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# Solar Surgery Optical System Design

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## Abstract

The sunlight is suggested to be used in solar surgery as an alternative to the laser surgery. The rays of powerful sunlight are collected, concentrated and transported to the operating theatre from outside through a system of optical fibers in order to use this solar energy in tumor and cancer cell evaporation instead of lasers. The idea of solar surgery is still new and need more practical and design enhancements. This study is a step on this way. A Schmidt Cassegrainien arrangement is suggested for this optical solar system design calculations. It consists of a parabolic dish to concentrate the solar radiation on a secondary flat mirror which directs the light into a fused silica optical fiber cable used to carry the concentrated solar beam from the concentrating system to the operation room.The parabolic reflector dish rim half angle was chosen to be $45^o$ to realize high flux and high efficiency.
MATLAB program (version 7.00) has been used to calculate the diameter of the primary parabolic dish, the diameter of the secondary flat mirror and its recession from the fiber tips by two design procedures. The first procedure of these calculations is based on starting with the choice of the optical fiber diameter, while the second design procedure is based on the choosing first the distal end diameter of the optical fiber.The calculations of the second procedure showed more practical results. As the most often used fiber distal diameter in surgery is 0.6mm, then according to calculations the diameter of the primary parabolic dish reflector will be 180mm with a focal length of 108.64mm. The small secondary mirror is perfectly flat of 10.5mm in diameter and its recession from the fiber tip is 5.27mm.
Another MATLAB program has been written to find the suitable numerical aperture for the optical fiber of the concentrator system to reach maximum efficiency of the system. It was found to be 0.7 theoretically. The nearest available value of NA for fused silica fiber was 0.66. Fused silica optical fiber of 1mm for core diameter was chosen because of its ability to withstand the high degree of temperature. It is found that this optical system could deliver a flux density as high as $73Wmm^{-2}$ for contact surgery and $32Wmm^{-2}$ for noncontact surgery.

**Key words:** solar surgery; optical design; fiber optics; Schmidt Cassegrainien

## [1] Introduction

Solar radiation can offer a viable alternative to laser light because the desired tissue degradation requires elevated power density rather than coherence [1]. Laser fiber-optic surgery typically delivers from a few watts to tens of watts of radiation, at power densities that range from a few to tens of $W/mm^2$ [2].Sunlight is uniquely suitable for surgical use because it can be concentrated to these flux levels, in contrast to currently available light sources from which attainable power densities are far too low. Furthermore, the absorption spectrum of biological tissue is well-suited to the solar spectrum, especially when optical penetration depths of the order of millimeters are desirable
In 1998 D. Feuermann and J.M. Gorden were proposed using highly concentrated sunlight with $0.15W/mm^2$ and in IR wavelength range as an expensive alternative to laser light for certain surgical procedures. The proposed system consists of a high-flux solar concentrator mounted on a solar tracker and an optical fiber that transports concentrated sunlight to remote operating theater [3,4].
In 2003 J.M. Gorden*et, al*,.injected 2.0-2.5 watts into the upper region of the liver from the distal tip of an optical fiber of 1.00mm diameter.

**[2] Solar Surgery System**

The solar system suggested here in figure (1) consists of:

1. Parabolic dish concentrator;
2. Flat mirror reflector;
3. In dish or remote absorber as shown in Fig.4 and Fig.5, respectively;
4. Optical Fiber;
5. The whole concentrators enclosed in a cylinder topped with a transparent glazing window to protect the optical system completely;

6. Different types of optical filters to select a desired band of wavelengths if necessary;
7. A tracker to direct the optical system towards the sun during the day time.

The relatively low power requirements allow to minimize the design [3].

