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Reduction in Heat Loss of Flat Plate Solar Water Heater by Modification in Material and Properties – A Review

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A B S T R A C T

Efficiency of solar water heater is in the range of 25-35% as out of 100% solar insolation, only 45% solar insolation can be used for heating purpose while 55% was getting waste due to heat loss by conduction, convection, transmittance, absorbance and radiation through absorber plate, collector glass, insulation material, piping, support structure etc. Heat losses from the panel are considerable (more than 50 components) due to prolonged withstanding of heat & cool cycles, physio-chemical reaction, lumpy insulation, gasket rupture, heat and cool cycles, poor water chemistry, ambient factors like wind/rain etc., pipe internal scales, acid and scales formation, radiation, conduction and convection losses through solar panel, gasket erosion due to condensate and UV light cracking etc.Heat gain can be achieved if temp. difference reduced (i.e. heat gain equals to product of heat removal factor ,transmissivity and absorptivity factor with removal of product of heat coefficient with difference of inlet temperature , ambient temperature therefore efficiency increased up to 69 % as per calculation improving the variables and control without sacrificing the performance, going towards ideal Carnot cycle. The passive system design is preferred (as there is no external energy input neither the pumps for increasing velocity). There is tremendous scope for improvement of efficiency by reduction of heat loss by use/substitution of non-thermal conducting materials, changing the material of solar water heater with better characteristics, changing orientation, geometry etc. There are about three main areas to be worked out i.e. solar collector panel, water tank and the inlet and outlet piping network along with water quality and taps, fittings etc. Major advantages of efficiency improvement are like reduction in electricity consumption for domestic water heating by 70%, reduction in conventional energy problems like global warming, pollution, acid rain etc.(as no fossil fuel required), cheap energy cost (i.e. less expensive than natural gas), easiness in source availability i.e. (average solar radiation by earth in energy equals to 722 W/m2 as for every 20 minutes the Sun produce enough energy to supply earth its need of entire year which can be converted to heat), energy security, benefit of accelerated depreciation/tax saving, meeting of renewable energy obligation, low operating and maintenance cost, possibility of direct conversion of solar energy(using PV cells), inexhaustibility, ease for transport etc. .

Keywords: Solar water heater, passive system, insolation, non-conducting material, pipes, panel, absorber, water tank, water chemistry, serration, observations, future scope, frameless, tank, flat plate collector, climate, inclination, efficiency etc.(technical terms), heat losses, thermo siphon, heat gain, sankey diagram, heat loss, transmission loss, heat pipe, thermal performance, thermal conductivity, solar fraction, design, (thermal terms) project, renewal energy obligation, literature, research, performance etc. (management terms).

1. Introduction

1. **Introduction to solar water heater: -** Following parts has significance in solar energy system i.e. collector (flat plate and evacuated tube collector type), reflector (with reflector and without reflector), additional supply of energy (active system with pumps, passive system without pumps), electronic circuit (photovoltaic or thermal) etc. flat plate solar collector components are as follows i.e. frame of aluminium alloy, board inner core is purple copper, layer plating black chrome (absorptance 95%. emittance 10%), cover board 4mm toughened glass, heat conservation by rock cotton (back), polythene (side), back board 0.5 mm galvanized board, ordinary TXT coating absorptance is 93 %. emittance is 45 %~50 %., chrome plating coating, absorptance is 95 % and emittance is 10 %., TINOX (Germany) coating is 96 % and emittance is 6 %.

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a) **solar water heater applications:-** solar water heater applications includes as competitive solar electricity production, industrial applications like boiler feed water generation as an economizer, supplementary water heating as a co-generation unit etc. solar water heating and swimming pools, indirect gain solar water heater collects and stores the solar energy in one part of the house and use natural heat transfer to distribute heat to the rest of the house (e.g. trombe wall method uses massive black masonry that acts as a solar collector and heat storage medium), household food preparation like soup tomato, tea, coffee, rice boiling, milk cooker etc. Solar water heaters can be used for domestic and commercial housing society and community and hotels water heating for kitchen/pantry, cooking/drying/utensil cleaning (i.e.100 ml of hot water is sufficient to clean utensils and stains in place of 1-2 litre of cold water as oil in the form of dielectric expands causes removal of stains).

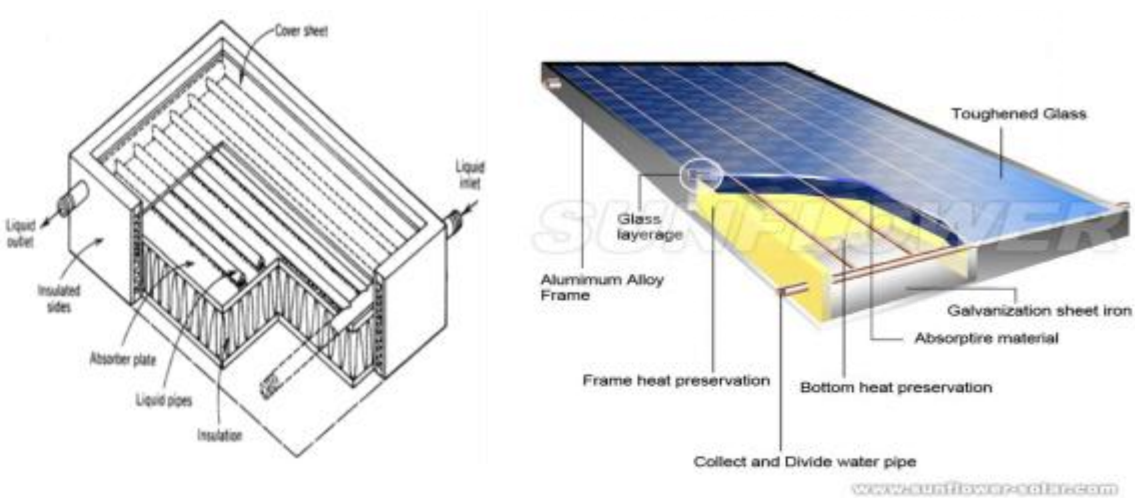


Fig.No. 1 :-Internal structure of solar flat plate collector and components (Courtesy: -internet)

a) **Types of solar water heater: -** Active solar water heating system (It uses water or air that the sun has heated and is then circulated by a fan or pump. Its types are flat plate collectors and batch water heaters etc.), passive solar water heating system (it is a Thermo siphon water heater. It places storage tank above solar collector. cold water from bottom of storage tank circulated through collector and pumped into top of the storage tank. House itself acts as a solar collector and storage facility, no pumps or external fans (energy source) required for it, there is use of materials of the house to store and absorb heat. Its types are direct gain, indirect gain and attached greenhouse type solar water heater, flat plate collectors etc.), other types are bread box heaters (which preheats water using sun by having black tank inside an isolated box with a glass cover. water outflow is sent to conventional water heater for further heating), storage gas type water heaters (which is designed to heat and store water at less than 80°c. water temperature is controlled with a thermostat), storage electric type water heaters (which is designed to heat and store water at less than 80°c. water temperature is controlled with a thermostat), storage heat pump type water heater (which uses a compressor to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water, it includes all necessary auxiliary equipment such as fans, storage tanks, pumps or controls).

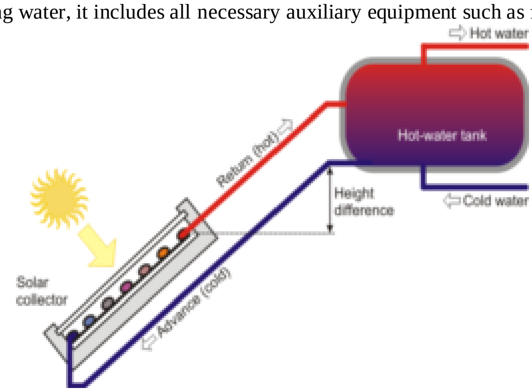
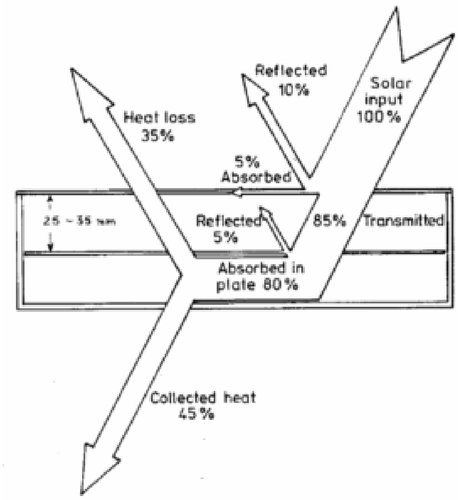


Fig.No. 2: -Solar flat plate collector functional circuit diagram (Courtesy: -internet)

b) **FPC vs ETC comparison:** -parameters in which flat plate solar water heater needs improvement to make it compatible with evacuated tube collector water heater includes technology upgradation, all year round performance (windy/cloudy, overcast conditions etc.), installation cost (expensiveness, Aesthetically pleasing aspect etc.), long term durability and reliability(over 15 years), collector performance (low temperature applicability, freezing in frost prone areas, corrosion in collector, overheating/stagnation, collector repair, collector orientation and placing etc.), basic structural construction(structural condition, area requirement, fragility etc.), sunlight tracking(effect of placement angle, absorber area ,heat transfer efficiency etc.), maintenance and servicing, functional aspects(quantity of water heating, overheat and freezing protection,efficiency,sensitivity, safety etc.) glass property, material cost, energy production etc. Efficiency of conventional energy sources is about 35% while of ETC is about 1.5 times to FPC.

