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From Editor's Desk

Dear Researcher,

Greetings!

Research articles in these issue discusses about demand of solar energy, heat transfer in an inclined channel.

Let us review research around the world this month; Google, New York City, Cornell University and Technion-Israel Institute of Technology join forces to form a school offering classes in computer coding, but it is looking to compete with online education empires offering courses in venture management and bent on building a good reputation. Twenty-two thousand feet of the Google campus in New York opens in July for this venture dubbed “CornellNYC Tech.” Intended to function like the entrepreneurial incubators of the dot com era, this new school combines entrepreneurial skills-building with science. Based on one of the largest surveys of entrepreneur alumni ever conducted, the report estimates that there were 25,600 active companies founded by living MIT alumni, employing 3.3 million people and generating annual world revenues of nearly $2 trillion by the end of 2006.

The fourth generation of mobile communications, to nobody’s surprise, offers extremely high downlink rates and in the case of Long Term Evolution (LTE), this can theoretically reach 100 MB per second. Technologies like LTE and NFC will only serve to augment changes in the ways we use our mobile phones today.

IPv6, the next generation in internet protocol, drastically increases the range of internet addresses available. It features improved host-to-router discovery with auto configuration capability. This new protocol also cuts down on congestion due to its enhanced multicast capability. Its security is also as good if not better than IPv4 due to its built-in IPsec encryption. Not all large corporations and businesses have restructured their networks. This means that their web content is not ready for IPv6 eitherWhile internet giants like Google, Yahoo and Facebook have made their sites available to both IPv6 and IPv4 users, many other businesses and privately owned companies—even some primarily web-based ones—still have not.

When the economy starts showing an ominous downward spiral, companies begin to cut jobs, wages start to decrease, the expressions on most business analysts’ faces seem to oscillate from grave to somber, and then you know that an economic recession has finally hit home.

It has been an absolute pleasure to present you articles that you wish to read. We look forward to many more new technology-related research articles from you and your friends. We are anxiously awaiting the rich and thorough research papers that have been prepared by our authors for the next issue.

Thanks,
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Contents

FLOW OF COUPLE STRESS FLUID IN CONTACT WITH A NEWTONIAN FLUID IN AN INCLINED CHANNEL BOUNDED BY PERMEABLE BEDS

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Abstract: The problem of steady laminar fully developed flow and heat transfer in an inclined channel consisting of a couple-stress fluid sandwiched between two Newtonian fluids with permeable beds is investigated. The flow in the permeable beds is governed by Darcy's law. The closed form solutions are obtained for the velocity and temperature fields in the channel. The effect of permeability on the velocity and temperature is discussed. We observed that for a given y, the velocity increases with increasing Darcy number and for a given y, the temperature increases with increasing couple stress parameter a.

Key words: couple-stress fluid, Newtonian fluid, inclined channel, permeable bed.

I. INTRODUCTION

The flow of non-Newtonian fluids through and past porous media have wider applications in many branches like petroleum Engineering, chemical engineering and such other important fields. There are several non Newtonian fluid models available in literature. Some of these models deal with theory of polar fluids. The theory of polar fluids was derived from a statistical mechanics model that assumed non central forces of interaction between particles. If the inter particle forces are not central forces in a particle interaction, there is an inter particle couple as well as an inter particle force. Due to action of this couple, the fluid particles will have a tendency to rotate relative to their neighbors. The idea of polar fluid is obtained by introducing a kinematic variable to model the forces that balance the action of the couple.

The couple stress fluid model is very useful to explain the behaviour of some slurries and some physiological fluids. Initial studies of experimental data on blood suggest that some derivations from Newtonian behaviour of blood may be explained through couple stress fluid model. Based on the couple stress theory of Stokes (1966), Chaturani and Kaloni (1976), Chaturani and Upadthya (1979) have studied some theoretical models for blood flow through narrow tubes.

Chaturani et.al., (1981) studied a three layered coquette flow model for blood flow and they assume that the top and bottom layers consist of plasma (Newtonian fluid) and the middle consist of a red cell suspension couple stress fluid. Umavathi and Malashetty (1999) studied the effects of couple stresses on the free convective flow in a vertical channel. Free convection flow of an electrically conducting couple-stress fluid for the radiating medium in a vertical channel has been studied by Umavathi (2000).T.K.V.Iyengar et.al, (2011) studied the pulsating flow of an incompressible couple stress fluid between permeable beds.

Umavathi et.al., (2005) made a detailed study on the flow of heat transfer of a couple stress fluids in contact with a Newtonian fluid. Keeping in view the practical applications described above we have analyzed laminar fully developed flow and heat transfer in an inclined channel consisting of a couple stress fluid sandwiched between two Newtonian fluids bounded by permeable beds. The flow in the permeable beds is governed by Darcy's law. The closed from solutions are obtained for the velocity and temperature fields in the channel. The effect of permeability on the velocity and temperature is discussed.

II. NOMENCLATURES

x, y	-	Cartesian coordinates
u_1, u_2, u_3	-	Velocity in region I, region II, region III
U_{B1}	-	Slip velocity at the upper permeable bed
U_{B2}	-	Slip velocity at the lower permeable bed
Da_1	-	Darcy number at the upper permeable

		bed $\left(\frac{k_1}{h^2}\right)$
Da_2	-	Darcy number at the lower permeable bed $\frac{k_2}{h^2}$
T_{B1}	-	Temperature at $y = 2h$
T_{B2}	-	Temperature at $y = -h$
θ	-	Angle of inclination of the channel with the horizontal.
α	-	Slip parameter
$\overline{u_1}$	-	Average velocity
a	-	Couple stress parameter $\left(\frac{\mu_1 h^2}{\eta}\right)$
C_p	-	Specific heat at constant pressure
Ec	-	Eckert number
h	-	Hight of the regions , I, II, III
K	-	Ratio of thermal conductivities $\frac{k_1}{k_2}$
K_1	-	Thermal conductivity of the fluid in regions I and III
K_2	-	Thermal conductivity of the fluid in region II
m	-	Ratio of viscosities $\frac{\mu_1}{\mu_2}$
P_1	-	Non dimensional pressure gradient , $-\mathrm{Re}\frac{\partial p}{\partial x}$
P	-	$p_1 - \frac{\mathrm{Re}}{F}\sin\theta$
T_1, T_2, T_3	-	Temperatures in region I, II and III
Pr	-	Prandtl number

III MATHEMATICAL FORMULATION OF THE PROBLEM:

Consider the steady laminar flow of a couple stress fluids in contact with a Newtonian fluid in a channel bounded permeable beds as shown in figure 1.

