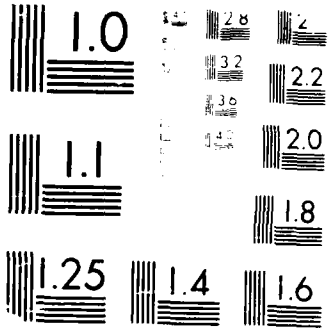
AD-A191 489 STUDY OF MIXING AND REACTION IN THE FIELD OF A VORTEX (U) CALIFORNIA UNIV IRVINE DEPT OF MECHANICAL ENGINEERING B M CETEGEN ET AL 20 NOV 87 1/1

UNCLASSIFIED AFOSR-TR-88-0251 AFOSR-86-0016 F/G 20/4 NL



MICROCOPY RESOLUTION TEST CHART

(2)

SECL

AD-A191 489

RT DOCUMENTATION PAGE

DTIC ELECTE MAR 15 1988 S D

1a. REPORT SECU... Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORIT... Unclassified	3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution unlimited; approved for public release
2b. DECLASSIFICATION/DOWNGRA...G SCHEDULE Unclassified	
4. PERFORMING ORGANIZATION R...O. NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 88-0252
6a. NAME OF PERFORMING ORGANIZATION University of California Dept. of Mechanical Engr. / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code) Irvine, CA 92717	7b. ADDRESS (City, State and ZIP Code) Bolling AFB DC 20332-6448
8a. NAME OF FUNDING SPONSORING ORGANIZATION Air Force Office of Sci. Res. / 8b. OFFICE SYMBOL (If applicable) AFOSR/NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-86-0016
8c. ADDRESS (City, State and ZIP Code) Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NOS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT NO
61102F	2308	A2	

11. TITLE (Include Security Classification) Study of Mixing and Reaction in the Field of a Vortex

12. PERSONAL AUTHOR(S) B.M. Cetegen and W.A. Sirignano

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr, Mo, Day)	15. PAGE COUNT
Publication	FROM 10/86 TO 10/87	November 20, 1987	3

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB GR	Turbulent Reacting Flows; Molecular Mixing and Reaction in Turbulent Structures

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In turbulent reacting flows, completion of chemical reactions requires diffusion of reactive species at a molecular level. Eddies rich in one reactant can be present in many turbulent flows involving finite rate chemical reactions. Local species stratifications are dissipated by molecular diffusion and chemical reaction under the influence of the local flow field. In many turbulent flows, the local flow field has a strong rotational character. It is mostly this rotational motion which enhances mixing through flow stretch and convection leading to mixing at the molecular level.

In this paper, molecular mixing and finite rate chemical reactions in a two dimensional viscous vortex are examined analytically. Two species initially separated across a plane are allowed to diffuse and react in the presence of a line vortex centered at this separation plane. Concentration fields and the probability density functions (pdf) are determined for a range of vortex strengths and for several values of Schmidt number

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☑	Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Julian M. Tishkoff	(202) 767-4965	AFOSR/NA

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

at different times during the growth of the vortex. Finite rate isothermal chemical reactions are also considered. The results for the reacting vrotex are compared with those for the nonreacting vortex and some insight is gained concerning the form of the pdf in such configurations.

Accession For
NTIS CRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

AFOSR-TR- 88-0251

STUDY OF MIXING AND REACTION IN THE FIELD OF A VORTEX*

B.M. Cetegen and W.A. Sirignano
University of California
Irvine, California 92717

Abstract

In turbulent reacting flows, completion of chemical reactions requires diffusion of reactive species at a molecular level. Eddies rich in one reactant can be present in many turbulent flows involving finite rate chemical reactions. Local species stratifications are dissipated by molecular diffusion and chemical reaction under the influence of the local flow field. In many turbulent flows, the local flow field has a strong rotational character. It is mostly this rotational motion which enhances mixing through flow stretch and convection leading to mixing at the molecular level.

In this paper, molecular mixing and finite rate chemical reactions in a two dimensional viscous vortex are examined analytically. Two species initially separated across a plane are allowed to diffuse and react in the presence of a line vortex centered at this separation plane. Concentration fields and the probability density functions (pdf) are determined for a range of vortex strengths and for several values of Schmidt number at different times during the growth of the vortex. Finite rate isothermal chemical reactions are also considered. The results for the reacting vortex are compared with those for the nonreacting vortex and some insight is gained concerning the form of the pdf in such configurations.

