

ISSN 1044-5110
ATSPE2

ATOMIZATION AND SPRAYS

Journal of the International Institutes for Liquid Atomization and Spray Systems

Volume 7

1997

ATOMIZATION AND SPRAYS

Journal of the International Institutes for Liquid Atomization and Spray Systems

Editor

NORMAN CHIGIER

Department of Mechanical Engineering
Carnegie-Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213-3890
Phone: (412) 268-2498
FAX: (412) 268-3348
email: chigier@andrew.cmu.edu

Assistant to the Editor

Kathleen McClintock
Phone: (412) 268-3050
FAX: (412) 268-3348
email: km63@andrew.cmu.edu

Associate Editors

Joachim Domnick
Fraunhofer-Institut
Produktionstechnik und Automatisierung
Nobelstr. 12
70569 Stuttgart, Germany
Phone: 49-711-970-1762
FAX: 49-711-970-1005
email:jhd@ipa.fhg.de

Masataka Arai
Mechanical Systems Engineering
Gunma University
Tenjin-cho 1-5-1
Kiryu, Gunma 376, Japan
Phone: 81-277-30-1522
FAX: 81-277-30-1521
email: arai@tech.gunma-u.ac.jp

Editorial Board

Nasser Ashgriz, SUNY, Buffalo, NY
William Bachalo, Aerometrics, CA
W. Balachandran, Univ. of Uxbridge, U.K.
Josette Bellan, Jet Propulsion Lab, CA
Winfried Buschulte, Neuenstadt, Germany
Antonio Cavaliere, Univ. of Napoli, Italy
Paul Chiu, NCKU, Tainan, Taiwan
Lee G. Dodge, Southwest Research, TX
Christophe Dumouchel, Rouen, France
Chris Edwards, Stanford University, CA
Jerry Faeth, Univ. of Michigan, Ann Arbor, MI
Zoltan Farago, DFVLR, Germany
Andrew Hewitt, Macon, MO

Hiroyuki Hiroyasu, Univ. of Hiroshima, Japan
Jan B. Kennedy, UTRC, Hartford, CT
Sang Yong Lee, KAIST, Korea
Arthur H. Lefebvre, Stratford, U.K.
Jim Peters, Univ. of Illinois, Urbana, IL
Rolf Reitz, Univ. of Wisconsin, Madison, WI
Scott Samuels, Univ. of CA, Irvine, CA
William Sirignano, Univ. of CA, Irvine, CA
Greg Smallwood, NRC, Ottawa, Canada
Paul Sojka, Purdue University, IN
Yoram Tambour, Technion, Israel
Leonardo Tognetti, Univ. of Pisa, Italy
Cam Tropea, Univ. of Erlangen, Germany
Andrew Yule, UMIST, Manchester, U.K.

CONTENTS OF VOLUME 7

NUMBER 1

- 1 Theory of Droplets (II): States, Structures, and Laws of Interacting Droplets
H. H. Chiu and S. P. Su**

**33 Analysis of High-Pressure Diesel Spray Formation in the Early Stage of Injection
H. Takahashi, H. Yanagisawa, S. Shiga, T. Karasawa, and H. Nakamura**

**43 Methods and Tools for Advanced Fuel Spray Production and Investigation
G. Brenn, F. Durst, D. Trimis, and M. Weclas**

**77 Structure of a Nonevaporating Swirl Injector Spray
D. A. Feikema, R. Eskridge, and J. J. Hutt**

**97 Optimization of a Plain-Jet Airblast Atomizer
R. Harari and E. Sher**

**115 Spray Synthesis of Superplastic Materials for Near-Net-Shape Manufacturing
Y. Wu and E. J. Lavernia**

**Book Review
Norman Chigier**

NUMBER 2

- ii Letter from the Editor, Norman Chigier

123 Holographic Investigation of the Effect of Elevated Ambient Temperature on the Atomization Characteristics of Impinging Jet Sprays **Y. Shen, C. Mitts, and D. Poulikakos**

143 Sensitivity of the Mode of Combustion of Partially Premixed Spray Flames to Flow, Transport, and Evaporation Effects **J. B. Greenberg and N. Sarig**

161 Independent Control of Liquid Flow Rate and Spray Droplet Size from Hydraulic Atomizers **D. Ken Giles**

183 Tomographic Reconstruction of Asymmetric Sprays from a Twin-Hole Air Shroud Injector **C. H. Lee and S. H. Chung**

199 Group Combustion Behavior of Droplets in a Premixed-Spray Flame **Fumiteru Akamatsu, Yukio Mizutani, Masashi Katsuki, Shohji Tsushima, Yong Dae Cho, and Kazuyoshi Nakabe**

219 A System for Determining Dynamic Surface Tension Using the Oscillating Jet Technique **D. L. Reichard, J. A. Cooper, S. E. Bechtel, and R. D. Fox**

