UNIVERSITI PUTRA MALAYSIA

THE TRANSMISSION OF LIGHT THROUGH CYLINDRICAL MIRROR LIGHT PIPE

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THE TRANSMISSION OF LIGHT THROUGH CYLINDRICAL MIRROR LIGHT PIPE

By

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LIST OF SYMBOLS AND ABBREVATIONS

β^+	positron
ν	neutrino
γ	gamma radiation
MLP	mirror light pipe
d	diameter
d_{eff}	effective diameter
$\boldsymbol{E}$	electric field
$\boldsymbol{D}$	electric displacement
$\boldsymbol{B}$	magnetic induction
$\boldsymbol{H}$	magnetic field
$\boldsymbol{J}$	current density
ρ	charge density
ε	dielectric permittivity
μ	magnetic permeability
σ	conductivity
k	wave number
c	light speed
ω	angular frequency
n	index of refraction
h	Plank constant
I	irradiance
α	absorption coefficient

r	reflection coefficient
t	transmission coefficient
$\boldsymbol{S}$	Ponyting vector
$\langle u \rangle$	energy density
R	reflectivity
T	transmission
A	cross sectional area
ψ	transmitted spectrum
λ	wavelength
l	pipe length
6	angle of incidence

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of requirements for the degree of Master of Science

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By

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Faculty : Science and Environmental Studies

A mirror light pipe (MLP) is an optical device consisting of a metallic reflective closed wall structure with highly transparent open ends. Light falling on the entrance is transmitted through the pipe to the exit by multiple reflections off the inner walls and used at the end. The spectral transmission through silver, aluminium and gold-coated inner walls of cylindrical mirror light pipes has been calculated theoretically based on the Swift and Smith model. The experimental data is also collected for MLP which is made by silverlux. The transmission is dependent upon the angle of incident light and the wavelength of incoming radiation. All pipes show a decrease in the spectral transmission of solar spectrum with an increase in the angle of incidence and the length of the pipes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan Ijazah Master Sains

PENYELIDIKAN UNTUK MENGUJI KECEKAPAN PAIP CAHAYA BERCERMIN (MLP) DALAM MENGHANTAR CAHAYA NAMPAK

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Paip cahaya bercermin (MLP) adalah alat optik yang diperbuat daripada logam berbentuk silinder yang mempunyai bukaan pada kedua-dua hujung dan dinding dalamannya memantul. Cahaya yang memasuki paip dari salah satu hujung akan mengalami multi pantulan pada dinding dalaman dan keluar dari hujung yang satu lagi untuk digunakan. Penghantaran spektrum melalui dinding dalaman paip cahaya bercermin yang disadur dengan perak, aluminium dan emas ditentukan secara teori mengikut model Swift dan Smith. Pengumpulan data bagi penghantaran spektrum dilakukan bagi MLP yang diperbuat daripada ‘silverlux’. Penghantaran cahaya bergantung kepada sudut tuju dan panjang gelombang. Penghantaran spektrum suria di dalam semua paip adalah berkurangan dengan pertambahan sudut tuju dan panjang paip.

CHAPTER I

INTRODUCTION

The Sun and Interplanetary Space

Our sun is one of the stars in the Galaxy. Its distance from the center of the Galaxy is about 33 000 light years. It is embedded in one of the spiral arms, the Orion arm. Its mass is about 1.99×10^{30} kg and the radius of its visible disc is 6.96×10^{5} km (Zirin, 1966). The temperature at its center is to be as high as 1.5×10^{7} K. Protons are converted into helium nuclei by thermonuclear reactions, such as the proton-proton and carbon-cycle chains in the sun. The former consists of the following reactions (Malitson, 1965) :

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + \beta^{+} + \nu + 0.42\ \text{MeV}$$

$$^{1}H + {}^{2}H \rightarrow {}^{3}He + \gamma + 5.5\ \text{MeV}$$

$$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,{}^{1}H + 12.8\ \text{MeV}$$

Here β^{+}, ν and γ denote a positron, a neutrino and γ-radiation respectively. Thus four protons are converted into a helium nucleus, liberating energy of 26.72 MeV including the release of energy by the annihilation of β^{+} by an electron, but excluding the kinetic energy of ν. This corresponds to 6.3×10^{8} joule per kilogram of hydrogen (Akasofu and Chapman, 1972).