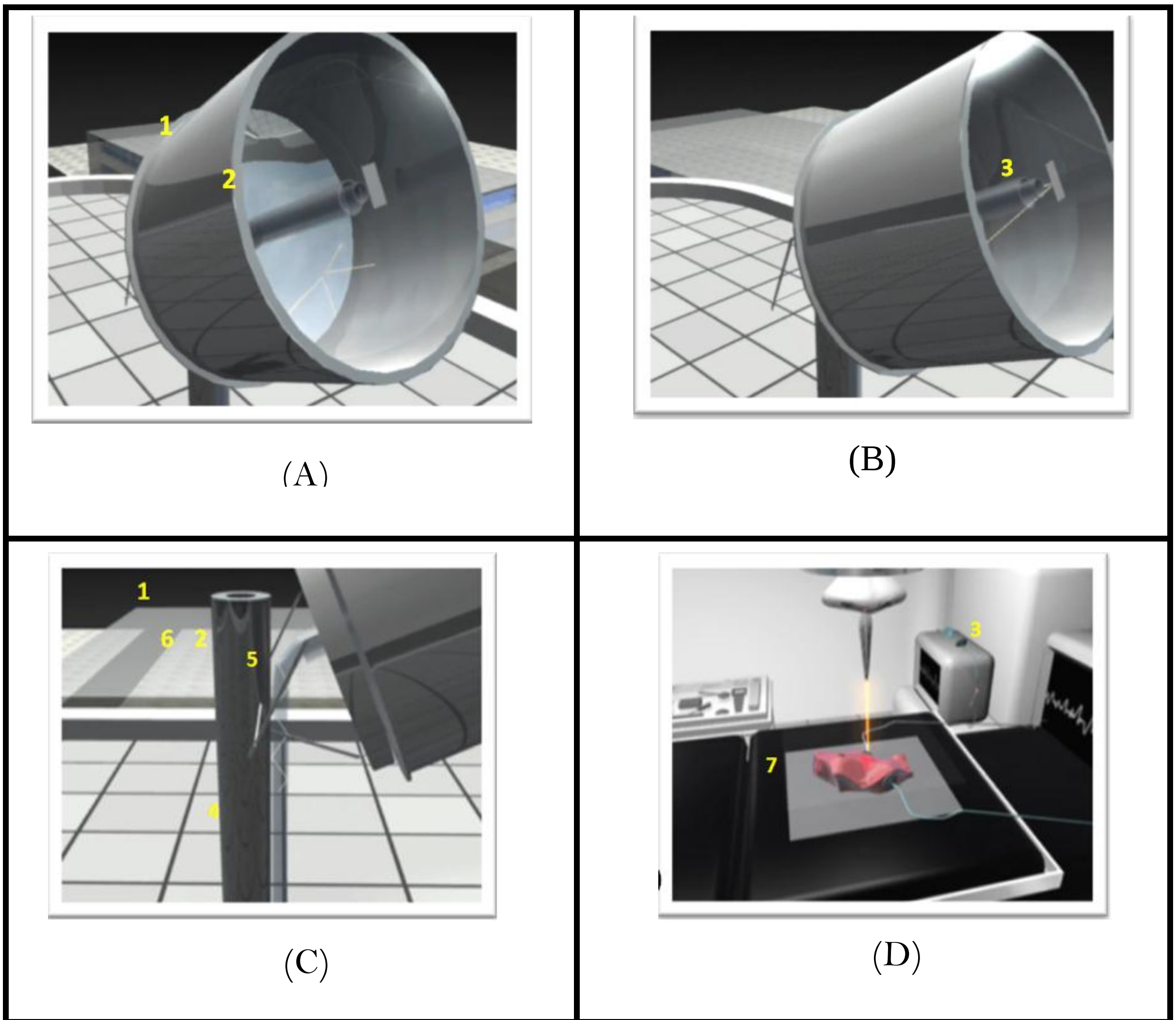



**Figure 1 :**Operation of mini-solar concentrator dish; (A) solar beam strike the primary concentrator; (B) solar beam strike the secondary concentrator; (C) concentrated solar beam transports by fiber optic to the operating room; (D) killing the infected tissue by concentrated solar beam. **1.** Cylindrical enclosed whole system**, 2.** Parabolic dish, **3.**Flat mirror**, 4.** Optical fiber**, 5.**Protective sleeve, **6.**Tracker, **7.**Tissue under concentrated solar radiation.

To realize high flux at high efficiency, the design is based on using a parabolic dish primary concentrator with a non-imaging secondary reflector to insure range of solar intensity ($10^{-1}$ to $10^{-2}$) $Wmm^{-2}$ which is comparable to the necessary laser energy used for surgery especially for cancer cell vaporization.

All the dimensions of this solar system dimensions depend on the rim angle of the parabolic dish, so the first step is choosing the optimum rim half angle. Then the design calculations may be based on either the optical fiber diameter or on the distal end diameter of the optical fiber.

Accordingly, a two design procedure is suggested to find the solar system parameters dimensions and its other calculations.

