REFERENSI

[1] Jalaluddin, E. Arif, and R. Tarakka, “Experimental study of an SWH system with V-shaped plate,” *J. Eng. Technol. Sci.*, vol. 48, no. 2, pp. 207–217, 2016, doi: 10.5614/j.eng.technol.sci.2016.48.2.7.

[2] P. Thantong and P. Chantawong, “Experimental Study of Solar-Phase Change Material Wall for Domestic Hot Water Production under the Tropical Climate,” *Energy Procedia*, vol. 138, pp. 38–43, 2017, doi: 10.1016/j.egypro.2017.10.042.

[3] M. A. Amen and D. Kuzovic, “The effect of the binary space and social interaction in creating an actual context of understanding the traditional urban space,” *J. Contemp. Urban Aff.*, vol. 2, no. 2, pp. 71–77, 2018, doi: 10.25034/ijcua.2018.3672.

[4] S. W. Pua, K. S. Ong, K. C. Lai, and M. S. Naghavi, “Natural and forced convection heat transfer coefficients of various finned heat sinks for miniature electronic systems,” *Proc. Inst. Mech. Eng. Part A J. Power Energy*, vol. 233, no. 2, pp. 249–261, 2019, doi: 10.1177/0957650918784420.

[5] S. Seddegh, X. Wang, and A. D. Henderson, “A comparative study of thermal behaviour of a horizontal and vertical shell-and-tube energy storage using phase change materials,” *Appl. Therm. Eng.*, vol.93,pp.348–358,2016,doi:10.1016/j.applthermaleng.2015.09.107.

[6] S. M. Shalaby, A. E. Kabeel, B. M. Moharram, and A. H. Fleafl, “Experimental study of the solar water heater integrated with shell and finned tube latent heat storage system,” *J. Energy Storage*, vol. 31, no. June, 2020, doi: 10.1016/j.est.2020.101628.

[7] K. K. Tse and T. T. Chow, “Dynamic model and experimental validation of an indirect thermosyphon solar water heater coupled with a parallel circular tube rings type heat exchange coil,” *Sol. Energy*, vol. 114, pp. 114–133, 2015, doi: 10.1016/j.solener.2015.01.032.

[8] C. Wannagosit, P. Sakulchangsatjatai, N. Kammuang-Lue, and P.

Terdtoon, “Validated mathematical models of a solar water heater system with thermosyphon evacuated tube collectors,” *Case Stud. Therm. Eng.*, vol. 12, no. July, pp. 528–536, 2018, doi: 10.1016/j.csite.2018.07.005.

[9] C. Garnier, T. Muneer, and J. Currie, “Numerical and empirical evaluation of a novel building integrated collector storage solar water heater,” *Renew. Energy*, vol. 126, pp. 281–295, 2018, doi: 10.1016/j.renene.2018.03.041.

[10] Z. Badiei, M. Eslami, and K. Jafarpur, “Performance improvements in solar flat plate collectors by integrating with phase change materials and fins: A CFD modeling,” *Energy*, vol. 192, 2020, doi: 10.1016/j.energy.2019.116719.

[11] F. Basim, “Design, developement and optimisation of a novel thermo-syphon system for domestic applications,” p. 292, 2016.

[12] L. Ma, Z. Lu, J. Zhang, and R. Liang, “Thermal performance analysis of the glass evacuated tube solar collector with U-tube,” *Build. Environ.*, vol. 45, no. 9, pp. 1959–1967, 2010, doi: 10.1016/j.buildenv.2010.01.015.

[13] ANSYS Fluent Tutorial Guide 18, “ANSYS Fluent Tutorial Guide 18,” *ANSYS Fluent Tutor. Guid. 18*, vol. 15317, no. April, pp. 724–746, 2018.

[14] P. N. Padang, “Surya Menjadi Energi Mekanik,” no. 1.

[15] A. Samanci and A. Berber, “Experimental investigation of single-phase and twophase closed thermosyphon solar water heater systems,” *Sci. Res. Essays*, vol. 6, no. 4, pp. 688–693, 2011, doi: 10.5897/SRE09.072.