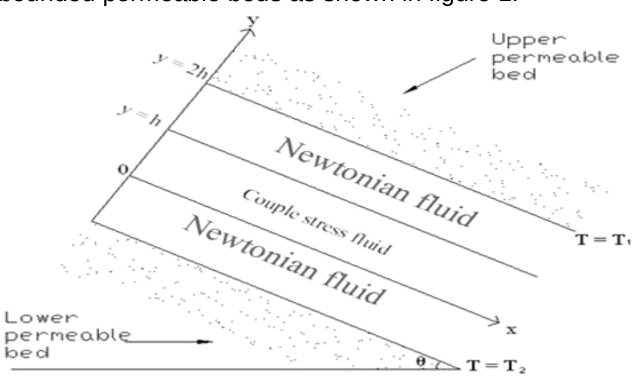

Fig 1: Physical model

The channel is inclined at an angle θ with the horizontal. The regions $-h \le y \le 0$ and $h \le y \le 2h$ are filled with a clear viscous fluid of viscosity μ_1 and thermal conductivity k_1 and the region $0 \le y \le h$ is occupied by a couple stress fluid viscosity μ_2 and thermal conductivity k_2. The fluids in all regions are assumed to be immiscible and the transport properties of the fluids in all regions are assumed to be constant the flow in the permeable beds is described by Darcy's law.

The following assumptions are made in simplifying the basic equations

i. The flow is steady, viscous, incompressible and fully developed.
ii. The flow is in x-direction. All the physical quantities, except the pressure are functions of y only.
iii. The motion is caused by a constant pressure gradient $\frac{\partial p}{\partial x}$.
iv. The permeability's of the lower and upper beds are k_1 and k_2.

In view of the above assumptions, the equations of motion for velocity take the following form:

Flow in the channel
Basic equations

$$\frac{\partial u}{\partial x} = 0 \qquad (1)$$

Region I $\quad (h \le y \le 2h)$

$$\mu_1 \frac{\partial^2 u_1}{\partial y^2} - \frac{\partial p}{\partial x} + \rho g_x = 0 \qquad (2)$$

$$-\frac{\partial p}{\partial y} + \rho g_y = 0$$

Region II $\quad (0 \le y \le h)$

$$\mu_2 \frac{\partial^2 u_2}{\partial y^2} - \frac{\partial^4 u_2}{\partial y^4} - \frac{\partial p}{\partial x} + \rho g_x = 0 \qquad (3)$$

$$-\frac{\partial p}{\partial y} + \rho g_y = 0$$

Region III $\quad (-h \le y \le 0)$

$$\mu_3 \frac{\partial^2 u_3}{\partial y^2} - \frac{\partial p}{\partial x} + \rho g_x = 0$$

$$-\frac{\partial p}{\partial y}+\rho g_y=0 \qquad (4)$$

Similarly the equations of motion for temperature in the three regions take the following form:

Region I $\quad (h \le y \le 2h)$

$$\frac{\partial^2 T_1}{\partial y^2}+C\frac{\mu_1}{k_1}\left(\frac{\partial u_2}{\partial y}\right)^2=0 \qquad (5)$$

Region II $\quad (0\le y \le h)$

$$\frac{\partial^2 T_2}{\partial y^2}+C\frac{\mu_2}{k_2}\left(\frac{\partial u_2}{\partial y}\right)^2=0 \qquad (6)$$

Region III: $\quad (-h \le y \le 0)$

$$\frac{\partial^2 T_3}{\partial y^2}+C\frac{\mu_3}{k_3}\left(\frac{\partial u_3}{\partial y}\right)^2=0 \qquad (7)$$

Flow in the porous medium

The flow in the lower and upper beds is governed by the following Darcy's law.

$$Q_i = \frac{k_i}{\mu}\frac{\partial p}{\partial x}-\rho g_x$$

Where
$i=1$ for upper permeable bed and
$i=2$ for lower permeable bed

Boundary Conditions

$$U_1=U_{B1},\quad \frac{\partial u_1}{\partial y}=\frac{-\alpha}{\sqrt{k_1}},\quad \left(U_{B1}-\overline{Q_1}\right)\ at\ y=2h \qquad (8)$$

$$U_1=U_2 \quad at \quad y=h \qquad (9)$$

$$U_2=U_3 \quad at \quad y=0 \qquad (10)$$

$$U_3=U_{B2}\ ,\frac{\partial u_3}{\partial y}=\frac{\alpha}{\sqrt{k_2}}\left(U_{B2}-Q_2\right) \quad at \quad y=-h \qquad (11)$$

$$\mu_1\frac{\partial u_1}{\partial y}=\mu_2\frac{\partial u_2}{\partial y}-\eta\frac{\partial^3 u_2}{\partial y^3} \quad at \quad y=h \qquad (12)$$

$$\mu_2\frac{\partial u_2}{\partial y}-\eta\frac{\partial^3 u_2}{\partial y^3}=\mu_1\frac{\partial u_3}{\partial y} \quad at \quad y=0 \qquad (13)$$

$$\frac{\partial^2 u_2}{\partial y^2}=0 \quad at \quad y=h \qquad (14)$$

$$\frac{\partial^2 u_2}{\partial y^2}=0 \quad at \quad y=0 \qquad (15)$$

$$T_1=T_{B1},\quad \frac{\partial T}{\partial y}=\frac{-H}{\sqrt{k_1}}\left(T_{B1}-T_0\right) \quad at \quad y=2h \qquad (16)$$

$$T_1=T_2 \quad at \quad y=h \qquad (17)$$

$$T_2=T_3 \quad at \quad y=0 \qquad (18)$$

$$T_3=T_{B2},\frac{\partial T}{\partial y}=\frac{H}{\sqrt{k_2}}\left(T_{B2}-T_0\right) \quad at \quad y=-h \qquad (19)$$

$$K_1\frac{\partial T_1}{\partial y}=K_2\frac{\partial T_2}{\partial y} \quad at \quad y=h \qquad (20)$$

$$K_2\frac{\partial T_2}{\partial y}=K_3\frac{\partial T_3}{\partial y} \quad at \quad y=0 \qquad (21)$$

IV. NON-DIMENSIONALIZATION OF THE FLOW QUANTITIES:

Introduced to make the basic equations and the boundary conditions dimensionless:

$$x^*=\frac{x}{h},\qquad y^*=\frac{y}{h},\qquad u_i^*=\frac{\overline{u_i}}{u}\quad (i=1,2)$$

$$Q_i^*=\frac{\overline{\overline{Q_i}}}{u_1},\qquad \theta=\frac{T-T_{B2}}{T_{B1}-T_{B2}};\qquad m=\frac{\mu_1}{\mu_2};\qquad p^*=\frac{p}{\rho u^2}$$

In view of the above dimensionless quantities the basic equations and the boundary conditions for the velocity take the following form (Neglecting the bars).

