.18	0.58	0.87	0.89	0.92

In a case, the thermal insulation chosen according to the insulating power, thickness, resistance to temperature and price is installed. Finally, the cans are laid and then the plexiglass, which is also chosen according to an elevated degree of transparency to that of the glass "89%'", a high rigidity, a high melting temperature "160 °C", and a fairly huge impact resistance "30 times high compared to glass".

2.3. Calculation of the Thermal Efficiency of Solar Collector

The Figure 2, presents the solar collector from soda cans, that we established in our laboratory.

Figure 2. View of solar collector from soda cans

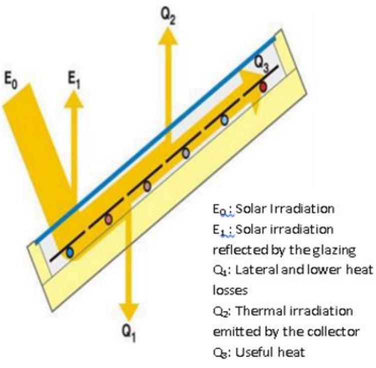


Figure 3. Energy balance schema of the collector [9]

According to Figure 3, and by applying the energy balance [9-15] we have the Equations (1) and (2).

$$Q_3 = E_0 - E_1 - Q_1 - Q_2 \quad (1)$$

As well the efficiency as:

$$\eta = \frac{Q_3}{E_0} \quad (2)$$

Besides, the absorbed energy and the thermal losses are calculated by the follow relations (3) and (4).

$$E_0 - E_1 = E_0 \alpha \tau \quad (3)$$

$$Q_1 + Q_2 = a_1 \Delta T + a_2 \Delta T^2 \quad (4)$$

In the end, the efficiency is defined in the equation (5)

$$\eta = (E_0 \alpha \tau - a_1 \Delta T - a_2 \Delta T^2) / E_0 \quad (5)$$

where,

α: Absorber absorption factor
τ: Glazing transmission factor
a_1: Coefficient of heat loss by conduction (W/(m^{2}K))
a_2: Coefficient of heat loss by convection (W/(m^{2}K^2))
ΔT: Difference between the average temperature of the absorber and the average ambient temperature.

The Table 3, presents the values of the coefficients a_1 and a_2 depending on the type of glass.

Table 3. The values of the coefficients a_1 and a_2

	a_1	a_2
Collector without glass	20-25	-
Simple glass collector	4-6	0.05-0.1
Selective glass collector	3-5	0.005-0.015
Collector under space with internal surface AL/ AL-N	2-3	0.006-0.01
Collector under space with internal surface SS-C/CU	1-2	0.004-0.007

2.4. Presentation of the Experimentation Region

The Table 4 and Figure 4 characterize the geographical coordinates of the chosen site: Khouribga Morocco, as well as its geographical location [16].

Table 4. Geographical coordinates of chosen site: Khouribga, Morocco

Altitude (m)	803
Longitude	32°52'53"
Latitude	-06°54'47"
Annual DNI (Kwh/m^2)	2138
Annual average temperature (°C)	16.8
Autumn average temperature (°C)	25

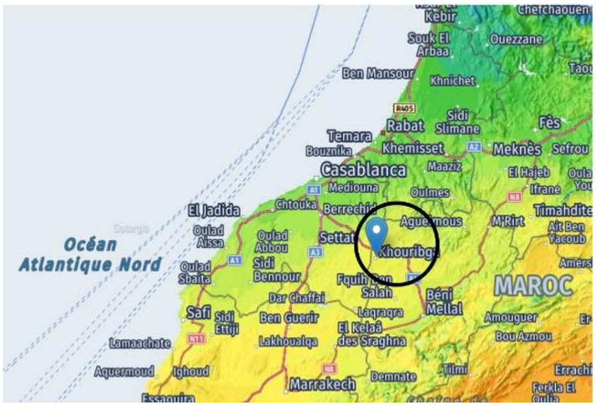


Figure 4. Geographical location of Khouribga, Morocco

2.5. Modeling under COMSOL Multiphysics

This simulation was established using the COMSOL Multiphysics software in 3D, the Figure 5 shows the geometry of solar collector as well as its mesh [17-18].

