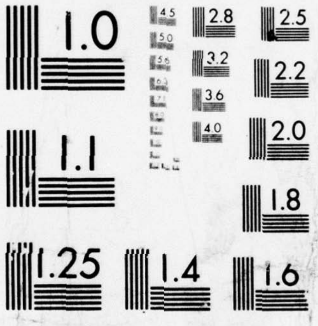
AD-A069 668   INDIANA UNIV AT BLOOMINGTON DEPT OF CHEMISTRY   F/G 20/9
HYDRODYNAMIC FLOW PATTERNS AS A SIMPLE AID TO EFFECTIVE ICP TOR--ETC(U)
MAY 79 E SEXTON, R N SAVAGE, G M HIEFTJE   N00014-76-C-0838
UNCLASSIFIED   TR-21   NL

1 OF 1
AD
A069668

END
DATE
FILMED
7-79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(12)

AD A069668

DDC FILE COPY

LEVEL

REPORT DOCUMENTATION PAGE	**READ INSTRUCTIONS BEFORE COMPLETING FORM**
1. REPORT NUMBER TWENTY-ONE	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER (9)	
4. TITLE (and Subtitle) (6) Hydrodynamic Flow Patterns as a Simple Aid to Effective ICP Torch Design	5. TYPE OF REPORT & PERIOD COVERED ~~Interim~~ Technical Report,
	6. PERFORMING ORG. REPORT NUMBER 27 (14) TR-21
7. AUTHOR(s) Earl Sexton, Richard N. Savage ~~and~~ Gary M. Hieftje (10)	8. CONTRACT OR GRANT NUMBER(s) N-14-76-C-0838 N00014-76-C-0838
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Chemistry Indiana University Bloomington, IN 47405	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 051-622
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Washington, D. C.	12. REPORT DATE (11) 30 May ~~30,~~ 1979
	13. NUMBER OF PAGES (12) 15p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (15) N00014-76-C-0838 ✓ NSF-CHE-76-10896 p6	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)	
18. SUPPLEMENTARY NOTES Prepared for publication in APPLIED SPECTROSCOPY	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) inductively coupled plasma, emission spectroscopy, multielement analysis, plasma torch	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A new method is described for simplifying the design and construction of inductively coupled plasma torches. In the method, tap water is directed into the torch's gas inlet tubes and the swirl pattern of the exiting liquid is observed. From this pattern, irregularities in the torch can be readily noted and operating behavior of the plasma can be predicted.	

DDC
RECEIVED
JUN 11 1979
C

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

176685

79 06 08 058

OFFICE OF NAVAL RESEARCH

Contract N14-76-C-0838

Task No. NR 051-622

TECHNICAL REPORT NO. 21

HYDRODYNAMIC FLOW PATTERNS AS A SIMPLE AID TO EFFECTIVE ICP TORCH DESIGN

by

Earl Sexton, Richard N. Savage and Gary M. Hieftje

Prepared for Publication

in

APPLIED SPECTROSCOPY

Indiana University

Department of Chemistry

Bloomington, Indaina 47405

May, 1979

Reproduction in whole or in part is permitted for
any purpose of the United States Government

Approved for Public Release; Distribution Unlimited

In the past five years interest has soared in the inductively coupled plasma (ICP) as an excitation source for optical emission spectrochemical analysis. As a result, the ICP has rapidly made the transition from research laboratory to industrial application facility and the number of ICP users has grown correspondingly. This report describes a simple yet effective technique to aid users in constructing, modifying and repairing the most important component in their ICP system--the plasma torch.

The heart of every ICP system is the specially arranged quartz tubes which comprise the plasma torch. It is the unique gas flow patterns produced by this device which enable a plasma to be easily ignited and sustained and to accept sample. Unfortunately, the critical parameters in torch construction have not been clearly defined and the fabrication of a functioning torch is an art which few have been able to master. In an attempt to construct highly efficient miniaturized ICP torches in our laboratories, we have developed a diagnostic method for evaluating critical parameters in torch design. The technique is based on hydrodynamic principles and has enabled us to evaluate and build our own torches with a minimum amount of effort and a high rate of success. This capability can result in a significant savings for users since torch damage frequently occurs during routine operation.

