# LAPORAN KEMAJUAN PENELITIAN MULTI TAHUN

ID Proposal: 7ca4f5c5-1712-454a-9dc9-1e01abd3cf16
Laporan Kemajuan Penelitian: tahun ke-2 dari 3 tahun

## 1. IDENTITAS PENELITIAN

### A. JUDUL PENELITIAN

Pengembangan Cold Storage Tenaga Surya untuk Meningkatkan Kapasitas dan Kualitas Produksi Perikanan Nasional

### B. BIDANG, TEMA, TOPIK, DAN RUMPUN BIDANG ILMU

| Bidang Fokus RIRN / Bidang Unggulan Perguruan Tinggi | Tema | Topik (jika ada) | Rumpun Bidang Ilmu |
|---|---|---|---|
| Energi | Teknologi Konservasi Energi | Teknologi hybrid dalam pemanfaatan sumber energi terbarukan | Teknik Refrigerasi |

### C. KATEGORI, SKEMA, SBK, TARGET TKT DAN LAMA PENELITIAN

| Kategori (Kompetitif Nasional/ Desentralisasi/ Penugasan) | Skema Penelitian | Strata (Dasar/ Terapan/ Pengembangan) | SBK (Dasar, Terapan, Pengembangan) | Target Akhir TKT | Lama Penelitian (Tahun) |
|---|---|---|---|---|---|
| Penelitian Kompetitif Nasional | Penelitian Terapan | SBK Riset Terapan | SBK Riset Terapan | 5 | 3 |

## 2. IDENTITAS PENGUSUL

| Nama, Peran | Perguruan Tinggi/ Institusi | Program Studi/ Bagian | Bidang Tugas | ID Sinta | H-Index |
|---|---|---|---|---|---|
| I NYOMAN SUAMIR<br><br>Ketua Pengusul | Politeknik Negeri Bali | Teknik Pendingin Dan Tata Udara | | 5979082 | 3 |
| SUDIRMAN S.T<br><br>Anggota Pengusul 1 | Politeknik Negeri Bali | Teknik Pendingin Dan Tata Udara | 1) Membantu merencanakan pengadaan bahan dan peralatan; 2) Membantu membuat cold room lengkap dengan sistem pemasangan bio-PCM; 3) Membantu membuat sistem refrigerasi dengan | 6024583 | 1 |

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| | | | tenaga surya; 4) Membantu melakukan pengujian sistem cold storage tenaga surya tanpa bio-PCM; 5) Membantu melakukan pengujian sistem cold storage tenaga surya dengan bio-PCM; 6) Membantu melakukan pengolahan data dan analisis hasil pengujian; 7) Membantu melakukan kajian pengaruh teknologi yang diusulkan terhadap kapasitas dan kualitas produksi perikanan nasional: 8) Membantu melakukan analisis komparatif energi dan temperatur performansi antara teknologi yang diusulkan dengan sistem konvensional yang digunakan saat ini; 9) Membantu menyusun artikel untuk publikasi; 10) Membantu mempersiapkan usulan HKI material hayati bio-PCM untuk temperatur kerja -20oC s.d -26oC; 11) Membantu mempersiapkan usulan paten; 12) Membantu mempersiapkan dan membuat laporan kegiatan penelitian | | |
| I NENGAH ARDITA S.T, M.T<br><br>Anggota | Politeknik Negeri Bali | Teknik Pendingin Dan Tata Udara | 1) Merancang sistem packing dan pemasangan bio-PCM pada | 6022883 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| Pengusul 2 | | | cool room; 2) Merancang dan membuat dudukan solar panel; 3) Mempersiapkan spesimen sebagai produk yang didinginkan untuk pengujian cold storage dan sistem penempatannya menurut ASHRAE Standard 72 (2005); 4) Membantu merencanakan pengadaan bahan dan peralatan; 5) Membantu membuat cold room lengkap dengan sistem pemasangan bio-PCM; 6) Membantu membuat sistem refrigerasi dengan tenaga surya; 7) Membantu melakukan pengujian sistem cold storage tenaga surya tanpa bio-PCM; 8) Membantu melakukan pengujian sistem cold storage tenaga surya dengan bio-PCM; 9) Membantu melakukan pengolahan data dan analisis hasil pengujian; 10) Membantu melakukan kajian pengaruh teknologi yang diusulkan terhadap kapasitas dan kualitas produksi perikanan nasional; 11) Membantu melakukan analisis komparatif energi dan temperatur performansi | | |

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| | | | antara teknologi yang diusulkan dengan sistem konvensional yang digunakan saat ini; 12) Membantu menyusun artikel untuk publikasi; 13) Membantu mempersiapkan usulan HKI material hayati bio-PCM untuk temperatur kerja -20oC s.d -26oC; 14) Membantu mempersiapkan usulan paten; 15) Membantu mempersiapkan dan membuat laporan kegiatan penelitian | | |
| Dr GEDE SANTANU S.E., M.M.<br><br>Anggota Pengusul 3 | Politeknik Negeri Bali | Administrasi Bisnis | 1) Membuat kajian ekonomis dari sistem cold storage tenaga surya; 2) Membantu melakukan survei kapasitas produksi perikanan nasional dan berbagai daerah di Indonesia; 3) Membantu melakukan survei cara penanganan ikan hasil tangkap nelayan pesisir; 4) Membantu melakukan survei ketersediaan cold storage pada pelabuhan perikanan nasional; 5) Membantu mengolah data dan melakukan analisis hasil survei sebagai informasi pengembangan teknologi yang diusulkan; 6) Membantu melakukan kajian pengaruh teknologi yang | 6034464 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| | | | diusulkan terhadap kapasitas dan kualitas produksi perikanan nasional; 7) Membantu melakukan analisis komparatif energi dan temperatur performansi antara teknologi yang diusulkan dengan sistem konvensional yang digunakan saat ini; 8) Membantu menyusun artikel untuk publikasi | | |

**3. MITRA KERJASAMA PENELITIAN (JIKA ADA)**

Pelaksanaan penelitian dapat melibatkan mitra kerjasama, yaitu mitra kerjasama dalam melaksanakan penelitian, mitra sebagai calon pengguna hasil penelitian, atau mitra investor

| Mitra | Nama Mitra |
|---|---|
| Mitra Pelaksana Penelitian | I Gst. Ngr. Putra Astawa, ST |
| Mitra Calon Pengguna | Pratama Wahyudi Mulyana |

