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Improvements to the solar wax smelter

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SYNOPSIS

A number of papers have established the feasibility of melting waxes for candle making using solar energy. In this paper, methods of upgrading the systems and alternative systems of better efficiency are proposed. The following aspects of optimal collection of energy are dealt with: (a) optimal orientation of collector, (b) azimuthal tracking and (c) the use of four mirrors to boost the energy incident on the collector.

An improvement to the heat transfer to the wax is effected by incorporation of a freely convecting heat transfer liquid loop. The wax is now placed in a liquid bath to encourage immediate and rapid melting. Design factors which improve user convenience and safety are also mentioned and an estimation of the improvement in energy collection over previous models and practice is indicated.

INTRODUCTION

There appears to be a wide interest among candle makers in the utilization of solar energy as a source of process heat and several papers [1, 2, 3] testify the efforts made in this direction. These efforts have established the feasibility of using the solar heat and appear to have gained user acceptance. The stage is now set for major improvements of the wax melting stills. The improvements can be achieved immediately by adopting the engineering knowledge in this field. A few of the possibilities of such adoption are described in this paper.

Waxes with a low melting temperature are used in candle making. The melting temperature is usually between 60° to 70°C and latent heat of melting is around 40 cal/gm (168 kJ/kg). Therefore melting such waxes is an ideal application for solar energy.

Usually the following further criterion has to be met. Wax is a highly inflammable material either in the form of liquid or vapour. The low melting temperatures mean that vapours are readily formed. Therefore either a flame should not be present near the melting still or at least the flame and vapours should be segregated as in the case of Davy's safety lamp. Solar energy by-passes such hazards and problems of high temperatures (greater than the flash point) are absent. It also provides clean heat free from pronounced hot spots which induce local boiling. Since temperatures are low, and the rate of application of heat is slow, vapour formation is minimized.

The current technology as discerned from published work is simple and rudimentary. Wax smelters resemble a storage type hot water-still of a rather small capacity. No efforts are made to maximize solar energy collection. Only one charge per day is practised while potential for a greater yield exists.

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Review of current wax smelters. The models reviewed here were made and tested by CAZRI, Jodhpur. They are 0.48 m^2 in area and the depth of the melting chamber in different models has been varied from 50 to 90 mm. It has been found that various models in different modes operate at efficiencies between 7 to 20% [1, 2]. For a solar thermal device such efficiencies are rather low when compared to 30% achieved in water heaters and stills. The low efficiencies can only be attributed to poor heat transfer from the absorber plate to the wax. It is stated that the wax slab is broken up into lumps and then fed into the melting chamber. The weakness of the system is apparent here. The smelting chamber is an inclined rectangular chamber. The top face of the chamber is the heat absorbing face while most of the wax rests on the cooler bottom face. Heat is transferred to the wax through small contact patches. Once the wax in those areas melts, only the bottom region of the absorber face is effective in transferring heat to the wax. This explanation could possibly account for the low performance efficiency of the smelter.

Methods of improving the performance of the system are now apparent. They can be classified into two groups as follows:

(a) Methods of improving heat transfer from the absorber to the wax and
(b) Methods of increasing solar radiation incident on the heat absorber plate.

Improvements in heat transfer to wax. Wax is commercially available in slabs. The breaking up of the slab into smaller lumps is a needless task if the slab itself could be loaded into the smelter. An inclined smelting chamber is used at present. The inclination of the chamber is dictated by the geometry of the solar radiation. In such a case the wax slab will rest on the bottom face of the smelter as shown in Figure 1. An air gap between the wax slab and the absorber results in preventing effective heat transfer by conduction. The contact in such cases can be expected to be less than 30 to 40%, resulting in poor heat transfer and consequent low efficiency.