## [4] Parabolic Dish Rim Half Angle Calculations

To choose the optimum rim half angle it is important to consider eq.(1) and eq.(2) for the maximum concentration and the maximum efficiency strategy design respectively [5]:

| | |
|---|---|
| $C_{dish}(\text{max.conc.}) = \sin^2(\phi)/\sin^2(\theta_s)$ | 1 |
| $C_{dish}(\text{max.eff.}) = \sin^2(\phi)\cos^2(\phi)/\sin^2(\theta_s)$ | 2 |

where $\phi$,is the rim half angle diameter and $\theta_s$ is the solar half angle subtended by the earth or incidence angle (= 0.005radians $\cong$ 0.27 degree).
A MATLAB program has been written to calculate the results of these two equations according to the flowchart shown in figure( 2) .
These results are shown in table (1) and in fig. (3), which show that the optimum rim half angle is 45$^o$ as it gives maximum efficiency and reasonable good concentration.

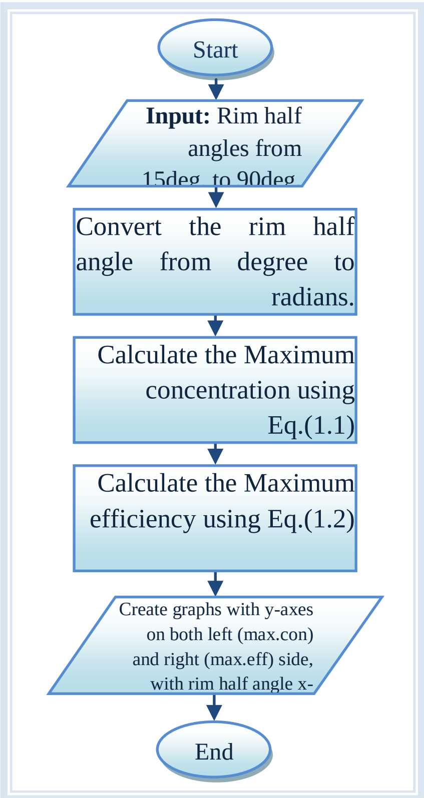



**Figure 2:** Flowchart represents the sequence of MATLAB steps for max. concentration and max. efficiency as a function of rim half angle.

**Table 1**: Variation of concentration & efficiency with dish rim angle.

| Rim angle ø (deg.) | Design technique concentration | |
|---|---|---|
| | Max. Conc. | Max. Effic. |
| **15** | 3016.57 | 2829 |
| **20** | 5267.74 | 4676 |
| **25** | 8042.99 | 6641 |
| **35** | 14815.06 | 9994 |
| **45** | **22515.99** | **11317** |
| **55** | | 9994 |
| **60** | 33773.98 | 8488 |
| **65** | 36988.98 | 6641 |
| **75** | 42015.40 | 2829 |
| **85** | 44689.90 | 3410 |
| **90** | 45031.97 | 0.00 |

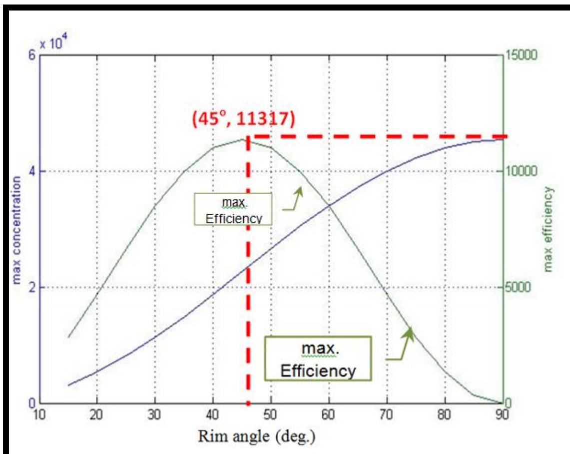



**Figure 3:** The rim half angle effect on the max. concentration and max.efficiency of the parabolic dish. It seen that most suitable angle for the max.efficiency is 45°.

The minimum loss $L_o$, when the shading and blocking losses are equal was calculated by using eq.(3), [5]:

| | |
|---|---|
| $L_o = \dfrac{\theta_s \tan(\phi)}{8\tan^2(\phi/2)}$. | 3 |

$L_o$=0.0034 unit less.

The *f/no.* of the dish that is related to *Ø* was calculated using eq.(4):

| | |
|---|---|
| $f/no. = \dfrac{f}{D} = \dfrac{1}{4\tan(\phi/2)}$ | 4 |

*f/no.*= 0.6 unit less.

## [5] First design Procedure Calculations

The optical fiber diameter is chosen to be the starting point of the following calculations. The concentration can be performed with in-dish or remote absorber. A fused silica fiber is considered in these two cases (in-dish and remote) with a diameter ($d_{fiber}$=1mm), as a typical and the most available fiber type.

