Delft University of Technology
Department of Aerospace Engineering
Delft

Prins Maurits Laboratory
Organization for Applied
Scientific Research TNO
Rijswijk

Report LR - 415
Report PML 1983 - 173

SOLID FUEL COMBUSTION CHAMBER PROGRESS REPORT IV

Third Phase, July-December 1983

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P.A.O.G. Korting
J.B. Vos
J.P.M. Versmissen

Delft/Rijswijk, The Netherlands

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CONTENTS

1. INTRODUCTION

The third phase (July-December 1983) of the Solid Fuel Combustion Chamber Project, 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 extensively been 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.

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

Finally this report outlines the intended activities for the next halfyear period (January-June 1984).

2. FINANCIAL SUPPORT

With regard to the previous progress report(2) there are no differences in the financial support. However, as severe delays have been met in the fabrication of experimental equipment by the Central Workshop of DUT (CWDUT), STW has been asked for additional funding of HFL 100.000,--. By the time of writing of this report, no decision had been taken by STW.

3. FINANCES

During the period July-December 1983 the following expenditures have been paid by STW.

Rent pressure vessels	HFl. 6000,--
Small travel expenses	HFl. 159,32
Gassupply system and various components (investment)	HFl. 72284,36
Total amount	HFl. 78443,68

In addition, the following expenses have been made by PMLTNO but have not yet been submitted to STW for refunding:

Small components and rent of pressure vessels	HFl. 21822,25

Furthermore equipment has been ordered totaling approximately HFl. 48.000,--. DAEDUT contributed to the project by the purchase of small equipment and fuel for a total amount of HFl 12.500,--. PMLTNO will contribute HFl 20.000,-- over 1983.

4. PROJECT MANAGEMENT

The project management is the same as outlined before(3). It is anticipated that by January 1984 a computer programmer will be added to the project group. He will belong to the DAEDUT Faculty (Beleidsruimte).

5. LIST OF PEOPLE INVOLVED IN THE SFCC PROJECT DURING THE PERIOD JULY-DECEMBER 1983.

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

T. Breed	Apprentice MTS Alkmaar Aug. 2, 1982 - July 15, 1983 Installation and testing of gassupply system. Calibration of Sonic Choke.
G. Alton	Student Technion, Haifa Aug. 1, 1983 - Sept. 9, 1983 Determination of regression rate by ultrasonic pulse echo method.
H.N. van Reenen	Apprentice MTS Den Haag Aug. 15, 1983 - June 15, 1984 Testing of gassupply system. Calibration of Sonic Choke.Experiments.
V.A. Kramers	Apprentice HTS Haarlem Sept. 1, 1983 - Dec. 1, 1983 Determination of regression rate by ultrasonic pulse echo method. Performance calculations.
D. Dijkstra	Apprentice HTS Amsterdam Sept. 1, 1983 - Dec. 1, 1983 Preparatory work for patchboards.
J. Mosselman	Apprentice HTS Amsterdam Sept. 1, 1983 - Dec. 1, 1983 Regeneration of molecular sieves.
F.H. van der Laan	Student-assistent DAEDUT Data reduction of experiments.
Dr. R.H. van der Wal	Consultant Aug. - December 1983 Development of software for gassupply control system.

Mr. J. Hoogkamer in partial fulfillment of the requirements for his engineering degree (HTS) is designing a thruststand for the SFCC.

Mr. J. Kops in partial fulfillment of the requirements for his engineering degree (DUT) investigates the elementary structure of a PMMA/airflame. His advisers are prof.ir. H. Wittenberg and ir. H.F.R. Schöyer.

6. EXPERIMENTS

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

A preliminary computerized data reduction of combustion experiments of various fuel grains and oxidizers has been performed on the AMDAHL 470 V/7B computer of DUT. 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 pressure or absence of a diaphragm (stepholder).

The first impression is that although the literature generally assumes a relation between regression rate, r, mass flux, G, and combustion pressure, p, of the type

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

such a correlation seems to be poor and certainly has no general validity. The latter also follows from theoretical arguments.
Figure 1 shows the regression rate in relation to G and p for a group of testruns.

The effect of a diaphragm directly manifests itself in a higher regression rate, while a diaphragm makes sustained combustion possible in cases where no sustained combustion could be achieved without a diaphragm.

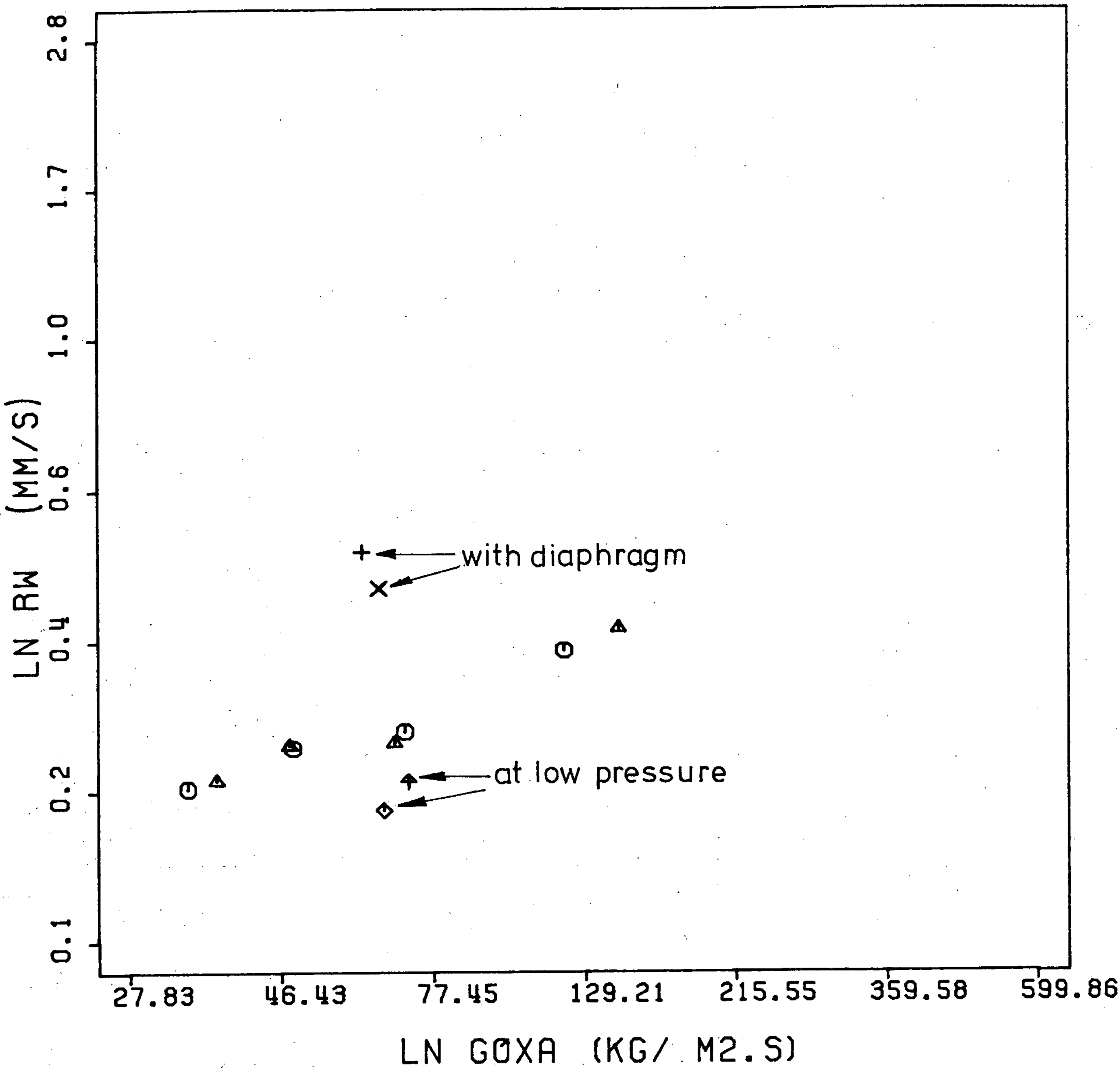
6.2. Determination of the regression rate by means of the ultrasonic pulse echo technique

