PROSIDING SNTTM XXI 2023
Volume 21, Tahun 2023, 5 Oktober 2023

e-ISSN 2623-0313
p-ISSN 3032-1972

Fabrication of a working fluid filler for cooling photovoltaic module

Toto Supriyono[a,b,1], Ghazali Omar[b], Noreffendy Tamaldin[b], Hery Sonawan[a], Mi'raj Novahardi[a], Fachrul Sidik[a], M. R. Sumartono[a], M. S. Kasim[c]

[a]Program Studi Teknik Mesin, Universitas Pasundan, Bandung
[b]Fakulti Teknologi dan Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka
[c]Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin, Malaysia

[1]supriyono.toto@unpas.ac.id

ABSTRACT

This paper discusses manufacturing a special tool (Filler) to fill the working fluid of a photovoltaic module (PVM) cooler. PVM needs to be cooled because its performance is susceptible to temperature changes. An increase in PVM temperature can reduce its performance. Due to their low thermal resistance, heat pipes can be used as PVM coolers. The greatest heat release occurs through the evaporation process of the working fluid within the heat pipe. The filling of the working fluid into the heat pipe is carried out under vacuum pressure, so a special tool or a special filler is required so that the filling of the working fluid corresponds to the specified amount. The filler consists of a liquid reservoir (water tank and support), an isolation valve, a check valve, and a liquid transfer pipe. The manufacture of the filler has been performed in several stages, from material selection to fabrication and assembly of parts. The assembly of the parts of the copper material was performed using the brazing joint method, while for the thread parts, a seal tape was added, combining the top and bottom of the tank using epoxy glue. The water tank support and tables were fabricated using 3D printing. Copper pipes 12.7 mm (1/2 inch) were cut to obtain a length of 50 mm, as many as six pieces, for the acrylic pipe cut along 48 mm. The acrylic sheets were cut in a circle with a diameter of 60 mm, as many as two pieces, and holes and grooves in the middle, in sizes M6 and M16. After the cutting process is complete, assemble the filler parts by connecting the brazing, threading, and gluing processes. The support table has dimensions of 150 mm x 150 mm and a height of 125 mm made using a 3D printing process. The results of the filler function test show that the filler that has been made can be used to vacuum the heat pipe or PVM coolant and fill the working fluid according to the specified amount.

Keywords: Heat pipe, fabrication, photovoltaic module, photovoltaic cooling, brazing

Received 30 September 2023; **Presented** 5 Oktober 2023; **Publication** 27 Mei 2024

INTRODUCTION

Energy demand is increasing rapidly, and fossil fuels dominate the global energy landscape. According to the US Energy Information Administration, fossil fuels (coal, oil, and gas) currently provide approximately 80 percent of the world's energy needs [1–4]. This reliance on fossil fuels has significant environmental and health impacts, including air and water pollution, and contributes to global warming [1–4]. In summary, while fossil fuels continue to dominate the global energy landscape, there is a growing need to transition to cleaner, renewable energy sources to meet increasing energy demands while mitigating environmental and health impacts.

Solar energy is one of the renewable energy sources that can be converted into electrical energy (DC) and transported as thermal energy [5–7]. A photovoltaic module (PVM) is required to convert solar energy into electrical energy. PVM, widely used commercially, is a c-Si PVM type composed of two layers, namely p-type and n-type, and has one junction called the p-n junction [8–10]. Energy transported by light hits the p-n junction of the photovoltaic cell and generates pairs of electrons and holes from the p-n junction. Electrons accumulate in the n-type layer, and holes accumulate in the p-type layer to cause voltage. When both the p-type and n-type are connected to a load, the electrons move to the hole layer through the load, and an electric current flows in the opposite direction of the electron flow.