[16] F. Jafarkazemi and E. Ahmadifard, “Energetic and exergetic evaluation of flat plate solar collectors,” *Renew. Energy*, vol. 56, pp. 55–63, 2013, doi: 10.1016/j.renene.2012.10.031.

[17] H. Syah, S. Yadi, P. Studi, T. Pertanian, F. Pertanian, and U. S. Kuala, “Studi Performansi Alat Pemanas Air Dengan Menggunakan

Kolektor Surya Plat Datar," no. 3, pp. 1–5, 2013.

[18] Jalaluddin , E. Arief, and R. Tarakka, "Analisis Performansi Kolektor Surya Pemanas Air Dengan Pelat," vol. 1, no. Snttm Xiv, pp. 7–8, 2015.

[19] Adnan Kamil, Muhammad., "Analisis Unjuk Kerja Solar Water Heater Termosipon dengan PCM Storage" Skripsi Departemen Teknik Mesin Universitas Hasanuddin, 2019.

[20] Hamdana Syam, Ari., "Analisis Unjuk Kerja Solar Water Heater Mini dengan PCM Storage", Skripsi Departemen Teknik Mesin Universitas Hasanuddin, 2019.

[21] A. Sharma, V. V. Tyagi, C. R. Chen, and D. Buddhi, "Review on thermal energy storage with phase change materials and applications," *Renew. Sustain. Energy Rev.*, vol. 13, no. 2, pp. 318–345, 2009, doi: 10.1016/j.rser.2007.10.005.

[22] M. Chaabane, H. Mhiri, and P. Bournot, "Thermal performance of an integrated collector storage solar water heater (ICSSWH) with phase change materials (PCM)," *Energy Convers. Manag.*, vol. 78, pp. 897–903, 2014, doi: 10.1016/j.enconman.2013.07.089.

[23] A. Reyes, L. Henríquez-Vargas, J. Rivera, and F. Sepúlveda, "Theoretical and experimental study of aluminum foils and paraffin wax mixtures as thermal energy storage material," *Renew. Energy*, vol. 101, pp. 225–235, 2017, doi: 10.1016/j.renene.2016.08.057.

[24] A. Reyes, D. Negrete, A. Mahn, and F. Sepúlveda, "Design and evaluation of a heat exchanger that uses paraffin wax and recycled materials as solar energy accumulator," *Energy Convers. Manag.*, vol. 88, pp. 391–398, 2014, doi: 10.1016/j.enconman.2014.08.032.

[25] M. Nadjib, "Penggunaan Paraffin Wax Sebagai Penyimpan Kalor Pada Pemanas Air Tenaga Matahari Thermosyphon," *Rotasi*, vol. 18, no. 3, p. 76, 2016, doi: 10.14710/rotasi.18.3.76-85.

[26] Munahar., Analisis Unjuk Kerja Kolektor Pemanas Air dengan Pelat Absorber Berbentuk-V, Jurusan Mesin Universitas Hasanuddin,

2015.

[27] A. Cengel, Yunus., Heat Transfer A Practical Approach, Second Edition, 2008.

[28] Holman, JP., *Heat Transfer 5th Edition, Mc Graw-Hill International Book Company*, New York, 1981.

[29] A. U. Manual, “Adina Engineering,” *Inc., Sept.*, pp. 81--1, 1981.

[30] J. A. Duffie (Deceased), W. A. Beckman, and N. Blair, *Solar Engineering of Thermal Processes, Photovoltaics and Wind*. 2020.

[31] Selmi, M., Al-Khawaja, MJ., Marafia, A., *Validation of CFD Simulation for Flat Plate Solar Energy Collector*, No. 33, Pp. 383 – 387, 2008.

[32] Woyessa, Lemi Negera., Koteswararao, Basam., Zeru, Balewgize A., Vijay, P., *Design and CFD Simulation of Solar Water Heater Used In Solar Assisted Biogas System*, Vol. 9 No. 3, ISSN : 2278 – 3075, 2020.