**4. LUARAN DAN TARGET CAPAIAN**

**Luaran Wajib**

| Tahun Luaran | Jenis Luaran | Status target capaian ( *accepted, published, terdaftar atau granted, atau status lainnya*) | Keterangan (*url dan nama jurnal, penerbit, url paten, keterangan sejenis lainnya*) |
|---|---|---|---|
| 3 | Dokumentasi hasil uji coba produk | Ada | - |

**Luaran Tambahan**

| Tahun Luaran | Jenis Luaran | Status target capaian (*accepted, published, terdaftar atau granted, atau status lainnya*) | Keterangan (*url dan nama jurnal, penerbit, url paten, keterangan sejenis lainnya*) |
|---|---|---|---|
| 3 | Publikasi Ilmiah Jurnal Internasional | accepted/published | International Journal of Refrigeration |
| 3 | Prosiding dalam pertemuan ilmiah Internasional | sudah terbit/sudah dilaksanakan | International Join Conference on Science and Technology |
| 3 | Paten Sederhana | terdaftar | - |
| 3 | Purwarupa/Prototipe | penerapan | - |

**5. ANGGARAN**

Rencana anggaran biaya penelitian mengacu pada PMK yang berlaku dengan besaran minimum dan maksimum sebagaimana diatur pada buku Panduan Penelitian dan Pengabdian kepada Masyarakat Edisi

12.

**Total RAB 3 Tahun Rp. 387,200,000**

**Tahun 1 Total Rp. 0**

**Tahun 2 Total Rp. 193,600,000**

| Jenis Pembelanjaan | Item | Satuan | Vol. | Biaya Satuan | Total |
|---|---|---|---|---|---|
| Analisis Data | Biaya konsumsi rapat | OH | 58 | 40,000 | 2,320,000 |
| Bahan | ATK | Paket | 1 | 1,580,000 | 1,580,000 |
| Bahan | Barang Persediaan | Unit | 1 | 77,380,000 | 77,380,000 |
| Bahan | Bahan Penelitian (Habis Pakai) | Unit | 50 | 475,000 | 23,750,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Biaya seminar internasional | Paket | 1 | 9,450,000 | 9,450,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Publikasi artikel di Jurnal Internasional | Paket | 1 | 9,450,000 | 9,450,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Luaran KI (paten, hak cipta dll) | Paket | 1 | 5,500,000 | 5,500,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Biaya Luaran Iptek lainnya (purwa rupa, TTG dll) | Paket | 1 | 12,050,000 | 12,050,000 |
| Pengumpulan Data | Tiket | OK (kali) | 6 | 3,000,000 | 18,000,000 |
| Pengumpulan Data | Penginapan | OH | 8 | 800,000 | 6,400,000 |
| Pengumpulan Data | Uang Harian | OH | 14 | 530,000 | 7,420,000 |
| Pengumpulan Data | Biaya konsumsi | OH | 137 | 40,000 | 5,480,000 |
| Pengumpulan Data | HR Pembantu Peneliti | OJ | 168 | 40,000 | 6,720,000 |
| Pengumpulan Data | HR Pembantu Lapangan | OH | 324 | 25,000 | 8,100,000 |

**Tahun 3 Total Rp. 193,600,000**

| Jenis Pembelanjaan | Item | Satuan | Vol. | Biaya Satuan | Total |
|---|---|---|---|---|---|
| Analisis Data | Biaya konsumsi rapat | OH | 105 | 40,000 | 4,200,000 |
| Bahan | ATK | Paket | 1 | 1,580,000 | 1,580,000 |
| Bahan | Barang Persediaan | Unit | 4 | 26,700,000 | 106,800,000 |
| Bahan | Bahan Penelitian (Habis Pakai) | Unit | 100 | 135,000 | 13,500,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Biaya seminar internasional | Paket | 1 | 9,450,000 | 9,450,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Publikasi artikel di Jurnal Internasional | Paket | 1 | 9,450,000 | 9,450,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Luaran KI (paten, hak cipta dll) | Paket | 1 | 5,500,000 | 5,500,000 |
| Pelaporan, Luaran Wajib, dan Luaran Tambahan | Biaya Luaran Iptek lainnya (purwa rupa, TTG dll) | Paket | 1 | 7,020,000 | 7,020,000 |

| Jenis Pembelanjaan | Item | Satuan | Vol. | Biaya Satuan | Total |
|---|---|---|---|---|---|
| Pengumpulan Data | Tiket | OK (kali) | 4 | 3,000,000 | 12,000,000 |
| Pengumpulan Data | Penginapan | OH | 6 | 800,000 | 4,800,000 |
| Pengumpulan Data | Uang Harian | OH | 10 | 530,000 | 5,300,000 |
| Pengumpulan Data | Biaya konsumsi | OH | 71 | 40,000 | 2,840,000 |
| Pengumpulan Data | HR Pembantu Peneliti | OJ | 144 | 40,000 | 5,760,000 |
| Pengumpulan Data | HR Pembantu Lapangan | OH | 216 | 25,000 | 5,400,000 |

**6. KEMAJUAN PENELITIAN**

**A. RINGKASAN:** Tuliskan secara ringkas latar belakang penelitian, tujuan dan tahapan metode penelitian, luaran yang ditargetkan, serta uraian TKT penelitian.