According to Reed[1] and others[2,3] the key to a successful torch lies in its ability to create a vortex in the support gas (typically argon or nitrogen) flowing through the torch. It is the creation of a low-pressure zone within the vortex which enables a plasma to be formed and stabilized in the end of the torch. However, because the support-gas vortex cannot be seen, it has been difficult to determine exactly which parameters in torch design influence vortex formation. We have observed that by introducing a stream of water into a properly designed torch in the same fashion as would the support gas, one can visually observe the formation of a vortex. By repeatedly modifying torch construction and observing the influence each change has on the effectiveness of the torch at forming a vortex, one can empirically determine which parameters are important in torch design. Once the important parameters are known it becomes easy to build a torch which will operate properly. In fact the person involved in actually building the torch can use the hydrodynamic technique during each stage of torch construction as a quick means of determining if the pieces have been properly assembled. Using this technique we were able to construct the miniature torch shown in Fig. 2 of reference 4. This torch will sustain a mini-plasma at low RF power levels and with reduced amounts of argon support gas with no deterioration in analytical capability; thereby increasing its efficiency.[4]

The photograph in Fig. 1 illustrates the flow pattern produced when water is introduced into the coolant gas inlet tube of a properly constructed miniature torch. As the water spirals through the torch, a well-shaped vortex is created in the end of the torch just above the plasma tube. Then, as the spiraling water exits the torch, an umbrella-shaped spout is generated. These characteristic patterns will only be developed by a properly constructed torch. Typically the water is introduced into either the coolant or plasma gas inlet tubes at a rate of approximately 900 ml min^{-1} (for a torch with a 14 mm o.d. coolant tube); of course this flow should vary with torch size.

Now, using flow patterns of this nature let us evaluate the critical features in torch design. All of our discussion will refer specifically to the miniature torch we developed.[4]

One of the most important features in torch construction is the tangential orientation of the gas inlet tubes. Reed[1] was one of the first to recognize that the surest way to establish a vortex is to orient the inlet tubes of a torch so that their central axes lie on tangent lines to the coolant tube. If the plasma and coolant gas inlet tubes are properly oriented in this manner, water introduced through these tubes will be forced to spiral up through the torch and will produce a vortex as shown in Fig. 1. However, if the inlet tubes are improperly oriented, a pattern such as the one in Fig. 2 will be generated. With the new method it is easy to empirically optimize the position of the inlet tubes; one simply changes their orientation until the water is forced to spiral up through the torch at the highest swirl velocity possible.

Internal diameters of the inlet tubes are also important in torch design.[3,4] Not surprisingly, smaller i.d. tubes increase the swirl velocity of the water as it spirals up the torch. Accordingly a stable vortex could be formed at lower water flow rates, indicating that a savings in support gas consumption could also be realized. Significantly, there appears to be a limit to the amount the inlet tubes can be constricted. We observed with our miniature torch that inlet diameters less than 2 mm produced unstable flow patterns. Apparently, if the introduction velocity is too high, the water does not form a stable spiraling pattern but becomes non-uniform, resulting in a turbulent flow similar to the one demonstrated in Fig. 2.

Another important parameter in torch design is the shape of the intermediate or plasma tube. We have observed that a flared plasma tube such as the one ordinarily used creates an excellent vortex. Fig. 3A demonstrates the hydrodynamic pattern created in a torch with a straight plasma tube (8 mm o.d.). Notice the small and confined vortex which is created. We also observed that if a 10 mm o.d. straight plasma tube was employed in our 14 mm mini-torch, the spiraling nature of the water was distored and a more turbulent condition arose. In Fig. 3B is shown the flow pattern for a flared shaped plasma tube. Clearly, a better vortex is created with the flared design as evidenced by the larger, more well defined hole created in the tip of this torch. By observing flow patterns such as these, we concluded that a 4 mm gap between the plasma and coolant tubes in the lower part of the mini-torch is necessary to ensure that a stable spiraling flow pattern is established; a 2 mm gap between the flared out portion of the plasma tube and the coolant tube then constricts the water path and increases flow velocity which enhances vortex formation. Moreover, this design directs the flow against the inner wall of the coolant tube and thereby provides maximum thermal isolation for the torch. If the distance between the coolant and the flared portion of the plasma tube is decreased below 2 mm then the velocity of the water exiting the mini-torch becomes too high and an unstable flow pattern is produced.