### [5.1] In dish design Calculations

The design structure of the in-dish concentrator is shown in fig.4 (a and b).

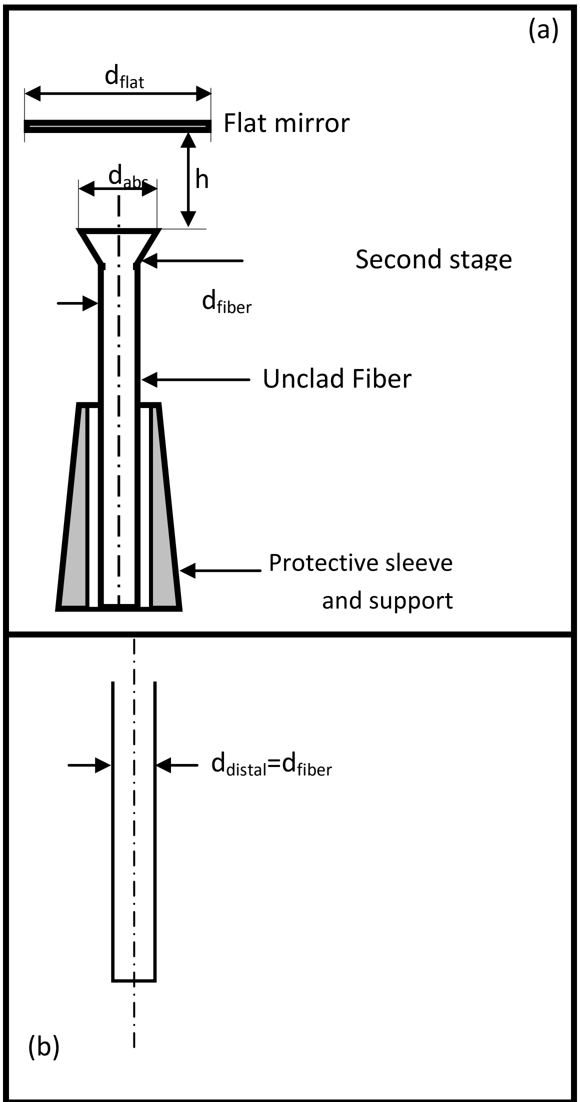



**Fig 4:** In-dish design structure of the second stage (a) Cross section of the fiber absorber where the concentration performed in the dish, (b)Cross section of the distal end of the fiber [5].

### [5.1.1] Parabolic Dish Parameters, Diameter and Focal length Calculations

The diameter of the parabolic dish depends on the absorber diameter as seen from eq. (5) and eq.(6), [5]:

| | |
|---|---|
| $d_{\mathrm{abs}}(\mathrm{max.conc.}) = D\theta_{\mathrm{s}} /(2\tan(\phi/2))$ | 5 |
| $d_{\mathrm{abs}}(\mathrm{max.eff.}) = D\theta_{\mathrm{s}} /(\sin(\phi)\cos(\phi))$ | 6 |

The absorber diameter is the diameter of the optical fiber that absorbs the rays reflected from the flat mirror is shown in fig.4a. The absorbing diameter is calculated by:

$d_{\mathrm{abs}}=d_{\mathrm{fiber}}/\sin Ø$ (7)

so$d_{\mathrm{abs}}$=1.4mm. quations (5) and (6) are used to calculate the parabolic dish diameter for maximum concentration and maximum efficiency respectively. The results of calculations are $D_{\mathrm{max.conc}}$=249mm and $D_{\mathrm{max.eff.}}$=150mm, so the average considered to be $D_{\mathrm{average}}$=199.5 ≈ 200mm .The average focal length calculated by eq.(4), which implies that $f$ =120mm.

### [5.1.2] Flat mirror and Its Recession

The diameter and the recession of the flat mirror $d_{\mathrm{flat}}$ and $h$ were calculated by eq.(8) and eq.(9), respectively.

| | |
|---|---|
| $d_{\mathrm{flat}} = D\sqrt{L_{\mathrm{o}}}.$ | 8 |
| $h = f\left[\dfrac{\theta_{\mathrm{s}}}{2\tan(\phi)}\right]^{1/2},$ | 9 |

According to the previous calculations of the parabolic dish diameter $D$ and the minimum losses $L_o$, the values of $d_{\mathrm{flat}}$ and $h$ will be as follows:

$d_{\mathrm{flat}}$=200× $(0.0034)^{0.5}$=11.6mm,

$h$ =5.86mm.

