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ANALYSIS OF FLAT PLATE COLLECTOR EFFICIENCY IN SOLAR WATER HEATER

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ABSTRACT

In Solar Water Heaters require collectors to absorb solar radiation. This absorbed radiation is useful for heating fluid (water) which is used to heat water for domestic use. To get the desired water temperature, the collector must meet certain criteria. In this test, conducted in the Testing Laboratory of Solar Water Heater B2TKE-BPPT for 3 days at 08.30 to 16.00 WIB using a flat plate collector covering an area of 2 m^2 with a tank capacity of 150 liters, testing refers to SNI 3021-1992 1st edition. The data taken are Solar Radiation (W/m^2), Ambient Temperature (T-amb), Temperature of Inlet Collector (T-in), Water Temperature Out of Collector (T-out) using the help of sensors that have been installed in accordance with the provisions and data generated will be managed via a computer every 30 minutes interval on an ongoing basis. This test, obtained results that the daily average of the efficiency of a flat plate collector of 2 m^2 is 46.55%, which means that a solar panel is only able to absorb 46.55% of the solar radiation that illuminates the solar collector. For optimal results, testing should be carried out during clear weather so that collector efficiency can be achieved.

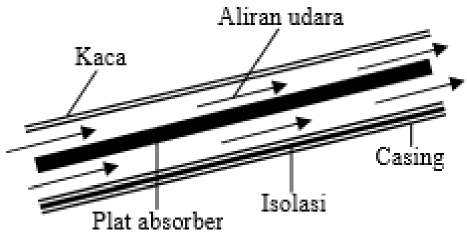
Keywords: Collector Efficiency, Solar Water Heaters.

INTRODUCTION

Solar heaters are heat collector devices from solar energy that are used to heat fluid. This heater uses a solar collector as its main component. According to Duffie & Beckman on a heat exchanger that converts radiation energy into heat. According to the ASHRAE standard the definition of a solar collector is a device designed to absorb solar radiation and transfer energy through it.[1] Judging from the types of solar collectors, this solar water heater has various types including flat plate collectors, vacuum tube collectors, and compound parabolic collectors.

Collector of solar water heaters consists of: a) Absorber Plate, functions to absorb solar radiation that arrives, convert it into heat into the working fluid. b) Fluid flow, functions where the working fluid or flowing liquid has good thermal contact with the absorber plate. c) translucent, functions as a successor to solar radiation and isolation of the absorber plate against the cooler outside air, as well as a protector against the weather. d) Isolator, serves to reduce heat loss through the back and side of the collector. e) collector box, serves to place other collector components in a certain position.

Figure 1. Collector Parts



(Source: Ekechukwu, O.V., Norton, B. 1999)

Solar water heater tank consists of: a) inner tank, is a place to store water that will be used both water that has been heated by solar power and water to be heated, b) Isolator, serves to reduce heat loss from the outer surface of the tank inside, c) The tank sheath, serves to place the position of other components in the specified position. An additional heating source, which functions to heat the water in the tank when solar radiation is not enough to heat the water as needed. When additional heating is used, a temperature controller (thermostat) is required. Which serves to control the temperature of the water in the tank. In general, the components of a Solar Water Heater are shown in figure 2.

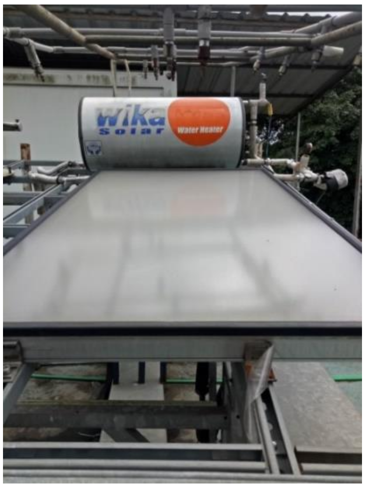


Figure 2. Test Specimens of Solar Water Heater Materials
(Source: Personal Photos)

In conducting collector efficiency testing, sensors are needed to find out the amount obtained, then the data captured by the sensor will be forwarded to the computer for retrieval of data that are running programs. These sensors will be placed according to their functions. Active sensors for testing collector efficiency can be seen in table 1.

Table 1. Measured Parameters

No	Measuring Variable	Description	Unit
1	*Pyranometer*	Solar Radiation	W/m^2
2	T_{amb}	Ambient Temperature	^oC
	T_{c-in}	Water Temperature Enter Collector	^oC
4	T_{c-out}	Water Temperature Out of Collector	^oC
5	V_{dotl}	Flow Rate Speed	dm^3/m en
6	W_c	Wind velocity	m/s

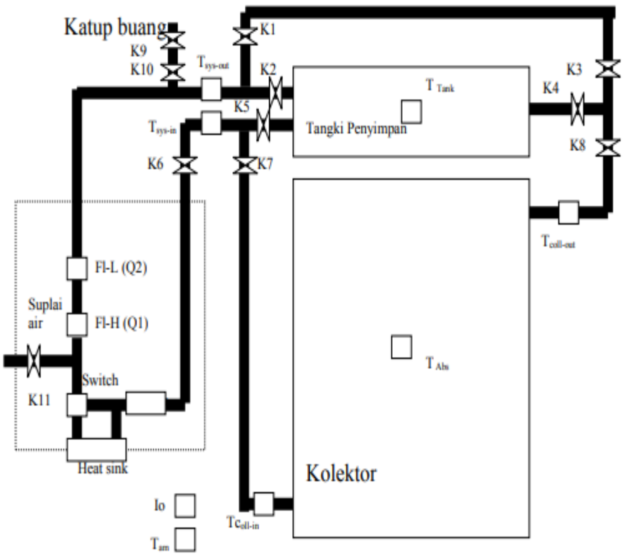
The process of testing the efficiency of a flat plate collector with a collector area of 2 m^2 using a tank with a capacity of 150 liters carried out in a Solar Water Heater refers to SNI 3021-1992 1st edition.