Changes of internal structure result from the nuclear reactions play a vital role in determining the evolutionary course taken by the sun. The hydrogen-burning reactions of a star lead to the development of a helium core and as this core grows these reactions must occur near its outer layer. Meanwhile the core temperature may become high enough for the carbon-cycle reaction to become the major process there, yielding helium nuclei as end product :

$$^{12}C + {^1H} \rightarrow {^{13}N} + \gamma$$

$$^{13}N \rightarrow {^{13}C} + e^+ + \nu$$

$$^{13}C + {^1H} \rightarrow {^{14}N} + \gamma$$

$$^{14}N + {^1H} \rightarrow {^{15}O} + \gamma$$

$$^{15}O \rightarrow {^{15}N} + e^+ + \nu$$

$$^{15}N + {^1H} \rightarrow {^{12}C} + {^4He}$$

The hydrogen in the core will eventually be exhausted. A further increase of the central temperature then initiates the helium-burning process :

$$\left.\begin{array}{l} 3\,{^4He} \rightarrow {^{12}C} + \gamma \\ {^{12}C} + {^4He} \rightarrow {^{16}O} + \gamma \end{array}\right\} \Delta E = 6.15 \times 10^7 \ \mathrm{J\,m^{-2}s^{-1}}$$

As the sun evolves further, heavier nuclei will be created by more complicated nucleosynthetic reactions (Eddington, 1926). Owing to such changes the sun seems likely to move from the main sequence toward the red-giant group. The evolutionary track will then continue from the red-giant toward the white-dwarf group. If the structure of the sun should become unstable during this stage it may explode as a supernova and its debris might then serve as material for new stars.

The nuclear energy thus generated in the sun is rapidly transformed into local thermal energy and flows outward by processes of two kinds, radiative transfer and convection. The photons and energetic particles emitted by the core are absorbed in the above layer immediately. This layer emits new photons, according to Kirchhoff's law (Aller, 1954). Planck's formula gives the intensity distribution of the radiation emitted by a layer if the temperature is known (Schwarzschild, 1958). The luminosity generated at the solar surface from the reactions above has been calculated to be 3.90 x 10^{26} Js^{-1}.

In the outer part of the sun, however, convection is more effective than radiative transfer. Heat energy is carried upward by ascending hot gas. The energy diffuses as the rising gas expands and then the gas cools and descends (Akasofu and Chapman, 1972).

Extraterrestrial and Terrestrial Solar Radiation

Extraterrestrial solar radiation is the solar radiation outside the earth's atmosphere. Solar energy approaches the earth are electromagnetic radiation extending from X-rays 0.1 μm in wavelength to 100 m radio waves (Henderson, 1976).

The earth is covered with a layer of atmosphere consisting of air, gases, water vapour, dust and other particles. Much energy is lost when solar radiation reaches the earth surface through the atmosphere. In the absence of atmosphere effects, solar radiation intensity reaching the earth's surface would be approximately 1395 Wm^{-2} (Lynes, 1980). However, measured data show that the average intensity around noon is approximately 600 Wm^{-2} in the presence of atmosphere effects.

On reaching the earth's atmosphere, approximately 35% of the extra terrestrial solar radiation is reflected back to space. Another 19% is absorbed by the atmospheric constituents. Thus, only approximately 46% reaches the earth's surface. X-ray, γ-ray and other very short wavelength radiation are absorbed highly in the ionosphere by oxygen. Longer wavelength radiation up to 2900 angstrom (A) are absorbed by ozone. Hence, only radiation of wavelength longer than 2900 angstrom (A) proceed through the atmosphere undergoing scattering and absorption (Chia, 1969).

Because of the reflection and scattering by the atmosphere, the total radiation received on the earth's surface is made up of two components, namely, direct radiation and diffuse radiation. Direct radiation comes from the sun in straight line whereas diffuse radiation comes from the sky and the surrounding due to reflection and scattering.

On clear days, the direct component may be as high as 90% of the total radiation, whereas the diffuse component may contributes as much as 100% of the total during cloudy weather (Longmore and Petherbridge, 1984). However the effect of clouds on solar radiation is highly complex. The cloud types and patterns vary with the time of the day, the season and geographical conditions, resulting in large variations in the solar radiation patterns.

Solar Radiation for Daylighting

The survey by Warring (1977) shows that 8% to 20% of the total electric consumption is for interior lighting, especially for office purposes (Warring, 1977). Besides, Pritchard (1987) attributed that a lot of energy lost by the light source itself. Tungsten filament lamps experience a great due of losses to heat because the radiation that produced are mainly infrared. Infrared is about 76% and ultraviolet radiation is about 13% of the output radiation. Tungsten filament lamp produce only 11% of visible light. Whereas fluorescent lamp produce a lot of ultraviolet radiation which is about 46% of the total radiation. Only 19% of the visible light is obtained it. Infrared and ultraviolet radiation do not contribute to interior lighting (Pritchard, 1987). For interior lighting only visible light is interested. Hence, for interior lighting purposes, it is very impractical to convert solar radiation to electricity and then back to light again which involve almost 70% losses.