[33] Setiawan, Haris., "Simulasi Komputasi Dinamika Fluida Untuk Fluktuasi Tekanan Pada Kondensasi Steam Pada Pipa Konsentrik Horisontal Dengan Pendinginan Searah Didalam Ruang Anulus", Skripsi Teknik Mesin Universitas Muhammadiyah Yogyakarta, 2016.

[34] Wiratama, Caesara.,"Modul Pengantar Ansys Simulasi Fluida", aeroenggineering.co.id, 2021.

[35] Lahlou, Yasmine., *Design of A Biogas Pilot Unit for Al Akhawayn University*, Dr. El Asli, 2017.

[36] Syahrinaldy Syahruddin, Andi.,"Pengembangan Sistem Pemanas Air Tenaga Matahari Dengan Variasi Pcm Storage", Tesis Departemen Teknik Mesin Universitas Hasanuddin, 2020.

[37] Nurhidayat, "Analisi Pengaruh PCM Storage Pada Pelat Absorber Pemanas Air Tenaga Matahari" Skripsi Departemen Teknik Mesin Universitas Hasanuddin, 2022.

[38] Hamka, Faisal., "Pengaruh Penggunaan Material Komposit Sebagai Termal Storage Terintegrasi Pada Pelat Absorber Berbentuk Datar Terhadap Efisiensi Pemanas Air Tenaga Matahari" Skripsi

Departemen Teknik Mesin Universitas Hasanuddin, 2022.

[39] Fregah, B., *Design , Development And Optimisation Of A Novel Thermo-Syphon System For Domestic Applications*, 2016.

[40] Vladimirova, Natalia., *Model Flame In The Boussinesq Limit: Rising Bubbles*, Vol. 111, No. 3, Pp. 377 – 400, 2007.

[41] Ansys Fluent 18.1, *Software Used Of Numerical Simulation Study*, 2020.

LAMPIRAN

1. Tabel Sifat - Sifat Udara Pada Tekanan 1 Atm

TABLE A–9

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter, Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306067020-8.