What are the alternatives? One possible solution to the problem is that heat could be applied through the rear surface. In such a case the problem of transferring heat from the absorber plate to the rear face will arise. A convecting fluid system is indicated. Since the temperature requirements are low (< 100°C) water itself could be a suitable medium. Alternatively heat transfer fluids such as ethelyne glycol or any other proprietary (heat transfer) fluid can be used. These fluids with their lower specific heat reduce the thermal inertia and therefore reduce the heat-up time. Further, the problem of corrosion is also significantly

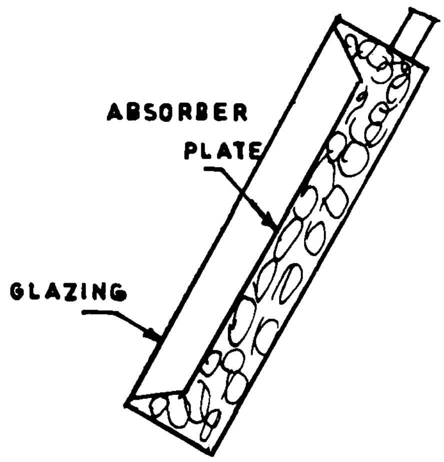

Figure 1 Traditional wax smelter.

reduced. In such an eventuality the slab could rest on a reservoir of hot fluid. The resulting design is shown in Figure 2. It must be pointed out here that the unloading spout in current designs (for molten wax) is located at the top and is therefore extremely inconvenient and could even be dangerous to the operator. The molten wax is quite fluid if heated to a temperature 10°C above the melting point (say about 70° to 75°C) and could be tapped conveniently at the bottom, through a taper plug and stopper system. If metal surfaces – which are very good conductors – are used then the thin film of wax flowing out will cool rapidly and clog the system. Therefore it is essential that the plug and stopper be made of an inert and poorly conducting material such as bakelite. The design is illustrated in Figure 3.

NOMENCLATURE

A_c = Area of the absorber plate (m^2)
CR = Concentration ratio
I = Intensity of radiation
TEM = Top edge mirror
WM = Wing mirror

Greek letters

α = Altitude (°)
γ = Azimuth (°)
δ = Declination of the sun (°)
η = Efficiency of the system
θ = Angle between the incident ray and the normal to the receiver (°)
ϕ = Latitude (°)
ω = Hour angle (h)

Super scripts

° = Degrees

Subscripts

$_b$ = Beam component
$_d$ = Device
$_{max}$ = Maximum
$_s$ = Sun
$_T$ = Total (incident + reflected)

