PROCEEDINGS OF
TSME
ICoME
2018

The 9th Thai Society of Mechanical Engineers International Conference on Mechanical Engineering

Hosted by Mechanical Engineering Department, Thammasat School of Engineering, Thammasat University

11-14 December 2018 Thavorn Palm Beach Resort, Phuket, Thailand

PROCEEDINGS OF TSME ICoME 2018

Proceeding of
The 9th TSME
International Conference on
Mechanical Engineering
(ICoME 2018)

1. **Without the presentation the paper will not be published.**

2. **This Book contains only articles with "Proceeding Option".**

December 11 - 14, 2018

Thavorn Palm Beach Resort,

Phuket, Thailand.

Welcome Speech

The 9th TSME International Conference on Mechanical Engineering (TSME-ICoME 2018)

Thavorn Palm Beach Resort, Phuket

Distinguished guests, ladies and gentlemen

On behalf of Thammasat University, we would like to welcome all of you to the 9th TSME International Conference on Mechanical Engineering. Thammasat university has the honor of organizing the conference this year. Phuket is chosen as the venue of the conference because we believe that this famous tourist destination has a lot to offer to participants of the conference.

This conference is a platform where advanced researches in mechanical engineering will be presented. A lot of research has been conducted to solve increasingly more complex problems faced by the world today. Most of these problems usually exceed the capability of an individual researcher. Collaboration among researchers from different disciplines will make these problems easier to tackle. This is why the theme for this year's conference is Multi-Disciplinary and Multiple Partnerships Approach.

I have learned with great pleasure that this conference has received a lot of interest from not only leading Thai researchers but also researchers from many countries. It is equally pleasurable to see a large number of young scholars today. My special advice to you is that, in order to gain maximum benefits from this conference, you should focus not only on the exchange of ideas and the sharing of experience. Equally important are forming friendships and establishing collaborations with your peers. Research collaboration is indeed the research paradigm of the future.

Thank you for participating in this conference. I wish each of you an enjoyable and fruitful stay in Phuket.

Assoc.Prof.Gasinee Witoonchart

Rector of Thammasat University

Welcome Speech

The 9th TSME
International Conference on Mechanical Engineering
(TSME-ICoME 2018)
Thavorn Palm Beach Resort, Phuket

Distinguished guests, ladies and gentlemen

I am Naoya Sasaki, president of the Japan Society of Mechanical Engineers. First of all, on behalf of JSME, I would like to express my deep appreciation to the organizers of TSME-ICoME 2018 and those who have worked hard to make this conference possible. Additionally, please accept my sincere apologies for my absence. I really regret that I am not be able to participate in the conference. Last year our Society celebrated its 120th anniversary. We will continue to devote our efforts to the development of mechanical engineering in the future.

The Thai Society of Mechanical Engineers (TSME), which is a sponsor of TSME-ICoME 2018, in partnership with JSME will conclude a cooperative agreement during this conference. I look forward to the development of joint activities between TSME and JSME in the near future. In today's highly connected society, information has become easier to obtain. However, I think that most Internet discussion channels are superficial lacking information and data, and it is necessary to have a place to hold discussions, acquire knowledge and wisdom, and exchange ideas with others in order to explore further problems and find solutions in greater depth. I believe that face-to-face communication at conferences such as this one is becoming increasingly important to create new value.

In addition, the valuable lessons that Thailand and Japan have learned through the natural disasters in recent years, must be shared together and all over the world. I strongly believe that we both have the responsibility to convey these lessons to the countries of the world. I think the role of mechanical engineering has been re-evaluated in various fields, such as Alternative Energy and Combustion, Applied Mechanics, Materials and Manufacturing, Computation and Simulation Techniques, Dynamic Systems, Robotics and Controls, and Thermal System and Fluid Mechanics. This includes the role of mechanical engineering regarding disaster measures. Since TSME-ICoME 2018 also covers those fields, the role of TSME-ICoME 2018 has also become even more important.

I sincerely hope that the practical discussions held and updated knowledge presented at this conference are rewarding and fruitful. I would like to end my address with an earnest wish for the great success of this conference.

Thank you very much.

Dr. Naoya Sasaki
President
The Japan Society of Mechanical Engineers (JSME)

Welcome Speech

The 9th TSME International Conference on Mechanical Engineering (TSME-ICoME 2018)

Thavorn Palm Beach Resort, Phuket

Distinguished guests, ladies and gentlemen

For the past 30 years, as TSME has strived to form the organization to offer a great opportunity to Mechanical Engineering in Thailand. The first Conference of Mechanical Engineering Network of Thailand, ME-NETT was held in 1987 and is continuing until present to build up network yields the development of a verity of quality researches that can be utilized to serve the social and country's need while the International Conference of Mechanical Engineering, TSME-ICoME, was first held in 2010 to offer for an international forum to Mechanical Engineering communities. More over the Journal of Research and Applications in Mechanical Engineering, JRAME, published twice a year, has provided new interesting articles related to mechanical engineering issues.

The TSME-ICoME conference is one of the key mechanism to develop the researches from the knowledge exchanging which has contributed association networks and constituted a unique research community. The Mechanical Engineering research pays an important role to enhance the growth of country especially in the industry sectors.

In this regard, I would like to express my congratulation and appreciation to the department of Mechanical Engineering, Faculty of Engineering, Thammasat University for the dedication to organize the TSME-ICoME 2018 where will be held at Thavorn Palm Beach Resort, Phuket ,Thailand during 11-14th December 2018. Thank you for your supporting team and all staff for hard working to make this conference possible. I hope the conference will be success and belief that this collaboration will be further strengthened not only the network of mechanical engineers in Thailand but also the network of mechanical engineers in this region.

Thank you

(Asst.Prof.Dr.Chinda Charoenphonphanich)
President of Thai Society of Mechanical Engineer

The 9th TSME
International Conference on Mechanical Engineering
(TSME-ICoME 2018)
Thavorn Palm Beach Resort, Phuket

Distinguished guests, ladies and gentlemen

It is a great honour for the Thammasat School of Engineering that our Department of Mechanical Engineering is the organising body for this year's conference. So on behalf of everyone from TSE, I would like to welcome everyone to Phuket and the 9th International Conference on Mechanical Engineering.

The objective of conferences have always been to allow researchers the space and opportunity to share and learn from others in their respective fields. But as times have progressed, so has the requirements of engineering, and so must us Mechanical Engineers in how to handle our work. For our accomplishments for tomorrow, we need to learn and let learn from all other fields of knowledge, and not restrict ourselves to only our own disciplines. Embracing a multidisciplinary approach to our work opens vast new possibilities that I hope we can explore together through this conference.

With that, I would like to express my sincerest gratitude to everyone involved in the organisation of this year's conference, to TSME for their continued support of TSE, and to all the participants who have made this happen.

I am most delighted to welcome you all to ICoME 2018, and thank you again for being here with us at this conference.

Thank you.

Assoc, Prof.Dr. Thira Jearsiripongkul,
Dean of Thammasat School of Engineering,
Thammasat University

Members of Thai Society of Mechanical Engineering (TSME)

1. Chulalongkorn University
2. Thammasat University
3. Mahidol University
4. Kasetsart University
5. Chiang Mai University
6. Prince of Songkla University
7. King Mongkut's University of Technology Thonburi
8. King Mongkut's University of Technology North Bangkok
9. King Mongkut's Institute of Technology Ladkrabang
10. Mahanakorn University of Technology
11. Silpakorn University
12. Khon Kaen University
13. Suranaree University of Technology
14. Ubon Ratchathani University
15. Mahasarakham University
16. Rajamangala University of Technology Thanyaburi
17. Sripatum University
18. Navaminda Kasatriyadhiraj Royal Air Force Academy
19. Naresuan University
20. Pathumwan Institute of Technology
21. Burapha University
22. Rajamangala University of Technology Rattanakosin
23. Chulachomklao Royal Military Academy
24. Pathumthani University
25. Siam University
26. Rangsit University
27. Thai-Nichi Institute of Technology
28. Srinakharinwirot University
29. Rajamangala University of Technology Isan
30. Rajamangala University of Technology Lanna
31. Kasetsart University Sriracha Campus
32. Saint John's University

PROGRAM COMMITTEE

Honorary Chair

Asst.Prof.Chinda Charoenphonphanich, D.Eng. — King Mongkut's institute of technology Ladkrabang, Thailand
(President, Thai Society of Mechanical Engineers)

General Chair

Assoc.Prof. Thira Jearsiripongkul, Dr.-Ing. — Thammasat University
(Dean, Thammasat School of Engineering)

Prof, OSHIMA Marie, PhD — The University of Tokyo
(Former President of Japan Society of Mechanical Engineers)

Conference Chair

Asst.Prof. Monchai Prukvilailert, D.Eng. — Thammasat University, Thailand
(Head of Mechanical Engineering)

