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Solid fuel combustion chamber Progress Report V

Fourth Phase January-June 1984

Report LR-438
Report PML 1984-C63
July 1984

TH Delft
Delft University of Technology

Department of Aerospace Engineering
Prins Maurits Laboratory
Organization for Applied Scientific Research TNO Rijswijk

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1. INTRODUCTION

The fourth phase (January-June 1984) of the Solid Fuel Combustion Chamber Project, DLR 14.0120 (formerly DLR 11.0120)/PBE 90753.140 is described.
The primary aim of the project is to gain a thorough understanding of the flow and combustion processes in solid fuel grains, which will be achieved by a combination of experimental and theoretical research. The project has been extensively described elsewhere [1] and the scope of the project has remained the same since this publication. SFCC's have a potential for energy conversion systems, coal gasification, "clean" combustion of waste, aerospace propulsion (ramjets) and possible others.

This project is sponsored by the Technology Foundation (Stichting voor de Technische Wetenschappen STW) and the Project Office for Energy Research (Project Bureau Energie Onderzoek). In addition, money and manpower is made available by a special funding from DUT (Beleidsruimte) while manpower and computer facilities are provided by DAEDUT and PMLTNO. Also PMLTNO provides the project with funding.

At the end of this report the intended activities for the next half year period (July-December 1984) are outlined.

2. FINANCIAL SUPPORT

A request for continuation of support for this project has been honored by STW by February 1984. The following amounts have been allocated to this project:

- 190 kf for materials, instrumentation and travel within the Netherlands,
- 50 kf for large investments,
- 20 kf for foreign travel.

If necessary, an additional amount of 100 kf may be spent for the construction of the large SFCC.

3. FINANCES

During the period January-June 1984, the following expenses have been made by PML but have not yet been submitted to STW for refunding:

Rent pressure vessels	12 kf
Air and CH_4 SCMC	30 kf
Small components	15 kf
Allocated for courses	5 kf

Furthermore materials for the construction of the large SFCC have been ordered totaling approximately 15 kf.

In addition travel allowances have been spent on a "Window on Science Visit" to the U.S.A. As no money has been received as yet from the American Armed Forces, the total amount of expenditures to be charged to STW is unknown at present.

4. PROJECT MANAGEMENT

The project management is the same as outlined before [2]. Since January 1, 1984, Mr. J.H. van Dijk has been added to the project group as a computer programmer. He is employed by DUT (Beleidsruimte) for two years.

5. HIRING OF PERSONNEL

It is anticipated that by August 1, 1984, Dr. T. Wychers will join the project group as a flame spectroscopist. Dr. Wychers will be employed by DUT but charged to STW (or ZWO). It turns out that employment conditions through the University are more favourable than through STW (or ZWO), while the total gross costs are the same. This has to do with unexplainable situations in the Dutch laws!
Mr. Wychers got his Ph.D in spectroscopy at Utrecht University with prof. Alkemade.

6. LIST OF PEOPLE INVOLVED IN THE SFCC PROJECT DURING THE PERIOD JANUARY-JUNE 1984

In addition to people employed by DAEDUT, PMLTNO and ZWO, the following people have contributed directly to the project:

H.N. van Reenen	Apprentice MTS Den Haag Aug. 15, 1983 - June 30, 1984 Testing of gassupply system Calibration of O_2-SCMC
F.H. van der Laan	Student assistent DAEDUT Data reduction of experiments Support Flow Modeling
P.J.H.H. de Witte	Student KMA January - March 1984 SFRJ design study

Mr. J. Hoogkamer in partial fulfillment of the requirements for his engineering degree (HTS) designed a thrust stand for the SFCC.

Mr. J.J.T. Kops in partial fulfillment of the requirements for his engineering degree (DUT) calculated a PMMA-Air diffusion flame, including finite chemical kinetics.

7. THEORETICAL DEVELOPMENT

7.1. Development of a computational model describing the flow through an SFCC

7.1.1. Model assumptions

In this period, attention has been given to testing the computer program describing a 2-dimensional turbulent flow without combustion, heat and mass transfer at the boundaries. It has been mentioned in the previous progress report[3] that problems had arisen due to the strong coupling between the pressure and the velocity field. These problems have been overcome by treating the pressure instead of the density as a dependent variable. This is because it is the pressure which determines the velocity field. The pressure is calculated from the continuity equation using the SIMPLER (Semi Implicit Method for Pressure Linked Equations Revised) -algorithm. A description of the solution procedure may be found in (4).

7.1.2. Test results

The program has been tested by calculating the following flow conditions.