With an ultrasonic pulse-echo technique one may measure the time interval between an emitted pulse and the reception of its reflection. If this pulse is transmitted trough a material of thickness, d, which is of a constant temperature, this time interval is a measure for the thickness of the material. If there is a temperature profile in the material this will affect the measured time interval. In the case of the fuel in an SFCC this temperature profile is a function of the regression rate, r. On the other hand the time derivative of the measured thickness equals this regression rate. By calculating the temperature profile as a function of the regression rate and the location in the material, one may estimate the time interval. This may be compared with the measured time interval. Iteratively the regression rate may be determined in this way.
A computer program is being developed to determine the regression rate history from experimental data.

During ignition and after extinguishment the temperature profile in the fuel undergoes severe changes. It has still to be investigated whether the regression rate can be determined reliably during these phases.
At present the program is able to determine the instantaneous regression rate from measured data during the major part of a testrun where the temperature profile is only slowly changing. Figure 2 shows an example of the regression rate determined in this way together with a measured pressure history during the testrun.

6.3. Sonic control and measuring choke (SCMC)

In the previous report[2], it was mentioned that calibration of the O_2-SCMC had been performed. The results showed that the SCMC behaved as anticipated. According to theory the mass flow, m, should be a linear function of the pressure, p, in the SCMC. As is evident from Figure 3, the experimental results confirm this. However, some small scatter is still present which is believed to be due to different temperatures in the gas vessel that is used for calibration purposes.
Therefore, some new calibrations are necessary. To this end, the amount of mass that will be used for calibration purposes will be determined as accurate



MEAN LENGTH FUEL BLOCK : 300.2 MM.
INITIAL DIAMETER : 18.97 MM.
MEAN MASS FLUX OXIDIZER :50.18 G/S
MEAN PRESSURE : 10.62 BAR
OXIDIZER/FUEL : N2-O2 : 0.66 / PMMA
MEAN BURNING TIME : 9.84 SECONDS

Fig. 1: Overall correlation of regression rate r_w and oxidizer mass flux, G_{OXA}. The effect of the use of a diaphragm (step) is clearly visible. At lower pressures the regression rate is lower too.

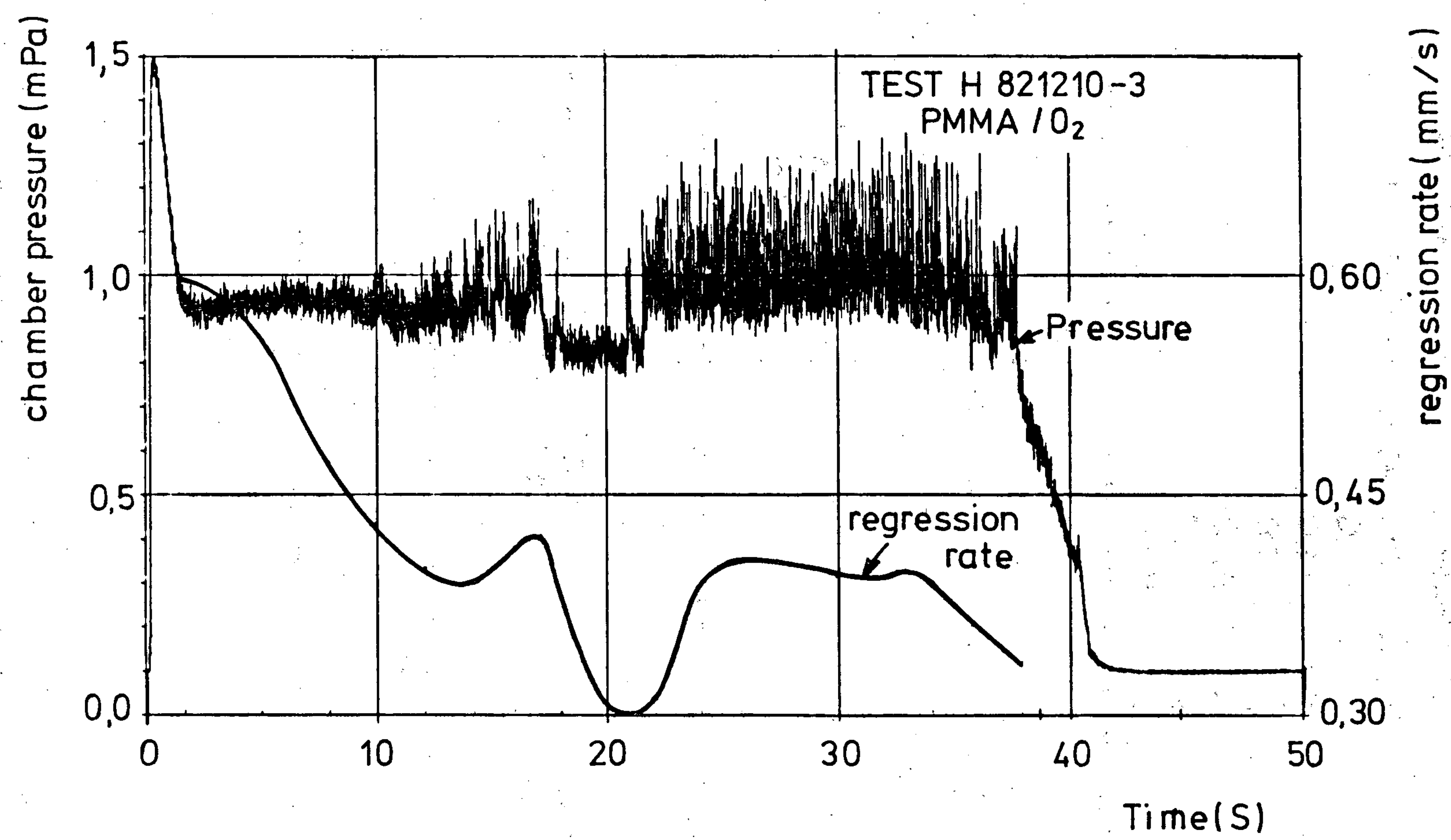


Fig. 2: Local regression rate during an experiment as determined with the ultrasonic pulse-echo technique. The occurrence of pressure oscillations clearly affects the regression rate.