We also noted that it is easier to ignite and sustain a low-power plasma with a torch employing the flared plasma tube design. Other investigators have come to this same conclusion.[5] One possible explanation can be derived from hydrodynamic theory, which predicts that a fluid flowing through a flared shaped tube of this design will produce sheds vortices.[6]

In other words, as the fluid moves through the torch, that part which is in contact with the plasma tube will be slowed down as it flows around the flared portion, relative to the fluid which is traveling along the inner wall of the coolant tube. As the fluid flowing along the plasma tube passes the end of the tube, some of it will break off from the mainstream and flow in the opposite direction. Indeed, it has been shown[7] that a counter or reverse flow of this nature facilitates plasma ignition and stability.

Another important feature of the plasma tube is its length beyond the flared region (i.e., the length of the 10 mm o.d. portion of the plasma tube in Fig. 2 of ref. 4). If this section is too long, water will shoot straight out of the end of the torch and collapse inward toward the central axis of the torch instead of breaking off sharply into an umbrella-shaped spout (cf. Fig. 1). We have observed that torches which flow patterns of this type do not produce stable plasmas. When this section of the plasma tube is of the appropriate length (11 mm for the miniature torch in Fig. 2 of ref. 4) the umbrella-shaped spout shown in Fig. 1 will be formed. If the length is too short, the spiraling flow of water directed towards the inner wall of the coolant tube by the flared portion will not be properly confined and will bounce off the walls, producing a turbulent flow condition.

A final important feature in ICP torch construction is the concentricity of the tubes. If the plasma and coolant tubes are not aligned concentrically, a distorted water flow pattern such as the one in Fig. 4 will result. Instead of the water forming a symmetrically shaped spout it will be noticeably skewed. Concentric alignment can be assured during torch construction by placing a precisely machined graphite sleeve between the coolant and plasma tubes. This technique can also be employed to ensure that the sample injection tube is concentrically aligned.

ACKNOWLEDGEMENT

Supported in part by the National Science Foundation through grant CHE 76-10896 and by the Office of Naval Research.

REFERENCES

1. T. B. Reed, J. Appl. Phys., 32, 821 (1961).
2. S. Greenfield, I. Ll. Jones and C. T. Berry, Analyst, 89, 713 (1964).
3. J. L. Genna and R. M. Barnes, Anal. Chem., 49, 1450 (1977).
4. R. N. Savage and G. M. Hieftje, Anal. Chem., 51, 408 (1979).
5. C. D. Allemand, ICP Inform. Newsl., 2, 1 (1976).
6. Chem. Eng. News, Dec. 19, 1977, p. 20.
7. C. D. Allemand and R. M. Barnes, Appl. Spectrosc., 31, 434 (1977).

FIGURE LEGENDS

Figure 1. HYDRODYNAMIC FLOW PATTERNS PRODUCED BY A PROPERLY CONSTRUCTED MINI-TORCH.