- Laminar pipe flow.
  For this flow, an analytical solution exists. This type of flow is parabolic (there is no reverse flow); the velocity field is determined by the pressure gradient in flow direction and the shear stress at the wall. It is not possible, for this type of flow, to calculate the pressure from the continuity equation. An additional equation which determines the pressure from overall continuity is required. Using this procedure, it has been possible to calculate the velocity field within 0,35 % of the theoretical value, using a 40x20 grid.

- Turbulent pipe flow.
  The pressure is determined analogously to the laminar pipe flow. The wall-function method for the k-ε turbulence closure model as described in (4) could not be applied to this type of flow. The assumed profile of the turbulent kinetic energy, k, near the wall, only occurs at a very short distance from the wall. It was not possible to decrease the grid-size near the wall in such way that the assumed k-profile would hold during the whole iteration process. Therefore another wall function method was incorporated in the model. The calculated velocity agrees within 3,5 % with experimental values. The value of the turbulent kinetic energy, k, at the near-wall grid point was 15 % lower than found experimentally.

- Laminar recirculation flow in a cylindrical pipe expansion.
  This type of flow is elliptic (there is a reverse flow, and pressure gradients in y- or r-direction are important), and the pressure is determined with the SIMPLER-algorithm. Experimentally, it has been found that the reattachment length increases linearly with the Reynolds number for flows with the Reynolds-number below 400. The calculated reattachment lengths for several Reynolds numbers show a similar behaviour, although the reattachment lengths are smaller than those determined experimentally.

- Turbulent recirculation flow.
  This type of flow is presently being investigated. Experimental results are available from the literature, and will be compared with the calculations. The first calculations show that the calculated reattachment point lies within the experimentally determined range. The velocity profiles and the profiles of the turbulent kinetic energy differ much from the experimentally found values. Figure 1 shows a plot of the calculated velocity field.

7.1.3. Structure of the computer program

As already mentioned in the previous progress report[3], the computer program has been written in ANSI X3.9-1978 (Fortran 77). The program has a modular structure, and may be regarded as consiting of four parts:

1) Input: - problem dependent input
   - process-dependent input
   - reads data from disk to be used as an intial guess for the iteration process.

2) Main : - performs the calculations.

3) Output: - prints the calculated values of the variables at the end of the iteration process
   - prints information of the iteration process
   - writes calculated variables to disk.

4) Analyze: - reads calculated variables from disk, and calculates additional information such as reattachment length, maximum reverse velocity, etc.

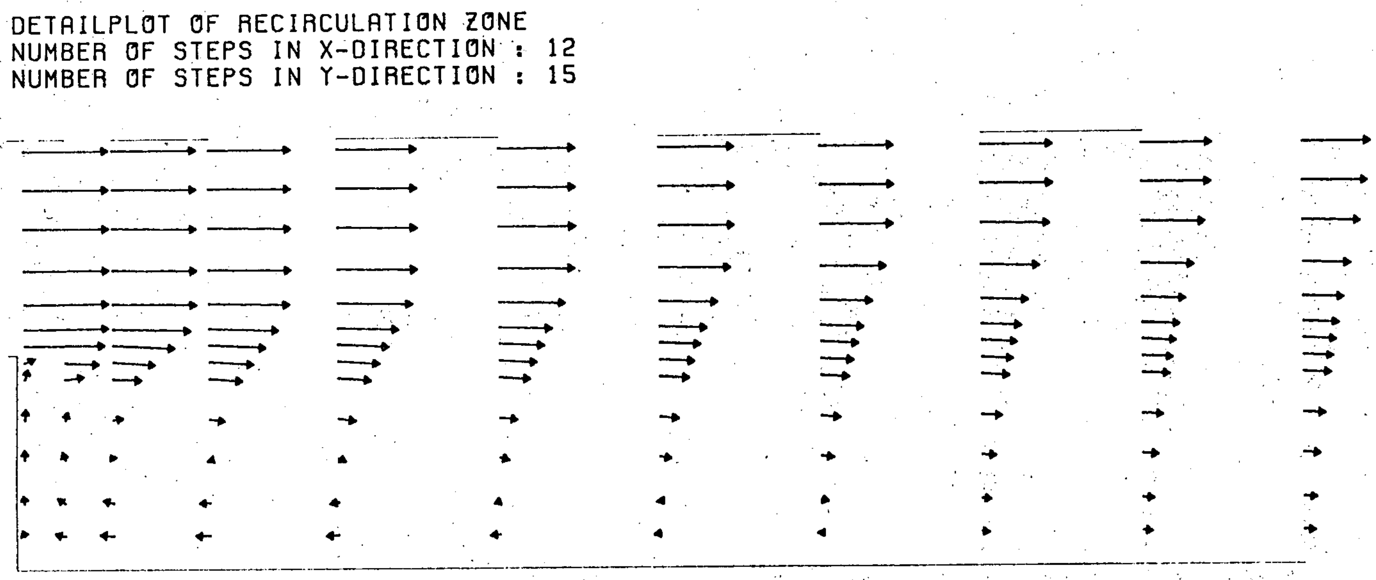

Fig. 1: Velocity fields after a sudden expansion in a turbulent pipe flow.