2.Need and objective of efficiency gain of solar water heater -

Table No.2: - efficiency of solar collectors (Source: -internet)

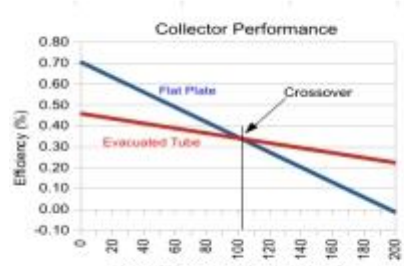


Sr.No.	Manufacturer	Efficiency (%)
1	Sanyo Electric of Panasonic group	17.24
2	Sun Power	16.08
3	Trina power	15.85
4	Canadian solar	15.82
5	Suntech power	15.66
6	Jinko Solar	15.66
7	Renesola Jiangsu	15.66
8	Kyocera Solar	14.74
9	Schuco USA	14.21
10	BP Solar	14.17
11	Yingli Energy	13.6
12	Sharp solar power	12.3

Fig. No. 3 -SANKEY diagram of heat transmission

a) Heat loss through existing solar water heater and improvement/modification:

1. Years	2. Temp.	3. Rated capacity litres	4. Loss 5. Kwh/day	6. Capacity 7. litres	8. Loss 9. Kwh/day
10. New	11. 60	12. 6	13. 0.792	14. 50	15. 1.8
16. 5	17. 55	18. 10	19. 0.9	20. 70	21. 2.0
22. 10	23. 50	24. 15	25. 1.13	26. 100	27. 2.3
28. 15	29. 40	30. 25	31. 1.3	32. 140	33. 2.6
34. 20	35. 30	36. 35	37. 1.5	38. 200	39. 2.9



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. **Fig. No.4: - Collector performance and efficiency chart (courtesy: - internet) and table for loss in Kwh/day**

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b) Maximum collector efficiency by heat gain principle: - Maximum efficiency from flat plate collector solar water heater was found to be maximum limited up to 17-18 % (as out of 100% solar insolation, only 45% solar insolation can be used for heating purpose while 55% was getting waste due to heat loss by orientation, evaporation, condensation, conduction, convection, transmittance, absorbance and radiation through absorber plate, collector glass, insulation material, piping and support structure etc.)

Whellier-Bliss equation = $Q_u = F_R * A [I_{\text{transmissivity factor} * \text{absorbivity factor}} - U_L (T_i - T_a)$

c) **maximisation of whillier –bliss equation by transfer principle of matter and energy: -**

Useful energy gain can be achievedby reduction in heat loss by internal transfer principle of matter and energy, reduction in inlet and ambient temperature difference (as heat gain equals to product of heat removal factor with transmissivity and absorptivity factor with removal of product of heat coefficient with difference of inlet temperature with ambient temperature), optimisation of overall heat loss coefficient, heat removal factor etc.

Whellier-Bliss equation = $Q_u = F_R *A [I_{\text{transmissivity factor * absorbivity factor}} - U_L (T_i\text{-}T_a)$

Minimization of difference of t_{inlet} and $t_{ambient}$: - Solar collectors operate 5°C to 30°C above ambient temperatures to produce end-use temperatures from 35°C to 55°C. As the inlet temperature increases, the potential for heat transfer from the absorber to the surrounding air increases i.e. heat lost to the atmosphere (due to increase in the difference between inlet and ambient temperature (Ti–Ta)) is the heat not transferred to the

3.- Reasons of heat loss and improvement/modification for remedial measures: -

	Heat loss through existing solar water heater and improvement/modification:-	
1	**Heat loss by collector panel**	**Improvement/modification**
	aluminium frame was conductor of heat and lacking in strength	FRP material serrated frame with M. S support and brushable ceramic paints for all 4 sides
2	Heat loss between the gap of absorber plates and tubes	Hydrophobic nylon separator for reduction in distance between absorber plate and tubes and painting at bottom side body by ceramic paint
3	M.S. support having pitting, scaling and erosion/corrosion problem	Provision of nylon bushes for reduction of heat loss to steel support
4	Conductance heat loss of copper plate	Ceramic painted composite tubing of press fitted PE-AL-PE kytech or keolite material
5	Sticky and spongy rock wool /mineral wool with density 62-65 kg/m^3	Use of ceramic glass wool or rock wool insulation with ceramic papers on top with density 96 kg/m^3.
6	Sticking and sponginess problem of cellulose sealing	Provision of silicone sealant (i.e. white lube oil) and glass to serration interface of silicone material
7	Less refractive index and total internal reflection of indium coating	Double glazed coating and glass on the top of panel (aluminium containable glass)
9	Heat loss through single glazed low density(0.80 $kg/m^{3)}$ toughened glass with silicates contents and	Double glazed crystal clear glass (density 0.96 kg/m^3 and free from silicates) resting on serrated aluminium frame covered with a plate of M.S. such that the glass is 1-2 mm below draining the water
10	Requirement of brazing and anodising for copper pipes, plates, aluminium foil as well as between the gap of absorber plates and tubes	Anodization of chromium paint to copper plate and aluminium foil (to increase total internal reflection) and provision of ceramic paint coating (for back plate with 15-35 micron)
11	Gasket is getting damaged and worn out as no interface is available for water tunnelling, condensation of water due to moisture trap in frame	Provision of additional M.S. support for serration at bottom side holes i.e. glass resting on serrated aluminium frame covered with a plate of M.S. such that the glass is 1-2 mm below draining the water
12	high transmission, conductance heat loss from collector box of aluminium alloy with need of reflectors	Double covered polycarbonate housing structure with polymer film with reflectors to increase re-radiation, reflection ,absorption collection efficiency inside panel
14	heat loss from bottom side , from inner side of panel	ceramic coated painting at bottom side and inner side as a black body
16	heat loss from outer side of panel	ferrotrol/ceramic coating at outside to store heat
17	heat loss from panel M.S. supports to ground slab	Provision of nylon supports for panel
18	Heat loss due to improper orientation	Orientation get matched with optimum shade/shadow

19	heat loss due to improper provision of fins	Use of two layer chromium- nickel –copper bottom fins
20	heat loss through absorber	Ceramic paint at back of absorber
	Heat loss by gasket	**Improvement**
21	Gasket worn out due to leakage through mechanical screw bolts, brazed joints and coupling	provision of special type gasket of neoprene/silicon/EPDM rubber ,use of tar felt or paper cloth fitting
22	Leakage through coupling /gaskets	G.I. coupling are provided causing heat loss, reduction in efficiency
23	cracking of bolts	Provision of channel section for both gaskets for sealing the glass with collector box , grommets for sealing the collector box and header
	Heat loss by insulation	**Improvement**
24	Sticking, spreading and sponginess problem with loss of heat to surrounding by Rockwool /mineral wool of 15 mm size	Improved insulation by ceramic paint, Aluminium foil shall be used for covering the back as well as side insulation
25	Low insulation density (varies from 32 to 48 kg/m^3) and thickness (15mm)	Insulation density thickness in the range of 62-96 kg/m^3 or 25mm thick to withstand and temp. of 250^0C be used.
26	conduction, convection and radiation losses of solar water heater due to improper insulation.	Use of high R value of insulation (greater than or equal to 0.74 m^2k/w), use of isolated nylon bush to prevent conduction losses
	Heat loss by supports	**Improvement**
27	Increase in structural loading of M.S. support structure due to heavy weight (tank-100 kg, panel-100 kg, piping-50 kg)	Heat loss can be reduced by support structure modification and material replacement, overall support structure can be made up of nylon material
28	Vibration and pulsations in flow making supports getting vibrate.	Safety relief valves and vibration dampener of nylon bushes
29	Heat loss through support frame bushes and foundation materials	Nylon bushes will reduce conduction of heat loss to steel support
	Heat loss by valves and fitting	**Improvement**
30	Leakage and worn out of gasket due to non-availability of interference for water tunnelling	Provision of diaphragm inserted EPDM/thermoplastic natural rubber and nylon separator to avoid metal to metal contact
31	Cracking of bolts and leakage through screw bolts, coupling etc. due to thermal gradient	Installation of drain water waste heat recovery system, provision of silicon rubber seal
32	Heat loss through valves, brazed joints and G.I. coupling	Use of heat resistant teflon ball valves ½” instead of 1” to avoid heat and water loss,
33	Additional requirement of steam traps, safety valve etc.	Provision of safety relief valve, Tee or 3 way fitting, quadruple type fitting etc.
34	Heat loss due to mixing of cold and hot water	Provision of mixer type additional tap for converting latent heat of bled water heat for feed heating for increasing proper mixing of cold and hot water for proper water temperature control.