Basic Equations
Region I:

$$\frac{d^2u_1}{dy^2}=H_1 \qquad (22)$$

$$\frac{\partial p}{\partial y}+\frac{\cos\theta}{F}=0 \qquad (23)$$

Region II:

$$\frac{d^4u_2}{dy^4}-\frac{a^2}{m}\frac{d^2u_2}{dy^2}=H_2 \qquad (24)$$

$$\frac{\partial p}{\partial y}+\frac{\cos\theta}{F}=0 \qquad (25)$$

where $H_2=\frac{\text{Re}}{F}a^2\sin\theta-a^2P$

Region III:

$$\frac{d^2u_1}{dy^2}=H_1 \qquad (26)$$

$$\frac{\partial p}{\partial y}+\frac{\cos\theta}{F}=0 \qquad (27)$$

Where $H_1=P_0-\frac{\mathrm{Re}}{F}\sin\theta$, $P_0=\mathrm{Re}\frac{\partial p}{\partial x}$, $F=\frac{gh}{u^2}$

Boundary conditions are

$$U_1=U_{B1} \quad at \quad y=2 \qquad (28)$$

$$\frac{du_1}{dy}=\frac{-\alpha}{\sqrt{Da_1}}\left(U_{B1}-Q_1\right) \quad at \quad y=2 \qquad (29)$$

$$U_1=U_2 \quad at \quad y=1 \qquad (30)$$

$$U_2=U_3 \quad at \quad y=0 \qquad (31)$$

$$U_3=U_{B2} \quad at \quad y=-1 \qquad (32)$$

$$\frac{du_3}{dy}=\frac{\alpha}{\sqrt{Da_2}}\left(U_{B2}-Q_2\right) \quad at \quad y=-1 \qquad (33)$$

$$\frac{du_1}{dy}=\frac{1}{m}\frac{du_2}{dy}-\frac{1}{a^2}\frac{d^3u_2}{dy^3} \quad at \quad y=1 \qquad (34)$$

$$\frac{du_2}{dy}=\frac{m}{a^2}\frac{d^3u_2}{dy^3}=m\frac{du_3}{dy} \quad at \quad y=0 \qquad (35)$$

$$\frac{d^2u_2}{dy^2}=0 \quad at \quad y=1 \qquad (36)$$

$$\frac{d^2u_2}{dy^2}=0 \quad at \quad y=0 \qquad (37)$$

Similarly the basic equations and the boundary conditions for the temperature take the following form.

Basic equations

Region I:

$$\frac{d^2\theta_1}{dy^2}+Ec\,\mathrm{Pr}\left(\frac{du_1}{dy}\right)^2=0 \qquad (38)$$

Region II

$$\frac{d^2\theta_2}{dy^2}+\frac{K}{m}Ec\,\mathrm{Pr}\left(\frac{du_2}{dy}\right)^2=0 \qquad (39)$$

where $K=\frac{k_1}{k_2}$

Region III:

$$\frac{d^2\theta_3}{dy^2}+Ec\,\mathrm{Pr}\left(\frac{du_3}{dy}\right)^2=0 \qquad (40)$$

Boundary conditions are

$$\frac{d\theta_1}{dy}=\frac{-H}{\sqrt{Da_1}}\theta_{B1} \quad at \quad y=2 \qquad (41)$$

$$\theta_1=\theta_2 \quad at \quad y=1 \qquad (42)$$

$$\theta_2=\theta_3 \quad at \quad y=0 \qquad (43)$$

$$\frac{d\theta_3}{dy}=\frac{H}{\sqrt{Da_2}}\theta_{B2} \quad at \quad y=-h \qquad (44)$$

$$\frac{d\theta_1}{dy}=\frac{1}{K}\frac{d\theta_2}{dy} \quad at \quad y=h \qquad (45)$$

$$\frac{d\theta_2}{dy}=K\frac{d\theta_3}{dy} \quad at \quad y=0 \qquad (46)$$

V. SOLUTION

Solving the equations (21) – (23) subject to the boundary conditions (27) – (36), we obtain the velocity field as

$$U_1=\frac{Py^2}{2}+c_1y+c_2,$$ Where

$$p=\frac{h^2}{\mu_1 u_1}\left(\frac{\partial p}{\partial x}-\rho g_x\right) \quad 1\le y\le 2 \qquad (47)$$

$$U_2=c_3+c_4y+c_5\cosh\left(A_4y\right)+c_6\sinh\left(A_4y\right)+A_5y^2, 0\le y\le 1 \qquad (48)$$

$$U_3=\frac{py^2}{2}+c_7y+c_8 \qquad -1\le y\le 0 \qquad (49)$$

Where $A_5=\frac{-G_2}{2A_2}$, $A_2=\frac{a^2}{m}$, $A_4=\sqrt{A_2}$, $G_2=-a^2p$

$$C_1=\frac{mc_7+2A_5-mp}{m},\ C_2=\frac{mB_3-B_4\left(mc_7+2A_5-mp\right)}{m}$$

$$C_3=c_8-c_5,\ C_4=mc_7,\ C_5=\frac{-2A_5}{A_4^2}$$

$$C_6=-C_5D_1, \qquad C_7=\frac{m^2C_7+mD_2-mB_1-mC_5-B_5}{m\left(1-B_2-B_4\right)},$$

$$C_8=B_2C_7-B_1, \quad D_1=\frac{\cosh A_4-1}{\sinh A_4}$$

$$D_2=C_5\cosh A_4+C_6\sinh A_4+2A_5-P/2$$

$$B_1=\left(\frac{1}{2}+\frac{\sqrt{Da_2}}{\alpha}\right)p.Q_2\ B_2=\left(1+\frac{\sqrt{Da_2}}{\alpha}\right),$$

$$B_3=Q_1-2p\left(1+\frac{\sqrt{Da_1}}{\alpha}\right), \qquad B_4=\left(2+\frac{\sqrt{Da_1}}{\alpha}\right)$$

$$B_5=2A_5-mp+mB_3+mB_4P-2B_4A_5,$$

The slip velocity at the upper permeable bed is obtained as

$$U_{B1} = 2C_1 + C_2 + 2P \quad (50)$$

The slip velocity at the lower permeable bed is obtained as

$$U_{B2} = -C_7 + C_8 + \frac{P}{2} \quad (51)$$

Solving the equations (38)–(40) subject to the boundary conditions (41)–(46) we obtain the temperature as

$$\theta_1 = \alpha_1 y^4 + \alpha_2 y^3 + \alpha_3 y^2 + B_1 y + B_2 \quad (52)$$

$$\theta_2 = \alpha_{14}\cosh(2A_4 y) + \alpha_{15}\sinh(2A_4 y) + \alpha_{16} y\cosh(A_4 y)$$

$$+\alpha_{17} y\sinh(A_4 y) + \alpha_{18}\cosh(A_4 y) + \alpha_{19}\sinh(A_4 y)$$

$$+\alpha_{20} y^4 + \alpha_{21} y^3 + \alpha_{22} y^2 + B_3 y + B_4 \quad (53)$$

$$\theta_3 = \alpha_{23} y^4 + \alpha_{24} y^3 + \alpha_{25} y^2 + B_5 y + B_6 \qquad -1 \le y \le 0 \quad (54)$$