- plots velocity-profiles, k-profiles, shear-stress profiles, etc.
- compares calculated values with experimental or theoretical values
- compares results with results of previous calculations.

Presently the input part is revised as to allow to feed input data in an interactive way into the program. The routine which reads input data from disk to be used as an initial guess for calculation with a finer grid is still under development.
The Main-routine is fully developed while the development of the Output routine is almost completed. The Analyze routine is still under development. Several analyses and plot routines are already available.

Contacts have been established as to investigate whether a super computer would lead to a reduction in CPU-time and or costs. Runs on the Cray-1 Supercomputer showed an acceleration by factor 10 in CPU-time. Costs are estimated to 30 % of the present costs. However, as CPU-time on the AMDAHL of DUT is financed through DUT-Special projects it is not yet clear whether this money could be allocated to the Cray Supercomputer.

7.2. Combustion of PMMA in a Laminar Diffusion Flame

It was mentioned in the previous progress report[3] that a computer program was being developed to solve the partial differential equations that describe the model for the steady state axisymmetric laminar MMA-air diffusion flame.
The explicit finite difference scheme used was found to be numerically stable, only for very small integration steps. Therefore an unconditionally stable implicit finite difference scheme was adopted, resulting in an accurate and far less time-consuming method.

Results from computations were compared with experimental results from the literature, to verify the model. These results show a good agreement in shape and length of the flame. Temperatures are predicted too high, which is probably due to the neglect of incomplete combustion of the fuel and to the formation of soot particles in the fuel-rich zone which causes a large heat loss by radiation.
Computations concerning the effect of finite chemical reaction rates on the flame show that this effect is practically limited to the lower part of the flame. Here the temperature and therefore the chemical reaction rate is too low to consume directly all fuel and oxidizer that diffuse into each other. This results in a broadened zone where oxidizer and fuel exist together and react to form products, though at a slow rate. With increasing height the temperature rises and the reaction rate increases, causing the relative oxidizer and fuel concentrations to diminish quickly. At a certain height (about 40 % of the total height of the flame) the temperature becomes so high that all oxidizer and fuel that diffuse into each other react immediately. Diffusion becomes the limiting factor in the fuel consumption rate. The narrow reaction zone places itself so that fuel and oxidizer diffuse into each other in stoichiometric proportions and the flame takes the shape as if chemical reactions were infinitely fast. Because of the broadened reaction zone in the lower part of the flame the temperature profile in radial direction is flattened leading to higher temperatures in the vicinity of the narrow reaction zone higher in the flame, as compared with the case of infinitely fast chemical reaction rates. This leads, because of the dependency of the diffusion coefficients on temperature, to higher diffusion rates, resulting in a higher fuel consumption rate.
In an overall view this flame length decreasing effect is of less importance than the flame length increasing effect of the slow reaction rates in the lower part of the flame. This results in a flame length 12 % higher as compared with the case of infinitely fast chemical reaction rates (fig. 2).
With respect to the experimental work no useful results were obtained.

