

**NAVIGATION**

[Home](#)
[About the Journal](#)
[Editors](#)
[Submit a Manuscript](#)
[Author Guidelines](#)
[Search](#)
[Current Volume](#)
[Archives](#)
[Reviewers](#)
[Special Issues](#)
[New Journal Proposals](#)

[Author/Reviewer/Editor Login](#)

Frontiers in Heat and Mass Transfer (FHMT)

An International Journal

A premiere open-access and peer-reviewed frontier journal site, serving the needs of the Heat and Mass Transfer community. Frontiers in Heat and Mass Transfer has the same submission and acceptance process - including peer review - as traditional publishing, but the works are published online and are available globally to view and download. See the latest research or submit an article.

All papers published by in Frontiers in Heat and Mass Transfer are indexed in [Web of Science](#), [Compendex](#), [Scopus](#), [Directory of Open Access Journals \(DOAJ\)](#), Google, Google Scholar and [Open J-Gate](#).



The Frontiers in Heat and Mass Transfer is a peer-reviewed online journal that provides a central vehicle for the exchange of basic ideas in heat and mass transfer between researchers and engineers around the globe. It disseminates information of permanent interest in the area of heat and mass transfer. Theory and fundamental research in heat and mass transfer, numerical simulations and algorithms, experimental techniques and measurements as they applied to all kinds of applied and emerging problems are welcome. Contributions to the journal consist of original research on heat and mass transfer in equipment, thermal systems, thermodynamic processes, nanotechnology, biotechnology, information technology, energy and power, security and related topics.

[ARCHIVES](#) | [CURRENT VOLUME](#)

Frontiers in Heat Pipes (FHP) has been merged into *Frontiers in Heat and Mass Transfer (FHMT)* in 2017. The papers published in FHP between 2010 and 2016 (Vol. 1 – 7) can be accessed [here](#).

Read [Editorial Announcement](#) about the merge.

JOURNAL CONTENT

Search

Browse

[By Volume](#)
[By Author](#)
[By Title](#)
[Other Journals](#)

FONT SIZE



Front. Heat Mass Transf.

NAVIGATION

[Home](#)
[About the Journal](#)
[Editors](#)
[Submit a Manuscript](#)
[Author Guidelines](#)
[Search](#)
[Current Volume](#)
[Archives](#)
[Reviewers](#)
[Special Issues](#)
[New Journal Proposals](#)

[Author/Reviewer/Editor Login](#)

Editorial Policies

- » [Scope](#)
- » [Types of Articles](#)
- » [Peer Review Process](#)
- » [Copyright Policy](#)
- » [Why publish in Frontiers in Heat and Mass Transfer \(FHMT\)](#)
- » [Indexing](#)

Scope

Frontiers in Heat and Mass Transfer is a free-access and peer-reviewed online journal that provides a central vehicle for the exchange of basic ideas in heat and mass transfer between researchers and engineers around the globe. It disseminates information of permanent interest in the area of heat and mass transfer. Theory and fundamental research in heat and mass transfer, numerical simulations and algorithms, experimental techniques and measurements as applied to all kinds of current and emerging problems are welcome. Contributions to the journal consist of original research on heat and mass transfer in equipment, thermal systems, thermodynamic processes, nanotechnology, biotechnology, information technology, energy and power applications, as well as security and related topics.

Types of Articles

Thermal-Fluids Central accepts submissions of the following types of articles. All types articles submitted are subject to rigorous peer review.

- Editorials
- Review Articles
- Research Papers
- Technical Briefs
- Discussions
- Closures
- Book Reviews
- Announcements
- Errata

Peer Review Process

Once the paper is submitted, it will be assigned to an editor who will screen the paper to make sure that it fits the scope of the journal. The editor will also assess the quality of the paper before assigning it to reviewers. If it is deemed that the paper does not fit into the scope of the journal or the quality of the paper is obviously below the standard of publication, the authors will be notified promptly, and the paper will not be sent to reviewers.

Once the paper passed the initial screen and assessment by the editor, it will be assigned to the reviewers who are active researchers in the subject of the paper. The single-blind review process is employed in that the identity of the reviewers is completely anonymous to the authors while the authors' identity is known to the reviewers. The reviewers are asked to comment on the quality of the paper based on its originality and quality of writing in three weeks. The reviewers who did not submit their reviews on time will be reminded, and additional reviewers may be sought if necessary.

Based on the comments received from the reviewers, the editor will make an initial decision to (a) accept the paper, (b) ask the authors to revise the paper, or (c) reject the paper. If the authors are asked to revise their paper, they will have two weeks to submit the revised paper and rebuttal. The final acceptance of the paper will be based on the assessment of the editor based on the revised paper and rebuttal.

Once the paper is accepted for publication, the authors will be asked to format the paper based on the template of the journal before the paper can be sent to the publisher for publication.

Copyright Policy

The articles that appear in all journals published by Global Digital Central are distributed under the [Creative Commons Attribution](#)

JOURNAL CONTENT

Search

Browse

[By Volume](#)
[By Author](#)
[By Title](#)
[Other Journals](#)

FONT SIZE



Front. Heat Mass Transf.

NAVIGATION

[Home](#)
[About the Journal](#)
[Editors](#)
[Submit a Manuscript](#)
[Author Guidelines](#)
[Search](#)
[Current Volume](#)
[Archives](#)
[Reviewers](#)
[Special Issues](#)
[New Journal Proposals](#)

[Author/Reviewer/Editor Login](#)

Editors

Founding Editor and Editor-in-Chief

[Amir Faghri](#)
University of Connecticut
E-mail: faghri@engr.uconn.edu

Co-Editor-in-Chief

[Yuwen Zhang](#)
University of Missouri
E-mail: zhangyu@missouri.edu

Editorial Board

[Aliakbar Akbarzadeh](#), RMIT University, Australia
[Cristina H. Amon](#), University of Toronto, Canada
[Yutaka Asako](#), Universiti Teknologi Malaysia, Malaysia
[Theodore L. Bergman](#), University of Kansas, USA
[Yiding Cao](#), Florida International University, USA
[Gang Chen](#), Massachusetts Institute of Technology, USA
[Li Chen](#), Xi'an Jiaotong University, China
[Jacob N. Chung](#), University of Florida, USA
[Vijay K. Dhir](#), University of California, Los Angeles, USA
[Ashley Emery](#), University of Washington, USA
[Mohammad Faghri](#), University of Rhode Island, USA
[Manfred Groll](#), University of Stuttgart, Germany
[Z.Y. Guo](#), Tsinghua University, China
[Je-Chin Han](#), Texas A&M University, USA
[Ya-Ling He](#), Xi'an Jiaotong University, China
[John R. Howell](#), University of Texas at Austin, USA
[Yogesh Jaluria](#), Rutgers University, USA
[Massoud Kaviany](#), University of Michigan, USA
[Masahiro Kawaji](#), The City College of New York, USA
[Yasushi Koite](#), Kumamoto University, Japan
[Stéphane Launay](#), Université d'Aix-Marseille, France
[W.J. Minkowycz](#), University of Illinois at Chicago, USA
[Masataka Mochizuki](#), Fujikura Ltd., Japan
[Patrick H. Oosthuizen](#), Queen's University, Canada
[G.P. "Bud" Peterson](#), Georgia Institute of Technology, USA
[Joel Plawsky](#), Rensselaer Polytechnic Institute, USA
[Bengt Sundén](#), Lund Institute of Technology, Sweden
[Raymond Viskanta](#), Purdue University, USA
[Chao Xu](#), North China Electric Power University, China
[Jinliang Xu](#), North China Electric Power University, China
[Yimin Xuan](#), Nanjing University of Science and Technology, China
[T.S. Zhao](#), Hong Kong University of Science and Technology, Hong Kong

JOURNAL CONTENT

Search

Browse

[By Volume](#)
[By Author](#)
[By Title](#)
[Other Journals](#)

FONT SIZE

ISSN: 2151-8629

[Back](#)

**NAVIGATION**

[Home](#)
[About the Journal](#)
[Editors](#)
[Submit a Manuscript](#)
[Author Guidelines](#)
[Search](#)
[Current Volume](#)
[Archives](#)
[Reviewers](#)
[Special Issues](#)
[New Journal Proposals](#)

[Author/Reviewer/Edito](#)
[Login](#)

Front. Heat Mass Transf. in heat and mass transfer, numerical simulations and algorithms, experimental techniques and measurements as applied to all kinds of current and emerging problems are welcome. Contributions to the journal consist of original research on heat and mass transfer in equipment, thermal systems, thermodynamic processes, nanotechnology, biotechnology, information technology, energy and power applications, as well as security and related topics.

Types of Articles

Thermal-Fluids Central accepts submissions of the following types of articles. All types articles submitted are subject to rigorous peer review.

- Editorials
- Review Articles
- Research Papers
- Technical Briefs
- Discussions
- Closures
- Book Reviews
- Announcements
- Errata

Peer Review Process

Once the paper is submitted, it will be assigned to an editor who will screen the paper to make sure that it fits the scope of the journal. The editor will also assess the quality of the paper before assigning it to reviewers. If it is deemed that the paper does not fit into the scope of the journal or the quality of the paper is obviously below the standard of publication, the authors will be notified promptly, and the paper will not be sent to reviewers.

Once the paper passed the initial screen and assessment by the editor, it will be assigned to the reviewers who are active researchers in the subject of the paper. The single-blind review process is employed in that the identity of the reviewers is completely anonymous to the authors while the authors' identity is known to the reviewers. The reviewers are asked to comment on the quality of the paper based on its originality and quality of writing in three weeks. The reviewers who did not submit their reviews on time will be reminded, and additional reviewers may be sought if necessary.

Based on the comments received from the reviewers, the editor will make an initial decision to (a) accept the paper, (b) ask the authors to revise the paper, or (c) reject the paper. If the authors are asked to revise their paper, they will have two weeks to submit the revised paper and rebuttal. The final acceptance of the paper will be based on the assessment of the editor based on the revised paper and rebuttal.

Once the paper is accepted for publication, the authors will be asked to format the paper based on the template of the journal before the paper can be sent to the publisher for publication.

Copyright Policy

The articles that appear in all journals published by Global Digital Central are distributed under the [Creative Commons Attribution License](#).

A brief summary of this license agreement is given below:

- The authors of the article retain the copyright.
- Global Digital Central is granted a license to publish the article as the original publisher in any medium.
- Authors grant any third party the right to unrestricted use, distribution and reproduction in any medium, provided that the original authors, citation details, and publisher are identified.

The deed of the license may be found

at <http://creativecommons.org/licenses/by/3.0/>. The full legal code of the license is available at <http://creativecommons.org/licenses/by/3.0/legalcode>.