	Heat loss by poor water chemistry	**Improvement**
35	Clogging of water ,corrosion/erosion, pitting and turbidity due to improper water siphoning due to more	application of proper filtration and water treatment methods and accessories
36	Reduction in insulating property due to poor waste heat recovery of saturated worn out glass wool	Use of damaged glass wool for filtering sewage water/river side and for fine filtering of non-potable water
37	Coldness of water causing more water requirement for kitchen utensil cleaning due to cold water(1 to 2 litre per plate)	Use of hot water used for cleaning utensils (100 ml per plate) and sticky oil stains
38	Worn out gasket, spongy and sticky insulation due to thermal gradient, tap diameter ½” causing more water loss.	use of retort design which involves copper heating rod and quadruple Tee at input point of panel tank , utilization of waste heat for feed water heating, use of heat pipe concept as passive heating etc.
	Heat loss through glass	**Improvement**
39	Water overheating due to worn out gasket as non-availability of interference for water tunnelling	Serration at bottom side holes i.e. a glass resting on aluminium frame covered with a M.S. plate 1-2 mm below draining the water
40	Transmission, absorption, reradiation losses through collector glass material	Ceramic paint at the back side of the copper plate, aluminium heat resisting paint with graphite/ resins and silicone options
41	Heat loss through collector glass single glazing	Provision for additional glass cover and polycarbonate glass with double glazing
42	Tempered /toughened glass with low transmission value(0.82)	Use of crystal clear glass (having more transmissivity.i.e.0.92)
43	Heat loss through reflection (10% reflection) by less efficient glass coating	Provision of anti-glaze coating (5% reflection), anodizing and coating of ceramic paint coating for back plate with 15-35 micron
44	Changes in orientation in installation of panel cause changes in angle of inclination of cover glass causing less absorption of solar heat.	The cover glass of the solar collector mounted on a frame facing due south. The tilt of the cover glass facilitate measurement of solar radiation on the glass surface near normal incidence
45	Heat loss from front, back ,inner and outer side of glass	Ceramic paint at the back side of the copper plate , use of aluminium heat resisting paint with graphite/ resins and silicone options, provision of coating of ceramic paint for back plate with 15-35 micron
	Heat loss through frame	**Improvement**
46	Condensation at bottom frame plate and at all sides due to temperature difference between panel and surrounding.	Provision of tapered serration with key hole type arrangement for collection and draining of water and smooth flow, reduction in dew point condensation
47	Conduction, convection and radiation losses through all frames structure	Provision of polycarbonate housing for improvement of nocturnal performance of panel
48	Heat loss through aluminium frame	Provision of tar felt or paper cloth fitting to avoid heat loss and reduction in weight
49	Prolonged condensate eroding the gasket and UV light cracking together develops shear on the gasket	Provision of special type gasket with metal to metal contact type to avoid worn out

50	lumpy insulation unable to store heat thereby the reduced performance and less temperature at the output etc.	Heat loss through frame structure can be reduced by use of silicon sealant i.e. white lube oil
51	Heat loss through single cover of the panel	Additional glass cover to improve the efficiency by 4 %
	Heat loss by water condensation effect	**Improvement**
52	Condensation of water vapour at night causes rupturing the gasket, UV light cracking and corroding, scaling due to acidic nature of rainwater damaging the outside gasket and inside insulation	Reduction in dew point condensation by serration with weep/key holes, provision of special type gasket with metal to metal contact type
53	Water clogging due to entry of water in the solar panel from the bottom to the mid-level of the panel	Reduction in dew point condensation, evaporation rate, formation of fungi etc. by tapered serration with key hole type provision for collection, draining and smooth flow by increase in labyrinth /surface area by 100 %.
54	Weakening of bottom side of the solar panel due to prolonged withstanding of heat & cool cycles physio-chemical reaction	Provision of tar felt or paper cloth fitting, use of non-thermal conducting tubes similar to that of the ETC solar water heater
55	Lumpy insulation inside solar panel causing less temperature of hot water for service.	Provision of silicone sealant i.e. white lube oil and glass to serration interface of silicone material with 1*1mm in combing form.
56	Corrosion of bottom plate due to UV crack and acid scaling due to hard water	Provision of water treatment accessories, hard water treatment methods etc.
	Heat loss in input feed	**Improvement**
57	Heat loss due to improper heating of inlet feed water from overhead tank to solar water heater tank through inlet piping	Provision of keolite piping from overhead tank to solar water inlet with 4-way Tee valve with one quarter angle connection and 20 litre retort basking parallel to existing system from inlet header to tank outlet
	Heat loss by cover plate	**Improvement**
58	Transmittance heat loss through cover plate due to low solar transmittance	Increase in solar transmittance of the cover plate with minimum 82 percent at near normal incidence
59	Heat loss due to improper orientation and tilt	Mounting of the cover glass on a test frame facing due south. The tilt of the cover glass facilitate measurement of solar radiation on the glass surface
60	Heat loss through cover glass plate	Tempered glass free from bubbles and rough surface
61	Heat loss through sides of cover plate	Ceramic paint at the anodized back side of copper plate
62	Improper insulation of cover plate	Aluminium heat resisting paint with 50 mm graphite/ resins and silicone
	Heat loss by miscellaneous factors	**Improvement**
63	Freezing of water in piping and equipment during nocturnal period and cold temperature	Use of anti-freeze solution for constant all round year performance and frost prone zone
64	Mirror sun reflection, scattered reflection due to improper collector orientation	Sun tracking and reflectors provision for maximum utilisation of solar insolation

65	Minimum efficiency due to non-availability of circulating pump, heat exchanger, booster, auxiliary heater etc.	Minimisation of log mean temperature difference of collector by mixing of hot and cold water
66	Insufficient feed water heating	utilization of waste heat for feed water heating
67	Depreciation of material, structure and overall piping due to presence of X rays and gamma rays in sunlight	Provision of polycarbonate housing ,double glazed glass and kytec piping
68	Effect of topography, vegetation in adjacent structures and wind convection loss etc.,	Wind mapping and proper location orientation will be done to avoid heat loss.
69	Increase in acidity of structure due to chemical reaction of piping and water	Provision of chlorinated PVC pipe to avoid it.
70	Over tunnelling of flow causing increasing in overall pressure due to improper instrumentation causing inability to get proper signal and feedback	Feedback or bypass loop, proper instrumentation like flow element and temperature element for safety for over tunnelling of flow
71	Difficulty for maintenance of equipment due to internal/external roof straightening	Proper orientation and space provision for installation and maintenance
	Heat loss through piping	**Improvement**
72	Water siphoning problem due to improper orientation, piping layout and foundation of inlet and outlet piping, fittings, supports etc.	Provision of feedback loop, proper orientation of piping ,proper support and clamp with suitable size stand/civil structure (cement concrete ratio 1:4) ISI mark strainer of standard make should be fitted in the main cold water supply line before the system
73	Weak insulation of thin rock wool/mineral wool up to 15 mm causing sticking and sponginess problem with loss of heat to surrounding along and high heat conductance property of GI or copper piping with high thickness with brazing and anodizing, joints, piping to wall conductance of heat etc.	Use of insulation piping like kaolite or chlorinated CPVC piping and outside glass wool insulation to be stick with alumininum cladding (25mm thick insulation of 48kg/m^3 density and K value 0.03W/Mk R value 1.67 sq.m. C/W to withstand and temp. of 250 ^{0}C)
74	Increase in pulsation and vibration as well as cavitation in flow	Provision of Tee valve, safety valve and accumulator for dampening effect.
75	Cellulose sticking and sponginess problem with loss of heat to surrounding.	Washing with dilute acid for scale removal, flushing with water and hot air blower
76	Provision of asbestos rope and thin aluminium cladding will increase heat loss	26 SWG thick aluminium sheet shall be used for cladding the insulated pipe with thin plastic sheet as covering between glass wool and aluminium cladding besides other retaining material like chicken mesh etc.
77	Conduction, convection and radiation losses through piping,	Use of non-thermal conducting plastic material like keolite or plastic material for tap and piping with nylon separator and medium class (B class) GI as per IS 1239.
78	Improper sizing , ID, OD, schedule (dia meter ½”) and material of piping	Selection of suitable appropriate sizing and schedule of piping, change in diameter to 3/8”.
	Heat loss through storage tank	**Improvement**
79	high weight and heavy structure of M.S. /S.S tank and structure (MS tank tare with 10 kg and Support structure of 5 kg)	Provision of low weight F.R.P./C.P.V.C. tank (industrial grade plastic with ceramic paint and nylon separator(hydrophobic) to withstand 80^{0}C water continuous