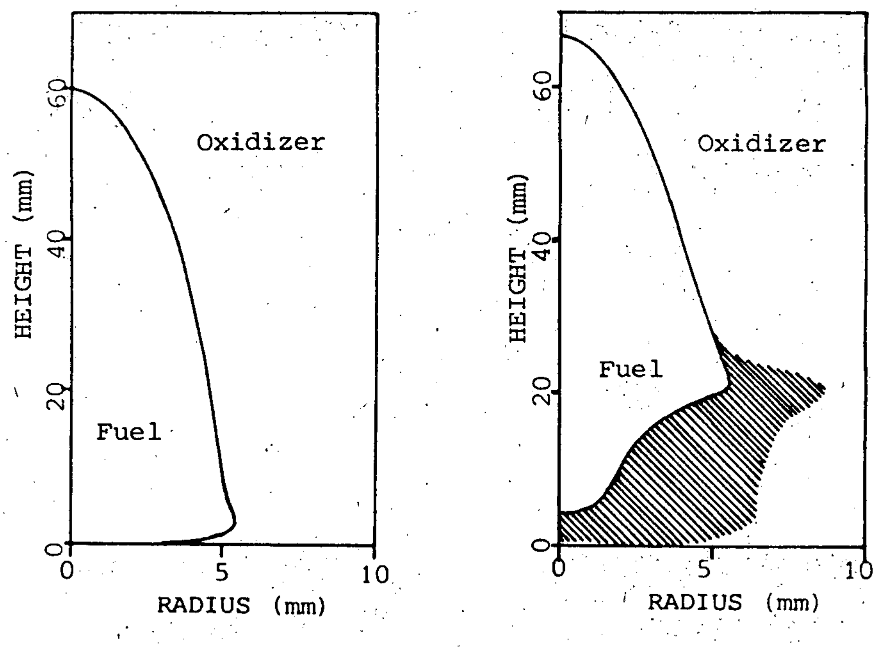

Fig. 2: Shape of the reaction zone in the laminar MMA-air diffustion flame in the case of a: infinitely fast chemical reaction rates and b: activation energy $E_A = 1,55.10^5$ (J/mol MMA) for the overall combustion reaction. The shaded area indicates the zone where oxidizer and fuel exist together.

8. EXPERIMENTS

8.1. Combustion of PE and PMMA with N_2-O_2 mixtures

A survey of experiments that has been performed to date using the small SFCC, is given in Table 1. They roughly total 200 experiments. For a detailed analysis of these combustion experiments a computer program is being developed; preliminary data reduction has been grouped according to

- fuel composition (PE or PMMA)
- composition of the oxidizer (varying between 100 % and 20 % O_2)
- combustion pressure
- oxidizer mass flux
- fuel grain length
- the presence or absence of a rearward facing step.

For PE it has been found that the regression rate depends on pressure and mass fluxes but at low pressures also on fuel grain length in that sense that short grains seem to have a higher regression rate than the longer ones.

Table 1: Compilation of experiments with the small SFCC.

Oxidizer	Fuel	Grain length (m)	Pressure range (MPa)	Step
100 % O_2	PE	0,3	0,4 - 1,8	no
100 % O_2	PE	0,12	0,3 - 1,3	no
100 % O_2	PMMA	0,3	0,5 - 2,5	no
100 % O_2	PMMA	0,3	1,4	yes
80 % O_2 + 20 % N_2	PMMA	0,3	1 - 1,3	no
80 % O_2 + 20 % N_2	PMMA	0,3	0,6	yes
60 % O_2 + 40 % N_2	PMMA	0,3	1 - 1,2	no
60 % O_2 + 40 % N_2	PMMA	0,3	1,3	yes
40 % O_2 + 60 % N_2	PMMA	0,3	0,8 - 1,1	no
40 % O_2 + 60 % N_2	PMMA	0,3	0,8 - 1	yes
20 % O_2 + 80 % N_2	PMMA	0,3	0,8 - 1,6	yes
Air	PMMA	0,3	0,7 - 1,3	yes

With PMMA the burning time was varied too. Surprisingly it was found that the burning time had a tremendous effect on the combustion behaviour: there is a tendency of a high regression rate at short burning times. This behaviour was confirmed by measuring the local instantaneous regression rate by means of the ultrasonic pulse-echo technique.
This phenomenon is not understood as yet. Its understanding will be of prime importance for a good functioning of SFCC's.

By lowering the oxygen content in the oxidizer it has been found that the dependence of the regression rate on the chamber pressure decreases systematically. The use of a step is favourable to increase the regression rate. We have the impression that its effectiveness is highest at lower pressures.

8.2. Determination of the regression rate by means of the ultrasonic pulse-echo technique

A computer program has been developed that determines the regression rate of the burning fuel from ultrasonic pulse-echo measurements. Furthermore it calculates the instantaneous oxidizer mass flux and it correlates the regression rate, the oxidizer mass flux and the chamber pressure according to the relation

$$r = a\, G^{m}\, p^{n} \; .$$

Testruns where the ultrasonic technique has been applied, have been analyzed using this program. The following phenomena have been observed for PMMA as a fuel:

- a very high regression rate occurs during the first 5 to 10 s after ignition,
- the regression rate is very pressure sensitive at low pressures,
- during oscillatory combustion, the regression rate may increase by a factor 2.

8.3. Sonic Control and Measuring Choke (SCMC)

In the previous progress report[3] it has been pointed out that calibration of the O_2-SCMC yielded some scatter in the data. This was primarily due to an inadequate measurement of the gastemperature in the supply bottle while also the volumes of the tubing system and the SCMC itself were neglected.
A considerable improvement could be found by installing two thermocouples in the gassupply bottle, and by taking into account the volumes of the tubing system and the SCMC.