Cold storage memiliki peran penting dalam mengurangi kerugian pasca panen, meningkatkan kapasitas dan kualitas produksi perikanan dan akuakultur serta menjaga kestabilan pasokan pangan ke masyarakat. Tetapi perkembangan cold storage secara umum khususnya untuk industri perikanan di Indonesia masih sangat kurang. Sebagai produsen perikanan tertinggi kedua di dunia setelah Cina, Indonesia hanya memiliki 2 dari total 6 pelabuhan perikanan samudera dilengkapi fasilitas cold storage dan hanya 4 dari total 14 pelabuhan perikanan nasional dengan fasilitas cold storage. Kurangnya fasilitas cold storage telah membatasi perkembangan industri perikanan di tanah air. Dalam situasi ini, teknologi yang dapat mendorong pengembangan infrastruktur termasuk cold storage di Indonesia akan meningkat seiring dengan pembangunan ekonomi yang semakin baik. Proyek penelitian ini akan menyelidiki teknologi refrigerasi untuk aplikasi cold storage yang efisien dan ramah lingkungan serta mampu mendukung pembangunan infrastruktur ketahanan pangan nasional. Pendekatan penelitian yang dilakukan adalah menggabungkan keunggulan penggunaan refrigeran alami seperti hidrokarbon pada sistem refrigerasi cold storage (energy efficient refrigeration technology) dan teknologi energi terbarukan (renewable energy technology) dan teknologi penyimpanan dingin (cold thermal storage) berbasis vegetable oil phase change materials (bio-PCM) sebagai sustainable energy technology. Sebuah prototipe cold storage bertenaga surya akan dirancang dan dibangun agar dapat dievaluasi dan dikaji kinerja energi, temperatur, dampak lingkungan serta keunggulan ekonomis pada aplikasi sebagai sistem penyimpanan produk perikanan nasional. Prototipe cold storage ini akan dibangun di Laboratorium Refrigerasi, Politeknik Negeri Bali. Penelitian akan dilakukan secara bertahap selama 3 tahun. Pada tahun-1 akan diawali dengan menemukan bahan bio-PCM dari bahan-bahan lokal. Kemudian melakukan pengujian untuk dapat diterapkan pada temperatur kerja dari -20 ºC sampai dengan -26 ºC. Beberapa pengujian juga dilakukan seperti Gas Chromatography Mass Spectrometry (GCMS) pengujian komposisi kimia, Differential Scanning Calorimetry (DSC) dan T-history thermal analyses pengujian sifat-sifat termal dari calon bio-PCM. Secara simultan juga dilakukan simulasi kinerja Cold Storage Tenaga Surya dengan menggunakan model numerik, kemudian membuat rancangan sesuai hasil simulasi numerik. Sebagian proses konstruksi yaitu cold room dari cold storage juga dapat dilakukan. Termasuk mempersiapkan bio-PCM dan penempatannya di dalam cold room. Pada tahun-2 akan dibuat sistem refrigerasi dengan refrigeran hidrokarbon. Sistem ini akan dilengkapi dengan instrumentasi dan kontrol yang

memadai. Pada tahun-3 akan dibangun sistem suplai listrik dengan tenaga surya yang dirancang khusus untuk menggerakkan sistem Cold Storage. Dilakukan juga pengujian kinerja sistem cold storage dan validasi model numerik serta kajian pengaruh teknologi cold storage, terhadap kapasitas dan kualitas produksi perikanan nasional. Hasil yang diharapkan dari penelitian ini tahun-2 mencakup: desain dan prototipe cold storage bertenaga surya terintegrasi, sebuah paten sederhana draft, 2 artikel pada jurnal conference sries terindex scopus, dan laporan penelitian.

**B. KATA KUNCI:** Tuliskan maksimal 5 kata kunci.

Teknologi energi terbarukan; cold storage; energi surya; dampak lingkungan; keunggulan ekonomis

Pengisian poin C sampai dengan poin H mengikuti template berikut dan tidak dibatasi jumlah kata atau halaman namun disarankan seringkas mungkin. Dilarang menghapus/memodifikasi template ataupun menghapus penjelasan di setiap poin.

**C. HASIL PELAKSANAAN PENELITIAN:** Tuliskan secara ringkas hasil pelaksanaan penelitian yang telah dicapai sesuai tahun pelaksanaan penelitian. Penyajian dapat berupa data, hasil analisis, dan capaian luaran (wajib dan atau tambahan). Seluruh hasil atau capaian yang dilaporkan harus berkaitan dengan tahapan pelaksanaan penelitian sebagaimana direncanakan pada proposal. Penyajian data dapat berupa gambar, tabel, grafik, dan sejenisnya, serta analisis didukung dengan sumber pustaka primer yang relevan dan terkini.

Pengisian poin C sampai dengan poin H mengikuti template berikut dan tidak dibatasi jumlah kata atau halaman namun disarankan seringkas mungkin. Dilarang menghapus/memodifikasi template ataupun menghapus penjelasan di setiap poin.

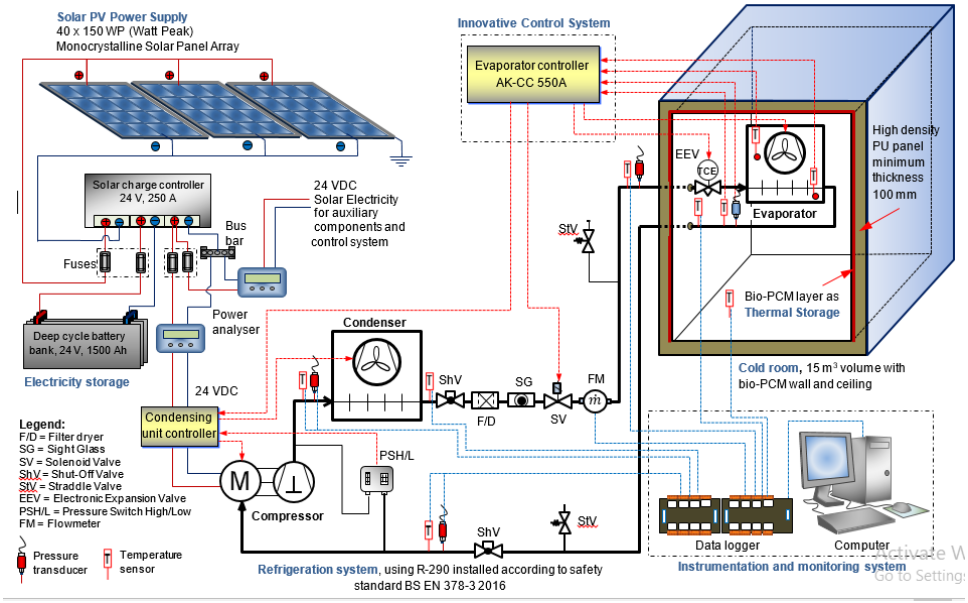
C. **HASIL PELAKSANAAN PENELITIAN:** Tuliskan secara ringkas hasil pelaksanaan penelitian yang telah dicapai sesuai tahun pelaksanaan penelitian. Penyajian meliputi data, hasil analisis, dan capaian luaran (wajib dan atau tambahan). Seluruh hasil atau capaian yang dilaporkan harus berkaitan dengan tahapan pelaksanaan penelitian sebagaimana direncanakan pada proposal. Penyajian data dapat berupa gambar, tabel, grafik, dan sejenisnya, serta analisis didukung dengan sumber pustaka primer yang relevan dan terkini.