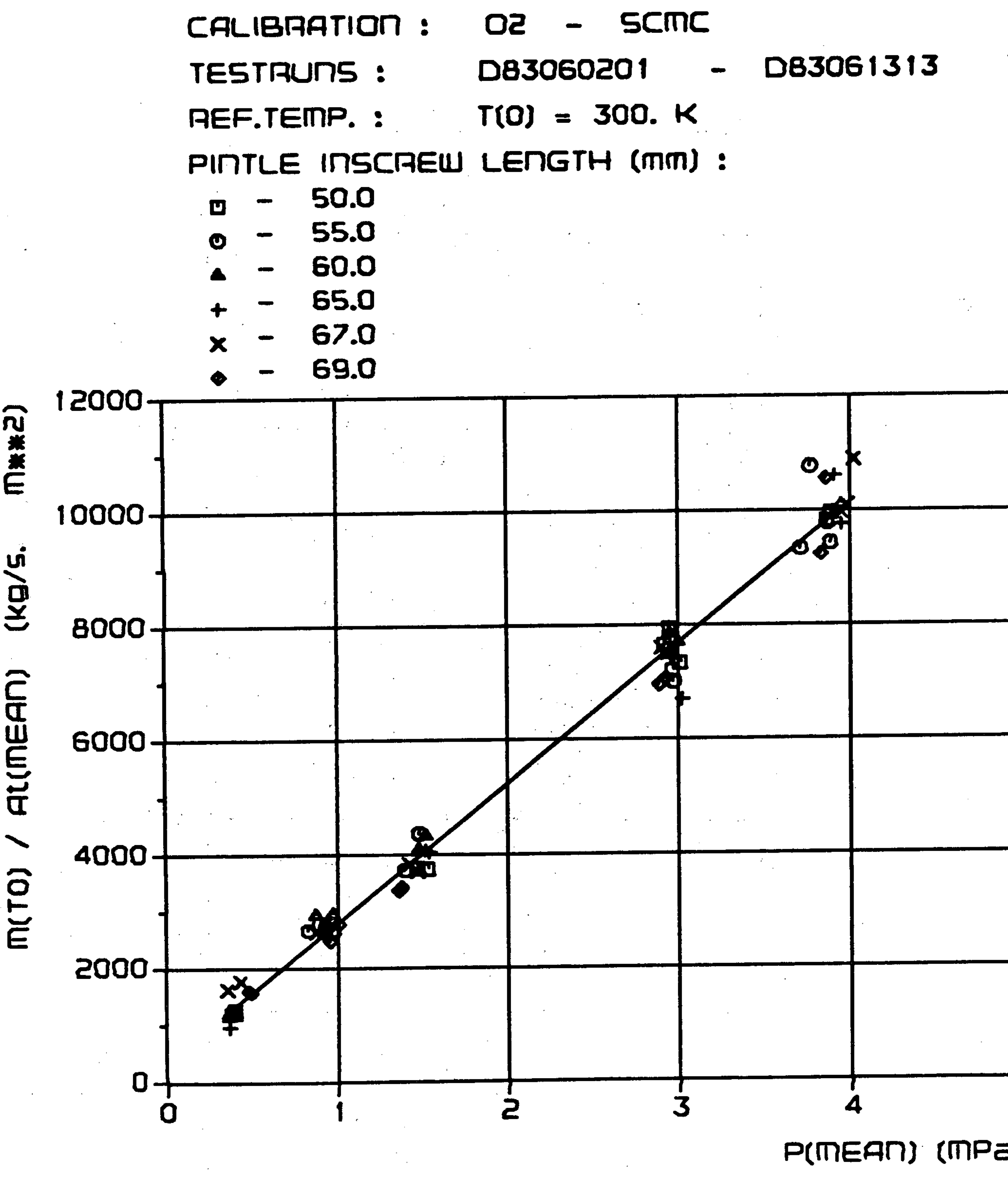


Fig. 3: Calibration of O_2-SCMC. According to theory m/A_t is a linear function of pressure for constant temperature gases. The data have been corrected for temperature effects. Pressure along the horizontal axis, mass-flow per unit throat area along the vertical axis.

as possible. By a new calibration the volume of the gas storage bottle has been determined within 0,33 % accuracy. The volumes of the tubing and the SCMC still have to be determined. For calibration purposes temperature effects in the gas bottle will be taken into account by using thermocouples. This had been neglected with previous calibrations.
Due to malfunctioning of the gassupply system and the necessity of preliminary spectroscopic experiments (see 6.4), calibration could not take place earlier.

6.4. Spectroscopy

In the project proposal(1) spectroscopic diagnostic techniques had been planned. Although there is a tremendous experience in flame spectroscopy doubt arose whether this technique could be used to gather detailed information about the flow and combustion processes in the SFCC. This was mainly due to a simple measurement with a hand-held spectroscope that indicated the occurrance of black body radiation. Therefore more detailed spectroscopic measurements have been performed to establish whether indeed black body radiation was emitted or whether spectra, molecular or atomic, could be traced.

A spectroscope was borrowed from the Department of Chemistry of DUT (Section Analytical Chemistry). Dr. G.R. Kornblum from this Section assisted with these experiments. The optical system that was used was by no means optimized, as the measurements only served to establish the feasibility of spectroscopy. Figure 4 outlines the experimental situation. A general impression may be obtained from Figure 5. Results with this experimental set up, see Figure 6, confirmed the validity of the concept. A large number of lines may be seen even while glass lenses and windows, and red insensitive photographic plates have been used.
Some spectroscopic measurements where the light is collected through the plexiglas remain to be performed.

After these succesful measurements two suppliers of Optical Multichannal Analyzers (OMA) were invited to demonstrate the capabilities of their instruments. The instrument from TRACOR did not yield good results which is believed to be due to the use of a grid with only 300 lines per mm. The instrument from EG & G equipped with a grid having 2400 lines per mm gave reasonable results.

7. THEORETICAL DEVELOPMENTS

7.1. Flow modeling

In this period, attention has been given to the development of a computational model, describing a 2 Dimensional turbulent flow without combustion and without heat and mass transfer at the boundaries. Special attention has been given to the boundary conditions for the $\tilde{k}$-$\tilde{\varepsilon}$ turbulence closure model. The $\tilde{k}$-$\tilde{\varepsilon}$ model is only valid for high Reynolds number flows. Near solid walls, the Reynolds number is low and low Reynolds number-effects must be taken into account. This is done by means of wall-functions.
To solve the system of partial differential equations describing a 2 Dimensional flow, these equations are converted into a system of algebraic difference equations by integrating them over control volumes. The grid system used to obtain these algebraic equations is a socalled staggered grid in which the normal and radial velocities are stored at the boundaries of the control volume. Due to the strong coupling between the equations, it is necessary to use an iteration procedure to solve them. The line-Gauss-Seidel procedure is used whereby along a comstant grid line the variables are solved by means of