Increasing the temperature of the PVM can affect its performance and cause the generated voltage to drop [11,12]. Results of the experiment performed by Hindi et al. [11] regarding research on improving the performance of solar photovoltaics through the use of PCM and fin walls show that PVM temperature significantly impacts the performance of PVM in power generation. Experiments were conducted with two PVMs, namely PVMs with and without cooling. The experiment aimed to investigate three PVM performance parameters tested simultaneously under the same conditions. Experiments were conducted in Basra, Iraq, with the OREX-170W PVM model to study the effect of cooling techniques on the thermal and electrical behavior of OREX-170W PV modules oriented south at an angle of 30° were installed. The experimental results showed that uncooled PVM had an average efficiency of about 13.6% in July 2022, while cooled PVM with an aluminium fin wall was 15.2%. In addition, the performance of the PV aluminium fin wall increased by 16.8%.

Chandel et al. [13] have conducted coolant studies using phase change material for PVM. The study results showed that Solar energy hitting PVM is converted into heat, reducing power generation efficiency. Generally, PVM performance drops by 0.5% for every one-degree increase in temperature, depending on the type of solar cell used. Therefore, temperature regulation in PV power plants is important, especially for high-temperature areas, to improve PVM efficiency.

PVM temperature can be regulated via a cooler or heat absorber [5,13–17]. According to Murtadha [17], the cooling process on PVM can improve its performance. The research used a hybrid nanofluid coolant containing two wt% Al_2O_3/TiO_2. Three PVMs have the same specifications but apply different cooling techniques in a single-pass flow. PVM-1 was cooled with a two-wt% Al_2O_3/TiO_2 hybrid nanofluid. PVM-2 is cooled with water only, while the third PVM-3 is uncooled. The maximum output power was 46.6, 45.1, and 41.9 W for hybrid nanofluid cooling, water-only, and uncooled panels. These results show that cooled PVMs perform better than uncooled ones.

The research being carried out by the author is the development of a PVM cooler using heat pipes. Heat pipes are widely used to cool electronic devices such as cell phones, computers, and electric motors [18–21]. A heat pipe is a heat conductor with very low thermal resistance. The greatest heat generation occurs through the evaporation of the working fluid in the heat pipe. The working fluid within the heat pipe, for example, water, must be filled under vacuum conditions. Therefore, a unique tool or filler is required to fill the working fluid into the heat pipe so the work fluid quantity within the heat pipe is as per specification.

Heat pipes are the most efficient passive heat transfer technology. Heat pipes have high thermal conductivity, allowing heat transfer while maintaining an almost uniform temperature along the heated and cooled part. In general, heat pipes are passive thermal conductors that can move large amounts of heat over relatively long distances without using moving parts. Heat pipes use the process of phase change and steam diffusion to transfer heat. The heat pipe structure consists of tubes evacuating the inside and partially filling with the working fluid in the liquid and vapour phases [18–21].

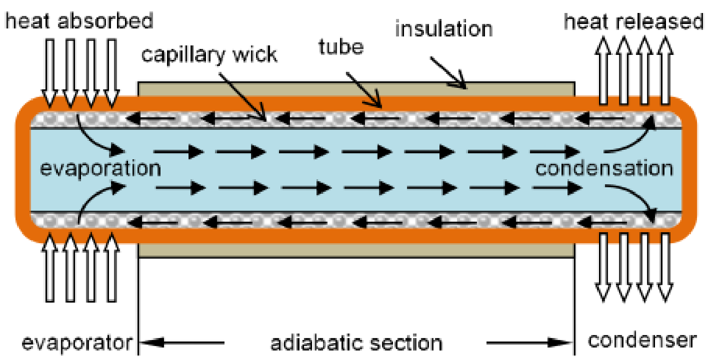

Figure 1. Straight heat pipe [18]

This article explains the fabrication of a special filler to fill a working fluid into the heat pipe or the PVM cooler so that the filling process is more accessible and uncomplicated, the amount of the working fluid is as desired, and it can be carried out under vacuum conditions. With this special filler, the amount of working fluid filled is adjusted according to the specified amount so that the heat absorption of any developed heat pipes is according to the given specifications. The working fluid filled into the heat pipe or PVM cooler is pure water (Aquades) or acetone.

e-ISSN 2623-0313
p-ISSN 3032-1972

This working fluid can absorb/transfer heat in the 30–80 °C temperature range. Thus, the special filler fills the working fluid as much as desired and ensures the working fluid state in the heat pipe is vacuum.