General Conference Secretariat

Assoc.Prof. Watit Pukdee, Ph.D. — Thammasat University

International Scientific Committee

Prof. Dr.-Ing. Heinz Peter Berg	Brandenburg University of Technology Cottbus-Senftenberg, Germany
Prof. Dr. Ashim K. Datta	Cornell University, USA
Prof. Dr. Ashwani K. Gupta	University of Maryland, USA
Prof. Dr. Katsunori Hanamura	Tokyo Institute of Technology, Japan
Prof. Dr.-Ing. Lothar Kroll	Chemnitz University of Technology, Germany
Prof. Dr. Ocktaeck Lim	University of Ulsan, Korea
Prof. Dr. Jau-Huai Lu	National Chung Hsing University, Taiwan
Prof. Dr. Naoki Maruyama	Mie University, Japan
Prof. Dr. Shinichi Nakasuka	University of Tokyo, Japan
Prof. Dr. Hironori Saitoh	Sojo University, Japan
Prof. Dr. Marco P. Schoen	Idaho State University, USA
Prof. Dr. Ning Zhu	Shizuoka Institute of Science and Technology, Japan
Assoc. Prof. Dr. Elmi Abu Bakar	Universiti Sains Malaysia, Malaysia
Assoc. Prof. Dr. Huynh Thanh Cong	Ho Chi Minh City University of Technology, Vietnam
Assoc. Prof. Dr. Seokwoo Jeon	Korea Advanced Institute of Science and Technology, Korea
Assoc. Prof. Dr. lman K. Reksowardojo	Institute of Technology Bandung, Indonesia Institute
Assoc. Prof. Dr. Hendri Syamsudin	of Technology Bandung, Indonesia
Assoc. Prof. Dr. Le Anh Tuan	Hanoi University of Science and Technology, Vietnam
Assoc. Prof. Dr. Pham Huu Tuyen	Hanoi University of Science and Technology, Vietnam
Asst. Prof. Dr. Pham Tuan Anh	Ho Chi Minh City University of Technology, Vietnam

PROGRAM COMMITTEE

Local Scientific Committee

Prof. Dr. Viboon Sangveraphunsiri	Chulalongkorn University
Prof. Dr. Tanongkiat Kiatsiriroat	Chiang Mai University
Prof. Dr. Somchai Wongwises	King Mongkut's University of Technology Thonburi
Prof. Dr. Sumrerng Jugjai	King Mongkut's University of Technology Thonburi
Prof. Dr. Phadungsak Rattanadecho	Thammasat University
Prof. Dr. Chaosuan Kanchanomai	Thammasat University
Prof. Dr. Somchai Hanklar	Navaminda Kasatriyadhiraj Royal Air Force Academy
Prof. Dr. Suwat Kuntanapreeda	King Mongkut's Univ. of Technology North Bangkok
Assoc. Prof. Dr. Withaya Yongcharoen	Chulalongkorn University
Assoc. Prof. Dr. Kanit Wattanavichien	Chulalongkorn University
Assoc. Prof. Dr. Worawut Wisutmetthangoon	Prince of Songkla University
Assoc. Prof. Dr. Jarruwat Charoensuk	King Mongkut’s Institute of Technology Ladkrabang
Assoc. Prof. Dr. Ratchaphon Suntivarakorn	Khon Kaen University
Assoc. Prof. Dr. Smith Eiamsa-ard	Mahanakorn University of Technology
Assoc. Prof. Dr. Sinchai Chinvorarat	King Mongkut's Univ. of Technology North Bangkok
Asst. Prof. Dr. Jackrit Suthakorn	Mahidol University
Asst. Prof. Dr. Petch Jearanaisilawong	King Mongkut's Univ. of Technology North Bangkok
Asst. Prof. Dr. Tonkid Chantrasmi	King Mongkut's Univ. of Technology North Bangkok

ORGANIZING COMMITTEE

CHAIRPERSON
Assoc. Prof. Dr. Thira Jearsiripongkul

ORGANIZING CHAIRPERSON
Asst. Prof. Dr. Monchai Prukvilailert
Prof. Dr. Phadungsak Rattanadecho

SECRETARY
Assoc. Prof. Dr. Watit Pakdee
Asst. Prof. Dr. Charnnarong Assavatesanupap

COMMITTEE
Prof. Dr. Somchart Chantasiriwan
Prof. Dr. Chaosuan Kanchanomai
Assoc. Prof. Dr. Wiroj Limtrakarn
Assoc. Prof. Dr. Dulyachot Cholaseuk
Assoc. Prof. Dr. Chainarong Chaktranond
Assoc. Prof. Dr. Isares Dhuchakallaya
Asst. Prof. Dr. Chatchai Marnadee
Asst. Prof. Dr. Witawats Satasook
Asst. Prof. Dr. Bunyong Rungroungdouyboon
Asst. Prof. Dr. Krit Jiamjiroch
Asst. Prof. Dr. Sappinandana Akamphon
Asst. Prof. Dr. Somsak Vongpradubchai
Asst. Prof. Dr. Jakkrapun Chuanasa
Asst. Prof. Dr. Chonlada Luangarpa
Dr. Nattadon Pannucharoenwong
Dr. Snunkhaem Echaroj

List of Reviewer

Prof.Dr. Ashwani K.Gupta	University of Marylandม USA
Prof.Dr. Chaosuan Kanchanomai	Thammasat Univeristy.Thailand
Prof.Dr. Sakamon Devahastin	KMUTT .Thailand
Prof.Dr. Somchai Hanklar	Royal Air Force Academy.Thailand
Prof.Dr. Sujin Bureerat	Khon Kaen University .Thailand
Prof.Dr. Suwat Kuntanapreeda	KMUTNB.Thailand
Prof.Dr. Thananchai Leephakpreeda	SIIT, Thammasat University.Thailand
Assoc.Prof.Dr. Chakrit Suvanjumrat	Mahidol University.Thailand
Assoc.Prof.Dr. Ekachai Juntasaro	KMUTNB.Thailand
Assoc.Prof.Dr. Isares Dhuchakallya	Thammasat Univeristy.Thailand
Assoc.Prof.Dr. Jarruwat Charoensuk	KMITL.Thailand
Assoc.Prof.Dr. Kanit Wattanavichien	Chulalongkorn University .Thailand
Assoc.Prof.Dr. Kittipong Boonlong	Burapha University.Thailand
Assoc.Prof.Dr. Kulachate Pianthong	Ubo Ratchathani University.Thailand
Assoc.Prof.Dr. Naoki Maruyama	Mie university.Japan
Assoc.Prof.Dr. Nopdanai Ajavakom	Chulalongkorn University.Thailand
Assoc.Prof.Dr. Pairod?? Singhatanadgid	Chulalongkorn University.Thailand
Assoc.Prof.Dr. Pattaramon Jongpradist	KMUTT.Thailand
Assoc.Prof.Dr. Pinit Ngamsom	Rangsit University.Thailand
Assoc.Prof.Dr. Sinchai Chinvorarat	KMUTNB.Thailand
Assoc.Prof.Dr. Smith Eiamsa-ard	Mahanakorn University of Technology.Thailand
Assoc.Prof.Dr. Somchai Chanchaona	KMUTT.Thailand
Assoc.Prof.Dr. Supachart Chungpaibulpatana	SIIT, Thammasat University.Thailand
Assoc.Prof.Dr. Tanakorn Wongwuttanasatian	Khon Kaen University.Thailand
Assoc.Prof.Dr. Thanakom Soontornchainacksaeng	KMUTNB.Thailand
Assoc.Prof.Dr. Thira Jearsiripongkul	Thammasat Univeristy.Thailand
Assoc.Prof.Dr. Varangrat Juntasaro	Kasetsart University.Thailand
Assoc.Prof.Dr. Vejapong Juttijudata	Kasetsart University.Thailand
Assoc.Prof.Dr. Vitoon Uthaisangsuk	KMUTT.Thailand
Assoc.Prof.Dr. Wanchai Asvapoositkul	KMUTT.Thailand
Assoc.Prof.Dr. Wiroj Limtrakarn	Thammasat Univeristy.Thailand
Asst.Prof. Julaporn Benjapiyaporn	Khon Kaen University.Thailand
Asst.Prof.Dr. Jirapong Kasivitamnuay	Chulalongkorn University.Thailand
Asst.Prof.Dr. Alongkorn Pimpin	Chulalongkorn University.Thailand
Asst.Prof.Dr. Ananchai Ukaew	Naresuan University.Thailand
Asst.Prof.Dr. Annop Ruangviset	KMUTT.Thailand
Asst.Prof.Dr. Teerapot Wessapan	Eastern Asia University.Thailand
Asst.Prof.Dr. Thana Radpukdee	Khon Kaen Univ..Thailand
Asst.Prof.Dr. Thanapat Wanichanon	Mahidol University.Thailand
Asst.Prof.Dr. Thibordin Sangsawang	Silpakorn University.Thailand
Asst.Prof.Dr. Thosapon Katejanekarn	Silpakorn University.Thailand
Asst.Prof.Dr. Wirapan Seehanam	Ubon Ratchatani University.Thailand
Asst.Prof.Dr. Yossapong Laoonual	KMUTT. Thailand
Asst.Prof.Mr. Akapot Tantrapiwat	KMUTL .Thailand
Dr. Amornrat Kaewpradap	KMUTL .Thailand
Dr.Denchai Woradechjumroen	Sripatum University.Thailand
Dr.Jitti Pattavanitch	Burapha University.Thailand
Dr.Kitchanon Ruangjirakit	KMUTT.Thailand
Dr.Makatar Wae-hayee	Prince of Songkla University, Thailand Royal
Dr.Mason Thammawichai	Thai Air Force Academy .Thailand Burapha
Dr.Montana Rungsiyopas	University.Thailand
Dr.Nattadon Pannucharoenwong	Thammasat University.Thailand
Dr.Nattawut Suwannapum	RMUT-Rattanakosin.Thailand
Dr.Rattana Borrisutthekul	Suranaree University of Technology .Thailand
Dr.Ratthasak Prommas	RMUT-Rattanakosin.Thailand Chulalongkorn
Dr.Saran Salakij	University.Thailand
Dr.Sarawuth Srinakaew	Royal Thai Naval Academy.Thailand
Dr.Snunkhaem Echaroj	Thammasat.Thailand
Dr.Sukit Nitinai	RMUT-Krungthep.Thailand
Dr.Thada Suksila	KMUTNB.Thailand
Dr.Usa Makmool	KMUTT .Thailand
Mr.Niwat Suksam	RMUT-Rattanakosin.Thailand

