Delft University of Technology
Department of Aerospace Engineering

Prins Maurits Laboratory TNO
Rijswijk

Report LR - 363
Report PML 1982 - 159

SOLID FUEL COMBUSTION CHAMBER PROGRESS REPORT II

First Phase. July - December 1982

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P.A.O.G. Korting
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CONTENTS

SUMMARY

This is a report about the activities of the SFCC project group during the period July 1982 - December 1982.
It presents a survey of the funding and expenses, lists the people involved in the project during this period, it describes the status of experimental and theoretical work, and describes the status of the development of experimental tools. Finally the users committee and a proposal for a parallel research project are briefly mentioned.

1. INTRODUCTION

In this report the first phase (July - December 1982) of the Solid Fuel Combustion Chamber project DLR 11.0120 is described. The scope of this project is given in ref. 1. SFCC's have potential for energy conversion systems with very high efficiencies, clean combustors of waste and Solid Fuel Ramjets. There may be more applications.

This research project is sponsored by the Netherlands Foundation for Technical Research (Stichting voor de Technische Wetenschappen, STW) and the Project Office for Energy Research (Projectbureau Energie onderzoek, PBE).

The initial phase of this project is described in ref. 2.

In this report also an outline of the intended activities for the period January - July 1983 is given.

2. FINANCIAL SUPPORT

A support of Hfl. ƒ 100.000,--, which was mentioned already in progress report I, was received from the Project office for Energy Research (PBE) on 14 June, 1982. This grant is intended for large investments.
Mr. Korting is directly responsible for expenditures charged to this grant.

Financial support in accordance to the budget breakdown, as presented in ref. 1, is available from PML-TNO.

At the time of preparation of this report there was no indication as yet that the Department of Aerospace Engineering of Delft University of Technology will fulfill its commitment with respect to financial support and computer facilities.
If DAEDUT indeed would not on a very short term provide its financial support, this may seriously endanger the complete project.
To circumvent the above mentioned problems, a request has been made for special support (Beleidsruimte) from DUT. Although no reply was received at the time of writing of this report, the indications are that this request will not be granted.

3. EXPENDITURES

At the time of writing this report, no bills have been sent to STW; this does not mean, however, that no payments or obligations for payments have been made. Payments have been made by PML-TNO, which later on, will submit requests for refunding to STW.

a. A gas supply system has been ordered at the end of July from Hoekloos.
   Total costs Hfl. 198.149,--
   (A first payment has been made of the amount of Hfl. ƒ 59.106,--)
   There will be additional bills for additional work, pipes, tubes etc.
b. The total rent for the storage vessels which will become property of the project group after two years amounts to Hfl. 48.000,--
   During this phase no payments have been made.

c. The control panel which is being constructed at PMLTNO required the procurement of various components, for which the following payments have been made.

c_1	microprocessor	Hfl.	29.145,--
c_2	interfaces	Hfl.	4.004,--
c_3	small components (switches, cables, fittings, displays, racks, connectors, etc.)	Hfl.	13.461,--
d.	Hardware, groundwork etc. for the installation of the gassupply system	Hfl.	11.593,--
	Total amount of expenditures to be paid by STW	Hfl.	304.352,--

From DAEDUT bills have been received for the manufacturing of the SCMC and for reproduction of SCMC drawings. As the financial situation with respect to DAEDUT is not clear at present, these bills have not been paid.

4. PROJECT MANAGEMENT

The project management is the same as outlined in ref. 2.

5. HIRING OF PERSONNEL

A great many canditates (40) applied on announcements that appeared in "PT-Aktueel" and "Intermediair". The selection committee consisted of Ir. H.F.R. Schöyer (DAEDUT), Ir. P.A.O.G. Korting (PMLTNO) and Ir. J.B. Vos (ZWO). Members of the propulsion group of PMLTNO were consulted. As a result ing. J.P.M. Versmissen joined our group on September 15, 1982. He is an applied physics engineer from HTS-Rijswijk, and graduated this summer.