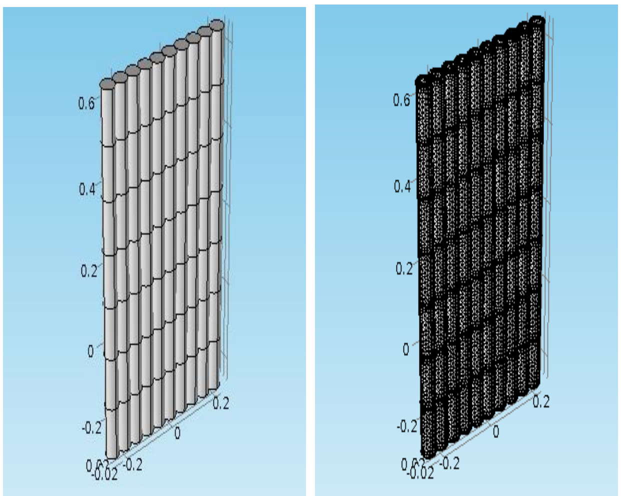


Figure 5. Geometry and mesh of solar collector in COMSOL Multiphysics

2.6. Economic and Environmental Approach

2.6.1. Calculation of the Power Required to Heat

In order to measure the energy requirements to heat a 20 m^2 room [19-21], the equation (6) is used

$$P = C.\Delta T.V \qquad (6)$$

where, the coefficient C is generally:
1.5 for a well-insulated house;
1.6 for a normally insulated house;
2 for a poorly insulated house.
V is the volume of the room to be heated
ΔT is difference between ambient temperature and desired temperature.

Taking heat losses into account, the power required is calculated using the equation (7)

$$P' = 1.1 \times 1.2 \times P \qquad (7)$$

2.6.2. Economic Cost

The Table 5, presents the unit price of a kwh in Moroccan dirham "MAD"

Table 5. Unit price

Sources	Unit price (MAD/Kwh)
Coal	1.65
Electricity	0.951
Solar	0.13

2.6.3. CO_2 Emissions

For air heating in the Khouribga region of Morocco, the most used sources are traditional heating 'by coal', electric heating and solar energy. The Table 6 shows the CO_2 emissions from these three sources per Kwh.

Table 6. CO_2 emissions

Sources	CO_2 emissions (g/Kwh)
Coal	820
Electricity	756
Solar	41

3. RESULTS AND DISCUSSIONS

3.1. Model Validity

The reliability of the code was tested by comparing the numerical results obtained by the COMSOL Multiphysics software with the experimental results obtained during the first seven days of November 2020 at 1 p.m. The Figure 6 presents the numerical and experimental outlet temperature during the seven days of November 2020.

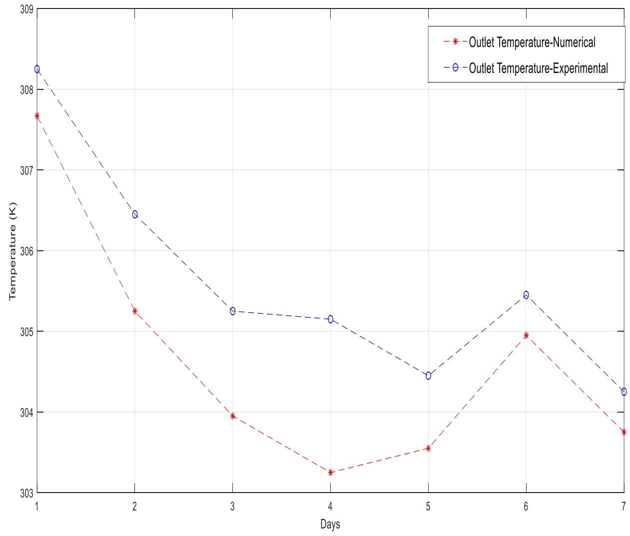
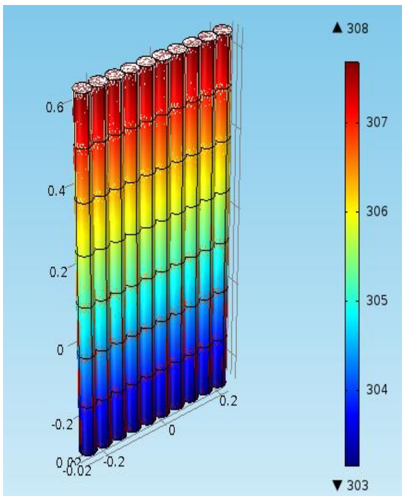