The test was carried out in a testing laboratory for solar water heaters using a flat plate collector covering an area of 2 m^2 and a water capacity of 150 liters. In the testing period of 08.30 to 16.00 West Indonesia Time carried out for 3 days, the data taken are solar radiation (W/m^2), ambient temperature (T-amb), temperature of the water entering the collector (T-in), temperature of the water out of the collector (T-out) by using the help of sensors that have been installed in accordance with the provisions and the resulting data will be managed through a computer every 30 minutes intervals on an ongoing basis.

RESEARCH METHOD

Basically, solar collector testing is done every day for 1-2 years, but only for 1-3 days collector testing is adjusted to the needs. Tests carried out on 11 to 13 February 2019 at 08.30 to 16.00 WIB. A schematic of the solar water heater quality test circuit is given in Figure 3. The collector slope 15^{o} so that the radiation is perpendicular to the collector's plane.

Figure 3. Testing Scheme of solar water



heaters
(Source: Scientific Journal of Energy Technology, Vol.1, No.1, August 2005)

After the collector is installed as configured in Figure 11, initially all valves are opened except for K2, K4, K5, K9, and K11 which are closed so that the water path to the tank is closed and forms a closed water circulation in the collector system. The sensors remain installed in the data recording system, the test device can be activated. The flow rate of working fluid (water) is attempted at a rate that produces turbulent flow, for the case of solar water heaters it is recommended around 2 - 2.5 liters / minute (minimum 0.0136 kg / (det.m^{2})), with a maximum change of 1%. Fluid pressure around 2.4 bar (minimum 2 bar) must be obtained after the collector is filled with water and no air bubbles are trapped inside.

The maximum wind speed across the collector is 4.5 m / sec. The Heat Sink in the test installation is turned on, the thermal-switch is adjusted until the water which becomes the input of the collector approaches stationary at a certain temperature, and if sufficient solar radiation. The collector input temperature is ideally conditioned in 3 stationary regions between 32^{o}C to 60^{o}C, for example 40^{o}C, 50^{o}C, 60^{o}C. Changing the thermal-switch must be done every day in order to obtain water input at a certain temperature. Data is recorded from an average of 300-600 samples in 30 minutes.

The data recorded for the calculation is presented in tabular form. The accumulation of solar radiation is calculated based on linearity assumptions for 30 minutes of data recording, so that solar radiation is obtained every square meter collected during the count time.

From each data (recorded every 30 minutes) a momentary collector efficiency price calculation is performed. From daily data, i.e. data accumulated in one day, daily efficiency calculations are performed. The instantaneous efficiency (η_s) of the collector is based on the formula:

$$\eta_s = \frac{W_u}{I_o . A_c} = \tau . \alpha . F_p - U_k . F_p . \frac{(T_{avg-c} - T_{amb})}{I_o} \quad 3)$$

$$W_u = \tau . \alpha . F_p . A_c . I_o - U_k . F_p . A_c . (T_{avg-c} - T_{amb}) \quad 4)$$

τ is the glass transmission factor, α is the absorber's absorbance, A_c is the collector's area, F_p is the absorber's efficiency, I_o is the solar radiation in Watt/m², U_k is the thermal loss factor of the collector in W/m²K.

Daily efficiency is obtained from the equation:

$$\eta_d = \frac{Q_u}{\sum I_o . A_c . 0{,}6} \quad 5)$$

W_u (watt) is the use of energy collected by the collector and its accumulation Q_u (in joules) given in the equation:

$$W_u = \dot{m} . C_p . dT \quad 6a)$$

$$Q_u = \sum_{i=1}^{\infty} W_u . 600 \quad 6b)$$

Mass rate (Kg/det) given in equation 7.

$$\dot{m} = \frac{\rho . Fl}{60000} \quad 7)$$

Fl is the water flow rate (liters/minute), while ρ is the water fluid density (Kg/m³) given in equation 8:

$$\rho = 1000.205 + 0{,}01928318 \; . \; T_{avg-c} - 0{,}00610612 \; T_{avg-c}^2 + 0{,}00001828 T_{avg-c}^3 - 0{,}0000000119633 T_{avg-c}^4 \quad 8)$$

The fluid heat capacity (J/Kg°C) is given in equation 9:

$$C_p = 4216956 - 3{,}47519 . T_{avg-c} + 0{,}1218524 . T_{avg-c}^2 - 0{,}00248039 . T_{avg-c}^3 + 2{,}246634 \text{ x } 10^5 T_{avg-c}^4 - 1{,}20792 \; x \; 10^7 . T_{avg-c}^5 + 2.711372 \; x \; 10^{10} . T_{avg-c}^6 \quad 9)$$

T_{avg-c} is average $T_{coll-in}$ and $T_{coll-out}$, while dT is the difference between $T_{coll-out}$ and $T_{coll-in}$. The desnsity ρ and C_p of hot water is calculated based on the T_{avg-c} price. The quantity Ω is the quantity defined as $(T_{coll-in} - T_{amb})/I_o$, which will be used to determine the parameters of thermal collector losses. This will be discussed later.

It was agreed that the calculation of collector efficiency was carried out on data obtained under daily insulation conditions greater than 4 kWh/m², while the calculation of thermal losses was carried out on data obtained at instantaneous insulation above 500 W/m².

Then the efficiency of the collector can be defined as the ratio between the useful heat from the collector and the intensity of solar radiation. The efficiency of the momentary collector for testing is:[6]

$$\eta_{kolektorsesaat} = Q_u \left(\frac{W}{m^2}\right) / (1{,}6 \; x \; Q_{radiasi} \left(\frac{W}{m^2}\right) \quad 10)$$

For daily collector efficiency for testing are:

$$\eta_{kolektor} = (Q_u\,(\frac{J}{m^2}) x\ 100) \div (Q_{radiasi}\left(\frac{J}{m^2}\right) x\ 1{,}6) \quad 11)$$

In general, a solar panel has its own efficiency, which means that easily a solar panel can only convert the efficiency obtained from all the light energy received by the collector. While the rest is reflected back into the air.