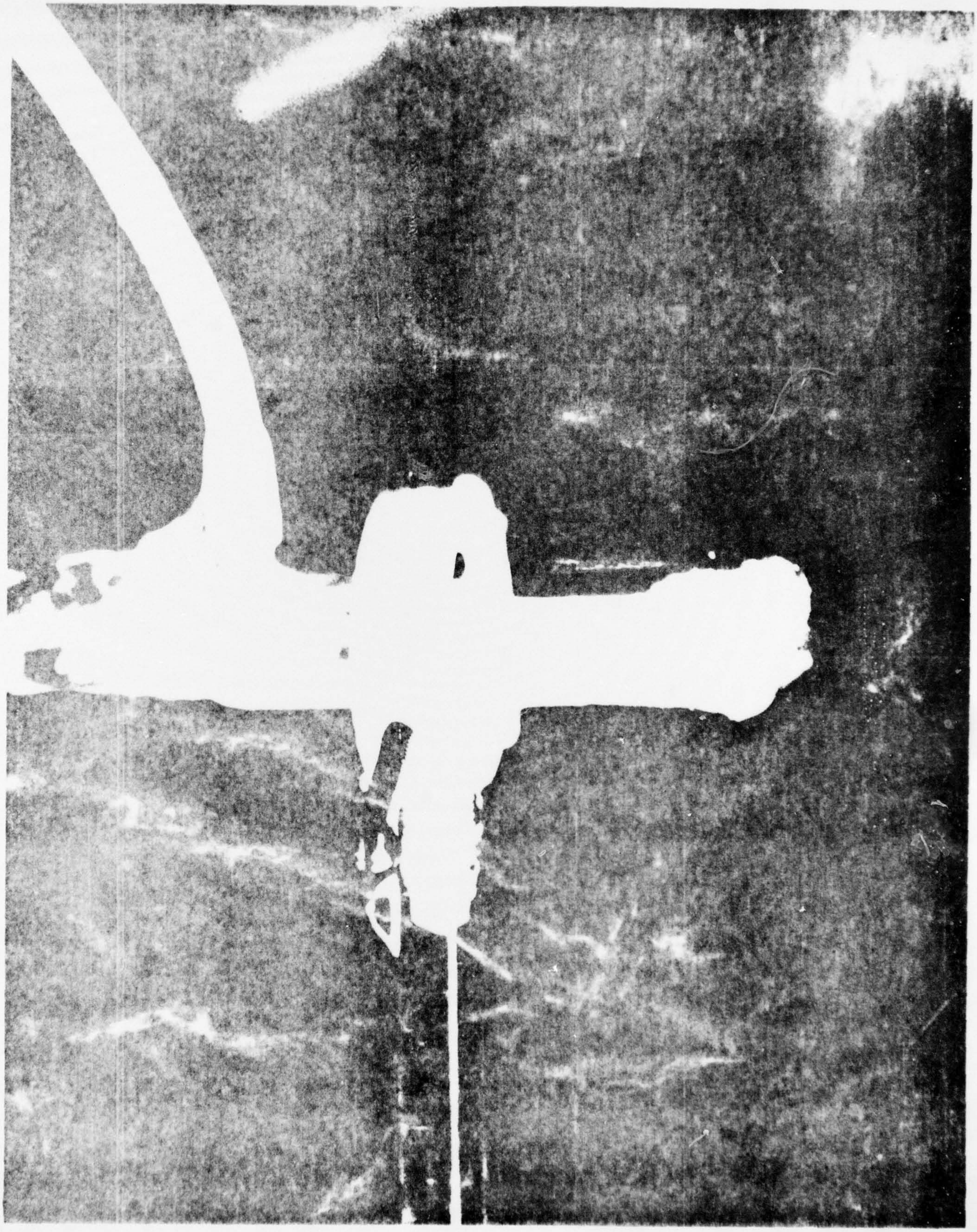
Figure 2. FLOW PATTERN ESTABLISHED WHEN COOLANT GAS INLET TUBE IS NOT TANGENTIALLY ORIENTED.