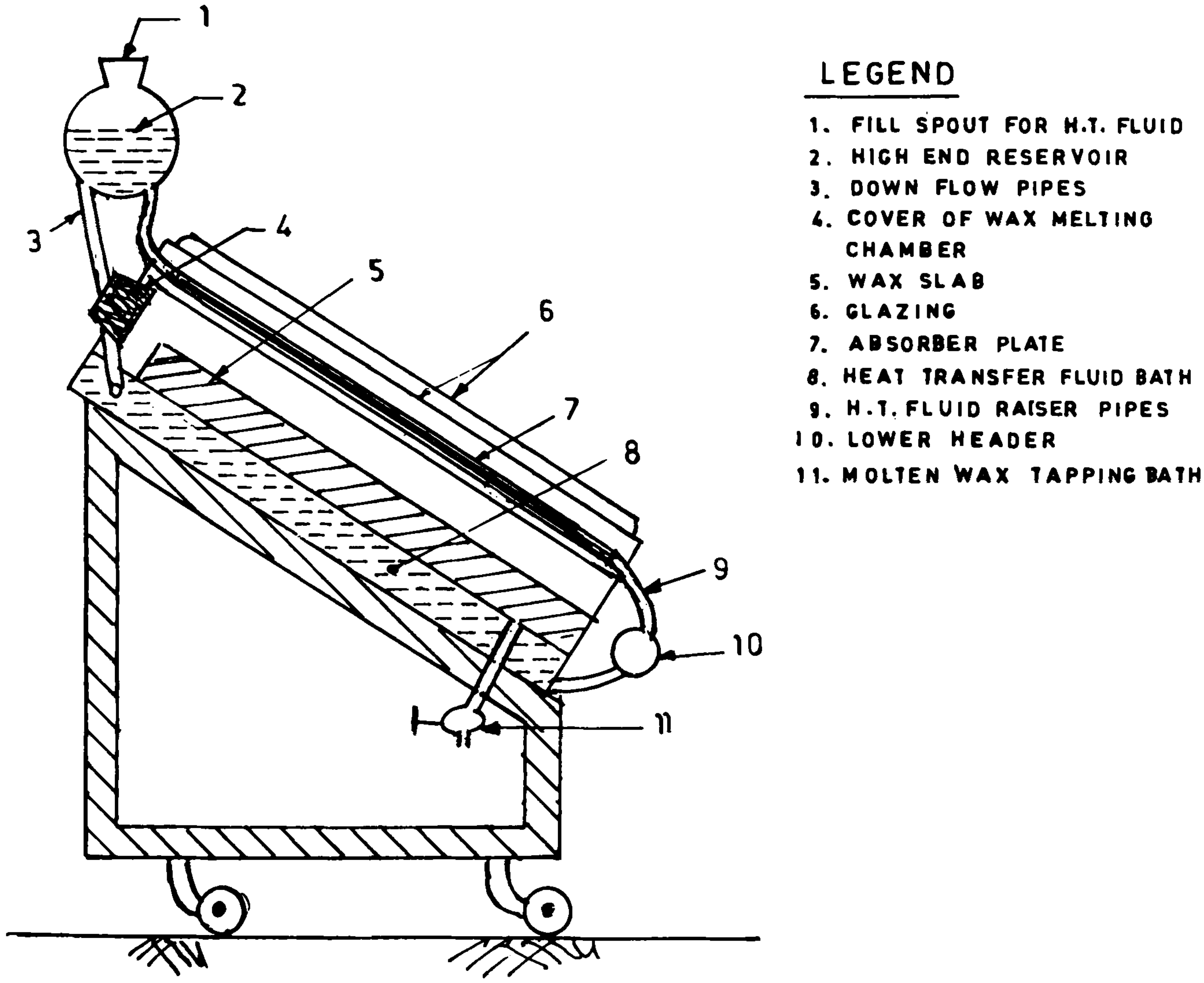

Figure 2 Modified wax smelter.

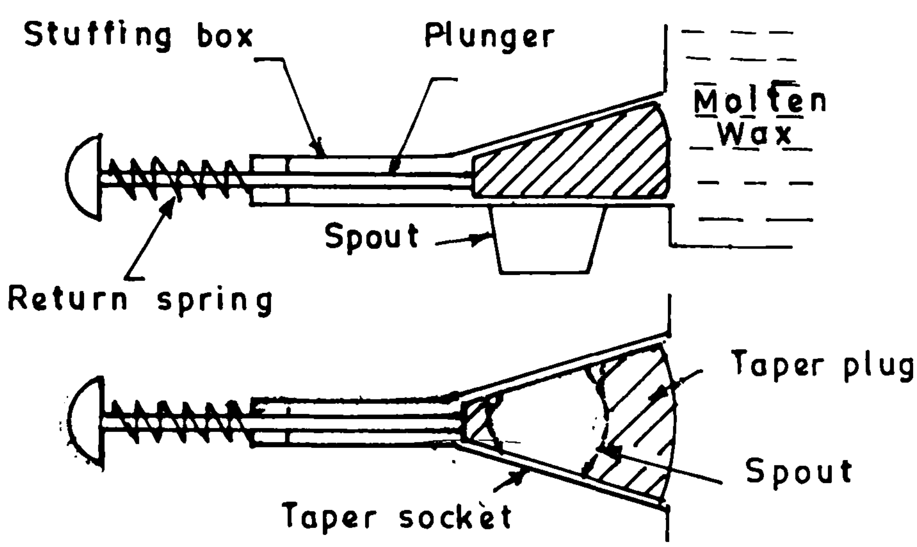

Figure 3
Design of spout.