Authors' Certification

In submitting an article to any of the journals published by Global Digital Central authors agree that:

1. They are authorized by their co-authors to submit their work for publication to Global Digital Central.

JOURNAL CONTENT

Search

All

Browse

[By Volume](#)
[By Author](#)
[By Title](#)
[Other Journals](#)

FONT SIZE

2. They warrant, on behalf of themselves and their co-authors, that:

- a.** the article is original, has not been published in any other journal, is not under consideration by any other journal and does not infringe any existing copyright or any other third party rights;
- b.** They have already obtained permission from the original copyright owners if they are using materials including figures and/or tables from other sources in their article to be published by Global Digital Central;
- c.** They are the sole author(s) of the article and have full authority to publish their work with Global Digital Central and they are not in breach of any other obligation. The article contains nothing that is unlawful or which would, if published, constitute a breach of contract of commitment given to secrecy.

Why publish in Frontiers in Heat and Mass Transfer (FHMT)

The following is a list of the specific advantages and benefits Frontiers has over other thermal-fluids journals:

- Premiere open-access and stringent peer and rapid review
- No cost to readers
- Unlimited world-wide use and distribution
- No color constraints
- FHMT peer reviewed journal issues and volumes are made permanently available electronically on a technical central website (**Thermal-Fluids Central**) that is used globally by the thermal-fluids community. This website also provides users with access to all relevant materials on heat and mass transfer, thermodynamics, fluid mechanics, combustion, and multiphase systems. Best of all, access to the materials is provided free-of-charge, with few licensing and copyright restrictions
- The **Thermal-Fluids Central** website also provides the global community with instant, free access to e-books, journals, encyclopedia, e-resources, events, jobs, news, who is who, and forums (all without any advertisements). **Thermal-fluids Central's** philosophy is to provide the thermal community free and easy access to and exchange of relevant information for maximum impact at a one-stop information resource center
- FHMT articles reach a wider audience faster than traditional distribution methods
- Increased readership often means increased citations and research impact
- The journal system features a powerful search engine for user convenience
- Frontiers journals have access to over 8,000 comprehensive directories of who is who in global thermal-fluids community for review and marketing
- Gives users the option of having automatic notification when new issues are published.

Indexing

All papers published by in Frontiers in Heat and Mass Transfer are indexed in [Web of Science](#), [Compendex](#), [Scopus](#), [Directory of Open Access Journals \(DOAJ\)](#), [Google](#), and [Google Scholar](#). Global Digital Central is an active member of [CrossRef](#), which is a citation linking network that spans millions of resources (including journals, books, conferences, dissertations, datasets, gray literature and other materials), spanning several centuries. This membership ensures the papers published in all Global Digital Central journals will be accessible to and cited by authors of other peer-reviewed journal papers published by thousands of publishers around the globe.

TCCN-2151-9670



←

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

Frontiers in Heat and Mass Transfer

COUNTRY

United States

Universities and research institutions in United States

SUBJECT AREA AND CATEGORY

Engineering
Engineering (miscellaneous)

PUBLISHER

Global Digital Central

22

Materials Science
Materials Science (miscellaneous)

Physics and Astronomy
Physics and Astronomy (miscellaneous)

PUBLICATION TYPE

Journals

ISSN

21518629

COVERAGE

2010-2021

INFORMATION

[Homepage](#)

How to publish in this journal

faghri@engr.uconn.edu

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

SCOPE

Frontiers in Heat and Mass Transfer is a free-access and peer-reviewed online journal that provides a central vehicle for the exchange of basic ideas in heat and mass transfer between researchers and engineers around the globe. It disseminates information of permanent interest in the area of heat

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

Join the conversation about this journal

←

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

Quartiles
USA

←

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

FIND SIMILAR JOURNALS ⓘ

1
Heat Transfer - Asian Research
USA

85%
similarity

2
Heat Transfer Research
USA

83%
similarity

3
Computational Thermal Sciences
USA

82%
similarity

4
Journal of Thermal Science and Engineering Applications
USA

81%
similarity

SJR

↗ ↘

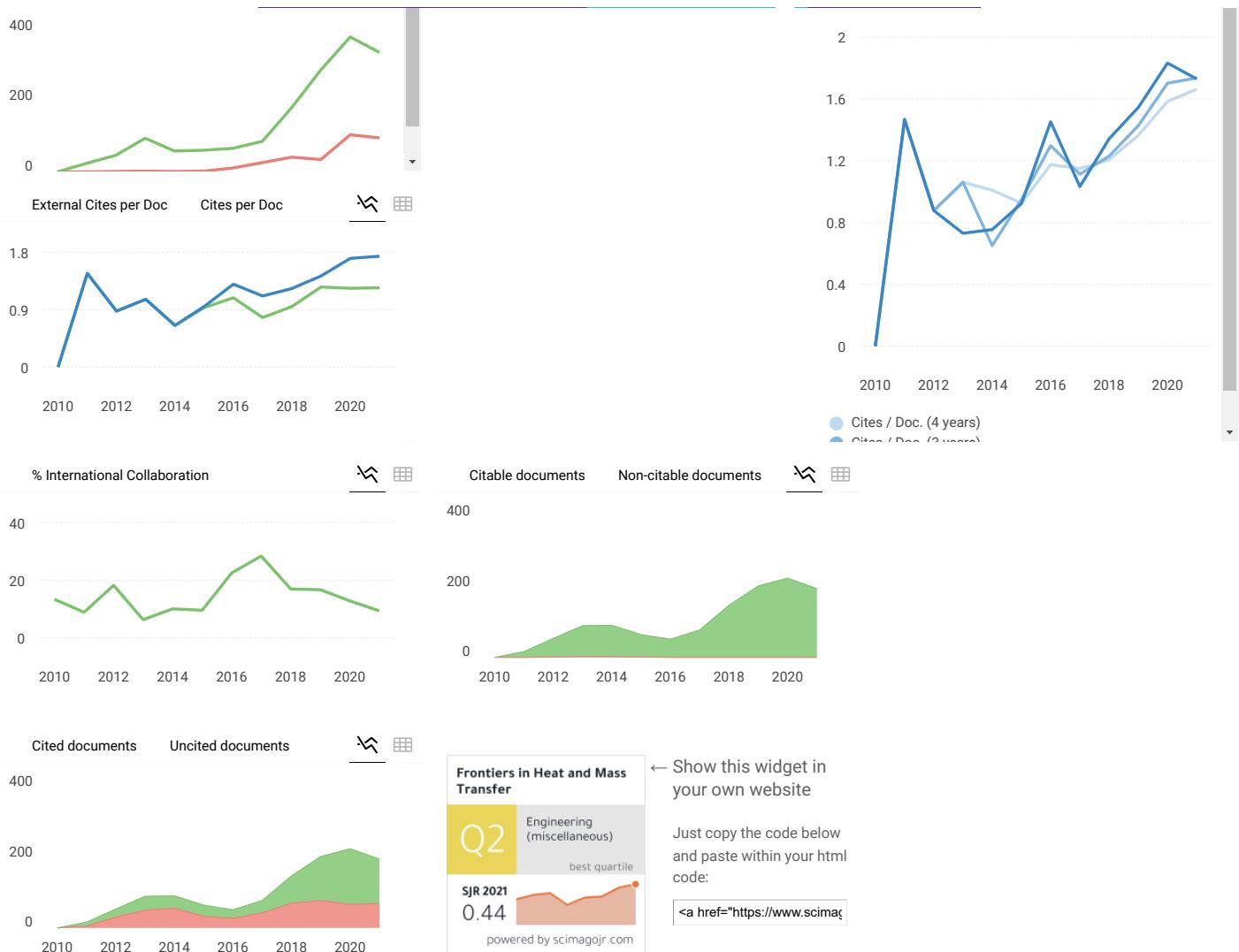
Total Documents

↗ ↘



Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)



SCImago Graphica

Explore, visually communicate and make sense of data with our [new data visualization tool](#).



←

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)

Metrics based on Scopus® data as of April 2022

▼

←

Ads by Google

[Send feedback](#) [Why this ad? ⓘ](#)



Source details

Frontiers in Heat and Mass Transfer

CiteScore 2021

3.4

Open Access

Scopus coverage years: from 2010 to Present

Publisher: Global Digital Central

SJR 2021

0.439

ISSN: 2151-8629

Subject area: Engineering: General Engineering, Physics and Astronomy: General Physics and Astronomy

SNIP 2021

0.697

Source type: Journal

[View all documents >](#)[Set document alert](#)[Save to source list](#)[Export content for category](#)[CiteScore](#)[CiteScore rank & trend](#)[Scopus content coverage](#)

CiteScore rank 2021

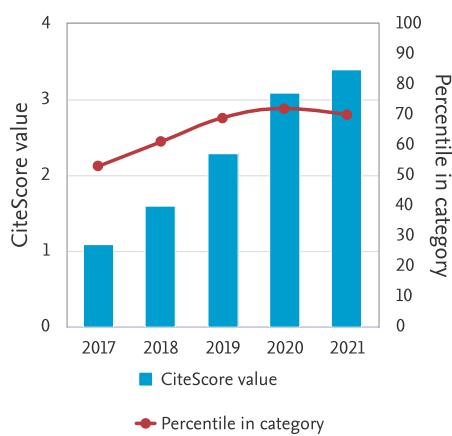


In category: General Engineering



	#89	Frontiers in Heat and Mass Transfer	3.4	70th percentile
	Rank	Source title	CiteScore 2021	Percentile
	#1	ACS Nano	24.3	99th percentile
	#2	Advanced Science	20.8	99th percentile
	#3	Computers in Industry	16.9	99th percentile
	#4	Engineered Science	16.6	98th percentile
	#5	Composites Science and Technology	14.7	98th percentile
	#6	Engineering	14.5	98th percentile
	#7	International Journal of Engineering Science	14.0	97th percentile
	#8	Nano Convergence	12.4	97th percentile
	#9	Expert Systems with Applications	12.2	97th percentile
	#10	Engineering with Computers	10.7	96th percentile
	#11	Technovation	10.1	96th percentile
	#12	Computers and Industrial Engineering	9.7	96th percentile
	#13	Advances in Engineering Software	9.3	95th percentile
	#14	International Journal of Human Computer Studies	9.2	95th percentile
	#15	Journal of Technology Transfer	9.2	95th percentile

CiteScore trend



[General Information](#)[Web of Science Coverage](#)[Journal Citation Report](#)[Open Access Information](#)[Peer Review Information](#)[!\[\]\(4e9db7091c22bfa9fd8343485308f15c_img.jpg\) Return to Search Results](#)

FRONTIERS IN HEAT AND MASS TRANSFER

[!\[\]\(eb1074bfd91059c9cff57cf6b5c22a5b_img.jpg\) Share This Journal](#)ISSN / eISSN **2151-8629**Publisher **GLOBAL DIGITAL CENTRAL, PO BOX 257, COLUMBIA, USA, MO, 65201**

General Information

Journal Website [!\[\]\(cab4bf952ad41dda9681cfcbefe1a76e_img.jpg\) Visit Site](#)**Publisher Website** [!\[\]\(6bc4b343b861c616a5d1dab713eb3b6d_img.jpg\) Visit Site](#)**1st Year Published** 2010**Frequency** Semi-annual**Issues Per Year** 2**Country / Region** UNITED STATES OF AMERICA**Primary Language**  English**Aims and Scope**  [!\[\]\(e6ec33cda9d7d6ff9602f3d99b50365f_img.jpg\) Visit Site](#)**Editorial Board**  [!\[\]\(465c8f2d92edf7347825fb00e1ffc0be_img.jpg\) Visit Site](#)**Instructions for Authors** [!\[\]\(655ca49b60b1fb606a1a3d8b3606d885_img.jpg\) Visit Site](#)**Avg. Number of Weeks from Submission to Publication**  6**Article DOIs**  Yes**Host Platform** Global Digital Central**Full-Text Formats**  PDF

Web of Science Coverage

Collection	Index	Category	Similar Journals
------------	-------	----------	------------------

[!\[\]\(cec9952b0974eeec17ee4fad502e6e34_img.jpg\) Find Similar Journals](#)[Search a topic within this journal](#)

5



Search a topic within this journal...