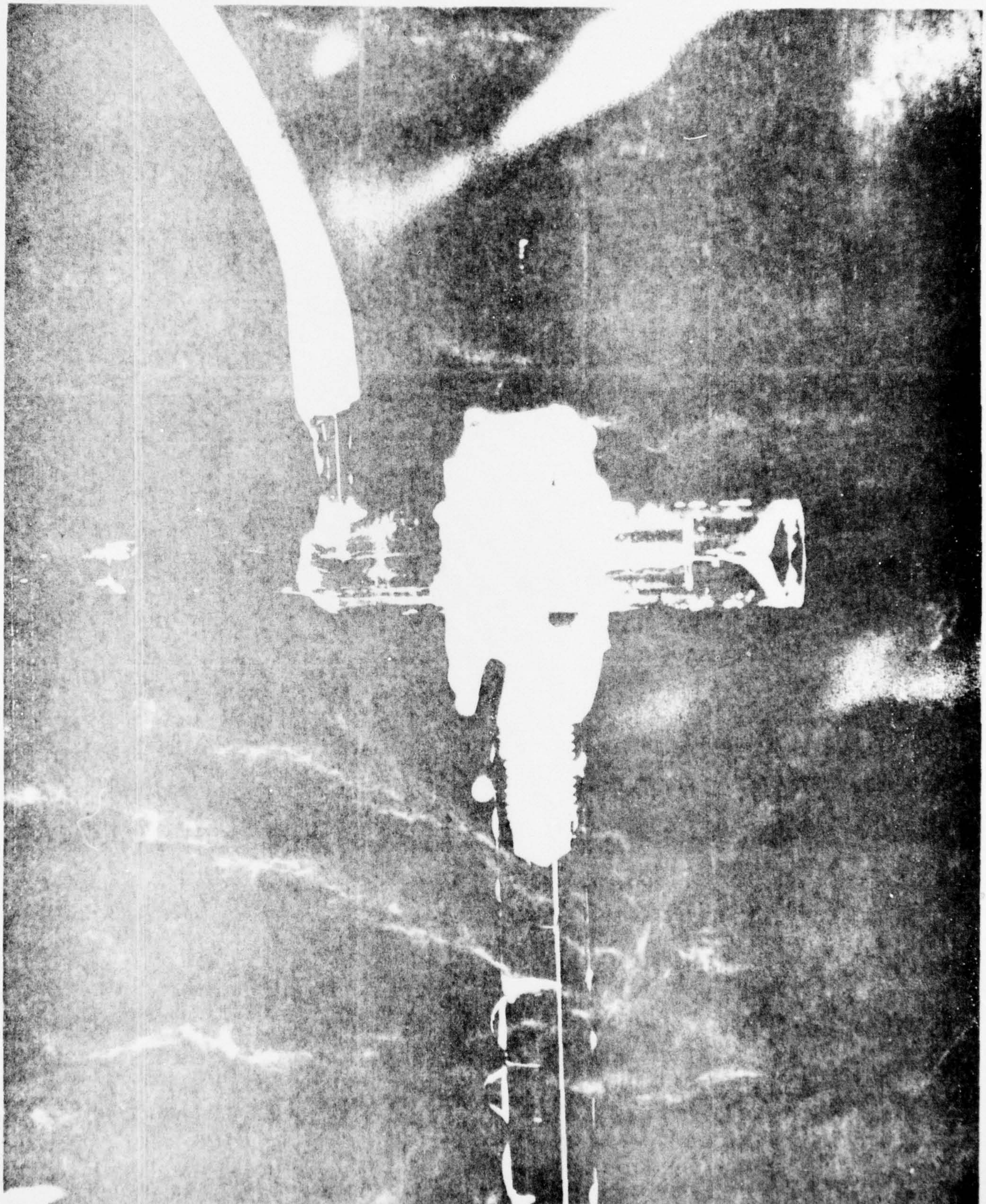
Figure 3. EFFECT OF PLASMA TUBE SHAPE ON VORTEX FORMATION. In both cases water is introduced into the coolant gas inlet tube. However, the torch in Fig. 4A was not equipped with a plasma gas inlet tube.