2. Tabel Sifat - Sifat Air Jenuh

TABLE A–9

Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³ Liquid	Density Vapor	Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg·K Liquid	Specific Heat Vapor	Thermal Conductivity k, W/m·K Liquid	Thermal Conductivity Vapor	Dynamic Viscosity μ, kg/m·s Liquid	Dynamic Viscosity Vapor	Prandtl Number Pr Liquid	Prandtl Number Vapor	Volume Expansion Coefficient β, 1/K Liquid
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	-0.068×10^{-3}
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015×10^{-3}
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195×10^{-3}
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247×10^{-3}
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294×10^{-3}
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377×10^{-3}
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415×10^{-3}
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451×10^{-3}
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548×10^{-3}
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578×10^{-3}
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670×10^{-3}
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702×10^{-3}
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716×10^{-3}
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255×10^{-3}	1.261×10^{-5}	1.58	1.00	0.798×10^{-3}
120	198.53	943.4	1.121	2203	4244	2120	0.683	0.0275	0.232×10^{-3}	1.296×10^{-5}	1.44	1.00	0.858×10^{-3}
130	270.1	934.6	1.496	2174	4263	2177	0.684	0.0288	0.213×10^{-3}	1.330×10^{-5}	1.33	1.01	0.913×10^{-3}
140	361.3	921.7	1.965	2145	4286	2244	0.683	0.0301	0.197×10^{-3}	1.365×10^{-5}	1.24	1.02	0.970×10^{-3}
150	475.8	916.6	2.546	2114	4311	2314	0.682	0.0316	0.183×10^{-3}	1.399×10^{-5}	1.16	1.02	1.025×10^{-3}
160	617.8	907.4	3.256	2083	4340	2420	0.680	0.0331	0.170×10^{-3}	1.434×10^{-5}	1.09	1.05	1.145×10^{-3}
170	791.7	897.7	4.119	2050	4370	2490	0.677	0.0347	0.160×10^{-3}	1.468×10^{-5}	1.03	1.05	1.178×10^{-3}
180	1,002.1	887.3	5.153	2015	4410	2590	0.673	0.0364	0.150×10^{-3}	1.502×10^{-5}	0.983	1.07	1.210×10^{-3}
190	1,254.4	876.4	6.388	1979	4460	2710	0.669	0.0382	0.142×10^{-3}	1.537×10^{-5}	0.947	1.09	1.280×10^{-3}
200	1,553.8	864.3	7.852	1941	4500	2840	0.663	0.0401	0.134×10^{-3}	1.571×10^{-5}	0.910	1.11	1.350×10^{-3}
220	2,318	840.3	11.60	1859	4610	3110	0.650	0.0442	0.122×10^{-3}	1.641×10^{-5}	0.865	1.15	1.520×10^{-3}
240	3,344	813.7	16.73	1767	4760	3520	0.632	0.0487	0.111×10^{-3}	1.712×10^{-5}	0.836	1.24	1.720×10^{-3}
260	4,688	783.7	23.69	1663	4970	4070	0.609	0.0540	0.102×10^{-3}	1.788×10^{-5}	0.832	1.35	2.000×10^{-3}
280	6,412	750.8	33.15	1544	5280	4835	0.581	0.0605	0.094×10^{-3}	1.870×10^{-5}	0.854	1.49	2.380×10^{-3}
300	8,581	713.8	46.15	1405	5750	5980	0.548	0.0695	0.086×10^{-3}	1.965×10^{-5}	0.902	1.69	2.950×10^{-3}
320	11,274	667.1	64.57	1239	6540	7900	0.509	0.0836	0.078×10^{-3}	2.084×10^{-5}	1.00	1.97	
340	14,586	610.5	92.62	1028	8240	11,870	0.469	0.110	0.070×10^{-3}	2.255×10^{-5}	1.23	2.43	
360	18,651	528.3	144.0	720	14,690	25,800	0.427	0.178	0.060×10^{-3}	2.571×10^{-5}	2.06	3.73	
374.14	22,090	317.0	317.0	0	—	—	—	—	0.043×10^{-3}	4.313×10^{-5}			

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/\text{Pr}$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties listed above (except the vapor density) can be used at any pressure with negligible error except at temperatures near the critical-point value.

Note 2: The unit kJ/kg·°C for specific heat is equivalent to kJ/kg·K, and the unit W/m·°C for thermal conductivity is equivalent to W/m·K.

3. Tabel Hasil Perhitungan

	Direct Radiation	Inlet	Outlet	Temp. Plate	Temp. Water In Pipe	Temp. Paraffin	Efficiency
	W/m^2	(C)					%
Without PCM Storage 0 Derajat	400	40	43.9	46	44.5	0	50.59782205
Without PCM Storage 0 Derajat	700	40	45.6	48.2	46.5	0	57.80154197
Without PCM Storage 0 Derajat	1000	40	47	50.4	48.2	0	61.86979605
With PCM Storage 0 Derajat Tebal 4mm	400	40	55	58.1	55	60	51.61576587
With PCM Storage 0 Derajat Tebal 4mm	700	40	58	59	58	60.8	60.26814068
With PCM Storage 0 Derajat Tebal 4mm	1000	40	59	60	59	62.7	64.65292013
With PCM Storage 0 Derajat Tebal 7mm	400	40	50.3	52	50.3	52.5	51.91149984
With PCM Storage 0 Derajat Tebal 7mm	700	40	55.3	57	55.3	57.5	60.54451021
With PCM Storage 0 Derajat Tebal 7mm	1000	40	60	62	60	62	64.53795792
With PCM Storage 0 Derajat Tebal 10mm	400	40	49	49	49	50.7	50.82912003
With PCM Storage 0 Derajat Tebal 10mm	700	40	53	57	53	58.1	61.22092678
With PCM Storage 0 DerajatTebal 10mm	1000	40	57	61	56	62	65.15987836
Experimental Termal Storage	1000	39.83	48.3	63.2	56.3	51.8	64.93335325
Experimental without Termal Storage	1000	38.43	46.1	59.6	53.20	0	61.03236891
Experimental without PCM Storage	1000	40.4	58.1	67.1	58	53.4	58.87236074