Search

Journal Citation Report™ (JCR)



Journal Citation Reports™ 2022

Journal Citation Indicator (JCI)

NEW METRIC

The Journal Citation Indicator is a measure of the average Category Normalized Citation Impact (CNCI) of citable items (articles & reviews) published by a journal over a recent three year period. It is used to help you evaluate journals based on other metrics besides the Journal Impact Factor (JIF).

2021

0.32

Category:
Thermodynamics

2020

0.33

Category:
Thermodynamics

[Learn About Journal Citation Indicator](#)

Open Access Information



OA Statement i

[Visit Site](#)

License i



[Visit Site](#)

**Author Holds Copyright without
Restrictions i**

Yes

Full-Text Crawling Permitted i

Yes

**Unrestricted Reuse in Compliance with
BOAI i**

Yes

DOAJ Seal i

No

DOAJ Subjects / Keywords i

Energy, Heat transfer, Mass transfer,
Science: Physics: Heat, Thermal systems,
Thermodynamics

5





Front. Heat Mass Transf.

NAVIGATION

[Home](#)
[About the Journal](#)
[Editors](#)
[Submit a Manuscript](#)
[Author Guidelines](#)
[Search](#)
[Current Volume](#)
[Archives](#)
[Reviewers](#)
[Special Issues](#)
[New Journal Proposals](#)

[Author/Reviewer/Editor Login](#)

Vol. 19 (2022)

Table of Contents

[AN ULTIMATE SOLUTION TO PHASING OUT FOSSIL FUELS - PART I: UTILITY-SCALE UNDERGROUND HOT-WATER STORAGE \(USUHWS\) FOR POWER PRODUCTION AND HEAT SUPPLY](#)

Yiding Cao
Florida International University,

Frontiers in Heat and Mass Transfer (FHMT) 19 - 1 (2022)

[PDF](#)

[AN ULTIMATE SOLUTION TO PHASING OUT FOSSIL FUELS - PART II: AIR-WATER THERMAL POWER PLANTS FOR UTILITY-SCALE POWER PRODUCTION AT LOW TEMPERATURES](#)

Yiding Cao
Florida International University, United States

Frontiers in Heat and Mass Transfer (FHMT) 19 - 2 (2022)

[PDF](#)

[EFFECT OF TERM OF ERROR ON WET BULB TEMPERATURE MEASUREMENT USING ASPIRATION PSYCHROMETER](#)

V. W. Bhatkar^a, Anirban Sur^b, Anindita Roy^b
^a Marathwada Mitra Mandal's College of Engineering, India
^b Symbiosis Institute of Technology, India

Frontiers in Heat and Mass Transfer (FHMT) 19 - 3 (2022)

[PDF](#)

[COMBINED NATURAL CONVECTION AND SURFACE RADIATION IN A SQUARE CAVITY WITH THE INVERSELY LINEARLY HEATED OPPOSITE SIDE WALLS](#)

Ravi Shankar Prasad , Ujjwal Kumar Nayak , Rajen Kumar Nayak , Amit Kumar Gupta
B.I.T. Sindri, India

Frontiers in Heat and Mass Transfer (FHMT) 19 - 4 (2022)

[PDF](#)

[NUMERICAL STUDY ON HEAT TRANSFER CHARACTERISTICS OF CORRUGATED TUBE PHASE CHANGE THERMAL ENERGY STORAGE UNIT](#)

Kun Zhang , Zhiyong Li , Jia Yao
Lanzhou Jiaotong University, China

Frontiers in Heat and Mass Transfer (FHMT) 19 - 5 (2022)

[PDF](#)

[CFD SIMULATION IN THERMAL-HYDRAULIC ANALYSIS OF AIRFLOW ON DIFFERENT ATTACK ANGLES OF ROW FLAT TUBE](#)

Farhan Lafta Rashid^a , Sarmad Kamal Fakhrulldin^b , Muhammad Asmail Eleiwi^c , Ahmed Kadhim Hussein^d , Tahseen Ahmad Tahseen^e , Obai Younis^f , Mohammed Ibrahim Ahmed^f
^a University of Kerbala, Iraq
^b University of Kirkuk, Iraq
^c Tikrit University, Iraq
^d University of Babylon, Iraq
^e University of Kirkuk, Iraq
^f Prince Sattam Bin Abdulaziz University, Saudi Arabia

Frontiers in Heat and Mass Transfer (FHMT) 19 - 6 (2022)

[PDF](#)

[ANALYTICAL STUDY OF THERMAL PERFORMANCE OF A JET PLATE SOLAR AIR HEATER WITH THE LONGITUDINAL FINS UNDER THE CROSS FLOW AND NON-CROSS FLOW CONDITIONS](#)

Rajen Kumar Nayak , Ravi Shankar Prasad , Ujjwal Kumar Nayak , Amit

JOURNAL CONTENT

Search

 All

Browse

[By Volume](#)
[By Author](#)
[By Title](#)
[Other Journals](#)

FONT SIZE

Kumar Gupta
B.I.T. Sindri, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 7 (2022)

[THE EFFECTS OF NUSSELT, REYNOLDS NUMBER, AND PRESSURE DROP ON THE THERMAL PERFORMANCE OF PIERCED PIN FINS](#)

[PDF](#)

Wadahah Hussein Al doori
University of Tikrit, Iraq

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 8 (2022)

[VISUALIZATION OF INDUCED COUNTER-ROTATING VORTICES FOR ELECTRIC VEHICLES BATTERY MODULE THERMAL MANAGEMENT](#)

[PDF](#)

A.C. Budiman^a, S. M. Hasheminejad^b, S. Sudirja^a, A. Mitayani^a, S.H. Winoto^c

^a National Research and Innovation Agency, Indonesia

^b Iran University of Science and Technology, Iran, Islamic Republic Of

^c National University of Singapore, Singapore

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 9 (2022)

[STUDY ON HEAT TRANSFER AUGMENTATION IN AN AIR HEATER USING RECTANGULAR WAVY FIN TURBULATORS](#)

[PDF](#)

Nitesh Kumar , Shiva Kumar
Manipal Institute of Technology, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 10 (2022)

[NUMERICAL AND EXPERIMENTAL INVESTIGATION OF NONLUBRICATED AIR SCROLL EXPANDER DERIVED FROM A REFRIGERANT SCROLL COMPRESSOR](#)

[PDF](#)

Aparna Kottapalli , Rama Krishna Konijeti
Koneru Lakshmaiah Education Foundation, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 11 (2022)

[EFFECT OF DIFFUSION-THERMO ON MHD FLOW OF MAXWELL FLUID WITH HEAT AND MASS TRANSFER](#)

[PDF](#)

Muhammad Ramzan^a, Zaib Un Nisa^b, Mudassar Nazar^a
^a Bahauddin Zakariya University, Pakistan
^b University of Education Lahore, Pakistan

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 12 (2022)

[RESEARCH ON A NOVEL CONCEPT OF SELF-FORMING AIR COOLING BATTERY RACK](#)

[PDF](#)

Mingjie Zhang^a, Kai Yang^a, Le Qin^b, Xiaole Yao^b, Qian Liu^b, Xing Jub
^a China Electric Power Research Institute, China
^b North China Electric Power University, China

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 13 (2022)

[NUMERICAL ANALYSIS TO PREDICT THE BEHAVIOR OF LIQUID VAPOR SLUG FLOW IN VERTICALLY PLACED U-SHAPED CLOSED CAPILLARY TUBE](#)

[PDF](#)

Roshan Devidas Bhagat , Samir J. Deshmukh
Prof. Ram Meghe Institute of Technology and Research, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 14 (2022)

[EXERGY ANALYSIS OF A REFRIGERATION SYSTEM WITH A MINICHANNEL CONDENSER USING R134A REFRIGERANT](#)

[PDF](#)

Vijay W. Bhatkar^a, Anirban Sur^b, Anindita Roy^b
^a Marathwada Mitra Mandal's College of Engineering, India
^b Symbiosis Institute of Technology, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 15 (2022)

[NUMERICAL INVESTIGATION OF COUPLED NATURAL CONVECTION AND SURFACE RADIATION IN A SQUARE CAVITY WITH THE LINEARLY HEATED SIDE WALL\(S\)](#)

[PDF](#)

Ravi Shankar Prasad^a, S. N. Singh^b, Amit Kumar Gupta^a

^a B.I.T. Sindri, India^b Indian Institute of Technology, India

Frontiers in Heat and Mass Transfer

(FHMT) 19 - 16 (2022)

[ENTROPY GENERATION OF THREE DIMENSIONAL BINGHAM NANOFIUID FLOW WITH CARBON NANOTUBES PASSING THROUGH PARALLEL PLATES](#) [PDF](#)

P.S.S. Nagalakshmi , N. Vijaya
Koneru Lakshmaiah Education Foundation,
India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 17 (2022)

[STUDY ON THERMAL-HYDRAULIC PERFORMANCE OF THE PRINTED CIRCUIT HEAT EXCHANGER WITH AIRFOIL FINS FOR SUPERCRITICAL LIQUEFIED NATURAL GAS](#) [PDF](#)

Yulin Tian^a , Chengyi Long^b , Linghong Tang^a

^a Xi'an Shiyou University, China
^b Wuhan Second Ship Design and Research Institute, China

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 18 (2022)

[PREDICTING THE WAX DEPOSITION RATE BASED ON EXTREME LEARNING MACHINE](#) [PDF](#)

Qi Zhuang^a , Zhuo Chen^b , Dong Liu^c , Yangyang Tian^c

^a PetroChina Changqing Oilfield Company, China
^b Sinopec Northwest Oil field Company, China
^c Xi'an Shiyou University, China

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 19 (2022)

[EXAMINATION OF CONVECTIVE HEAT TRANSFER AND ENTROPY GENERATION BY TWO ADIABATIC OBSTACLES INSIDE A CAVITY AT DIFFERENT INCLINATION ANGLES](#) [PDF](#)

Olanrewaju M. Oyewola^a , Samuel I. Afolabi^b

^a Fiji National University, Fiji
^b University of Ibadan, Nigeria

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 20 (2022)