Kegiatan Penelitian Tahun-2: mencakup dua kegiatan utama yaitu:

(i) Membuat cool room dan sistem refrigerasi dengan refrigerant R-290: kegiatan mencakup pembuatan pondasi, dinding panel, atap serta pintu dan akses pipa dan kabel; kerangka pemasangan bio-PCM, lengkap dengan sistem alarm dan sensor kebocoran dan perangkat safety lainnya yang terdiri atas saluran udara (ducting) dan exhaust fan. (ii) Membuat sistem refrigerasi primer (refrigeran R-290): mencakup identifikasi dan pengadaan komponen kontrol dan instrumentasi termasuk sistem pemipaan.

Untuk publikasi dan pelaporan, ditargetkan penyelesaian publikasi artikel-1 untuk publikasi conference series pada proceeding teridex scopus, artikel untuk jurnal nasional dan seminar internasional dan draft artikel baru untuk jurnal internasional. Draft paten material maju mulai dipersiapkan, juga laporan tahun-2. Indikator Capaian Penelitian Tahun-2 ditargetkan: Sistem refrigerasi R-290 sudah terpasang lengkap dengan selesainya ruang cold storage yang akan menjadi bagian teritegrasi dari sebuah prototipe sistem Solar driven cold storage yang ramah lingkungan; artikel ilmiah pada jurnal nasional tak terakreditasi, artikel pada proceeding internasional terindex publish-1 dan 2 artikel tambahan sudah dipresentasikan pada konferensi Internasional; draft paten; dan laporan kemajuan kegiatan penelitian Tahun-2.

Hasil pelaksanaan penelitian khususnya pada pembuatan cold storage dan sistem refrigerasinya sudah selesai dibangun sesuai dengan rancangan sistem seutuhnya yang dihasilkan pada tahap tahun-1 dari penelitian ini seperti yang disajikan pada Gambar 1.




Gambar 1. Skematik dari prototipe cold storage tenaga surya hasil rancangan tahun 1

Proses pembuatan sistem cold storage mulai dari pemasangan panel kemudian penyiapan door set dapat dilihat pada Gambar 2.

Gambar 2. Sebagian foto tahapan konstruksi dinding panel cold storage dan pintunya

Proses pemasangan indoor unit dan penyiapan outdoor unit dari sistem refrigerasi dengan refrigeran R-290 yang ramah lingkungan dapat dilihat pada Gambar 3.


Gambar 3. Sebagian foto pada proses pemasangan indoor dan outdoor dari cold storage

Untuk publikasi dan pelaporan, ditargetkan pencapaian pada tahun kedua sudah berhasil menyelesaikan publikasi pada kegiatan tahun 1 berupa: artikel publikasi conference series pada proceeding teridex scopus, artikel untuk jurnal nasional. Untuk publikasi tahun kedua sudah berhasil menyelesaikan dan melakukan presentasi dua buah artikel pada ICAST (International conference on Applied Science and Technology). Kedua paper ini sedang proses review untuk diterbitkan pada Sebuah Journal conference series terindex scopus. Draft paten material maju juga sudah dibuat yang siap didaftarkan untuk mendapatkan diproses untuk pengakuan paten.

Hasil penelitian tentang bio-PCM sebagai bagian integral dari penelitian ini dapat dijelaskan konsepnya melalui sebuah artikel berbahasa inggris yang sudah dipublikasi pada proceeding terindex.

Phase change material (PCM) is one of thermal energy storage (TES) technology which can improve the performance and reliability of energy systems. The technology could also potentially provide energy savings, which in turn could reduce environmental impact related to energy use [1]. Phase change materials (PCMs) store heat by using latent heat, commonly from solid to liquid, as they can exhibit latent heat of phase change and have attracted interest as possible heat thermal storage [2]. Phase change storage with PCMs is one of the most efficient ways to store thermal energy [3]. One advantage of the PCMs is it has high energy storage density with small temperature variation during the process of phase change [4]. They have been used to improve the TES capacity of different systems [5]. PCMs with large latent heat of fusion are also increasingly being used for thermal management of air conditioning in buildings in order to achieve a better balance between cooling supply and demand [6]. In the last 15 years PCMs have also been gradually used for food storage and transportation system [7].

Many researchers have also carried out investigations on the feasibility of application of PCMs in improving the performance of refrigerated cabinets, chest freezer and domestic refrigerators. Applications of integrated thermal energy storage with PCMs have the potential to increase the energy efficiency of the refrigeration systems. The improvement can be achieved by reducing compressor cycling frequency and cycling losses. Moreover, the use of PCMs can also maintain product temperature within a safe temperature range in the event of electrical power failure [8,9]. Experimental investigations on the performance of household refrigerators using PCM were carried out by Azzouz et al. [10,11]. The PCM was placed in a container at the back of the evaporator plate between. The results showed that the response of the refrigerator to the addition of PCM and its efficiency were strongly dependent on the thermal load. The integration of PCM allowed 5 to 9 hours of continuous operation without electrical supply. This could increase the coefficient of performance (COP) of the system by 10% - 30% depending on the cooling load. While studies on the use of PCMs in freezers were reported by [9,12,13]. The PCM was introduced close to the evaporator wall. The results indicated that, during electrical power failure the use of PCM could maintain product temperature for longer compared to the freezer without PCM. Lu et al. [14] and Jouhara et al. [15] investigated the use of PCM and heat pipes to provide product temperature uniformity on the shelves of vertical multi-deck food display cabinets. The PCMs were placed within the structure of the shelves of the display cabinet. The results showed that the use of heat pipes could homogenize the temperature profile of the products and improve the heat transfer between the cabinet, the shelves and the products.

PCMs are generally grouped into organic and inorganic compounds [16,17]. Organic PCMs are very important class materials because of their unique thermal properties such as congruent melting process and narrow melting-freezing temperature ranges [18,19]. Paraffin, the most commonly used organic PCM, have been widely used for energy storage due to its wide range of phase change

temperatures, negligible super-cooling, no corrosive behavior and chemical stability [6,20]. However, paraffin relatively has higher cost, high volume change, lower latent heat and lower thermal conductivity. Another serious issue of the paraffin is its high flammability [20]. The low thermal conductivity of paraffin requires heat transfer enhancement methods such as the incorporation of materials with high thermal conductivity [21-23], increasing heat transfer surface area [24-28] or application of compact heat exchanger [6,29]. While salt water solutions are very common inorganic PCMs. The solutions have advantages of higher thermal conductivity, fusion heat and density, and lower flammability. However, salt water solutions possess serious issues of corrosion and super-cooling.