4. Jurnal Publish

A. Jurnal 1 "Performance Investigation of Solar Water Heating System with Flat-plate Absorber Integrated with Thermal Storage"

EPI International Journal of Engineering

Performance Investigation of Solar Water Heating System with Flat-plate Absorber Integrated with Thermal Storage

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Abstract

A solar water heater (SWH) is equipment that utilizes solar energy as its energy source and has been widely used in various countries worldwide. This work focus to investigate the performance of SWH experimentally by integrating Aluminum-alumina ($Al+Al_2O_3$) to flat-plate collector at the bottom as a thermal storage. Adding thermal storage to the collector is very important to improve the efficiency of the heat transfer process and the water heating system. Therefore, the performance of a SWH integrated with $Al+Al_2O_3$ thermal storage has been investigated. Two models of absorber plates including standard flat-plate (SFP) collector and SFP with $Al+Al_2O_3$ as thermal storage (SFP-TS) are tested for 180 minutes operation with constant solar intensity. The results show that the SFP-TS model has a higher outlet temperature than that of the SFP model. In addition, the thermal efficiency of the SFP-TS model increase about 6% compared with that of the SFP model. The benefit of adding $Al+Al_2O_3$ as the thermal storage to the absorber plate contributes to increase the absorption of radiant heat energy, heat storage time in the collector, and thermal efficiency of the plate collector.

Keywords: Solar Water Heater (SWH), Aluminum-alumina ($Al+Al_2O_3$), *Standard Flat Plate (SFP), Standard Flat Plate with Thermal Storage (SFP-TS)*

1. Introduction

A solar water heater (SWH) is an equipment that uses solar energy as its source of power and is commonly utilized in many nations throughout the world. Numerous research has been conducted, however, there are still several issues with the solar water heaters that are now available. One of them is an integrated water heating system is water heating system that combines a solar collector and heat storage. The system's output can reduce the energy needs of domestic-scale water heaters at low costs [1].

Researchers have worked on various SWH advances, including modifying the transparent cover glass using Tin Oxide Fluorine Doped Nanomaterials, altering the absorbent plate's shape, and using a porous substance [2]. The current development of the Solar Water Heater System (SWHS) is to modify the Flat-Plate Collector (FPC) material. Jalaluddin et al. [3] utilized a V-shaped absorber plate to research the thermal efficiency of SWH. Compared to systems using standard absorber plates, the results showed that SWH using a V-shaped one had an efficiency of 3.6–4.4 percent. Further research by Jalaluddin et al. [4], With a discharge of 0.5, 1, and 1.5 L/min, respectively, the addition of phase change material (PCM) to the V-shaped SWHS considerably boosted the average efficiency by 20%, 14%, and 13%. Fluid leakage, though, is a disadvantage of this design.

On the other hand, the high temperature on the surface of the plate causes the heat loss on the surface of the collector to be large, so it need a heat energy storage that can maximize the solar collector's performance. Experimental performance investigations of thermal storage have been carried out and discussed by Pisut Thantong [5] in tropical climates. Experiments have proven that collectors integrated with thermal storage are more energy efficient in reducing heat collection and energy savings. Saddegh [6] has also compared the thermal behavior in vertical and horizontal shell-and-tube energy storage systems using thermal storage. Similarly, Shalaby [7] has experimented with a solar water heater integrated with a shell and finned-tube latent heat storage system. The results show that the highest daily efficiency of 65% is achieved when the combined thermal storage and water storage tank configuration is used.