When using the O_2-SCMC at discrete settings of the pintle, the maximum error in the measured mass flows does not exceed 3 % LSO. A master curve, which can be deducted from the testresults obtained at these discrete settings, is given in Figure 3. Although easier in use, its drawback is a lesser accuracy: the maximum error in the measured mass flows using this master curve is approximately 5 % LSO.

8.4. Spectroscopy

Some additional experiments have been performed, using the spectroscope from the Department of Chemistry of DUT, to establish whether valuable information could be obtained from light collected through the plexiglass wall. No spectral lines could be distinguished. However, it is believed this may be due to the experimental setup. The experiments will be repeated.

A spectroscopic system consisting of a Optical Multichannel Analyzer (OMA) with a very sensitive detector and a suitable monochromator still have to be ordered. It is expected that this equipment will be ordered by the end of July.

9. STATUS OF THE EXPERIMENTAL FACILITY

9.1. Gassupply system

Although the inherently unsafe HAENNI pressure transducers have been replaced by modified (safe) ones, the gassupply system still poses serious problems:

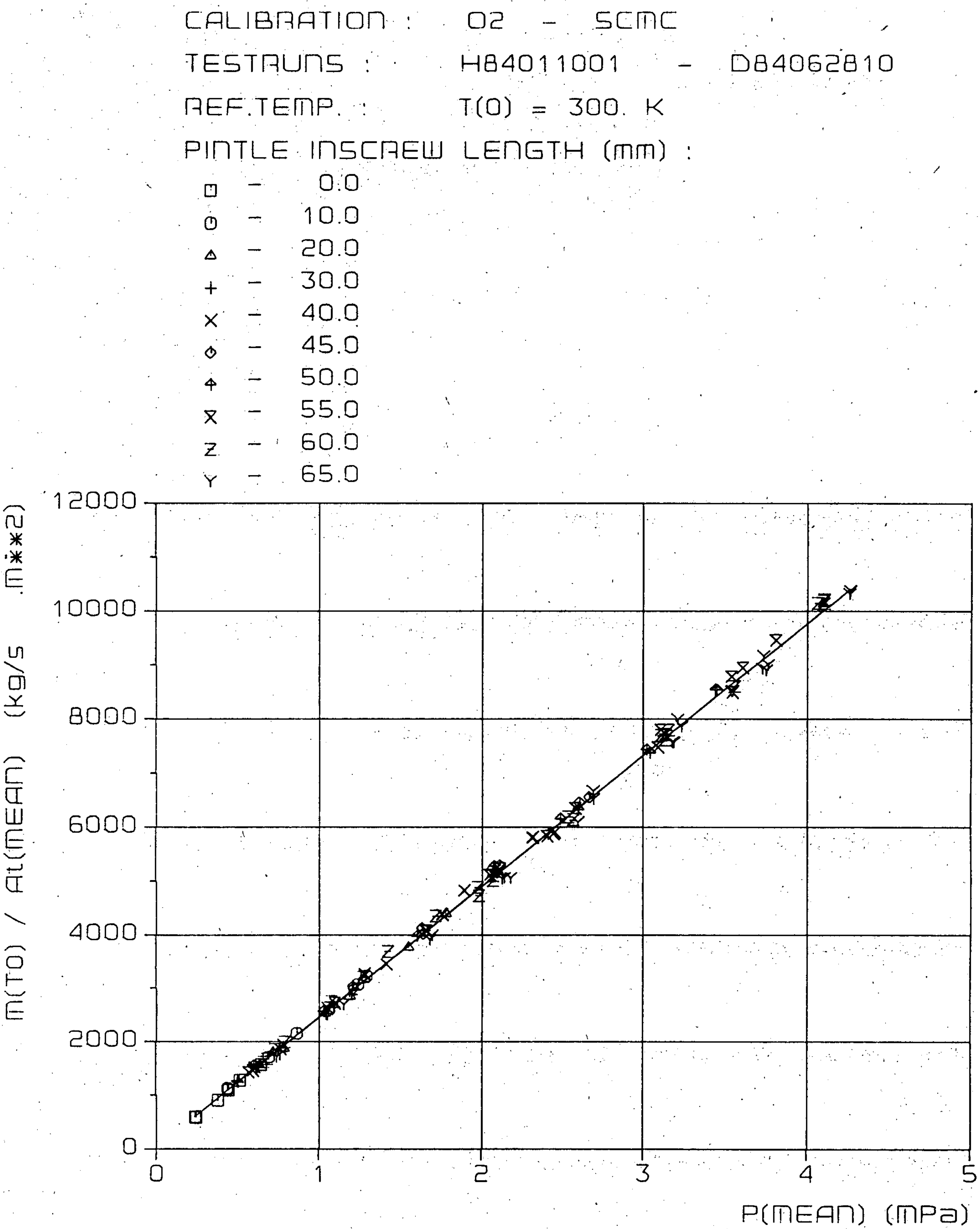

Fig. 3: Mastercurve O_2 - SCMC.