MATERIAL AND METHOD

Material

Figure 1 and Table 1 show the working fluid-filling device's structure (Filler). The device has several copper pipe connections, four branches, and a shut-off valve. The branches are connected by heat pipes, pressure gauges, working fluid tanks, and vacuum compressors, as shown in Figure 1. The materials used are pipes and fittings (copper), socket, tee, reducer, copper check valve, brass socket, pressure gauge, steam ball valve, acrylic plate, acrylic pipe, filling valve, distribution hose, copper wire, sealing tape, epoxy glue, and 3D printing filament.

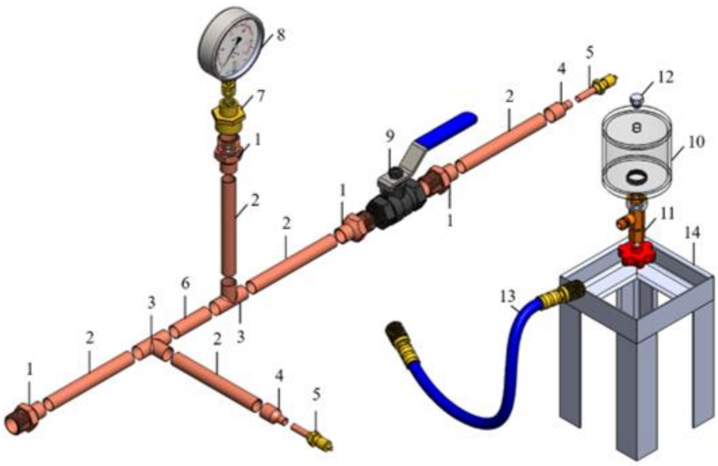

Figure 2. Design working fluid filler

Table 1. Parts of working fluid filler

No.	Part specification	Qty
1.	Outer thread socket ½ in x ½ in	4
2.	Cooper pipe ½ in x 100 mm	5
3.	Tee ½ in	2
4.	Reducer ½ in x ¼ in	2
5.	Check valve ¼ in	2
6.	Copper pipe ½ in x 50 mm	1
7.	Inner thread socket ½ in x ¼ in	1
8.	Pressure gauge (-1 s/d 3 barg)	1
9.	Ball valve ½ in (steam)	1
10.	Water tank	1
11.	Filler valve	1
12.	Bolt M6 x 1.0 x 5 mm	1
13.	Manifold hose	1
14.	Tank support	1

Method

The manufacturing process of this filler includes cutting parts, assembling parts, and fabrication of tank supports using a 3D printing machine. However, the production of this tool involves simple devices such as cutting grinders, acetylene welding machines, and 3D printing machines. The manufacturing process includes several stages, starting from the preparation of the material and ending with its final use. The flow chart of the filler manufacturing process is shown in Figure 2.

The manufacturing process began with reviewing the filler shop drawing from the previous design process. Then, the material preparation

e-ISSN 2623-0313
p-ISSN 3032-1972

referred to the design specifications and any equipment required to produce the filler parts. Twenty-four filler parts were produced, as shown in Table 1. In addition, material cutting and the production of water tank supports were carried out in parallel using 3D printing. The filler parts were connected/joined using the brazing process. The final assembly connects the filler to the water tank and the tank support or bracket. After assembling all the parts, a leaking test was carried out on all connecting/joining parts. The leaking test was carried out by applying compressed air at a pressure of 2.5 barg and observing the pressure gauge indicator for 24 hours. If there is a pressure drop, this indicates a leak in any joints or the valve. The leaking test shall be carried out continuously until there is no pressure drop within the filler. When the test is successful, the working fluid can be filled into the heat pipe using the filler.