[THERMAL-HYDRAULIC ANALYSIS OF TRANSIENT CONJUGATE HEATING BETWEEN HEMI-SPHERICAL BODY AND AIR](#) [PDF](#)

Farhan Lafta Rashid^a , Abbas Fadil

Khalaf^a , Ahmed Kadhim Hussein^b , Mohamed Bechir Ben Hamida^c , Bagh Ali^d , Obai Younis^e
^a University of Kerbala, Iraq
^b University of Babylon, Iraq
^c Imam Mohammad Ibn Saud Islamic University, Saudi Arabia
^d Superior University, Pakistan
^e Prince Sattam Bin Abdulaziz University, Saudi Arabia

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 21 (2022)

[PERFORMANCE ANALYSIS OF LONGITUDINAL FIN JET PLATE SOLAR AIR HEATER UNDER CROSS FLOW CONDITION](#) [PDF](#)

Rajen Kumar Nayak , Ravi Shankar Prasad , Ujjwal Kumar Nayak , Amit Kumar Gupta
B.I.T. Sindri, India

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 22 (2022)

[EFFECTS OF VISCOS DISSIPATION AND AXIAL HEAT CONDUCTION ON FORCED CONVECTION DUCT FLOW OF HERSCHEL-BULKLEY FLUID WITH UNIFORM WALL TEMPERATURE OR CONVECTIVE BOUNDARY CONDITIONS](#) [PDF](#)

Rabha Khatyr , Jaafar Khalid Naciri
Hassan II University, Morocco

Frontiers in Heat and Mass Transfer
(FHMT) 19 - 23 (2022)

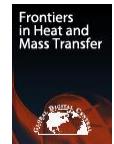
[USE OF SILVER NANOPARTICLES MIXED WITH DEIONIZED WATER IN A RECTANGULAR TWO-PHASE CLOSED THERMOSYPHON: A CASE STUDY OF THE TWO-PHASE FLOW](#) [PDF](#)

Namphon Pipatpaiboon^a , Teerapat Chompookham^b , Sampan Rittidech^b , Yulong Ding^c , Thanya Parametthanuwat^d , Surachet Sichamnan^a

^a Rajamangala University of Technology

*Isan, Thailand**^b Mahasarakham University, Thailand**^c University of Birmingham, United Kingdom**^d King Mongkut's University of Technology, Thailand**Frontiers in Heat and Mass Transfer
(FHMT) 19 - 24 (2022)*[PDF](#)THERMAL STUDY OF THE DRYER WITH
HEAT EXCHANGER PIPE INSTALLED IN RICE
HUSK DOUBLE FURNACE DURING DRYING
WHITE TURMERIC*Ida Bagus Alit^a, I Gede Bawa Susana^a, I Made Mara^a**University of Mataram, Indonesia**Frontiers in Heat and Mass Transfer
(FHMT) 19 - 25 (2022)*[PDF](#)IMPACT OF THREE DIFFERENT DOUBLE
BAFFLE DESIGNS ON THE THERMAL
PERFORMANCE OF SQUARE DUCTS*Amnart Boonloj^a, Withada Jedsadaratanachai^b**^a King Mongkut's University of Technology North Bangkok, Thailand**^b King Mongkut's Institute of Technology Ladkrabang, Thailand**Frontiers in Heat and Mass Transfer
(FHMT) 19 - 26 (2022)*[PDF](#)THERMOPHORESIS IMPACT ON A
MICROPOLAR FLUID UNDER CHANGEABLE
HEAT FLUX IN CONDUCTING FIELD*P. Chandra Reddy^a, B. Hari Babu^b, K. Sreenivasulu^b**^a Annamacharya Institute of Technology & Sciences, India**^b - - - - -*[About Us](#) | [Contact Us](#) | [Terms of Use](#) | [Privacy Policy](#) | [Disclaimer](#)

Copyright © 2010-2022 by Global Digital Central. All Rights Reserved.



THERMAL STUDY OF THE DRYER WITH HEAT EXCHANGER PIPE INSTALLED IN RICE HUSK DOUBLE FURNACE DURING DRYING WHITE TURMERIC

Ida Bagus Alit, I Gede Bawa Susana*, I Made Mara

Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125 Indonesia

ABSTRACT

The study compared solar dryers with hot air from a heat exchanger double furnace during the drying of white turmeric. Solar drying is the process of drying the product in the sun. The hot air dryer consists of two furnaces with heat exchanger pipes and a drying chamber with six vertical shelves. During the test, the use of rice husk energy in a constant amount of 35 kg. Temperature and drying rate are higher in hot air dryers. Tests carried out for 420 minutes resulted in a change in moisture content from 88% to 35.88% and an average temperature of 30.91°C in solar drying. For hot air, it was 2.7% at an average temperature of 73.65–119.12°C. The distribution of the average drying temperature on shelves 1 (bottom shelf), 2, 3, 4, 5, and 6 (top shelf) are 119.12°C, 104.99°C, 93.24°C, 79.99°C, 74.69°C, and 73.65°C. Dryer efficiency reached 32.81% at the beginning and 4.06% at the end. At the initial drying, efficiency occurs very high because the energy absorbed by the white turmeric from the dryer is very high. During the drying process, there is a decrease in efficiency because the energy absorbed by white turmeric decreases due to reduced moisture content.

Keywords: heat exchangers, rice husk, white turmeric

1. INTRODUCTION

Drying is one of the post-harvest handling methods to extend the storage life of the produce. The drying process with a dryer is needed to replace the disadvantages of the sun drying process. Small farmers desperately need a dryer that is easy to operate, affordable, energy-efficient sustainable drying. As in Indonesia, especially Lombok, with unpredictable weather, small farmers need the right dryer model. The dryer model utilizes rice husk as the primary energy through a conversion process into thermal. This process will increase the temperature and speed up the drying time of post-harvest agricultural products.

One of the agricultural products of concern today is turmeric. Turmeric is a spice plant as a cooking spice, a raw material for natural medicine and traditional herbal medicine. Turmeric or white turmeric is one of the herbal products that can be used to improve the body's immune system. White turmeric is known by the scientific name Curcuma Zedoaria. White turmeric is a traditional medicinal herb that is part of history in Ayurveda (Lobo *et al.*, 2009). In Indonesia, white turmeric is used as an ingredient in traditional herbal medicine and is widely consumed by many people. In the Yogyakarta Agriculture and Food Service (2021), it is explained that white turmeric functions to stimulate the immune system. This is caused by the content of specific active substances such as curcuminoide and ukanon types A, B, C, and D. To maintain the quality of turmeric, post-harvest handling is necessary, one of which is the drying process. This is because turmeric has a high moisture content at harvest of 90%. In the turmeric trade, the main product is in the form of dried turmeric. Some of the processed turmeric products include dried turmeric slices, flour, essential oils, oleoresins, and curcuminoid dyes (Manoi, 2013). To produce dry products of good quality, a dryer is needed. Inappropriate drying facilities in some developing countries cause post-harvest losses in the agricultural sector

(Nguimdo and Noumegnie, 2020). A dryer will shorten the drying time, and the resulting product will be cleaner and more hygienic than drying in the sun. Drying in the sun causes the resulting product to be dusty and hard, damaging the sensory and nutritional properties, especially in vegetables and fruits (Manaa *et al.*, 2013; Ochoa-Martinez *et al.*, 2012). In drying turmeric by drying, it takes up to 15 days, and the impact is that some of the turmeric are exposed to fungi (Widodo and Setyawan, 2018). The use of dryers that are easy to operate, affordable, and sustainable is very much needed by small farmers. This is suitable for small-scale drying conditions, and costs are limited. The dryer model is by utilizing agricultural waste as an energy source. One of the agricultural wastes that are easily found and cheap is rice husk.

Rice husk is a by-product of rice processing. Rice production in Indonesia in 2019 was 54.6 million metric tons, and 20% was in rice husks (Shahbandeh, 2021; Hossain *et al.*, 2018). For Lombok Island, rice production based on data in 2020 is 1.31 million tons of GKG (Badan Pusat Statistik, 2020), and the potential for rice husks is 269,420.20 tons in Lombok Island and 533,150.80 tons in West Nusa Tenggara (RUED, 2019). The potential of rice husk as an energy source can also be seen from its calorific value. The calorific value of rice husk is equivalent to half the calorific value of coal, namely 13–19 MJ/kg with an average of 18 MJ/kg (Smith, 2007) and 11–15.3 MJ/kg (Awulu *et al.*, 2018). The maximum temperature of direct combustion in the middle of a pile of rice husks is 560°C (Yan *et al.*, 2022) and 556.5°C in the combustion process using a stove (Tangka *et al.*, 2018). Using rice husks as an energy source can reduce agricultural waste and increase the income of small farmers. Biomass energy sources can expand economic status and meet the energy needs of rural communities in developing countries (UI Haq *et al.*, 2020). Rice husk is used as an energy source and produces clean and hygienic drying products through an energy conversion process. The energy conversion method uses a heat exchanger added to the furnace. Heat exchanger functions in the heat transfer process of two fluids with

* Corresponding author. Email: gedebawa@unram.ac.id

different temperatures and are separated by walls (Incropera *et al.*, 2006). This method produces hot air, which is used for the drying process. This method has been used in several studies on various types of biomass and foodstuffs (Nain *et al.*, 2021; Nwokolo *et al.*, 2020; Hamdani *et al.*, 2018). The method is also used for single-pipe and furnace variations with rice husk energy (Susana *et al.*, 2019a; Susana *et al.*, 2019b; Alit *et al.*, 2020).

The community commonly uses the direct sun-drying process. Nevertheless, it depends on the weather and the relatively long drying time. NTB, including Lombok Island, produced turmeric plant production in 2020, reaching 610,626 kg (NTB SATU DATA, 2020). Turmeric is indispensable to the community and requires optimal drying and heating. Slow drying rate and improper heating cause a loss of nutritional and medicinal value (Lakshmi *et al.*, 2019). The high moisture content of turmeric at harvest should be reduced to a safe storage limit of 6% (Singh *et al.*, 2010). This study aims to evaluate the performance of a dryer with rice husk as the main energy to dry white turmeric on a small scale as a substitute for sun drying. The conversion of rice husk to thermal using a double furnace and heat exchanger to optimize the drying temperature. This study also compared direct sun drying.

2. MATERIALS AND METHODS

This research is the development of research Alit and Susana (2021), which utilizes rice husk as an energy source by burning in a single furnace equipped with a heat exchanger. Research development Alit and Susana (2021) through double furnace and modification of drying chamber. The study used the same dryer design by Alit *et al.* (2021) and applied it to the white turmeric drying process on the scale of small farmers. Furnace and drying chamber designs are tailored to the needs of smallholders. The materials and tools used include white turmeric, rice husks, aluminum plates, stainless steel pipes, iron plates, exhaust fans, solar panels, batteries, type K thermocouples, and data loggers. Rice husk is used as the main energy source. Post-harvest agricultural products use white turmeric. The diameter of the heat exchanger pipe is 1 inch. The furnace dimensions are 40 cm x 50 cm x 60 cm from the iron plate. The dimensions of the drying chamber are 50 cm x 50 cm x 140 cm from the aluminum plate. Solar panels and batteries as energy storage for driving the exhaust fan.