Where

$$\alpha_1 = -\frac{Ec\Pr P^2}{12}, \qquad \alpha_2 = -\frac{Ec\Pr \rho c_1}{3}$$

$$\alpha_3 = -\frac{Ec\Pr \rho c_1^2}{2} \qquad \alpha_4 = A_6 A_4^2 C_5^2$$

$$\alpha_6 = A_6 C_5 C_6 A_4^2 \qquad \alpha_7 = 4A_6 A_4 A_5 C_6$$

$$\alpha_8 = 4A_6 A_5 A_4 C_5 \qquad \alpha_9 = 2A_6 C_4 C_6 A_4$$

$$\alpha_{10} = 2A_6 C_4 C_5 A_4 \qquad \alpha_{11} = 4A_6 A_5^2$$

$$\alpha_{12} = 4A_6 A_5 C_4 \qquad \alpha_{13} = A_6 C_4^2$$

$$\alpha_{14} = \frac{(\alpha_4 + \alpha_5)}{8A_4^2} \qquad \alpha_{15} = \frac{\alpha_6}{4A_4^2}$$

$$\alpha_{16} = \frac{\alpha_7}{4A_4^7} \qquad \alpha_{17} = \frac{\alpha_8}{A_4^2}$$

$$\alpha_{18} = \left(\frac{-2\alpha_8}{A_4^3} + \frac{\alpha_9}{A_4^2}\right) \qquad \alpha_{19} = \left(\frac{-2\alpha_7}{A_4^3} + \frac{\alpha_{10}}{A_4^2}\right)$$

$$\alpha_{20} = \frac{\alpha_{11}}{12} \qquad \alpha_{21} = \frac{\alpha_{12}}{6}$$

$$\alpha_{22} = \frac{2\alpha_{13} + \alpha_5 - \alpha}{4} \qquad \alpha_{23} = \frac{-Ec\Pr P^2}{12}$$

$$\alpha_{24} = \frac{-Ec\Pr P C_7}{3} \qquad \alpha_{25} = \frac{-Ec\Pr c_7^2}{2}$$

$$T_{B2} = -B_5 + B_6 + e_2 \qquad e_1 = -4\alpha_{23} + 3\alpha_{24} - 2\alpha_{25}$$

$$e_2 = \alpha_{23} - \alpha_{24} + \alpha_{25} \qquad B_6 = \left(\frac{\sqrt{Da_2}}{H} + 1\right)B_5 + \frac{\sqrt{Da_2}}{H}$$

$$T_{B1} = -\frac{\sqrt{Da_1}}{H}(32\alpha_1 + 1 \qquad e_3 = 32\alpha_1 + 12\alpha_2 + 4\alpha_3$$

$$e_4 = 16\alpha_1 + 8\alpha_2 + 4\alpha_3 \qquad e_5 = 2A_4\alpha_1^5 + \alpha_{16} + A_4\alpha_{19}$$

$$e_6 = 2A_4\alpha_{14}\sinh 2A_4 + 2A_4\alpha_{15}\cosh 2A_4$$

$$+A_4\alpha_{16}\sinh A_4 + A_4\alpha_{18}\sinh A_4 + A_4\alpha_{17}$$

$$\cosh A_4 + A_4\alpha_{19}\cosh A_4 + \alpha_{16}\cosh A_4$$

$$+\alpha_{17}\sinh A_4 + 4\alpha_{20} + 3\alpha_{21} + 2\alpha_{22}$$

$$e_7 = 4\alpha_1 + 3\alpha_2 + 2\alpha_3, \qquad e_8 = \alpha_{14} + \alpha_{18}$$

$$e_9 = \alpha_{14}\cosh 2A_4 + \alpha_{15}\sinh 2A_4 + \alpha_{16}\cosh A_4$$

$$+\alpha_{18}\cosh A_4 + \alpha_{17}\sinh A_4$$

$$+\alpha_{20} + \alpha_{21} + \alpha_{22} - \alpha_1 - \alpha_2 - \alpha_3$$

VI. DEDUCTIONS AND DISCUSSIONS

From equations (1) – (4) we have calculated velocities U (i.e. U_1, for region I, U_2 for region II, and U_3 for region III) as function of y, for different values of Darcy number Da for fixed $P=-5$, $a=1$, $m=2$, $\alpha=0.3$ and is shown in figure 2. We observe that the velocity increases with the increase in y initially and then it decreases with the increment in y. For a given y, we notice that the velocity increases with increasing Darcy number.

The variation of velocity U with y, are calculated from equations (1)-(4) for different values of couple stress parameter a and is shown in figure 3. We observe that for a given y, the velocity increases with increasing couple stress parameter a.

The variations of U1, U2 and U3 with y are calculated from equations (1)-(4) for different values of viscosity ratio and are shown in figure 4. We observe that for a given y, the velocity decreases with the increasing in the viscosity ratio m.

From equation (52)-(54) we have calculated temperature θ (θ_1 for Region I, θ_2 for Region II, and θ_3 for Region III)as a function of y for different values of Darcy number and for fixed $P=-5, a=1, m=2, \alpha=0.3, K=1, E=1, Da=0.1$ and $H=0.6$ and is shown in figure 5. We observe that the temperature increases with the increasing in y and then it decreases with the increment in y. For a given y, we notice that the temperature increases with an increase in the Darcy number.

The variation of temperature θ with y are calculated from equations (52)-(54) for different values of couple stress parameter and shown in figure 6, for fixed $P=-5, a=1, m=2, \alpha=0.3, K=1, \in=1, Da=0.1, H=0.6.$ We observe that for a given y, and temperature increase with increasing couple stress parameter a. The variation of temperature θ with y are calculated from equations (52)-(54) for different values of ratio of viscosities m and is shown in figure 7, for fixed $P=-5, a=1, m=2, \alpha=0.3, K=1, \in=1, Da=0.1, H=0.6.$ We observe that for a given y, the temperature decreases with increasing viscosity ratio m.