RESULTS AND DISCUSSION

TEST RESULTS

The first test was on February 11, 2019. Obtained from the data logger and the calculation results, as follows:

Waktu	Radiasi Surya		Tamb (°C)	Tfi (°C)	Tfo (°C)	Flow (dm3/men)	Laju Massa (Kg/sec)	Cp (J/Kg°C)	Delta T (°C)	Energi Guna		Efisiensi Kolektor	
	W/m2	Akumulasi (J/m2)								W/m2	Akumulasi (J/m2)	Sesaat (%)	Harian (%)
8:36:09	578.0230373	346.81	28.76	26.76	30.48	2.334068249	0.04	4172.06	3.72	602.08	361.25	0.65	56.39
8:46:09	610.6001967	713.17	28.99	30.00	33.18	2.331283944	0.04	4169.42	3.18	512.63	668.82	0.52	
8:56:09	639.6265483	1096.95	29.47	32.28	35.52	2.327699444	0.04	4167.22	3.24	521.70	981.84	0.51	
9:06:09	670.7026183	1499.37	29.41	34.44	37.80	2.321647444	0.04	4164.94	3.36	537.76	1,304.50	0.50	
9:16:09	688.0880767	1912.22	29.99	36.52	39.98	2.336598167	0.04	4162.55	3.45	556.01	1,638.10	0.51	
9:26:09	712.5330983	2339.74	30.60	38.50	42.08	2.339577361	0.04	4160.06	3.59	577.04	1,984.32	0.51	
9:36:09	726.3493933	2775.55	31.36	40.39	44.08	2.336825583	0.04	4157.46	3.69	592.72	2,339.96	0.51	
9:46:09	745.672825	3222.96	31.17	42.19	45.95	2.337867972	0.04	4154.81	3.75	602.22	2,701.29	0.50	
9:56:09	757.9223283	3677.71	32.14	43.92	47.75	2.335995306	0.04	4152.06	3.83	612.63	3,068.86	0.51	
10:06:09	834.078495	4178.16	32.86	45.54	49.75	2.320735139	0.04	4149.01	4.21	667.67	3,469.46	0.50	
10:16:09	883.717815	4708.39	33.48	47.10	51.60	2.288511528	0.04	4145.92	4.50	703.45	3,891.53	0.50	
10:26:09	896.6068933	5246.35	33.65	48.63	53.19	2.266795611	0.04	4142.9	4.56	705.27	4,314.70	0.49	
10:36:09	907.5157683	5790.86	33.72	49.67	54.53	2.265000861	0.04	4140.46	4.87	750.63	4,765.07	0.52	
10:46:09	912.4637567	6338.34	33.80	42.07	48.78	2.261984278	0.04	4152.71	6.71	1039.80	5,388.96	0.71	
10:56:09	914.9044867	6887.28	34.04	40.00	45.73	2.258054222	0.04	4156.57	5.73	888.14	5,921.84	0.61	
11:06:09	908.349825	7432.29	34.37	40.24	45.93	2.254381944	0.04	4156.26	5.69	881.13	6,450.52	0.61	
11:16:09	924.278635	7986.86	34.47	39.98	45.79	2.2619685	0.04	4156.54	5.81	901.99	6,991.71	0.61	
11:26:09	923.19937	8540.78	34.66	40.01	45.75	2.264956472	0.04	4156.56	5.74	892.21	7,527.04	0.60	
11:36:09	921.34622	9093.59	34.94	40.34	46.09	2.269127667	0.04	4156.07	5.75	896.36	8,064.86	0.61	
11:46:09	911.4793333	9640.48	34.86	40.10	45.88	2.272587972	0.04	4156.39	5.78	902.04	8,606.08	0.62	
11:56:09	916.5522417	10190.41	35.14	39.88	45.64	2.283099806	0.04	4156.72	5.76	903.68	9,148.29	0.62	
12:06:09	914.0593983	10738.84	35.41	40.12	45.80	2.274936389	0.04	4156.44	5.68	887.19	9,680.60	0.61	
12:16:09	901.3886333	11279.68	35.53	40.36	46.07	2.270173278	0.04	4156.07	5.72	890.69	10,215.02	0.62	
12:26:09	913.5252033	11827.79	35.76	40.14	45.98	2.267276917	0.04	4156.29	5.84	909.18	10,760.53	0.62	
12:36:09	913.32129	12375.78	35.86	40.02	45.86	2.273076028	0.04	4156.47	5.84	911.93	11,307.69	0.62	
12:46:09	910.5977633	12922.14	35.91	40.04	45.78	2.273524444	0.04	4156.52	5.74	895.57	11,845.03	0.61	
12:56:09	885.242795	13453.29	35.82	40.24	45.82	2.262628556	0.04	4156.34	5.59	867.72	12,365.66	0.61	
13:06:09	870.5340867	13975.61	35.56	40.35	45.76	2.261797694	0.04	4156.3	5.41	840.41	12,869.90	0.60	
13:16:09	848.291935	14484.58	35.83	40.19	45.47	2.262776306	0.04	4156.63	5.28	820.89	13,362.44	0.60	
13:26:09	824.682285	14979.39	36.17	40.01	45.15	2.263770278	0.04	4156.98	5.15	800.34	13,842.64	0.61	
13:36:09	812.623915	15466.97	35.97	40.34	45.25	2.26491175	0.04	4156.67	4.91	764.18	14,301.15	0.59	
13:46:09	775.9340017	15932.53	35.97	40.34	45.08	2.264521861	0.04	4156.79	4.74	737.16	14,743.44	0.59	
13:56:09	740.12282	16376.60	35.90	39.97	44.46	2.264970944	0.04	4157.49	4.49	698.01	15,162.25	0.59	
14:06:09	702.00256	16797.80	35.92	40.18	44.31	2.269264417	0.04	4157.45	4.13	643.10	15,548.11	0.57	
14:16:09	668.3234717	17198.80	36.00	40.41	44.28	2.26912325	0.04	4157.32	3.87	602.95	15,909.88	0.56	
14:26:09	622.6035417	17572.36	35.50	40.21	43.83	2.265261917	0.04	4157.76	3.61	562.52	16,247.39	0.56	
14:36:09	604.1394317	17934.84	35.27	39.98	43.34	2.262582611	0.04	4158.25	3.37	523.76	16,561.64	0.54	
14:46:09	577.8249233	18281.54	35.40	40.20	43.32	2.263606944	0.04	4158.12	3.11	484.51	16,852.35	0.52	
14:56:09	540.2080283	18605.66	34.99	40.35	43.18	2.268184472	0.04	4158.12	2.83	441.14	17,117.03	0.51	
15:06:09	507.8178683	18910.35	34.93	40.16	42.79	2.264582222	0.04	4158.5	2.63	409.39	17,362.66	0.50	
15:16:09	477.3166683	19196.74	35.00	39.85	42.26	2.267012861	0.04	4159.06	2.41	376.28	17,588.43	0.49	
15:26:09	446.9415233	19464.91	34.51	39.82	41.93	2.261838389	0.04	4159.3	2.12	329.51	17,786.14	0.46	
15:36:09	409.703155	19710.73	34.34	39.88	41.72	2.265555056	0.04	4159.39	1.84	286.14	17,957.82	0.44	
15:46:09	365.92112	19930.28	34.21	39.92	41.45	2.269327111	0.04	4159.54	1.53	239.24	18,101.36	0.41	
15:56:09	324.481655	20124.97	34.00	39.92	41.18	2.271605222	0.04	4159.72	1.26	196.71	18,219.39	0.38	
16:06:09	285.1761517	20296.08	33.95	39.91	40.91	2.268755611	0.04	4159.9	1.00	155.50	18,312.69	0.34	