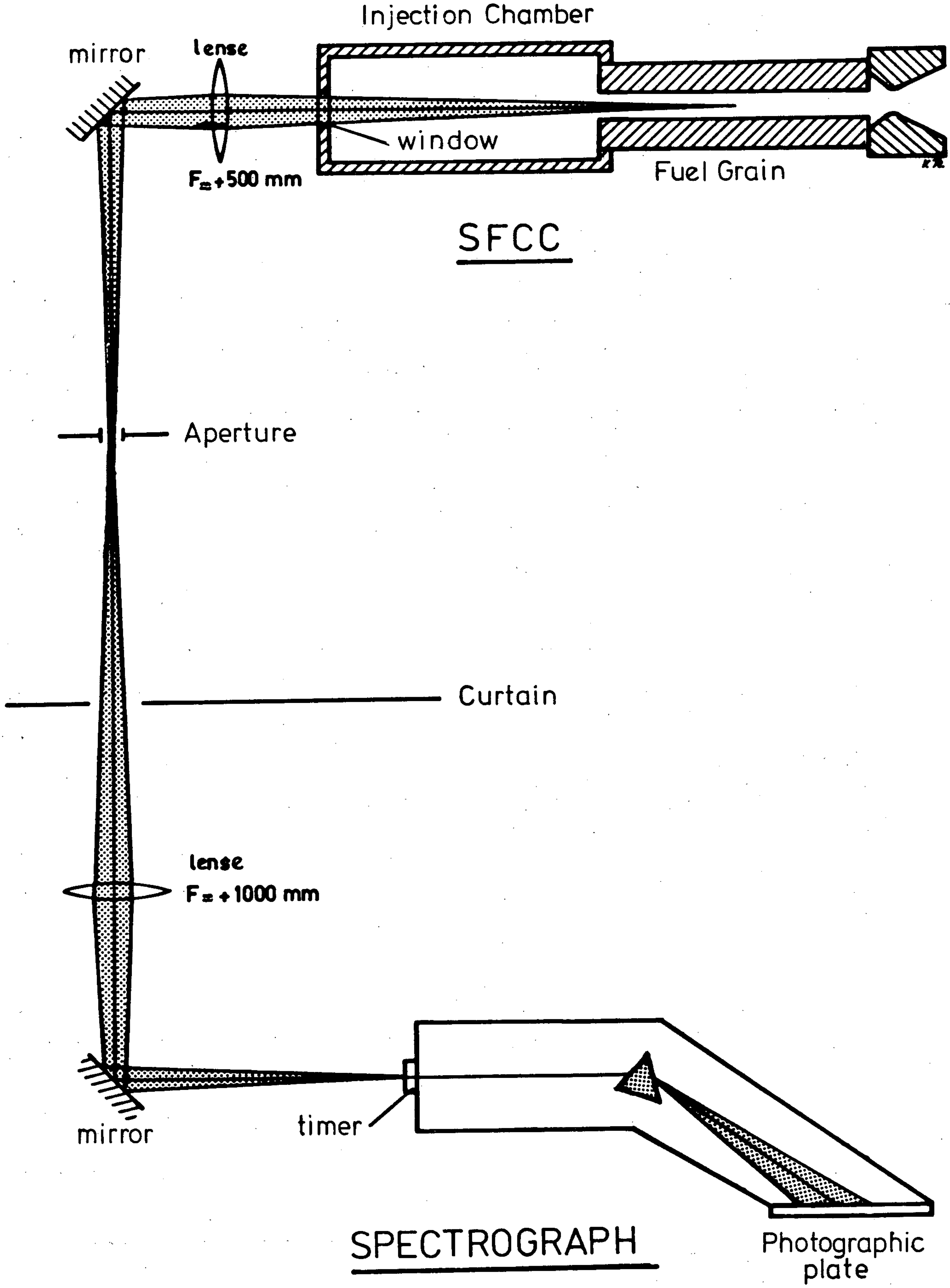


Fig. 4: Schematic of the experimental set-up during spectrographic measurements.

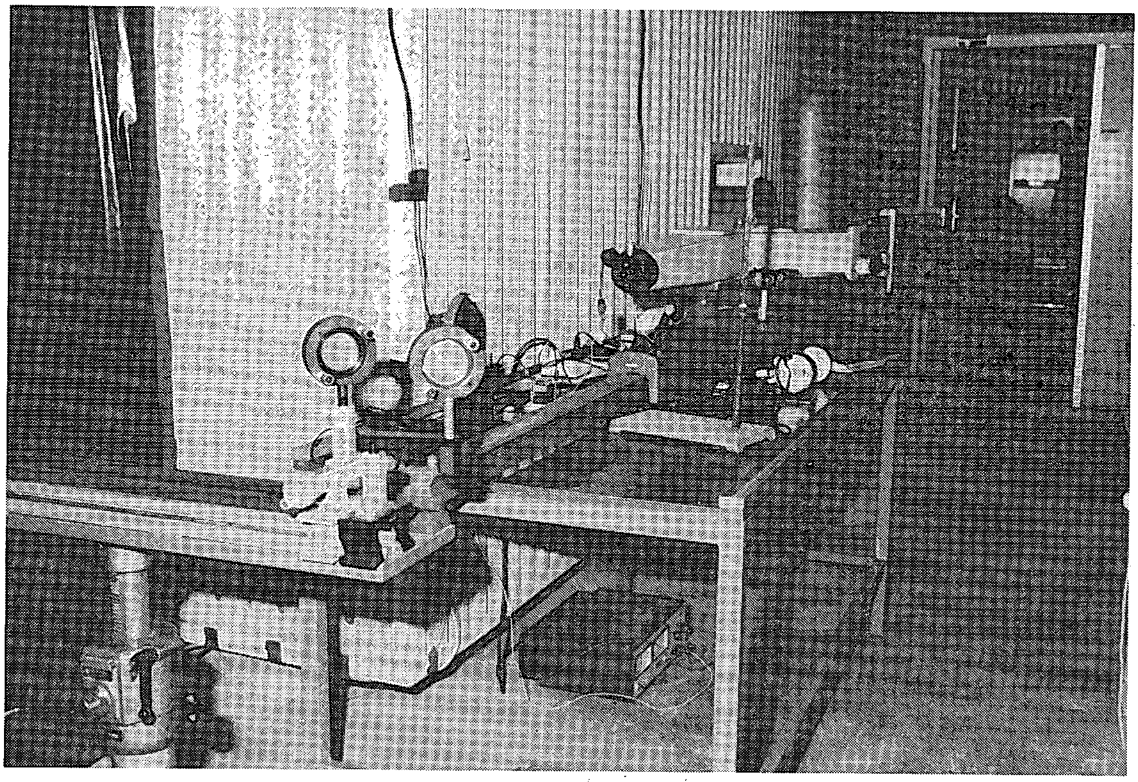


Fig. 5: Experimental situation during spectrographic measurements.