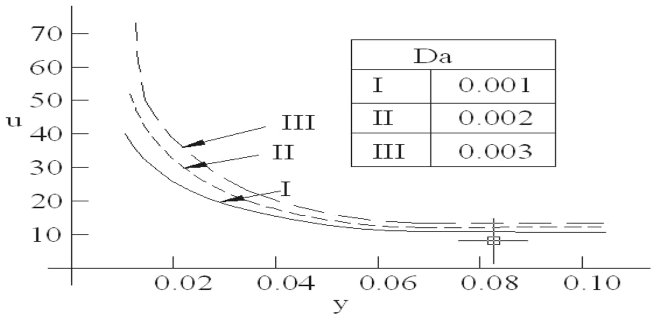

Fig. 2 Velocity profiles for different values of Da with fixed values of p=-5, a=1, m=2, α=0.3

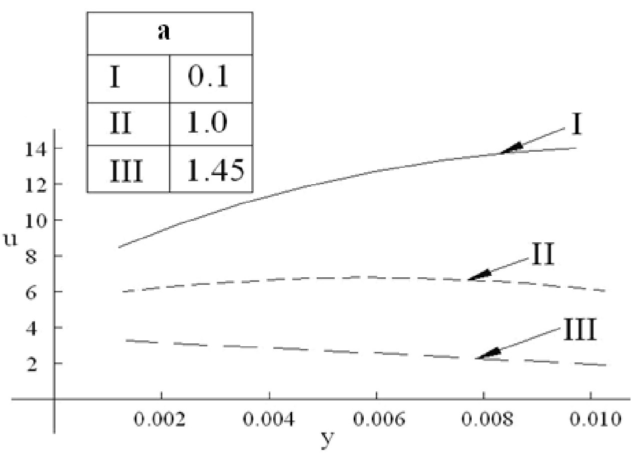

Fig. 3 Velocity profiles for different values of ‘a’ with fixed values of p=-5, a=1, Da=0.1, m=2

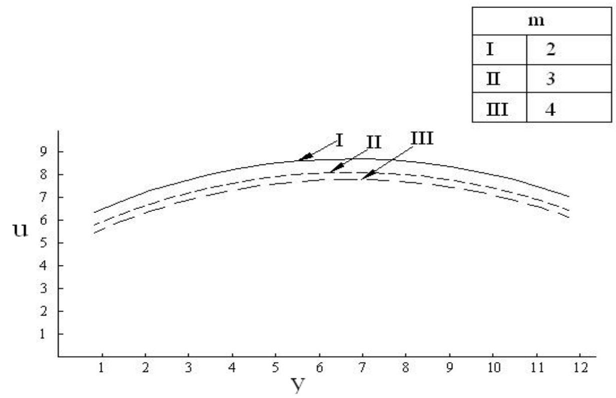

Fig. 4 Velocity profiles for different values of m with fixed values of p=-5, a=1, α =0.3, Da=0.1

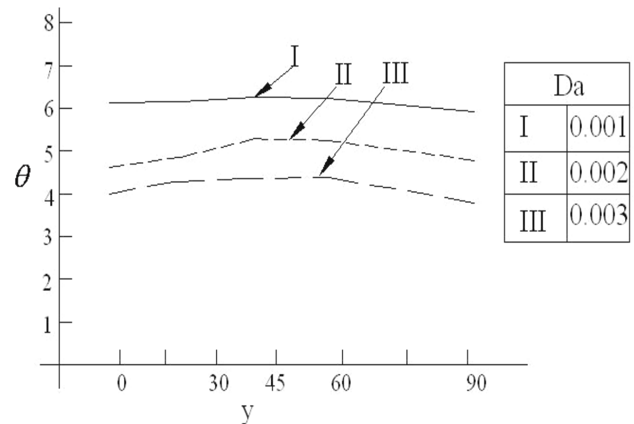

Fig.5 Temperature profiles for different values ofDa with fixed values of p=-5, m=2, K=1, H=0.6, $\alpha=0.3$

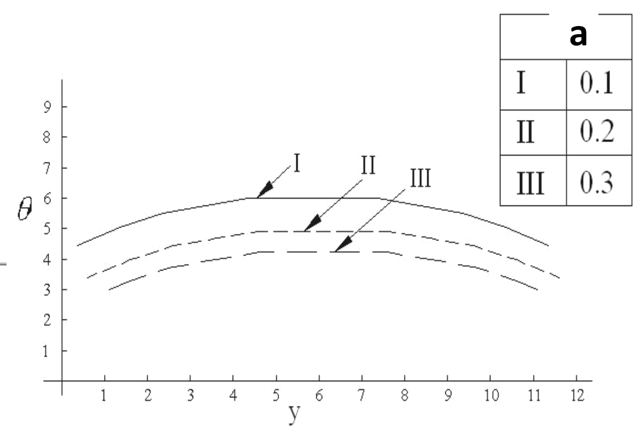

Fig. 6 Temperature profiles for different values of **‘a’** with fixed values of p=-5, m=2,Da=0.1,K=1,H=0.6.

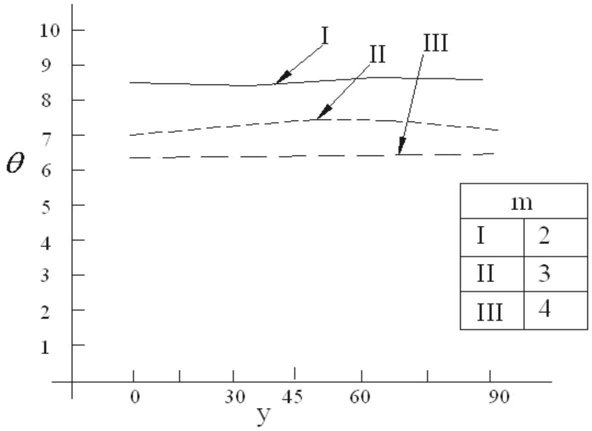

Fig.7 Temperature profiles for different values of m with fixed values of p=-5, Da=0.1, K=1, H=0.6, $\alpha = 0.3$.

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FORESEEABLE DEMAND OF SOLAR ENERGY PERSPECTIVE BANGLADESH

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***Abstract*—Exhaustion of conventional sources of energy, environmental degradation caused by the burning of fossil fuels and the ongoing energy crisis has driven the need to explore alternative and sustainable sources of energy. Solar energy is such an enormous potential in this regard, that its one minute radiation surpasses the amount of energy the world has used since the time began. As a developing country, Bangladesh is encountering a great difficulty in supplying sufficient energy to maintain its economic growth. The current demand for energy exceeds the available resources and this gap is projected to increase further in a significant proportion in the near future. This paper presents a comprehensive study of the contemporary energy scenario and its foreseeable growth in the country. It reflects on the energy resources and the problems caused by the various forms of energy. It analyzes the prospect of solar energy, its advantages over other sources, the current scenario of it and its growth trend in Bangladesh.**

Keywords: Photovoltaic (PV) systems ,Solar home systems ,Crystalline silicon solar cell, Thin film photovoltaic.