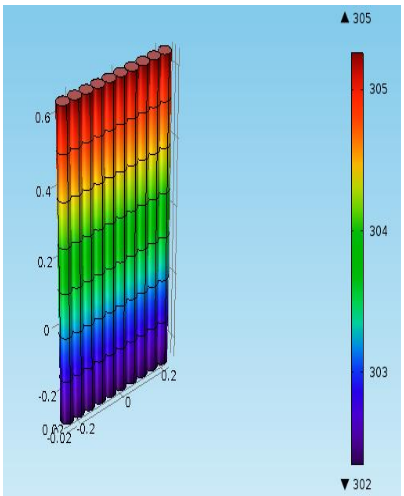
Figure 6. The numerical and experimental outlet temperature during the seven days of November 2020

3.3. Simulation in COMSOL Multiphysics

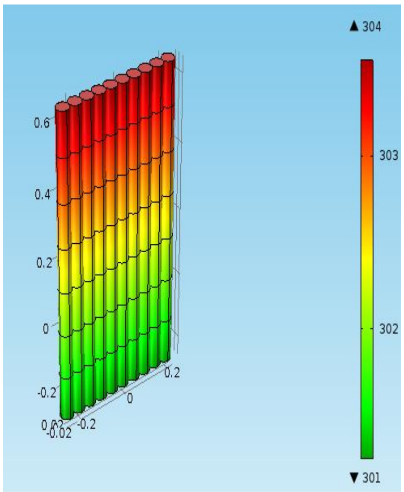
The Figure 7 presents the temperature profile at 1 p.m., in soda cans, we observe that the temperature increases as the tube length of cans increases, this is due to the high density of cold water compared to hot water, recording for the temperature of 304 K, a density of order of 994 Kg/m^3. On the other hand, at the level of a temperature of 308 K note a density of 992 Kg/m^3.



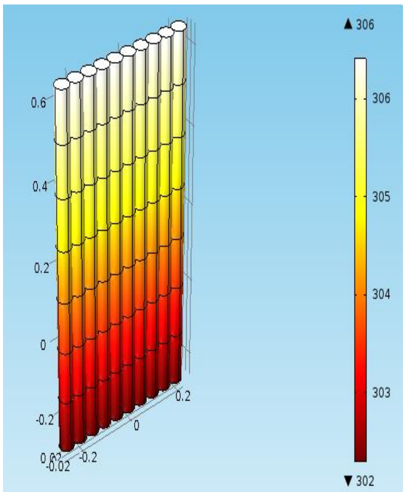
a. Temperature profile on the 1st November 2020 at 1 pm



b. Temperature profile on the 2nd November 2020 at 1 pm



c. Temperature profile on the 4th November 2020 at 1 pm



d. Temperature profile on the 5th November 2020 at 1 pm

Figure 7. Temperature profile under COMSOL Multiphysics

3.4. Outlet Temperature and Efficiency

The Table 7 above presents the results of the tests of the recycled solar collector "CanSol" during the first seven days of the month of November 2020, at 1 p.m. in Khouribga, Morocco.

We notice that the results are satisfactory compared to the average temperature in the autumn season in Khouribga by providing outlet temperatures bounded by 31.1 °C and 35.1 °C, also an efficiency between 40.85% and 70.01%.

On the one hand and on the other hand, we point out that the 5th day records a very satisfactory efficiency of 70.01, while the 7th day records a low efficiency of 40.85, this is due to the impact of the wind speed at the entrance as well as the irradiation.

Table 7. Outlet temperature and efficiency

	1	2	3	4	5	6	7
Ambient temperature (°C)	27	26	23	20	23	24	21
Ambient temperature (K)	300	299	296	293	296	297	294
Solar irradiation (KW/m^2)	0.61	0.61	0.61	0.6	0.6	0.6	0.59
Inlet wind speed (Km/h)	12	10	16	24	33	28	9
Inlet temperature (°C)	30.1	29.2	28.6	27.5	28.1	29.3	27.9
Inlet temperature (K)	303.2	302.3	301.8	300.6	301.2	302.4	301
Outlet temperature (°C)	35.1	33.3	32.1	31.9	31.3	32.3	31.1
Outlet temperature (K)	308.3	306.4	305.2	305	304.4	305.4	304.2
Efficiency (%)	68.1	56.5	60.7	63.7	70	64.3	40.8

3.5. Economic and Environmental Approach

3.5.1. Calculation of the Power Required to Heat

Using the equations (6) and (7) presented above we obtained P=870 W and P'=1148 W. The air heating is used during the winter season and for 7 hours therefore power consumed to heat a room of 20 m^2 is 723.24 Kwh.