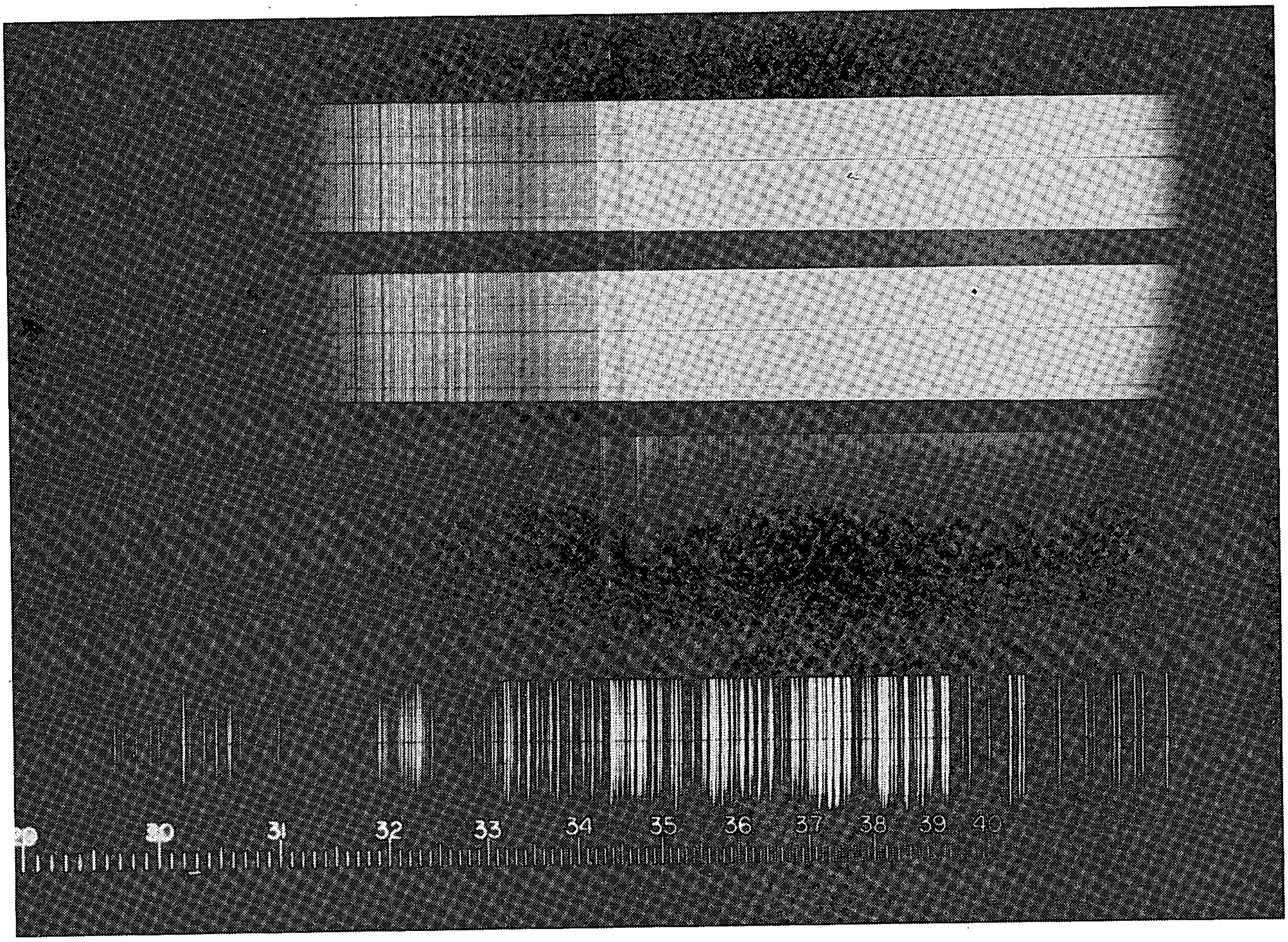


Fig. 6: Example of spectrum taken with the small spectrograph. The lower spectrum is an iron-reference spectrum. The next three spectra are taken during ignition, transition from ignition to buring of the fuel grain and during burning of the fuel grain.

the Thomas algoritm. The program is being written in ANSI X3.9-1978 Fortran (Fortran 77) on the Ahmdahl 470 V/7.B computer of the DUT. The program has a modular structure. At present most of the subroutines have been written, and the program is being tested. Problems have arisen with the strong coupling between the velocity field and pressure field. The pressure is calculated from the enthalpy, h, and the density, ρ. A relatively small pressure change causes a great velocity gradient. When solving the energy equation in the next iteration cycle, the enthalphy, h, gets a value from which it is impossible to calculate the temperature, T, and the program terminates. This particular problem is solved by introducing a false numerical source in the algebraic difference equations, but, at this time, it is still impossible to get a convergent iteration process when solving the momentum equations together with the energy and continuity equation. An other problem which has arisen is by implementing the wall function method for the $\tilde{k}$-$\tilde{\varepsilon}$ turbulence model in the program. Because the cubic equation which must be solved to obtain the turbulent kinetic energy, k_v, at the edge of the viscous sublayer contains only one real negative root, which is physically impossible. This problem is still under examination.

7.2. Combustion of PMMA

In partial fulfullment of the requirements for an engineering degree (DUT), a PMMA-laminar diffusion flame is modelled.

The combustion of PMMA in an SFCC is, amongst others, governed by chemical reactions and mixing of the reacting components by diffusion.
It has been found that in a surface layer of the solid PMMA the polymer pyrolizes almost entirely into the monomer MMA by a free radical supported unzipping reaction. Since the system of chemical reactions involving the combustion of MMA in air is very complicated, the system is modelled by a simple second order overall chemical reaction, involving two reactants and one product.
The general equations describing the steady state axisymmetric laminar flow field with chemical reactions are rather complicated. Therefore the set of equations is simplified in a way similar to Prandtl's boundary layer assumptions, resulting in a set of three non-linear partial differential equations which have to be solved simultaneously. A computerprogram is being developed for numerical solution of these equations; it makes use of an explicit finite difference method.
Observations have been made on a vertically placed PMMA rod burning in quiescent air.
To prevent burning of the rod perimeter an inhibitor was used. Experiments of measuring the local temperature in the flame by means of a thermocouple look promising.

7.3. Performance estimates

It is desirable to have a theoretical prediction of the performance of an SFCC available when performing a test run. This allows adjustment of the measurement equipment before a testrun is being made and secondly it allows comparison between experimental and theoretical values after a testrun has been performed.
To this end performance calculations have been made based on chemical equilibrium calculations. The results of these calculations have been curve fitted so that for a wide range of parameters information is available. A report is being prepared.

7.4. Determination of regression rate

It has been mentioned in Section 6.2 that for a determination of the regression rate knowledge of the temperature profile in the fuel is required. The temperature profile history during ignition and after extinguishment is unknown at present.
The temperature profile during operation of the SFCC has been modeled
As the speed of sound in PMMA is strongly dependent on the temperature, a literature survey, supplemented with measurements at PMLTNO, to determine this relation, has been carried out. As measurements are only possible up to about 185° C while the pyrolysis temperature of PMMA is estimated at about 300° C, the range between 185 and 300° C has to be extrapolated.

8. STATUS OF THE EXPERIMENTAL FACILITY

(See ref. 2)

8.1. Gassupply system

Final delivery of the gassupply system has yet not taken place. This is mainly due to a number of malfunctions:

i. It has been discovered that the Haenni pressure transducers are inherently unsafe. These transducers do not have a pressure relief; one of the transducers exploded. The Swiss manufacturer is modifying the transducer as a result of this event.

ii. A number of times the domes for pressure reduction were leaking.

iii. It has been discovered that valves had been installed of a different type than specified. These valves regularly caused problems and have been replaced by valves of the specified type.

Although malfunctioning of the gassupply system caused delays in the experimental program (calibration of O_2-SCMC, calibration of the feed lines), a large number of testruns (spectroscopy) could be performed. In addition to the direct delays, these malfunctionings required special attention and time of the group.

Figures 7, 8, 9 and 10 give an impression of parts of the gassupply system.

8.2. Vitiator, threeway valve, air-SCMC and CH_4-SCMC

The construction drawings of the two SCMC's have been submitted to the CWDUT by mid-June, while those of the vitiator and threeway valve arrived at CWDUT at the end of June.
Problems arose as CWDUT could only deliver the two SCMC's by the end of January 1984 and the other components not before July 1984. This would cause an unacceptable delay in the experimental program.
With regard to the SCMC's, DAEDUT asked CWDUT to speed up production. As a result, CWDUT promised to have the SCMC's ready by October 1st, 1983. A few weeks later, however, CWDUT informed DAEDUT that manufacturing of the SCMC's could not be terminated before the end of January 1984. Therefore, it was decided to have them manufactured by DINFA, 's-Gravenzande, which required unexpected expenses amounting HFl 30.000,--. The SCMC's will be delivered by the end of December 1983.
Because CWDUT now did not have to fabricate the SCMC's they reluctantly