A unique method in developing the latest collector is the heat transfer augmentation technique with the addition of an inserting porous material. First, absorbent material, metal foam, is inserted between the absorber plate and the insulator. The goal is to absorb the heat transmitted by the plate (absorber) and store the heat for an extended time (storage); then, the heat is transferred to the working fluid. Types of porous materials in collector applications include aluminum foam block, copper foam, nickel foam, Reticulated Virtuous Carbon foam [8], and ceramic foam [9].

Several experimental studies and simulations have been carried out related to the use of foam in the collector. The focus is on the aspects of geometry, position, and fluid flow rate. For example, Gunjo et al. [10] simulated the

B. Jurnal 2 “Analysis Of Solar Water Heater With Modification Absorber Plate Integrated Thermal Storage”

Analysis Of Solar Water Heater With Modification Absorber Plate Integrated Thermal Storage

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Abstract. A solar water heater (SWH) is equipment that utilizes solar energy as its energy source and has been widely used in various countries worldwide. This work focus on investigating the performance of SWH numerical simulation by integrating phase change material (PCM) paraffin wax into an absorber plate collector at the bottom as thermal storage. The thermal performance of an SWH system using an absorber plate with PCM as thermal energy storage is presented in this study. In this test there are 4 variations of the model tested, i.e. a) standard flat plate (SFP), b) standard flat plate with PCM storage thickness 10mm (SFP+PCM 10mm), c) standard flat plate with PCM storage thickness 7mm (SFP+PCM 7mm), and d) standard flat plate with PCM storage thickness 4mm (SFP+PCM 4mm), were investigated by numerical simulation. First, the material properties of paraffin wax as PCM storage were analyzed analytically. Then, every shape model of SWH systems was imported and simulated at three variations of constant solar radiation i.e 400 W/m^2, 700 W/m^2, and 1000 W/m^2. The simulation uses computational fluid dynamic (CFD) software. The results showed that the absorber plate with 7mm thickness of PCM (SFP+PCM 7mm) had better efficiencies if compared with the absorber plate without PCM storage (SFP) and the other thickness of PCM at the absorber plate with PCM storage (SFP+PCM 10mm and SFP+PCM 4mm). Its efficiency was 4% higher compared with the absorber plate without PCM storage. And the increase in efficiency is in line with the increase in radiation intensity i.e. about 18%.

Keywords: Solar Water Heater (SWH), Phase Change Material (PCM), Paraffin-Wax, Standard Flat Plate (SFP), Standard Flat Plate With PCM Storage (SFP+PCM).

INTRODUCTION

A solar water heater (SWH) is equipment that utilizes solar energy as its energy source and has been widely used in various countries worldwide. However, because there are still many shortcomings of existing solar water heaters, multiple studies have been carried out. The previous research was an experimental study of a solar water heating system with a V-shaped absorber plate. Two solar water heating systems were installed and tested at a low discharge of 0.5 L/min and a high release of 2 L/min. The results showed that the solar water heating system with a V-shaped absorber plate had a performance of 3.6 - 4.4% better than that with a flat absorber plate [1].

On the other hand, the high temperature on the surface of the V-shaped plate causes the heat loss on the surface of the collector to be large, so we need a heat energy storage that can maximize the performance of the solar collector. Experimental performance investigations of solar phase change material (PCM) have been carried out and discussed by Pisut Thantong [2] in tropical climates. Experiments have proven that collectors integrated with PCM are more

C. Thermal Properties Characteristic of Aluminium-Alumina Composite for Solar Water Heating System Application

Thermal Properties Characteristic of Aluminium-Alumina Composite for Solar Water Heating System Application

