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Theoretical Study of the Effect of Packing on the Temperature of Fiber Optic Cables

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The aim of this study is to show the impact of the packing on a fiber optic cable carrying concentrated solar radiation using a solar equivalent cutting center. This solar radiation is taken on a specific day and hour in Wilaya of Ouargla-Algeria. In this study, we developed a mathematical model and obtained differential equations using the MATLAB program, using the properties of both plastic and glass fibers for normal and hexagonal packing by choosing a certain energy value at the cable output. After analyzing the obtained results, we compared them with the results of previous studies for two types of fiberglass and plastic cables in the cases of hexagonal and normal packing. The results showed that the temperature of the hexagonally packed fiber optic cable was lower than that of the normally packed fiber optic cable regardless of the type of fiber material. In addition, the total amount of solar radiation required to be transmitted through the hexagonal-packed fiber optic cable is less than that required to be transmitted through the conventional fiber optic cable in order to get the same energy at the cable output.

Keywords: Glass fibers, Plastic fibers, Hexagonal packing, Normal packing, Temperature.

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1. INTRODUCTION

Energy is an economic and strategic problem for all oil-importing countries of the world, but this problem is a more serious issue in the case of developing countries because of their total dependence on imported energy, as energy from other sources, such as fossil fuels or nuclear energy reactors, is accompanied by environmental pollution and its negative repercussions on all living organisms, deterioration of health and environmental conditions, the spread of diseases and epidemics, and an increase in desert encroachment.

The world is aware of the danger of pollution that threatens all of humanity, and, therefore, more than a quarter of a century ago it began conducting research and experiments to find alternative sources of energy that are characterized by renewal and continuity without polluting the environment by concentrated solar energy. In this regard, a French research team put forward the idea of transmitting it via optical fibers (Cariou, et al., 1982) [1].

A packet image-carrying optical fibers have good image quality and vivid colors, so their use has become important in fields such as optical analogs, image-carrying telephone, TV transmission, etc. [1-3]. Fiber optic cables provide a better and suitable solution in the field of communications, in terms of industrial safety compared to traditional communication devices in an industrial environment prone to explosions, or in a climate full of oxidizing gases and vapors, such as chemical plants or oil refineries [1, 2]. Optical fibers are especially used in surgery with a laser beam that allows to break up stones in the kidneys, divide the tumor and repair the retina.

Optical fibers have also been successfully used to transmit solar energy. Studies have been conducted to transmit concentrated solar energy through optical fibers in various ways identified in the work of Kandilli et al. [2], while Liang et al. emphasized that flexible optical fibers can be used to transmit solar energy to a desirable location where a crystal pump laser could be used [4], as shown by Feuermann et al. (1998) that fiber optic surgery instead of lasers requires a high concentration of solar energy. Some of the researchers such as Jaramillo et al. were also interested in developing the thermal theory of optical fibers that transmit concentrated solar energy [5].

2. DETAILS OF CALCULATIONS

The idea of transmitting concentrated solar radiation through optical fibers has provided promising options in many areas such as solar lighting, solar energy generation, solar surgery, hydrogen generation and lasers for pumping solar energy. In this study, we use the center of a parabola of the sun, which produces high radiation intensity in its center, which must be properly integrated with the optical fiber bundle to transmit solar radiation completely and effectively.

In this study, we will consider the most important phenomena in the presented model shown in Fig. 1 and the mathematical model based on this study.

2.1 Solar Radiation Reaching the Central Hole

The total solar flow that reaches the surface of the solar equivalent cutting center is:

$$Q_1 = G_b . A_a \,, \quad (1)$$

where A_a is the area of the solar equivalent cutting center given by:

$$A_a = \pi D_a^{\,2} / 4 \,, \quad (2)$$

D_a is the diameter of the solar complex.