Method of Analysis

Nonreacting Vortex

The concentration field within a nonreacting viscous line vortex imposed coincident with an interface separating the two species is calculated by analyzing the local behavior in a Lagrangian frame of reference. Computation of the successive locations of a material element starting from its initial position is achieved by integration of the flow field with respect to time. In this study, the analytical solution for the flowfield of a viscous line vortex [1] is utilized. Across the material surface separating the two species, molecular diffusion takes place as this interface is stretched and transported in the vortex flow field. The local concentration distribution around interfaces can be obtained analytically. Until this point, the analysis generally follows References 2 and 3. In the solution for the concentration field within the vortex, the concentration at a given location is composed from superposition of analytical solutions. Concentrations at many locations are obtained and used to construct the pdfs assuming periodicity of the vortices and utilizing Taylor's frozen flow assumption.

Chemically Reacting Vortex

In case of finite rate chemical reactions within the vortex, an approximate method based on Green's function solution of the reacting species conservation equation is implemented. Solution for the mass fraction of one reactive species, together with the solution for the appropriate Shvab-Zel'dovich variable, allows determination of both fuel and oxidizer distributions within the vortex.

In this paper, a dilute isothermal reaction between NO and O_3 is considered. The reaction products are NO_2 and O_2 and both reactants are diluted in N_2. The mass fractions far from the vortex are taken to be 0.01 for both reactants. The second order reaction rate was taken from Givi, et al[4].

Detailed description of the analyses for nonreacting and chemically reacting vortices can be found in Reference (5).

Results

The first four figures present results for the nonreacting case. Of course, they also apply to the passive scalar in the reacting case. Figure 1a shows the distortion of an initially horizontal material line located along the x axis at a certain instant after the vortex initiation for a nondimensional vortex strength ($Re = \Gamma/2\pi\nu$) of 50. The initial concentration field corresponds to the upper half plane of

* This work was supported by an AFOSR grant.

concentration 0.0 and the lower half plane of concentration 1.0. The computed concentration profiles in the x direction at different y locations show a well-mixed core region surrounded by concentration variations in the outer regions and the arms of the vortex for Schmidt number of unity. The character of the concentration profiles for large Schmidt numbers, typical of liquids, is considerably different showing sharp variations of concentration between adjacent stratifications within the vortex which have not diffused because of the low molecular diffusivity. The pdfs constructed from such concentration profiles are shown in Figures 2, 3, and 4 to delineate the effects of vortex strength, Schmidt number and time.

Figure 2 shows the pdf as a function of the concentration and normalized transverse distance for two vortex strengths at a given time and Sc = ν/Γ of unity. The length scale chosen to normalize the transverse distance approximately accounts for the growth of the vortex with time and its dependence on the vortex strength. Therefore, the normalized coordinates $\bar{X} = x/\sqrt{4\nu t}$ Re and $\bar{Y} = y/\sqrt{4\nu t}$ Re are convenient in presentation of results. The probability density function shows two peaks at the unmixed concentrations outside the mixing region. Probabilities at intermediate concentrations develop as a result of mixing by molecular diffusion and vortex interaction. As the vortex strength increases, the probability of the concentrations in the mid-range (0.4 - 0.6) increases in the core of the vortex. The peaks at $\bar{Y} > 0$ for $C > 0.5$ and those at $\bar{Y} < 0$ for $C < 0.5$ are results of the vortex motion bringing the high concentrations from lower plane to the upper and vice versa. The counterclockwise vortex motion is also apparent in these pdfs. The continuing line of peaks on each side joining to the peaks at C = 0.0 and C = 1.0 result from diffusive regions around the interfaces. The shapes of the pdfs are similar to those computed in shear layers. It also resembles the qualitative features of the experimentally determined pdfs in shear layers.

Figure 3a and 2b shows the time evolution of pdf at a vortex strength of Re = 50. At early time instant, the probabilities of intermediate concentrations are small and in fact the shapes of the probability peaks at the minimum and maximum concentrations are similar to those observed for the high Schmidt number case shown in Figure 4. At a later instant, the effect of the vortex becomes more pronounced and the higher probabilities of mixing appear in the center of the vortex.