Second testing on date; 12 February 2019. Obtained from the data logger and the results of the calculation, as follows:

Waktu	Radiasi Surya		Tamb	Tfi	Tfo	Flow	Laju Massa	Cp	Delta T	Energi Guna		Efisiensi Kolektor	
	W/m2	Akumulasi (J/m2)	(°C)	(°C)	(°C)	(dm3/men)	(Kg/sec)	(J/Kg°C)	(°C)	W/m2	Akumulasi (J/m2)	Sesaat (%)	Harian (%)
8:30:00	492.65701	295.59	28.33	38.53	40.43	2.354753556	0.04	4161.07	1.89	306.48	183.88982	0.39	41.63
8:40:00	496.9282133	593.75	29.19	39.68	41.62	2.35237125	0.04	4159.59	1.94	313.18	371.79562	0.39	
8:50:00	550.3587567	923.97	29.13	40.79	43.00	2.360389972	0.04	4157.94	2.21	358.32	586.7866	0.41	
9:00:00	572.0332683	1267.19	29.53	41.90	44.25	2.3564875	0.04	4156.28	2.35	380.12	814.85916	0.42	
9:10:00	580.7297417	1615.62	29.43	42.95	45.33	2.356621389	0.04	4154.7	2.38	384.15	1045.3485	0.41	
9:20:00	635.5192867	1996.94	29.78	44.00	46.69	2.357356278	0.04	4152.84	2.69	434.56	1306.0875	0.43	
9:30:00	686.0591167	2408.57	30.76	45.07	48.04	2.360426056	0.04	4150.87	2.97	479.22	1593.6166	0.44	
9:40:00	731.8136267	2847.66	30.83	46.16	49.44	2.351029694	0.04	4148.74	3.28	527.68	1910.2262	0.45	
9:50:00	735.9248667	3289.21	31.13	47.26	50.55	2.348430056	0.04	4146.75	3.29	528.31	2227.2099	0.45	
10:00:00	723.1247967	3723.09	31.07	48.29	51.49	2.340933806	0.04	4144.9	3.19	510.55	2533.5388	0.44	
10:10:00	759.5132867	4178.80	31.43	49.29	52.71	2.334181778	0.04	4142.72	3.42	544.82	2860.4305	0.45	
10:20:00	751.5556133	4629.73	31.92	50.31	53.71	2.332836222	0.04	4140.65	3.40	540.73	3184.8657	0.45	
10:30:00	717.9193433	5060.48	31.55	51.26	54.33	2.328148694	0.04	4138.99	3.07	486.37	3476.6869	0.42	
10:40:00	823.26036	5554.44	32.50	52.13	56.04	2.268785028	0.04	4136.16	3.91	603.06	3838.5233	0.46	
10:50:00	862.71738	6072.07	32.95	53.08	57.30	2.241427889	0.04	4133.6	4.21	641.22	4223.2531	0.46	
11:00:00	866.452135	6591.94	33.40	54.10	58.33	2.236344861	0.04	4131.13	4.23	641.90	4608.3926	0.46	
11:10:00	916.00632	7141.54	33.90	55.11	59.71	2.226976056	0.04	4128.16	4.60	694.25	5024.9402	0.47	
11:20:00	890.8329217	7676.04	33.28	56.11	60.40	2.223301306	0.04	4125.96	4.30	646.42	5412.7912	0.45	
11:30:00	865.4982383	8195.34	33.58	56.98	61.07	2.220309639	0.04	4123.93	4.09	613.95	5781.1635	0.44	
11:40:00	853.6600733	8707.54	33.83	57.78	61.80	2.218655917	0.04	4121.83	4.02	601.97	6142.3438	0.44	
11:50:00	855.6602717	9220.93	33.63	58.42	62.36	2.217095917	0.04	4120.14	3.94	589.41	6495.987	0.43	
12:00:00	910.0295933	9766.95	34.26	58.99	63.33	2.216248639	0.04	4117.94	4.34	648.15	6884.8756	0.45	
12:10:00	934.577215	10327.70	34.17	59.62	64.07	2.213646361	0.04	4115.91	4.45	663.96	7283.2508	0.44	
12:20:00	715.0774083	10756.75	34.07	60.25	63.47	2.207769833	0.04	4115.87	3.21	478.03	7570.0705	0.42	
12:30:00	803.1740417	11238.65	34.33	60.49	63.87	2.205183917	0.04	4114.92	3.38	501.59	7871.0272	0.39	
12:40:00	852.46613	11750.13	34.34	60.66	64.59	2.19746075	0.04	4113.56	3.93	581.07	8219.6702	0.43	
12:50:00	673.6257417	12154.30	34.30	61.05	64.12	2.193341278	0.04	4113.69	3.07	452.78	8491.3376	0.42	
13:00:00	333.4914667	12354.40	33.14	61.06	61.34	2.193139139	0.04	4117.83	0.28	41.24	8516.0794	0.08	
13:10:00	467.2516383	12634.75	33.44	60.29	61.50	2.183822056	0.04	4118.7	1.22	179.11	8623.5464	0.24	
13:20:00	464.0311867	12913.17	33.46	48.83	53.99	2.225411694	0.04	4141.89	5.17	783.57	9093.6866	1.06	
13:30:00	469.1328383	13194.65	33.57	39.81	42.62	2.223271139	0.04	4158.85	2.81	429.79	9351.5599	0.57	
13:40:00	424.6839633	13449.46	33.32	41.93	43.82	2.233927222	0.04	4156.56	1.88	288.67	9524.7592	0.42	
13:50:00	579.9633367	13797.44	33.63	43.13	45.91	2.232584917	0.04	4154.13	2.79	426.79	9780.8325	0.46	
14:00:00	604.3221433	14160.03	34.08	44.54	47.59	2.230052389	0.04	4151.69	3.05	466.47	10060.717	0.48	
14:10:00	345.7983783	14367.51	33.13	48.56	48.97	2.211544944	0.04	4147	0.42	63.18	10098.627	0.11	
14:20:00	301.6052783	14548.47	32.71	50.41	51.14	2.211131056	0.04	4143.16	0.73	110.66	10165.021	0.23	
14:30:00	295.566615	14725.81	32.68	50.48	51.03	2.209627639	0.04	4143.21	0.56	83.69	10215.233	0.18	
14:40:00	416.068415	14975.45	32.76	50.56	51.71	2.213610139	0.04	4142.45	1.15	173.83	10319.531	0.26	
14:50:00	345.8629833	15182.97	32.75	50.84	51.84	2.211806389	0.04	4142.03	0.99	149.85	10409.442	0.27	
15:00:00	273.3888767	15347.01	32.26	42.84	45.29	2.226831722	0.04	4154.82	2.45	373.81	10633.727	0.85	
15:10:00	438.94397	15610.37	32.51	41.42	42.72	2.220751917	0.04	4157.7	1.31	199.16	10753.221	0.28	
15:20:00	404.46989	15853.05	32.30	47.43	48.51	2.214328778	0.04	4148.44	1.07	162.46	10850.699	0.25	
15:30:00	325.8295383	16048.55	32.23	47.71	48.46	2.216355389	0.04	4148.23	0.75	113.54	10918.824	0.22	
15:40:00	294.2393017	16225.09	32.00	48.12	48.62	2.2161725	0.04	4147.72	0.51	76.74	10964.87	0.16	
15:50:00	270.1433083	16387.18	31.90	48.34	48.69	2.219266111	0.04	4147.46	0.35	52.79	10996.543	0.12	
16:00:00	241.6761117	16532.19	31.76	48.46	48.62	2.224659639	0.04	4147.42	0.16	24.18	11011.054	0.06	