- Regularly leaking occurs in the domes for pressure reduction. This may be caused by the use of sintered metal filters.
- Regularly malfunctioning of the compressor.
- "Freezing" of the pressure reduction dome for air.

In addition, during this period problems occurred with leaking H_2 ball-valves, leaking oxygen supply bottles, failing safety valves due to moisture, and bad connectors between the air storage bottles and the airsupply line. Although HOEK-LOOS, who installed this gassupply system, is very helpful in repairing failing components, the malfunctioning of the gassupply system causes severe delays in the experimental program and requires special attention and unforeseen time of the group. In addition also microswitches had to be replaced twice.
For these reasons, a final delivery of the gassupply system has to date not taken place.

9.2. Vitiator, three way valve, air-SCMC and CH_4-SCMC

For reasons as explained in the previous progress report, the air-SCMC and the CH_4-SCMC have been manufactured by DINFA, 's-Gravezande. They have been mounted in the corresponding gas supply lines by the machine shop of PML. Due to malfunctioning of the gassupply system, these SCMC's still have to be calibrated.

CWDUT delivered the Vitiator-Three way valve by mid-April. It's testing wait presently for the installation on the new test support.

In the previous progress report it has been mentioned that additional money might be necessary if CWDUT could not deliver the vitiator-three way valve in time. This request was honored by STW. However, as CWDUT was able to produce the system for much lower costs than the commercial industry, this amount of money will not be required for the production of the vitiator-three way valve.
It is anticipated however, that part of the allocated funds may be necessary for the construction of the SFCC and for provisions that ensure reliable spectroscopic measurements.

9.3. The SFCC

Detailed construction drawings of the large SFCC became available by March 1984.

CWDUT informed the group that manufacture of the SFCC could be started immediately and that its production would be completed by the beginning of July 1984.

As the costs of the SFCC is much higher than anticipated, it is expected that the SFCC has to be funded partially from additional money from STW (see Section 9.2).

9.4. Teststand for the Experimental System

Detailed construction drawings for the new teststand are being made by the PML construction office. It is expected that the support will be delivered by October.

9.5. Control System for SCMC's

The characteristics of the oxygen-supply line (with regard to reaction/response times) have been determined experimentally. Based upon these results, a design for the O_2-SCMC control system has been made, and components have been ordered. It is expected that installation will take place around August 1984. After that the system has proved itself, similar systems will be installed on the Air- and

CH_4-SCMC's.

10. USERS COMMITTEE

The users committee was convened for the fourth time on Friday, June 22, 1984 at PML-TNO.

The following members were present:

H.F.R. Schöyer P.A.O.G. Korting J.B. Vos J.P.M. Versmissen J.H. van Dijk	SFCC project group

H.J. Reitsma	PMLTNO
Cdr. b.d. R.H. Kerkhoven	TNO
C.W. van Koppen	THE
H. Wittenberg	THD
A.J.W. Oude Alink	Thomassen Holland B.V.
C.A.L. Kemper	VMF-Stork/FDO
J. Claus	TNO

The following themes were presented:

- Status of the project	H.F.R. Schöyer
- Control System for SCMC's	J.P.M. Versmissen
- Progress on Flow Modeling	J.B. Vos
- Structure of the Computer Program	J.H. van Dijk
- Window on Science Visit to the U.S.A.	P.A.O.G. Korting

Preliminary data for the next meeting will be either on Tuesday, December 11 or Friday afternoon, December 21, 1984.

11. UTILIZATION

With regard to the reaction from PBE to our proposal (see previous progress report Section 10), no reaction has been received.
Sproncken B.V. showed interest in the possible application of the SFCC for solid waste combustion. Sproncken will approach the Ministry of Economic Affairs after having consulted the project group about their proposal.
Heidemij has asked the project group about the possibility to burn organic material in the SFCC. The project group has offered to perform some tests. Material has been received from Heidemij.
DINFA will receive a copy of the evaluation report of the O_2-SCMC.
The project group will prepare an article for publication in a Dutch technical journal.
Following the receipt of the evaluation report DINFA will take action as to the possible production and marketing of SCMC's.