80	Pitting, scaling and erosion of storage tank	Use of descaling solution like alum for sedimentation
81	Insufficient pressure to keep constant fluctuation in velocity and mass flow rate for heat transfer due to variable pressure	Provision of steam trap, safety relief valve etc. to keep constant velocity and mass flow rate
82	Gasket worn out due to mechanical screw bolt coupling	Provision of special type gasket with metal to metal contact type and tar felt or paper cloth fitting to avoid heat loss and reduction in weight.
83	Heat loss from piping between tank to collector panel	Use of gasket, sealant, teflon etc. for sealing from leakage to ambient.
84	Spongy and sticky insulation getting spread overall	increase in density of insulation (62-96 kg/m^3), flashing with aluminium, replacement of steel tank insulation by industrial grade plastic to withstand 80^0C
85	Water is getting clogged as no filtration	Water chemistry will be maintained using water treatment methods ,water treatment , purification check valves etc.
86	Water siphoning problem due to improper piping layout and foundation installation	Provision of feedback loop and proper orientation of piping
87	Horizontal orientation of water tank causing more heat loss to surrounding	Vertical tank provided using separator for cold /hot water as more surface area exposed to surrounding atmosphere.
88	Convective heat losses from tank to piping due to improper insulation to all exposed pipes	Use of composite piping (Keolite , Kytec pipe or CPVC) and suitable appropriate sizing and schedule of piping with use of high density insulation of 64-96 kg/m^3
89	heat loss from tank bottom to surrounding ambient due to more convection and radiation losses	Provision of pebbles stones (of 10 kg) inside to increase latency and efficiency and keeping the temperature of water in tank hot by storing heat
90	heat loss from tank inside and outside of tank	Ceramic or ferrotrol coating for inner side with black paining to act as a black body and aluminium heat resistant paint from outside as it is non-thermal conduction material
91	Heat loss due to improper venting arrangement of MS/SS pipe	Provision of safety relief valves, vent pipe of CPVC material with SS balls and improved size and schedule
92	Heat loss due to tank MS/SS supports and GI coupling	Provision of nylon bushes and nylon material for overall support structure with PTFE or nylon coupling.
93	Heat loss due to leak from taps/valves etc. of 1” and improper mixing of hot and cold water	Taps/ valves are made with heat resistant Teflon ball valves ½” and provision of mixer type valve for converting latent heat of bled water heat for feed heating

4. Design

Design: - Some references and steps used for design process are as follows,

a) Indian standards and materials used: -IS 12933 (solar flat plate collector specification, collector components, measuring instruments, test methods etc.), IS 12934 (terminology, solar energy thermal application), ISO 10217 (for material selection to internal corrosion), IS 13129 (efficiency requirement ,performance rating procedure, performance characterisation, durability and reliability etc.) , IS 12976(code of practice), IS 9806(Indian and international solar standards), IS 1960(rules for rounding off numerical values), IS 2082(safety and performance requirement),ISO 9488(vocabulary) ,ISO 9847(calibration of field pyrometer) etc.

b) Materials used :- 2 covers (t*a equals to 0.96) ,ceramic paint, clear glass (transmissivity of 0.81- 0.96), aluminium serration, insulation(PUF of 32 to 48 kg/cm^2),pebbles (10 kg), keolite for blank pipe, fitting, tap etc., PTFE (for tap and ball valve), polymer glass cover (as T_c-T_a equals to 15^0C and efficiency equal to 0.692), bank of copper plate (with ceramic paint or aluminium and HR paint at back side), compound wall along with ceramic paint at front side, isolator area of absorption etc.

c) **Technical specification of solar water heater:-** IS No.(12933), capacity(200 litre), dimensions (2030 mm*1090 mm* 95 mm), header (1100*22g*25.4 dia.), riser (1925*24g*12.5 dia.), no. of fins per collector (9), absorber area (2.06 m^2),absorber material(copper tubes and copper sheets), absorber coating(black chrome on copper),absorptivity(0.92),emissivity(0.10), hydraulic test pressure(5 kg/cm^2),rated pressure (2.5 kg/cm^2),reflector(aluminium foil 0.05 mm thick),glazing(toughened and tempered glass 4 mm thick), transmittance(0.82),sealing(silicone rubber sealant), method of sealing (triple sealing of glass), collector box (specially extruded aluminium sections),insulation(resin bonded rockwool 50 mm thick), grommets and gaskets(EPDM rubber) etc.

d) **Selection of solar water heater: -**It is decided by estimation of the cost and energy efficiency of a solar water heating system, evaluation of site's solar resource ,determination of the correct system size ,investigation of local codes, covenants and regulations etc.

e) **Materials used for improvements: -**PE-AL-PE composite material (as black body of polythene absorbs more amount of heat which heats to AL sandwich sheet which again stores heat in inner polythene which insert in white in colour which heats water to substantially high point), keolite piping material (clay material of keoline as liquid water expellant, it stores temperature of 31 ^{0}C to lukewarm water 41 ^{0}C), ferrotrol (single pack black graphite in bituminous medium with flash point above 30^0 C, anti-corrosive, best suitable for hot wet metal surfaces cleaning and descaling for its excellent performance in continuous contact with hot water and steam above 100 ^{0}C),brushable ceramic blue (low-viscosity, alumina-filled, brushable epoxy compound, when applied to a 15-20 mil coating, provides a smooth protective barrier against wear, abrasion, corrosion, erosion, and chemical attack, temperature range up to 350°F, low-friction surface reduces turbulence, wear, and cavitations, outstanding chemical resistance to acids, solvents, and alkalis etc.), high thermal resistant insulation material (minimum 0.96 m^2 °C/W for back insulation and minimum 0.48 m^2 °C/W for side insulation, thermal resistance (R)= l_i *k (where l is thickness of insulation material and k is thermal conductivity).

f) **Equipment efficiency: -**Service water heating equipment shall meet or exceed the performance and minimum efficiency requirements of available Indian standards and thermal efficiency of the water heaters (under test conditions) shall not be less than 84 percent for water heaters with a nominal heat input exceeding 10 KW.

g) **Standby losses: -**These losses account for energy lost while storing heated water(heat losses through the water heater tank wall, fittings, flue, any pilot light energy etc) which should not exceed the values of IS 2082 (Part 1): 1993 (reaffirmed 2004) edition 5.4(2002-05) stationary storage electric water heaters (fourth revision).

h) **Piping insulation: -** The entire hot water system including the storage tanks, pipelines insulated conform to the relevant IS standards on materials and applications comply with code 5.2.4.1. i.e. 0.74 (insulation with Minimum R-value (m·°K/W) for designed operating temperature of piping 60°C and above) and 0.35(insulation with Minimum R-value (m·°K/W) for designed operating temperature between 40°C and 60°C),usage of wire, twine or straps to insure that the blanket stays in place, installation of the water heater in heated location (the colder the air surrounding the heater. the more the standby loss), the R-value of pipe insulation is dependent on wall thickness (thicker is better), 5/8” wall thickness considered minimum for foam insulation while 3” is the minimum for fibre glass wrap, heat trap nipples (to eliminate convective losses from the tank to piping) etc.

i) **Scalding: -** Periodic flushing of the fixtures with high temperature water or other biological controls to avoid accidental scalding by temperature as low as 60°C which cause bacteria born disease in service water.

j) **Heat Traps:** - Heat traps (to prevent convective heat losses through pipes), paired valves (differently for use in either the hot or cold water line), vertical pipe risers, after-market add-on or site-fabricated, site fabricated heat traps may be constructed by creating a loop or inverted U-shaped arrangement to the inlet and outlet.

k) **Heat recovery: -**The application of approval shall furnish calculation of the design to ensure that at 20% heating requirement met from solar heat/heat recovery and not more than 80% of the heat met by electrical heating.

l) **Sizing a new water heater: -** Information required for sizing solar water heater is type of water heaters (tank less or demand, storage and heat pump (with tank), rating of water heater (temperature rise, flow rate),application (whole house or a remote application), flow rate (listing of the number of hot water devices and then, add flow rates), temperature rise (subtraction of the incoming water temperature from the output temperature), 2 square meters of collector area for each of the first two family members (addition of 0.7 square meters for additional person),150 litre storage tank (for 2-3 people), 200 litre (for 3-4 people, the size of the storage tank proportional with the size of the collector, orientation and tilt of the solar collector, first hour rating (hot water the heater can supply per hour), the tank capacity, estimation of peak hour demand etc.

m) **Bureau of Indian Standards (BIS): -** A statutory institution established under the bureau of Indian standards act 1986 to promote harmonious development of standardization, marking and quality certification of goods and attending to connected matters in the country. The BIS Standard has been developed from Doc: No. ME 04 (0549) and amendments are issued to standards as the need arises on the basis of comments.

n) **Design steps flowchart:-**Tests and readings of existing panel to find transmission, absorption, radiation, conduction, evaporation losses, differential temperature loss between panel and ambient, insolation values, percentage of heat loss, efficiency at various points and overall efficiency for existing panel, temperature and thermal imaging readings at various points by IR camera like collector panel, storage water tank, piping, fittings and support structure for existing panel and preparation of set of temperature data etc., design by application of formulas, reference books, literatures, fundamentals with use of IS standards for specifications for components, measuring instruments, tests methods, standards etc., modified improvement data temperature and thermal imaging readings for modified panel at points like collector panel, storage water tank, piping, fittings and support structure etc. and preparation of set of temperature data, observation and calculations for finding transmission, absorption, radiation, conduction, evaporation etc. losses and calculate differential temperature loss between panel and ambient, insolation values, percentage reduction of heat loss, increase in efficiency at various points and overall efficiency for modified panel to conclude the observations /findings of various timed data and make necessary charts, graphs and projections rate as well as calculations by appropriate formulas and finally check gain in efficiency, reduction in heat loss, performance of water heater, various areas applicability etc.), future scope and conclusion **(**confirmed necessary findings from observations and prediction of future scope for application at various areas and achieve the conclusion of success of project work by defining various parameters like increase in efficiency and reduction in heat loss etc.).