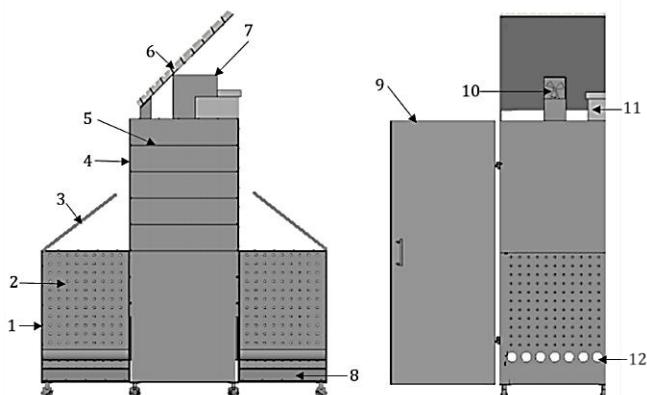
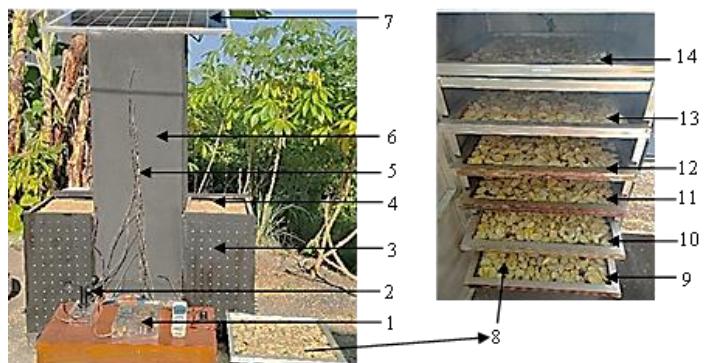


Fig. 1 Design of double furnace type dryer with rice husk energy

The dryer arrangement consists of two furnaces for directly burning rice husks and a drying chamber with six vertical shelves. At the bottom of the furnace, heat exchanger pipes are placed. Furnaces are placed on both sides of the drying chamber. Hot air in the drying chamber is obtained due to convection heat transfer from the heat exchanger pipe and conduction from the furnace. The drying chamber is isolated with 3 mm rubber insulating material and is equipped with an exhaust fan on the exhaust duct. The process of burning rice husks is assisted by the presence

of air circulation holes on the walls of the furnace. The diameter of the furnace wall hole is 8 mm. This diameter is used because the resulting temperature pattern is more stable and the smallest, based on previous studies (Alit *et al.*, 2021). The study evaluated the dryer's performance in drying white turmeric and compared it with sun drying. Evaluation based on drying temperature, moisture content of white turmeric, and drying rate. The drying time was set at 420 minutes, with the measurement of the moisture content carried out every 60 minutes. The mass of the sample is 4500 grams, distributed evenly on each shelf in the drying chamber. The sample mass of each shelf is 750 grams. For direct sun drying, use a sample of 1175 grams. Before drying, white turmeric is washed and sliced lengthwise with a thickness of 3 mm. The test uses a dryer design, as shown in Fig. 1, with the sample test method shown in Fig. 2.



1. Data logger; 2. Cup anemometer; 3. Furnace; 4. Rice husk; 5. Thermocouple K type; 6. Drying chamber; 7. Solar panel; 8. White turmeric; 9. Shelf 1; 10. Shelf 2; 11. Shelf 3; 12. Shelf 4; 13. Shelf 5; 14. Shelf 6

Fig. 2 White turmeric sample testing

The research data measured were the ambient temperature, the temperature of the heat exchanger pipe, the temperature of each shelf exiting the drying chamber, the initial mass, and the dry mass of white turmeric. The moisture content, drying rate, and drying efficiency can be calculated based on these data. The mass of white turmeric includes the initial mass, m_t (kg), and dry mass, m_k (kg). The dry mass of white turmeric, m_k (kg), was obtained by heating for 3 hours at a temperature of 105-110°C. The initial and dry masses were used to calculate the moisture content, K_a (%) (Henderson and Perry, 1976; Fridh *et al.*, 2014; Hamdani *et al.*, 2018).

$$K_a = \frac{m_t - m_k}{m_t} 100\% \quad (1)$$

The drying rate, \dot{m}_p (kg/s) was calculated based on the ratio of the mass of evaporated water, m_w (kg), to the drying time, t (hours) (Brooker *et al.*, 1992; Nazghelichi *et al.*, 2010).

$$\dot{m}_p = \frac{m_w}{t} \quad (2)$$

m_w was calculated based on the mass of white turmeric after drying m_p (kg) and the initial mass of white turmeric, m_t (kg).

$$m_w = m_t - m_p \quad (3)$$

The calculation of drying efficiency uses the ratio of the heat used for drying, Q (kJ), to the energy transfer from the air to the material being dried, q (kJ) (Cengel and Turner, 2004).

$$\eta = \frac{Q}{q} 100\% \quad (4)$$

Q (kJ) is the heat used for drying, as in Eq. (5).

$$Q = Q_1 + Q_2 \quad (5)$$

Q_1 is the heat to heat the material water (kJ). Q_2 is the amount of heat evaporating the water (kJ) (Hamdani *et al.*, 2018; Çengel and Boles, 2006). C_{pb} is the specific heat of white turmeric ($\text{kJ}/\text{kg}^\circ\text{C}$), T_b is the temperature of white turmeric ($^\circ\text{C}$), T_a is the ambient temperature ($^\circ\text{C}$), and h_{fg} is the latent heat of evaporation of water (kJ/kg).

$$Q_1 = m_t C_{pb}(T_b - T_a) \quad (6)$$

$$Q_2 = m_w h_{fg} \quad (7)$$

Based on Eq. (4), the energy transfer from the air to the dried material or q (kJ) is calculated using Eq. (8) (Incropera *et al.*, 2006).

$$q = \rho_u V_u C_{pu}(T_{in} - T_{out}) \quad (8)$$

ρ_u is the density of drying air (kg/m^3), C_{pu} is the specific heat of the air ($\text{kJ}/\text{kg}^\circ\text{C}$). T_{in} is the inlet air temperature, and T_{out} is the outlet air temperature.

3. RESULTS AND DISCUSSION

Initial measurement results show that white turmeric has a moisture content of 88%. Fig. 3 compares the moisture content of the drying process using a dryer and the sun.

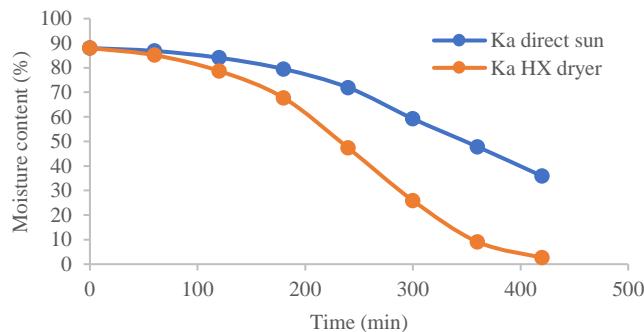


Fig. 3 The comparison of white turmeric moisture content (Ka) between direct sun drying and heat exchanger drying

The decrease in the moisture content of the material in the use of hot air is faster than direct sun drying. Hot air is generated using a double furnace dryer and heat exchanger with rice husk energy. At minute 420, white turmeric's moisture content reached 35.88% in direct sun drying, while for hot air, it reached 2.7% for all samples. The moisture content in hot air is calculated based on the total initial mass of white turmeric, 4500 grams, and a total dry mass of 540 grams. White turmeric experienced a significant decrease in moisture content when using hot air for drying. There was a decrease in the mass of the material by 88%. The moisture content of white turmeric based on all samples was calculated every 60 minutes. At 60 minutes, it is 85.108%, 120 minutes is 78.681%, 180 minutes is 67.703%, 240 minutes is 47.317%, 300 minutes is 25.926%, 360 minutes is 9.09%, and 420 minutes is 2.7%. This result is in line with Sharma *et al.* (2021), which showed that hot air drying of turmeric sliced with a thickness of 3 mm required a shorter time than direct sun drying.

Fig. 4 shows the distribution of moisture content and mass of white turmeric on each shelf in the drying chamber from drying with hot air. Slower drying occurs from 0 to 120 minutes. This follows the nature of rice husks. Namely, the combustion process begins with the evaporation of the moisture content of rice husks. Rice husk contains 8.8% moisture (Mhilu, 2014). The drying temperature increases as the rice husk turn into charcoal. The highest change in moisture content occurred in shelf 1 (ka-s1) followed by a rapid decrease in the mass of the material (ms1). The distribution of samples on each shelf is an initial mass of 750 grams with

an initial moisture content of 88%. On-shelf 1, it was found that at 240 minutes, the moisture content of the material was zero, and the mass did not change, which was constant at 90 grams (ms1) until 420 minutes. On-shelf 1, it was also found that a large change in moisture content occurred from 120 to 180 minutes, from 37.9 % to 1.1%. A different phenomenon was found on the shelf above it. The moisture content of the ingredients on shelf 2 (ka-s2) at minute 360 is zero with a mass of 90 grams (ms2) and at minute 300 is 5.3% with a mass of 95 grams. On-shelf 3, the moisture content of the material (ka-s3) reaches zero at 420 minutes with a mass of 90 grams. Unlike what happened on shelves 4, 5, and 6, it was found that the moisture content of the material at the end of the test (420 minutes) was 3.2% (ka-s4), 4.3% (ka-s5), and 8.2%, respectively (ka-s6) with a final mass of 93 grams (ms4), 94 grams (ms5), and 98 grams (ms6), respectively. The drying time is shorter when compared to the study by Borah *et al.* (2015) drying slices of turmeric samples using a solar conduction dryer which takes 12 hours to effectively reduce the moisture content from 78.65% to 5.5%.