6. LIST OF PEOPLE INVOLVED IN THE SFCC-PROJECT DURING THE PERIOD JULY-DECEMBER 1982.

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

P. Kuypers	Apprentice HTS Haarlem until 1 September 1982. Performing of testruns.
Z. Nadler	Apprentice Technion Haifa (Israel) 2 August-17 September 1982. Calibration of radiation thermometer.
T. Breed	Apprentice MTS Alkmaar since 2 August 1982. Performing of testruns Calibration Sonic Choke
R.G. van Bruggen	Apprentice HTS Haarlem 16 August-1 December 1982. Design vitiator.
A. van Lingen	Apprentice HTS Zwolle since 2 August 1982. Design and construction of control system.
R. Surquin	Apprentice HTS Haarlem since 1 December 1982. Design vitiator.

Mr. P. Kuypers in partial fulfillment of the requirements for his engineering degree, will make a design for a Solid Fuel Combustion Chamber.

7. EXPERIMENTS

About 20 testruns were made with PMMA as a fuel and N_2-O_2 mixtures as gaseous oxidizer.
The mixture ratio was varied between 100 % O_2 and 20 % O_2/80 % N_2. At the latter mixture ratio which agrees more or less with air it was possible to achieve sustained combustion using a suitable diaphragm (see Figure 1).

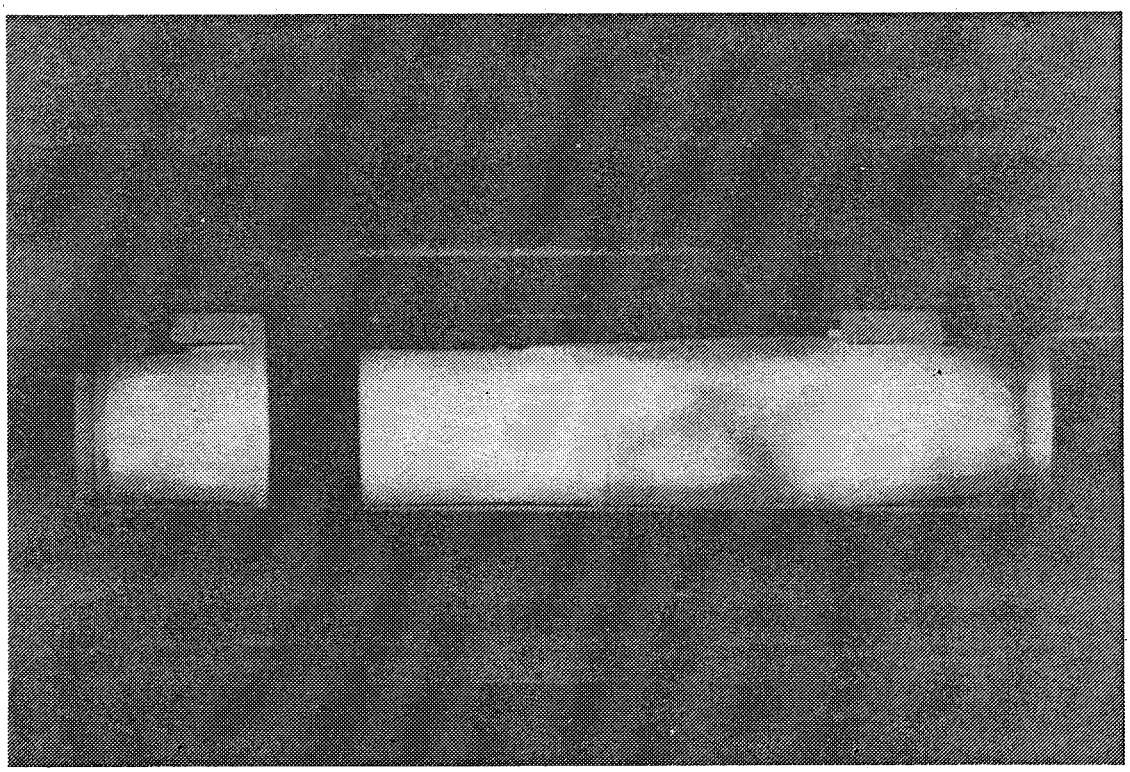

Figure 1. Testrun with PMMA as fuel and a mixture of 20 % O_2 and 80 % N_2 as oxidizer; to achieve sustained combustion a diaphragm with a 5 mm diameter hole was used. The inlet is at the right, the nozzle at the left. A dark region in the conduit of the burning fuel is clearly visible, indicating a transition region between the recirculation zone and the boundary layer zone.