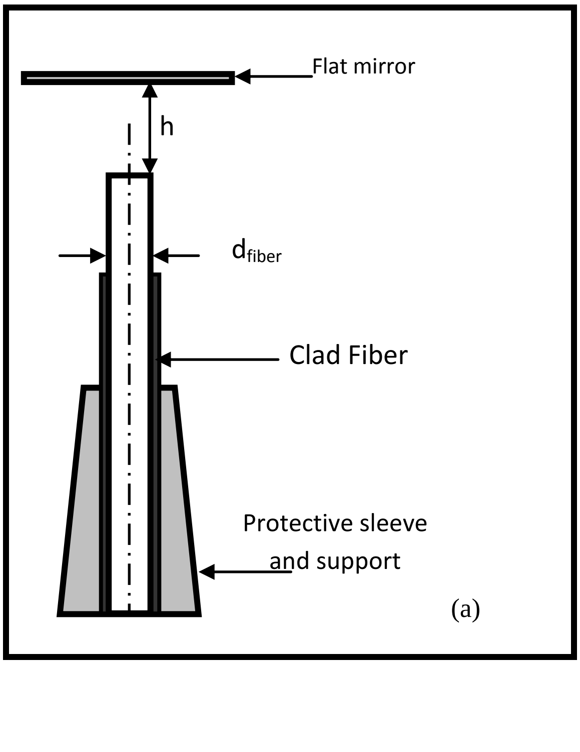
### [5.1.3] Fiber tips Distal End Diameter

The optical fiber distal end diameter was equal to the fiber diameter because the concentration performed in-dish, in the tip of the fiber that represents the absorber, as shown in fig.(4), so:

$d_{\mathrm{fiber}}$=1mm , $d_{\mathrm{abs}}$= 1.4mm (as calculated before, then$d_{\mathrm{distal}}$=1mm.)

### [5.2] Remote design calculations

The design structure of the in-dish concentrator is shown in fig.(5 a and b).



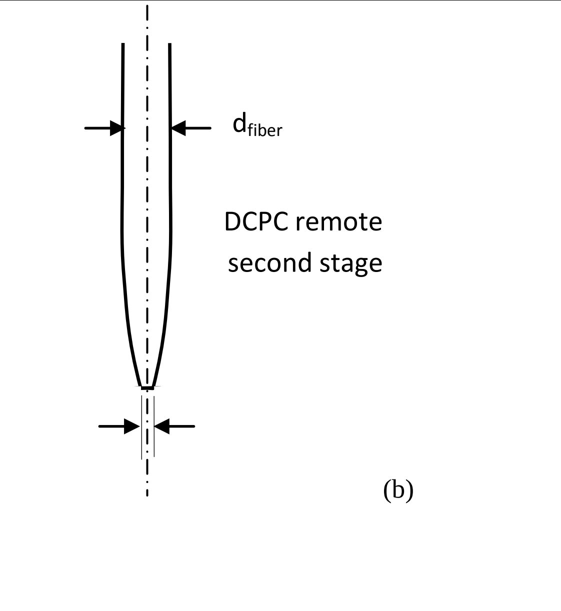



**Fig 5:** Remote design structure of the second stage (a) Cross section of the fiber absorber, (b)Cross section of the distal end of the fiber where the concentration performed remotely in the operating room [5].

### [5.2.1] Parabolic dish parameters, diameter and focal length calculations

The absorbing diameter is calculated by ($d_{abs}$=$d_{fiber}$), so $d_{abs}$=1mm. Equations (5) and (6) are used to calculate the parabolic dish diameter for maximum concentration and maximum efficiency respectively. The results of calculations are $D_{max.conc.}$=176mm and $D_{max.eff.}$=106mm. These are imply that $D_{average}$=141mm. The average focal length is calculated by eq.(4) which implies that $f$=84.6mm.

### [5.2.2] Flat mirror and its recession

The diameter and the recession of the flat mirror $d_{flat}$, $h$ are calculated according to eq.(8) and eq.(9), respectively, where the parabolic dish diameter $D$ is substituted by 141mm, and the minimum losses $L_o$ is substituted by 0.0034 as calculated before. The results of flat mirror diameter and its recession will be;

$d_{flat}$=141× $(0.0034)^{0.5}$=8.22mm, $h$ =4.1mm.