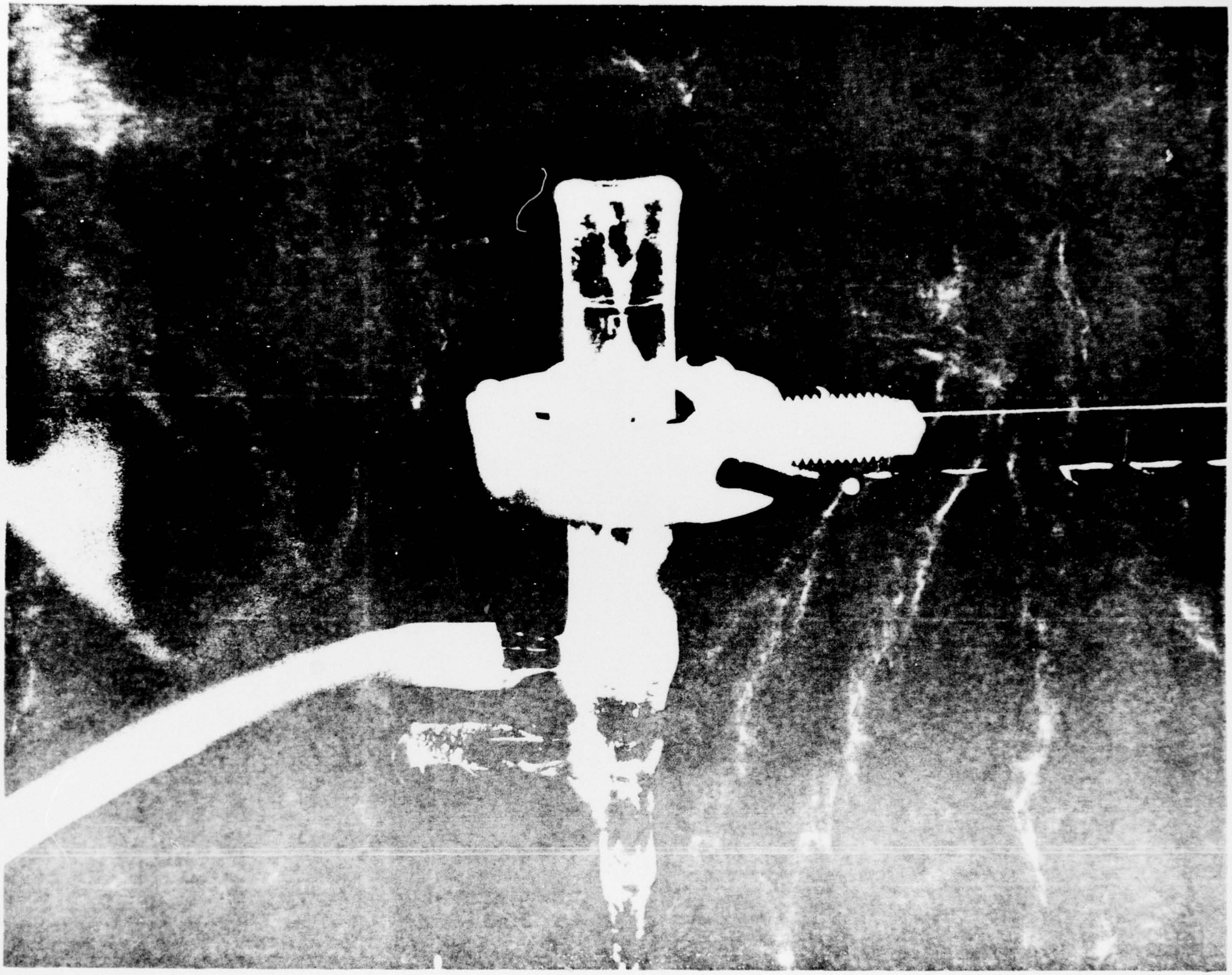
A. Straight Design

B. Flared Design

Figure 4. WATER FLOW PATTERN PRODUCED BY NON-CONCENTRIC TORCH







TECHNICAL REPORT DISTRIBUTION LIST, GEN

	No. Copies
Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217 Attn: Code 472	2
ONR Branch Office 536 S. Clark Street Chicago, Illinois 60605 Attn: Dr. George Sandoz	1
ONR Branch Office 715 Broadway New York, New York 10003 Attn: Scientific Dept.	1
ONR Branch Office 1030 East Green Street Pasadena, California 91106 Attn: Dr. R. J. Marcus	1
ONR Area Office One Hallidie Plaza, Suite 601 San Francisco, California 94102 Attn: Dr. P. A. Miller	1
ONR Branch Office Building 114, Section D 666 Summer Street Boston, Massachusetts 02210 Attn: Dr. L. H. Peebles	1
Director, Naval Research Laboratory Washington, D.C. 20390 Attn: Code 6100	1
The Assistant Secretary of the Navy (R,E&S) Department of the Navy Room 4E736, Pentagon Washington, D.C. 20350	1
Commander, Naval Air Systems Command Department of the Navy Washington, D.C. 20360 Attn: Code 310C (H. Rosenwasser)	1

	No. Copie
Defense Documentation Center Building 5, Cameron Station Alexandria, Virginia 22314	12
U.S. Army Research Office P.O. Box 1211 Research Triangle Park, N.C. 27709 Attn: CRD-AA-IP	1
Naval Ocean Systems Center San Diego, California 92152 Attn: Mr. Joe McCartney	1
Naval Weapons Center China Lake, California 93555 Attn: Dr. A. B. Amster Chemistry Division	1
Naval Civil Engineering Laboratory Port Hueneme, California 93401 Attn: Dr. R. W. Drisko	1
Professor K. E. Woehler Department of Physics & Chemistry Naval Postgraduate School Monterey, California 93940	1
Dr. A. L. Slafkosky Scientific Advisor Commandant of the Marine Corps (Code RD-1) Washington, D.C. 20380	1
Office of Naval Research 800 N. Quincy Street Arlington, Virginia 22217 Attn: Dr. Richard S. Miller	