According to Zastrow and Wittwer (1986), the lighting of a room 3m high with an illuminance of 200 lx using fluorescent tubes consumes about 11 W/m^2. Hence, the yearly costs of the electrical lighting of a 1000 m^2 floor may thus amount to a few thousands of Ringgit Malaysia (RM). It is therefore worthwhile to think about better utilization of daylight, not only from the point of view of energy saving but also of economy (Zastrow and Wittwer, 1986).

Daylighting System

Daylighting system may be divided into two categories namely passive daylighting system and active daylighting system. Passive daylighting system is mainly to design a building in such a way that daylight illuminated into a building is maximum. No moving part is involved and window is the only device that allows daylight to enter the building. The design of window or ceiling is very important in this system.

However active daylighting system is a system which is capable of bringing natural light further into the interior zones of large building than is possible with windows or skylights (Selkowitz, 1982). They consist, in principle of three components :

(a) The light collector, which is located at a well illuminated point outside the building or in a room with a high illuminance level.
(b) The light guiding system, which has to guide the light into the room to be daylighted.
(c) The light distribution system, which has the task of achieving an acceptable homogeneous illuminance in the room.

If active daylighting systems are to operate cost effectively, it is necessary to develop highly efficient system for the collection, guiding and distribution of the light.

Mirror Light Pipe (MLP)

Mirror light pipe (MLP) consists of a reflective closed walled structure with open ends. Both direct and diffuse radiation falling on one end of the pipe can be channelled, after multiple reflections off the inner walls and used at the exit. MLP applies the theory of ordinary reflection.

Mirror light pipe must be made of a material with high reflectivity for all angles of incidence and all wavelengths across the spectral range of interest. Any variation in the spectral reflectivity of the pipe surface leads to a change in the spectral distribution of the transmitted radiation (Swift and Smith , 1994).

The ratio of output irradiance to input irradiance is defined as the transmission, T, of the MLP. Transmissions are measured as function of some physical parameters including the length and diameter of mirror light pipe, the incident angle, material reflectivity, radiation wavelength, solar geometry, direct and diffuse solar radiation. Pipe length and incident angle dictate the average number of reflections that rays must undergo to pass through the pipe.

Objective

After studying in detail of an MLP, we found that the performance of an MLP is affected by three main factors. They include the pipe length, the incident angle and the reflectivity of the inner wall material. Looking into the above factors, we intend to improve the performance of MLP by carrying out a research to study these three factors practically.

Therefore, the objectives of this project are :

1) To study the spectral transmission of light in a MLP by changing the incident angle of the incident light.

2) To study the spectral transmission of light in a MLP by changing the length of MLP.

3) To study the spectral transmission of light in a MLP by changing the wavelength of the incident light.

Scope of The Project

Daylighting system can be divided into passive and active daylighting systems. Active daylighting system consists of three components : the light collecting system, the light guiding system and the light distributing system. Whereas, the passive daylighting system concentrates on the building design.

In this project, we would only concentrate on the light guiding system. This is because the light guiding system is the most important component of the active daylighting system. We also intended to develop a better light guiding system by using mirror light pipe (MLP) as our light guiding medium.

The spectral range of interest in this project consists of the visible wavelength since mirror light pipes (MLPs) are of interest primarily for daylighting applications.

A very general outline of this study has been given in this chapter. Specific theoretical and experimental details and other related considerations are contained in the following sequence of chapters. Chapter II reviews the works that has been done by other researchers in this field. Basic theory will be included with adequate references in Chapter III. However, Chapter IV will explain the equipment used as well as the methodology of this project. Results are discussed in Chapter V. Lastly, conclusion and some suggestions for further work are given in Chapter VI.

CHAPTER II

LITERATURE REVIEW

Historical Background

Man has realized for thousands of years that life and energy flow from the sun. Socrates (470 - 399 B.C.) is believed to have been the earliest philosopher to describe some of the fundamental principles governing the solar energy in applications to buildings (Heywood, 1954).

Indirect Use of Solar Energy

The sun transfers energy in the form of radiation to the earth and this energy is considered as pure energy. When reaching the earth, some of the radiation is reflected to the atmosphere, some absorbed by earth surface and some absorbed by plants for their photosynthesis processes. At this stage, energy is stored as food in the plant. When the plant is eaten by animal, the energy thus transferred to the animal. After over millions of years, fossil fuels will formed from the remains of animals and plants. The fossil fuel includes coal, petroleum and gas that we use today to generate electricity, cooking and heating.