o) **Table 4: -Various material properties considered for design: -**

Property	**Value**
T_f-T_a	0
Ceramic paint of HR panel to copper plate loss	210
T_a	0.96
A_p/A_c	1
Aluminium serration	glass rest , scale and holes
Bank of copper plate	ceramic paint, aluminium ceramic paint
Insulation	32 to 48 kg/cm^2 PUF
Inside tank painting	Ferrotrol
Outside tank painting	AL-HR-ceramic
Pebbles	10 kg
Keolite	blank pipe, fitting and tap
Tap .ball valve	PTFE
Glass cover	polymer
Clear glass emissivity	0.81 to 0.96
T_c-T_a	15 ^{0}
efficiency	0.692
back side	GI sheet and AL, HR paint
front side	Compound wall, ceramic paint
Maximum number of collectors in series	more than ten
Maximum number of collectors in parallel in one row without the use of any piping connections	Less than six
Prevention of air locking in the system	Air venting at appropriate places without hindrance of a spring leaded valve
expansion/make up tank at a high point in the system	collectors run full all the times
Capacity of this expansion/make up tank	1.5% of the system capacity
Shell in tube type heat exchanger	if U-type construction is not employed
V-type construction is employed.	minimum 4 Nos. of heat exchangers used in series
Shell design	1.5 times of designed operating pressure and testing for two times the operating pressure as per BIS-2825 and Indian Standard or TEMA Class C construction
corrosion allowance of mild steel shell	1.6 mm
Tube Thickness	22 SWG or higher depending upon the designed pressure requirements
Coil-type Heat Exchanger	For thermosyphon systems only by incorporating Cu/SS coils/retender inside the storage tank
No. of coils and flow Pattern	the pressure drop less than 0.3kg/cm^2
The surface area of the heat exchanger	Greater than /equal to absorber area of the system (for 100 LPD heater ,copper tube length of 7 meter

p) Absorber plate: -Material (copper, aluminium, steel etc.) with types **(**corrugated, finned, expanded metal, finned beer, tube in tube,water bag, dimpled, under plate, finned, double glazed etc.), conduit of attached tubes (corrugations, dimples, quilted) pattern with black painted and selective coating etc.

q) Absorber: - Use of high conductivity material copper, aluminium, SS or MS with proper protective coating with thickness of the sheets for adequate strength and stability against the pressures to prevent swelling, distortion or ruptures etc. and conform to the temperature test performed. The paint material satisfies the requirements of withstanding temperature without showing any damage or discoloration. Selective black chrome with absorptivity of 0.96 and emissivity of 0.10 (emissivity of absorber plate has impact on top loss coefficient)

r) Reflector: - Pleated design with aluminium 0.25 mm thick and need to place below panel of polyvinyl material readymade having reflection more than glass.

s) Collector Box:- Aluminium alloy (conform to IS 737 or IS 733), fibre glass conforming to IS 10192, CRCA (Cold rolled carbon annealed) sheet conform to IS 513, Galvanized steel sheets conform to IS 277 and HRC (Hot rolled carbon steel sheet) sheets conform to IS 1079 and collector box insulation at back and sides with thermal resistance (R) of insulation material of minimum 0.96 m^2 °C/W for back insulation and minimum 0.48 m^2 °C/W for side insulation (IS 3346) and aluminium foil shall for covering the back as well as side insulation.

t) Collector: - Collectors in which the thermal storage unit is an integral part of the collector so that the collection and the storage processes cannot be separated (Unglazed flat plate collector, glazed flat plate collector, rectangular, trapezoidal, modified absorber parabolic trough collector etc.), installation or mounting of solar collectors and tracking mechanism of the sun follows collector system.

u) Profile Shapes:-Improved contact between tubes and absorber plate has effect on conversion efficiency. Collector front losses reduced by insulation material which rear losses by integrated vacuum super insulation. Uniform flow distribution leads to homogeneous temperature distribution and higher collector efficiency. For good flow distribution, outlet header manifold has higher diameter compared to inlet header and step changes in local thickness with flat geometry. Thermal efficiency and heat gain of water increase with non-flow rate.

v) **Glazing: -** No brittleness to coating, free from ferrous, no impurity, toughened glass (transmissivity equals to 0.82), clear glass (transmissivity equals to 0.929) i.e. saint gobain, astir Mercedes), green glass (heat transfer coefficient equals to back 0.9 and side 0.12), low iron tempered glass (for glazing for transmission of more energy through conventional glass) etc., change in capacity and tube numbers with same structure for optimum performance, absorber surface coated with silica based black paint and silica gel used as filling material (absorber of short wave length solar irradiance and poor emitter of long wavelength radiant energy) etc.

w) Cover Plate: -Material of tempered or toughened glass (free from bubbles and rough surface and mounted on a test frame facing to south. The tilt of cover glass kept to facilitate measurement of solar radiation on the glass surface near normal incidence. In no case, the angle of incidence shall deviate more than 1 5° from the normal incidence. The solar transmittance of the cover plate shall be minimum 82 percent at near normal incidence.

x) **Collector tilt and orientation: -**

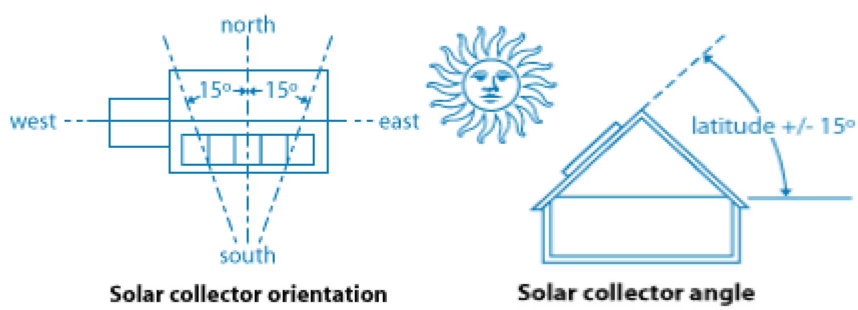

Fig.No: -4. Solar collector orientation (courtesy: - internet)

The optimum orientation for a solar collector is true south, depending on location and collector tilt, collector can face up to 45º east or west of true south without significantly decreasing its performance. To mount the collector on roof, local landscape features that shade the collector daily or seasonally and local weather conditions (foggy mornings or cloudy afternoons) taken into consideration. The angle of collector tilt varies based on latitude and the length (tilt for summer-only heating equal to latitude minus 10º–15º, year-round heating angle equal to latitude, 55 ^{0} tilt angle optimal for year round), roof angle need to take into account when sizing system (vertical collectors most effective than horizontal collectors in winter and least effective in summer and vice versa).

y) **Riser /header and gaskets / grommets: -** Full length of all risers welded with absorber sheet (for working pressure of 2.5 kg/cm^2). Neoprene, silicon, EPDM rubber are used for sealing the glass with collector box.

z) **Brazing/ soldering/ TIG welding: -** Unbrazed or unsoldered portion less than 10 percent of the length of riser, for brazing or soldering minimum 60 percent tin solder or suitable brazing material used, the flux used is non- greasy, for bonding of aluminum sheet and copper tube, rolled bond/pressure bond absorber joint used.

5. Experimental testing methodology

a) **Prerequisites (Materials or instruments used for measurement): -** Cap, araldite, zeolite, 20-meter pipe, tar felt paper, PC, neoprene rubber sheet, tap valve pipe, nipple, elbow, nozzle, Tee, IR camera, spanners, tackles, wrenches, thermometer (PT 100), flow meter, tool box, binding wire, hammer, monkey pliers, black tape paper , teflon coupling flange or union etc. and one existing design solar panel as reference study, provision of location for thermometer, flow gauge and IR camera , cleaning of overhead tank by alum or salt etc.

b) **5-point program for existing and modified system study: -** The existing system (4 to 5 main areas i.e. Piping, fitting, storage water tank, input water, panel, glass etc.) studied with a simple photographs and videos initially after which same reading taken by IR thermal imaging camera (i.e. 24 set of readings will be taken for 3 consecutive days including nocturnal heat loss readings to prepare 2 sets of data i.e. one for standard existing design and one for modified design (i.e. on the panel, about 12 readings were taken by IR camera i.e. at top, upper middle, lower middle and bottom, vertical centre, left /right, cold water inlet, outlet of tank, below tank area, in the bath room at tap outlet etc. and same for piping, fitting, storage tank etc.) and comparative analysis data prepared with colour-correlated temperatures for further study. Some existing parameters for reduction in heat loss and improvement in efficiency by modification in properties and characteristics i.e. for parameters like size/area, glass thickness, output, capacity, insulation etc., study of water storage tank for parameters like capacity, material thickness, heat loss, insulation, cladding, density etc., study of support frame for parameters like weight, orientation, material etc., study of piping for parameters like diameter. schedule, length, flow rate, material etc., study of water tap at outlet for parameters like application, design, mixer, Tee design, boiling ratio etc., study of general ambient for parameters like insolation, radiation, area, tilt, location, wind velocity etc., study of coating for parameters like flash point. drying time, spreading time, abrasion resistance etc.