2.2 Solar Radiation Reaching the Focus

Part of the solar flux Q_1 arriving at the mirror and reflected by it is $Q_2 = \rho G_b A_a$. Then it lowers this flux by the viewing factor F (and is related to $\theta_{\max}$). When it reaches the center, $Q_3 = F\rho G_b A_a$ becomes:

$$Q_3 = F\rho G_b.A_a C_{\max}\,, \tag{3}$$

where ρ is the reflectivity of the complex surface and F written as follows [6]:

$$F = \frac{\sin^2\theta_{\max} - \sin^2\phi_s}{4\tan^2\left(\dfrac{\theta_{\max}}{2}\right)}\,, \tag{4}$$

$C_{\max}$ is the geometric focus and its expression [7]:

$$C_{\max} = \frac{A_a}{A_{bundle}} = \frac{\sin^2\theta_{\max}\cos^2\left(\theta_{\max} + 0.267° + \dfrac{\delta}{2}\right)}{\sin^2\left(0.267° + \dfrac{\delta}{2}\right)}\,, \tag{5}$$

where $Q_{\max}$ is the angle at which the beam inside the cable must enter at an angle equal to or less in order to achieve the internal total reflection, A_{bundle} is the fiber optic package space, ϕ_s is the angle shading, $\delta/2$ is the error in measuring the deviation angle of the reflective surface, 0.267° is the angle of the cone, and the roses of the solar radiation beam are cleared.

In this study, we consider that the cut-out center (mirror) is ideal and the angle of shading $\varphi_s = 0$.

2.3 Solar Radiation Contained in the Cable

Solar radiation from the focus has a partial reflection called Fresnel reflection. Therefore, the solar radiation coming to the cable can be written as:

$$Q_{\text{inc}} = F\rho G_b.A_a C_{\max}\left(1 - R_f\right)\,, \tag{6}$$

$$R_f = (n-1)(n+1)\,, \tag{7}$$

where n is the refractive index of the optical fiber core.

This last solar radiation is subjected to another loss which is the loss through the pores, accordingly, the solar radiation entering the cable becomes as follows:

$$Q_{\text{inc}} = F\rho G_b.A_a C_{\max}\left(1 - R_f\right)\varphi_{pf}\,, \tag{8}$$

where φ_{pf} is the fill factor.

The loss through the pores causes the fiber optic cable to heat up and thus the temperature changes along the cable according to the following equation:

$$T(X) = \frac{Q_{inc}\varphi_{pore}\left(-\dfrac{\exp(-mL)}{\exp(mL)}\right)\exp(mX) + \exp(-mX)}{K_{eff}m\left(\dfrac{\exp(-mL)}{\exp(mL)} + 1\right) + h_{con-in}\left(1 - \dfrac{\exp(-mL)}{\exp(mL)}\right)} + T_a\,,$$

$$m^2 = \frac{2h_{con-sid}}{r_{bundle}.K_{eff}}\,, \tag{10}$$

where φ_{pore} is the porosity coefficient, L is the cable length, $h_{con\text{-}in}$ is the coefficient of convective heat transfer between the surface of the fiber optic cable section and air, T is the temperature gradient along the cable, $h_{con\text{-}sid}$ is the heat transfer coefficient by convection between the side section surface of the profile for fiber optic cable and air, K_{eff} is the thermal conductivity coefficient, r_{bundle} is the radius of fiber optic cable bundle, T_a is the ambient air temperature.

In our study, we consider the following hypotheses:

- ✓ Temperature changes only along the length of the fibers.
- ✓ We take the convective loss on the face of the optical fiber bundle and at the end of the bundle as well.
- ✓ The study is limited to wavelengths in the visual spectrum.
- ✓ We consider the temperature change over time to be negligible.
- ✓ We consider the cable to be a homogeneous group of optical fibers.
- ✓ Fiber optic power transmission systems do not store any energy.
- ✓ The energy loss from the solar equivalent has been neglected.
- ✓ We assume that the solar radiation is placed in the vertical direction when the eq collector is opened.
- ✓ We assume that the reflectivity of the parabolic-solar collector material is high.
- ✓ We assume that the sun tracking error is non-existent.

3. RESULTS AND DISCUSSION

3.1 Temperature Along the Cable

Previously, we discussed the temperature relationship along the fiber optic cable and used the properties of glass fibers and plastic fibers for normal connection. We programmed all this using the program MATLAB, where we got a shape that gives changes in temperature along the fiberglass and plastic fiber cable, and this is between 10:00 am and 12:00 pm.