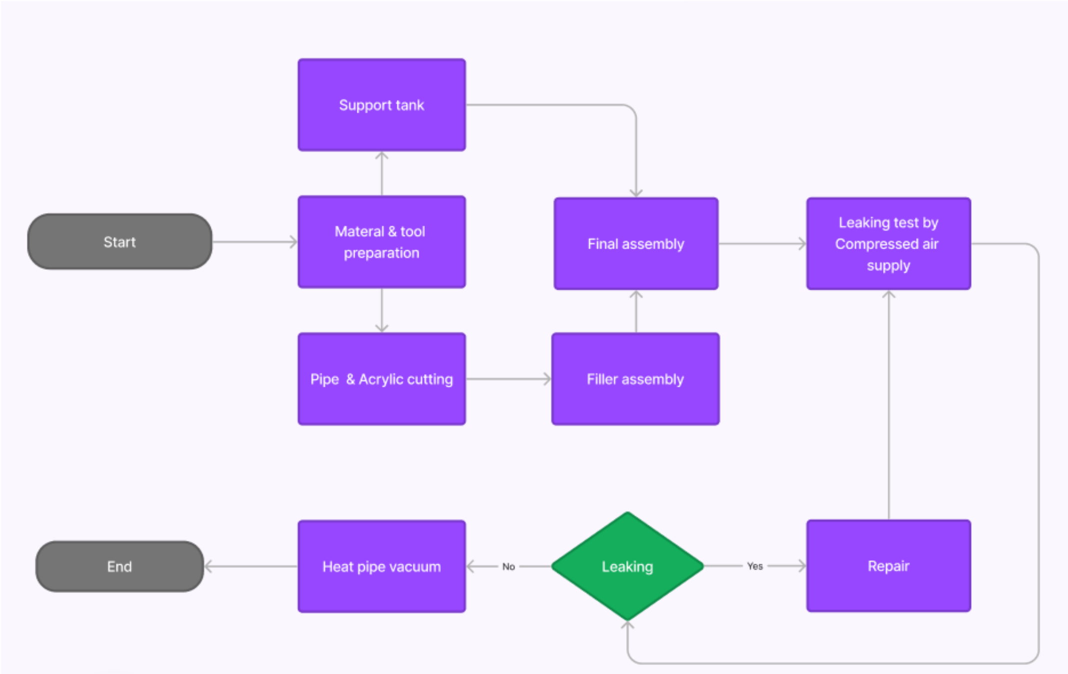

Figure 3. Fabrication process

Material and tools preparation

The materials and tools to be used were prepared in advance. The materials to be used include copper pipe, copper outer socket, copper tee, copper reducer, copper check valve, brass inner socket, pressure gauge, steam ball valve, sheet acrylic, acrylic pipe, filler valve, manifold hose, copper wire, seal tape, glue epoxy, and 3D printing filament. The tools used were cutting grinders, acetylene welding, and 3D printing machines.

Copper pipe and acrylic cutting

The prepared copper and acrylic pipes were cut to size from the design of the working fluid filler. Copper pipes were cut along 50 mm, making as many as 6 (six) pieces. As for the acrylic pipe, it was cut along 48 mm as calculated. Acrylic sheets were cut in a circle according to the acrylic pipe's outer diameter, which is 60 mm. Acrylic cut in a circle as many as 2 (two) pieces and given holes and threads in the middle with sizes M6 and M16.

Parts filler assembly

The copper and acrylic pipes that had been cut were then combined with other components. In copper pipe components, copper outer drat sockets, copper tees, copper reducers, and copper check valves were used in the brazing joining method. As for the steam ball valve, pressure gauge and filler valve thread joints were used. Covering the top and bottom of the acrylic pipe into a tank using acrylic sheets that have been cut in a circle with epoxy glue as the greeter.

Support tank fabrication

Water tank support fabrication using a *3D printing* process. The tank support was shaped like a table with dimensions of 150 mm x 150 mm and a height of 125 mm. With this size, the tank support requires a *filament* of 140 grams and a 10-hour process.

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Combining heat pipes with fillers

After completing all the parts, the filler and heat pipe were combined, and the filler was connected to the vacuum pump.