NUMBER 3

- 235** Droplet Size and Agricultural Spraying, Part 1:
Atomization, Spray Transport, Deposition, Drift, and Droplet Size
Measurement Techniques **Andrew Hewitt**
- 245** Atomization Characteristics of Airblast Fuel Injection inside a
Venturi Tube **H. Sun, T.-H. Chue, M.-C. Lai, and R. R. Tacina**
- 267** Modeling of Multiple Vaporizing Droplet Streams in Close Spacing
Configurations **Jun Xin and Constantine M. Megaridis**
- 295** Characterization of a Spray from an Ultrasonically Modulated
Nozzle **I. P. Chung, D. Dunn-Rankin, and A. Ganji**
- 317** Experimental Study of Pure and Multicomponent Fuel Droplet
Evaporation in a Heated Air Flow **G. Chen, S. K. Aggarwal,**
T. A. Jackson, and G. L. Switzer

NUMBER 4

- 339** Influence of Operating Variables on Average Droplet Size During Linear
Atomization **Yizhang Zhou, Steven Lee, Vincent G. McDonell,**
Scott Samuelson, Robert L. Kozarek, and Enrique J. Lavernia
- 359** Deformation and Breakup of an Annular Liquid Sheet in a Gas Stream
Satoyuki Kawano, Hiroyuki Hashimoto, Hidenori Togari, Akio Ihara,
Takashi Suzuki, and Toshikazu Harada
- 375** The Nonaerosol Haircare Business: A Growing Need for Atomization
Technology **Andrew Gaynor**
- 383** Ligament-Controlled Effervescent Atomization
J. J. Sutherland, P. E. Sojka, and M. W. Plesniak
- 407** Droplet Formation with Single and Multiple Nodes from a Liquid Jet
in Immiscible Liquids **Tapas K. Das**
- 417** Theoretical Investigation of the Spray from a Pressurized Metered-Dose
Inhaler **C. A. Dunbar, A. P. Watkins, and J. F. Miller**
- 437** Gasoline Injection Against Surfaces and Films
C. Arcoumanis, D. S. Whitelaw, and J. H. Whitelaw

NUMBER 5

- 457** Drop Size Modification in Black Liquor Sprays from Commercial Nozzles Using Pulsed Flow **H. Jeff Empie, Steven J. Lien, and Wenrui Yang**
- 467** Experimental Characterization of Shear Coaxial Injectors Using Liquid/Gaseous Nitrogen **C. Puissant, M. J. Glogowski, and M. M. Micci**
- 479** Multistate Behavior of a Droplet in Dilute Sprays
Jiunn-Shyan Huang and Huei-Huang Chiu
- 507** Disintegration of Liquid Jets from a Coaxial Dual Nozzle, Part I: Observation of Breakup Phenomena **Masataka Arai, Kenji Amagai, and Soo-Young No**
- 519** Disintegration of Liquid Jets from a Coaxial Dual Nozzle, Part II: Surface Wave and Its Frequency Analysis **Kenji Amagai, Masataka Arai, and Soo-Young No**
- 531** Atomization of Thin Liquid Films by Droplet Impact
Marwan Al-Roub and Patrick V. Farrell
- 549** Prediction of Jet Breakup Length in Liquid-Liquid Systems Using the Rayleigh-Tomotika Analysis **Tapas K. Das**

NUMBER 6

- 561** The Structure of an Acoustically Forced, Droplet-Laden Jet
Tait R. Swanson and Cill D. Richards
- 581** Application of the RNG $k-\epsilon$ Model to the Analysis of Flows and Spray Characteristics **H. C. Yang, H. S. Ryou, K. B. Hong, H. S. Kim, and S. K. Park**
- 603** Analytical Prediction of the Exit Flow of Cavitating Orifices
David P. Schmidt and M. L. Corradini
- 617** Possibility of Reduction of NO_x Emission by Shaping the Microstructure of Atomized Oil **R. Wilk and A. Szłęk**
- 629** Fuel Delivery in a Port Fuel Injected Spark Ignition Engine
R. M. Wagner, L. M. Nemecek, and J. A. Drallmeier
- 649** Microbubble Medium: Production and Hydrodynamic Properties
Igor V. Chernyshev
- 663** Modeling Atomization Processes of Pressure-Swirl Hollow-Cone Fuel Sprays **Zhiyu Han, Scott Parrish, Patrick V. Farrell, and Rolf D. Reitz**

Following page 684:

[Title page to Volume 7](#)

[Contents of Volume 7](#)

[Author Index to Volume 7](#)

[Subject Index to Volume 7](#)

AUTHOR INDEX TO VOLUME 7

- Aggarwal, S. K., 317
Akamatsu, Fumiteru, 199
Al-Roub, Marwan, 531
Amagai, Kenji, 507, 519
Arai, Masataka, 507, 519
Arcoumanis, C., 437