Third testing on February 13, 2019. Obtained from the data logger and calculation results, as follows:

Waktu	Radiasi Surya		Tamb	Tfi	Tfo	Flow	Laju Massa	Cp	Delta T	Energi Guna		Efisiensi Kolektor	
	W/m2	Akumulasi (J/m2)	(°C)	(°C)	(°C)	(dm3/men)	(Kg/sec)	(J/Kg°C)	(°C)	W/m2	Akumulasi (J/m2)	Sesaat (%)	Harian (%)
8:30:00	537.1293467	322.27761	28.09	44	45.98	2.20636775	0.04	4153.4	1.97	298.57	179.14277	0.29	41.65
8:40:00	587.56062	674.81398	28.96	44.76	47.04	2.204338833	0.04	4151.95	2.28	343.91	385.4875	0.31	
8:50:00	645.72038	1062.2462	29.25	45.6	48.31	2.201297083	0.04	4150.2	2.72	409.35	631.09653	0.33	
9:00:00	670.884325	1464.7768	29.11	46.49	49.37	2.198453306	0.04	4148.51	2.88	433.37	891.12013	0.34	
9:10:00	682.8572733	1874.4912	29.81	47.39	50.36	2.196602167	0.04	4146.8	2.97	445.21	1158.2457	0.34	
9:20:00	696.6442433	2292.4777	29.41	48.25	51.29	2.192307889	0.04	4145.12	3.04	455.42	1431.5003	0.34	
9:30:00	707.2557733	2716.8312	29.86	49.08	52.21	2.190534222	0.04	4143.42	3.13	467.22	1711.8315	0.35	
9:40:00	738.93583	3160.1927	31.21	49.92	53.35	2.186283611	0.04	4141.43	3.43	511.27	2018.5957	0.36	
9:50:00	739.9356167	3604.154	31.82	50.77	54.23	2.178526333	0.04	4139.62	3.46	513.27	2326.5593	0.37	
10:00:00	806.08632	4087.8058	31.82	51.66	55.57	2.171587417	0.04	4137.2	3.91	578.02	2673.371	0.38	
10:10:00	815.4227433	4577.0595	32.09	52.65	56.59	2.171234611	0.04	4134.93	3.94	580.99	3021.9636	0.37	
10:20:00	805.1658567	5060.159	32.86	53.6	57.5	2.161050417	0.04	4132.75	3.90	571.76	3365.0172	0.37	
10:30:00	852.7299067	5571.7969	33.22	54.53	58.74	2.155895417	0.04	4130.11	4.22	616.30	3734.7952	0.38	
10:40:00	868.5112533	6092.9037	33.09	55.44	59.66	2.149870389	0.04	4127.79	4.22	614.85	4103.7081	0.37	
10:50:00	880.8335933	6621.4038	33.72	56.36	60.69	2.143891917	0.04	4125.25	4.32	626.95	4479.8804	0.37	
11:00:00	894.6601483	7158.1999	33.95	57.25	61.74	2.136556889	0.04	4122.64	4.49	647.97	4868.6647	0.38	
11:10:00	879.503545	7685.9021	34.16	58.14	62.43	2.1302355	0.04	4120.44	4.29	616.50	5238.5647	0.37	
11:20:00	930.5750933	8244.2471	34.51	58.9	63.56	2.112031444	0.04	4117.73	4.66	663.37	5636.5854	0.38	
11:30:00	916.9803083	8794.4353	34.21	59.73	64.24	2.106561389	0.04	4115.5	4.52	641.27	6021.3446	0.37	
11:40:00	932.46423	9353.9138	34.55	60.45	65.06	2.106457028	0.04	4113.17	4.61	653.84	6413.651	0.37	
11:50:00	931.2779633	9912.6806	34.90	61.06	65.64	2.110035917	0.04	4111.33	4.57	648.87	6802.9719	0.37	
12:00:00	919.7757917	10464.546	35.01	61.61	66.13	2.098211361	0.04	4109.7	4.52	637.30	7185.3531	0.36	
12:10:00	909.58653	11010.298	35.06	62.14	66.64	2.091950722	0.04	4108.03	4.50	631.80	7564.4311	0.37	
12:20:00	903.3004283	11552.278	35.06	62.57	66.96	2.090141222	0.04	4106.82	4.38	614.86	7933.3449	0.36	
12:30:00	867.355785	12072.692	35.43	62.95	67.09	2.088130917	0.04	4105.99	4.15	580.79	8281.817	0.35	