Figure 4 shows the probability densities at large Schmidt numbers typical of liquids. These pdfs are characterized by two peaks at the unmixed concentrations with a minute amount of mixing in the core region. The shapes of the probability peaks can be approximately correlated by the length scale chosen in the transverse direction. These pdfs also resemble the earlier time pdf for Schmidt number of unity.

One convenient measure of molecular mixing can be defined in terms of the probabilities and concentrations as,

$$f = \frac{1}{2L}\int_{-L}^{+L}\left[1 - 4\int_0^1 P(C,y)(C-0.5)^2 dC\right]dy \qquad (1)$$

In this expression, P(C) is the normalized probability. This parameter can be referred to as "mixedness" and its values range from zero for no mixing (C = 0 or 1 only) to unity for complete mixing (C = 0.5 everywhere). The values of this parameter were computed for a range of values of vortex strengths (Re = 10-500) and Schmidt number (Sc = 1 -1000). In these calculations, 2L was taken to cover the whole extent of the largest vortex considered here (L = 10.0). Empirical correlation of the computed mixing factors suggests an expression given by,

$$f = 0.8\ Sc^{-1/2}\left[\frac{4\nu t}{L^2}\right]^{1/2} + 0.1\ Re\left[\frac{4\nu t}{L^2}\right] \qquad (2)$$

The "mixedness" increases continuously with increasing vortex strength. The mixing at zero Reynolds number limit, the first term, corresponds to a diffusion layer growing in the y direction with time. The second term is the mixing enhancement by the vortex. Current results indicate that the enhancement factor is linear in Re. However, there appears to be negligible dependence of this factor on Schmidt number.

Figures 5a and 5b show the concentration distributions in the $(\bar{X}, \bar{Y})$ plane for nonreacting and reacting vortices of a nondimensional strength of 50. The nonreacting vortex is characterized by a well-mixed core around C = 0.5 and the diffusive regions surrounding the core and the vortex arms. The vortex with finite rate chemical reactions has a considerably different character. As expected, the reactive species has been depleted in the core region. Around the core, the spatial mass fraction gradients appear to be steeper than the nonreacting vortex. Below the vortex center, a tongue of unreacted species is observed. This region corresponds to the zone between the outer arm of the vortex and the core where one reactant is abundant.

The corresponding pdfs are shown in Figures 3a and 3b. Figure 3a displays the typical features of nonreacting vortex pdf at early times. In comparing the two pdfs, the reacting vortex pdf does not contain the vortex core peaks and the effect of the reacted core on the pdf appears as modification of the probability peak topography at C = 0.0. The new probability peak at C = 0.0 near the vortex center corresponds to the reacted core region.

References

1. Batchelor, G.K., An Introduction to Fluid Dynamics, Cambridge University Press (1979).

2. Marble, F.E., "Growth of a Diffusion Flame in the Field of a Vortex," Recent Advances in the Aerospace Sciences, No. 19, pp. 395-413. Ed.: Corrado Casci, Plenum Pub. (1985).

3. Karagozian, A.K. and Marble, F.E., "Study of a Diffusion Flame in a Stretched Vortex," Combustion Science and Technology, Vol. 45, pp. 65-84 (1986).

4. Givi, P., Ramos, J.I., and Sirignano, W.A., "PDF Calc in Turb. Chemically React. Round Jets, Mixing Layers and One-Dim. Reactors," J. Non-Equilib. Thermodyn., Vol. 10, pp. 75-104 (1985).

5. Cetegen, B.M. and Sirignano, W.A., "Study of Mixing and Reaction in the Field of a Vortex," to be submitted to Combustion Science and Technology (1987).

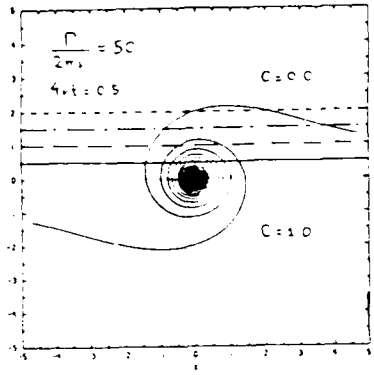


Figure 1. Distortion of a horizontal material line by a viscous line vortex.

