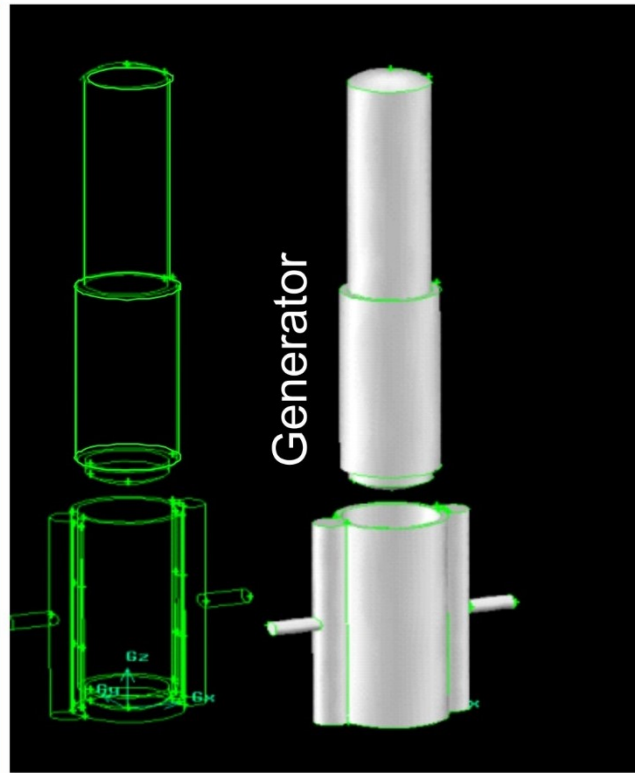
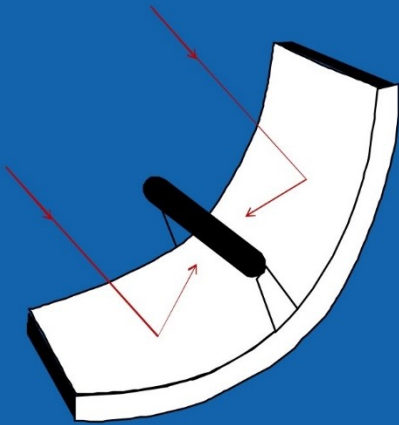




SOLAR ENERGY FOR FOOD REFRIGERATION

Prospective Application in Indonesia
a Hot Climate Country



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

SOLAR ENERGY
FOR FOOD REFRIGERATION
Prospective Application in Indonesia
a Hot Climate Country

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 eksklusif 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.

**SOLAR ENERGY
FOR FOOD REFRIGERATION**
Prospective Application in Indonesia
a Hot Climate Country



Cerdas, Bahagia, Mulia, Lintas Generasi.

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

I Nyoman Suamir

Desain Cover :

Herlambang Rahmadhani

Sumber :

I Nyoman Suamir

Tata Letak :

Gofur Dyah Ayu

Proofreader :

Mira Muarifah

Ukuran :

Xx, 119 hlm, Uk: 15,5x23 cm

ISBN

978-623-02-3651-8

Cetakan Pertama:

November 2021

Hak Cipta 2021, Pada Penulis

Isi di luar tanggung jawab percetakan

Copyright © 2021 by Deepublish Publisher
All Right Reserved

Hak cipta dilindungi undang-undang
Dilarang keras menerjemahkan, memfotokopi, atau
memperbanyak sebagian atau seluruh isi buku ini
tanpa izin tertulis dari Penerbit.

PENERBIT DEEPUBLISH
(Group Penerbitan CV BUDI UTAMA)
Anggota IKAPI (076/DIY/2012)

Jl. Rajawali, G. Elang 6, No. 3 Drono, Sardonoharjo, Ngaglik, Sleman
Jl. Kaliurang Km 9.3 – Yogyakarta 55581
Telp/Fax: (0274) 45334527
Website: www.deepublish.co.id
www.penerbitdeepublish.co.id
Email: deepublish@ymail.com

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 CO₂ emissions. Solar energy systems would be as an option to reduce the CO₂ 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 CO₂ 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 m² 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 CO₂ 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