Conference Program

Conference Program

TSME-ICoME 2018   11-14 December 2018
Thavorn Palm Beach Resort, Phuket, Thailand

11 December 2018	
13.00-18.00	Registration

12 December 2018	
08.15-09.00	Registration
09.00-09.30	Welcome Speech by **Assoc.Prof. Gasinee Witoonchart** Rector of Thammasat University **Asst.Prof.Dr.Chinda Charoenphonphanich** **Honorary Chair** President, Thai Society of Mechanical Engineers (TSME) **Prof.Dr.Mari Oshima** Former President (2017), Japan Society of Mechanical Engineers (JSME) **Assoc.Prof.Dr.Thira Jearsiripongkul** Dean of Thammasat School of Engineering (TSE) Thammasat University
09.30-09.50	TSME-JSME MOU Signing
09.50-10.00	Ribbon Cutting Ceremony
10.00-10-45	Keynote Speaker **Dr.Keiko Fujioka** President of Functional Fluids Ltd., Japan "Thermochemical Energy Storage for Utilization of Unused Heat"
10.45-11.00	Coffee Break
11.00-11.45	Keynote Speaker **Asst.Prof.Dr.Bunyong Rungroungdouyboon** Excellence Center in Creative Engineering Design and Development (CED^2) Department of Mechanical Engineering, Thammasat University (TU) "Engineering Innovation Practice in Engineering Education: Case Study of Rehabilitative and Assistive Innovation"
11.45-12.00	

Keynote Presentations

Keynote Presentations

Dr. Keiko Fujioka
President of Functional Fluids Ltd., Japan
Title: Thermochemical energy storage for utilization of unused heat

Thermochemical Energy Storage for Utilization of Unused Heat

Keiko Fujioka

Functional Fluids Ltd.,
1-4-5, Utsubohonmachi, Nishi-ku, Osaka, 550-0004, Japan

kfujioka@functional-fluids.co.jp, +81-6-6445-5433, +81-6-6445-5432

Abstract

More than half of the annual primary energy consumption, about 20000 PJ, is disposed in Japan every year as waste heat, in spite that its energy consumption per GDP is the minimum level in the world. Utilization of waste heat and unused heat such as terrestrial heat and solar heat would contribute the reduction of greenhouse gas, however, the problem is the differences in time, location and quality between supply and demand sides of thermal energy. Thermochemical energy storage can recover, store and transport thermal energy, by using reversible endothermic and exothermic chemical reactions, to eliminate the above-mentioned mismatch. Among many systems for thermal energy storage, chemical heat storage/pump using reversible reactions of inorganic salts with gas substances (gas-solid CHP) have been expected to be an attractive way of effective use of thermal energy for their large energy density, long-term energy storage without heat loss, and wide range of working temperature. To develop highly efficient CHPs, improvement of heat transfer in reactor beds has been one of the most important subjects, since gas-solid reactions are often controlled by heat transfer. In this paper, heat transfer mechanism of porous materials is examined by taking account into the effect of variations of thermophysical properties with reaction progress, which is typical feature of gas-solid reaction. Then, technology development focusing on heat transfer enhancement is described. The effective thermal conductivity of the bed with inorganic salts or oxides is generally in the range of 0.1-0.2 W/mK. Various ways have been developed to increase it without decreasing gas permeability mainly by combining high thermal conductivity materials. Finally challenges in achieving social implementation of thermochemical energy storage, including thermal demand/supply data construction and waste heat analysis using remote sensing methods are presented.

Curriculum Vitae

Keiko FUJIOKA

Affiliation: President of Functional Fluids Ltd.
Chiyoda Bldg. Annex, 1-4-5 Utsubo-honmachi, Nishi-ku, Osaka 550-0004, Japan

1. Academic Qualifications

1992	B.Eng	Division of Chemical Engineering, School of Engineering Science, Osaka University
1994	M.Sc.	Division of Chemical Engineering, Department of Chemical Science and Engineering, Graduate School of Engineering Science, Osaka University
1999	Dr.Eng.	Division of Chemical Engineering, Department of Chemical Science and Engineering, Graduate School of Engineering Science, Osaka University

2. Professional Carriers

1984	Founded Shinsei Cooling Water System Ltd. and assumed position of the president (Company name changed to Functional Fluids in 2006)

3. Activity of Academic Societies

2011-	Associate Member of Science Council of Japan
2013-2014	Vice President of Heat Transfer Society of Japan
2013-2015	Chairman of Gender Equality Promotion Committee of the Society of Chemical Engineers, Japan (SCEJ)
2016-2017	President of Heat Transfer Society of Japan
2016-2017	Vice Chair of Japan Inter-Society Liaison Association Committee for Promoting Equal Participation of Men and Women in Science and Engineering (EPMEWSE)
2018年-	Vice President of Society of Chemical Engineers, Japan (SCEJ)

4. Awards

2012 SCEJ Award for Outstanding Women’s Activity

5. Research Areas

Heat-transfer in Porous Materials
Energy Conversion, Energy Storage, Energy Transportation
Chemical heat storage/heat pump system

Assistant Professor Dr. Bunyong Rungroungdouyboon
Excellence Center in Creative Engineering and Development (CED[2])
Department of Mechanical Engineering
Thammasat University, Thailand

Engineering Innovation Practice in Engineering Education: Case Study of Rehabilitative and Assistive Innovation

Bunyong Rungroungdouyboon

Excellence Center in Creative Engineering Design and Development, (CED[2])
Department of Mechanical Engineering, Thammasat School of Engineering,
Thammasat University, Klong Lueng, Pathumthani, 12121, Thailand

rbunyong@engr.tu.ac.th, +66-(0)-2564-30005 ext 3159

Abstract

At present, the world's education has changed from being teacher-centered to learner-centered. Also, the 21st century learning skills have been introduced. The new set of skills is required for working in industry. Even, it's required for doing startup company. However, the education in Thailand, especially the engineering education, just start to prepare their students for this situation.

Center of Creative Engineering Design and Development was established in 2005 at faculty of engineering, Thammasat University. The main goal of center is to use engineering innovation practice to improve the quality of engineering leaning and to solve the main country's problems by innovation simultaneously. The problems of rehabilitative and assistive technology in Thailand have been used for the target problem. Design thinking processes have been taught and practiced. After working more than ten years, the student's skills have been improved obviously. They show the improvement in ability to ask good questions, to categorize the data, to create conceptual solution, to find solution creatively, to design and prototype, to communicate and to work as a team. In addition, the newly designed innovations have been developed and can be commercialized.

Curriculum Vitae

Bunyong Rungroungdouyboon

Affiliation: Department of Mechanical Engineering, Faculty of Engineering,
Thammasat University (Rangsit Campus),
Klong Luang, Pathumthani, 12121, Thailand
E-mail: rbunyong@engr.tu.ac.th

1. Academic Qualifications

B.Eng	Mechanical Engineering, King Mongkut Institute of Technology North Bangkok
M.S.	Mechanical Engineering, Lehigh University, USA
Ph.D.	Mechanical Engineering, Lehigh University, USA

2. Professional Carriers

1995	Mechanical Engineer, Siam Cement Group Public Company
1996 – Present	Lecturer at Department of Mechanical Engineering,
1997 -2002	Faculty of Engineering, Thammasat University (Rangsit Campus)
2005	Research Assistant at Department of Mechanical Engineering,
	Lehigh University, USA.
	Assistant Professor at Thammasat University

3. Area of Expertise
Product Design, Mechanical Design, Innovation Development

4. Selected International Awards:

4.1 Silver Award: Student Design Challenge from I-CREATE 2008, Thailand
4.2 Grand Prize: Seoul International Invention Fair (SIIF) 2011, Seoul, Republic of South Korea
4.3 Silver Medal and Special Prize from Tiawan: 40th International Exhibition of Inventions of Geneva, Geneva Switzerland, 2012
4.4 First Runner Up and Best Presentation: International Convention for Rehabilitation Engineering & Assistive Technology (iCREATe) 2013, Republic of South Korea
4.5 Gold Award: Seoul International Invention Fair (SIIF) 2014, Seoul, Republic of South Korea
4.6 Gold Medal and Special Prize from Tiawan: 42nd International Exhibition of Inventions of Geneva, Geneva Switzerland, 2014
4.7 Gold Award: International Convention for Rehabilitation Engineering & Assistive Technology (iCREATe) 2017, Kobe Japan
4.8 Gold Award: International Convention for Rehabilitation Engineering & Assistive Technology (iCREATe) 2018, Shanghai China

5. Patents:

5.1 Manual Standing Wheelchair, Petty Patent No. 4,648
5.2 Manual Standing Wheelchair for Children with Cerebral Palsy , Petty Patent No. 7,596
5.3 Gait training machine for stroke patients, Petty Patent No. 11,462
5.4 Power added on for manual wheelchair, Petty Patent No. 12,735

Invited Presentations

Alternative Energy and Combustion (AEC)

Comprehensive Conversion of Biomass and Waste to Super Clean Fuels

Assoc. Professor Dr Kanit Wattanavichien
Department of Mechanical Engineering
Chulalongkorn University

Biomechanics and Bioengineering (BME)

Evolution of Science of Thermodynamics

Assoc. Prof. Dr. Anchasa Pramuanjaroenkij

Department of Mechanical and

Manufacturing Engineering

Kasetsart University

Thermal System and Fluid Mechanics (TSF)

Some Energy Saving Opportunites in Sugar Mill Cogeneration Plant

Prof. Dr. Chullaphong Chullabodhi

School of Energy, Environment and Materials

King Mongkut's University of Technology Thonburi

List of Sessions

Without the presentation the paper will not be published.