I. INTRODUCTION

Energy is one of the most important ingredients required to alleviate poverty and realize socio-economic and human development. It is directly interconnected to the prominence of life. Bangladesh has 144 million people on 144,000 sq. km area [1]. The high growth of her population has made it extremely difficult to cope up with its growing energy demand. Bangladesh is experiencing a severe electric power capacity crisis that is only likely to be worsening over the next 15 years. At present, the electricity supply deficiency is about 2500 MW/day [2]. To alleviate poverty with its limited resources and high population density, Bangladesh requires an economic growth rate of more than 7%. In order to achieve this growth rate electricity growth need to be achieved by 10% [3]. To prevail over this situation, expanded searches of energy sources are needed. Inadequate oil and gas reserve of the country has excelled the necessity of examining the prospect of solar energy as an alternative energy source in Bangladesh.

In this paper, investigation has been done on the potentials of solar energy as an effective sustainable source and its impact on tackling the power crisis of Bangladesh. Section 2 deals with the complete energy scenario in Bangladesh, section 3 explains the necessity of exploration of solar energy as a potential sources other than terrifically polluting present energy sources, section 4 describes current attempt & program that has already been taken in Bangladesh to use solar energy, section 5 demonstrates the future plans to meet the screaming demand of energy, section 6 describes the potentiality of more efficient solar cell as a remedy of energy crisis. Section 7 draws the conclusion.

II. PRESENT ENERGY RESOURCES OF BANGLADESH

Energy infrastructure of Bangladesh is reasonably small, insufficient and also unreliably managed. Primary commercial energy resources of Bangladesh include natural gas, oil, condensates from gas, coal, peat, bio-mass & renewable energy. The energy situation in Bangladesh is characterized by low consumption of energy as compared to other Asian countries. The per capita energy consumption was 201.31 kgoe in 2009 according to a world bank report , published in 2010. Annual Per capita electricity consumption was 251.63 KWh in 2009, according to a world bank report, published in 2010.

The main source of energy is Natural gas and it accounts for 13.2% of the total energy consumption. Bangladesh currently has got an estimated proved natural gas reserves of around 310 billion cubic meters in approximately 20 fields (mainly onshore).The current average daily gas production is about 1970 MMCF against actual demand of 2200 MMCF resulting deficit of around 230 MMCF per day. About 3.3 billion tons of coal reserves comprising 5 deposits at depths of 118-1158 meters have been discovered so far. Out of which 4 deposits (118-509 meters) are extractable at present while one deposit may not be viable for extraction by present day's technology due to greater depth (640-1158 meters). Only one deposit (Barapukuria) has been developed and coal is being extracted mainly for one thermal power plant [3].

TABLE I
Present Scenario of Coal and Gas:

Serial no	Items	Status(2009)
1	Current average daily gas production	1970 MMCF
2	Current daily actual gas demand	2200 MMCF
3	Estimated coal reserve	3.3 billion tons
4	Present annual coal extraction	858000 tons

TABLE II
presents a comparison of electricity and primary energy sources [4]

Country	Fossil Fuels			Renewable		Per Capita Electricity Consumption
	Coal	Oil	Gas	Hydro,solar,wind,g	Biomass & wastes	
Norway	2.4	44.1	16.1	36.6	4.1	26657
Japan	21.1	47.4	13.3	2	1.2	8459
USA	23.7	40.7	21.8	1.5	3.2	14240
Germany	23.7	35.8	23.47	1.3	3.5	7442
S. Korea	23.1	45	12.8	0.2	1	7710
India	38.7	23.9	5.4	1.7	29.4	618
Pakistan	5.3	21.9	33	3.5	35.5	564
Bangladesh	1.4	19.1	44.7	0.5	34.3	154
Sudan	0	23.2	0	0.9	75.8	116
Nigeria	0	13.9	7.5	0.7	64.8	157
Benin	0	33.3	0	0	64.7	81

TABLE III
presents the effect of electrification on human life[4]

Country	HDI Ranking	Electrification Rate	Population Without Electricity(Millions)
Norway	2	100	-
Japan	8	100	-
USA	12	100	-
Germany	22	100	-
S.Korea	26	100	-
India	128	56	487.2
Pakistan	136	54	71.1
Bangladesh	140	32	96.2
Sudan	147	30	25.4
Nigeria	158	46	71.1
Benin	163	22	6.5

From the above tables it is evident that, energy consumption is closely related to life standard.

Based on the information obtained, a comparative scenario of the five aforementioned renewable energy sectors of Bangladesh is illustrated in Fig. 1 in terms of the installed capacity [5].

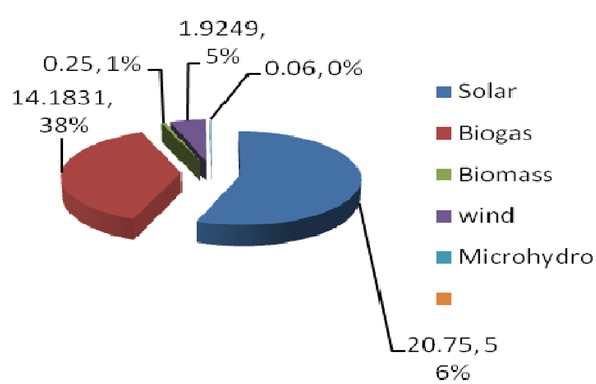

Fig. 3. Contribution of Different Implemented Renewable Energy Technologies in Bangladesh [in terms of installed capacity in MWp, up to July, 2009

Unfortunately, it has been found that out of the total 42,211 biogas plants installed till July 2009, about 47 percent has been functioning well, while another 32 percent are partially functioning because of lack of proper maintenance and knowledge on appropriate use of bio-slurry and noncompliance with the suitable quality standards [6]. Based on the estimation that the average installed capacity per SHS is 53Wp, the total solar energy related wattage is 20.75MWp.From the figure, it is obvious that solar and biogas energy sectors are the most dominant sources of renewable energy in Bangladesh, the total solar energy related wattage is 20.75MWp.but it is not sufficient enough to meet our energy demand as far.

III. SOLAR ENERGY AS A POTENTIAL SOURCE

Biomass has been the mostly used form of energy in Bangladesh. It terrifically pollutes the environment and creates serious health hazards. Again, due to lighting problem the education of the children has been hampered badly. Development activities stop after dusk. The rural children spend most of their time in collecting dried leaves, crops and other woody biomass instead of going to school. Even their parents allow them to do so because they do not have other chap resources for cooking. Rural people use mud made stoves for cooking which are very inefficient and produce a lot of wastages. These stoves also create huge smoke and several of kinds of health hazards. A huge number of people do not have the access to the grid electricity and to the up to date cooking technologies, Country can currently generate about 4500 megawatts (MW), while peak demand can be as high as 6000 MW[7]. Following table presents the Bangladesh power development board estimation up to 2020.