The best-known PCM is water. It has very good thermal properties such as reliability, low cost, high specific heat, high density, high latent capacity of 335 kJ/kg and safe [30]. Unfortunately, water cannot be used on its own as a PCM in food refrigeration of temperature range below 0 °C [31]. Water also has a big degree of super-cooling during solidification process [32]. In some applications, degree of super-cooling can have major effect on a system performance [33]. In order to make water applicable as PCMs at temperatures below 0 °C, nucleation agent could be added to trigger heterogeneous nucleation. This could also eliminate the super-cooling of water [34]. A food grade antifreeze or nucleation agent in the water would be required [35]. This will maintain the high percentage of water in the solution and the high latent heat of the PCM making it a good candidate for applications just below 0 °C.

The main objective of this paper is to develop phase change material candidates for medium and low temperature food refrigeration applications. The PCM candidates were made by mixing corn-oil ester which worked as nucleation agent. Corn-oil ester and water solutions to be investigated are applicable for medium and low temperature food refrigeration of evaporating temperature of the system between -35 °C and -8 °C. The solutions contain only small portion of corn oil ester. Larger part of the solutions is water which makes them become strong PCM candidates for food refrigeration applications. Moreover, corn-oil ester also contains various types of fatty acids which have many superior properties as organic PCM materials [36-38]. Fatty acids are also derivatives of materials that are readily found in nature such as vegetable oils and labeled as bio-based materials [39]. However, fatty acid ester is more expensive compared with corn-oil ester. Another advantage is that corn-oil ester offers a continuous supply [40,41], no corrosive behavior, non-flammable, and non-toxic, therefore it is suitable for food refrigeration

Materials used in this study were tap water and corn oil ester as nucleating agent resulted from esterification of corn oil. Corn oil ester was chosen because it contains a lot of unsaturated fatty acids so it has low freezing and melting points. The corn oil ester is composed mainly by methyl esters of 38.54%. The oil ester also contains benzene (17.45%), 1,3-cyclohexadiene (8.29%), beta-sesquiphellandrene (23.83%) and others of about 11.89%. Esters are polar molecules that have a very important role on the solubility of corn oil in water. These chemical compositions of corn-oil ester were obtained from Gas Chromatography Mass Spectrometry (GCMS) [42]. The test method comprised analysis of corn oil ester which was performed on a GC-MS Shimadzu type QP 2010 with a split/split less injector. The GCMS test results are presented in Table 1.

Table 1. Chemical composition of investigated corn-oil ester

| Component name | Formula | Area (%) |
|---|---|---|
| 3-Isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris (trimethylsiloxy) | C18H52O7Si7 | 0.61 |

| | | |
|---|---|---|
| Benzene, 1-(1,5-dimethyl-4-hexenyl) | C15H22 | 17.45 |
| 1,3-Cyclohexadiene, 5-(1,5-dimethyl-4-hexenyl) | C15H24 | 8.29 |
| Copaene | C15H24 | 0.28 |
| 8-Nonenoic acid, 5,7-Dimethylene-, methyl ester | C12H18O2 | 0.50 |
| Cyclohexene, 1-methyl-4-(5-methyl-1-methylene-4-hexenyl) | C15H24 | 8.45 |
| Dodecanoic acid, methyl ester | C13H26O2 | 10.92 |
| Beta-sesquiphellandrene | C15H24 | 23.83 |
| Hexadecanoic acid, methyl ester | C17H34O2 | 13.28 |
| 3-Butoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris (trimethylsiloxy) | C19H54O7Si7 | 0.68 |
| Dodecanoic acid, (2,2-dimethyl-1,3-dioxolan-4-yl) methyl ester | C18H34O4 | |
| | C22H42O4 | 2.95 |
| Hexadecanoic acid, (2,2-dimethyl-1,3-dioxolan-4-yl) methyl ester | C23H44O4 | |
| 2-Heptadecanone, 1- (2,2-dimethyl-1,3-dioxolan-4-yl) methoxy | | |
| Anodendroside G, monoacetate | C32H42O11 | 0.48 |
| 9-Octadecenoic acid (Z), methyl ester | C19H36O2 | |
| 7-Hexadecenoic acid, methyl ester | C17H32O2 | 6.21 |
| 9-Octadecenoic acid, methyl ester | C19H36O2 | |
| Cyclopropanebutanoic acid | C25H42O2 | 1.38 |
| Oxiraneoctanoic acid, 3-octyl, methyl ester, trans | C19H36O3 | |
| Heptasiloxane, hexadecamethyl ester | C16H48O6Si7 | 1.63 |
| Octadecanoic acid, methyl ester | C19H38O2 | 1.99 |
| Heptasiloxane, hexadecamethyl ester | C16H48O6Si7 | 1.06 |

Methyl ester, which mainly contained in corn oil ester, is a small ester with single carbon chain. Small esters are soluble in water. This plays a key role in solubility of corn oil ester in water. The solubility of corn oil ester can also be explained as certain acid molecules of ester in water solution having -OH cluster which are ionized by releasing hydrogen atom to make ion H+. Even though esters cannot hydrogen bond with themselves but esters can hydrogen bond with water molecules. Individual positive hydrogen atom in a water molecule can be attracted to one of the single pairs on one of the oxygen atoms in an ester for a hydrogen bond to be formed. Moreover, there are also dispersion forces and dipole-dipole attractions between the ester and the water molecules which release energy. This helps to supply energy required to separate water molecule and ester molecule from others

before they can mix together [43]. This explains why corn oil ester dissolves in water. The corn-oil esters were chosen as nucleating agents for the purpose of obtaining a food grade PCM which was considered as one important factor for food refrigeration applications. PCMs made from the mixture of tap water and corn oil esters are also economically competitive compared to paraffin based PCM. At present, the market price of fatty acid esters is relatively high. This is because of the cost of producing the fatty acid esters is higher than that of corn oil esters because the production line of fatty acid ester includes purification process. While the corn-oil esters can be used without further purification.

Thermal properties of the PCM candidates (of corn-oil ester in water mixtures) were measured by differential scanning calorimeter (Perkin Elmer Jade DSC). The properties included melting and freezing temperatures and latent heat of melting and freezing. The analyses were performed at temperatures between 25 °C and -100 °C for cooling and from -100 °C to 25 °C for heating at 2 °C per minute of cooling and heating rate. The analyses were also performed under a constant stream of nitrogen gas at flow rate of 20 mL per minute. The temperature accuracy was ± 0.01 °C and heat flow repeatability was 0.2 µW. A 30 mg sample of PCM candidate was sealed in an aluminum pan. The melting and crystallization points were taken as onset temperatures.