In few cases no combustion was achieved; the cause is still unclear.
The regression rate appeared to be pressure dependent and was severely affected by the occurence of oscillations.
Although the ultrasonic technique to determine the local and instantaneous regression rate looks very promising, there are still severe problems with data reduction and interpretation of the results.

About 30 testruns with polyethylene as a fuel and pure oxygen as oxidizer have been made.

A preliminary radiation temperature measurement with the hybrid rocket motor yielded a temperature within 10 % of the expected theoretical temperature. Future experiments are necessary.

In a few cases the combustion has been filmed with a high-speed camera (10.000 frames/second, 500 frames/second, and 50 frames/second). These films give a very interesting impression of the combustion process.

For the next phase no experiments are foreseen as by January the construction of the new gassupply system is to start, and the existing system will be incorporated into the new facilities. It is expected that the new facilities will be operational by July 1983.

8. THEORETICAL DEVELOPMENTS

Modeling of the flow and combustion process in the SFCC encompasses:
viscous flow for a multicomponent mixture
solid fuel pyrolysis and
chemical reactions.
During this phase, attention has mainly been given to: Derivation of basic equations for 3-D time dependent flow (without boundary conditions) of a multicomponent mixture involving chemical reactions and heat transfer. In addition to the classical approach, also the equation of conservation of angular momentum has been derived. As far as turbulence goes, attention has been given to Reynolds decomposition and Favre averaging.

In the next phase attention will be given to the boundary conditions at the pyrolyzing wall and a first simple numerical routine will be written.

9. STATUS OF THE NEW EXPERIMENTAL FACILITY

The new experimental facility will consist of
- a gas supply system
- a vitiator
- an SFCC
- a control system and
- 3 SCMC's

9.1. Gassupply system

A diagram of the gassupply system was already given in ref. 2. It will be manufactured and installed by HOEKLOOS.
All preliminary work, necessary for the installation of the system is done by PMLTNO.
This comprises:
- construction of storage facilities for gas cylinders
- construction of mounting frames for gas cylinders
- various groundwork; e.g. platforms.

It is expected that HOEKLOOS will start the construction by January 1983.

9.2. Vitiator

The vitiator will provide the SFCC with heated "air".

To this end oxygen and methane are mixed with cold air and burned in the vitiator, in such a ratio that the hot combustion products contain the same molar mass fraction of oxygen as ambient air.
The vitiator design is based on a similar device that has succesfully been used by CSD-UTC and NWC.
The mixture ratios of CH_4, O_2 and Air have been determined in dependence of the required "hot air" temperature and the requirement that the "hot air" should simulate ambient air in oxygen contents[3]. The hot air temperature range is between 300 K and 1000 K.
An estimate of the temperatures of the construction elements of the vitiator has been made.
Presently detailed construction drawings are being made.

9.3. SFCC

Specifications for a new SFCC have been formulated.
These specifications are:
- The SFCC has to be suitable for combustion of PMMA, PE, PS, wood, coal and refuse.
- Pressures up to 4 MPa.
- Maximum temperature of inlet air 1000 K.
- Maximum operating time 90 s at maximum air flow rate.
- Maximum mass flow inlet air, 2 kg/s.

Interchangeable combustion chambers should be possible to accomodate both for hollow cylinderical charges or to use the SFCC as a slab burner (window motor).

At present a design is being made by a student of the HTS-Haarlem in partial fulfillment of his engineering degree.

9.4. Control System

Figure 2 is a diagram of the control system for the test facility.
A central micro-processor controls the whole system.
In addition it processes experimental data and finally the microprocessor ensures the safe operation of the system.

In the case that the microprocessor goes down during an experiment, an additional safety device (external) will stop the testrun.

A flow panel visualizes the status of the testequipment.

The whole experimental facility is operated from a control panel (Fig. 3) and a terminal.

The system will be connected with a Data Aquisition System linked with the PMLTNO computersystem.