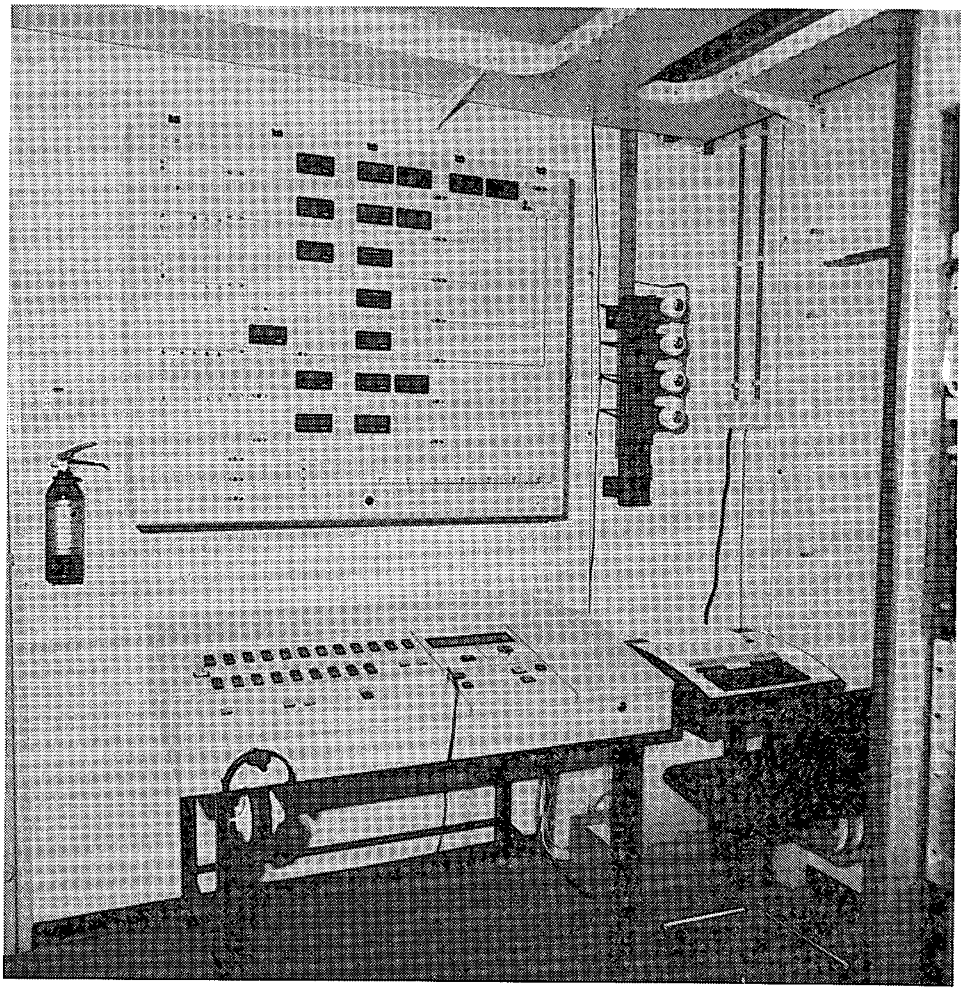


Fig. 7: The control and operating console for the gassupply system. At the right the terminal for programming the sequence of events during a testrun.

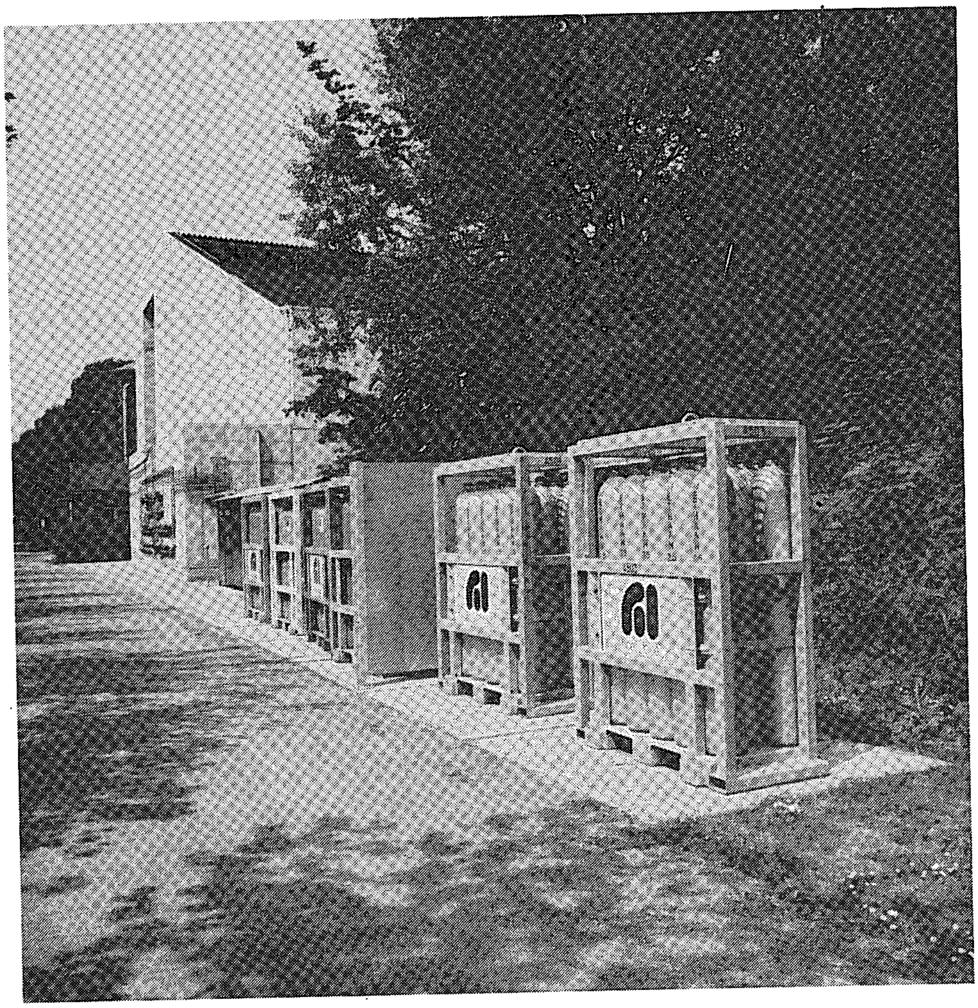


Fig. 8: Methane, oxygen and hydrogen supply.

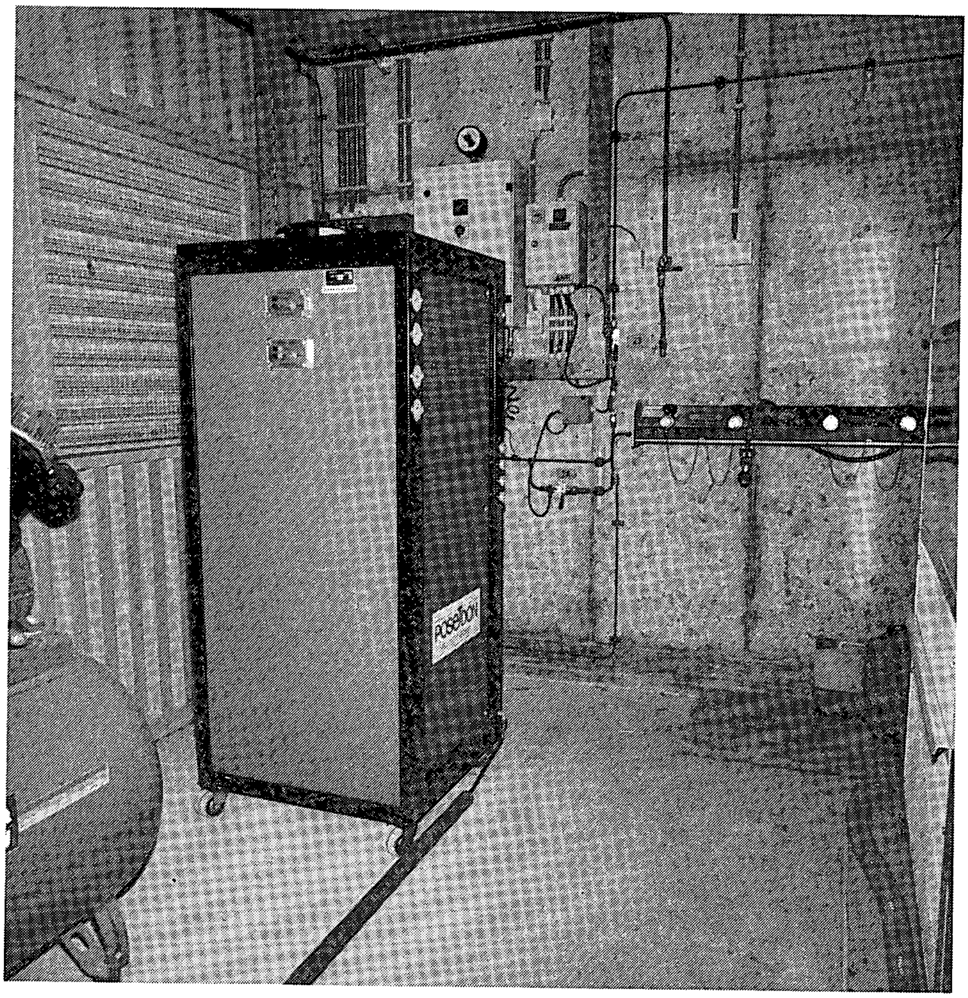


Fig. 9: The compressor for the air.

