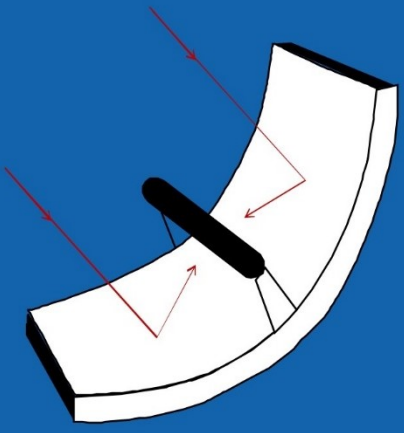
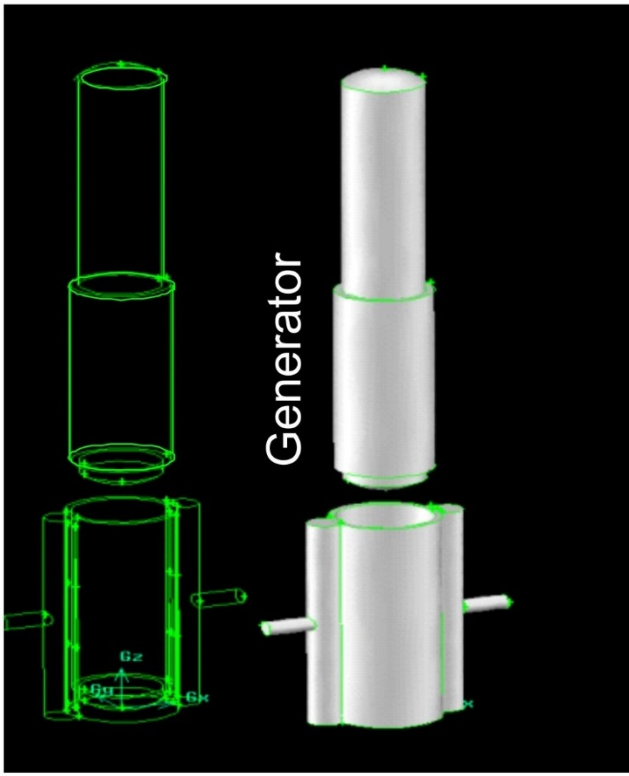
SOLAR ENERGY FOR FOOD REFRIGERATION

Prospective Application in Indonesia a Hot Climate Country





I Nyoman Suamir, A.Md.T., S.T., M.Sc., Ph.D.

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UU no. 28 tahun 2014 tentang Hak Cipta

Fungsi dan sifat Hak Cipta Pasal 4
Hak Cipta sebagaimana dimaksud dalam Pasal 3 huruf a merupakan hak ekslusif yang terdiri atas hak moral dan hak ekonomi.

Pembatasan Perlindungan Pasal 26
Ketentuan sebagaimana dimaksud dalam Pasal 23, Pasal 24, dan Pasal 25 tidak berlaku terhadap:

i. Penggunaan kutipan singkat Ciptaan dan/atau produk Hak Terkait untuk pelaporan peristiwa aktual yang ditujukan hanya untuk keperluan penyediaan informasi aktual;
ii. Penggandaan Ciptaan dan/atau produk Hak Terkait hanya untuk kepentingan penelitian dan pengetahuan;
iii. Penggandaan Ciptaan dan/atau produk Hak Terkait hanya untuk keperluan pengajaran, kecuali pertunjukan dan fonogram yang telah dilakukan Pengumuman sebagai bahan ajar, dan
iv. Penggunaan untuk kepentingan Pendidikan dan pengembangan ilmu pengetahuan yang memungkinkan suatu Ciptaan dan/atau produk Hak Terkait dapat digunakan tanpa izin Pelaku Pertunjukan, Produser Fonogram, atau Lembaga Penyiaran.