At a specific wavelength in the optical field, Fig. 1 presents the temperature changes along the glass and plastic cables installed at 10:00 am and 12:00 pm. We can see from Fig. 1 that temperature at the cable entrance for both plastic and glass fibers is high and gradually decreases until it is installed at the same temperature as the air surrounding the cables [8]. And we explain the high temperature in the cable hole by the fact that some of the frequencies of the incident radiation are absorbed in the first part of the cable, which heats it up.

We also note from Fig. 1 that the temperature along the glass fiber optic cable is lower than the temperature along the plastic fiber optic cable due to the fact that fiber optic glass has an absorption factor lower than the absorption factor of fiber optic plastic. We also note from the figure, that the temperature of the fiber optic cable changes with time. For example, the temperature of fiber optic cable at 12 noon is higher than that of fiber optic cable at 10:00 am for the same cable due to the fact that the total solar radiation at 12:00 noon is higher than the total solar radiation at 10:00

am. The results we got are consistent with those of previous studies [5].

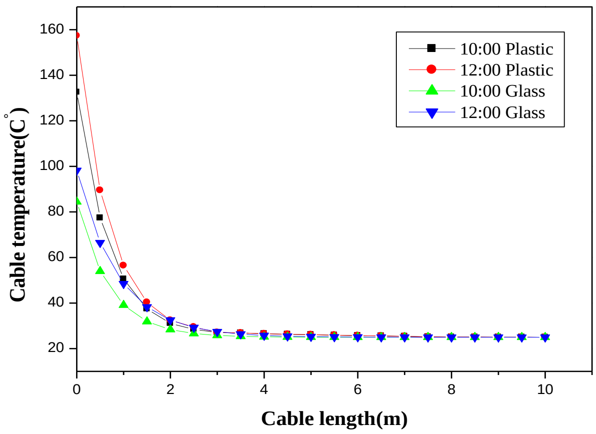

Fig. 1 – Temperature along plastic and glass optical fiber

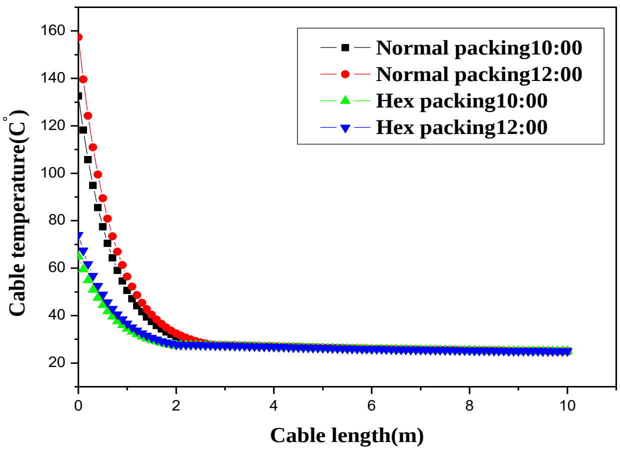

Fig. 2 – Temperature of two packing states of the plastic optical fiber

In order to find the figure that represents the temperature changes along the plastic fiber optic cable for both packing (normal and hexagonal), we use the same temperature relationship along the cable but with special values of the plastic fiber cable (for hexagonal and normal packing). We obtained the curve shown in Fig. 2 during 10:00 am and 12:00 pm at a specific wavelength in the optical field.

We notice from Fig. 2 that temperature at the cable entrance is high and gradually decreases until it is fixed at the same temperature as the air surrounding the cable. By comparing the hexagonal and normal packing of plastic fiber cables, we note that the cable temperature in hexagonal packing is lower than the cable temperature in normal packing due to the filling factor, which is close to the value of the hexagonal packing factor. But in the case of normal packing, it is small, that is pores in hexagonal packing are almost non-existent, while in the normal packing they are large, and therefore the larger the pores, the greater the temperature of the cable.

Fig. 3 represents the temperature changes along the hexagonal spliced plastic fiber optic cable and the normal spliced glass fiber optic cable at 12:00 noon and at a specific wavelength in the visible spectrum.

We note from Fig. 3 that temperature at the cable entrance is high and gradually decreases until it is fixed at the same temperature as the air surrounding the cable. By comparing the hexagonal packing of plastic fiber optic cable with the normal packing of glass fiber optic cable, we notice that the cable temperature in the hexagonal packing is lower than the cable temperature in the normal packing, and this is due to the filling factor close to one in the hexagonal packing, but in the normal packing it is small, that is, pores in the hexagonal packing are almost non-existent, while in the normal packing they are large, and the larger the pores, the higher the temperature of the cables.