12. CONTACTS

During the period January-June 1984, Korting and Schöyer made, on invitation of the U.S. Army, U.S. Air Force and U.S. Navy, a "Window on Science Visit" to the U.S.A.

The following institutions have been visited:

Ballistic Research Laboratory, Aberdeen
Air Force Office of Scientific Research, Bolling AFB
Atlantic Research Corporation, Gainesville
NASA-Langley, Hampton
Aero Propulsion Laboratory, Wright-Patterson AFB, Dayton
Purdue University, West-Lafayette
Georgia Institute of Technology, Atlanta
Brigham Young University, Provo
Aerojet, Sacramento
CSD, Coyote
Naval Post Graduate School, Monterey
Naval Weapons Center, China Lake
Air Force Rocket Propulsion Laboratory, Edwards AFB
The Marquardt Corporation, Van Nuys
California Institute of Technology, Pasadena
Jet Propulsion Laboratory, Pasadena.

As an extensive travel report will become available, no specific names and subjects are mentioned here. The visit was extremely useful for making contacts, exchange of ideas, to become informed about the status of SFCC research and development in the U.S.A. and for obtaining a general impression of laboratory facilities, computer facilities and possible interest of American industries to cooperate with Dutch industries.
In addition it was seen that improvements in our new thrust-stand could be made which may prevent the occurrence of many experimental difficulties as encountered in the past by American research and development groups.

For the remainder, the following contact should be noted.

Institute	Person(s)	Subject
IMI Summerfield	G.I. Evans	Testing of Ducted Rockets at our test-stand
German Ministry of Defense, Bonn	O. Wolf	Visit to MBB Ducted Rocket Test Stand near München
Heidemij, Apeldoorn	A.C.M. Groenendijk R.W.J. Smulders	Combustion of Organic Material in SFCC
Sproncken B.V., Bunde (L)	J. Tillie Hr. Postmes	Application of SFCC for Solid Waste Combustion
DINFA, 's-Gravenzande	W. Kluvers	SCMC
ENR, Petten	H.P. Struch G. Leendertse	The use of the Cray Supercomputer for flow modeling
VMF/FDO, Amsterdam	G.K. Troost	Application of SFCC's for Ramjets

Institute	Person(s)	Subject
DUT Dept. Chemical Engineering	L. de Galan G.R. Kornblum	Flame Spectroscopy
University Utrecht	C.Th.J. Alkemade	Flame Spectroscopy
TNO-MT, Apeldoorn	J. Claus A. Verbeek	SFCC-project
DUT Dept. of Physics	P. van de Leur	Numerical solution methods
NLR Amsterdam	J.P.F. Lindhout	Numerical methods

13. STATUS OF THE PLANNING PERIOD JANUARY-JUNE 1984

	Planning	Status
i	Testing and calibration of the three SCMC's	Testing & calibration of O_2-SCMC nearly completed
ii	Characterization of the gas-supply system: characteristic times, response times, amplification factors, volumes etc.	Done for O_2-system
iii	Design and fabrication of an SCMC control system	Design ready; components received
iv	Design and fabrication of the large SFCC	Delivery expected by July 1984
v	Specification of the pneumatic system for the threeway valve	Ready
vi	Preliminary installation and testing of the vitiator and threeway valve	Waiting for support
vii	Design support for the SFCC, vitiator and threeway valve	In progress
viii	Testing software for microprocessor gassupply control system	Partly finished
ix	Hiring of spectroscopist	Expected to employ a spectroscopist by August 1, 1984
x	Ordering of a system for spectrographic measurements	In preparation
xi	Data reduction, including software development	Partly ready; more detailed analysis still necessary

Planning		Status
xii	Correlation of cold flow experiments with computer code	No cold flow experiments
xiii	Hiring of a computer programmer	By January 1, 1984
xiv	Development of an elementary computer simulation model for flow (without combustion) in an SFCC	Development nearly completed
xv	Development of models that account for heat and mass transfer at the boundaries and implementation of these models in the computer code	Nothing done
xvi	Description of a PMMA diffusion flame and experimental verification	In final stage, awaiting reporting
xvii	Initial work for the selection of a combustion model	Nothing done
xviii	Analysis of the regression rate by means of the ultrasonic pulse echo method	Very successful