Sanksi Pelanggaran Pasal 113

1. Setiap Orang yang dengan tanpa hak melakukan pelanggaran hak ekonomi sebagaimana dimaksud dalam Pasal 9 ayat (1) huruf i untuk Penggunaan Secara Komersial dipidana dengan pidana penjara paling lama 1 (satu) tahun dan/atau pidana denda paling banyak Rp 100.000.000 (seratus juta rupiah).
2. Setiap Orang yang dengan tanpa hak dan/atau tanpa izin Pencipta atau pemegang Hak Cipta melakukan pelanggaran hak ekonomi Pencipta sebagaimana dimaksud dalam Pasal 9 ayat (1) huruf c, huruf d, dan huruf f dan/atau huruf h untuk Penggunaan Secara Komersial dipidana dengan pidana penjara paling lama 3 (tiga) tahun dan/atau pidana denda paling banyak Rp 500.000.000 (lima ratus juta rupiah).

I Nyoman Suamir, A.Md.T, S.T., M.Sc., Ph.D.

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deepublish

Cerdas, Bahagia, Mulia, Lintas Generasi.

SOLAR ENERGY FOR FOOD REFRIGERATION
PROSPECTIVE APPLICATION IN INDONESIA A HOT CLIMATE COUNTRY

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FOREWORD

I should be grateful to the All-Mighty God, with His Spirit, I can accomplish this monograph. The monograph presents investigation results on the prospective application of solar energy for food refrigeration in Indonesia a hot climate country.

Indonesia has abundant renewable energy resources. However, the country only consumed 11.3% renewable energy of the total energy consumption in 2020 and only 0.05% was from solar energy. It results in high CO_2 emissions. Solar energy systems would be as an option to reduce the CO_2 emissions of this country. The investigation aims to study the application of solar energy to provide cooling for medium temperature food refrigeration based on Indonesian weather conditions. The project additionally analyses the environmental impact relating to CO_2 emissions, and to investigate the economical aspect. CFD software is applied on modelling the modification of the chiller generator, while F-Chart and Microsoft Excel spreadsheet are used to analyse the solar system and the economics of the technology.

The optimum configuration of solar driven absorption chiller consists of an ammonia-water absorption chiller of cooling capacity 12.8 kW with 800 litres storage tank and 44 m^2 parabolic trough collectors. The system can harness 71,643 kWh renewable energy with average solar fraction of 0.38. It was found to have a payback period of 20 years. However, the replacement of a vapour compression cycle in Indonesia with a solar driven absorption chiller provides a tremendous impact to the environment. A reduction of 23.4% of CO_2 emission would be achieved.

This monograph can be used as an intellectual and scientific medium for especially lecturers in the Politeknik Negeri Bali and generally researchers who work in the fields of renewable energy and refrigeration. Of course, this monograph still has many inadequacies and weaknesses, for those the author is happy to receive inputs for the improvement of this monograph. Thank you.

Badung, October 2021

Author

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NOTATIONS

A = area (m^2)

α = permeability (m^2) (for porous media) or absorptance (for solar collector)

C_2 = porous jump coefficient (m^{-1})

C_p = heat transfer coefficient (J/kgK)

δ = the plate thickness (mm)

d = diameter (mm)

ξ = pressure loss factor

η = efficiency

F_R = collector heat removal factor

h_s = surface heat transfer coefficient (W/m^2K)

$I_{b,a}$ = normal incident solar irradiation (W/m^2)

k = thermal conductivity (W/mK)

$\dot{m}$ = mass flow rate (kg/s)

μ = dynamic viscosity (Pa.s)

T_a = ambient temperature (°C)

T_{avg} = average temperature (°C)

T_f = fluid temperature (°C)

T_{max} = maximum temperature (°C)

T_{min} = minimum temperature (°C)

T_s = surface temperature (°C)

τ = transmittance

p = pressure (Pa)

Q = heat flow (kW)

q = the rate of heat flow (heat flux) (W/m^2)

U_L = solar collector overall heat transmittance (W/m^2K)

v = velocity (m/s)

$\dot{V}$ = Volume flow rate (m^3/s)

ABBREVIATIONS AND GLOSSARY

ARI	Air conditioning and Refrigeration Institute
ASHRAE	American Society of Heating Refrigerating Air- conditioning Engineers
BOE	Barrel Oil Equivalent (1 BOE equivalent to 0.2 ton coal; 0.1437 kilolitres fuel oil; 0.1242 ton LNG or 1.631 MWh electricity))
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon dioxide
Commercial sector	Business establishments that are not engaged in transportation or in manufacturing or other type of industrial activities (mining, agriculture or construction). This sector includes hotels, motels, restaurants, wholesale businesses, retail stores, laundries and other services enterprises: health, social and educational institutions (Purwanto *et al.,* 2006)
DEFRA	Department for Environment, Food and Rural Affairs
Fossil fuel	An energy source formed in the earths crust from decayed organic material. The common fossil fuels are petroleum, coal and natural gas.

