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Effect of Colored Absorbers on the Performance of a Built-In-Storage Type Solar Water Heater

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Abstract-Four built-in-storage type solar water heaters (BSWH) of equal volume, equal projected area is tested simultaneously under identical working conditions for their performance comparison in terms of efficiency and heat energy absorbed. Three of these heaters of BSWH are painted with three different colours (black, blue and red brown) and one is left colorless. The BSWH with different colours are used to heat 138 liters of water. Maximum temperature of water is found for black painted heater. In the month of March, temperature of water is achieved 54¬^{0}C for black absorber absorbing 542 W/m^2, 50^{0}C for blue absorber absorbing 448 W/m^2, 43^{0}C for red brown absorber absorbing 341 W/m^2 and 41¬^{0}C for colorless absorber absorbing 336 W/m^2. Monthly average efficiency of BSWH are found to be with black absorber 57% in February and 56.5% in March, with blue absorber 53% in February and 50% in March, with red brown absorber 41% in February and 40% in March and with colorless absorber 35% in February and 35% in March respectively.

Keywords-Solar energy; solar water heater; collector; colored absorbers.

1. Introduction

Solar collectors with colored absorbers can be mainly of flat plate type for water heating applications, because they are usually integrated on the horizontal or on the inclined roof and the facade of buildings. Flat plate collectors for water heating are the most widespread solar thermal systems and a possible change of their colored appearance could result in an aesthetic improvement of future solar collector installations.

The first detailed study of performance of flat plate collectors, by Hottel and Woertz [1] was based on energy balance measurements of an array of collectors on an experimental solar heated building. They used performance calculation based on mean plate temperature and developed correlation for thermal losses.

Ecevit et al. [2] carried out a comparative evaluation on the performance of three built-in-storage type solar water heaters (SWH) of equal volume. They found triangular SWH without baffle plate was the most efficient whose average efficiency was 46%. The efficiency of rectangular and triangular one with baffle plate heaters was 43 % and 40 % efficient respectively.

Y.Tripanagnostopoulos et al. [3] constructed and tested flat plate solar collectors with colored absorbers for water heating applications. The comparison of the yearly efficiency of glassed, insulation type collectors shows that for usual temperature (40^{0}C) the collectors with blue color (α = 0.85) and red-brown (α = 0.75) have a 20% and 40% lower efficiency, respectively, to that of the collector with black absorber (α = 0.95).

Akhanda et al. [4] used a built-in-storage type solar water heater (BSWH) having flat absorber plate at BUET campus, Dhaka during the months of January, February and March, 1993.This heater can heat 114 liters of water to a temperature of 50^{0}C absorbing 0.743 kW/m^2 in February and to

61^0C absorbing 0.979 kW/m^2 in March. From February to March energy absorption increased by 32 percent but the water temperature increased by 22 %.

Akhanda et al. [5] carried out an experimental investigation to compare the performances between two collector-cum-storage type solar water heaters having flat absorber plate and the other having vee corrugated absorber plate (CSWHC). Both collectors are of 114 liters of capacity having 1.25m^2 of collector projected surface area and 9.2 cm of average depth were studied at Dhaka during the months of November 1994 to March 1995. Rajib [6] carried out an experimental study to compare performance between a Built-in-Storage type solar water heater (BSWH) and a natural flow type solar water heater in Dhaka. The collector of the BSWH was 114 liters in capacity having corrugated absorber plate of 1.25 m^2 projected area and natural flow type solar water heater (NFSWH), had a cylindrical tank of 900 mm length and 600 mm depth having a capacity of 150 liters. Experiments were carried out in the month of August-September, 2002. Efficiency of BSWH was found to be 37 to 42% and 30 to 46% in the month of August and September respectively. Das et al. [7] carried out performance test with three built in storage type solar water heater using V-corrugated absorber plate of different corrugation heights at BUET campus, Dhaka, Bangladesh.

M.H.Al-Nahal [8] carried out an experimental investigation to compare two built-in-storage type solar water heaters one having boosters. The average efficiency of the solar water heater with boosters (BSWHB) was found to be 54%, 52% and 48% in the months of March, April and May respectively. Whereas the average efficiency of the solar water heater without using boosters (BSWH) was found to be 36%, 29% and 26% in the months of March, April and May respectively.