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Abstract. A sensible Thermal Energy Storage (TES) is an energy storage mechanism or material with modern technology at low cost, such as metal, concrete, composite, and others. Aluminium (Al)-Alumina (Al_2O_3) composite is a TES solid with high strength and hardness characteristics that can work in low-temperature applications, especially solar water heating systems. This study aims to determine the effects of mass fraction content on an alumina-reinforced aluminium composite's physical and thermal properties. Composites with 35%, 50%, and 65% mass fractions of alumina are manufactured using the powder metallurgy technique. Three types of specimens of different compositions, such as C1(65%Al+35%Al_2O_3), C2(50%Al+50%Al_2O_3) and C3(35%Al+65%Al_2O_3), were prepared with 20-25 MPa compaction load. Then, all the specimens were sintered in a furnace at temperatures 550 °C and 30 minutes holding time. The microstructure of the composite was analyzed using an optical microscope. The thermal conductivity of the composites was determined using thermal conductivity measuring apparatus, and the heat of the composite was determined using a Differential Scanning Calorimetry (DSC) analyzer. It was found that the composite with smaller alumina (C1 Composite) particles had higher thermal conductivity values. The thermal conductivity values of the composites were 0.37 W/m.°C (C3), 4.28 W/m.°C (C2) and 24.7 W/m.°C (C1), respectively. While the heat value obtained is 0.95 J/g (C3), 1.27 J/g (C2), and 1.42 J/g (C1). This study concludes that the greater the percentage of alumina content, the lower the value of the thermal properties of the composite obtained.

INTRODUCTION

Solar energy is the largest source of renewable energy and is available throughout the day, so it is necessary to develop sustainable technologies such as energy storage and energy conversion technologies. High energy storage effectiveness will significantly impact the cost of solar energy application systems [1].

D. Experimental Study of Modified Absorber Plate Integrated with Aluminium Foam of Solar Water Heating System

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Experimental Study of Modified Absorber Plate Integrated with Aluminium Foam of Solar Water Heating System

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Abstract- The Solar Water Heating System (SWHS) is a water heater equipment that utilizes solar energy for domestic scale needs. The potential generated by this system can reduce the energy demand of the building sector, reduce peak demand for electricity, and reduction in pollution. This study aims to analyze the performance of SWHS experimentally by modifying the addition of aluminium foam material at the bottom of the absorber plate and the top of the absorber plate. The absorber plate models are Standard Flat-Plate (SFP), SFP with Bottom Aluminium Foam (SFP-BAF), and SFP with Top Aluminium Foam (SFP-TAF). The experimental study was carried out for the three models under similar conditions using a Solar Thermal Energy Unit. The effect of flowrate variations and slope angles were also investigated. The study results show that the SFP-BAF model with the angle of 30° achieved the highest efficiency of 88.4%, 86.9%, and 83.9% at a flow rate of 8 L/h, 10 L/h, and 12 L/h, respectively. The benefits of adding aluminium foam to the absorber plate is to increase the absorption of radiant heat energy transmitted from the absorber plate, the storage time of thermal energy, and the thermal efficiency of the collector.

Keywords Solar water heating system; absorber flat-plate; aluminium foam; efficiency.

1. Introduction

The Solar Water Heating System (SWHS) is a water heater equipment that utilizes solar energy for domestic scale needs. The potential generated by this system can reduce the energy demand of the building sector, and peak demand for electricity [1]. Renewable energy sources can be combined with conventional energy sources or energy storage systems [2], as well as smart control element heating minimizes energy cost [3], electricity consumption and pollution [4].

Researchers have worked on a variety of SWHS advances, including changing the shape of the absorber plate, using porous materials, and modifying the transparent cover glass using Fluorine Doped Tin Oxide Nanomaterials [5]. The current development of SWHS is modifying the Flat-Plate Collector (FPC) material. Jalaluddin et al. [6] conducted a study to analyze the thermal efficiency of SWHS using a V-shaped absorber plate. The results showed that the SWHS using a V-shaped absorber plate had an efficiency of 3.6-4.4 % against systems that use standard plates. Further research by Jalaluddin et al. [7], adding phase change material (PCM) to the V-shaped SWHS is increased the average efficiency significantly of 20%, 14% and 13% with flowrates of 0.5; 1 and 1.5 L/min respectively. However, this design has disadvantage due to fluid leakage.

Another development of FPC is by adding porous materials such as asphalt material, aluminium foam and copper foam. Pukdum et al. [8] investigated the performance