Food refrigeration	Application of a refrigeration system on the prevention and retardation of microbial, physiological, and chemical changes in foods. It also plays a major role in maintaining a safe food supply, nutritional content and retaining characteristics such as flavour, colour and texture (ASHRAE, 2006)
GAX	Generator absorber heat exchange
GW	Gigawatt (one billion watts or one thousand megawatts)
HX	Heat Exchanger
IDR	Indonesian Rupiah (Currency of Indonesia)
Insolation	Incident solar radiation: the energy flux from the sun falling onto a surface on the earth in watts per square meter of collector
IPPC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt hour
LNG	Liquefied Natural Gas (natural gas–primarily methane that has been liquefied by reducing its temperature to -162^{o}C at atmospheric pressure
LPG	Liquefied petroleum gas such as propane and butane produced at refineries or natural gas processing plant
MW	Megawatt
MWh	Megawatt hour = 1000 kilowatt hour
NASA	National Aeronautics and Space Administration
NO_x	Oxides of nitrogen, the sum of NO and NO_2
Primary energy	All energy consumed by end users, excluding electricity but including the energy consumed at electric utilities to generate electricity

PLN	Perusahaan Listrik Negara (State-owned Electricity Company)
ppb	Part per billion
ppm	Part per million
RH	Relative Humidity, the unit in %
SO_x	Oxides of sulphur, in emissions, predominantly SO_2

Dr. I Nyoman Suamir joined the Bali State Polytechnic (Politeknik Negeri Bali) early in his career after completing his Diploma III in Bandung in 1990 as an instructor in the mechanical engineering department. At the same time, he also did an industrial internship at a hotel in Bali as a mechanical supervisor.

He obtained a bachelor's degree (ST) in Mechanical Engineering Energy Conversion at the Bandung Institute of Technology (ITB). His MSc and PhD degrees were obtained at Brunel University, London, UK in the field of Building Services Engineering with Sustainable Energy, Refrigeration and Built Environment. He has accumulated more than 12 years of research and development experience in the fields of refrigeration, HVAC (Heating Ventilating and Air Conditioning) and sustainable energy technology. He has unique skills in modelling refrigeration and air conditioning systems and other energy systems with the U-CoolS, U-RefS and U-MEPS programs based on the EES (Engineering Equations Solver) program. The models developed have been used intensively in the teaching and learning process at the Department of Mechanical Engineering at the Bali State Polytechnic and have gained copyrights from the Ministry of Law and Human Rights of the Republic of Indonesia.

Dr. I Nyoman Suamir has also developed a novel solar driven food cold storage system utilizing Bio-Nano PCM as thermal energy storage. As a principal investigator, he has obtained significant research funding to support his various projects. He has also published over 48 peer reviewed scientific journal and conference papers.

Dr. I Nyoman Suamir has more than 20 years of teaching experience. He has taught a number of subjects related to Refrigeration, HVAC (Heating Ventilating and Air Conditioning), Building Utilities, Energy and Sustainable Technology. His many teaching achievements include setting up new study programs: Refrigeration and Air Conditioning Study Program (Diploma III) and Utility Engineering Technology Study Program (Diploma IV or Applied Bachelor's Degree), curriculums development, editing teaching books and materials, developing teaching facilities and organizing industrial collaborations. He is also very active in professional organizations both nationally and internationally. He served as a chair of Chapter Technology Transfer Committee (CTTC) of the ASHRAE chapter Indonesia in 2016-2017 and now remains as a member of ASHRAE (American Society of Heating Refrigerating and Air Conditioning Engineers), PII (Indonesian Engineers Association) and ISAS (Indonesian Society of Applied Science).

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