Please note that the time allocated for each presentation is 15 minutes, with a further 5 minutes allowed for questions and discussion.

Please ensure that your presentation is loaded onto the presentation PC and checked at least 30 minutes before the start of your session. We also ask that you go to the presentation room 10 minutes before the start of your session to introduce yourself to the chair of your session and familiarise yourself the equipment set up. There will be a technician who can assist with any technical queries. The technician will resolve any technical issues.

SESSION 1 & 2

12.00-13.00	Lunch					
Session 1						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	VIP
Chair persons	Prof. Dr. Chullaphong Chullabodhi Assoc. Prof. Dr. Wiroj Limtrakarn	Assoc. Prof. Dr. Anchasa Pramuanjaroenkij Asst. Prof. Dr. Chonlada Luangarpa	Assoc. Prof. Kanit Wattanavichien Assoc. Prof. Dr. Isares Dhuchakallaya	Assoc.Prof.Dr. Jarruwat Charoensuk Dr. Snunkhaem Echaroj	Assist. Prof. Dr. Keerati Suluksna Dr. Nattadon Pannucharoen wong	Assoc. Prof. Dr. Thira Jearsiripongkul Asst. Prof. Dr. Sappinandana Akamphon
13.00-13.20	TSF Invited Talk	BME Invited Talk	AEC Invited Talk	AME0002	AMM0003	DRC0001
13.20-13.40				AME0003	AMM0005	DRC0002
13.40-14.00	TSF0001	BME0001	AEC0001	AME0005	AMM0006	DRC0003
14.00-14.20	TSF0002	BME0002	AEC0002	AME0006	AMM0007	DRC0005
14.20-14.40	TSF0003	BME0004	AEC0003	AME0007	AMM0009	
14.40-15.00		BME0005	AEC0024			
14.40-15.00	Coffee Break / ASEAN Poster Session					
Session 2						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	VIP
Chair persons	Assoc. Prof. Dr. Bundit Krittacom Assoc. Prof. Dr. Chainarong Chaktranond	Assoc. Prof. Dr. Nopdanai Ajavakom Assist.Prof.Dr. Bunyoung Rungroung douyboon	Col. Assist. Prof.Dr.Anotai Suksangpa nomrung Assoc.Prof.Dr. Wiroj Limtrakarn	Assist. Prof. Dr. Ananchai U-Kaew Dr. Snunkhaem Echaroj	Assoc.Prof. Dr. Thongchai Fongsamootr Dr. Nattadon Pannucharoen wong	Assoc. Prof. Dr. Kulachate Pianthong Asst. Prof. Dr. Sappinandana Akamphon
15.00-15.20	TSF0005	BME0006	CST0001	AME0008	AMM0008	ETM0001
15.20-15.40	TSF0007	BME0007	CST0002	AME0009	AMM0010	ETM0002
15.40-16.00	TSF0008	BME0009	CST0003	AME0010	AMM0011	ETM0004
16.00-16.20	TSF0010	BME0010	CST0004	AME0011	AMM0012	ETM0005
16.20-16.40	TSF0011	BME0012	CST0013	AME0013	AMM0013	ETM0006
16.40-17.00	TSF0012	BME0013	CST0007			ETM0007
17.10-18.30	TSME Meeting					

SESSION 3~5

13 December 2018						
Session 3						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	VIP
Chair persons	Assoc. Prof. Dr. Thira Jearsiripongkul Assoc.Prof. Dr. Isares Dhuchakallaya	Prof. Dr. Sumrerng Jugjai Asst. Prof. Dr. Amornrat Kaewpradap	Assoc. Prof. Dr. Withaya Yongchareon Assoc. Prof. Dr. Wiroj Limtrakarn	Dr. Nattawut Suwannapum Asst. Prof. Dr. Phonthip Keangin	Assoc. Prof. Dr. Smith Eiamsa-ard Assoc. Prof. Dr. Chainarong Chaktranond	Paiboon Limpitipanich Asst. Prof. Dr. Sappinandana Akamphon
09.00-09.20	DRC-0006	AEC-0005	BME-0014	CST-0008	TSF-0006	AMM-0014
09.20-09.40	DRC-0008	AEC-0006	BME-0015	CST-0009	TSF-0015	AMM-0016
09.40-10.00	DRC-0010	AEC-0007	BME-0016	CST-0006	TSF-0016	AMM-0017
10.00-10.20	DRC-0011	AEC-0008	BME-0017	CST-0011		AMM-0018
10.20-10.40	Coffee Break / ASEAN Poster Session					
Session 4						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	VIP
Chair persons	Assoc. Prof. Dr. Isares Dhuchakallaya Asst. Prof. Dr. Patcharin Saechan	Assoc. Prof. Dr. Jarruwat Charoensuk Dr. Snunkhaem Echaroj	Asst. Prof. Dr. Bunyong Rungroung Douyboon Dr. Nattadon Pannucha roenwong	Asst. Prof. Dr. Thanapat Wanichanon Asst. Prof. Dr. Chonlada Luangarpa	Assoc.Prof.Dr. Chainarong Chaktranond Assoc.Prof.Dr. Tawit Chitsomboon	Asst. Prof. Dr. Sutapat Kwankaomeng Asst. Prof. Dr. Sappinandana Akamphon
10.40-11.00	DRC-0012	AEC-0009	BME-0018	AME-0015	TSF-0014	AMM-0019
11.00-11.20	DRC-0013	AEC-0010	BME-0019	AME-0016	TSF-0017	AMM-0020
11.20-11.40	DRC-0014	AEC-0011	BME-0020	AME-0017	TSF-0018	EDU-0001
11.40-12.00	DRC-0015	AEC-0012	BME-0021	AME-0014	TSF-0019	
12.00-13.00	Lunch					
Session 5						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	VIP
Chair persons	Asst. Prof. Dr. Akapot Tantrapiwat Dr. Snunkhaem Echaroj	Asst. Prof. Dr. Preecha Khantikomol Assoc. Prof. Dr. Watit Pakdee	Asst. Prof. Dr. Thanapat Wanichanon Assoc. Prof. Dr. Wiroj Limtrakarn	Gp.Capt. Prasatporn Wongkam chang Dr.Nattadon Pannuchroen wong	Asst. Prof. Dr. Patcharin Saechan Assoc. Prof. Dr. Isares Dhuchakallaya	Asst. Prof. Dr. Nuchida Suvapat Assoc. Prof. Dr. Cattaleeya Pattamaprom
13.00-13.20	DRC-0016	AEC-0014	AME-0029	AME-0018	TSF-0020	ETM-0010
13.20-13.40	DRC-0017	AEC-0015	AME-0030	AME-0019	TSF-0021	ETM-0011
13.40-14.00	DRC-0018	AEC-0016	AME-0021	AME-0020	TSF-0023	ETM-0012
14.00-14.20	DRC-0019	AEC-0017	AME-0023	AME-0024	TSF-0013	ETM-0013
14.20-14.40	DRC-0020	AEC-0019				
14.20-14.40	Coffee Break / ASEAN Poster Session					

SESSION 6~7

13 December 2018						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B	Palm Flower C	
Chair persons	Dr.Pareecha Rattanasiri Dr. Nopparat Khamporn	Assoc. Prof. Dr. Watit Pakdee Dr.Snunkhaem Echaroj	Assoc. Prof. Dr. Wittaya Yongchareon Asst. Prof. Dr. Sappinandana Akamphon	Gp.Capt. Prasatporn Wongkam chang Dr.Nattadon Pannuchroen wong		
14.40-15.00	CST-0014	AEC-0018	ETM-0014	AME-0025	Korea-Thai Automotive Sessions	
15.00-15.20	CST-0015	AEC-0022	ETM-0015	AME-0026		
15.20-15.40	CST-0016	AEC-0023	ETM-0016	AME-0027		
16.00-16.20	CST-0017	AEC-0025	ETM-0017	AME-0028		
16.20-16.40	CST-0018	AEC-0020				
16.40-17.00	CST-0019					
18.00-20.00	Banquet Dinner					

14 December 2018						
Session 7 (**Best Paper Candidates**)						
@	Banquet Hall A	Banquet Hall B	Palm Flower A	Palm Flower B		
Chair persons	Gp.Capt. Professor Dr.Noppon Hankra Dr. Snunkhaem Echaroj	Professor Dr. Somchart Chantasiriwan Asst. Prof. Dr. Sarocha Charoenvai	Asst. Prof. Dr. Warakom Nerdnoi Asst. Prof. Dr. Sappinandana Akamphon	Asst. Prof. Dr. Amornrat Kaewpradap Dr. Nattadon Pannucharoenwong		
09.00-09.20	DRC0004	CST0005	AMM0002	ETM0008		
09.20-09.40	DRC0007	CST0010	AMM0004	ETM0003		
09.40-10.00	DRC0009	CST0012	AMM0015	ETM0009		
10.00-10.20	Coffee Break					
Chair persons	Gp.Capt. Prof. Dr. Noppon hankra Dr. Snunkhaem Echaroj	Prof. Dr. Sumrerng Jugjai Assoc. Prof. Dr. Watit Pakdee	Assoc. Prof. Dr. Anchasa Pramuanjaroenkij Asst. Prof. Dr. Somsak Vongpradubchai	Asst. Prof. Dr. Amornrat Kaewpradap Dr. Nattadon Pannucharoenwong		
10.20-10.40	AME0001	AEC0004	BME0003	TSF0004		
10.40-11.00	AME0004	AEC0013	BME0008	TSF0009		
11.00-11.20	AME0012	AEC0021	BME0011	TSF0022		
11.20-11.40	AME0022					
11.40-12.00	Closing Remarks and Awarding Ceremony (**Banquet Hall A**)					
12.00-13.00	Farewell Lunch & Bon Voyage!					