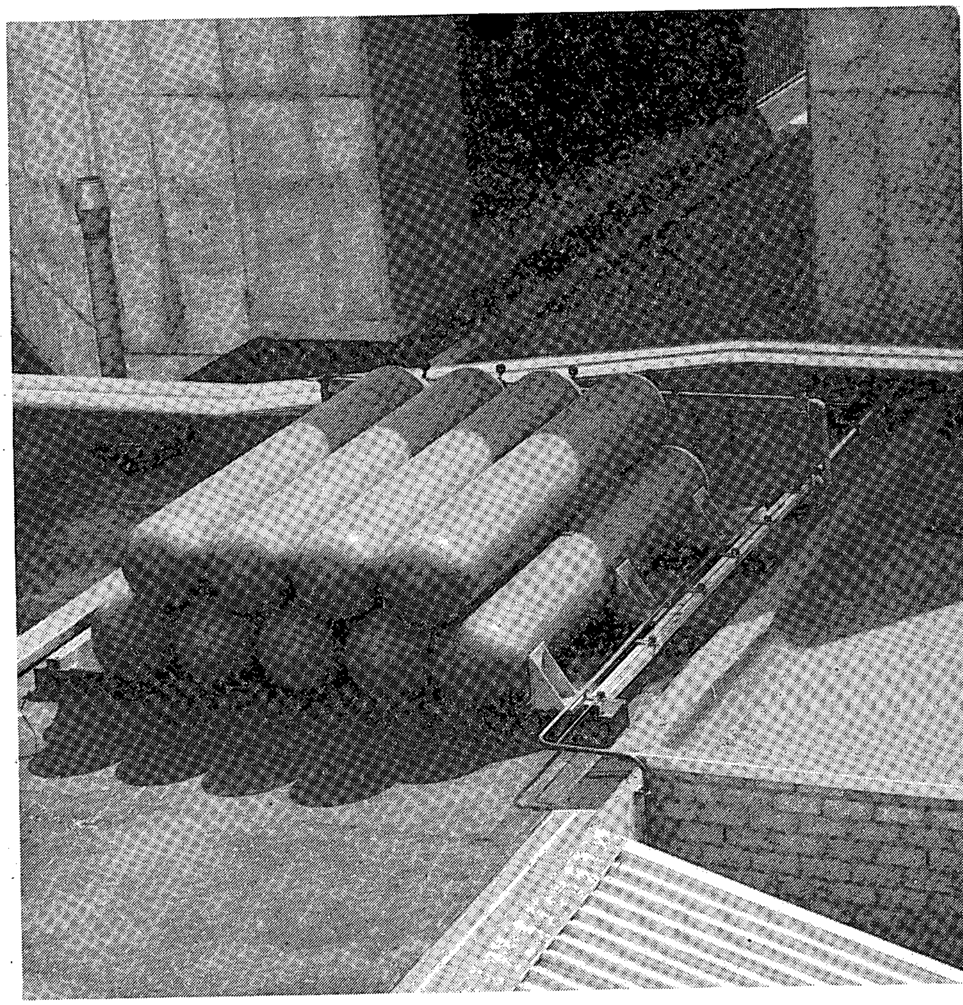


Fig. 10: Air storage bottles (3000 l).

agreed to complete the vitiator/threeway valve by the beginning of April 1984. In the meantime the board of DUT had been asked either to help speed up production or to provide money for construction elsewhere. As DUT could not find funding for the latter solution, STW was also asked for additional funding amounting HFl 100.000,--.
By the end of November, the board of DUT took measures to accelerate production. At the time of writing of this report CWDUT has informed DAEDUT that this has caused an additional delay of one month!!
As STW could not honor the request for additional money immediately, no industrial firm has been contracted until now. At the Users Committee (Section 9) Mr. Troost from VMF-Stork (FDO) has offered to investigate whether his company could help.

It may be anticipated that:

i. delivrance of the vitiator/threeway valve will take place much later than planned,
ii. if STW is willing to make additional funding available, the vitiator and threeway valve might be ready around mid March 1984,
iii. as similar difficulties with CWDUT may be expected for the construction of the SFCC it is felt that possible additional funding is better spent for the fabrication of the SFCC.

It should be mentioned that ir. G.A. Bohlander from the DUT Center for Energy Research has been very helpful in trying to solve the problems with the manufacturing of the vitiator/threeway valve.

8.3. The SFCC

The detailed construction drawings of the large SFCC have been delayed and are expected to be ready by March 1984.

Based upon our experience with CWDUT, it is not anticipated that the construction at this facility can be done at a great pace. Of course it will be investigated whether CWDUT is able to deliver the SFCC in a short time. As the machine shops of the PML have already agreed to produce the stand for the experimental system, there is no possibility for production at PML. The only alternative is to ask the industry to produce the SFCC if indeed additional money from STW becomes available, see 8.2.

8.4. Stand for the experimental system

As soon as the detailed construction drawings of the large SFCC become available, PML will start design and construction of a frame to support the vitiator, threeway valve and the SFCC. Based upon previous experiences no difficulties are foreseen with regard to planning and time schedules.

8.5. Gassupply control system

The control system for the gassupply system uses a microprocessor to perform the sequence of events before during and after a testrun. A program has been developed which until now performs satisfactorily. In the near future the program has to be extended for the control of the vitiator-temperature and the mass flows through the three SCMC's.

8.6. Control system for SCMC's

A design has been made of the control system for the three SCMC's. Before this system can be built, the characteristics of the feed lines have to be determined. As the deliverance of two SCMC's has been delayed (see 8.2) and due to malfunctioning of the gassupply system and the necessity of spectroscopic experiments, only a limited number of measurements has been made to determine the afore mentioned characteristics.

8.7. Ultrasonic regression rate analyzer (URRA)

An electronic analyzer has been built by the Electronic Department of PML-TNO to measure the time interval between an emitted and received pulse through the burning fuel. This tremendously facilitates taking data during operation of the SFCC. It is a much improved version of an earlier experimental analyzer.