From literature review, it is found that lot of works were carried out on Built-in-storage type solar water heaters (BSWH) with and without boosters. But no work is done with colored absorbers. To see the effect of colored absorbers on BSWH this work is undertaken. This present work of Effect of colored absorbers on the performance of a Built-in-storage type solar water heater was carried out by Khaled M.A. Nakoa [9] (2006). Four built-in-storage type solar water heaters (BSWH) of equal volume, equal projected area are tested simultaneously under identical working conditions for their performance comparison in terms of efficiency and heat energy absorb ability.

2. Experimental setup and Test procedure

Figure 1 & 2 shows the experimental apparatus and measurement devices. Four built–in-storage type solar water heaters (BSWH) of the same size have been used for the test. Each of these heaters consists of a built-in-storage insulated tank, corrugated absorber plate with one selective coating, glass plate reflector, wooden box and steel stand with measuring equipment (digital thermometer and selector switch). To monitor and record water temperature, five thermocouples are incorporated at different levels in BSWH, which are connected with the digital thermometers as shown in Figure 2.

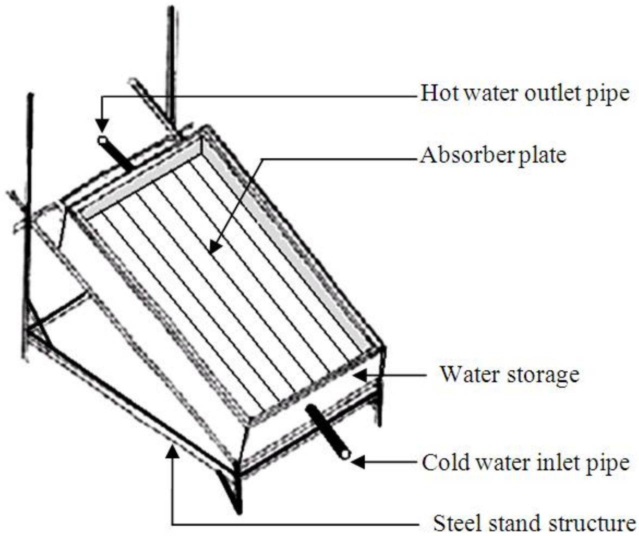


Fig. 1. Schematic diagram of BSWH with steel stand structure.

The storage tank and solar collector are combined and built as one unit.

The external dimensions of tank are (1.45 x 0.95 x 0.1) m^3 with capacity of 138 liters. It is made of 16-gauge G.I. sheets with its top covered with absorber plate.

The top of surface of first tank is painted with black colour of absorptivity (α) of 0.95, following the second one is painted with a blue color of absorptivity (α) of 0.85, the third one is painted with red brown color with absorptivity (α) of 0.75 and the fourth one is left without painting.

In order to admit as much solar radiation as possible as well as to reduce heat losses from the collector by radiation and convection to a minimum value, a glass cover of (140cm x 91cm), with optimum air gap of 25.4mm, is used. For insulation purpose glass wool having thickness of 2.86 cm at the bottom surface and 2.54 cm at the sides is used because of its low thermal conductivity of 0.041W/mK, and of low cost. A piece of glass sheet of 5 mm thickness is set on the top of the wooden box as a transparent cover.

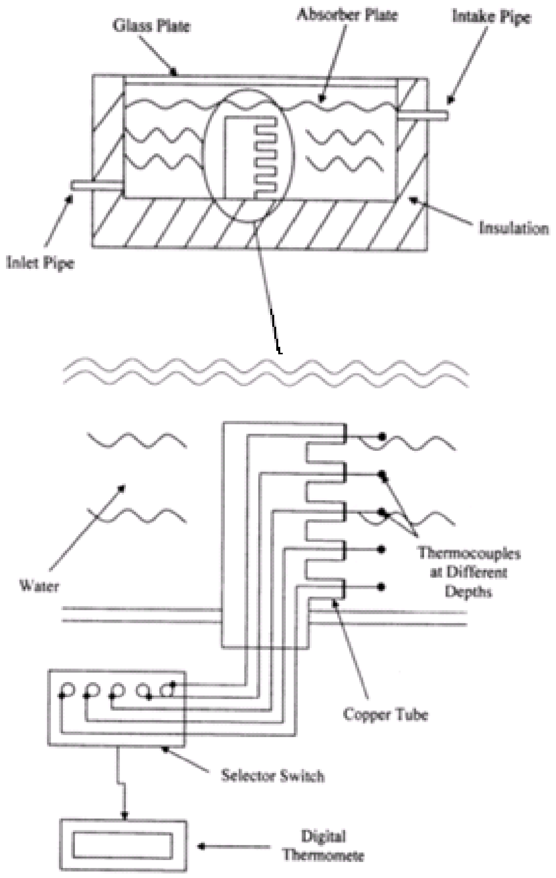


Fig. 2. Schematic diagram showing locations of thermocouples inside a BSWH tank.