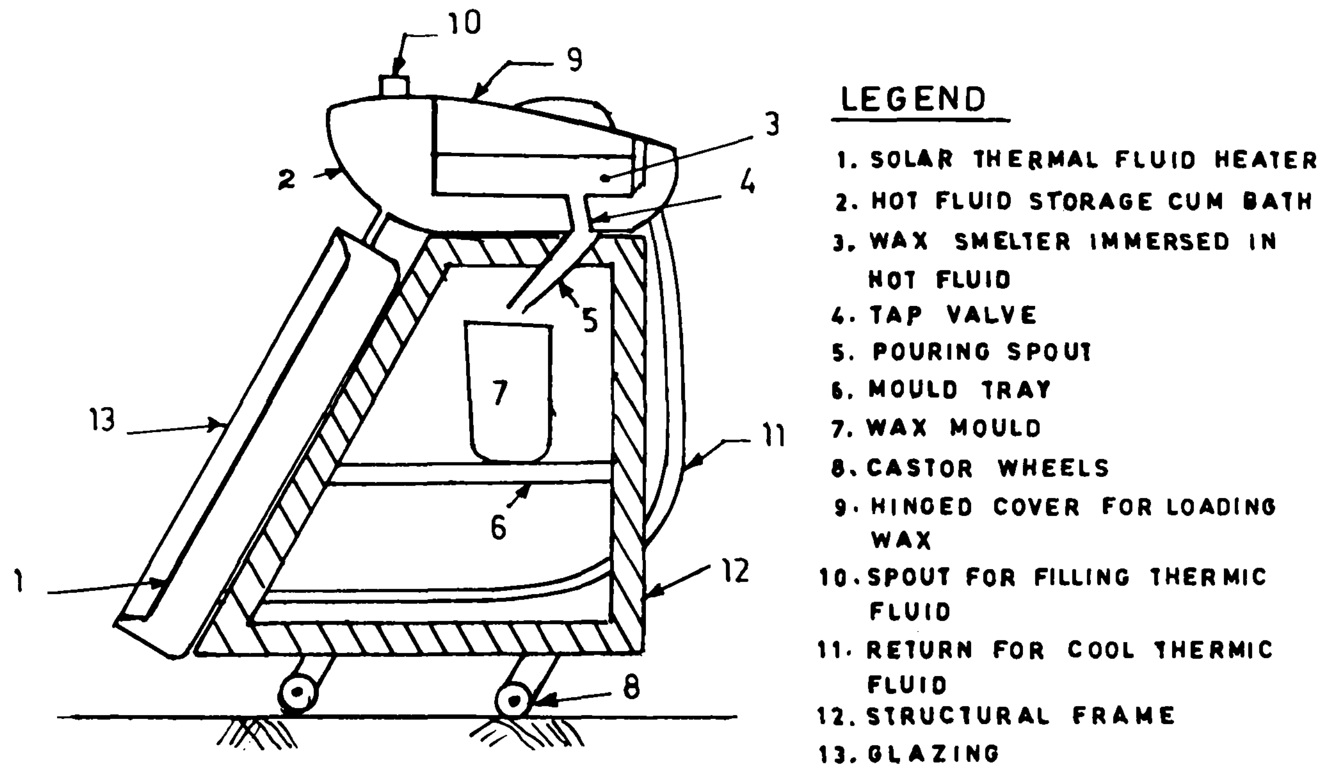

Figure 4 Liquid bath wax smelter.

The proposal of using a liquid bath for smelting wax as suggested above opens out another design possibility. A solar hot water system can be modified for smelting wax by changing the hot water storage drum. A liquid bath smelter should be substituted in its place. By such a modification it would be possible to lift the efficiency of the system to some 30%, which is easily achieved in many solar water heaters of good design. Such a modification is illustrated in Figure 4.

METHODS OF MAXIMIZING INCIDENT SOLAR RADIATION

The quantum of incident solar radiation can be increased by 30 to 100% by adopting simple methods and strategies that do not make a significant demand on the designer, constructor or operator. Two such strategies will now be described.

Azimuthal tracking. The present device already has a provision for taking care of changes in the sun's declination. Tracking of a solar device is necessary to reduce (if not eliminate) the angle between the device axis and the sun's direction. The situation in Jodhpur could be analysed as follows:

The range of motion of the sun over the Jodhpur horizon is tabulated in Table 1.