9. USERS COMMITTEE

The users committee was convened for the third time on December 9, 1983 at PMLTNO. The following members were present:

Ir. H.F.R. Schöyer Ir. P.A.O.G. Korting Ir. J.B. Vos Ing. J.P.M. Versmissen	SFCC-projectgroup
Dr. H.J. Reitsma Dr.ir. H.J. Pasman	PMLTNO
Cdr. b.d. R.H. Kerkhoven	TNO
Prof.ir. C.W. van Koppen	THE
Prof.ir. H. Wittenberg	THD
Ir. H.J.M. Kruydenberg	PBE
Ir. A.J.W. Oude Alink	Thomassen Holland B.V.
Ir. C.A.L. Kemper Ir. G.K. Troost	NMF-Stork/FDO
Ir. F.C.H.D. van den Beemt Mw. A. Rijksen	STW

The following themes were presented:

- Status of the project	: Ir. Schöyer
- Regression rate measurement	: Ir. Korting
- Spectroscopy - Control system for SCMC's	Ing. Versmissen
- Progress on theoretical work	: Ir. Vos

The difficulties with the production of the vitiator/threeway valve prompted Mr. Troost (VMF-Stork/FDO) to offer help. He offered to investigate whether his company could help producing the vitiator/threeway valve in a shorter time. Preliminary data for the next meeting will be 15 or 22 June 1984.

10. UTILIZATION

Until now, no official reaction has been received from PBE upon the proposal for the investigation of the combustion of waste in our SFCC which had been submitted by PMLTNO. For a similar proposal submitted to TNO Special Projects (Beleidsruimte) no funding was available.

As agreed on the second meeting of the users committee Dr.Ir. Roos (NIVR) has investigated a possible industrial interest in the SCMC's. This resulted in contacts with DINFA, 's-Gravenzande. This company presently investigates the marketing prospects for SCMC's. If these prospects look promising DINFA is interested in producing and marketing SCMC's.

At the last meeting of the users committee, Ir. Troost (VMF-Stork/FDO) expressed the particular interest of VMF-Stork for Solid Fuel Ramjet applications of the SFCC. It has been agreed that early next year discussions about this subject will take place.

11. CONTACTS

During the period July-December 1983, the following contacts should be noted.

Institute	Person(s)	Subject
DINFA 's-Gravenzande	Ir. R.A. Mees Ir. W. Kluvers	SCMC
DUT Section Analytical Chemistry	Dr. G.R. Kornblum	Spectroscopy
TRACOR Bilthoven	Ing. J. Hondius	Spectroscopic Measurements
EG & G Nieuwegein	P.J. van Rijswijk Dr. S. v.d. Bent	Spectroscopic Measurements
Technion Haifa, Israel	Prof. A. Gany	SFRJ
BRL Aberdeen, USA	Dr. J.M. Heimerl	Chemical kinetics
IMGTNO	Dr.Ir. F.B. de Walle	Combustion of waste
Georgia Institute of Technology Atlanta, USA	Ir. W.A. de Groot	SFCC
Greek Air Force Athens, Greece	Dr. M.E. Metochianakis	SFRJ
DUT Centre for Energy Research	Ir. G.A. Bohlander	Help with trouble CWDUT

A preliminary travel schedule has been submitted to Lt.Col. O. Mancarella of AFOSR, London for a four weeks visit to the following institutes/companies in the USA:

1. AFOSR, Washington DC
2. Atlantic Research, Gainesville, Va
3. Nasa Langley, Hampton, Va
4. Aero Prop. Lab., Dayton, Ohio
5. Georgia Tech, Atlanta, Georgia
6. Brigham Young Univ., Provo, Utah
7. Aerojet, Sacramento, Ca
8. CSD, Coyote, Ca
9. NPS, Monterey, Ca
10. NWC, China Lake, Ca
11. AFRPL, Edwards AFB, Ca
12. Marquardt, Van Nuys, Ca
13. Cal tech, Pasadena, Ca

Additional funding for a visit to naval institutions has been requested from Cdr. Strada, ONR, London.

12. STATUS OF THE PLANNING PERIOD JULY-DECEMBER 1983

	Planning	Status
i	Testing gas-supply system.	Still some testing and evaluation necessary.
ii	Integration control system with gas-supply system.	Ready.
iii	Control system for SCMC's.	Measurements of time constants and characteristics of the system are taking place. After completion this system can be built and installed.
iv	Manufacturing and testing of two SCMC's.	Manufacturing delayed. No testing as yet.
v	Manufacturing and installing the vitiator and valve system.	Severely delayed. Not expected to be ready before May 1984.
vi	Designing, manufacturing and installing support for vitiator and SFCC.	Waits for construction drawings large SFCC.
vii	Design of large SFCC.	At design office (expected to be ready by March 1984).
viii	Experiments with small SFCC for: spectrographic analysis, correlation with computer code.	Successful. Code not ready as yet.
ix	Decision about use of spectrograph.	Yes, made. Either an OMA or a fast scanning monochromator.
x	Cold flow computer simulation model.	Under development, delayed.
xi	Software for data reduction.	Software at DUT ready. Performance estimate ready. Burning rate measurement in development.

	Planning	Status
xii	Theoretical work:	
	heat and mass transfer at boundaries,	Nothing done.
	initial work for selection of combustion model.	Nothing done.

13. PLANNED PROGRAM FOR THE PERIOD JANUARY-JUNE 1984

i. Testing and calibration of the three SCMC's.

ii. Characterization of the gassupply system: characteristic times, response times, amplification factors, volumes etc.

iii. Design and fabrication of an SCMC control system.

iv. Design and fabrication of the large SFCC.

v. Specification of the pneumatic system for the threeway valve.

vi. Preliminary installation and testing of the vitiator and threeway valve.

vii. Design support for the SFCC, vitiator and threeway valve.

viii. Testing software for microprocessor gassupply control system.

ix. Hiring of spectroscopist*)

x. Ordering of a system for spectrographic measurements*)

xi. Data reduction, including software development.

xii. Correlation of cold flow experiments with computer code.

xiii. Hiring of a computer programmer.

xiv. Development of an elementary computer simulation model for flow (without combustion) in an SFCC.

xv. Development of models that account for heat and mass transfer at the boundaries and implementation of these models in the computer code.

xvi. Description of a PMMA diffusion flame and experimental verification.

xvii. Initial work for the selection of a combustion model.

xviii. Analysis of the regression rate by means of the ultrasonic pulse echo method.

14. PUBLICATIONS

1. H.N. van Reenen, "Bepaling van het volume van een gasfles voor het ijken van een SMRD", Memorandum M-492/Report PML 1983-166, SFCC publication no. 7,

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*) It is anticipated that STW will honour the request for a spectroscopist.

Delft University of Technology, Department of Aerospace Engineering/Prins Maurits Laboratory TNO, Delft/Rijswijk, December 1983.

15. PROPOSAL FOR CONTINUATION OF SUPPORT BY STW

A final decision regarding the request for continuation of support for this project is expected to be taken by the end of January 1984.

16. 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, J.B. Vos and J.P.M. Versmissen, "Solid Fuel Combustion Chamber Progress Report III, Second Phase, Report LR-392/Report PML 1983-128, January-June, 1983, DAEDUT/PMLTNO, Delft/Rijswijk, June 1983.

3. 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.

17. ACRONYMS

AFB	-	Air Force Base
AFOSR	-	Air Force Office of Scientific Research
AFRPL	-	Air Force Rocket Propulsion Laboratory
CSD	-	Chemical Systems Division of United Technologies
CWDUT	-	Central Workshop DUT
DAEDUT	-	Department of Aerospace Engineering DUT
DUT	-	Delft University of Technology
MMA	-	Methyl Methacrylate
NIVR	-	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart
NPS	-	Naval Post Graduate School
NWC	-	Naval Weapons Center
OMA	-	Optical Multichannel Analyzer
ONR	-	Office of Naval Research
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	-	Solid Fuel Combustion Chamber
STW	-	Stichting voor de Technische Wetenschappen
URRA	-	Ultrasonic Regression Rate Analyzer
ZWO	-	Organisatie voor Zuiver Wetenschappelijk Onderzoek.