All the water heaters are installed at a place in IUT campus where there is no obstruction to sunshine during the day. These are held and fixed at an angle of 23.5^0. As mentioned earlier five thermocouple probes are installed inside the tank of each of the water heater (BSWH) at a distance 2 cm apart from each other to measure water temperature at five different levels in the tank as shown in Figure 2. A Pyranometer is used to measure intensity of solar radiation at every hour during performance test.

All collectors are filled early in the morning with fresh water. Water temperature, ambient temperature, wind speed and solar radiation are recorded hourly everyday started from 8 AM to 5 PM.

The error in the study is given as follows:

Error due to thermocouple wire calibration =

± 1.0%

Error due to thermocouple wire itself = ± 0.75%

Error due to wind speed measurement by Kestrel 1000 (Anemometer) ± 3.0%

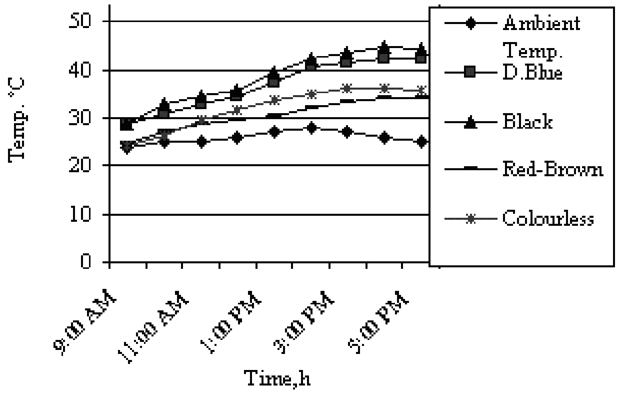
Error due to solar insolation measurement by Skye SP 1000 (Pyranometer) ± 1.20%

So the total error (uncertainty involved) in this study is ± 5.95%

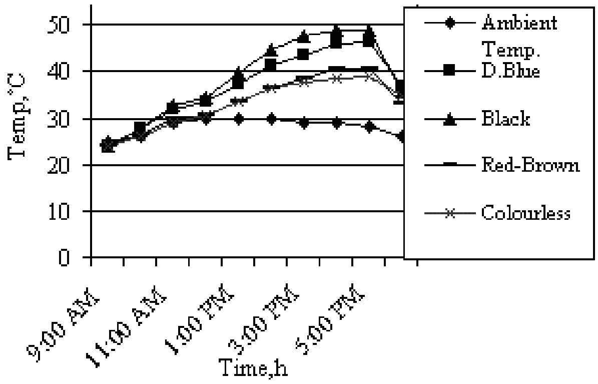
3. Results and Discussions

Using gathered data from the experimental study using four Built-in-Storage type solar water heaters (BSWH) with different colored corrugated absorber-plates, various curves are plotted as shown from Figure 3 to 12.

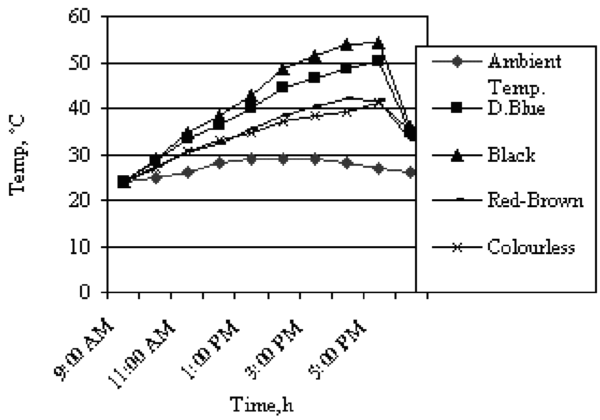
Ambient temperatures (Ta) and average water temperature (Tm) for all BSWH are shown from Figure 3(a) to 3(d). It is observed from these figures that as the ambient temperature increases the average water temperature also increases and it reaches to a maximum value at 2 PM everyday for all collectors. In the afternoon the ambient temperature decreases at faster rate than that of the mean water temperature. Average water temperature increases at faster rate from 8 AM to 12 PM at noon, and reaches to a minimum value at dusk time depends on heat loss rate for each collector.