TABLE OF CONTENTS

FOREWORD	v
TABLE OF CONTENTS	vii
FIGURES	x
TABLES	xv
NOTATIONS	xvi
ABBREVIATIONS AND GLOSSARY	xviii
CHAPTER 1 INTRODUCTION	1
1.1 Context of the Monograph	1
1.2 Aims and Objectives	3
1.3 Limitations.....	4
1.4 Brief Description of Contents	5
CHAPTER 2 COUNTRY OVERVIEW	7
2.1 General	7
2.2 Weather	8
2.3 Energy	12
2.4 Renewable Energy Resources	16
CHAPTER 3 LITERATURE REVIEW	22
3.1 Environment and Low Carbon Developments.....	22
3.2 Absorption Cooling.....	21
3.2.1 Absorption refrigeration technology	22
3.2.2 Ammonia-water absorption equipment	23
3.2.3 Commercial Refrigeration	26
3.3 Solar Energy Driven Absorption Chillers.....	32

3.4	Solar Collectors	33
CHAPTER 4 METHODS		31
4.1	Approach Adopted	31
4.2	Data Collection	33
4.3	Experimental Test Facility	33
4.4	Data Processing and Analysis	41
4.5	CFD Modelling Methods	41
4.6	F-Chart Solar System Analysis	42
CHAPTER 5 RESULTS		43
5.1	Modification on Existing Absorption Chiller	43
5.2	CFD Simulation	44
	5.2.1 Simulation conditions and results.....	45
	5.2.2 Generator jacket construction	52
	5.2.3 Variation on generator surface temperature	56
5.3	Solar Absorption Chiller Modelling.....	58
	5.3.1 Solar absorption chiller configuration and conditions .	58
	5.3.2 Solar absorption chiller modelling on Indonesian weather conditions	60
5.4	Economic analysis	70
5.5	CO ₂ Emissions.....	74
CHAPTER 6 DISCUSSION.....		76
6.1	Modified Chiller Generator Analysis	76
6.2	Analysis on the Solar Energy Driven Absorption Chiller.....	80
6.3	Environmental and Economic Viability	83
CHAPTER 7 CONCLUSIONS		86
7.1	Conclusions	86
7.2	Recommendation.....	88
REFERENCES.....		89
BIBLIOGRAPHY		94

APPENDICES96
Appendix-A: CFD on Modelling the Generator Jacket 96
Appendix-B: CFD on Modelling Generator Surface Temperature 100
Appendix-C: Generator Jacket’s Drawings..... 102
Appendix-D: Parabolic Trough Solar Collector 107
Appendix-E: Economic Analysis Spreadsheets..... 109
Appendix-F: CO2 Intensities of Fuels and Electricity 110
INDEX111
AUTHOR BIOGRAPHY 118

FIGURES

Figure 2.1	Location of Indonesia and neighbouring meteorological stations	10
Figure 2.2	The long-term daily average global irradiation of Indonesia and neighbouring countries	11
Figure 2.3	The daily average irradiation in Indonesia and neighbouring countries	11
Figure 2.4	The percentage occurrence of daily irradiation distribution in Indonesia	10
Figure 2.5	The percentage occurrence of daily irradiation distribution in neighbouring countries	11
Figure 2.6	Energy consumption growth of Indonesia in commercial sector.....	13
Figure 2.7	Energy consumption Indonesia in commercial sector (2005)	14
Figure 2.8	Indonesian energy share of total world energy (2006)	15
Figure 2.9	Electricity price variation in Indonesia (2001 up to 2006)	15
Figure 2.10	Price variation of diesel fuel for industry in Indonesia 2001 up to 2006	16
Figure 2.11	Electricity price in some countries over the world 2006	16
Figure 2.12	Renewable energy usage in Indonesia 2005. ..	20

Figure 2.13	New and renewable energy (NRE) share in Indonesia of the year 2020 and targeted share in 2025.....	21
Figure 2.14	Solar energy share in 2020 of total NRE share which accounted for only 0.05% of total energy Indonesia.....	21
Figure 3.1	Carbon dioxide intensities of fuels and electricity for selected countries.....	21
Figure 3.2	The similarities of compression and absorption cycle	23
Figure 3.3	Schematic of single effect direct-fired, air-cooled liquid ammonia-water chiller	24
Figure 3.4	Typical single effect ammonia-water direct-fired air-cooled absorption chiller.....	24
Figure 3.5	Percentage distribution of display refrigerators in a typical supermarket.....	31
Figure 3.6	US-National average electrical energy used in grocery and convenience stores 2002. .	32
Figure 3.7	Schematic of solar collectors for process heating and power generation	35
Figure 4.1	The flowchart of project activities	33
Figure 4.2	Experimental test facility with indirect heating generator for the absorption unit	40