c) **Input feed and water chemistry: -** Use of keolite or kytech piping from overhead tank to solar water inlet via retort , 20 litre retort basking parallel to existing system from inlet header to tank outlet (i.e. at hot water inlet 4 way Tee junction with one quarter angle connection with opposite copper rod inside is provided where hot water will heat the feed water), provision of screw arrangement for inserting temperature gauge and other end for removable plug for measurement (for IR heat image and temperature study), water chemistry maintained by provision of filtration, sedimentation, inlet water heating, descaling arrangement and water treatment methods.

e) **Support structure and fitting: -**Provision of nylon bushes and nylon support structure for reduction in conduction heat loss from steel support, replacement of GI coupling by PTFE or nylon coupling, use of heat resistant taps, mixers, ball valves of teflon or nylon (of ½" to avoid heat and water loss), provision of retort design or quadruple mixer type Tee or 3 way fitting of PTFE or nylon material (for converting latent heat of bled heat for feed heating of cold water for water temperature control), provision of safety relief valve etc.

f) **Serrations: -** Preparation of a new frame with higher schedule of the same size , shape and cut at 45^{o} angle for serration on shaper m/c at 1 mm spacing in 1*1 mm in combing form with provision of silicon sealant (i.e. white lube oil) , special type gasket with metal to metal contact type to avoid worn out, tar felt or paper cloth fitting to avoid heat loss and reduction in weight, flushing it to the glass with liquid sealant (silicone) with the support from bottom frame rear side followed by collection and measurement of poured water from a showered pot and repeating the same procedure for 0.5 mm spacing and 1.5 mm spacing for other 3 sides of support frame.

g) **Insulation: -** Study of existing contaminated wool behind the copper plate by photo, video and IR camera, replacement of insulation of density of glass wool as 64-96 kg/m^3.

h) **Glass: -** Provision for additional cover of polycarbonate glass with double glazing and anti-glaze coating to glass to convert 10% reflection into heat absorbance to improve the efficiency by 4 % as glazing, replacement of toughened glass (transmissivity of 0.82) by crystal clear glass (transmissivity of 0.92), anodization to increase total reflection and provision of coating of ceramic paint for back plate with 15-35 micron to avoid rusting,

i) **Tank: -** Study of existing MS tank (with PUF insulation) with photo, video and IR camera, descaling and draining of M.S.tank, cleaning with dilute acid, water and air blower respectively, removal of MS tank tare (of 10 kg) and support structure (of 5 kg), keolite painting to tank end, application of internal coating with ferrotrol to avoid heat loss, application of aluminium heat resistant paint from outside, provision of pebbles stones inside to increase heat latency, insulation of all exposed pipes by provision of heat trap to eliminate convective losses from tank to piping by insulation blanket with higher R value of pipe (5/8" wall thickness for foam insulation while 3" minimum for fibreglass wrap),replacement of material of M.S. tank by industrial grade plastic (FRP or MS tank with ceramic paint)and insulation and flashing with aluminium to withstand 80^{0}C water continuous, provision of steam traps to keep constant velocity and mass flow rate and suitable vent pipe with SS balls, Repeat study of tank structure with photo, video and IR camera for observation.

j) **Piping: -** Study of existing G.I. piping (with PUF insulation) with photo, video and IR camera, flushing of piping with dilute acid, water, hot air blower etc. respectively for scale removal, application of Keolite piping (non thermal conductor PE-AL-PE kytec piping) or chlorinated CPVC piping in lieu of GI piping, provision of a nylon Tee for taking hot water out to tap i.e. 15-20 meters , observation of temperature and heat by IR camera for temperature at outlet of 10 metre kaolite pipe (run parallel to existing GI pipe) to confirm comparative hotness of kaolite pipe , provision of outside glass wool insulation cladding of aluminium (with average outlet temperature of 57 to 62 ^{0}C as compared to average outlet temperature of 46 to 52 ^{0}C), provision of feedback loop and proper orientation of piping, selection of suitable appropriate sizing and schedule of piping. provision of vent pipe of CPVC material, application of heat pipe concept as passive heating, repeating study of piping structure with photo, video and IR camera for confirmation of increase in temperature and efficiency.

k) **Panel:-**Study of existing collector panel with photo, video and IR camera, provision of serrations to bottom plate with similar cross section and provision of new gasket and screws, replacement of low density insulation of 62 kg/m^3 to high density insulation of 96 kg/m^3, provision of copper fins, copper plate and brushable ceramic paints on front and back side, provision of crystal clear glass (free from silicates),application of nylon supports and nylon bushes in lieu of MS supports to reduce conduction of heat loss from support structure to slab/foundation, replacement of copper tubes by PE-AL-PE material with 6 to 12 meter risers (as polythene absorbs more heat which heats to AL sandwich sheet which again stores heat in inner polythene to heat water to high point of 54^{0}C), provision of aluminium plates of area 3 to 4 m^2 with backup insulation with placing of 6 to 12 tubes within area 1m^2 to increase the useful area of heat transfer by 4 times (i.e. 1200 W/m^2 in lieu of 300 W/m^2), application of ceramic coating for inner side (with black paining to act as a black body) , application of ferrotrol/ceramic coating outside to store heat equal to product of specific heat of ceramic/ferrotrol , application of brushable ceramic or aluminium heat resisting paint with graphite/ resins and silicone for all 4 sides inside aluminium and at the back side of the copper plate to improve heat storage with better reliability, repeat study of panel structure with photo, video and IR camera for observation of increase in temperature and efficiency.

6. Observation tables for existing panel readings

Table 5 and Fig. No.5: Solar insolation values for various temperature difference at various time period of the day

Solar insolation W/m^2	**Sr.No**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1000**	**900**	**800**	**700**	**600**	**500**	**400**
↓ **Delta Temp.**	Time →	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
45 ^{0}C	1	30	35	40	43	46	52	52	52	52	46	43	40	35	30
40^{0}C	2	33	38	43	47	49	53	53	53	53	49	47	43	38	33
35^{0}C	3	36	41	46	49	52	55	55	55	55	52	49	46	41	36
30^{0}C	4	39	44	49	52	54	57	57	57	57	54	52	49	44	39
25^{0}C	5	42	47	53	55	57	59	59	59	59	57	55	53	47	42
20^{0}C	6	45	50	56	58	59	61	61	61	61	59	58	56	50	45
15^{0}C	7	48	53	59	61	62	63	63	63	63	62	61	59	53	48
10^{0}C	8	51	56	63	63	64	65	65	65	65	64	63	63	56	51

Time	**Outboard temp**	**Panel diff.temp**		**Tank diff temp.**		**Piping diff temp**		**Outlet temp**	
		old	**new**	**old**	**new**	**old**	**new**	**old**	**new**
9-12 am	25	5	0-5(3)	5	0-5(3)	5	0-5(3)	5	0-5(3)
12-3 pm	30	2	0-2(1)	2	0-2(1)	2	0-2(1)	2	0-2(1)
3-6 pm	35	5	0-5(3)	5	0-5(3)	5	0-5(3)	5	0-5(3)
6-9 pm	30	8	0-8(5)	8	0-8(5)	8	0-8(5)	8	0-8(5)
9-12 pm	25	10	0-10(5)	10	0-10(5)	10	0-10(5)	10	0-10(5)
12-3 pm	23	13	0-13(8)	13	0-13(8)	13	0-13(8)	13	0-13(8)
3-6 pm	20	15	0-15(10)	15	0-15(10)	15	0-15(10)	15	0-15(10)
Total diff. temp loss		60 ^{0}**C**	45^0**C**	60^0**C**	45^0**C**	60^0**C**	45^0**C**	60^0**C**	45^0**C**

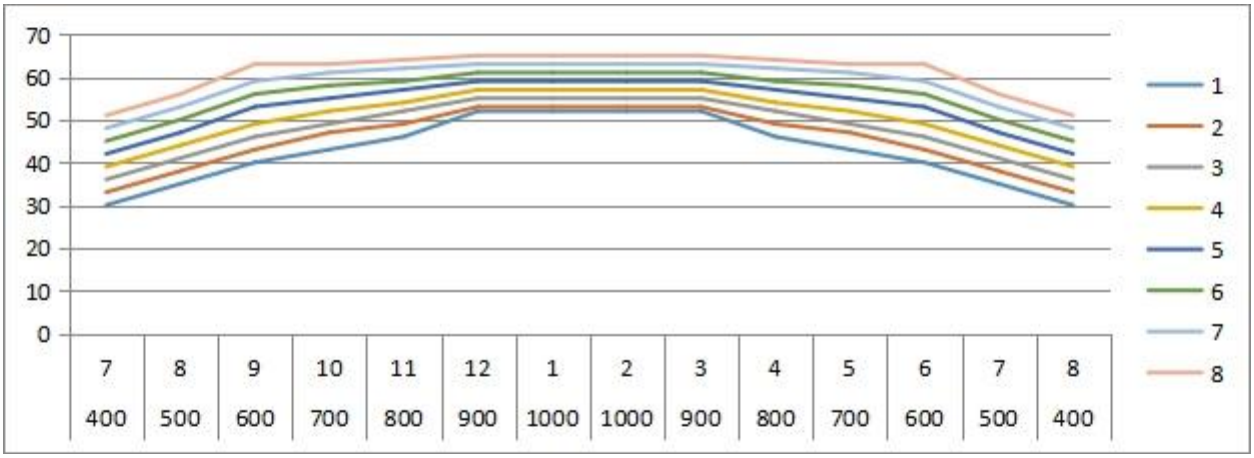

Table 6: - water temperature for outboard, panel, piping, tank, outlet, ambient, inlet, plate, storage tank