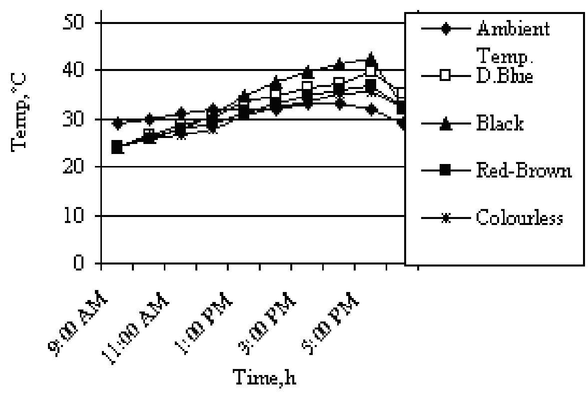
(a) February 14, 2006



(b) February 28, 2006



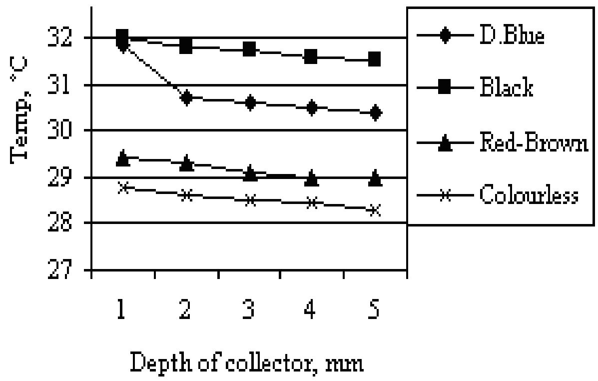
(c) March 12, 2006



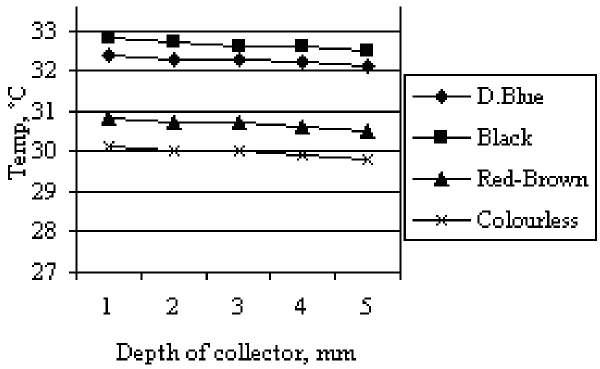
(d) March 27, 2006

Fig. 3. Temperature distribution at various hours in a day.

Typical temperature distribution inside tanks of all BSWH collectors are shown in Figure 4(a) & 4(b). It is evident from these figures that water temperature decreases with increasing of the depth of each tank.



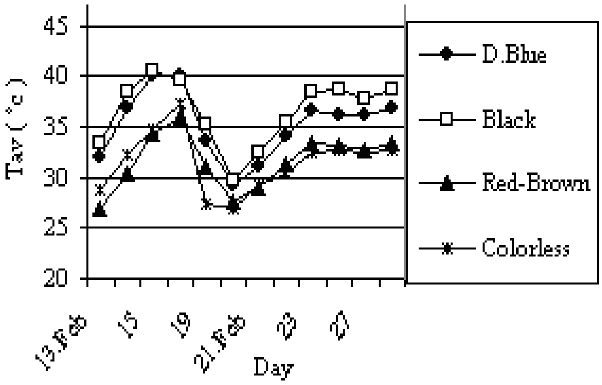
(a) February 19, 2006



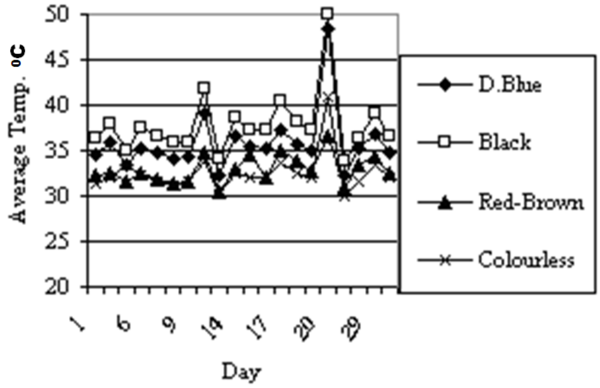
(b) March 28, 2006

Fig. 4. Temperature distribution of water along the depth of collector tank at 12 noon.