12:40:00	855.3884783	12585.925	35.77	63.27	67.39	2.087930861	0.04	4104.96	4.12	576.30	8627.5983	0.35	
12:50:00	832.1796767	13085.233	35.89	63.54	67.44	2.087395778	0.04	4104.44	3.90	545.86	8955.1146	0.35	
13:00:00	600.3770017	13445.459	34.64	63.67	65.83	2.081792611	0.04	4106.87	2.17	302.67	9136.7169	0.27	
13:10:00	779.1990483	13912.978	34.75	63.39	66.65	2.084178167	0.04	4105.98	3.26	455.73	9410.157	0.31	
13:20:00	766.7551433	14373.031	34.29	59.26	64.12	2.111780972	0.04	4116.38	4.86	691.17	9824.8572	0.47	
13:30:00	737.071725	14815.274	33.91	50.42	55.02	2.137317083	0.04	4139.15	4.59	668.55	10225.985	0.48	
13:40:00	703.08756	15237.127	33.85	49.18	52.89	2.137587556	0.04	4142.65	3.71	540.96	10550.562	0.40	
13:50:00	699.4217783	15656.78	33.84	49	52.56	2.140495056	0.04	4143.16	3.56	519.29	10862.138	0.39	
14:00:00	672.55227	16060.311	33.76	49.04	52.37	2.139374611	0.04	4143.31	3.33	486.52	11154.049	0.38	
14:10:00	634.3868817	16440.943	33.71	49.21	52.21	2.13677825	0.04	4143.29	3.00	437.14	11416.333	0.36	
14:20:00	600.20124	16801.064	33.72	49.48	52.22	2.13550175	0.04	4143.01	2.74	398.47	11655.415	0.35	
14:30:00	556.1273483	17134.741	33.57	49.62	52.06	2.134040389	0.04	4143.03	2.44	355.18	11868.521	0.34	
14:40:00	528.2360833	17451.682	33.49	49.57	51.81	2.133218944	0.04	4143.34	2.24	325.30	12063.701	0.32	
14:50:00	493.680575	17747.891	33.47	49.49	51.47	2.138078194	0.04	4143.75	1.98	288.16	12236.599	0.31	
15:00:00	465.11013	18026.957	33.03	49.23	51.03	2.137374611	0.04	4144.44	1.80	261.99	12393.792	0.30	
15:10:00	429.0114917	18284.364	32.91	48.97	50.47	2.134465167	0.04	4145.22	1.50	219.23	12525.331	0.27	
15:20:00	390.4933967	18518.66	32.87	48.9	50.09	2.139365417	0.04	4145.65	1.20	175.11	12630.396	0.24	
15:30:00	356.10407	18732.322	32.46	49.25	50.11	2.140437611	0.04	4145.29	0.86	125.29	12705.569	0.19	
15:40:00	319.1876217	18923.835	32.42	49.49	50.12	2.145783722	0.04	4145.05	0.63	92.59	12761.122	0.15	
15:50:00	272.1677017	19087.135	32.07	49.27	49.69	2.14095725	0.04	4145.67	0.42	61.69	12798.133	0.12	
16:00:00	235.9333567	19228.695	31.94	48.92	49.11	2.145007583	0.04	4146.54	0.19	27.69	12814.748	0.06	

Daily Collector Efficiency

No	Day testing	Collector Efficiency (%)
1	1	56.39
2	2	41.63
3	3	41.65
	Average Efficiency	46,55

DISCUSSION

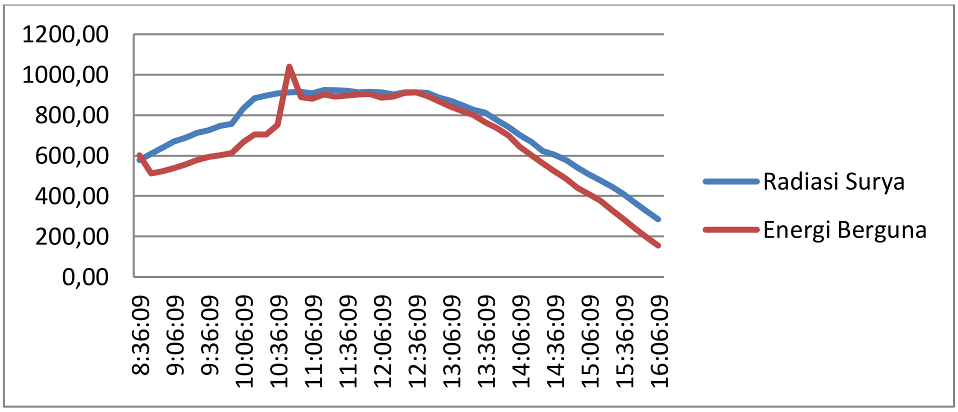


Figure 4. Graph of Useful Energy (Qu) and Intensity of Solar Radiation Against Time on the 1st test on 11 February 2019

From the graph shown in Figure 4. There is a useful energy for a moment since 12.36 West Indonesia Time decreases along with the intensity of solar radiation coming on the surface of the collector. This is due to the fact that useful energy is basically a function of the intensity of solar energy that comes on the surface of the collector.