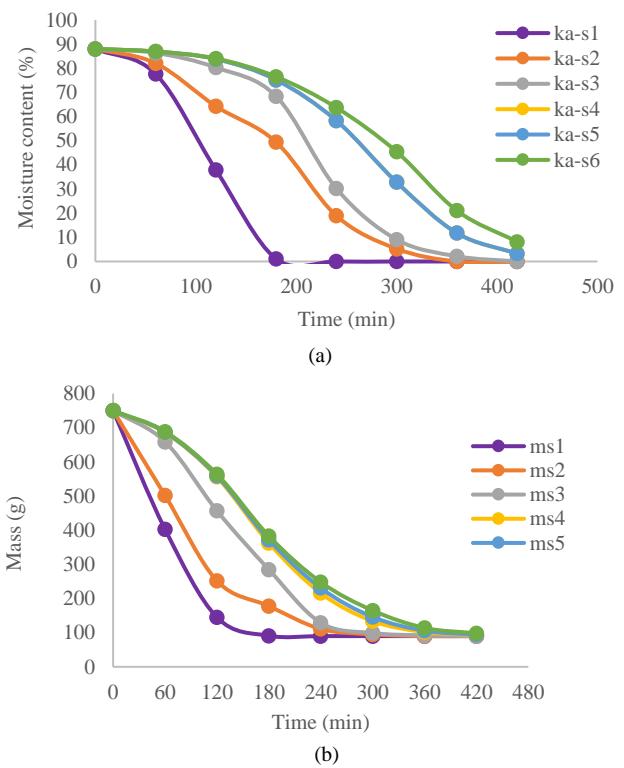
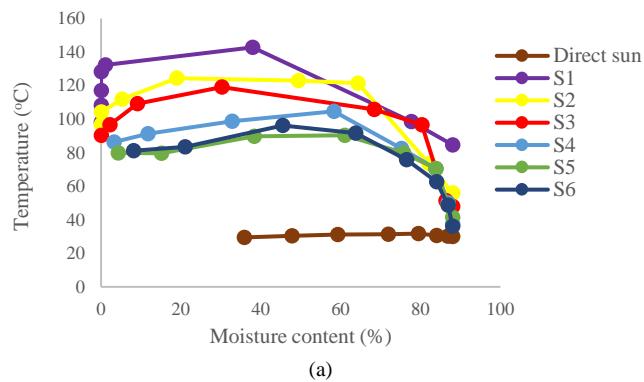


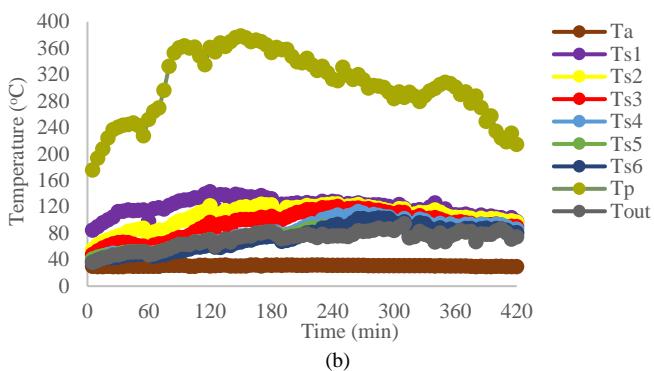
Fig. 4 The comparison of the (a) moisture content (ka-s), (b) mass (ms) of white turmeric on each shelf in the drying chamber

Differences in moisture content changes and material mass on each shelf follow the distribution pattern of hot air drying. The higher the drying temperature, the greater the reduction in moisture content of white turmeric, as shown in Fig. 5a. Shelf 1 has the closest position to the hot air source compared to shelf six, which is far away from the hot air source. This gives the impact of differences in changes in moisture content and mass of material. Based on the pattern of changes in moisture content, such as Fig. 4a, it was found that reaching the standard limit for the moisture content of dry white turmeric took a different time on each shelf in the drying chamber. This condition can be used as a reference for the drying time for each shelf. As in shelf 1, closest to the heat source, the highest drying temperature occurs, as shown in Fig. 5b. The average drying temperature on shelf 1 (T_s1) is 119.12°C with a range of 84.70 - 142.78°C . The highest temperature on shelf 1 compared to shelves 2, 3, 4, 5, and 6 with an average of 104.99°C (55.9 - 124.76°C), 93.24°C (48.02 - 120.79°C), 79.99°C (37.47 - 112.79°C), 74.69°C (41.43 - 95.44°C), and 73.65°C (36.15 - 103.22°C) respectively. The higher the drying temperature, the faster the white turmeric will decrease in moisture

content. This impacts the drying process of white turmeric on shelf one, which takes more time than the shelf above. This research is in line with Waheed and Komolafe (2019); Dasore *et al.* (2020) that an increase in temperature causes a decrease in drying time. In contrast, what happened to direct sun drying with a test time of 420 minutes was only able to reduce the moisture content of white turmeric by 47.826%. This is a result of the drying temperature not optimal. Drying only uses ambient temperature with an average of 30.91°C (29.48–32.06°C). The lower the temperature, the longer the operating time (Bevington and Robinson, 2003). The increase in the drying temperature causes the drying rate to be faster.



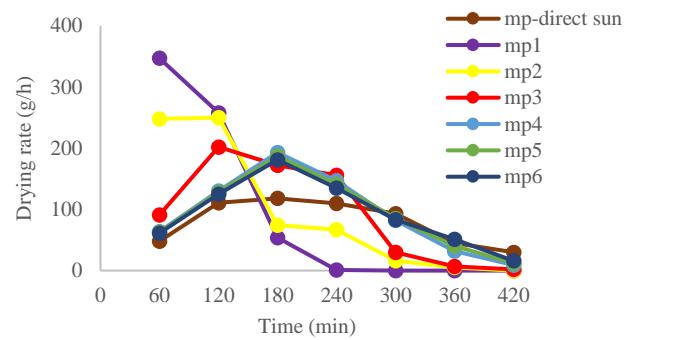
(a)



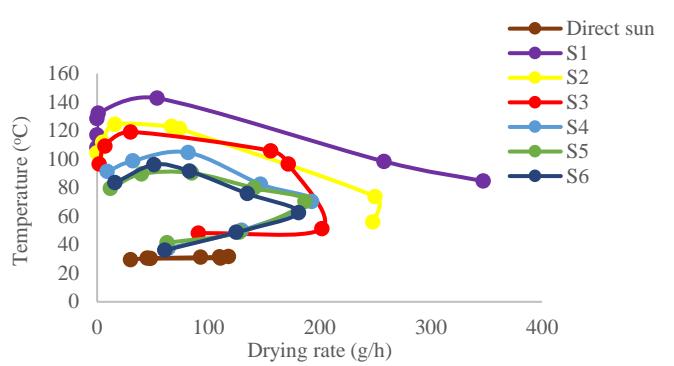
(b)

Fig. 5 (a) The comparison of white turmeric moisture content and (b) drying temperature distribution pattern

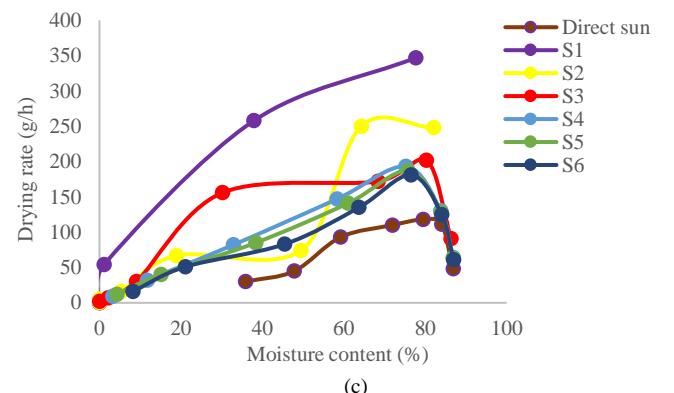
The comparison of drying rates using sun and hot air per hour is presented in Fig. 6a. In this study, it was found for a test time of 420 minutes that the drying rate using the sun (mp-direct sun) was much slower with a high-moisture content compared to using hot air. It is strongly influenced by the drying temperature as shown in Fig. 6b. Higher temperatures affect faster drying rates. The drying rate on shelf 1 (mp1) is the fastest because the drying temperature is the highest (S1). The farther the drying shelf is from the heat source, the slower the drying rate. In the use of hot air, the slowest drying rate occurs on shelf 6 (mp6). The drying rate after reaching the peak then decreases as the moisture content decreases. On-shelf 1, the drying rate (mp1) peaked at 180 minutes. On shelves 2 and 3 (mp2 and mp3) at 240 minutes, and shelves 4, 5, and 6 (mp4, mp5, mp6) at 300 minutes. Free moisture due to sensible heat transfer to the turmeric sample decreased after the peak drying rate was reached (Sharma *et al.*, 2021). The high drying rate occurs when the moisture content of white turmeric is still high, as in Fig. 6c. It was found that the drying rate is directly proportional to the moisture content. As the moisture content decreases, the drying rate also decreases. For the test time of 420 minutes, the initial moisture content of the turmeric sample as a whole was 88%, decreased to 2.7% in direct proportion to the drying rate, namely the average of 145.67 g/h decreased to 6.5 g/h. This is in line with the research of Lakshmi *et al.* (2019) that the drying rate is relatively higher at higher moisture content.



(a)



(b)



(c)

Fig. 6 The comparison of drying rate with (a) time, (b) temperature, and (c) moisture content

The slow drying rate of white turmeric with still high-moisture content occurs in direct sun drying. At the end of the test (420 minutes), the drying rate was 30 g/h. The moisture content was 35.88% with an average drying temperature of 30.91°C. In drying white turmeric with hot air for shelf 1, it was found that the drying process was sufficient for a maximum of 180 minutes. At that time, the drying rate reached 54 g/h, moisture content 1.1%, and mass 91 g, with an average drying temperature of 119.12°C. On-shelf 2, the drying process can be carried out for 300 minutes. In this condition, the drying rate reached 16 g/h, moisture content 5.3%, and mass 95 g, with an average drying temperature of 104.99°C. On-shelf 3, the drying process can be carried out for 300–360 minutes. In this condition, the drying rate reaches 30–7 g/h, moisture content 9.1–2.2%, mass 99–92 g, with an average drying temperature of 93.24°C. On shelves 4 and 5, the drying process can be carried out for 360–420 minutes. In this condition, each drying rate reached 32–9 g/h and 40–12 g/h, moisture content 11.8–3.2% and 15.1–4.3%, mass 102–93 g and 106–94 g, with an average drying temperature of 79.99°C and 74.69°C. On-shelf 6, the drying process can be carried out for 420 minutes. In this condition, the drying rate reached 16 g/h, moisture content 8.2%, and mass 98 g, with an average drying temperature of 73.65°C. The results of the dry moisture content test follow the required

standards. During the test, there was no additional mass of fuel, so the drying temperature changed after burning rice husks that burned out longer. The moisture content of dried turmeric has different standards or requirements. Singh *et al.* (2010) state that the safe limit for storage is 6%. The dry moisture content for turmeric slices with a thickness of 3 mm dried using a dryer is 6.9%, and the maximum US trade quality standard is 9% (Manoi, 2013). The study by Sharma *et al.* (2021) showed the moisture content of sliced turmeric with a thickness of 3 mm, which was dried using hot air within 2.5 hours, was 3.33%. Changes in moisture content were followed by changes in dryer efficiency, as presented in Fig. 7.