Bechtel, S. E., 219
Brenn, G., 43

Chen, G., 317
Chernyshev, Igor V., 649
Chiu, Huei-Huang, 1, 479
Cho, Yong Dae, 199
Chue, T.-H., 245
Chung, I. P., 295
Chung, S. H., 183
Cooper, J. A., 219
Corradini, M. L., 603

Das, Tapas K., 407, 549
Drallmeier, J. A., 629
Dunbar, C. A., 417
Dunn-Rankin, D., 295
Durst, F., 43

Empie, H. Jeff, 457
Eskridge, R., 77

Farrell, Patrick V., 531, 663
Feikema, D. A., 77
Fox, R. D., 219

Ganji, A., 295
Gaynor, Andrew, 375
Giles, D. Ken, 161
Glogowski, M. J., 467
Greenberg, J. B., 143

Han, Zhiyu, 663
Harada, Toshikazu, 359
Harari, R., 97
Hashimoto, Hiroyuki, 359
Hewitt, Andrew, 235
Hong, K. B., 581
Huang, Jiunn-Shyan, 479
Hutt, J. J., 77

Ihara, Akio, 359

Jackson, T. A., 317

Karasawa, T., 33
Katsuki, Masashi, 199
Kawano, Satoyuki, 359
Kim, H. S., 581
Kozarek, Robert L., 339

Lai, M.-C., 245
Lavernia, Enrique J., 115, 339
Lee, C. H., 183
Lee, Steven, 339
Lien, Steven J., 457

McDonell, Vincent G., 339
Megaridis, Constantine M., 267
Micci, M. M., 467
Miller, J. F., 417
Mitts, C., 123
Mizutani, Yukio, 199

Nakabe, Kazuyoshi, 199
Nakamura, H., 33
Nemecek, L. M., 629
No, Soo-Young, 507, 519

Park, S. K., 581
Parrish, Scott, 663
Plesniak, M. W., 383
Poulikakos, D., 123
Puissant, C., 467

Reichard, D. L., 219
Reitz, Rolf D., 663
Richards, Cill D., 561
Ryou, H. S., 581

Samuelson, Scott, 339
Sarig, N., 143
Schmidt, David P., 603
Shen, Y., 123
Sher, E., 97
Shiga, S., 33

- Sojka, P. E., 383
Su, S. P., 1
Sun, H., 245
Sutherland, J. J., 383
Suzuki, Takashi, 359
Swanson, Tait R., 561
Switzer, G. L., 317
Szlęk, A., 617

Tacina, R. R., 245
Takahashi, H., 33
Togari, Hidenori, 359
Trimis, D., 43
Tsushima, Shohji, 199

Wagner, R. M., 629
Watkins, A. P., 417
Weclas, M., 43
Whitelaw, D. S., 437
Whitelaw, J. H., 437
Wilk, R., 617
Wu, Y., 115

Xin, Jun, 267

Yanagisawa, H., 33
Yang, H. C., 581
Yang, Wenrui, 457

Zhou, Yizhang, 339

SUBJECT INDEX TO VOLUME 7

- Acoustically forced, droplet-laden jet, 561
Advanced fuel sprays, production and investigation, 43
Agricultural spraying, and droplet size, 235
Air flow, heated, 317
Air shroud injector, twin-hole, 183
Airblast atomizer, plain-jet, 97
Airblast fuel injection, 245
Ambient temperature, elevated, 123
Annular liquid sheet, 359
Asymmetric sprays, 183
Atomization
 for agricultural spraying, 235
 of impinging jet sprays, 123
 ligament-controlled effervescent, 383
 linear, 339
 of melts, following, 122
 of pressure-swirl hollow-cone fuel sprays, 663
 of thin liquid films, 531
Atomization characteristics
 of airblast fuel injection inside a venturi tube, 245
 of impinging jet sprays, 123
Atomization technology
 for haircare products, 375
Atomized oil, microstructure of, 617
Atomizer
 hydraulic, 161
 plain-jet airblast, 97
Average droplet size, 339

Black liquor sprays, 457
Breakup
 of an annular liquid sheet, 359
 length, jet, 549
Breakup phenomena, 507

Cavitating orifices, 603
Coaxial dual nozzle, 507, 519
Coaxial injectors, shear, 467
Combustion behavior, of droplets in a premixed-spray flame, 199
Combustion mode, sensitivity to flow, transport, and evaporation effects, 143
Control
 of liquid flow rate, 161
 of spray droplet size, 161