The angle between the device axis and the sun's direction at any moment is the factor which causes attenuation of incident solar radiation on the device plane. This factor is known as the cosine factor and it can be resolved into two components in horizontal and vertical planes. The component angles are given by the difference, i.e. $(\alpha_s - \alpha_d)$ and $(\gamma_s - \gamma_d)$. *Tracking aims to achieve an improvement of radiation density on the device plane by reducing these angles.*

The solar devices meant to be kept in a fixed position are kept oriented towards the sun during its meridian transit. The device coordinates are then $\gamma_d = 180°$ and $\alpha_d = \alpha_s$. Considering this position as the starting point of tracking strategy, it is clear that the range of azimuthal angle is much larger than range in altitudinal angle. The implication is that the azimuthal tracking is more fruitful and has a priority in tracking strategies.

The azimuthal tracking can be easily adopted as the current design has a provision made for moving the whole unit. The provision of castor wheels can easily be made for azimuthal tracking. A new requirement would be an orientation indicator to set the device. The indicator consists

Table 1 The sun's meridian altitude and azimuth at sunrise and sunset.

δ	γ_s (minimum east)	γ_s (minimum west)	Range in γ_s	$\alpha_{s,max.}$
+23° 27′	63° 51′	296° 09′	232° 18′	87° 09′
+10° 00′	78° 51′	281° 09′	202° 18′	73° 42′
0° 00′	90° 00′	270° 00′	180° 00′	63° 42′
−10° 00′	101° 09′	258° 51′	157° 42′	53° 42′
−23° 27′	116° 09′	243° 51′	127° 42′	40° 00′

Minimum value of α_s is evidently zero and therefore the range in $\alpha_s = \alpha_{s,max.}$

of a target board and a parallel slit board as shown in Figure 5. The tracking need not be continuous. Intermittent tracking is good enough and intervals of 1 or 2 hours would be more than adequate. The device should be kept at least a half interval (say $\omega = 7.5°$) ahead of the sun. The energy gain from beam radiation in ± 4 hours from the solar noon are indicated (when $\delta = 1°$, approximately, 25th March) in Table 2.

The relative gain due to azimuthal tracking is even more pronounced and valuable, with the larger hour angles of late evening or early morning. Table 2 highlights the many advantages of intermittent tracking. They are (i) a significant rise in overall energy collection, (ii) an increased low end performance so that the variations in output and performance are reduced, and (iii) the performance span is greatly increased. Gains due to the adoption of azimuthal tracking are illustrated in Table 2.

Use of booster mirrors. The use of booster mirrors to increase the intensity of incident energy density on solar devices is a well known technique. Evaluation of the contribution of such mirrors is currently taking place. Computations can be made on the basis of recent work by authors [4, 5, 6]. They can form the basis for evaluation of performance of mirrors located in various positions relative to the absorber plate of the smelter.

The following scheme of locating the mirrors is adopted. A mirror is hinged on the top edge of the absorber plate. In the literature dealing with horizontal aperatures (devices such as cookers) such a mirror is known as south facing mirror. Two mirrors are provided at a fixed angle of 60° along the sides of the absorber and these correspond to east and west facing mirrors of horizontal aperture devices.

In the case of the wax smelter, the strategy of azimuthal tracking has been adopted. Therefore the nomenclature of south, east and west facing mirrors would be inappropriate as the azimuths of the mirrors are not kept constant. For example the top edge mirror would be facing east in the early morning hours and west in the late evening hours and would face south only during noon.

Table 2 Energy gain from beam radiation in ± 4 hours from solar noon.

ω	$\alpha_s - \alpha_d$	$\gamma_d - \gamma_s$	θ (Fixed mode)	Cos θ	Cos $(\alpha_s - \alpha_d)$	Beam radiation, I_b W m^{-2}	Gain due to azimuthal tracking W m^{-2}
0	− 1° 0′	0°	− 1° 0′	0.9998	0.9998	771	0
1 hour (15°)	2° 48′	32° 6′	15° 01′	0.9659	0.9988	761	25.2
2 hour (30°)	12° 06′	53° 36′	30° 02′	0.8659	0.9978	730	96.3
3 hour (45°)	23° 48′	67° 12′	45° 02′	0.7067	0.9150	659	137.3
4 hour (60°)	36° 36′	76° 36′	60° 01′	0.4997	0.8028	511	154.9

NOTES: (1) A specimen computation when $\delta = +1°$ is displayed in this table.
(2) Cos θ is computed by solution of spherical triangle Zenith, Device axis and the sun (ZDS).
(3) When azimuthal tracking is adopted spherical triangle ZDS degenerates to a vertical plane, hence $\theta = (\alpha_s - \alpha_d)$.
(4) Net gain in energy due to azimuthal tracking = $\{I_b \times \text{Cos}(\alpha_s - \alpha_d) - \text{Cos}\,\theta\}$.