Figure 5(a) & 5(b) show the daily average water temperature (T_{av}) for all BSWH collectors during months of February and March, 2006 respectively. It is found from these figures that in the month of February the average water temperature of Blue-BSWH varies from 29ºC to 40ºC, Black-BSWH varies from 29ºC to 40ºC, Red-Brown-BSWH varies from 27ºC to 37ºC and Colorless- BSWH varies from 27ºC to 36ºC. In the month of March the average water temperature of Blue-BSWH varies from 32ºC to 48ºC, Black-BSWH varies from 34ºC to 50ºC, Red-Brown-BSWH varies from 31ºC to 36ºC and Colorless- BSWH varies from 30ºC to 34ºC. Blue and Black BSWH can heat 138 liters of water up to an average temperature 40ºC in February and 42ºC in March. On the other hand Red Brown and colorless BSWH can heat 138 liters of water up to an average temperature of 35ºC in February and 37ºC in March.



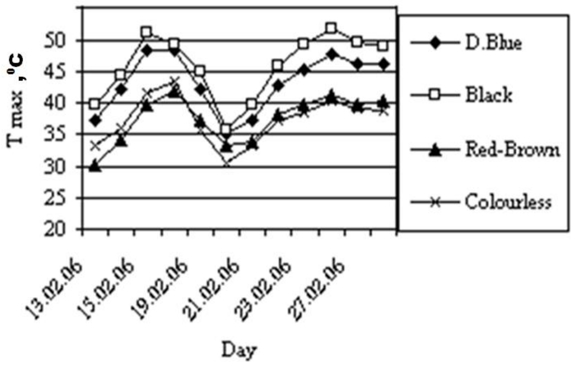
(a) February 2006



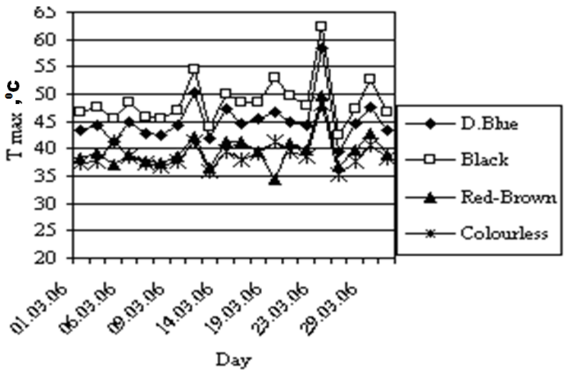
(b) March 2006

Fig. 5. Average temperature distribution in the months of February and March, 2006.

Figures 6(a) & 6(b) show the daily maximum water temperature of all BSWH collectors in the month of February and March respectively. It is found from these figures that maximum water temperatures of Blue and Black BSWH is around 50ºC and that of Red-Brown and Colorless BSWH is around 40ºC.



(a) February 2006

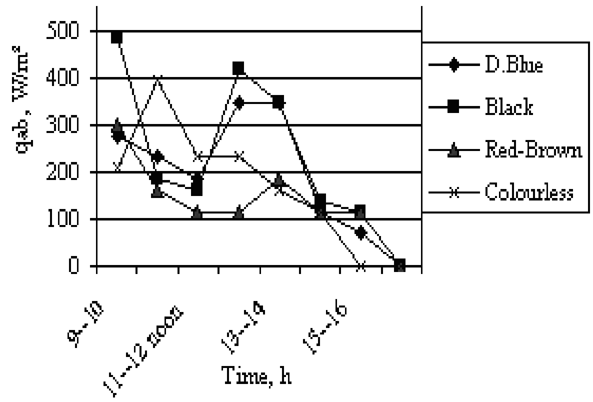


(b) March 2006

Fig. 6. Maximum temperature distribution in the months of February and March, 2006.

Figures 7(a) to 7(d) are the plots of typical heat energy absorbed (q_{ab}) during February and March respectively.

These Figures show that up to around 12 noon the absorbed energy increases and then decreases. The energy absorbed by Blue and Black BSWH is higher than that of Red Brown and Colorless BSWH.