TABLE IV
Future demand estimated by Bangladesh power development board[8]

Year	Net Peak demand/ MW	Net Generation Capacity/ MW	Net Generation/ GWh
2010	6008	7986	33828
2011	7148	8586	36622
2012	7732	9449	39647
2013	8364	9979	42922
2014	9047	10879	46467
2015	9785	11579	50306
2016	10512	12479	54079
2017	11291	13229	58135
2018	12128	14229	62496
2019	13027	15243	67183
2020	13993	16443	72222

Until a suitable alternative is found there is no other way than using these existing inefficient sources of energy. One of the alternative sources of energy can be the nuclear fusion reactions in the Sun. The Sun delivers about 7000 times more energy to the Earth's surface than we currently need for our global consumption [9]. Even if we could use only a small fraction of the solar energy, we could reduce our dependence on fossil fuels. In time we might even eliminate them altogether. We could clean the environment and improve the living conditions on our planet. Solar Energy is inexhaustible and pollution free. It is available everywhere; but the greatest amount is available between two broad bands encircling the earth between 15” and 35” latitude north and south. Fortunately, Bangladesh is situated between 20”40’ north and 26”38’ north latitude and 88”04’ and 92”44’east latitude which is an ideal location for solar energy utilization [10]. Maximum amount of radiation is available on the month of March and April and minimum on December and January [11]. For this reason solar energy is very effective in our country. Every hour, enough sunlight energy reaches the Earth to meet the world’s energy demand for a whole year. The amount of energy from the Sun that reaches the Earth annually is 4 x 1018 Joules.

4 x 1018 Joules/ Year ÷ 365 Days/ Year = 1 x 1016 Joules/Day

1 x 1016 Joules/ Day ÷ 24 Hours/ Day = 4 x 1014 Joules/Hour

The amount of energy consumed annually by the world's population is about 3 x 1014 Joules[12].

TABLE V
Average monthly insolation at different cities in Bangladesh (kWhr/m^2/day)[13]

Month	Dhaka	Rajshahi	Sylhet	Bogra	Barisal	jessore
January	4.03	3.96	4.00	4.01	4.17	4.25
February	4.78	4.47	4.63	4.69	4.81	4.85
March	5.33	5.88	5.20	5.68	5.30	4.50
April	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
June	4.8	5.25	4.53	5.26	4.39	5.12
July	4.41	4.79	4.14	4.34	4.20	4.81
August	4.82	5.16	4.56	4.84	4.42	4.93
September	4.41	4.96	4.07	4.67	4.48	4.57
October	4.61	4.88	4.61	4.65	4.71	4.68
November	4.27	4.42	4.32	4.35	4.35	4.24
December	3.92	3.82	3.85	3.87	3.95	3.97
Average	4.73	5.00	4.54	4.85	4.71	4.85

Annual amount of radiation varies from 1840 to 1575 kwh/m2 which is 50-100% higher than in Europe. Taking an average solar radiation of 1900 kwh per square meter, total annual solar radiation in Bangladesh is equivalent to 1010 X 1018 J. present total yearly consumption of energy is about 700 X 1018 J. this shows even if 0.07% of the incident radiation can be utilized, total requirement of energy in the country can be met. At present energy utilization in Bangladesh is about 0.15 watt/sq. meter land area, whereas the availability is above 208 watt/sq. meter. This shows the enormity of the potentiality of this source in this country (Eusuf, 1997) [14].

IV. ATTEMPT & PROGRAM

Solar photovoltaic (PV) systems are in use throughout the country, with over 200,000 household-level installations, a total capacity of about 12 MW, as of June 2008. solar PV, is being employed through the Rural Electrification Board (REB), the Local Government Engineering Department (LGED), the Bangladesh Power Development Board (BPDB), and other agencies. The Research Centre of the University of Dhaka has installed a 1.1kW grid connected PV system([15],[16]). Electrification and Renewable Energy Development Project (REREDP) aims to provide rural and remote households with solar energy systems. It is the largest scale, and actually the most successful solar energy project being developed in Bangladesh thus far. REREDP is jointly financed by the World Bank, Global Environment Facility (GEF), KfW, GTZ over 2002 to 2009, and promotes solar home systems (SHSs) primarily in remote rural areas. More than 120,000 rural households have been electrified thus far[17].

IDCOL a public investment company promotes SHSs under REREDP through 15 MFIs6, including Grameen Shakti, BRAC Foundation and TMSS. IDCOL provides refinancing facility to the MFIs and channel grants to reduce the SHSs costs as well as support the institutional development of the MFIs. IDCOL provides grants and refinance, sets technical specification for solar equipment, develops publicity materials, provides training, and monitors Partners Organizations' performance such as Grameen Shakti[17].

REREDP was successful beyond expectation; the initial target was to finance 50,000 SHSs over a period of five-and-half years (January 2003 - June 2008). This target was already achieved in September 2005, almost 3 years ahead of schedule and at US $2.0 million below the initially estimated project cost. Therefore, the target was revised to finance a total of 200,000 SHSs by the year 2009 with additional support from the World Bank, GTZ and KFW[17].

Grameen Shakti (shakti meaning "energy" in Bengali) was created in 1996 as a not-for-profit company under the Grameen Bank. The goal of Grameen Shakti is to promote and supply renewable energy technology at an affordable rate to rural households of Bangladesh. Solar home system (SHS) is introduced by Grameen Shakti under IDCOL.

Solar home systems are replacing kerosene lamps, avoiding the fumes and fire-risk.Using the carbon emission factor for kerosene (2.45 kg CO_2/liter), the avoided CO_2 emissions for the most commonly purchased solar home system (40–50 Wp) is about 76 kg CO_2 per year in the context of rural Bangladesh. Owners of a solar home system also save about Tk 400 to Tk 500 (USD 6.00 to 7.50) per month[18] .

Figure 2 indicates that the installations are very much distributed throughout the country as far as the six divisions are concerned.