Sr No.	Time (t. min)	Ambient Temperature (Ta. °C)	Inlet Water Temperature (Tf_i. °C)	Plate temperature (Tp. °C)	Outlet Water Temperature (Tf_o. °C)	Water temperature in the Storage tank (T. °C)
1	0	26	26	28	27	28
2	30	27	26	62	49	35
3	60	28	27	64	53	45
4	90	29	27	66	58	49
5	120	29	28	69	64	52
6	150	30	28	72	68	52
7	180	30	29	74	70	52
8	210	29	34	66	63	52

Table 7: -Avg. efficiency at various solar insolation and temperature difference

Panel insolation→	600	700	800	900	1000	1000	900	800	700	600	↓ **Avg. efficiency**
→**Time**	9	10	11	12	13	14	15	16	17	18	
↓ **Temp difference**											
45	0.40	0.43	0.46	0.49	0.52	0.52	0.49	0.46	0.43	0.40	45.8%
40	0.43	0.47	0.49	0.52	0.53	0.53	0.52	0.49	0.47	0.43	46.6%
35	0.46	0.49	0.52	0.54	0.55	0.55	0.54	0.52	0.49	0.46	47.1%
30	0.49	0.52	0.54	0.56	0.57	0.57	0.56	0.54	0.52	0.49	52%
25	0.53	0.55	0.57	0.58	0.59	0.59	0.58	0.57	0.55	0.53	56.7%
20	0.56	0.58	0.59	0.61	0.61	0.61	0.61	0.58	0.58	0.56	55.7%
15	0.59	0.61	0.62	0.63	0.63	0.63	0.63	0.61	0.61	0.59	59.5%
10	0.61	0.63	0.64	0.65	0.65	0.65	0.65	0.63	0.63	0.61	62%

Table 8: - Solar energy available at various points of water heater panel and total heat loss: -

Sr.No.	**Solar energy available at various points of water heater panel**	**1**	**2**	**3**	**4**
1	Incident solar insolation (watt)	**600**	**800**	**900**	**1000**
1.1	15 % transmission heat loss (watt)	90	120	135	9000
1.2	10% reflection heat loss loss(watt)	60	80	90	100
1.3	5% glass absorption heat loss(watt)	30	40	45	50
2	Remaining solar energy available inside solar heater panel between glass and absorber(watt)	420	560	630	700
2.1	20% absorption loss (watt)	84	112	126	140
2.2	5 % re-reflection loss (watt)	21	28	32	35
3	Remaining solar energy available inside solar heater panel between absorber plate and bottom	315	420	472	525
3.1	Heat loss 35% to ambient(watt)	110	147	165	184
3.2	Total heat available at collector (watt)	205	273	307	341
4	Total heat loss(watt)	395	527	593	659
5	Percentage heat loss (%)	**65.833**	**65.875**	**65.888**	**65.900**

7. Calculations: -

a) **Assumptions, prerequisites and guidelines:** - Solar water heater equipment should consider following assumptions, prerequisites and guidelines for minimum efficiency requirements as per Indian standards i.e. standard velocity (1m/s), flow rate (70-80 kg/m^3), rated capacity (200 litres), average solar insolation (300 w/m^2), heat loss in day (2.970 kwh/day), minimum R-value of insulation (0.74), absorbance of glass absorber plate (0.92), back loss co- efficient(0.9 w/m^{20}C), domestic hot water(50 ^{0}C), industrial hot water(80 ^{0}C), edge loss co efficient(0.12 w/m^{20}C), transmittance of glass cover (0.92), continuous medium incompressibility, steady and possess laminar flow characteristics, thermal properties of absorber plate, water, absorber tubes are independent of temperature ,density of copper (8978 kg/m^3), sp. heat of copper (381 J/kg k), thermal conductivity of copper (386 W/m k), water density (0.001003 kg/ms), sp. heat of water (4182 J /kg K), thermal conductivity of water (0.6 W/mk) , thermal conductivity of aluminium (177 W/mk), material of absorber tube (copper), inlet velocity (0.0170484 m/s), optimum mass flow rate (0.1 kg/m^2), slope as slope of panel (3 mm thickness), LMTD (1), total solar insolation (600 W/m^2 for 2m^2 area i.e. 300 W/m^2 considering 1200 W/m^2 with 25% efficiency).

b) **Terminology and technical specifications:** - Incident solar flux absorbed (**S),** area of absorber plate(Ap), rate at which heat loss by convection and re radiation from top and by conduction and convection from bottom and sides (Q_1), collector gross area (A_c), energy incident on collector face in one hour (I_t) etc.

Table No.12: -Parameters need to consider for defining technical specification of solar water heater: -

Sr.No.	**Parameter**	**Specification**	**Sr.No.**	**Parameter**	**Specification**
1	IS No	12933	12	No. of fins per collector	9
2	Capacity	200 Litre	13	Absorber area	2.06 M^2
3	Dimensions	2030 mm * 1090 mm * 95 mm	14	Absorber material	Copper tubes and copper sheets
4	Header	1100*22g*25.4 dia.	15	Absorber coating	black chrome on copper

5	Riser details	1925*24g*12.5 dia.	16	Absorptivity	0.92
6	Thermal performance	FRUL =< 6 W/M^2 ^0C FR>=0.65	17	Transmittance	> 0.82
7	Emissivity	0.10	18	Sealing material	silicone rubber
8	Hydraulic test pressure	5 kg/cm^2	19	Method of sealing	Triple sealing of glass
9	Rated pressure	2.5 kg/cm^2	20	Collector box	specially extruded aluminium sections
10	Reflector	aluminium foil 0.02/0.05 mm thick	21	insulation	resin bonded rock wool 50 mm thick R=1.67M^2 ^0C/W
11	Glazing:	toughened and tempered glass 4 mm thick	22	Grommets and gaskets:	EPDM rubber

c) **Formulas used for calculations: -**

1) Incident solar flux absorbed (S) = average incident temperature It*(average product of transmissivity and absorptivity) * area = =overall heat transfer coefficient [(diff in panel temp. and ambient temperature)/diff in temp. of inlet –ambient temp.) == $e^{-Ap*Ul*T)/mass*sp.heat}$
2) Amount of solar radiation received by collector($Q_{in)}$ = I. A = I. $Area_{(trans*absorb)}$
3) Overall heat loss co efficient = Rate at which heat is lost from top, bottom and sides/area of absorber plate*(temperature difference between average temperature of absorber plate and ambient temperature)
4) Heat loss = solar insolation – overall heat transfer coefficient [(diff in panel temp and ambient temperature)/diff in temp of inlet –ambient temp)]= mass *conductivity coefficient* temperature difference = $e^{-A_p*Ul*T)/mass*sp.heat}$
5) Useful heat gain(Qu) = Rate of useful energy absorbed by collector minus the amount lost by collector to its surrounding = mass * specific heat * temp difference between outlet and inlet water = Ap*S –q1 = m. Cp (T_i-T_a) = = F_R * A [$I_{transmissivity\ factor\ *absorbivity\ factor}$ – U_L (Ti-Ta)
6) Whellier-bliss equation for Qu = mass * specific heat * temp difference between outlet and inlet water=Ac.T*f_r(I_t*t_a) n-U_L(T_i-T_a) =I (T. A) A-U_L. A(T_c-T_a)
7) Collector efficiency factor (F)=1/W. U (1/U_L((W-D)(a+d_0)+d/ka.d_o+1/pi*d*h_f
8) Overall heat loss rate (Q_o): -U_L (overall heat transfer coefficient) *A(T_c-T_a)
9) Useful energy gain = collector heat removal factor* maximum possible useful energy gain = Actual useful energy gain by collector/useful energy gain = F_r. A_p (S-$e^{(-F\ U_l*A_p/mCp)}$
10) Instantaneous collector efficiency= useful heat gain (Qu)/radiation on collector(Ac*It)
11) estimated annual operating cost = (365 × kWh/day) ÷ (SEF × Electricity Cost)
12) Collector efficiency = 1/W.Ul[1/Ul{W-D)(a+d0) + d/ka.d0 + 1/pye*d*hf} = 1/1+ (ut+fl) =1/9 = 0.1
13) Collector heat removal factor = Fr.Ap(s-e(-f Ul*Ap/m.Cp))
14) Frame calculation: - For 2 kg, Q = m. Cp. dt =2000*.2*10 = 4000 cal*4.18 = 16.7KJ and for 6 hours, 16.7*6 = 100.2 KJ (As 3.6 MJ=1KWh) = 0.3 KWh while For 5 kg support structure: - 5000*0.1*10 = 5000 cal * 4.18 = 20.9KJ and for 6 hours of operation, 20.9*6 = 1.25MJ = 0.35 KWh and Kcal = 36 MJ/4180
15) Piping calculations, For 15 kg material, 15000*0.1*20 = 30000 and energy -30000*4.18 = 0.034 KWh
16) Sizing a solar water heating system involves, calculation of total flow rate (addition of flow rates of all hot water devices) , temperature rise (desired output temperature -- incoming water temperature), total collector area (2 square meters of collector area for each of the first two family members + 0.7 square meters collector area for every additional person), storage volume (200 litre for 2-3 people, 300 litre for 3-4 people etc.),size of the collector (6 litre per square foot of collector) etc.
17) Sizing of solar water heater- Quality of cold water = hot water temperature-- used water temperature = 60—40 = 20 and quality of hot water = used water temperature -- cold water temperature = 40—23 = 17 i.e. 20x+17x =37x=312 litre therefore cold water= 163 litre and hot water =150 litre
18) Efficiency= heat gain / (incident energy * length *watt) ==Q.U/Aperture area* G (solar irradiance W/m^2) = Q_u/Ai=F_R*T* Alfa -F_R*U_L(T_i-T_{abs})/I = 0.87*5*2/0.04*0.1 = 0.75
19) Energy efficiency of a solar water heater = SEF (solar energy factor i.e. the energy delivered by the system divided by the external energy put into the system) * SF (solar fraction i.e. the portion of the total conventional hot water heating load (delivered energy and tank standby losses).