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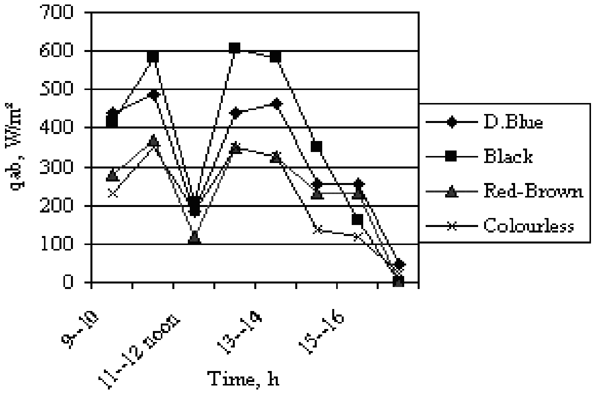
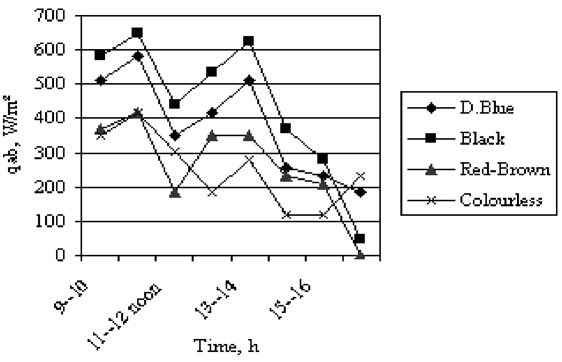
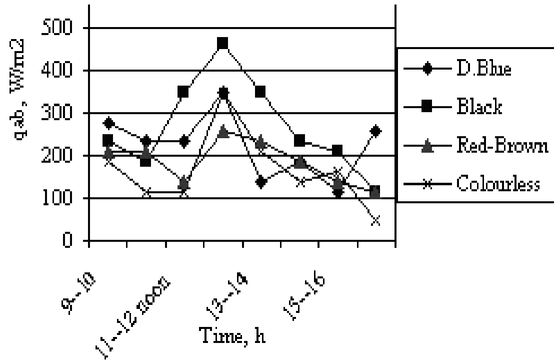


(b) February 28, 2006



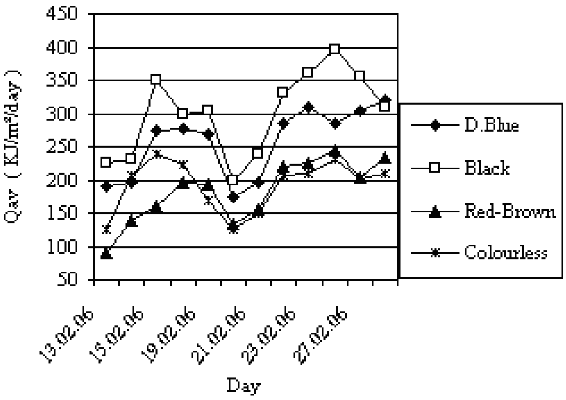
(c) March 12, 2006



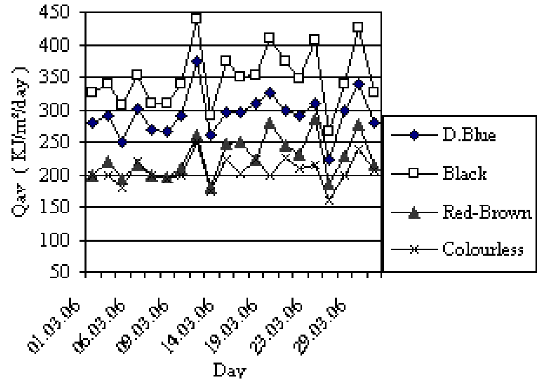
(d) March 27, 2006

Fig. 7. Heat absorbed at different hours in a day.

The daily average heat energy (q_{av}) absorbed during February and March are shown in Figures 8(a) & 8(b) respectively. The maximum daily average heat energy absorbed by water in container in the month of February for Blue, Black, Red-Brown and Colorless BSWH are found to be 340 W/m^2, 397 W/m^2, 248 W/m^2 and 233 W/m^2 respectively. In the month of March maximum daily average heat energy absorbed by water in the container for Blue, Black, Red-Brown and Colorless BSWH are found to be 377W/m^2, 438 W/m^2, 282 W/m^2 and 248 W/m^2 respectively.