Direct Use of Solar Energy

Beside indirect use of solar energy, we do utilize solar energy directly. It includes to dry up our clothes using the direct sunlight, as well as to supply energy for our water heater. We also need sunlight to lighting up our room and office at daytime.

Solar Energy Converter

Solar energy conversion is subdivided into natural and technological collection systems, and these are further subdivided as shown in Figure 1. The technological collection system is created by man which includes thermal and photovoltaic methods.

Wind Power Collector

The utilization of wind power has been widespread since medieval times. Windmills were used to power irrigation pumps and drive small electric generators. Electric generators are then used to charge batteries that provided electricity during the last century. A windmill or wind turbine converts the kinetic energy of moving air into mechanical motion, usually in the form of rotating shaft. This mechanical motion can be used to drive a pump or to generate electric power (Kreith and Kreider, 1978).

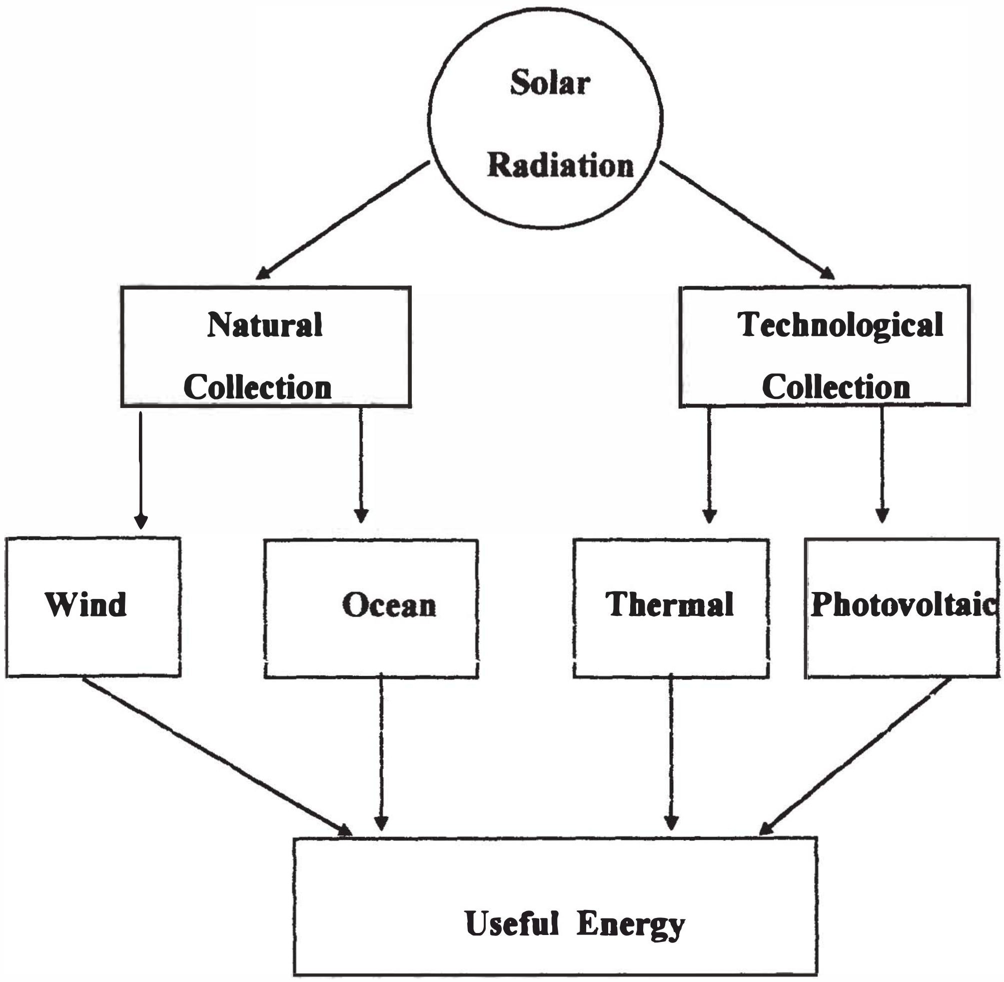

Figure1 : A summary of schemes for solar energy conversion

Conversion by Oceans

Almost 71% of the world's surface is covered by oceans. Oceans serve as a tremendous storehouse of solar energy because of the temperature differences produced by the sun as well as the kinetic energy stored in the waves. There are a number of places in the ocean where temperature differences of the order of 20 – 25 K exist at depths of less than 1000 m and these temperature differences could be used to operate low-pressure heat engines (Berg, 1974). Although the