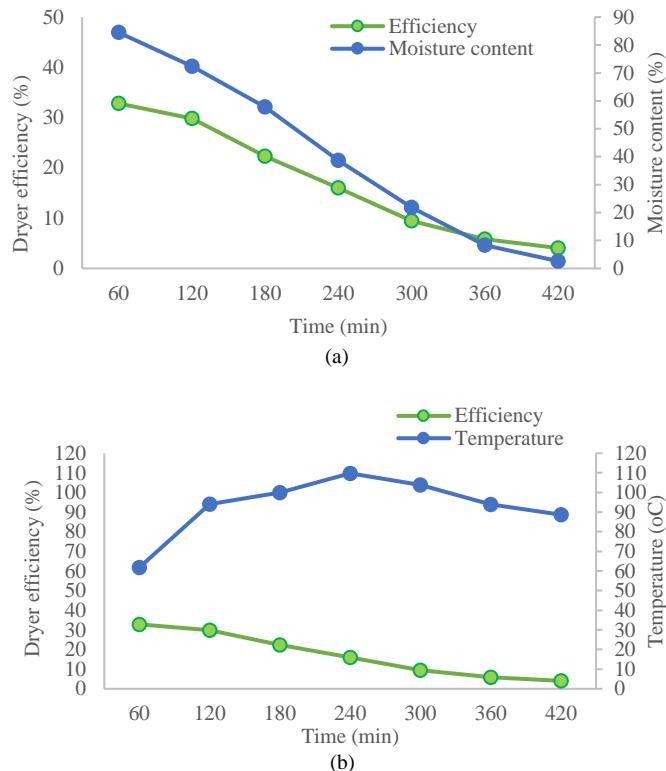


Fig. 7 Distribution pattern of dryer efficiency, moisture content, and temperature against time

Fig. 7 shows the dryer's efficiency during the testing time of the white turmeric sample and is calculated according to the moisture content measurement carried out every 60 minutes. Fig. 7 also shows the effect of temperature on dryer efficiency. The efficiency of the dryer decreases following the decrease in the moisture content of white turmeric. Dryer efficiency can reach 32.81% at minute 60. This is due to the moisture content in white turmeric being still high. At the end of the test, at minute 420, the efficiency reached 4.06%. This follows Djaeni *et al.* (2019), very high efficiency occurs in the initial drying due to the high energy of the dryer, which is absorbed by the product, and during the drying process, the energy absorbed by the product is reduced due to the reduced moisture content. In the study, it was found that for 240 minutes, an increase in drying temperature was seen, followed by a decrease in drying efficiency. For 240 minutes, there was a decrease in the high moisture content of white turmeric by 43.98%, from an average of 88% to 38.71%. Drying efficiency decreased due to reducing the high moisture content in white turmeric. Different that happened from 240 minutes to 420 minutes. A decrease follows the drying temperature decrease in the dryer's efficiency. This condition occurs because the heat used for drying is more wasted due to the smaller moisture content in white turmeric that has undergone evaporation.

The decrease in moisture content of white turmeric from 240 to 420 minutes was relatively small at 6.74%, namely from an average of 38.71%

to 2.61%. Efficiency decreases during the drying process (Balbine *et al.*, 2015). The decrease in drying temperature occurred because, during the drying process, the amount of rice husk was constant in both furnaces, each 17.5 kg or 35 kg. Testing on white turmeric using a desiccant design from the research of Alit *et al.* (2021) showed that the dryer's performance showed good results. This can be seen from the short drying time for white turmeric samples on the scale of small farmers, which is 4500 grams.

4. CONCLUSIONS

A double furnace-type hot air dryer and heat exchanger with rice husk energy were applied to dry white turmeric. White turmeric dried using hot air gives better results than sun drying. The drying process was carried out with white turmeric sliced 3 mm thick with an initial moisture content of 88% with a drying time of 420 minutes.

- Drying with hot air can achieve an overall final moisture content of 2.7%. While the final moisture content using sun drying is 35.88%.
- The sun-drying temperature, with an average of 30.91°C, is much lower than the hot air dryer, which reaches an average of 90.95°C.
- On each shelf in the drying room, there is a difference in drying time to reach the final moisture content of white turmeric. The moisture content on shelf one within 180 minutes reached 1.1% with an average drying temperature of 119.12°C. The longest occurs on shelf 6, which is within 420 minutes. The moisture content reaches 8.2% with an average drying temperature of 73.65°C.
- The highest drying efficiency occurred at the beginning of the drying process, namely 32.81%, and the lowest occurred at the end, 4.06%. This occurs due to the influence of the high initial moisture content. During drying, the moisture content of the material evaporates, which impacts the energy absorption process by white turmeric from the dryer.
- Using rice husks as an energy source will add value to agricultural waste and reduce smallholder post-harvest drying costs. Rice husk is a reliable and sustainable alternative energy because it is available in abundance.
- Further research is needed to reduce the relatively high fluctuation of drying temperature by adding a thermostat and exhaust fan.

ACKNOWLEDGEMENTS

The authors wish to acknowledge DRPM, the Ministry of Education, Culture, Research, and Technology, the Republic of Indonesia, for funding through the 2022 PTUPT research scheme with contract number 1256/UN 18.L1/PP/2022 for the second year of research. The author also wishes to thank the Department of Mechanical Engineering, University of Mataram, for facilitating the implementation of this research.

REFERENCES

- Alit, I.B., Susana, I.G.B., and Mara, I.M., 2020, "Utilization of Rice Husk Biomass in the Conventional Corn Dryer Based on the Heat Exchanger Pipes Diameter," *Case Studies in Thermal Engineering*, 22, 100764. <https://doi.org/10.1016/j.csite.2020.100764>
- Alit, I.B. and Susana, I.G.B., 2021, "Drying Performance of Jackfruit Dodol Using Rice Husk Energy on Household in Lombok, Indonesia," *Frontiers in Heat and Mass Transfer*, 17, 15. <https://doi.org/10.5098/hmt.17.15>
- Alit, I.B., Susana, I.G.B., and Mara, I.M., 2021, "Thermal Characteristics of the Dryer with Rice Husk Double Furnace-Heat Exchanger for Smallholder Scale Drying," *Case Studies in Thermal Engineering*, 28, 101565. <https://doi.org/10.1016/j.csite.2021.101565>

Awulu, J.O., Omale, P.A., and Ameh, J.A., 2018, "Comparative Analysis of Calorific Values of Selected Agricultural Wastes," *Nigerian Journal of Technology (NIJOTECH)*, 37(4), 1141-1146.
<https://doi.org/10.4314/njt.v37i4.38>

Badan Pusat Statistik, 2020, "Luas Panen dan Produksi Padi di Nusa Tenggara Barat (Angka Sementara)," Available online: <https://ntb.bps.go.id/> pressrelease/2020/11/02/704/luas-panen-dan-produksi-padi-di-nusa-tenggara-barat-2020--angka-sementara-.html (accessed on January 8, 2022).

Balbne, M., Marcel, E., Alexis, K., and Belkacem, Z., 2015, "Experimental Evaluation of the Thermal Performance of Dryer Air Flow Configuration," *International Journal of Energy Engineering*, 5(4), 80-86.
<http://dx.doi.org/10.5923/j.ijee.20150504.03>

Bevington, P.R. and Robinson, D.K., 2003, "Data Reduction and Error Analysis for the Physical Science," 3th ed., McGraw-Hill Companies.

Borah, A., Hazarika, K., and Khayer, S.M., 2015, "Drying Kinetics of Whole and Sliced Turmeric Rhizomes (*Curcuma Longa L.*) In A Solar Conduction Dryer," *Information Processing in Agriculture*, 2(2), 85-92.
<http://dx.doi.org/10.1016/j.inpa.2015.06.002>

Brooker, D.B., Bakker-Arkema, F.W., and Hall, C.W., 1992, "Drying and Storage of Grain and Oilseeds," 4th ed., Van Nostrand.

Cengel, Y.A. and Turner, R.H., 2004, "Fundamental of Thermal-fluid Sciences," 2th ed., McGraw-Hill Companies.

Cengel, Y.A. and Boles, M.A., 2006, "Thermodynamics An Engineering Approach," 5th ed., McGraw-Hill.

Dasore, A., Polavarapu, T., Konijeti, R., and Puppala, N., 2020, "Convective Hot Air Drying Kinetics of Red Beetroot In Thin Layers," *Frontiers in Heat and Mass Transfer*, 14(23), 1-8.
<http://dx.doi.org/10.5098/hmt.14.23>

Dinas Pertanian dan Pangan Yogyakarta, 2021, "Toga, Herbal Ngahits Jaga Imun di Masa Pandemi Covid-19," Available online: <https://pertanian.jogjakota.go.id/detail/> index/15674 (accessed on February 10, 2022).

Djaeni, M., Irfandy, F., and Utari, F.D., 2019, "Drying Rate and Efficiency Energy Analysis of Paddy Drying Using Dehumidification With Zeolite," *IOP Conf. Series: Journal of Physics*, 1295, 012049.
<http://dx.doi.org/10.1088/1742-6596/1295/1/012049>

Fridh, L., Volpe, S., and Eliasson, L., 2014, "An Accurate and Fast Method for Moisture Content Determination," *International Journal of Forest Engineering*, 25(3), 222-228.
<https://doi.org/10.1080/14942119.2014.974882>

Hamdani, Rizal, T.A., and Muhammad, Z., 2018, "Fabrication and Testing of Hybrid Solar-Biomass Dryer for Drying Fish," *Case Studies in Thermal Engineering*, 12, 489-496.
<https://doi.org/10.1016/j.csite.2018.06.008>

Henderson, S.M. and Perry, R.L., 1976, "Agricultural Process Engineering," The AVI Pub. Co., Inc., Westport, Connecticut.

Hossain, S.K.S., Mathurand, L., and Roy, P.K., 2018, "Rice Husk Ash as an Alternative Source of Silica in Ceramics: A Review," *Journal of Asian Ceramic Societies*, 6(4), 299-313.
<https://doi.org/10.1080/21870764.2018.1539210>

Incropera, F.P., DeWitt, D.P., Bergman, T., and Lavine, A., 2006, "Fundamental of Heat and Mass Transfer," 6th ed., John Wiley & Sons, New York.

Lakshmi, D.V.N., Muthukuma, P., Ekka, J.P., Nayak, P.K., and Layek, A., 2019, "Performance Comparison of Mixed Mode and Indirect Mode

Parallel Flow Forced Convection Solar Driers for Drying *Curcuma Zedoaria*," *J. Food Process Eng.*, 42(4), 1-12.
<https://doi.org/10.1111/jfpe.13045>

Lobo, R., Prabhu, K.S., Shirwaikar, A., and Shirwaikar, A., 2009, "Curcuma Zedoaria Rosc. (White Turmeric): A Review of its Chemical, Pharmacological and Ethnomedicinal Properties," *Journal of Pharmacy and Pharmacology*, 61(1), 13-21.
<https://doi.org/10.1211/jpp/61.01.0003>

Manaa, S., Younsi, M., and Moumni, N., 2013, "Study of Methods for Drying Dates; Review the Traditional Drying Methods in the Region of Touat Wilaya of Adrar-Algeria," *Energy Procedia*, 36, 521-524.
<https://doi.org/10.1016/j.egypro.2013.07.060>

Manoi, F., 2013, "Standar Prosedur Operasional Pasca Panen Kunyit," Available online: <https://balitro.litbang.pertanian.go.id/wp-content/uploads/2013/06/5-Pasca-Kunyit.pdf> (accessed on January 27, 2022).