Pressurize heat pipes and fillers

After all parts were connected, the heat pipe and working fluid filler were pressurized at about 2.5 barg. Then, the heat pipe and work fluid filler were checked for leaks by dipping the heat pipe and working fluid filler into water. Repairs must be performed to the leaking area if there is a leak, and the working fluid filler and heat pipe are again pressurized. However, the heat pipe and working fluid filler can be vacuumed without bubbles.

Vacuum the heat pipe using filler

After all parts had no leakage, the heat pipe was installed using the filler. All ball valves were opened during the vacuum process while the filler valve in the water tank was closed. The vacuum is carried out until the pressure reaches approximately 0.1 bar (abs). After the pressure has been reached, close the ball valve tightly on the working fluid filler, the channel to the vacuum pump, and slowly open the filler valve on the water tank. The working fluid will automatically enter the tool and heat pipe because the pressure in the heat pipe and tool is lower than in the tank.

Removing the heat pipe with the filler

After the heat pipe had been vacuumed and filled with the working fluid, the ball valve on the heat pipe was closed tightly; then, the heat pipe was removed with a working fluid filler, and the heat pipe could be used.

RESULT AND DISCUSSION

Figure 4 shows a photo of the filler that has been created. As previously explained, this filler fills the PVM cooling working fluid using a heat pipe. With this filler, the working fluid becomes more accessible and more straightforward, and the amount of working fluid entered into the heat pipe is as desired. As shown in Figure 4, the filler construction consists of a copper pipe with a diameter of 12 mm, has four branches, and is equipped with a pressure gauge, an insulation valve, and check valves. Four filler branches are connected by a heat pipe, working fluid tank, pressure gauge, and vacuum pump.

Table 2 presents the result function test of filler. The filler is used to fill three PVM coolers using heat pipes with 420, 640, and 860 mm lengths. The diameter of the coolant is 19.05 mm. The time required to generate vacuum pressure varies depending on the air volume in the heat pipe, as presented in Table 2. To get pressure up to 0.1 bar (abs), the time needed is 15, 20, and 30 minutes for heat pipes with 420, 640, and 860 lengths, respectively. Table 2 shows that this filler can be used to fill the working fluid per the specified amount and ensure the level of state of the working fluid is vacuum.

Figure 4. The Filler

Table 2. Filler function test

e-ISSN 2623-0313
p-ISSN 3032-1972

Test	*Heat Pipe Length* (mm)	*Heat Pipe Diameter* (mm)	*Filling Ratio* (%)	Air volume (cm^3)	Vacuum time (min)	Pressure Bar (abs)
1.	420	19.05	60	48.2	15	0.1
2.	640	19.05	60	62.2	20	0.1
3.	860	19.05	60	110.1	30	0.1