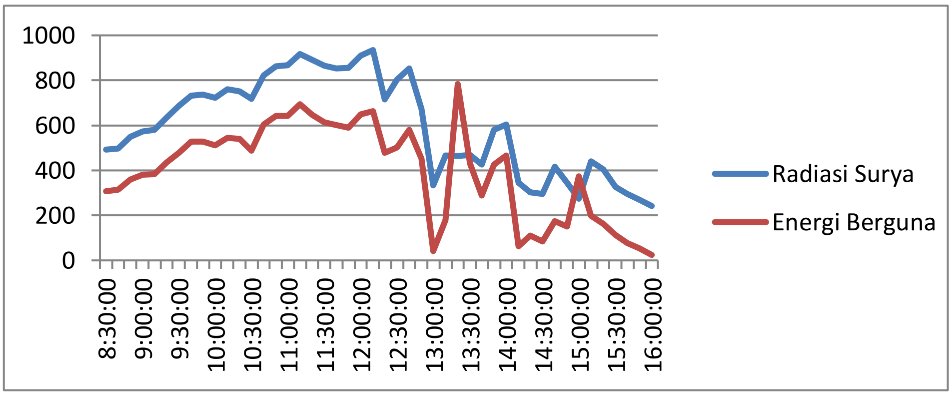
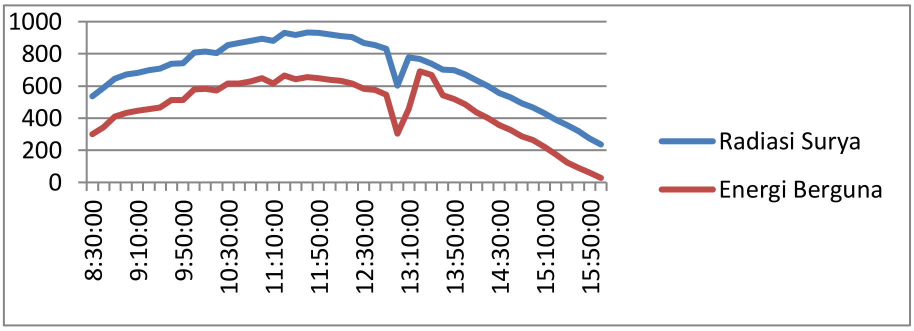


Figure 5. Graph of Useful Energy (Qu) and Intensity of Solar Radiation Against the Time on the 2nd test on 12 February 2019

From the graph shown in Figure 5. There is a useful energy for a moment since 12:30 WIB decreases along with the intensity of solar radiation coming on the surface of the collector. This is due to the fact that useful energy is basically a function of the intensity of solar energy that comes on the surface of the collector. However, at 12:30 to 13:00 West Indonesia Time there was a decrease in useful energy and the intensity of solar radiation was very sharp, because in that position there was very heavy rain and at 13.00 to 13.30 West Indonesia Time there was very intense heat resulting in an increase in useful energy which large, after 13.30 until 16.00 WIB erratic weather occurs making energy useful and irregular intensity of solar radiation.

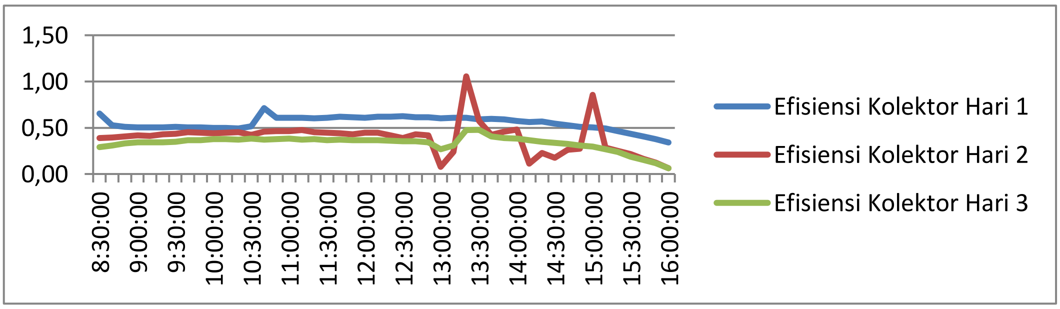
Figure 6. Graph of Useful Energy (Qu) and Intensity of Solar Radiation Against the Time on the



3rd test on 13 February 2019

From the graph shown in Figure 6. There is a useful energy for a moment since 13.30 West Indonesia Time decreases along with the intensity of solar radiation coming on the surface of the collector. This is due to the fact that useful energy is basically a function of the intensity of solar energy that comes on the surface of the collector. But at 12:30 to 13.30 WIB there was heavy rain accompanied by sufficient heat to make a significant decrease and increase.

Figure 7. Daily Collector Efficiency Graph Against the Testing Time



From the graph shown in Figure 7. That the highest daily collector efficiency occurs at 13.30 WIB with tests conducted on the 2nd day and the lowest daily collector efficiency occurs at 16.00 WIB on the 3rd day testing, due to the time of the afternoon until evening sun has shone a little on the surface of the collector.