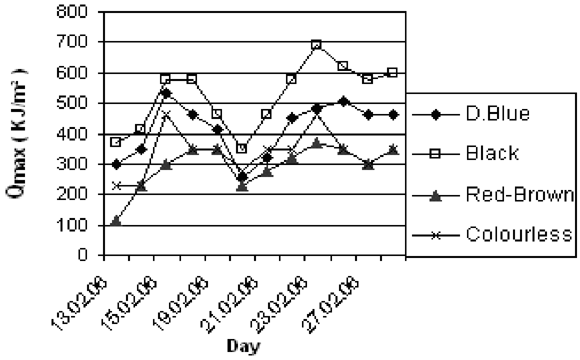
(a) February 2006



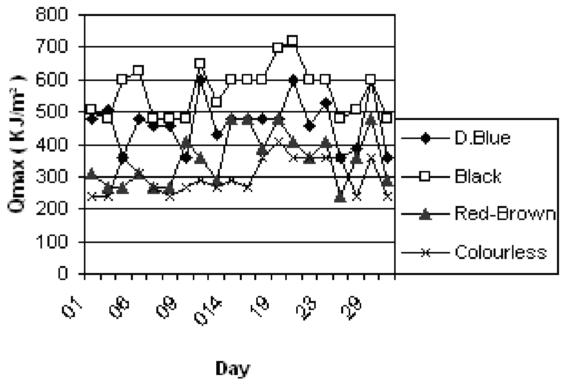
(b) March 2006

Fig. 8. Average heat energy absorbed on various days in a month.

Daily maximum heat energy absorbed (q_{max}) by water in containers of four BSWH during February and March are shown in the Figures 9(a) & 9(b) res pectively.Maximum heat energy absorbed by Blue, Black, Red-Brown and Colorless BSWH are found to be 530 W/m^2, 691 W/m^2, 461 W/m^2 and 346 W/m^2 respectively in the month of February. In the month of March q_{max} for Blue, Black, Red-Brown and Colorless BSWH are found to be 576 W/m^2, 691 W/m^2, 461 W/m^2 and 392 W/m^2 respectively.

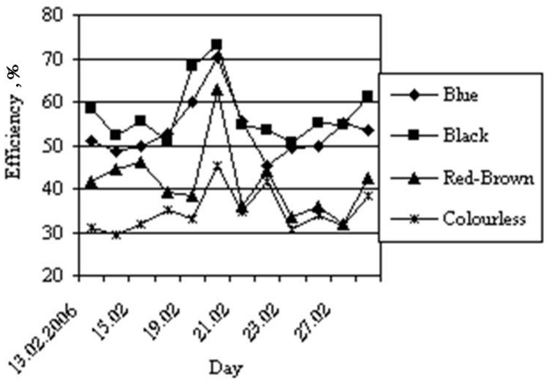


(a) February 2006

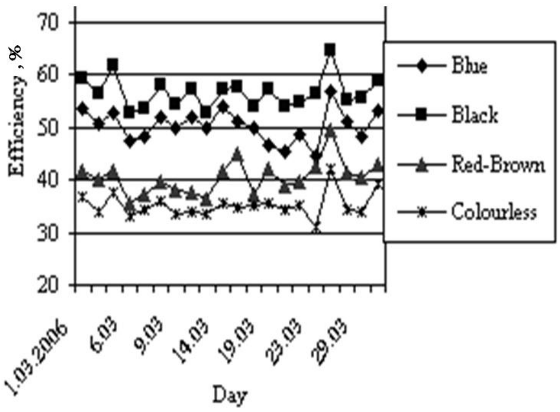


(b) March 2006

Fig. 9. Maximum heat energy absorbed on different days in a month.



(a) February 2006



(b) March 2006

Fig. 10. Efficiency distribution on various days.

Figures 10(a) & 10(b) show the daily average efficiency of all BSWH with colored absorbers and colorless absorber. It is observed from these figures that the efficiency of these BSWH both in February and March is around 50% for Blue BSWH. For Black BSWH it varies from 50% to 60%, for Red-Brown BSWH it varies around 40% and for Colorless BSWH it varies around 30% to 40%. The presented results regarding the effect of the absorptivity value on the collector efficiency of the blue BSWH with α =0.85 gives an efficiency 10% less than that of the Black BSWH for low BSWH operating temperatures.