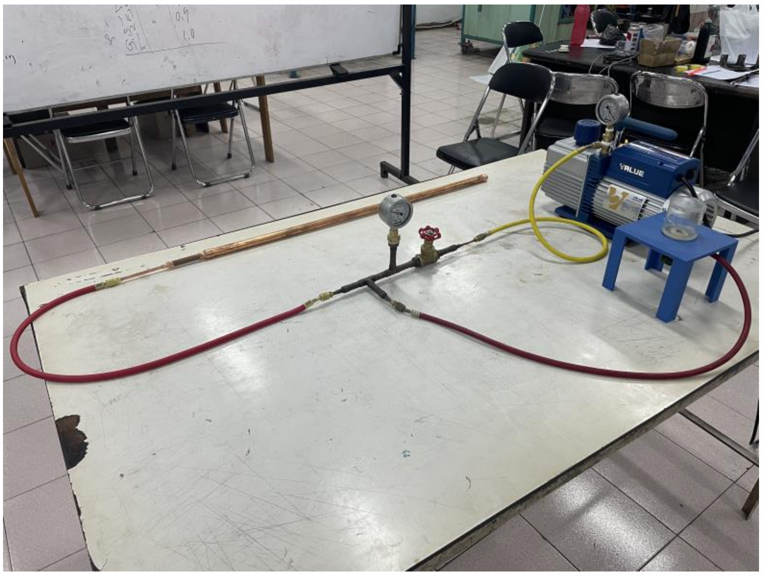

Figure 5. Vacuum process

Figure 5 shows the vacuum process of the heat pipe up to a pressure of 0.1 barg. The PVM cooler or heat pipe is connected to the filler, which is connected to the water tank and vacuum pump. Filling the working fluid means vacuuming the heat pipe, then transferring the working fluid into the heat pipe, closing the insulation valve, and releasing the heat pipe and filler connections. After the vacuum pressure of the air in the heat pipe is reached, the working fluid (pure water) flows into the heat pipe slowly so that the pressure does not increase dramatically.

Finding

From the function test result, several essential findings need to be considered in the development or refinement of the future filler, namely:

- Leakage occurs in the threaded connection even though a seal has been added,
- Leakage occurs in the valve insulation,
- Leakage occurs in the check valve,
- The copper pipe connecting the check valve and the main line broke because it was too long,
- The check valve is broken,
- Need a sturdy holder for filler to facilitate valve adjustment and pressure reading,
- The filler connecting the hose to the vacuum pump is not too long so that the pressure drop is small,
- The amount of working fluid exceeds the amount needed so that there is no increase in pressure in the heat pipe during the process of filling the working fluid,
- Heat pipe and filler are connected with two check valves to facilitate the release of heat pipes after filling the working fluid,
- The support water tank leg is too narrow, making it difficult to open the valve when filling the working fluid,
- The filler dimension must be evaluated to reduce pressure losses affecting the pressure difference () between the vacuum pump and the heat pipe.ΔP

CONCLUSION

The fabrication of work fluid filler (the filler) is done well and functions well during the test function. The filler can fill the work fluid or PVM cooler with a diameter of 19.05 mm and lengths varying from 420, 640, and 840 mm. Vacuum pressure has reached 0.1 barg with a long vacuum time between 15 – 30 minutes.

e-ISSN 2623-0313
p-ISSN 3032-1972

Using this filler, the filling of the working fluid and vacuum process becomes more accessible faster than manual filling, and the heat pipe or PVM cooler functions appropriately.

Filler fabrication has been carried out in several stages, starting from cutting copper pipes with a length of 50 mm, as many as six pieces, acrylic pipes cut along 48.1 mm, and there are also acrylic sheets cut in circles with a diameter of 60 mm as many as two pieces and given holes and grooves in the middle with sizes M6 and M16. After the cutting process is complete, proceed with the component connection process using the brazing process, thread connection, and gluing on the tank and thread connection. In addition, the manufacture of tank supports uses a 3D printing process. The tank support has dimensions of 150 mm x 150 mm and a height of 125 mm. The filler can fill pure water or acetone as much as 100 ml in one filling.

ACKNOWLEDGEMENT

The authors acknowledge the support of Dr. Ir. Yusman Taufik, M.P., as the Dean of the Engineering Faculty, and Dr. Ir. Sugiharto, M.T., as the Head of the Mechanical Engineering Study Program of Pasundan University for providing a laboratory facility to perform the research work.

AUTHOR CONTRIBUTION

Toto Supriyono contributed to the design experiment, analysis of results, and manuscript writing, Ghazali Omar, Noreffendy Tamaldin Hery Sonawan, and M. S. Kasim contributed to supervising the research and reviewing the manuscript, Mi'raj Novahardi, Fachrul Sidik contributed, and M. R. Sumartono contributed to the prepare shop drawing, fabrication, and testing the filler.

FUNDING

Research supported by: Fakultas Teknik Universitas Pasundan, Nomor: 049/Unpas-FT.D/G/I/2023.

ETHICAL COMPLIANCE

All procedures were performed in studies that did not involve human and animal participants.

DATA ACCESS STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST DECLARATION

The authors declare that they have NO affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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