An essential feature of this testfacility is that a well controlled mass flow of air (possibly enriched with a precisely controlled amount of oxygen) is to be fed into the SFCC. In addition the SFCC inlet temperature has to be controlled within narrow ranges.
The gas mass flows are precisely controlled by the SCMC's. The calculation of the mass flows is made by the microprocessor; if the mass flows deviate from the required ones, the microprocessor will provide a signal as to restore the mass flows to within the specified limits.

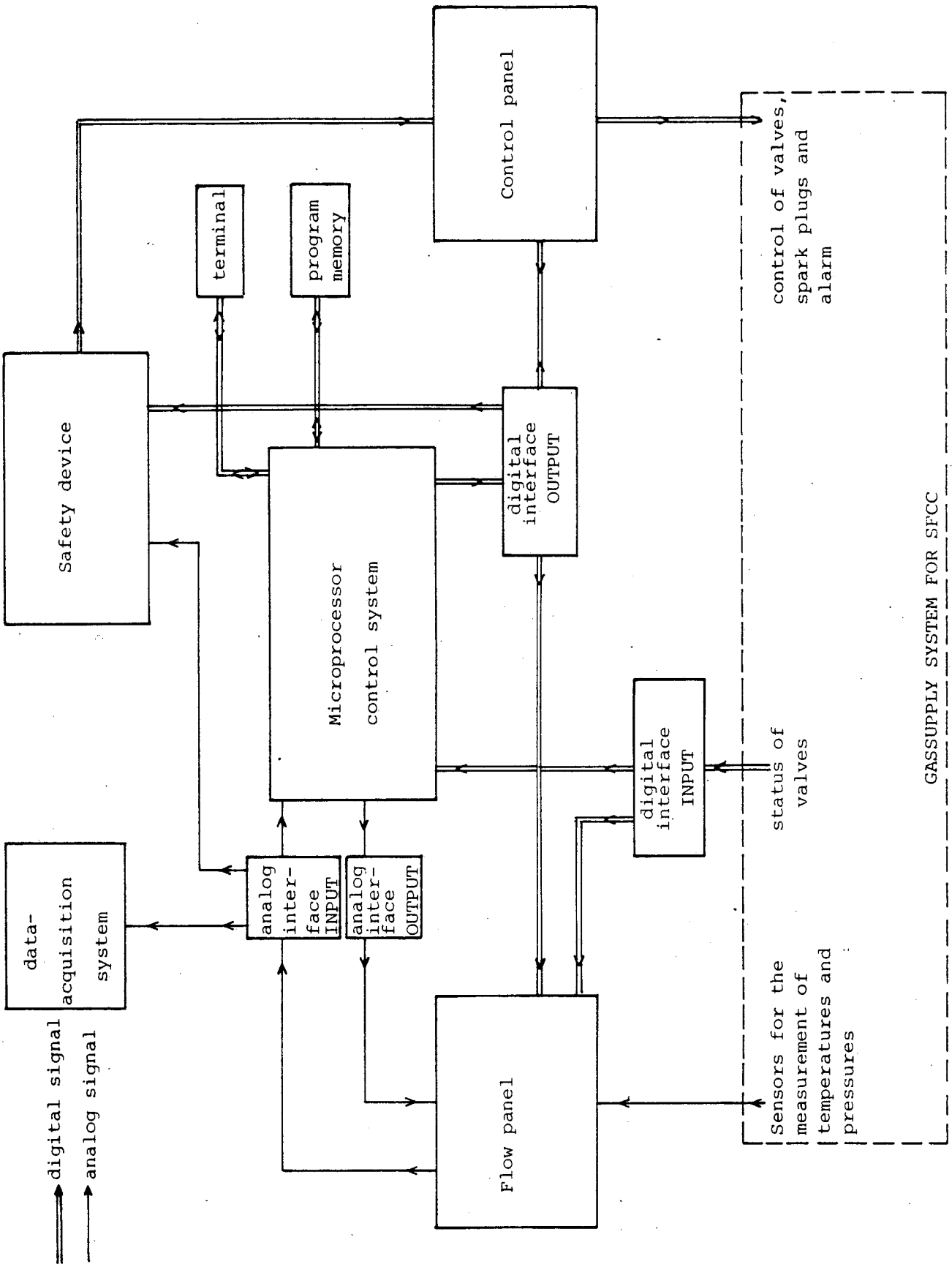

Fig. 2.: Diagram of the control system for gassupply system