14. PLANNED PROGRAM FOR THE PERIOD JULY-DECEMBER 1984

Subject	July	Aug	Sept	Oct	Nov	Dec
1. Calibration CH_4 and air SCMC	———	———	———			
2. Calibration report O_2-SCMC	———	———				
3. Mass flow control system for O_2, CH_4 and air gassupply lines	———	———	———	———		
4. Design and manufacture thrust stand for SFCC	———	———	———			
5. Installation of vitiator, shuttle valve and SFCC			———			
6. Testing of vitiator and shuttle valve				———	———	———
7. Testing of software for control gassupply system		———	———	———		
8. Testing of large SFCC						———
9. Marking of vitiator and SFCC components; Drafting of mounting drawings		———				
10. Modification of building for spectroscopic measurements		———	———	———		

Subject	July	Aug	Sept	Oct	Nov	Dec
11. Ordering of spectroscopic equipment	—	—				
12. Construction of switch panel for simulation unit			—	—		
13. Sound velocity versus temperature measurements of PE and PS			—	—		
14. Report experiments with small SFCC				—	—	—
15. Report mass flow control system				—	—	—
16. Development software for data reduction	—	—	—	—	—	
17. Theoretical work:						
improvement and extensions of existing program	—	—	—			
comparison with various experimental cold flow results	—	—	—			
study of heat and mass transport at the boundaries				—	—	—
selection of a combustion model				—	—	—

15. PUBLICATIONS

1. H. Albers, P. Korting en J. Versmissen, "Technische Gebruiksaanwijzingen voor het Regel/Bedieningssysteem van de Gastoevoerinstallatie voor de Vaste Brandstof Verbrandingskamer". Report LR 410/PML 1983-169, SFCC-publicatie no. 8, Januari 1984.

2. J. Mosselman, "Het Regenereren van Nareinigers", Memorandum M-499/Report PML 1983-171, SFCC publicatie no. 9, December 1983.

3. H.N. van Reenen, "Bepaling van het Leidingvolume voor het IJken van een SMRD", Memorandum M-503/Report PML 1984-C9, SFCC publicatie no. 10, Februari 1984.

4. V.A. Kramers, P.A.O.G. Korting en H.F.R. Schöyer, "Polynoombenaderingen voor de Karakteristieke Snelheid en Vlamtemperatuur", Report LR-421/PML 1984-C10, SFCC publicatie no. 11, Januari 1984.

5. P.A.O.G. Korting and H.F.R. Schöyer, "Experimental Connected Pipe Facility for Solid Fuel Ramjet Combustion Studies", Paper presented at the 15th International Congres ICT, Karlsruhe, June 1984. To be published in the Conference Proceedings.

16. CONTINUATION OF SUPPORT BY STW

STW has informed the project group that it will honour the request to support the group during the second two year period. STW has been informed by the group that the research project is expected to be continued after May 1986.

17. REFERENCES

1. An. "Proposal for the investigation of a Solid Fuel Combustion Chamber",

DAEDUT/PMLTNO, Memorandum M-395, Delft/Rijswijk, February 1981.

2. H.F.R. Schöyer, P.A.O.G. Korting, "Solid Fuel Combustion Chamber, Progress Report I, Initial Phase (until July 1982)", Report LR-354/Report PML 1982-134, DAEDUT/PMLTNO, Delft/Rijswijk, June 1982.

3. H.F.R. Schöyer, P.A.O.G. Korting, J.B. Vos, J.P.M. Versmissen, "Solid Fuel Combustion Chamber, Progress Report IV, Third Phase, July-December 1983", Report LR-415/Report PML 1983-173, DAEDUT/PMLTNO, Delft/Rijswijk, December 1983.

4. J.B. Vos, "The Development of a Computational for a 2-Dimensional Turbulent Flow, Part I: Mathematical Background", Report LR 436/Report PML 1984-C52, DAEDUT/PMLTNO, Delft/Rijswijk, January 1984.

18. ACRONYMS

AFB	-	Air Force Base
CSD	-	Chemical Systems Division of United Technologies
CWDUT	-	Central Workshop DUT
DAEDUT	-	Department of Aerospace Engineering DUT
DUT	-	Delft University of Technology
ENR	-	Energie Centrum Nederland Rekencentrum
MMA	-	Methyl Methacrylate
NLR	-	National Aerospace Laboratory Amsterdam
OMA	-	Optical Multichannel Analyzer
PBE	-	Project Bureau Energie Onderzoek
PE	-	Poly Ethylene
PMLTNO	-	Prins Maurits Laboratory of the Organization for Applied Scientific Research
PMMA	-	Poly MMA
SCMC	-	Sonic Control and Measuring Choke
SFCC	-	Solif Fuel Combustion Chamber
STW	-	Stichting voor de Technische Wetenschappen
ZWO	-	Organisatie voor Zuiver Wetenschappelijk Onderzoek.