Figure 5.1	Modified generator with heat transfer fluid jacket system	44
Figure 5.2	Generator jacket model produced on CFD pre-processor Gambit 2.3	45
Figure 5.3	Contours of fluid temperature (K) in the generator jacket interior	47
Figure 5.4	Contours of temperature on the generator's surface of all models	42
Figure 5.5	Contours of velocity magnitude (m/s) in the generator jacket interior	42
Figure 5.6	Flow path line s in the jacket interior coloured by velocity magnitude.....	50
Figure 5.7	Contours of absolute pressure (Pa)	51
Figure 5.8	Pressure loss factors on different shape of orifices	53
Figure 5.9	Generator jacket construction an AutoCAD drawing	55
Figure 5.10	Contours of generator's surface temperature (K) in various inlet temperature	56
Figure 5.11	Solar driven ammonia-water absorption chiller configuration	52
Figure 5.12	Indonesian weather data entry in F-Chart window.....	62
Figure 5.13	F-Chart window for entering the applied general solar heating system	63
Figure 5.14	Parabolic trough or one axis tracking collector data entry in F-Chart window	56
Figure 5.15	Collector efficiency for a typical parabolic trough and a typical parabolic dish	58

Figure 5.16	Optimum parabolic trough axis slope angle and axis azimuth angle for Indonesian weather conditions	59
Figure 5.17	Thermal output including collector heat, heat load for chiller, heat loss on thermal storage, heat supplied by auxiliary boiler and solar fraction (tabular presentation).....	59
Figure 5.18	Thermal output including collector heat, heat load for chiller, heat loss on thermal storage and heat supplied by auxiliary boiler (graphically presented)	60
Figure 6.1	Mechanism in selecting the appropriate model for the generator jacket.....	66
Figure 6.2	Variation on generator surface temperature at various temperatures input	67
Figure 6.3	Variation on generator surface temperature at different heat flow	68
Figure 6.4	Effect of thermal storage size on the heat loss, heat required by auxiliary boiler and renewable heat delivered by parabolic trough collector ...	69
Figure 6.5	The fluid temperature drop at various storage volumes and various time taken	70

Figure 6.6 The effect of solar collector area to the auxiliary boiler heat required, solar energy delivered and life cycle savings..... 71

Figure 6.7 Monthly renewable energy delivered and solar fraction achieved by the system 72

TABLES

Table 2.1	Ambient temperature (°C) for three cities in Indonesia	11
Table 2.2	NASA data -Ambient temperature (°C) and RH (%) for three cities in Indonesia	12
Table 5.1	Comparison matrix of the generator jacket models	45
Table 5.2	Diameter and number of orifices on the generator jacket	47
Table 5.3	Variation on generator surface temperature at various heats and temperature input	49
Table 5.4	Weather data for Kupang – Eastern Region of Indonesia	53
Table 5.5	Test slope value of parabolic trough based on Indonesian weather conditions	57
Table 5.6	The solar collector area and its effect to the auxiliary boiler heat required,	61
Table 5.7	Economic analysis on the solar absorption compared to vapour compression chiller	62

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 ($^{\circ}C$)
T_{avg}	= average temperature ($^{\circ}C$)
T_f	= fluid temperature ($^{\circ}C$)
T_{max}	= maximum temperature ($^{\circ}C$)
T_{min}	= minimum temperature ($^{\circ}C$)
T_s	= surface temperature ($^{\circ}C$)
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 <i>et al.</i> , 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°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).

Penerbit Deepublish (CV BUDI UTAMA)

Jl. Kaliurang Km 9,3 Yogyakarta 55581

Telp/Fax : (0274) 4533427

Anggota IKAPI (076/DIY/2012)

✉ cs@deepublish.co.id

📖 Penerbit Deepublish

📍 [@penerbitbuku_deepublish](https://www.instagram.com/penerbitbuku_deepublish)

🌐 www.penerbitdeepublish.com