### [5.2.3] Fiber tips and end diameter

The optical fiber tip diameter (absorber) is equal to the fiber diameter because the concentration performed remotely in the distal end of the fiber.Then the distal end diameter will be as follows;

$d_{distal}$ =$d_{fiber}$ ×sin($\phi$). The results were

$d_{fiber}$=1mm , $d_{abs}$= 1mm,$d_{distal}$=0.7mm.

Table 2 displays the whole results of the first procedure calculations for the solar system components in the two design cases in-dish and remote.

**Table 2: First Procedure Design; System components dimensions (all in mm)**

| Design | $d_{fiber}$ | $d_{abs}$ | $d_{distal}$ | $D_{average}$ | $f_{average}$ | $h$ | $d_{flat}$ |
|---|---|---|---|---|---|---|---|
| In dish | 1 | 1.4 | 1 | 200 | 120 | 5.86 | 11.6 |
| Remote | 1 | 1 | 0.7 | 141 | 84.6 | 4.1 | 8.22 |

## 6] Second Design Procedure Calculations

The optical fiber distal end diameter is chosen to be the starting point of this procedure of calculations. The most used fiber distal diameter in laser-tumors surgery is 0.6mm [3, 6]. Equation (7) gives the absorber diameter for both the two design cases in-dish and remote. The result is $d_{abs}$=0.848≈0.85mm at the relevant rim half angle $\phi$=45°. So for these two design cases the parabolic dish diameter is being equal because of its dependency on the absorber diameter, where eq.(5) and eq.(6) are used to calculate the parabolic dish diameter for maximum concentration and maximum efficiency, respectively. The results of calculations are $D_{max.conc.}$=149mm, and $D_{max.eff.}$=89.97mm. So the average parabolic dish diameter is $D_{average}$=119.5mm.

Equation (4) gives the average focal length, so $f_{average}$=71.69mm. The flat mirror diameter and its recession are calculated by Eq.(8) and Eq.(9) respectively, $d_{flat}$=6.97mm, $h$= 3.48mm.

In this procedure only the optical fiber diameter is different according to the design whether it is performed in-dish or remotely. For the in-dish design the fiber diameter equal to the distal diameter so $d_{fiber}$=$d_{distal}$=0.6mm, but for the remote design $d_{fiber}$=$d_{distal}$/sin($\phi$) =0.848≈ 0.85mm. Table 3 displays the whole results of the second procedure calculations for the solar system components in the two design cases, in-dish or remote.

<table>
<tr><th colspan="8">Table 3: Second Procedure Design; System components dimensions (all in mm)</th></tr>
<tr><th>Design</th><th>$d_{fiber}$</th><th>$d_{abs}$</th><th>$d_{distal}$</th><th>$D_{average}$</th><th>$f_{average}$</th><th>$h$</th><th>$d_{flat}$</th></tr>
<tr><td>In dish</td><td>0.6</td><td rowspan="2">0.85</td><td rowspan="2">0.6</td><td rowspan="2">119.5</td><td rowspan="2">71.69</td><td rowspan="2">3.48</td><td rowspan="2">6.97</td></tr>
<tr><td>Remote</td><td>0.85</td></tr>
</table>

## [7] Fiber Numerical Aperture Calculations

High numerical apertures are suggested to be used to deliver the collected solar energy due to their adequately low attenuation (less than 0.07% per meter) that fiber runs of the order of 100 m within low optical loss [5,7].

It is clear that the maximum concentration eq.(1) and the maximum efficiency eq.(2) were related to the numerical aperture of the fiber by substituting NA=sin($\phi$) in them as follows:

$$C_{dish}(\max.conc.) = NA^2/\sin^2(\theta_s) \qquad (10)$$

$$C_{dish}(\max.eff.) = NA^2(1-NA^2)/\sin^2(\theta_s) \qquad (11)$$

The relation between the maximum concentration and the maximum efficiency with the numerical aperture of the fiber is calculated using MATLAB program as shown by the flowchart in fig.6. The results are shown in fig.7 where the numerical aperture is varied from zero to 1.00. The results show that the best numerical aperture is 0.7 for maximum efficiency