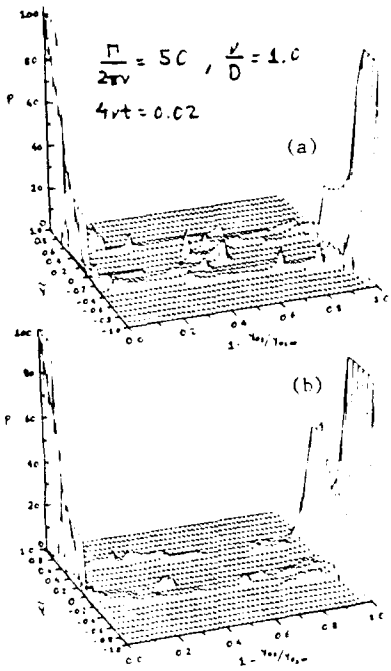


Figure 3. Comparison of pdfs for nonreacting (a) and reacting (b) scalars at Re = 50, 4νt = 0.02, Sc = 1.0.

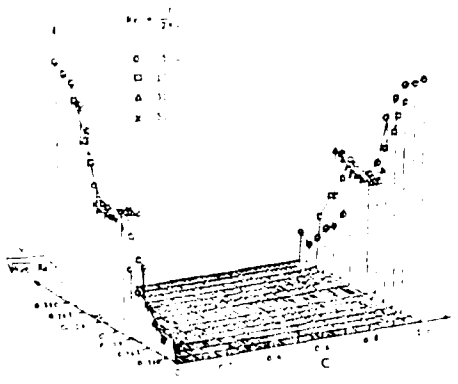


Figure 4. Pdf at a range of vortex strengths at Sc = 1.0.

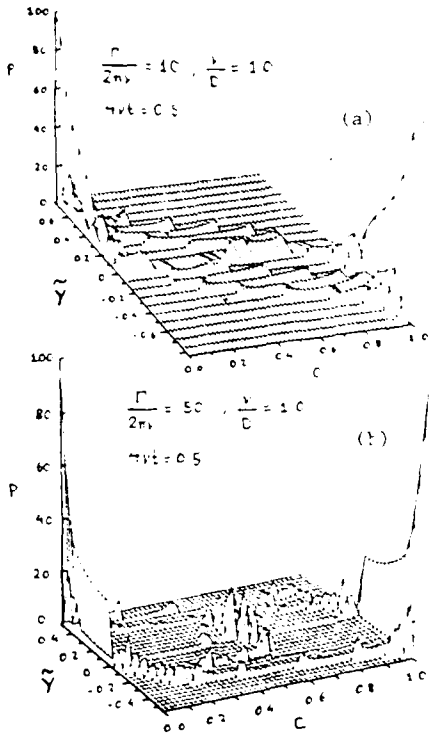
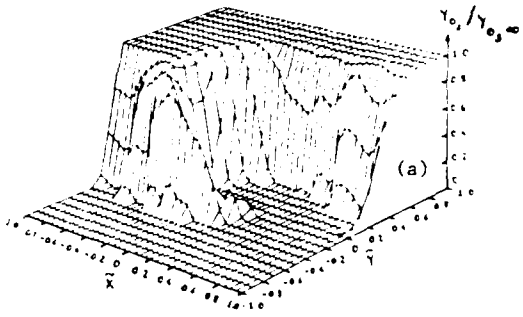


Figure 2. Effect of vortex strength on the pdf of a nonreacting scalar for Sc = 1.0.



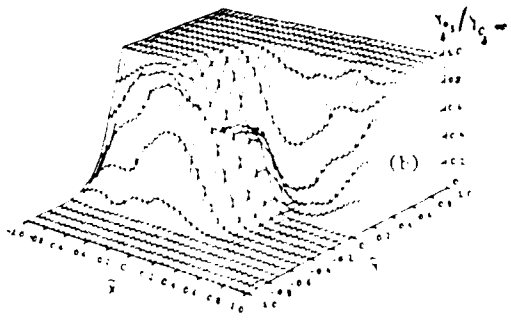


Figure 5. Concentration profiles for nonreacting (a) and reacting (b) species at Re = 50, 4νt = 0.02, Sc = 1.0.

END

DATE

FILMED

5-88

DTIC