3.5.2. Economic and Environmental Approach

The Table 8 presents the economic bill for heating a 20 m^2 room using three sources and their CO_2 emissions.

Table 8. Economic bill and CO_2 emissions

	Coal	Electricity	Solar
Economic bill (MAD)	1193	688	94
CO_2 emissions (Kg)	593	547	30

In the Table 8, we observe that using the solar collector will have a less economic bill and also, we contribute to minimize the CO_2 emissions.

3.6. Comparison with a Conventional System "Evacuated Tube Solar Thermal"

The results presented below in the table 9, from a comparison of our product, with an evacuated tube solar panel marketed for air heating [11, 22].

Table 9. Comparative table of the two systems

	Our product "CanSol"	Conventional solar panel
Efficiency (%)	60.58	50-70
Cost of panel ($)	300	500

According to the Table 9, we see that our product satisfies the technical approach with an efficiency of 60.58%, included in the margin [50%-70%], presented by the marketed solar collectors.

On the one hand, and on the other hand, the economic approach has a competitive advantage at the level of the national market. In addition, our product aims to protect the environment while recycling soda cans.

4. CONCLUSIONS

As part of the protection of the environment, this paper presented a recyclable solar collector, based on soda cans, while presenting the materials used, the process followed as well as the region where we installed our collector.

During this study, satisfactory results were obtained, such as : an outlet temperature bounded by 31.1 °C and 35.1 °C compared to the average temperature of 25 °C in the autumn season in Khouribga, Morocco then an efficiency between 40.85% and 70.01%, a high inlet air velocity creates a turbulent transfer favoring heat transfer between cans and air; a higher solar irradiation positively impacts the efficiency, plus a solar collector presents a low economic bill for heating a 20 m^2 room as 94 MAD, and a CO_2 emission of 30 Kg less than electricity emissions "547 Kg" and coal emissions "593 Kg". On the other hand, a comparison with a market solar collector at the technical level with an efficiency of 60.58%, responding the margin [50%-70%], then a competitive price at economic level.

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BIOGRAPHIES

Meryem El Badaoui was born in Khouribga, Morocco, on December 11, 1990. She is a Ph.D. student in Applied Thermodynamics and Solid Combustibles (ATSC) in Mohamedia School of Engineering, Morocco. She has a state engineering degree from National School of Applied Sciences, Morocco in 2014. She participated in Innova Project 2.0 about innovative projects in 2016. She participated in 1000 Fikra Project with Afrique in 2020, then she participated in entrepreneurial training for innovative projects under the Erasmus plus and Yabda Project in 2021.

Abdellatif Touzani was born in Morocco in December 1957. He obtained his Ph.D. in Process Engineering from Montreal Polytechnic School, Montreal, Canad in 1985. He is a Professor of Process Engineering in the Mohamadia School of Engineers, Morocco since 1986. He has a strong background in energy efficiency, sustainability and cleaner production during his career in industry and consulting. In the recent years its commitment to improving energy and environmental performance in several industries has led to concrete measures for setting targets and implementing cleaner production projects. For the past decade, he has been engaged in the sustainable design of industrial investment projects that have demonstrated considerable potential for improving the environmental performance of companies. As an energy advisor in the industry, and as an accompanist of cleaner production projects, he has accumulated extensive know-how of integrating sustainable development into projects. He has participated in several international programs including: Project set-up: Energy efficiency in the industrial sector in Morocco on behalf of the African Development Agency as national coordinator of the project, Strengthening the environmental performance of 15 Moroccan companies which the project funded by the Department of State (USA) in partnership with the World Environment Center, the Project on transfer of better environmental technologies in the southern Mediterranean region "MED-TEST", Morocco, Tunisia, Egypt on behalf of UNIDO and also energy audit of more than 100 national companies in Morocco.