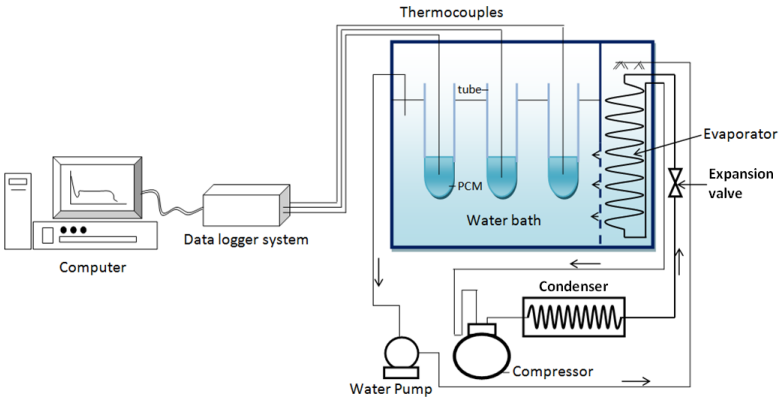



Fig. 1. Schematic diagram of T-history method

Thermal properties of the PCM candidates (of corn-oil ester in water mixtures) were measured by differential scanning calorimeter (Perkin Elmer Jade DSC). The properties included melting and freezing temperatures and latent heat of melting and freezing. The analyses were performed at temperatures between 25 °C and -100 °C for cooling and from -100 °C to 25 °C for heating at 2 °C per minute of cooling and heating rate. The analyses were also performed under a constant stream of nitrogen gas at flow rate of 20 mL per minute. The temperature accuracy was ± 0.01 °C and heat flow repeatability was 0.2 µW. A 30 mg sample of PCM candidate was sealed in an aluminum pan. The melting and crystallization points were taken as onset temperatures.

The latent heat of PCM candidates was determined by numerical integration of the area of peak thermal transition. Even though phase change temperatures of the solutions can be measured by the DSC system, the specimen used in DSC is very small (of about 10-30 mg) which is not applicable for practical use especially for samples that contain water with high degree of super-cooling [44,45]. Whereas degree of super-cooling is an important parameter for PCMs. In this research, phase change temperatures and degree of super-cooling of the PCM candidates were tested by using T-history method which is considered more suitable for this application. Schematic diagram of the T-history method is shown in Fig. 1. The PCM candidates tested include the mixtures of 5%, 7.5%, 10%, 12.5%, 15%, 20%, 25%, 30% and 35% corn oil ester in water.

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Super-cooling occurs when the temperature of a liquid is lowered below its freezing point without becoming a solid [46]. Fig. 2a shows that tap and mineral water was super-cooled to reach -7.5 °C and -8.5 °C respectively before the ice formation process started. The ice crystallization process involves combination of nucleation and growth of ice crystals within a crystalline structure. Ice crystal formation occurs after nucleation, at which the water molecules join the already formed nuclei. For comparison, in Fig. 2b the super-cooling of propylene glycol solutions is illustrated. Super-cooling occurs at lower concentration of propylene glycol solution. At higher concentration, the super-cooling disappears.

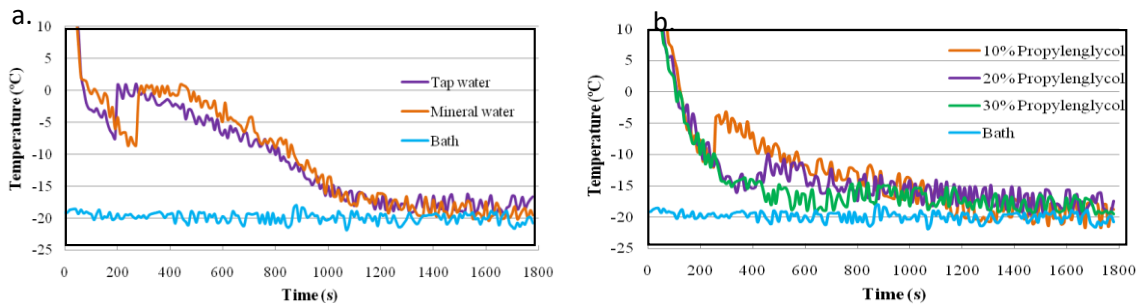


Fig. 2. Super-cooling: tested at bath temperature of -20 °C; a. pure water, b. propylene glycol in water solutions

Fig. 3a and 3b shows that PCM candidates with different concentration of corn-oil ester are able to initiate formation of ice nuclei quickly at somewhat higher temperature than its approaching freezing-point of the solution. For the history-T method, the test can be done up to 25% corn oil ester in water solution due to limitation of the minimum bath temperature. It can be seen the additions of 5%, 7.5%, 10%, 15%, 20% and 25% of corn-oil ester in the PCM candidates can decrease tap water freezing point to -3.5 °C, -6 °C, -7.5 °C, -10 °C, -15 °C and -19.5 °C respectively. They can also reduce super-cooling of the pure water. The addition of corn-oil ester as solute particle into the tap water as solvent produce some ions that contribute to intermolecular force between solvent and solute particles.

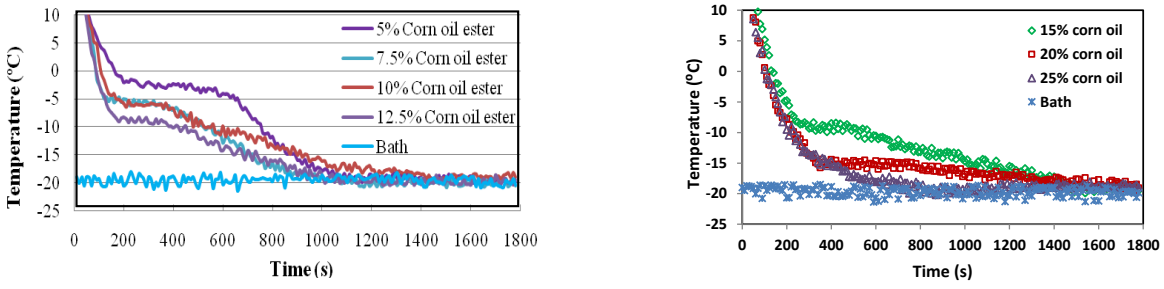


Fig. 3. Cooling process of corn-oil ester in tap water solutions at bath temperature of -20 °C

During cooling process, the pulling force between solvent and solute particles release more heat hence the freezing point of the solution is lowered. Therefore, corn-oil ester solution is able to reduce or even eliminate super-cooling due to: (i) faster nucleation and (ii) lower freezing point.