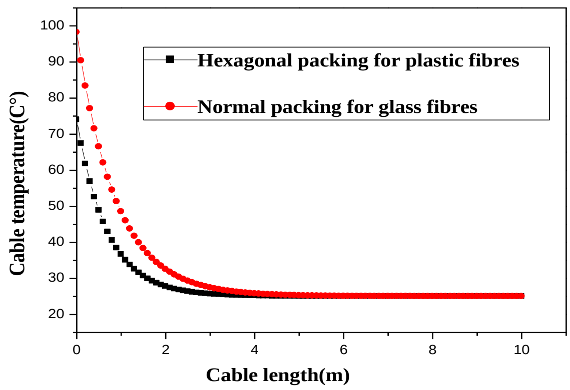

Fig. 3 – Temperature along the fiber optic cable

3.2 Factor Affecting the Surface Temperature of a Fiber Optic Cable Section

Fig. 4 represents the surface temperature changes of a fiber optic cable cross-section with a normal packing of plastic and glass fibers in terms of the total solar radiation entering the direction of the cable at a specific wavelength in the visible spectrum.

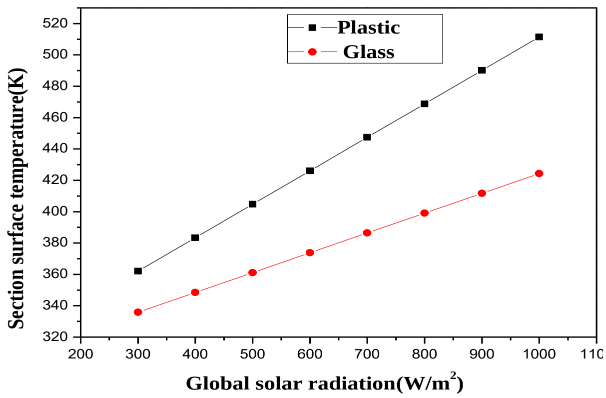

Fig. 4 – Surface temperature of a normally packed fiber optic cable

As we saw in the previous curve, the temperature along the fiber optic cable changes with time and this is due to the total solar radiation, and therefore the surface temperature of the fiber optic cable section is affected by the total solar radiation.

From Fig. 4 we note that the relationship between the surface temperature of the fiber optic cable section and the total solar radiation entering the cable is a proportional relationship and this is for both glass and

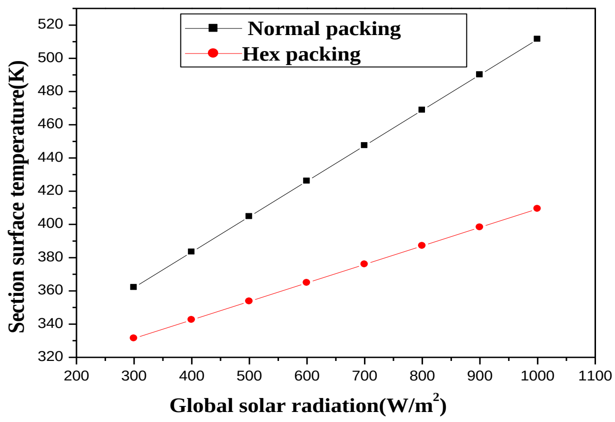

Fig. 5 – Surface temperature of the section of normally and hexagonally packed plastic fiber optic cables

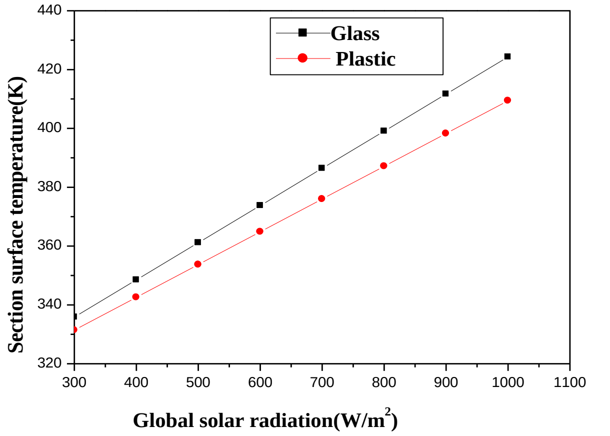

Fig. 6 – Surface section temperature of hexagonally packed fiber glass cables

plastic fibers. This means that the greater the total solar radiation entering the cable, the higher the temperature cut surface. These results are consistent with the results of previous experimental studies [9].