The selective absorbers can be considered effective for light tone colored absorbers ($\alpha < 0.85$) keeping the efficiency at sufficient level for a wider range of BSWH operating temperature.

4. Comparison of Results

Results in terms of heat energy absorbed (q_{ab}) and efficiency during the month of March are compared with those of Das [7] and Nahal [8]. Das (2002) studied a built in storage type solar water heater having a corrugated absorber plate (BSWH) with capacity of 125 liters at Bangladesh University of Engineering and Technology (BUET) campus, Dhaka. Nahhal (2003) studied two BSWH with capacity of 114 liters, one having a booster at IUT campus, Gazipur.

It is evident from Figure 11 that heat energy absorbed by Blue, Black, Red-Brown and Colorless BSWH are found to vary from 800 W/m^2 to 1200 W/m^2, 950 W/m^2 to 1500 W/m^2, 650 W/m^2 to 1000 W/m^2 and 600 W/m^2 to 900 W/m^2 respectively. Heat energy absorbed by Nahal's BSWH varies from 300 W/m^2 to 1200 W/m^2. Moreover, heat energy absorbed by Das's BSWH varies from 500 W/m^2 to 1300 W/m ^{2}.

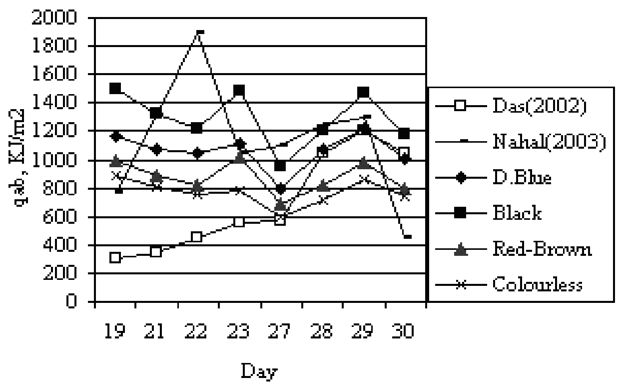


Fig. 11. Comparison of results with Das and Nahal in terms of average heat transfer in March.

Figure 12 show the comparison of results in terms of efficiency during the month of March with those of Das (2002) and Nahal (2003). It is evident from Figure 12 that the efficiency of Blue, Black, Red-Brown and Colorless BSWH are found to vary from 44 to 56%, 54% to 65%, 38% to 50% and 31% to 42% respectively. Nahhal's BSWH efficiency varies from 28% to 50% and Das's BSWH efficiency varies from 32 to 58%.

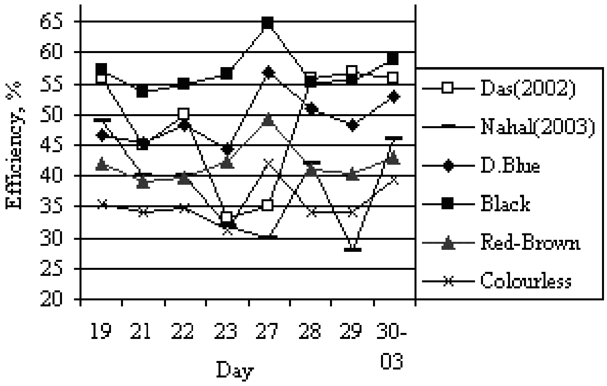


Fig. 12. Comparison of results with Das and Nahal in terms of efficiency in March.

5. Conclusion

The following conclusions may be drawn from this study

1. With increasing of ambient temperature, mean water temperature also increases and reaches a maximum value at a maximum ambient temperature around noon. Both water and ambient temperature then start to decrease.

2. Heat energy absorbed by water from 9 AM to noon is faster than that of absorbed by water in the afternoon for all collectors, studied here.

3. The daily average heat energy and daily average efficiency of BSWH with black and blue absorbers are found to be higher than those of the BSWH with red-brown and colorless absorbers.

4. In the month of March, temperature of water is attained 54^0C for black absorber absorbing 542 W/m^2, 50^0C for blue absorber absorbing 448 W/m^2, 43^0C for red brown absorber absorbing 341 W/m^{2}and 41^0C for colorless absorber absorbing 336 W/m^2.

5. Monthly average efficiency of BSWH is found to be with black absorber 57% in February and 56.5% in March, with blue absorber 53% in February and 50% in March, with red brown absorber 41% in February and 40% in March and with colorless absorber 35% in February and 35% in March respectively.

Acknowledgements

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