Deformation of an annular liquid sheet, 359
Deposition of droplets for agricultural spraying, 235
Diesel spray, high-pressure, 33
Disintegration of liquid jets, 507, 519
Drift of droplets in agricultural spraying, 235
Drop size modification, 457
Droplet
 behavior, in dilute sprays, 479
 in dilute sprays, 479
 evaporation, 317
 formation, with single and multiple nodes, 407
 impact, 531
 size
 and agricultural spraying, 235
 average, 339
 measurement techniques, 235
 spray, 161
 stream, multiple vaporizing, 267
Droplet-laden jet, acoustically forced, 561
Droplets
 in a premixed-spray flame, 199
 theory of, 1
Dual nozzle, coaxial, 507, 519
Dynamic surface tension, 219

Effervescent atomization, ligament-controlled, 383
Elevated ambient temperature, effect on atomization, 123
Evaporation
 effects, 143
 of fuel droplets, 317
Exit flow, cavitating orifices, 603

Flame
 partially premixed spray, 143
 premixed-spray, 199
Flow
 analysis of, 581
 effects, 143
 pulsed, 457
 rate, liquid, 161
Fuel
 delivery, in a port fuel injected spark ignition engine, 629
 droplet evaporation, 317

- Fuel injected spark ignition engine, 629
 Fuel injection, airblast, inside a venturi tube, 245
 Fuel spray,
 pressure-swirl hollow-cone, 663
 production and investigation, 43
 Gas stream, deformation and breakup in, 359
 Gasoline injection against surfaces and films, 437
 Group combustion behavior of droplets, 199
 Haircare, 375
 Heated air flow, 317
 High-pressure diesel spray formation, 33
 Hollow-cone fuel sprays, 663
 Holography, 123
 Hydraulic atomizers, 161
 Immiscible liquids, 407
 Impinging jet sprays, 123
 Inhaler, metered-dose, 417
 Injection
 early stage, 33
 gasoline, 437
 Injector spray
 nonevaporating, 77
 swirl, 77
 Injector
 shear coaxial, 467
 twin-hole air shroud, 183
 Interacting droplets, states, structures, and laws of, 1
 Jet
 acoustically forced, 561
 droplet-laden, 561
 Jet breakup length, 549
 Jet sprays, impinging, 123
 $k-\epsilon$ model, 581
 Laws of interacting droplets, 1
 Ligament-controlled effervescent atomization, 383
 Liquids, immiscible, 407
 Linear atomization, 339
 Liquid films, thin, 531
 Liquid flow rate, control of, 161
 Liquid jets
 disintegration of, 507, 519
 in immiscible liquids, 407
 Liquid sheet, annular, 359
 Liquid-liquid systems, 549
 Melts, atomization of, following, 122
 Metered-dose inhaler, 417
 Microbubble medium, 649
 Multicomponent fuel droplet evaporation, 317
 Multiple vaporizing droplet streams, 267
 Multistate behavior of a droplet, 479
 Near-net-shape manufacturing, 115
 Nitrogen, liquid/gaseous, 467
 Nodes, single and multiple, 47
 Nonaerosol haircare business, 375
 Nonevaporating swirl injector spray, 77
 NO_x emission, control of, 617
 Nozzles
 coaxial dual, 507, 519
 commercial, 457
 ultrasonically modulated, 295
 Oil, atomized, 617
 Operating variables, influence of, 339
 Orifices, cavitating, 603
 Oscillating jet technique, 219
 Partially premixed spray flames, 143
 Plain-jet airblast atomizer, 97
 Port fuel injected spark ignition engine, 629
 Premixed spray flames, 143
 Premixed-spray flame droplets, 199
 Pressure-swirl hollow-cone fuel sprays, 663
 Pressurized metered-dose inhaler, 417
 Pulsed flow, 457
 Pure fuel droplet evaporation, 317
 Rayleigh-Tomotika analysis, 549
 Renormalization group, 581
 RNG $k-\epsilon$ model, 581
 Shear coaxial injectors, 467
 Spark ignition engine, 629
 Spray
 advanced fuel, 43
 asymmetric, 183
 black liquor, 457
 characteristics, 581
 dilute, 479
 droplet size, control of, 161
 flames, partially premixed, 143

- impinging jet, 123
nonevaporating swirl injector, 77
from a pressurized metered-dose inhaler, 417
synthesis of superplastic materials for near-net-shape manufacturing, 115
transport, for agricultural spraying, 235
from an ultrasonically modulated nozzle, 295
Superplastic materials for near-net-shape manufacturing, 115
Surface tension, dynamic, 219
Surface waves, 519
Swirl injector spray, nonevaporating, 77
Temperature, elevated ambient, 123
Thin liquid films, atomization of, 531
Tomographic reconstruction, 183
Transport effects, 143
Twin-hole air shroud injector, 183
Ultrasonically modulated nozzle, 295
Vaporizing droplet streams in close spacing configurations, 267
Venturi tubes, airblast fuel injection in, 245