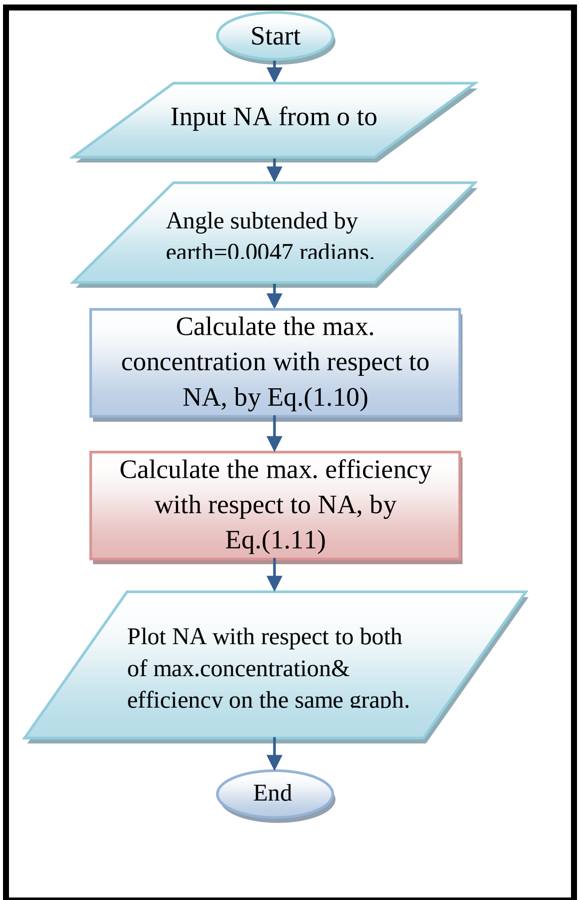



**Figure 6:** Flowchart represents the sequence of MATLAB steps for the concentration as a function of numerical aperture of optical fiber.

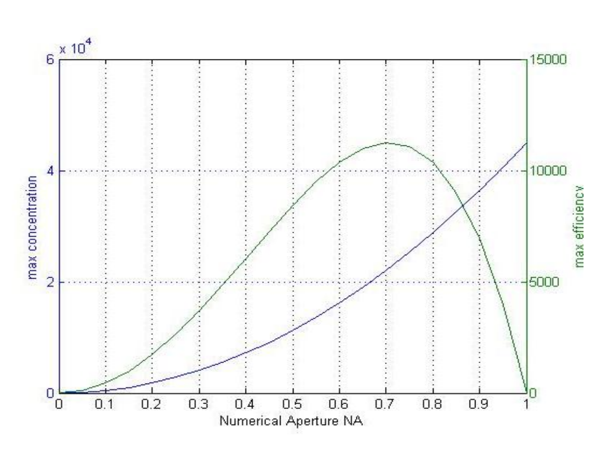



**Figure 7:** Solar concentration as a function of numerical aperture of the fiber of the concentrator system.

## [8] The Flux Intensity Calculations

The following practical assumptions have been considered for estimating the attainable flux intensity after the two stages of concentrations [5]:

a. The solar intensity at the system glazing window, between 0.0010-0.0008 W/mm$^2$

b. The solar half angle subtended by the earth, $\theta_s$= 0.27°.

c. The optical losses of the concentrator system of 20% .

d. For the contact surgery the refractive index of the tissue is included in the calculations, but for the non contact surgery, the flux is independent of this refractive index.

**[9]Contact and Non-Contact surgery**

The flux intensity calculations of the two cases are different due to the refractive index , which appears in the contact surgery as follows:

Flux intensity (noncontact) =optical efficiency (20% losses) × solar intensity (0.009 W/mm$^2$) × 1/(sin($\theta_s$))$^2$ = 31.6 ≈ 32 W/mm$^2$.

Flux intensity (contact) = optical efficiency (20% losses) × solar intensity (0.009 W/mm$^2$) × 1/(sin($\theta_s$)) $^2$ × (refractive index of tissue ($n_t$=1.5)) $^2$ ≈ 73 W/mm$^2$

**[10] Suggested Solar Surgery System**

Second procedure of calculations is the most suitable method to calculate the solar system size, as the power delivery must emerge from distal end of diameter 0.6mm. The optical system size doesn't change whether the second concentration performed in-dish or remotely.

Solar system size then appears to change with the type of surgery whether it is contact or noncontact. For contact surgery the dimensions of the system components must be increased by a factor of living tissue refractive index ($n_t$=1.5).

The optical fiber diameter must not exceed the limits between $d_{min}$and $d_{max}$, shown in eq.(12) and eq.(13), respectively.

$$d_{min}=2D\left({}^{f}/_{no.}\right)\theta_s \qquad (12)$$

$$d_{max} = \frac{D\theta_s\left(1+16\left({}^{f}/_{no.}\right)^2\right)^2}{8\left({}^{f}/_{no.}\right)\left(16\left({}^{f}/_{no.}\right)^2-1\right)} \qquad (13)$$

For noncontact surgery the limits are between $d_{min}$=0.678mm and $d_{max}$=1.126mm, and for contact surgery the limits are increased by refractive index of tissue ($n_t$=1.5). The limits were between $d_{min}$=1mm and $d_{max}$=1.689mm.