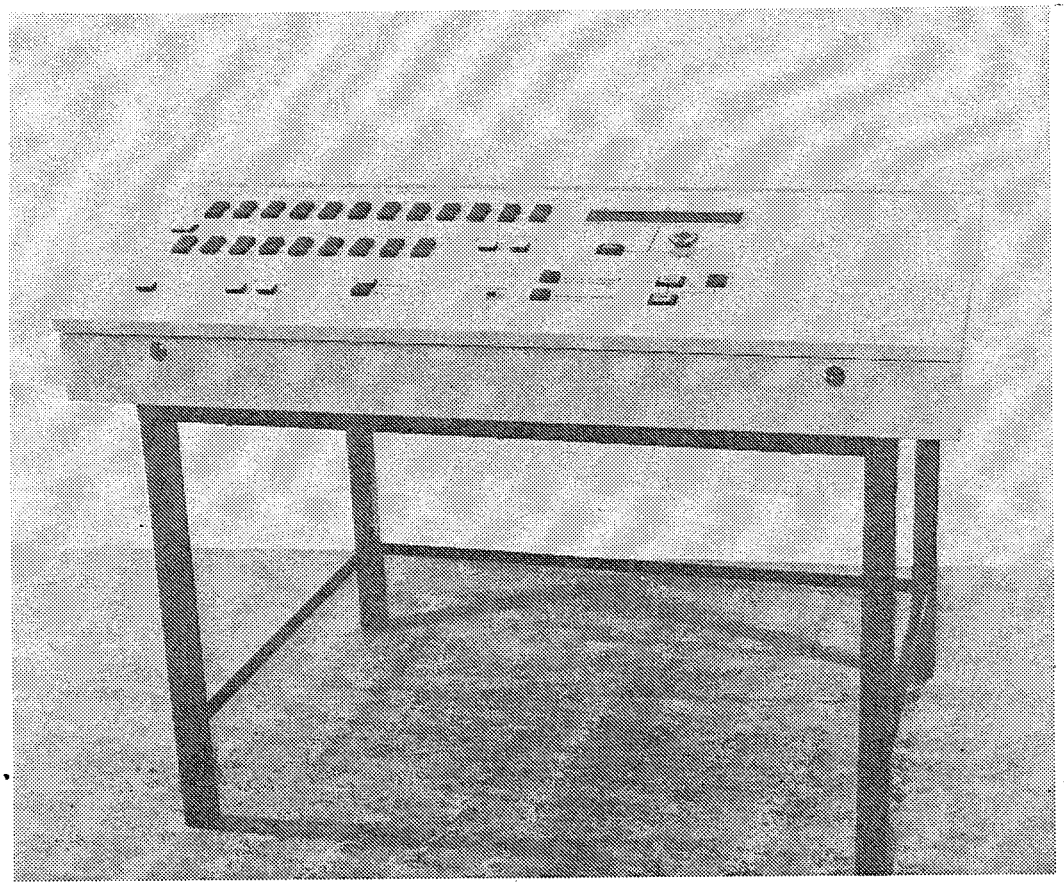

Fig. 3: The control panel for the gassupply system under construction.

The same applies for the SFCC-inlet temperature. If this deviates from the required one, the microprocessor will take action.

9.5. SCMC's

The gas supply system contains three SCMC's (see ref. 2 p.12). The first SCMC (for oxygen, see Figure 4) has been manufactured by DAEDUT. Calibration testruns have been made. Although not all data have been reduced, the first results look promising. After that the good performance of the O_2-SCMC has been proven, the CH_4-and Air-SCMC will be manufactured.