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CST0018

Circulating Flow Induced by Electric Field

Tossaphorn Klinmalee , and Chainarong Chaktranond *

Department of Mechanical Engineering, Faculty of Engineering, Thammasat University, Klong Luang, Pathumthani, 12120, Thailand

* Corresponding Author: cchainar@engr.tu.ac.th

Abstract. This research performs the three-dimensional simulations to investigate the circulating flow with high voltage electric field. Electrode wires are installed normal to flow direction and two ground wires are placed along both sidewalls of a square duct. Characteristics of electric fields and airflow velocity patterns are explored. In simulations, the inlet airflow velocity and applied electrical voltage are tested at 0.33 m/s and 20 kV, respectively. The results show that circulating flow in plane normal to flow direction is created. In addition, influence of electric field from each electrode occupies in a small region around electrode end. In other word, it steeply decrease from the center of electrode. The peak of electric field depends on the distance between electrode and ground wires. Additionally, the maximum peak occurs at the position of electrode nearest the ground. As a result, high airflow velocity occurs in this region. By installing the electrode closer to the center of ground, the whole airflow velocity becomes widely stronger.

1. Introduction

With rising of energy demand and global warming problems, many researchers have paid much attention to explore various effective strategies of energy saving. Hot-air drying method is widely used to preserve agricultural products and to improve the quality of materials, e.g. ceramic and wood. Due to the effects of the boundary layer or flow separation [1-3], the heat transfer on material surface is suppressed. As a result, drying period and energy consumption are much higher.

Flow manipulation by utilizing electric field is an interesting method to enhance drying efficiency because there are no moving parts and also it is able to control the drying temperature. The ideal of this method is to control the air motion by utilizing the high electrical voltage. The ionized air performed by electric force is moved faster from the electrode towards the ground, and this leads to the momentum transfer among the air particles. Simultaneously, with the influence of the velocity difference between the air flow layers or shear flow, vortices are generated. This causes the moisture and heat transfer on the surface of porous materials to enhance considerably[1-4].

Chaktranond and Rattanedecho [1] experimentally explore the hot air drying combined with electric fields to enhance the moisture removal and heat transfer of packed bed, which is used for porous material. Moreover, the effects of different porosity layers on drying are examined. It is found that when the electrical voltage is applied, air streams rotate around the ground wire. This causes a high amount of heat transfer onto the material surface, resulting in the enhancement of drying rate. Additionally, the arrangement of different porosity layers affects the capillary pressure the material, and also significantly influences the drying rate.

Lai and Lai [5] enhance the drying by installing copper electrode wire above packed bed and placing ground plates above and under packed bed, respectively. The experimental results show that the rate of drying depends on the magnitudes of applied voltage and the inlet wind velocity. Lai and Wang [6] are found that applying a heat source under the packed bed can enhance drying rate. Moreover, influence of corona wind has high effectiveness when high moisture content is in packed bed or is in early period of drying process.

Ahmedou and Havet [7] apply the two-dimensional channel-flow simulations to investigate the enhancement of heat transfer by electric field. In simulations, electrode wire is as a point. In addition, electrode is in the middle of the channel, while the ground electrode is put along the lower wall applied with heat flux. The results show that when the Reynolds number of air flow is low the corona wind can increases the convective heat transfer coefficient by 3 times that of the non-electric field.

Saenewong Na Ayuttaya et al. [8] investigate air flow under the electric fields with two-dimensional simulation in which electrode and ground are assumed as small circles. The results show that the air velocity driven by the electric forces varies inversely with the distance between the electrode and the ground.

Ghassem Heidarinejad and Reza Babaei [9] perform the large eddy simulations to investigate the enhancement of water evaporation by electric fields, so-called electrohydrodynamics (EHD). The results show that the rate of water evaporation is higher with applying electric field. Moreover, the effect of EHD is suppressed when Reynolds number is higher.

From mentioned above, details of flow subjected electric fields are lack in the spanwise direction. This research applies three-dimensional simulations to investigate the electric field distribution and flow patterns of electrically-induced circulating flow by following the experiments done by Nuknan et al. [10].

In experiments of Nuknan et al. [10] the packed bed is placed under the wind tunnel. This paper focused on the influence of electric field on airflow pattern. Therefore, heat transfer is not considered.

2. Simulation

We consider an experiment of drying enhanced electrically-driven swirling flow done by Nuknan et al. [10] as shown in Fig.1. The dimensions of square duct are *1.2* m long × *0.3* m wide × *0.3* m high. In present simulations, electrode is assumed as a point, and two ground wires are assumed as lines and laid along the side walls. Fig.2. shows the position of electrode and ground wire.

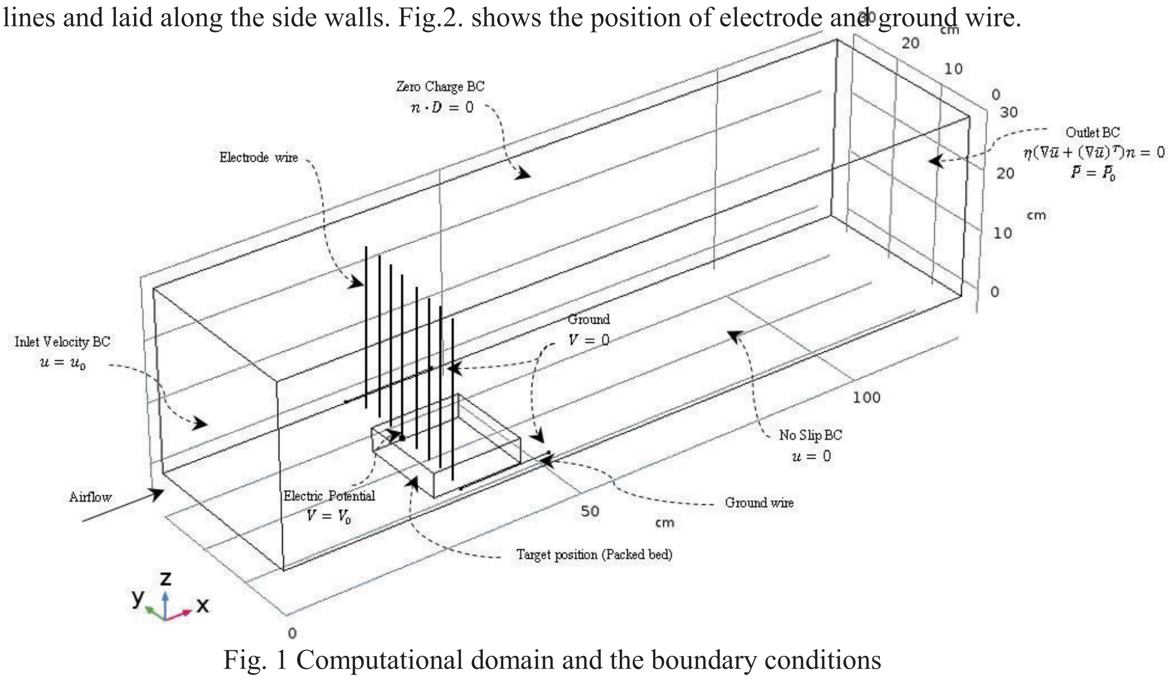

Fig. 1 Computational domain and the boundary conditions

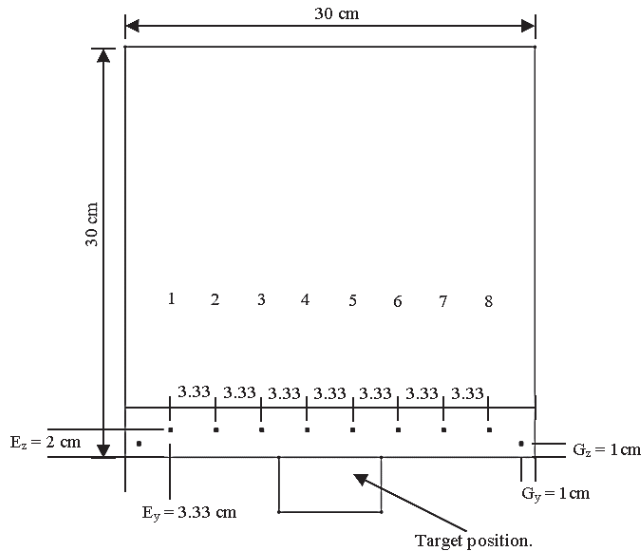

Fig. 2 Arrangement of electrode and ground positions.

The velocity of air in the channel is obtained by computing the continuity and Navier-Stokes equations, as shown in Eq.(1) and (2), where last term is body force term produced by electric force. Three-dimensional incompressible laminar flow simulations are computed by giving the inlet uniform velocity of 0.33 m/s. The pressure at the outlet is atmospheric pressure (P_0=101 kPa) and no viscous stress is used, as well as, no-slip condition on walls,

$$\nabla \cdot \vec{u} = 0 \qquad (1),$$

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \left(\vec{u} \cdot \nabla\right)\vec{u}\right) = -\nabla \vec{p} + \mu \nabla^2 \vec{u} + \vec{F}_{ee} \qquad (2),$$

where $\vec{u}$ is velocity, t is time, $\vec{p}$ is pressure, ρ is density (1.06 kg/m^3), μ is viscosity (19.99×10^{-6} Pa.s), and $\vec{F}_{ee}$ is body force term done by electric force. By assuming constant properties of air and electric fields, the electric force $\vec{F}_{ee}$ performing on fluid flow is computed from electrophoretic force or Coulomb force resulting from the net uncharged within the fluid or ions injected from the electrodes,

$$\overline{\vec{F}}_{ee} = q\vec{E} \qquad (3),$$

where q is the space charge density and $\vec{E}$ is the strenght of electric field. Additionally, the electric field strenght is computed through the Maxwell equations,

$$q = \nabla \cdot \varepsilon \vec{E} \qquad (4),$$

$$\vec{E} = -\nabla V \qquad (5),$$

where ε is the permittivity of air (8.85522 ×10^{-12} F/m) and V is the electric potential at electrode.In the simulations, the boundary conditions for electric field shown in Fig.2, are considered as zero charge symmetry. Electrical voltage at electrode and ground positions are V = 20 kV and V = 0, respectively.