For simplicity of practical applications one design for both contact and noncontact surgical applications should be used.

The system size for contact surgery can be used for noncontact surgery. Accordingly the suggested solar system dimensions for both types of surgery is shown in table (4).

**Table 4: Suggested system components dimensions; Remote design.**

| Components | $d_{distal}$ | $d_{fiber}$ | $d_{abs}$ | $D_{average}$ | $f_{average}$ | $h$ | $d_{flat}$ | $NA$ |
|---|---|---|---|---|---|---|---|---|
| | mm | | | | | | | Unit less |
| Contact | 0.6 | 1 | 1 | 180 | 108.64 | 5.27 | 10.5 | 0.66 |

## [11] Conclusions

1. The solar surgical unit is a passive optical system. It's cost is less than the current surgical lasers with fiber optic coupling.
2. The suggested solar surgical system that was described in this paper can produce flux density for contact surgery more than that produced for noncontact surgery.
3. The design procedure which starts from choosing the distal end diameter of the optical fiber gives better practical results of solar system dimensions, were the remote and in-dish design has the same dimensions.
4. In solar system a large NA preferred because there is a band of wave lengths to be passed through the fiber.

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# تصميم منظومه بصريه للجراحه الشمسيه


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**الخلاصة:**

يمكن استخدام ضوء الشمس في الجراحه الشمسيه كاختيار اخر بدلا من الجراحه الليزريه وذلك بتجميع الطاقه الكبيره في الاشعه الشمسيه وتركيزها ونقلها خلال الالياف البصريه من الخارج الى داخل صاله العمليات لاجل استخدامها في عمليات
استئصال الاورام و تبخير الخلايا السرطانيه بدلا من الليزر.
أستخدمت طريقه شميت – كاساغرين في تصميم هذه المنظومه البصريه للاشعه الشمسيه التي تتكون من الصحن ذو المقطع الدائري الذي يجمع الاشعه ويسقطها على مراة مستويه لتوجهها الى مدخل ليف بصري مصنوع من السليكا المنصهره لتوصيل هذه الطاقه الشمسيه المركزه الى داخل صاله العمليات, وتم اختيار زاويه حافه الصحن لتكون بقيمه 45 درجه للحصول على افضل كفائه واعلى طاقه اشعه.

استخدمت في البحث طريقتين للتصميم نفذتا على برنامج المصفوفات نوع 7.00 لاجراء حسابات قطر الصحن ذو المقطعالدائري وقطر المراة المستويه الثانويه والمسافه المناسبه بينها وبين مدخل الليف البصري.اما الطريقه الاولى فتستند الى اجراء حسابات التصميم ابتداء من اختيار قطر الليف البصري في حين ان حسابات الطريقه الثانيه تبداء من اختيار القطر المناسب لطرف الليف من الجهه البعيده ألتي تخرج منها الاشعه وقد اثبتت الحسابات ان هذه الطريقه تعطي نتائج عمليه افضل من الطريقه الاولى .
اظهرت حسابات التصميم في هذه الحاله ان قطر صحن المقطع الدائري يجب ان يكون 180 مللمتر وببعد بؤري قيمته108.6 مللمتر وكذلك حددت قطر المراة المستويه بمقدار 10.5 مللمتر وبعدها عن الليف البصري 5.27 مللمتر.
وللحصول على اعظم كفائه لهذه المنظومه الشمسيه تم اعداد برنامج اخر لاجل حساب افضل فتحه عدديه لليف البصري فتم تحديدها بقيمه0.7 للحصول على افضل كفائه لهذه المنظومه ولكن بما ان اقرب فتحه عدديه متوفره عمليا لهذا الليف هي 0.66 لذلك تم اختيارها هي وقطر الليف البالغ 1 مللمتر لهذا التصميم لضمان تحمل الحراره العاليه جراء نقل طاقه شمسيه بهذه المنظومه تصل كثافتها الى 73 واط/مللمتر مربعفي حاله الجراحه بالاتصال المباشر وكثافه 32 واط/مللمتر مربع في حاله الجراحه بالاتصال غير المباشر.

الكلمات الداله: الجراحه الشمسيه,التصميم البصري,الالياف البصريه,شميدت كاساكرين