10. USERS COMMITTEE

The users committee was convened for the first time on 21 October 1982, at PMLTNO. The following people were present:

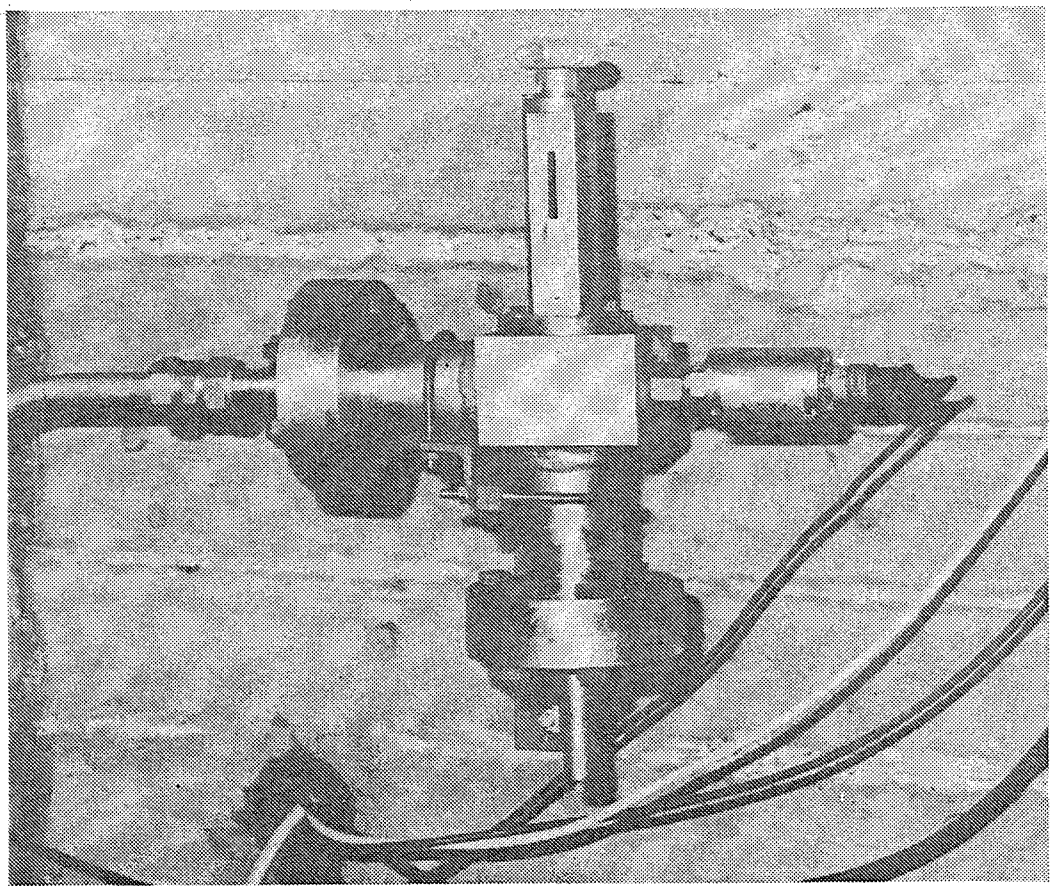

Figure 4. View on the Sonic Control and Measurement Choke. This device regulates and measures accurately the oxygen gas flow. Two more devices for air and methane are planned.

Ir. H.F.R. Schöyer
Ir. P.A.O.G. Korting
Prof. Ir. H. Wittenberg
Ir. J.B. Vos
Ing. J.P.M. Versmissen
} SFCC-project

Dr. H.J. Reitsma (PMLTNO)
Cdr.b.d. P.D. Kerkhoven (TNO)
Dr. R. van Duinen (Fokker)
Ir. R. Hendriks (Thomassen Holland)
Dr. Ir. M.E.A. Hermans (KEMA)
Prof. Ir. C.W.J. van Koppen (TH-Eindhoven)
Ir. H.J.M. Kruijdenberg (PBE)
Prof.Dr.Ir. J.A. Steketee (TH-Delft)
Ir. C.A.L. Kemper (VMF-Stork/FDO)
Dr. Ir. R. Roos (NIVR)
Ir. R.M. Neubauer (NIVR)

Ir. F.C.H.D. van den Beemt (STW)
Mevr. N.H. Klijn (STW)

The following themes were presented

Introduction into STW-projects	(Ir. v.d. Beemt)
Status of the project	(Ir. Schöyer)
Movie on combustion experiments	
Demonstration	
Experiments	(Ir. Korting)
Introduction to theoretical background	(Ir. Vos)

The next meeting will be around April 1983.