Thermal properties of the PCMs

In order to compare thermal properties and phenomena in melting and freezing processes of the PCM candidates, the results of DSC for melting and freezing processes of tap water is also presented in Table 2. The melting and freezing temperatures of tap water resulted from DSC were 0 °C and -19.5 °C respectively, and the latent heat of melting and freezing were 297.4 J/g and 102.4 J/g respectively. It is noteworthy that, whatever the sample size, ice melts at 0 °C. On the contrary, freezing occurs at different temperatures, depending on the water sample size [45]. From nucleation theory, it has been shown that the smaller the volume, the lower the freezing temperature. For bulk water, freezing occurs at -14 °C for a volume of 1 cm3 and at around -24 °C for a volume of 1 mm3, while for micro-sized droplets (1 µm3) freezing is found around -39 °C [44]. The energy released during the freezing process is evidenced on the DSC result as an exothermic peak with imperfect bell shape when compared with melting process.

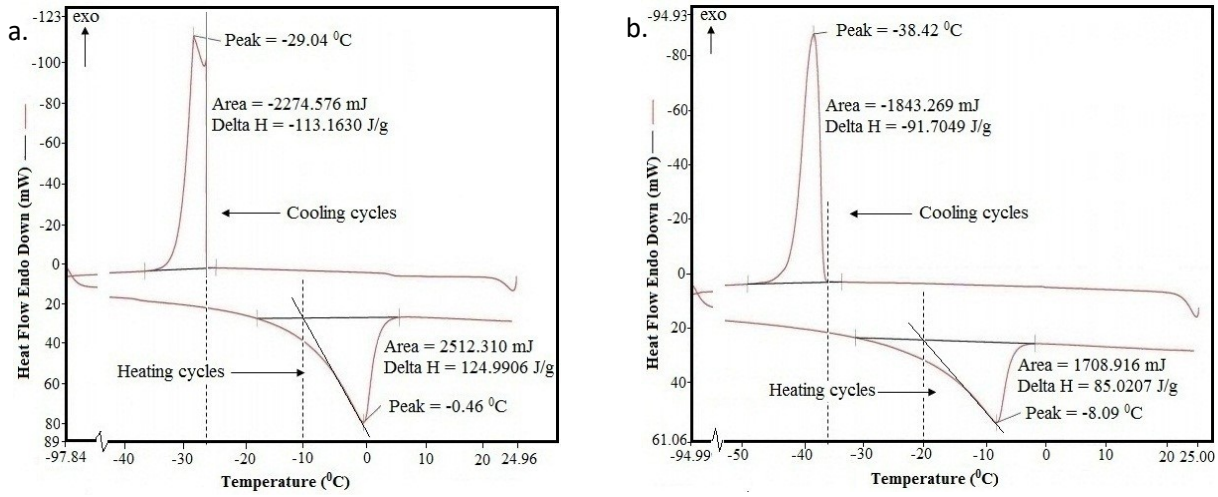


Fig. 4. DSC curves of heating and cooling processes: a. 15% corn-oil ester, b. 25% corn oil ester

Thermal properties of PCM candidates which contain tap water and various compositions of corn-oil ester can be seen in Table 2. While Fig. 4 shows only two DSC curves in order to show super-cooling. Other curves of the corn oil ester solutions are not presented. Fig. 4 shows thermal properties of PCM candidate with 15% and 25% corn-oil ester. From the figure it can be seen that the addition of 15% corn-oil ester into tap water still demonstrates the occurrence of super-cooling. Increasing the concentration of the corn-oil ester to 20% (it is not shown in the figure) causes degree of super-cooling of the PCM solution to decrease. Degree of super-cooling is totally disappeared as the concentration of corn-oil ester reaches 25% (Fig. 4b). This is indicated by a perfect bell shape shown in Fig. 4b.

The freezing temperatures vary from one sample to another, because nucleation is a stochastic phenomenon. Results of DSC test method are also summarized in Table 2. The table clearly shows that melting temperatures of the PCM candidates are lower than those of the tap. The melting and freezing temperatures of corn-oil ester in water solutions of concentration between 5% and 35% (by volume) range from -10 °C to -27 °C. While melting latent heat varies from 68.7 J/g to 227 J/g

respectively. The results indicated that by increasing concentration of corn-oil ester in water solution can reduce melting temperature and minimize or even negate the super-cooling. These properties make the solutions potential to be PCMs with large latent heat and suitable phase change temperatures for medium and low temperature food refrigeration applications. For comparison, Fig. 5 shows melting temperature of PCM candidate corn oil ester (COE) in water solutions, propylene glycol solutions and NaCL solutions at different concentrations. The PCM candidates (Corn oil ester solutions) require lower concentration to achieve the same melting temperature below 0 ºC. This indicates less material is needed for the corn oil ester PCM.

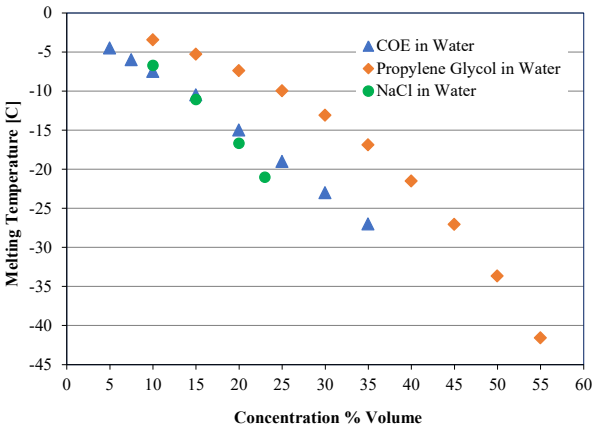


Fig. 5. Melting temperatures of Corn oil ester solutions in comparison to NaCl and Propylene glycol solutions

D. **STATUS LUARAN**: Tuliskan jenis, identitas dan status ketercapaian setiap luaran wajib dan luaran tambahan (jika ada) yang dijanjikan. Jenis luaran dapat berupa publikasi, perolehan kekayaan intelektual, hasil pengujian atau luaran lainnya yang telah dijanjikan pada proposal. Uraian status luaran harus didukung dengan bukti kemajuan ketercapaian luaran sesuai dengan luaran yang dijanjikan. Lengkapi isian jenis luaran yang dijanjikan serta mengunggah bukti dokumen ketercapaian luaran wajib dan luaran tambahan melalui Simlitabmas.