Fig. 5 shows changes in the surface temperature of the section of hexagonally and normally packed plastic fiber optic cables versus solar radiation entering the cable at a specific wavelength in the visible spectrum.

By comparing normal packing with hexagonal of the plastic fiber cable in Fig. 5, we note that when there is a certain total solar radiation, the surface temperature of the cross-linked fiber optic cable section is lower than the surface temperature of the normally packed fiber optic cable section, which explains the presence of pores in the case of hexagonal packing, there are fewer pores than in normal packing.

A glass fiber cable is normally bonded in terms of the total incoming solar radiation at a specific wavelength in the visible spectrum. Fig. 6 shows hexagonal packing of plastic and normal packing of glass fiber cables. We notice from this curve that there is a proportional relationship between the surface temperature of the fiber optic cable section and the total solar radiation entering the cable. This means that the higher the total solar radiation entering the cable, the higher the surface temperature of the plastic fiber optic cable section with hexagonal packing and also the surface temperature of the fiber optic cable section with normal packing. Comparing hexagonal packing of a plastic fiber cable and normal packing of a glass fiber cable in Fig. 6, we note that at a given total solar radiation, the surface temperature of the assembled hexagonal plastic fiber optic cable section is lower than the surface temperature of the assembled glass fiber cable. This is explained by the presence of fewer pores in the hexagonal packing than in normal packing.

4. CONCLUSIONS

In this work, we dealt with comparison and analysis of the results we obtained with the results of previous studies, and we also dealt with comparison between two types of fiber optic cables, namely plastic and glass, and this is in the case of connecting cables of hexagonal or normal packing, and we also compared the two types of packing.

We figured out how the temperature changes along the fiber optic cable, as well as the change in the surface temperature of the fiber optic cable section. Finally, we obtained the following results.

- The temperature along the glass fiber optic cable is lower than the temperature along the plastic fiber optic cable for the same packing.
- The temperature along the hexagonally packed fiber optic cable is lower than the temperature along the normally packed glass and plastic fiber optic cables.
- The surface temperature of the fiber optic cable section changes with the change in entry capacity (total solar radiation at a specific wavelength in the visible spectrum).
- The surface temperature of the fiber optic cable section changes with the change in the ingress energy (total solar radiation at a specific wavelength in the visible spectrum). The surface temperature of the hexagonally packed plastic fiber optic cable section is lower than the surface temperature of the normally packed plastic and glass fiber optic cables.

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Теоретичне дослідження впливу упаковки на температуру оптоволоконних кабелів

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Мета дослідження полягає в тому, щоб показати вплив упаковки на оптоволоконний кабель, який переносить концентроване сонячне випромінювання. Це сонячне випромінювання взято в певний день і годину в Wilaya Уаргла, Алжир. У дослідженні ми розробили математичну модель і отримали диференціальні рівняння за допомогою програми MATLAB, використовуючи властивості як пластикових, так і скляних волокон для нормальної та гексагональної упаковок шляхом вибору певного значення енергії на виході кабелю. Проаналізувавши отримані результати, ми порівняли їх з результатами попередніх досліджень для двох типів скловолоконних та пластикових кабелів у випадках гексагональної та нормальної упаковок. Результати показали, що температура оптоволоконного кабелю з гексагональною упаковкою нижча, ніж температура оптоволоконного кабелю з нормальною упаковкою незалежно від типу волоконного матеріалу. Крім того, загальна кількість сонячного випромінювання, необхідна для передачі через оптоволоконний кабель із гексагональною упаковкою, менша, ніж необхідна для передачі через звичайний оптоволоконний кабель для отримання тієї самої енергії на виході кабелю.

Ключові слова: Скловолокно, Пластикові волокна, Гексагональна упаковка, Нормальна упаковка, Температура.