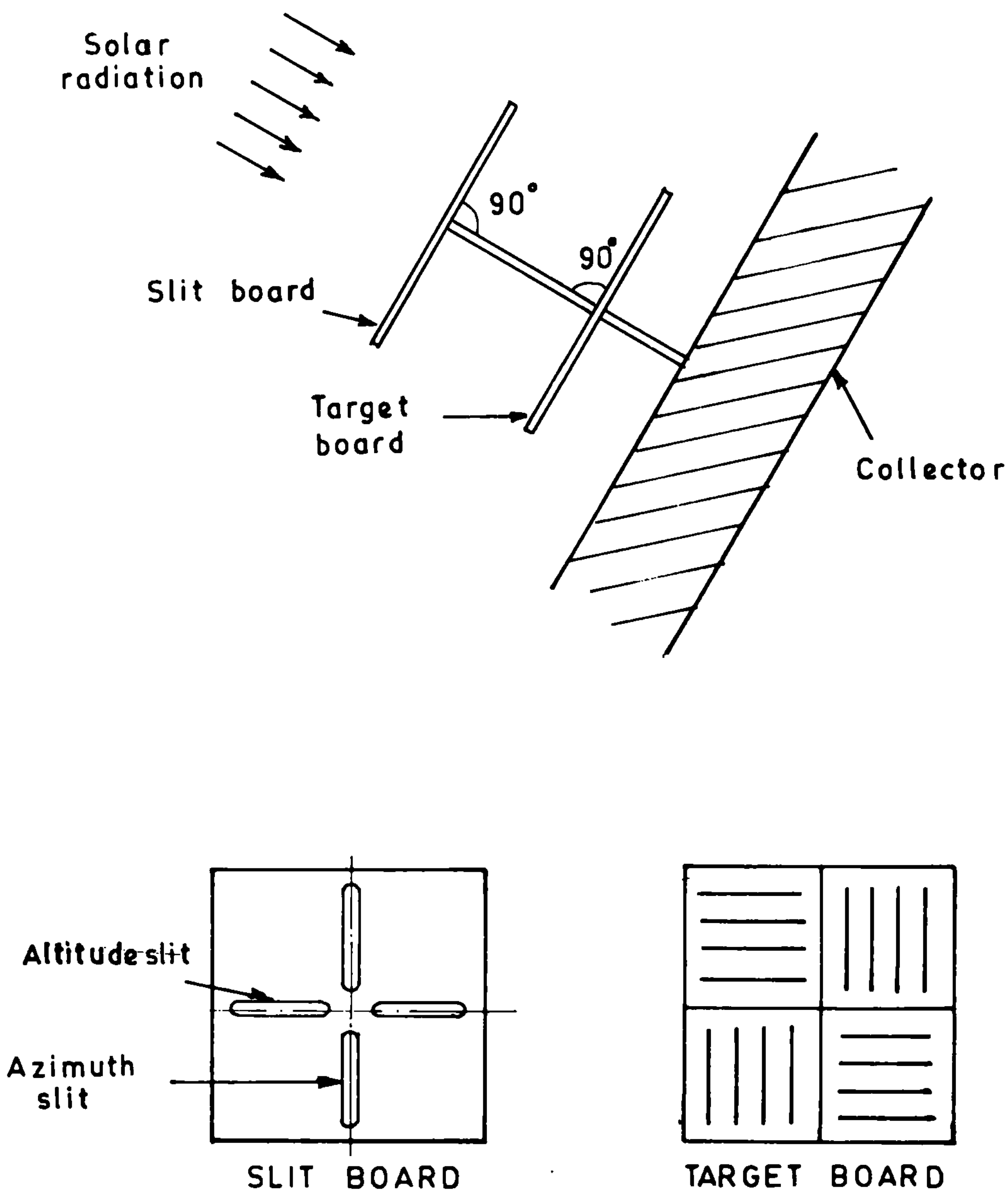

Figure 5 Slit board for tracking.