The computational scheme uses a finite element method of tetrahedral and a collocation grid. Due to limitation of CPU and machine memory, the number of elements is approximately 100,000 elements, however, it is enough for these simulations. The governing equations are solved by using COMSOL Muliphysics 4.4.

3. Results and discussion

3.1 Electric field distribution

Fig. 3 shows the distribution of electric fields from various electrode ends. It is clearly observes that the strength of electric field depends on the number of electrode applied. With increasing the number of electrodes, the electric field strength is higher. In addition, the peak strength occurs at the position of electrode end. Fig. 4 shows the electric field distribution in y-z plane at z = 2 cm when eight electrodes are applied. As shown in Fig. 4(a) plotted in half one, the strength rapidly decreases when electrode positions are far from the ground wire. In addition, electric field influences only in a certain region nearby the center of electrode. Moreover, it is found from simulation results that the strength is proportion to $1/r^5$, where r is the radius measured from the center of electrode. Furthermore, the distribution shape of electrode near ground wire is much steeper than other ends, as shown in Fig. 4(b). This means that Coulomb force performs on the airflow in a certain region around the electrode end, as well as, the high force occurs at the position of electrode end.

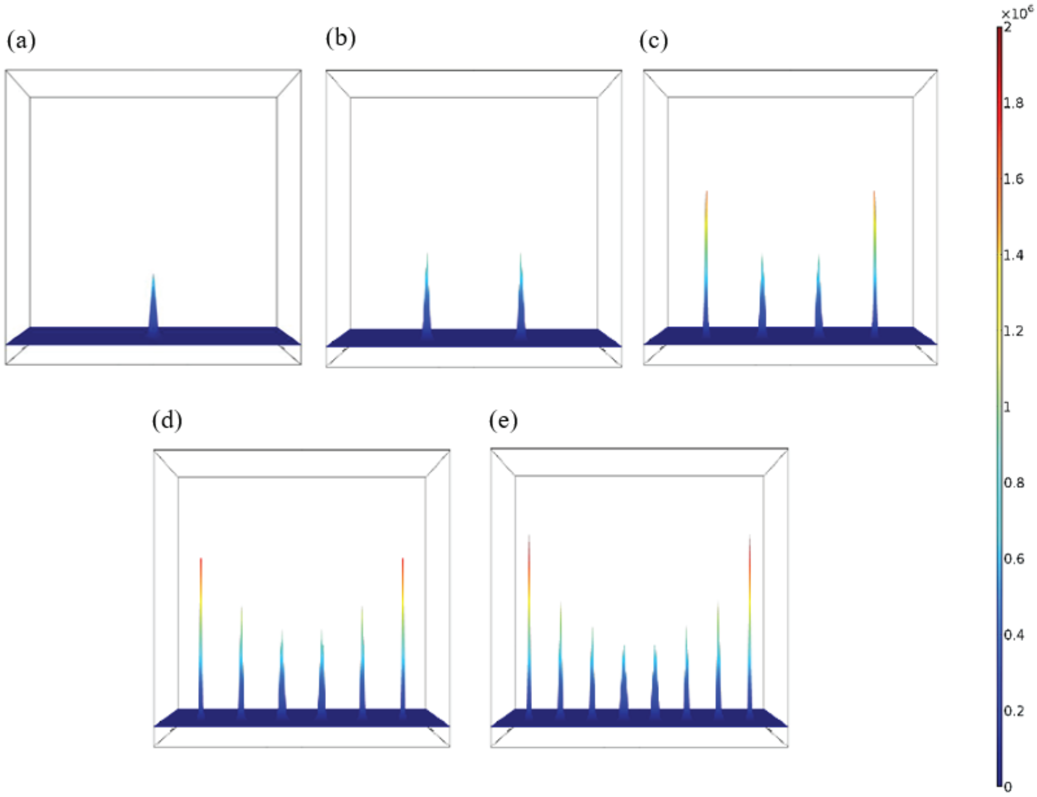

Fig. 3 Electric fields in various the number (n) of electrodes : (a) n = 1, (b) n = 2, (c) n = 4, (d) n = 6, and (e) n = 8.

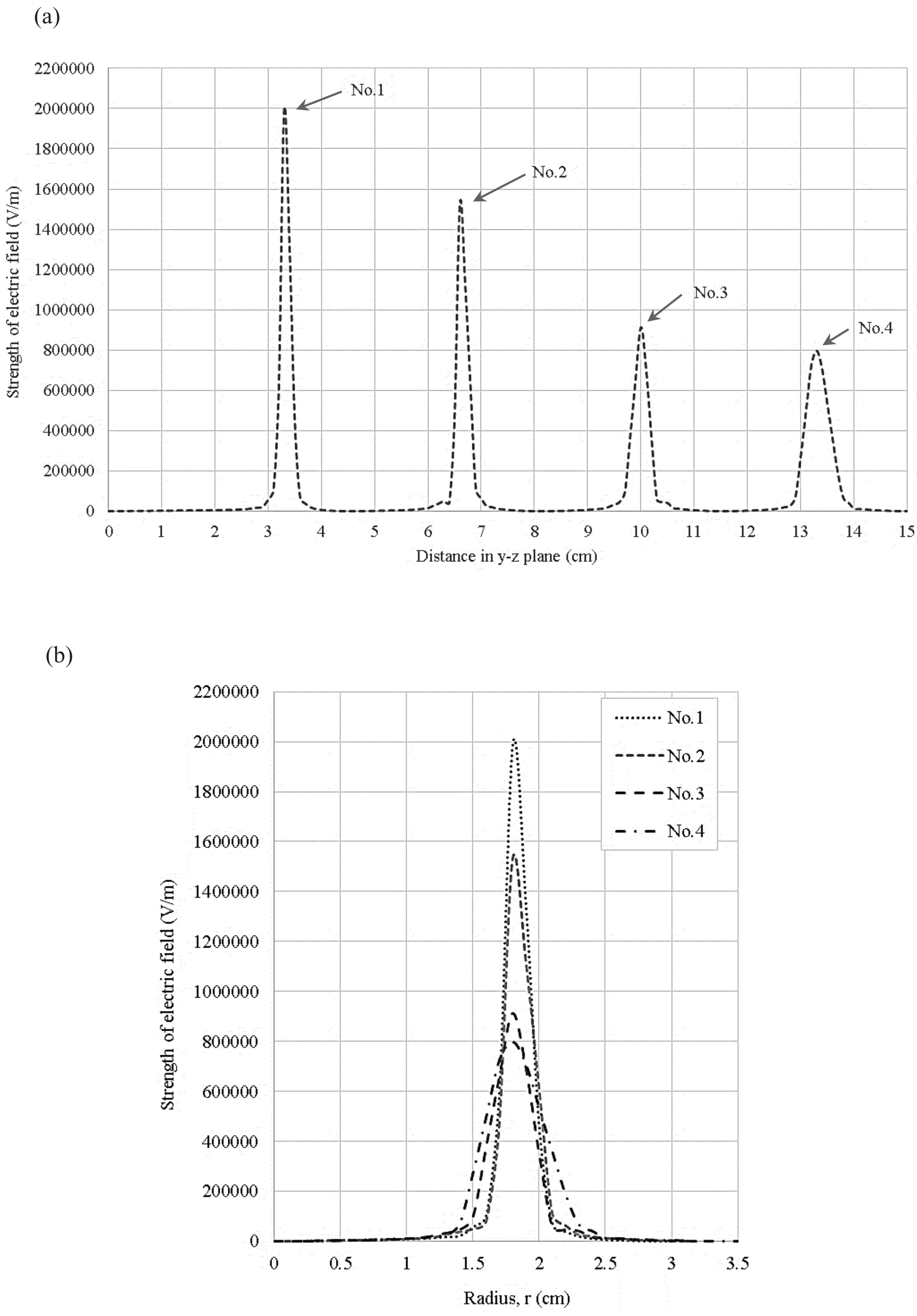

Fig. 4 Distribution of electric field strength from each electrode end in y-z plane when n = 8: (a) various electrode positions, (b) combination of electric field shape

Fig. 5 shows the electric field distribution in y-z plane when one and eight electrodes are applied. Electric fields are highly dense near electrode end. In addition, increase of the electrode numbers causes the gap between electrode and ground wire to become smaller, resulting in higher peak of electric field.