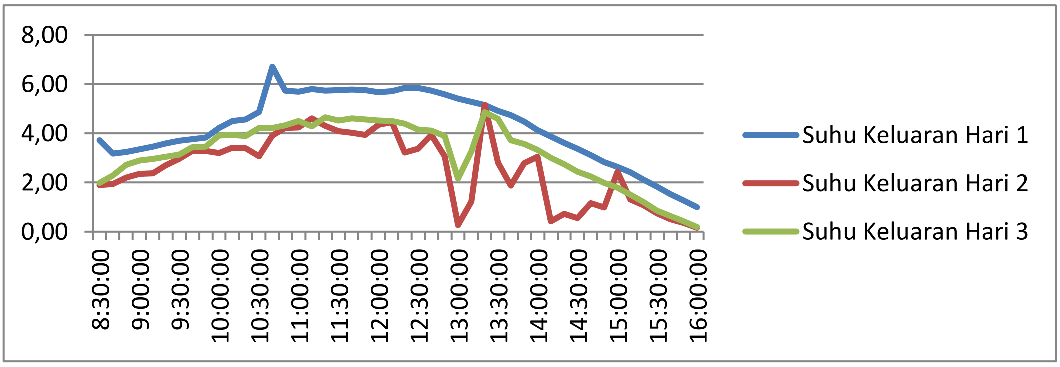


Figure 8. Graph of Output Temperature Against the Testing Time

From the graph in Figure 8. It is shown that the highest exit temperature is reached at 12:30 WIB and decreases closer to late afternoon. This is due to the collector not having sufficient intensity of solar radiation because the position of the sun is on the right.

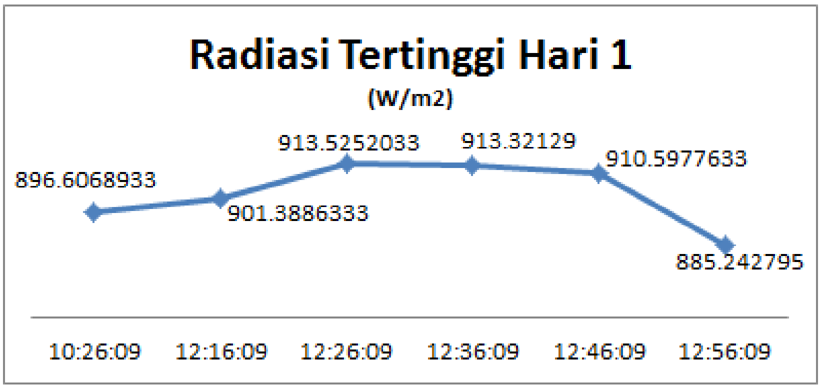


Figure 9. Highest Radiation Graph of Day 1 on 11 February 2019

From the graph in Figure 9. It was shown that the highest solar radiation testing day 1 on 11 February 2019 at 12:26 WIB amounting to 913,525 W/m² followed by 12:36 WIB amounting to 913.321 W/m²

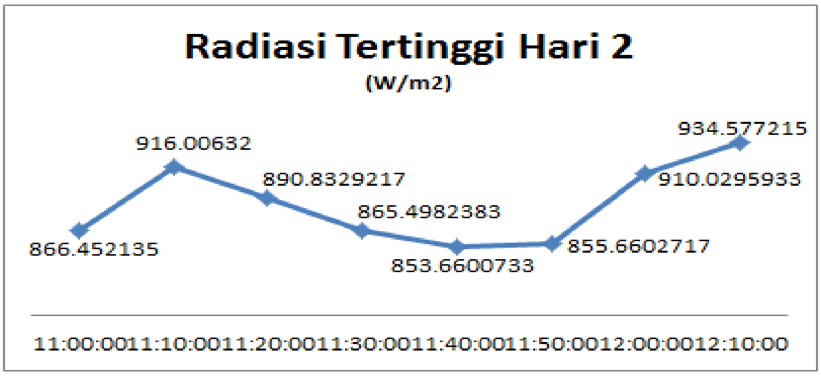
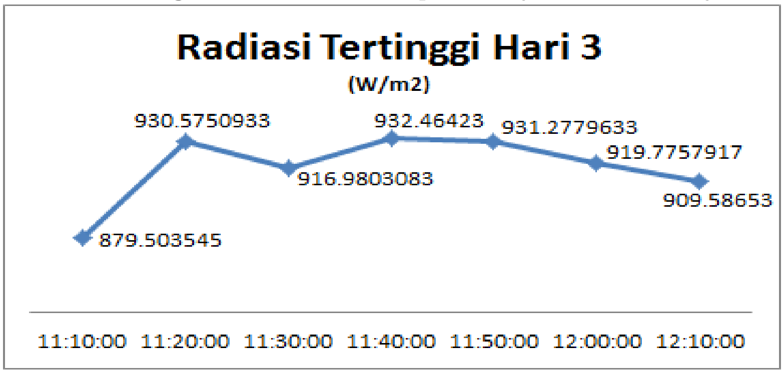


Figure 10. The Highest Radiation Graph of Day 2 on February 12 2019

From the graph in Figure 10. It is shown that the highest solar radiation testing day 2 on 12 February 2019 at 12:10 WIB at 934,577 W/m² followed at 11:10 WIB at 916,006W/m².

Figure 11. The Highest Radiation Graph of Day 3 on February 13 2019



From the graph in Figure 11. It was shown that the highest solar radiation testing day 3 on 13 February 2019 at 11:40 WIB amounting to 932,464 W/m² followed by 11:50 WIB amounting to 931,277 W/m².

CONCLUSION

The conclusions of the results of testing solar water heaters, namely: 1) The collector for testing uses a type of flat plate collector with a collector area of 2 m² with a capacity of 150 liters of water. 2) In the solar water heater laboratory in B2TKE-BPPT at the time of testing must follow procedures in accordance with SNI 3021-1992 1st edition. 3) Collector efficiency testing procedures, namely: 1) the collector is filled with water continuously with a flow to the collector alone without opening the valve to other components, 2) the sensor pairs on Solar Radiation (W/m²), Ambient Temperature (T-amb), Temperature of Inlet Collector (T-in), Temperature of Water Out of Collector (T-out), 3) testing is carried out for 7 hours 30 minutes, 4) waiting for the results of data obtained and managed through a computer every 30 minutes intervals. 4) In the use of solar collectors, useful energy that can be used to heat water is highly dependent on the intensity of solar radiation that illuminates the solar collector. 5) Flat plate type solar collectors on Solar Water Heaters have a collector efficiency of 46.55%. Which means that a solar panel can only absorb 46.55% of the solar radiation that illuminates the solar collector.

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