Therefore the mirrors have been named as top edge mirror and wing mirrors as being apt in describing their locations.

The top edge mirror (TEM) is hinged to the device so that its altitude can be varied (i.e. altitude tracking of mirrors is adopted). The criterion for such tracking is that all the energy intercepted by the mirror must illuminate the absorber plate fully. Even in this case the tracking need only be intermittent and can be carried out at hourly intervals. Computations have been made to illustrate the gains occuring due to adoption of azimuthal tracking and mirrors in various combinations. The absorber has been assumed to be a square of 1 m side and so are the three mirrors. A day on which the sun's declination was + 1° has been chosen to provide a link with the earlier published work [2]. The results are tabulated in Table 3.

DISCUSSION OF RESULTS

Column 2 of Table 3 indicates the incident energy on the absorber plate which is kept in fixed orientation facing south and altitude equal to that

Table 3 Energy accrued and concentration factors in various modes of development.

ω (h)	(Current practice) No tracking or boosting $I_b(W m^{-2})$/CR	Day optimum altitude and azimuthal tracking $I_T(W m^{-2})$/CR	Column 3 + top edge mirror tracked in elevation $I_T(W m^{-2})$/CR	Column 3 + 2 wing mirrors $I_T(W m^{-2})$/CR	Column 4 + 2 wing mirrors $I_T(W m^{-2})$/CR
1	2	3	4	5	6
0	771 1.000	771 1.00	1164 1.510/1.510	1421 1.843/1.843	1814 2.353/2.353
1	735 1.000	760 1.034/1.000	1163 1.582/1.530	1391 1.893/1.830	1794 2.441/2.361
2	632 1.000	728 1.152/1.000	1147 1.815/1.576	1306 2.066/1.794	1725 2.729/2.370
3	466 1.000	603 1.294/1.000	1017 2.182/1.682	1050 2.253/1.741	1464 3.142/2.428
4	255 1.000	410 1.608/1.000	760 2.980/1.854	715 2.804/1.744	1065 4.176/2.598

of the equator. Column 3 represents the case with azimuthal tracking the device and the altitude equal to that of meridian altitude of the sun. Column 4 represents the addition of TEM and Column 5 with the addition of wing mirrors. Column 6 represents the addition of both TEM and wing mirrors.

The total incident energy and the concentration ratio (CR) are tabulated. Two values of CR are indicated with respect to Column 2 and Column 3. To obtain the energy available for melting, the values in the table are to be multiplied by ηA_c; where η is the system efficiency (around 30%) and A_c is the area of the absorber plate.

The following conclusions can be drawn from the tables.

(a) At noon when inputs into the system are at a maximum, the TEM provides a 51% boost, the WM an 84% boost and together a 135% boost in energy collection.
(b) As solar altitude decreases the relative contribution of the TEM rises from 0.51 at noon to 1.98 at 4 hours ω.

A similar effect is seen in the case of the WM, though on a slightly less pronounced scale (0.84 to 1.84). They have the effect of flattening the performance curve, thereby counteracting a major criticism of solar energy, i.e. its variation in a day.

(c) The improved performance seen with the mirrors with decreasing solar altitude should also be advantageous in winter months characterized by lower solar altitudes. Thus not only diurnal variation but seasonal variation would also be greatly reduced leading to more stable and constant performance.
(d) Mirrors cost 10 to 20% of the cost of solar devices while they improve performance by 40–50%. Therefore economically they have a significance higher than that indicated by Table 3. Thus incorporation of mirrors in wax smelters is not a luxury or even an option but an essential requirement for high performance.

CONCLUSIONS

The present technology of wax smelting devices is in a rudimentary stage. It does not exploit even the currently well-understood technology to any extent. The following suggestions incorporated in this paper should provide major improvements in performance. They are:

(a) Use of an oil bath type smelter chamber for positive heat transfer.
(b) Provision of an adjustable mirror at the top end.
(c) Provision of wing mirrors at a fixed angle at the sides.

(d) Provision of indicators to eneable the device to be tracked in azimuth.

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