8 Observation of modified panel parameters for heat loss saving:

Table no.9: -Saving in Kwh using improved solar water heater

Part name	Weight	Factor coeff.	Temp diff.	KJ	Operation hours	6 hours KJ	Kwh
Tank	10 kg	0.1	45	188	6	1090	3.2

piping	15 kg	0.1	20	125.4	6	750	2.15
support	5 kg	0.1	10	20.9	6	125.6	0.35
Frame	2 kg	0.2	10	16.7	6	100.2	0.3
panel	10 kg	0.1	45	188	6	1090	3.2

Table no.10: -Saving in temperature loss using improved solar water heater

Time	**Temp diff between collector temperature and Ambient temp.**	**Existing design temp. loss**	**Modified design temp. Loss (avg.)**	**Temp loss saving degree**
9-12 am	25	5	0-5(3)	2
12-3 pm	30	2	0-2(1)	1
3-6 pm	35	5	0-5(3)	2
6-9 pm	30	8	0-8(5)	3
9-12 pm	25	13	0-13(8)	5
0-3 am	23	13	0-13(8)	5
3-6 pm	20	15	0-15(10)	5
Total temp diff.(temp loss saved)		60	37	**23^0**

Sr.No.	**M**	**s**	**d_t**	**Q**	**Efficiency**	**Conversion factor**	**MJ**	**KWh**
1)	10	1	30	300	0.25	1200	5.016	1.39
2)	15	1	30	450	0.25	1800	7.524	2.09
3)	20	1	30	600	0.25	2400	10.032	2.79
4)	30	1	30	900	0.25	3600	15.048	4.18
5)	40	1	30	1200	0.25	4800	20.064	5.57
6)	50	1	30	1500	0.25	6000	25.08	6.97
7)	60	1	30	1800	0.25	7200	30.096	8.36
8)	70	1	30	2100	0.25	8400	35.112	9.75
9)	80	1	30	2400	0.25	9600	40.128	11.15
10)	90	1	30	2700	0.25	10800	45.144	12.54

Table 11: - Observation for efficiency increase of modified panel

Sr. No.	**Description**	**Existing**	**Modified**
1	Angle of incidence of beam	20.3^0	20^0
2	Solar flux incident on collector(W/m^2)	900	1100

3	(T*a)b (L*a)d	0.8	0.7
4	Incident flux absorbed by absorber plate(S)	4700w/m2	800-900
5	Collector heat removal factor (Fr)	0.86	0.7
6	Overall loss coefficient (U)(W/m^2 k)	5	2
7	Collector efficiency factor	0.95	0.98
8	Water overall temperature (T_f)	70 ^{0} C	80 ^{0} C
9	Improved efficiency	40 %	60 %

9 Conclusion:

: -There is improvement/reduction in following factors,

a) **Reduction in internal work and heat loss: -** Substitution of non-conducting material (i.e. AL-PE-AL, KYTEC, ceramic, ferrotrol material etc.) reduces internal work done by tank, piping and collector panel (1/3rd lost energy). There is reduction of 3 Kwh/day (10 MJ) heat loss (half kg of coal equivalent), reduction in metal-metal heat lossesincluding conduction, convection, radiation, evaporation and condensation losses, standby losses etc. due to insulation for heat transfer loss to surrounding.

b) **Insulation effectiveness and waste heat recovery: -** Improvement in insulation effectiveness by using ceramic paint for reduction in pipeline, storage tank and standby losses etc. and reuse of glass wool for filtering sewage water/river side and for fine filtering of non-potable water purpose. Recovery and utilization of waste heat for feed water heating by improvement in water chemistry and utilization of solar water heating system passive heat.

c) **Minimisation of collector LMTD and proximity to ideal Carnot cycle efficiency: -**There is minimum difference between collector temperature, panel temperature and final temperature with respect to ambient temperature (i.e. minimization of log mean temperature difference of collector) and minimum rise in outlet temperature and efficiency by approximately 5-6 ^{0}C and 3 % respectively (i.e. outlet temperature of 57to 62^{0}C) and product of absorptivity and transmissivity will be close to unity.

d)Efficiency increase by various factors consideration: - Reduction in heat loss can be achieved by reduction in fluid boiling effect (to avoid melting of absorber surface & collector with cover sheet), isolating hot water storage tanks and pipelines and reducing metal-metal conduction losses, reducing heat evaporation losses in vertical tank. reduction in pipeline, storage tank and standby losses, reduction in conduction, convection and radiation losses of solar water heater, reduction in standby losses (3 KWh/day for 200 litres FPC), use of high R value of insulation (greater than or equal to 0.74 m^2K/w), recovery and utilization of waste heat for feed water heating (3 KWH/day or 10 MJ which is half kg of coal equivalent) etc. Therefore, increase in efficiency and temperature up to or more than 50 to 60 % and 80 ^{0}C respectively with high efficiency factor i.e. 0.69.

e) Compatibility with ETC: - There is improvement in the factors i.e. better all year round performance in windy/cloudy, nocturnal conditions irrespective of orientation and tilt angle, lower risk of collector damage due to corrosion and freezing in frost prone areas etc. makes FPC collector compatible to ETC collector water heater.

d) **Economy and job opportunities: -** Creation of job opportunities for rural and urban semiskilled labour and reduction in overall household electrical consumption due to easy availability of economical solar water heater.

10 Future scope

Further scope to flat plate solar water heater includes,

a) **Valves, fittings and frame: -** Use of copper heating rod and quadruple Tee at input point of panel tank, provision of check valve, pilot operated counter balance valve etc., GRP frame in place of aluminium, aluminium curtain wall frameless design etc.

b) **Use of software and glass wool: -**Computer aided special program (i.e.ANSYS, BECHMARK, ICEM, FLUENT etc.) with hardware development in conjunction, reutilization of glass wool for filtering sewage water/river side and for fine filtering of non-potable water purpose etc.

c) **Glass property: -** Usage of high absorptivity and less transmissivity glass types liketoughened glass, double glass glaze, optimum number of glazing for efficiency, change in glass material and specification i.e. gauge, emissivity, refractive index, coating durability etc., provision of internal coating of ceramic paint to copper tube.

d) **Tilt angle: -** Increase in optical efficiency by improvement in impact of tilt angle on top loss coefficient and overall heat transfer coefficient by provision of sun tracking system to increase radiation wave length of beam/diffuse radiation, 15-20-25-degree adjustable tilt angle, provision of additional glass sheet as reflector for more 4 sides etc.

e) **Storage tank modification and improved water heating methods: -** Stratified tank instead of horizontal tank (325 times more resistive to degradation due to thermal stratification) , improved methods for bled steam heating for uniformity of temperature to inlet temperature, provision of baffles at inlet of temperature,auxiliary heating during cloudy days with power failure option, passive heating , use of oil circulated pump and thermic fluid etc.

f) **Chemical reactions: -** Effect of chemical reactions on efficiency bymaterial properties and specifications change, increasing thickness of IR absorption coefficient etc., various improvement methods to achieve uniform heat transfer efficiency during change in atmospheric temperature, wind flow etc.

g) **Tubing: -** Choice of efficient tubing material, change in geometry like U shaped tubing with low requirement of regeneration tube cleaning, minimum no. of tubes for same outlet temperature, optimisation of heat collection surface area with minimum effect of stagnation temperature (i.e. choking, absorber surface melting, fluid boiling)

h) **Solar collector efficiency: -** Use of optimum material, coating, no. of tubes, collector area, mass flow rate, dimple solar collectors, insulation, gap thickness, transparent cover, GI sheet etc.

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