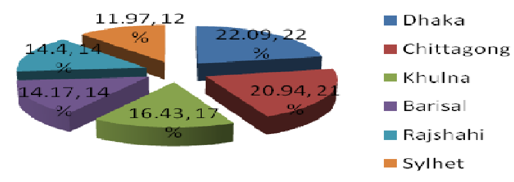

Fig.2. Distribution of the SHSs in six divisions[5]

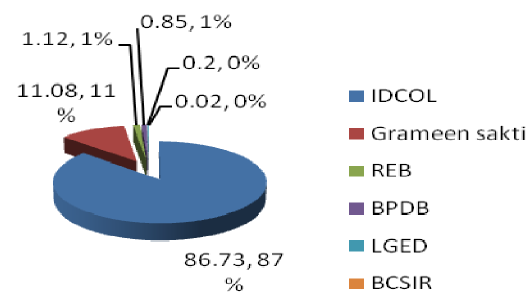

Fig.3. Relative contribution to the solar energy sector by different organizations in terms of installed capacity [up to July 2009. having a total installed capacity of 20.75MWp.[5]

In the country a 10 kWp Solar Wind hybrid at St. Martin's Island is a landmark. The initiative is providing power to a complex of the Forest Department on the island. A total of 4 solar submersible pumping systems (4 X 1800Wp) are underway at Barendra area in Rajshahi complementing another SEMP project of the Barind Multipurpose Development Authority (BMDA)[17].

RahimaFrooz on behalf of Bangladesh Power Development Board (BPDB) installed a communal PV plant for a local market for which it provides lighting loads and operates small industries like rice husking mills and saw mills. The 10 KWp system supplies 135 shops, and a board is put in charge of collecting the bills from the beneficiaries[17]. RahimaFrooz pointed out the system works pretty well. The additional advantage of those systems could be their direct link with income generation as compared to SHS at household level.

A 100-kilo watt (KW) plant has kicked in Sandwip recently. The plant-known is biggest of its kind- will provide electricity to 400 households which never enjoyed electricity from the national grid due to geographic barriers [19].

V. FUTURE PROGRAM

Though the use of solar energy in Bangladesh is increasing, it is not sufficient to meet energy crisis & to keep pace of life with present technological development. For this reason it is needed to accomplish sufficient project to give the people a better competitive modern life.

To achieve the projected global energy consumption in 2100 Bangladesh need to add some beneficial project plan parallel to the present running program.
The home ministry officials said the Border Guard of Bangladesh (BGB) would install 350 solar systems in the first phase in the remote border areas at a cost of Tk 300 million where power supply from the national grid is unavailable.The officials said each of the solar systems would have a capacity of 180 kilowatt hours (kwh) of generation. A planning ministry official said the BGB has sent a proposal on the solar system installation project. Bangladesh has still limited power coverage as it has so far been able to supply electricity to 52 per cent of the population due to shortage of adequate generation against the growing demand. Border areas of Bangladesh neighbouring India with a total length of 4,095 km & 270-km-long land border with Myanmar will get this facilities by this project [20]. Electricity generation in the country would be 7000 MW by the year 2013, 8000 MW by 2015 and 20,000 MW by the year 2021[20]. Meanwhile, the government has declared its vision for power sector to make the country free from load shedding beyond 2010 and to make electricity available for all by the year 2020. In order to fulfil the vision, additional 9000 MW electricity will be required to be produced within next 5 years under short, medium and long term out of which 5400 MW would be produced under private sector. Adequate transmission and distribution facilities would also be developed to get access to this electricity. Estimated total investment of 9.5 billion US $ would be required all together for generation, transmission and distribution of power[20].

The government has set a target of generating 500 megawatts (MW) of green energy – almost ten times the current amount – by 2015, in an attempt to narrow the gap between current supplies of grid electricity and the needs of the country's 160 million people. Only 49 percent of Bangladesh's population has access to electricity from the national grid. Fossil fuels account for almost all the current capacity of 5,500 MW, with renewable sources – mostly solar power – contributing just 55 MW.Burning fossil fuel emits greenhouse gases into the air, contributing to the warming of the globe. (And) fossil fuels are depleting very quickly which is a threat to future power generation[21].
The government says there are environmental and developmental imperatives behind its search for alternative energy sources. But we have to face different problem with other alternative sources, so more efficient solar energy sources will help us to overcome these crisis & as well as we will be able to avoid environmental calamity.

VI. COMPARATIVE ANALYSIS OF DIFFERENT SOLAR CELL

The bulk of the commercial market consists of bulk silicon solar cells. Crystalline silicon is a dominant material for solar cell production over 20 years.Single p-n junction crystalline silicon cells are now approaching the theoretical limiting power efficiency of 33.7%[22]. The industrial solar cells are in the range from 13% to 15% for monocrystalline and 12% to 13% for multicrystalline wafers[23]. Amorphous Silicon (a-Si:H) based optimized solar cell can provide efficiency about 16%[24]. Many of the processes used for the fabrication of high-efficiency laboratory cells are too complex and costly to be involved in mass production. Due to the economical factor the industrial technology must be simple, capable of high throughput and must be characterized by high yields. Crystalline silicon based solar cellsl are very common in Bangladesh,Whose efficiency is lower than that of amorphous silicon based solar cells. So,it is beneficial for Bangladesh to use amorphous silicon based solar cell to extract more solar energy to meet its energy crisis.

VII. AMORPHOUS SILICON BASED THIN FILM SOLAR CELL

Depending on construction, the photovoltaic can cover a range of frequencies of light and can produce electricity from them, but sometimes cannot cover the entire solar spectrum (specifically, ultraviolet, infrared and low or diffused light). Hence much of incident sunlight energy is wasted when used for solar panels, although they can give far higher efficiencies if illuminated with monochromatic light. So it is needed to choose a solar panel which can convert maximum solar photon energy to electrical energy.In *a*-Si:H, the diffusion length of the charge carriers is much shorter than in single crystal silicon. The design concept of this *a*-Si:H is to split the light into different wavelength ranges and direct the beams onto different cells tuned to the appropriate wavelength ranges. Panels with conversion rate of around 18% are in development incorporating innovations such as power generation on the front and back sides. Amorphous Silicon (a-Si:H) Based Optimized Solar cell can provide efficiency about 16% [24]. Simulation software AMPS -1D Device has been used to find the short circuit current and open circuit voltage for single junction p-i-n thin film solar cell. Also current density and electric field pattern has been analysed under different conditions. Which suggest choosing thin film solar panel instead of crystalline based solar panel for better means of use of solar energy. In a practical application amorphous silicon based thin film solar panel has been used to convert more solar energy to usable electrical energy in a solar powered vehicle which gave higher efficient solar energy conversion[25].

VIII. CONCLUSION

BP predicted that the solar industry in Asia may achieve 50% annual growth in 2016, up from 30% in 2006. Photon Magazine, citing Credit Lyonnais Securities Asia, projects that Asian solar panel sales may rise to $36.1 billion in 2010. Backing up these predictions, the Chinese government has announced that they want their solar consumption to go from 20 megawatts per year to 1000 megawatts per year in 2020. Solar power is predicted to become 10% of total worldwide energy in 2030, according to a Time article. Solar is not just growing,it is becoming more competitive in terms of price also .As a populous country with small energy resources, our concern should be even more greater. Since, the prospects of solar energy in Bangladesh looks promising we should engage more international and national resources to harness energy from this renewable energy source.

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