Mhilu, C.F., 2014, "Analysis of Energy Characteristics of Rice and Coffee Husks Blends," *ISRN Chemical Engineering*, 1-6.
<http://dx.doi.org/10.1155/2014/196103>

Nain, S., Ahlawat, V., Kajal, S., Anuradha, P., Sharma, A., and Singh, T., 2021, "Performance Analysis of Different U-Shaped Heat Exchangers in Parabolic Trough Solar Collector for Air Heating Applications," *Case Studies in Thermal Engineering*, 25, 1-8.
<https://doi.org/10.1016/j.csite.2021.100949>

Nazghelichi, T., Kianmehr, M.H., and Aghbashlo, M., 2010, "Thermodynamic Analysis of Fluidized Bed Drying of Carrot Cubes," *Energy*, 35(12), 4679-4684.
<https://doi.org/10.1016/j.energy.2010.09.036>

Nguimdo, L.A. and Noumegnie, V.A.K., 2020, "Design and Implementation of an Automatic Indirect Hybrid Solar Dryer for Households and Small Industries," *International Journal of Renewable Energy Research*, 10(3), 1415-1425.

NTB SATU DATA, 2020, "Produksi Tanaman Kunyit Tahun 2013-2020 Menurut Kabupaten Kota di NTB," Available online: [https://data.ntbprov.go.id/dataset/rekapitulasi-luas-panen-dan-produksi-tanaman-kunyit-di-ntb/resource/237dcfbe-7dc3-4cde-ad28#view-graph:{graph Options:{hooks:{processOffset: {},bindEvents: {}}},graphOptions:{hooks:{processOffset: {},bindEvents: {}}},view-grid:{columnsWidth:\[{column:!Kabupaten/Kota,width:219}\]}}](https://data.ntbprov.go.id/dataset/rekapitulasi-luas-panen-dan-produksi-tanaman-kunyit-di-ntb/resource/237dcfbe-7dc3-4cde-ad28#view-graph:{graph Options:{hooks:{processOffset: {},bindEvents: {}}},graphOptions:{hooks:{processOffset: {},bindEvents: {}}},view-grid:{columnsWidth:[{column:!Kabupaten/Kota,width:219}]}}) (accessed on February 15, 2022).

Nwokolo, N., Mukumba, P., and KeChrist Obileke, 2020, "Thermal Performance Evaluation of a Double Pipe Heat Exchanger Installed in a Biomass Gasification System," *Journal of Engineering*, 1-8.
<https://doi.org/10.1155/2020/6762489>

Ochoa-Martinez, C.I., Quintero, P.T., Ayala, A.A., and Ortiz, M.J., 2012, "Drying Characteristics of Mango Slices Using the Refractance Window™ Technique," *Journal of Food Engineering*, 109(1), 69-75.
<https://doi.org/10.1016/j.jfooodeng.2011.09.032>

RUED Provinsi Nusa Tenggara Barat, 2019, "Potensi Limbah Perkebunan untuk Biomassa," Peraturan Daerah Provinsi Nusa Tenggara Barat, 3.

Shahbandeh, M., 2021, "Paddy Rice Production Worldwide 2019," Statista, Jan. 13, 2021, Available online: <https://www.statista.com/statistics/255937/leading-rice-producers-worldwide/> (accessed on February 10, 2022).

Sharma, S., Dhalsamant, K., Tripathy, P.P., and Manepally, R.K., 2021, "Quality Analysis and Drying Characteristics of Turmeric (*Curcuma Longa L.*) Dried by Hot Air and Direct Solar Dryers," *LWT*, 138, 110687.
<https://doi.org/10.1016/j.lwt.2020.110687>

Singh, G., Arora, S., and Kumar, S., 2010, "Effect of Mechanical Drying Conditions on Quality of Turmeric Powder," *Journal of Food Science and Technology*, 47(3), 347–350.
<https://doi.org/10.1007/s13197-010-0057-6>

Smith, J., 2007, "Combined Heat and Power from Rice Husks," GMB Energy Central, England, London.

Susana, I.G.B., Mara, I.M., Okariawan, I.D.K., Alit, I.B., and Aryadi, I.G.A.K.C.A.W., 2019a, "Ash Hole Variation in Rice Husk Biomass Furnace with Parallel Flow Heat Exchanger to Drying Box Temperature," *ARPN Journal of Engineering and Applied Sciences*, 14(2), 583-586.

Susana, I.G.B., Alit, I.B., and Mara, I.M., 2019b, "Optimization of Corn Drying with Rice Husk Biomass Energy Conversion Through Heat Exchange Drying Devices," *International Journal of Mechanical and Production Engineering Research and Development*, 9(5), 1023-1032.
<https://doi.org/10.24247/ijmperdoct201991>

Tangka, J.K., Ngah, J.K., Tidze, V.C., and Sako, E.T., 2018, "A Rice Husk Fired Biomass Stove for Cooking, Water and Space Heating," *International Journal of Trend in Research and Development*, 5(6) (2018) 83-89.

Ul Haq, M.A., Nawaz, M.A., Akram, F., and Natarajan, V.K., 2020, "Theoretical Implications of Renewable Energy Using Improved Cooking Stoves for Rural Households," *International Journal of Energy Economics and Policy*, 10(5), 546-554.
<https://doi.org/10.32479/ijEEP.10216>

Waheed, M.A. and Komolafe, C.A., 2019, "Temperatures Dependent Drying Kinetics of Cocoa Beans Varieties In Air-Ventilated Oven," *Frontiers in Heat and Mass Transfer*, 12(8), 1-7.
<http://dx.doi.org/10.5098/hmt.12.8>

Widodo, B. and Setyawan, E.Y., 2018, "Pemanfaatan Box Pengering dalam Peningkatan Higienitas Produksi Kunyit Kering di Desa Wates Kecamatan Slahung," *Jurnal Aplikasi dan Inovasi Iptek SOLIDITAS*, 1(1), 24-28.
<https://doi.org/10.31328/jas.v1i1.568>

Yan, S., Yin, D., He, F., Cai, J., Schliermann, T., and Behrendt, F., 2022, "Characteristics of Smoldering on Moist Rice Husk for Silica Production," *Sustainability*, 14(1), 317.
<https://doi.org/10.3390/su14010317>



This author profile is generated by Scopus Learn more

Susana, I. Gede Bawa

University of Mataram, Lombok Strait, Indonesia

57200121122 <https://orcid.org/0000-0003-1597-154X>

Edit profile

Set alert

Potential author matches

Export to SciVal

Metrics overview

10

Documents by author

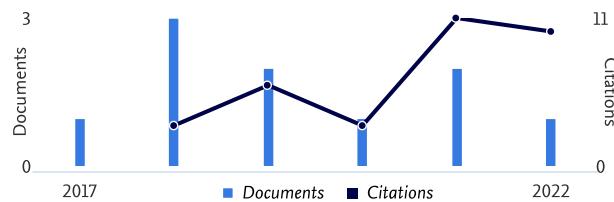
33

Citations by 17 documents

4

h-index: View *h*-graph

Document & citation trends



Most contributed Topics 2017–2021

Solar Heaters; Drying; Exergy

3 documents

Rotor; Solidity; Hydromechanics

1 document

Radiant Cooling; Air Conditioning; Heating Equipment

1 document

[View all Topics](#)

10 Documents Cited by 17 Documents Beta 0 Preprints 14 Co-Authors 7 Topics
0 Awarded Grants

Note:

Scopus Preview users can only view an author's last 10 documents, while most other features are disabled. Do you have [access](#) through your institution? Check your institution's access to view all documents and features.

[Export all](#) [Add all to list](#)

Sort by [Date \(...\)](#)

[View list in search results format](#)

• [Open access](#)

[View references](#)

THERMAL STUDY OF THE DRYER WITH HEAT EXCHANGER PIPE
INSTALLED IN RICE HUSK DOUBLE FURNACE DURING DRYING WHITE
TURMERIC

0

Citations

[Set document alert](#)

Alit, I.B., Susana, I.G.B., Mara, I.M.

Frontiers in Heat and Mass Transfer, 2022, 19, 25

Show abstract

Related documents

Alit, I.B., Susana, I.G.B., Mara, I.M.

Case Studies in Thermal Engineering, 2021, 28, 101565

Show abstract ▾

Related documents

Article • Open access

DRYING PERFORMANCE OF JACKFRUIT DODOL USING RICE HUSK ENERGY ON HOUSEHOLD IN LOMBOK, INDONESIA

Alit, I.B., Susana, I.G.B.

Frontiers in Heat and Mass Transfer, 2021, 17, 15

Show abstract ▾

Related documents

Article • Open access

Utilization of rice husk biomass in the conventional corn dryer based on the heat exchanger pipes diameter

Alit, I.B., Susana, I.G.B., Mara, I.M.

Case Studies in Thermal Engineering, 2020, 22, 100764

Show abstract ▾

Related documents

Article

Optimization of corn drying with rice husk biomass energy conversion through heat exchange drying devices

Gede Bawa Susana, I., Alit, I.B., Made Mara, I.

International Journal of Mechanical and Production Engineering Research and Development, 2019, 9(5), pp. 1023–1032, IJMPERDOCT201991

Show abstract ▾

Related documents

Article

Ash hole variation in rice husk biomass furnace with parallel flow heat exchanger to drying box temperature

Gede Bawa Susana, I., Made Mara, I., Dewa Ketut Okariawan, I., Alit, I.B., Chatur Adhi Wirya Aryadi, I.G.A.K.

ARPEN Journal of Engineering and Applied Sciences, 2019, 14(2), pp. 583–586

Show abstract ▾

Related documents

Article

Experimental performance of a modified savonius turbine for small scale portable wind power generation

Alit, I.B., Mirmanto, Adnyani, I.A.S., Mulyanto, A., Gede Bawa Susana, I.

International Journal of Mechanical Engineering and Technology, 2018, 9(6), pp. 1166–1173

Show abstract ▾

Related documents

Article

Enhancement of granite stone flat plate collector efficiency using multiple covers

Wirawan, M., Mirmanto, M., Susana, I.G.B., ...Wijana, M., Suartika, I.M.

International Journal of Mechanical Engineering and Technology, 2018, 9(5), pp. 24–32

Show abstract ▾

Related documents

Article

Improve of worker performance and quality of anchovy with ergonomic hybrid solar dryer

Susana, I.G.B.

ARPEN Journal of Engineering and Applied Sciences, 2018, 13(5), pp. 1662–1667

Show abstract ▾

Related documents

Article

Effect of hole spacing and number of pipe on dryer box temperature

Susana, I.G.B., Yudhyadi, I.G.N.K., Alit, I.B., Mirmanto, M., Okariawan, I.D.K.

International Journal of Mechanical Engineering and Technology, 2017, 8(11), pp. 1029–1035

Show abstract ▾

Related documents