11. PROPOSAL FOR WASTE COMBUSTION IN AN SFCC

The Project Office for Energy Research (PBE) has requested a revised proposal for the combustion of waste material in an SFCC. A decision is expected in the first half year of 1983.
It is expected to obtain processed waste material from ICOPOWER, Amsterdam.

12. CONTACTS

In addition with the previously mentioned contacts[2] the following contacts should be noted:

Institute:	Person(s):	Subject:
MT-TNO Apeldoorn	Ir. A. Kiers Ir. H. Bartelds	Combustion of Waste Material; Determination of composition of combustion gases; fluidized bed combustion.
ICOPOWER B.V. Amsterdam	Ing. B.C. de Pijper	Processing of Waste Material.
European office of Aerospace Research and Development London	Lt. Col. O. Mancarella	Visit to U.S. Laboratories and Industries.
Naval Weapons Center China Lake	Dr. R.L. Derr	Data Exchange Agreement Visit to U.S. Laboratories and Industry
PBE Apeldoorn	Ir. H.J.M. Kruijdenberg	Combustion of Waste Material
Department of Chemistry DUT	Prof.Dr. L. de Galan Dr. G.R. Kornblum	Spectrografic measurements; possible contribution to the project
Embassy of the Kingdom of the Netherlands Washington	Kol.Ir. H.J. de Bruine	Status of Solid Fuel Ramjets.

13. PLANNED PROGRAM FOR THE PERIOD JANUARY - JUNE 1983

The following subjects are expected to receive main attention:

i Installation and testing of the gassupply system.

ii Design, manufacturing and calibration of two SCMC's.

iii Design and manufacturing of the vitiator.

iv Design of SFCC.

v Construction, installation and testing of the control system.

vi Software for microprocessor.

vii Software for data reduction.

viii Theoretical work; main emphasis on flow and combustion modelling.

ix An elementary computer simulation model for flow (without combustion) in an SFCC.

x Preparatory work for flame spectroscopy.

14. PUBLICATIONS

1. R.G. van Bruggen, "Luchtverhitting d.m.v. een vitiator - berekeningen van de temperatuur van de uitstromende gassen". Afdeling Luchtvaart- en Ruimtevaarttechniek Technische Hogeschool Delft, Prins Maurits Laboratorium TNO, Memorandum M-435/Report PML 1982-147. SFCC Publication ~~#~~ 1, Delft/Rijswijk, oktober 1982.

2. J.B. Vos, "The Equation for a 3 Dimensional Transient Flow of a Multicomponent Gasmixture with Chemical Reactions", Dept. of Aerospace Engineering Delft University of Technology/Prins Maurits Laboratory TNO, Report LR-362/PML 1982-149. SFCC Publication no. 2, Delft/Rijswijk, November, 1982.

In the Monthly "Kijk", issue October 1982, a popular article about the SFCC-project appeared.

15. REFERENCES

1. AN.
"Proposal for the investigation of a solid fuel combustion chamber". Memorandum M-395. Department of Aerospace Engineering, Delft University of Technology/Prins Maurits Laboratory TNO, 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/PML 1982-134.
Delft University of Technology/Prins Maurits Laboratory TNO, Delft/Rijswijk, June 1982.

3. R.G. van Bruggen,
"Luchtverhitting d.m.v. een vitiator - berekening van de temperatuur van

de uitstromende gassen -."
Memorandum M-435, Report PML 1982-147. SFCC publication 1, Delft University of Technology/Prins Maurits Laboratory TNO, Delft/Rijswijk, Oktober 1982.

16. ACRONYMS

CSDUTC - Chemical Systems Division, United Technologies Center

DAEDUT - Department of Aerospace Engineering, Delft University of Technology

NWC - Naval Weapons Center

PBE - Projekt Bureau Energieonderzoek

PE - Polyethylene

PMLTNO - Prins Maurits Laboratorium van de Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek

PMMA - Polymethylmethacrylate (perspex)

PS - Polystyrene

SCMC - Sonic Control and Measuring Choke

SFCC - Solid Fuel Combustion Chamber

STW - Stichting voor de Technische Wetenschappen