Naval Ship Research and Development Center Annapolis, Maryland 21401 Attn: Dr. G. Bosmajian Applied Chemistry Division	
Naval Ocean Systems Center San Diego, California 91232 Attn: Dr. S. Yamamoto, Marine Sciences Division	

Encl 1

TECHNICAL REPORT DISTRIBUTION LIST, 051C

	No. Copies
Dr. M. B. Denton University of Arizona Department of Chemistry Tucson, Arizona 85721	1
Dr. R. A. Osteryoung Colorado State University Department of Chemistry Fort Collins, Colorado 80521	1
Dr. B. R. Kowalski University of Washington Department of Chemistry Seattle, Washington 98105	1
Dr. S. P. Perone Purdue University Department of Chemistry Lafayette, Indiana 47907	1
Dr. D. L. Venezky Naval Research Laboratory Code 6130 Washington, D.C. 20375	1
Dr. H. Freiser University of Arizona Department of Chemistry Tuscon, Arizona 85721	
Dr. Fred Saalfeld Naval Research Laboratory Code 6110 Washington, D.C. 20375	1
Dr. H. Chernoff Massachusetts Institute of Technology Department of Mathematics Cambridge, Massachusetts 02139	1

	No. Copic
Dr. K. Wilson University of California, San Diego Department of Chemistry La Jolla, California 92037	1
Dr. A. Zirino Naval Undersea Center San Diego, California 92132	1
Dr. John Duffin United States Naval Postgraduate School Monterey, California 93940	1
~~Dr. G. M. Hieftje~~ ~~Department of Chemistry~~ ~~Indiana University~~ ~~Bloomington, Indiana 47401~~	1
Dr. Victor L. Rehn Naval Weapons Center Code 3813 China Lake, California 93555	1
Dr. Christie G. Enke Michigan State University Department of Chemistry East Lansing, Michigan 48824	1
Dr. Kent Eisentraut, MBT Air Force Materials Laboratory Wright-Patterson AFB, Ohio 45433	1
Walter G. Cox, Code 3632 Naval Underwater Systems Center Building 148 Newport, Rhode Island 02840	1