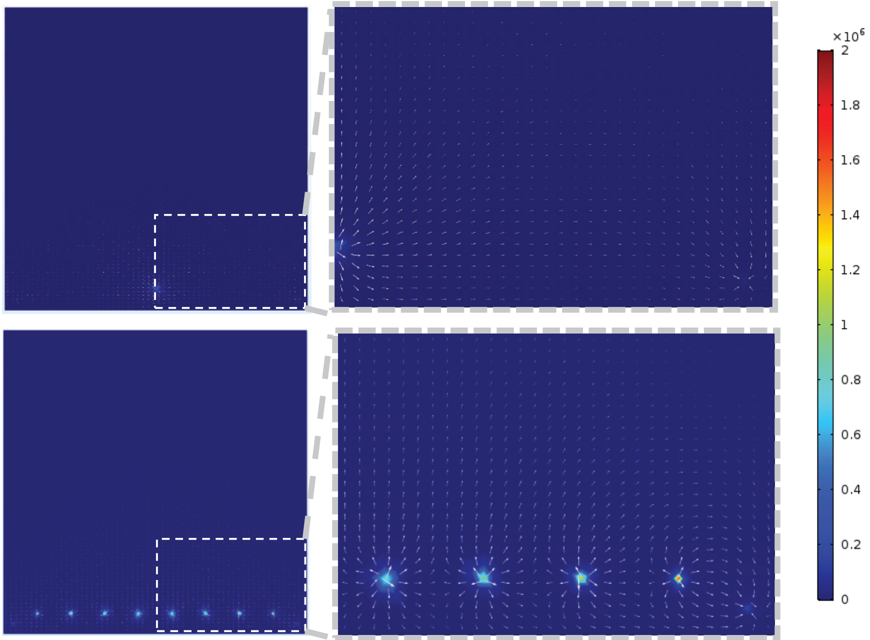

Fig. 5 Comparison of electric field distribution between one and eight electrodes.

Peak of electric field strength measured from each electrode shows in Fig. 6. In addition, it shows that the peak varies with the distance (d) between electrode and ground. From the graph, the strength is proportional to $1/d^2$. Therefore, the Coulomb force rapidly drops if the electrode is laid further away from the ground.

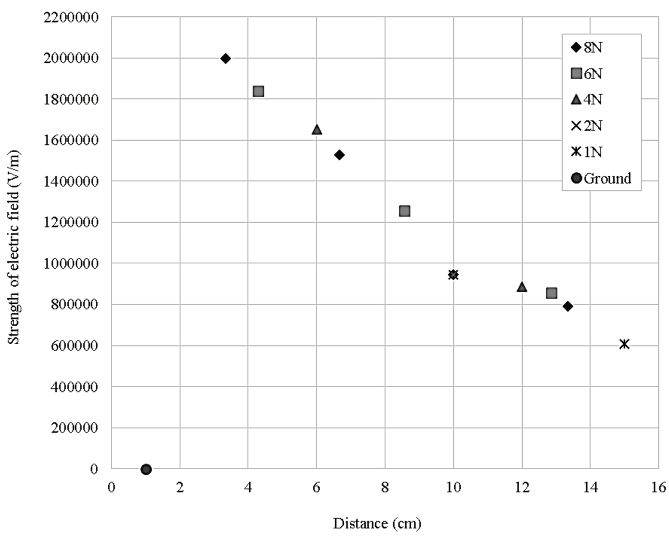

Fig. 6 Peak of electric field from electrode ends.

Fig. 7 shows the distribution of electric fields in various x-z planes when eight electrodes are installed at E_x = 30 and 33.75 cm. In addition, it is found that electrode installed near the ground provides the field shape wider and higher than the other planes. By comparing between Fig.7(a) and (b), the position of the peak follows the electrode position. Moreover, when electrodes are installed at E_x = 33.75 cm, the whole distribution become better. As a result, Coulomb force occupies airflow more wider.

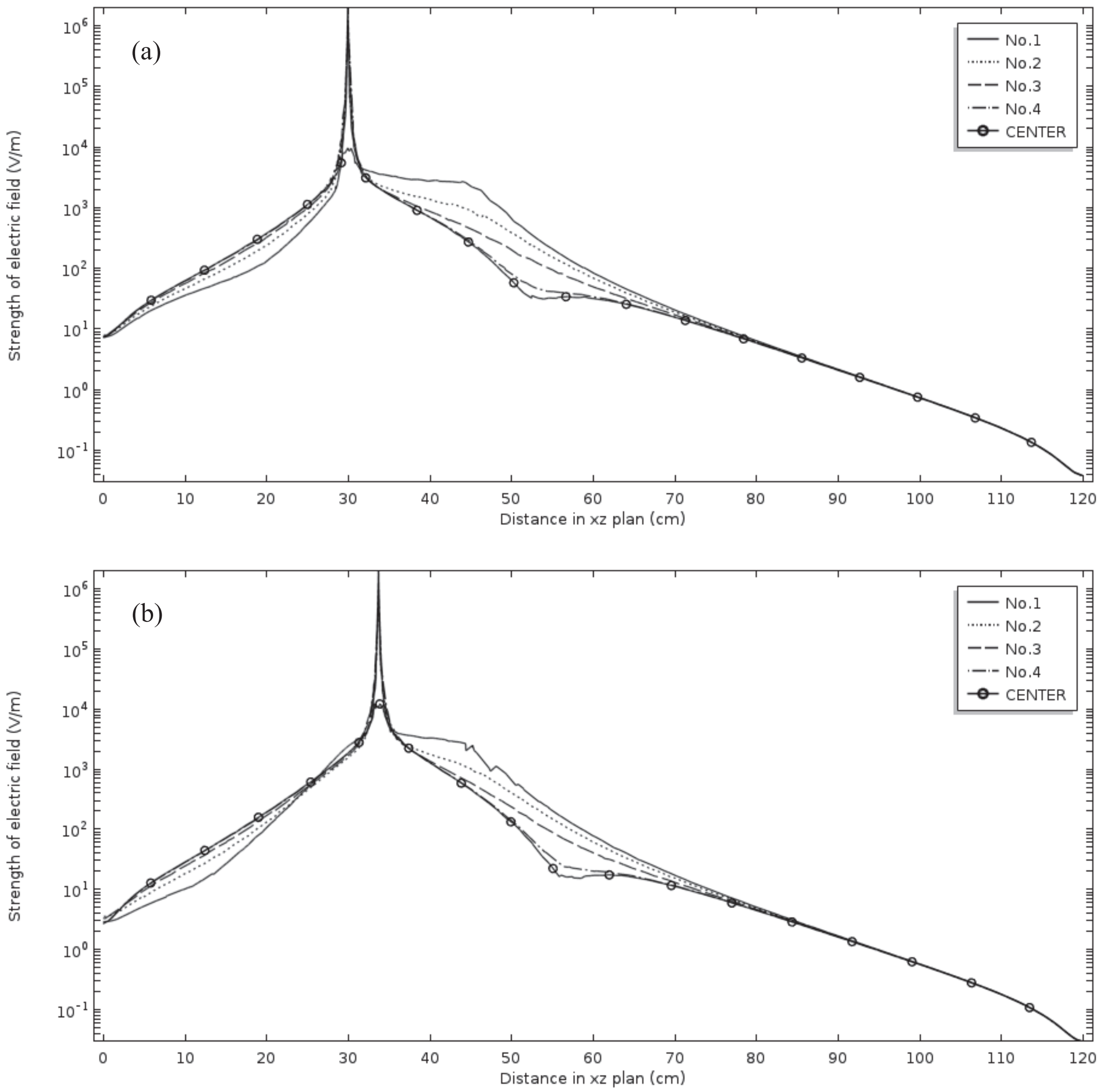

Fig. 7 Distribution of electric field in various x-z plane: (a) E_x = 30 cm, and (b) E_x = 33.75 cm.

3.2 Air flow under electric fields

Effects of electric field on airflow are shown in Fig. 8. By applying an electrode, the electric field does much influence the flow, resulting in low air velocity. When eight electrodes are applied, it clearly shows that influence of electric field can induces the velocity considerably higher, especially the position near the ground. Moreover, it shows that this electrode and ground arrangement induces the rotating flow around electrode ends. The maximum rotating occurs around electrode near the ground in where it is consistent with the position of high electric field strength in Fig.5.

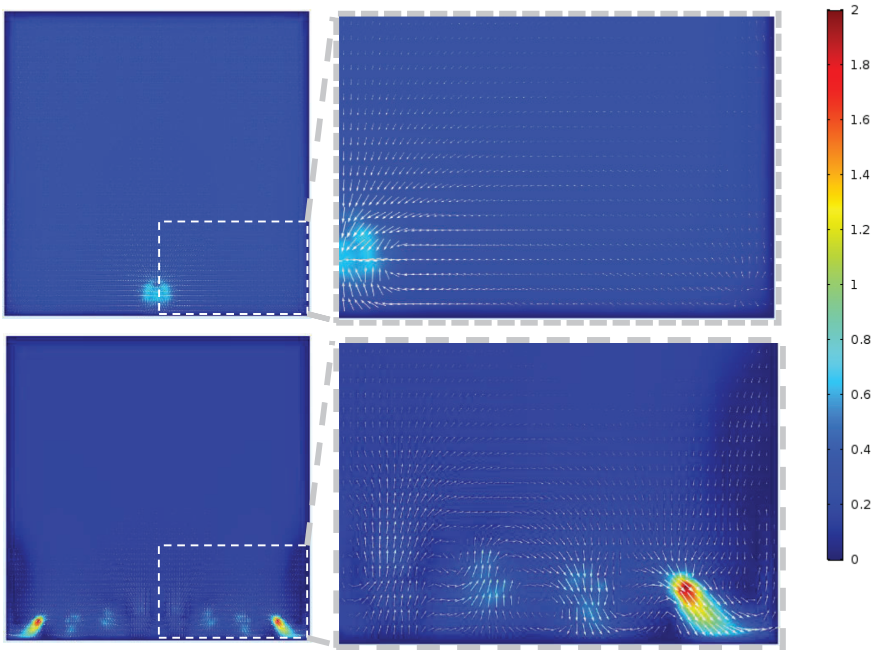

Fig. 8 Air velocity under electric force.