…Pencapaian penelitian tahun kedua dapat dirinci sebagai berikut:

1. Konstruksi prototipe cool room dengan sistem refrigerasinya sudah dapat diselesaikan, pada tahun ketiga tinggal diteruskan dengan integrasi panel surya dan sistem instrumentasinya

2. Sudah berhasil menyelesaikan publikasi yang belum rampung pada tahun 1 yaitu:

Suamir, I.N., Rasta, I.M., Winarta, A., and Suirya, I.W. (2019) 'Numerical simulations on evaporator coils of sustainable cold storages for food chain application', Journal of Applied Mechanical Engineering and Green Technology 1, 1, pp. 1-8

Suamir, I.N., Arsana, M.E., and Tsamos, K.M. (2019) 'Experimental Study on the Influences of Air Flow in an Integral Hydrocarbon Display Cabinet to its Temperature and Energy Performances', IOP Conf. Series: Materials Science and Engineering 494, 1, 012017, doi:10.1088/1757-899X/494/1/012017

Rasta, I. M. and Suamir, I. N. (2019) 'Study on Thermal Properties of Bio-PCM Candidates in Comparison with Propylene Glycol and Salt Based PCM for sub-Zero Energy Storage Applications', IOP Conf. Series: Materials Science and Engineering 494, 1, 012034 doi:10.1088/1757-899X/494/1/012024

Untuk publikasi tahun kedua sudah berhasil menyelesaikan dan melakukan presentasi dua buah artikel pada ICAST (International conference on Applied Science and Technology). Kedua paper ini sedang proses review untuk diterbitkan pada Sebuah Journal conference series terindex scopus.

Draft paten material maju juga sudah dibuat yang siap didaftarkan untuk mendapatkan diproses untuk proses pengakuan paten

……

E. **PERAN MITRA:** Tuliskan realisasi kerjasama dan kontribusi Mitra baik *in-kind* maupun *in-cash* (untuk Penelitian Terapan, Penelitian Pengembangan, PTUPT, PPUPT serta KRUPT). Bukti pendukung realisasi kerjasama dan realisasi kontribusi mitra dilaporkan sesuai dengan kondisi yang sebenarnya. Bukti dokumen realisasi kerjasama dengan Mitra diunggah melalui Simlitabmas.

Mitra pada penelitian ini lebih banyak perannya dalam membantu dalam mengusahakan perlatan dan komponen yang dibutuhkan serta pekerjaan instalasi yang cukup berat kalau dikerjakan sendiri

F. **KENDALA PELAKSANAAN PENELITIAN**: Tuliskan kesulitan atau hambatan yang dihadapi selama melakukan penelitian dan mencapai luaran yang dijanjikan, termasuk penjelasan jika pelaksanaan penelitian dan luaran penelitian tidak sesuai dengan yang direncanakan atau dijanjikan.

Kendala pelaksanaan penelitian yang dijumpai lebih pada pelaksanaan kegiatan yang berkaitan dengan kegiatan belajar-mengajar di laboratorium. Pada bulan-bulan aktif kegiatan praktek mahasiswa, maka kegiatan pembuatan dan pembangunan prototipe di lab harus dihentikan dahulu, karena dapat mengganggu kegiatan praktek. Perlu tersedianya ruang penelitian yang terpisah dari kegiatan pembelajaran praktek mahasiswa.

G. **RENCANA TAHAPAN SELANJUTNYA:** Tuliskan dan uraikan rencana penelitian di tahun berikutnya berdasarkan indikator luaran yang telah dicapai, rencana realisasi luaran wajib yang dijanjikan dan tambahan (jika ada) di tahun berikutnya serta *roadmap* penelitian keseluruhan. Pada bagian ini diperbolehkan untuk melengkapi penjelasan dari setiap tahapan dalam metoda yang akan direncanakan termasuk jadwal berkaitan dengan strategi untuk mencapai luaran seperti yang telah dijanjikan dalam proposal. Jika diperlukan, penjelasan dapat juga dilengkapi dengan gambar, tabel, diagram, serta pustaka yang relevan. Jika laporan kemajuan merupakan laporan pelaksanaan tahun terakhir, pada bagian ini dapat dituliskan rencana penyelesaian target yang belum tercapai.

Rencana penelitian tahun-3 dapat dijabarkan sebagai berikut:

Membuat sistem solar PV, kontrol dan instrumentasi serta pengujian: mencakup pembuatan sistem solar PV dan integrasinya dengan sistem refrigerasi dari cold storage; instalasi sistem instrumentasi dan kontrol; pengujian prototype.

Validasi model rancangan prototipe dan melakukan kajian komparatif dan komprehensif: melakukan kajian komparatif kinerja energi, dampak lingkungan dan analisis ekonomis; melakukan kajian yang komprehensif pengaruh teknologi cold storage terhadap kapasitas dan kualitas produksi perikanan nasional.

Untuk publikasi dan pelaporan, akan diselesaikan pengusulan paten dan publikasi artikel tahun 2 sampai published pada journal conference series terindex scopus dan untuk tahun 3 sendiri akan dibuat lagi artikel untuk jurnal nasional dan seminar internasional. Juga akan dipersiapkan laporan kemajuan dan laporan akhir tahun-3.

Indikator Capaian Penelitian Tahun-3: Sebuah prototipe penerapan Teknologi Cold storage R-290 tenaga surya terintegrasi dengan bio-PCM; sebuah paten; sebuah kajian komparatif keunggulan Cold storage tenaga surya; sebuah kajian yang komprehensif pengaruh teknologi cold storage tenaga surya terhadap kapasitas dan kualitas produksi perikanan nasional; artikel ilmiah pada jurnal nasional tak terakreditasi, jurnal internasional publish dan artikel ilmiah seminar internasional; dan laporan kemajuan serta laporan akhir kegiatan penelitian Tahun-3.

**H. DAFTAR PUSTAKA:** Penyusunan Daftar Pustaka berdasarkan sistem nomor sesuai dengan urutan pengutipan. Hanya pustaka yang disitasi pada laporan kemajuan yang dicantumkan dalam Daftar Pustaka.


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