Fig. 9 and 10 show the velocity fields in various x-z planes of which the electrodes are installed. It shows that influence of electric field affects the flow pattern of air. In addition, flow strongly circulates on the plane near the ground (No.1). By comparing between Fig. 9 and 10, strength of circulating flow becomes stronger and wider when electrodes are installed at E_x = 33.75 cm. This is because the whole electric fields become wider, as shown in Fig. 7.

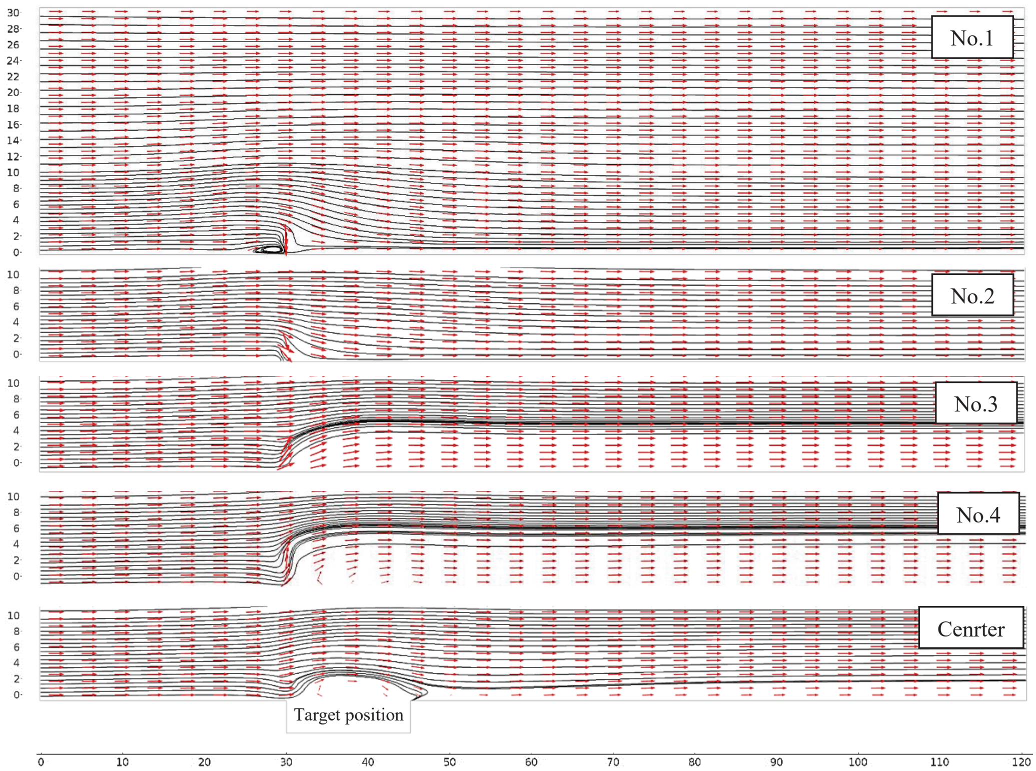

Fig. 9 Velocity field in various x-z planes when eight electrodes are at E_x = 30 cm.

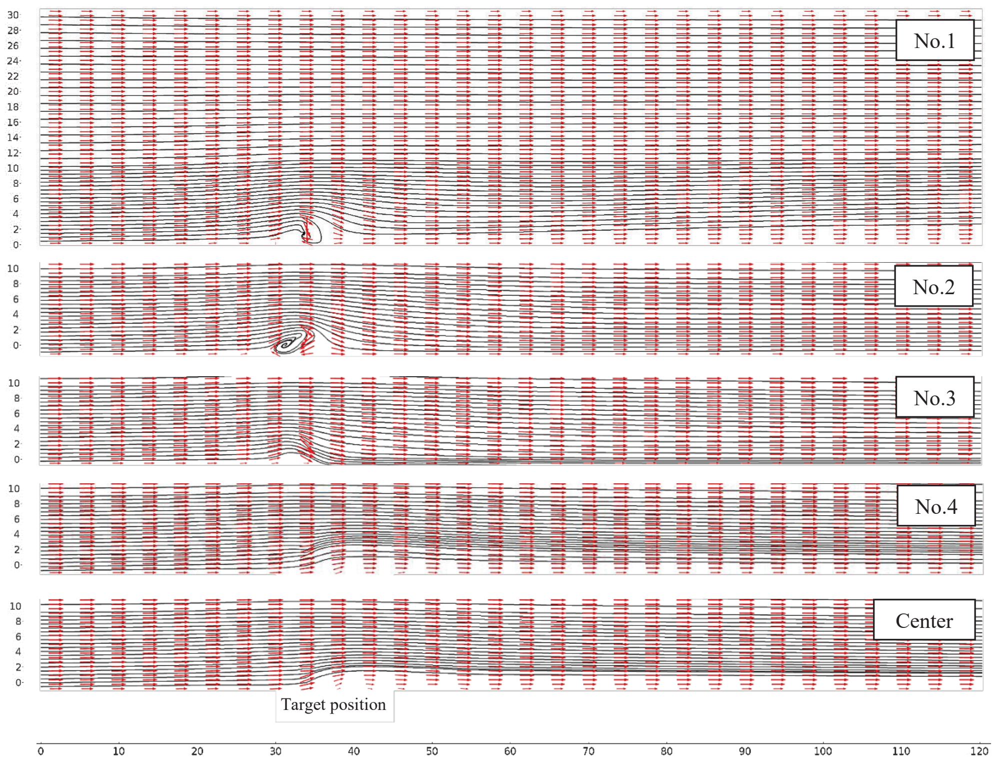

Fig. 10 Velocity field in various x-z planes when eight electrodes are at E_x = 33.75 cm.

4. Conclusion

This research investigates the electrically induced airflow pattern through the three-dimensional simulations. From the simulation results, we have reached the following conclusion:

1. High electric field strength occurs around the electrode ends and it steeply decreases by following the distance far away from the center of electrode ($E \propto 1/r^5$). Additionally, the electric field does not much influence nearby electrodes. By plotting the peak from electrode end, it is found that the peak *E* is proportional to $1//d^2$. The maximum peak occurs at the electrode installed nearest the ground wire.
2. Position of the high airflow velocity is consistent with the position of the peak electric field. Therefore, the rotating flow is highly strong around the electrode near the walls. In addition, electrode normal to flow direction and ground parallel to flow direction can induce the rotating flow in the plane normal to flow direction.
3. Adjusting the electrode position closer to the center of ground causes the whole airflow velocity to become wider and stronger on the surface of target position.

5. Acknowledgement

The authors would like to thank the faculty of engineering and Thammasat University for financial support.

6. References

[1] Chaktranond C and Rattanadecho P 2010 Analysis of heat and mass transfer enhancement in porous material subjected to electric fields (Effects of particle sizes and layered arrangement) *Experimental Thermal and Fluid Science* 34 1049-1056

[2] Wang W, Yang L, Wu K, Lin C, Huo P, Liu S, Huang D and Lin M 2017 Regulation-controlling of boundary layer by multi-wire-to-cylinder negative corona discharge *Thermal Engineering* 119 438-448

[3] Lai F C and Zhang J 2011 Effect of emitting electrode number on the performance of EHD gas pump in a rectangular channel *Journal of Electrostatics* 69 486-493

[4] Lee J R and Lau EV 2017 Effects of relative humidity in the convective heat transfer over flat surface using ionic wind *Applied Thermal Engineering* 114 554-560

[5] Lai F C and Lai K W 2002 EHD-Enhanced drying with wire electrode *Drying Technology* 20 1393-1405

[6] Lai F C and Wang C C 2009 EHD-enhanced water evaporation from partially wetted glass beads with auxiliary heating from below *Drying Technology* 27 1199-1204

[7] Ahmedou A O, Rouaud O, and Havet M 2009 Assessment of the electrohydrodynamic drying process *Food Bioprocess Technology* 2 240-247

[8] Sanewong Na Ayuttaya S, Chaktranond C, and Rattanadecho P 2013 Numerical analysis of electric force influence on heat transfer in a channel flow (Theory based on saturated porous medium approach) *Journal of Heat and Mass Transfer* 64 361-374

[9] Heidarinejad G and Babaei R 2015 Numerical investigation of electrohydrodynamics (EHD) enhanced water evaporation using large eddy simulation turbulent model *Journal of Electrostatics* 77 76-87

[10] Chaktranond C, Nuknan N, and Rattanadecho P 2014 Investigation of spiral flow generation using electrohydrodynamics for enhancement of hot-Air drying efficiency *Thai Science and Technology Journal* 22 906-913

Thanks for all of Sponsors

THAI TOHKEN THERMO CO.,LTD.

บริษัท โตเคน เทอร์โม เทรนนิ่ง เซ็นเตอร์ จำกัด

TAT

THAI AUTO TOOLS GROUP

บริษัท ไทย ออโต ทูลส์ แอนด์ ดาย จำกัด

บริษัท บีแอลซีพี เพาเวอร์ จำกัด

SCG
CEMENT-BUILDING MATERIALS

บริษัท ปูนซิเมนต์ไทย จำกัด (มหาชน) สำนักงานใหญ่

UHM
GROUP

บริษัท ยูเอชเอ็ม จำกัด่

บริษัท พีทีที โกลบอล เคมิคอล จำกัด (มหาชน)

บริษัท แอร์โรเฟลกซ์ จำกัด (สำนักงานใหญ่)

การประปานครหลวง (สำนักงานใหญ่)

Cafe Amazon

บริษัท เอฟที เอนเนอร์จี จำกัด

บริษัท ไอ.ที.ซี (1993) จำกัด

สมาคมพลังงานทดแทนสู่ชุมชนแห่งประเทศไทย

บริษัท โซเทค เอ็นจิเนียริ่ง จำกัด

Hydrocarbon Solutions (Thailand) Co., Ltd.