

# **One-Stage Cyclone Combustor For Coal Fired Test Stand Of 4Mw Thermal Power**

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ONE-STAGE CYCLONE COMBUSTOR FOR COAL FIRED  
TEST STAND OF 4MW THERMAL POWER.

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Abstract

During 1975-1977 the old "3MW-MHD" test rig in Świerk has been converted to burn coal to produce suitable plasma stream for MHD generator.

The pebble-bed air preheater has been also modified in order to suppress the observed pressure fluctuations caused by pneumatic transport device.

The test rig has been equipped with pulverised coal bunker of capacity sufficient for 6 hours of continued operation of combustor. Coal as powder is supplied to the combustor with warm air of approx. 420-550 K temperature.

The vortex combustion chamber, designed as a joint project of IBJ-Świerk and ENIN-Moscow, with the maximum thermal power of 3-3,8 MW has been designed, constructed and put in operation.

It is supplied with hot air of approx. 1470 K with possibility of enrichment with oxygen between 40-55%. Seed is fed as a water solution of  $K_2CO_3$ .

In order to increase the pressure inside the combustor the outlet of the chamber is equipped with a nozzle connected to the element simulating the future MHD generator.

First experiment started in 1977 with pure air preheated till 1300 K /at the chamber inlet, 1410 K at the preheater outlet/ and with thermal power from 2 MW till 4 MW.

In the report some details of the rig are given together with the design of combustor and characteristics of fuel used.

The results of the experiments performed during 1977 and 1978 are presented.

I. Introduction

1. The old test stand "3MW-MHD" has been adapted for coal firing and is presented in Fig.1.
2. The following items have been added to the existing installation:
  - a. the coal feeding system, consisting of powdered coal hopper and the pressure tank having the capacity of 5,8 m<sup>3</sup>. The coal bunker has enough capacity for continuous operation of 6 hours without recharging. Pressure in the bunker /hopper/ is maintained slightly above the pressure in the combustion chamber
  - b. powdered coal feeder of the screw type, D.C. motor driven with thyristor speed control; it enables to change feeding rate from 100-900 kg/h
  - c. powder ejectors, feed line, coal distribution device for distributing coal-air mixture between four injectors
  - d. Scrubber which forms the last part of the combustion gases train, where, the combustion gases are cleaned from the seed and slag before being exhausted to the atmosphere. The necessary mass flow of water is 6000 kg/h for the nominal rating of 4 MW thermal of the installation. Inlet part of the scrubber include three rows of the water injectors, nine additional water injectors are placed in the scrubber head.
3. The most important part of the retrofitted installation is the new combustion chamber, for coal, equipped with additional slag tank. Coal combustor has been designed and constructed based on the following assumptions:
  - thermal power approx. 4 MW
  - max temperature of the exhausting gases 2800-2900 K
  - air enriched till 45%-50% /by weight/ preheated till 1300-1500 K
  - minimum of heat losses through the walls of the combustor
  - protection of wall by slag layer
  - maximum intensity of heat release in the combustor in order to suppress the relative losses by cooling
  - rapid devolatilization of coal particles of 40-50  $\mu$ m size by injection to the stream of gas of 1600 K
  - rapid heating of coal particles 10<sup>5</sup> deg/sec
  - rapid and uniform mixing of coal particles with air and oxygen
  - use of dry coal;
4. In the first phase the existing pebble-bed oxidizer preheater is to be used limiting the maximum preheat temp. to 1500 K, in the next phase the vitiated air heater will be used with higher temperature of oxidizer preheat.

## II. Experimental Facilities and Test Hardware

### 1. Design of the combustion chamber

The cross-section of the combustion chamber is presented in Fig.2, and the cross-section of the inlet section in Fig.3.

The combustion chamber axis is inclined 30 degrees to the horizontal line. The inclination has been dictated as a compromise between the high losses of the vertical solution /high losses in the bend connecting chamber with the MHD nozzle/ and the high slag separation ability of the vertical arrangement.

The inlet section of the chamber is arranged as a scroll with  $Al_2O_3$  refractory lining. In order to distribute the air as uniformly as possible the swirl blade apparatus is provided, made of SiC blades, mounted at 15 degrees in the  $Al_2O_3$  cement. The velocity of air /enriched/ discharging through the swirl vanes is approx. 80-110 m/sec. The swirl vanes apparatus is shown in Fig.4. The main dimensions of the chamber are as follows:

internal diameter	D = 0,4 m
ratio of length to diameter	L/D = 1,45
length of combustion volume	L = 0,58 m
ratio of outlet from CC to internal diameter	d/D = 0,4

### 2. Internal structure of the combustor

The internal protection of the combustor walls is secured by the slag layer itself. The internal metallic structure is provided with machined grooves and fingers of 8 mm depth. The hollow spaces between them are filled with SiC mortar of 11 mm thickness /3 mm over the fingers surface/.

The chosen thickness of the SiC is sufficient to maintain the temperature at its surface at approx. 1270 K-1370 K, that is 200 - 250 K below the fluid temperature of the slag.

It is enough to generate the protective layer of the slag on the combustor walls.

During experiments the protective layer of 2+5 mm thickness of thoroughly fused slag is observed /Fig.5/. At the lower part of the chamber the slag tapping hole is provided, its diameter is 100 mm.

Fig.7,8,9 present the elements of the combustor.

### 3. Pulverized coal feeding

Dry pulverized coal is stored in coal bunker /hopper/ under pressure equal

to the pressure in the combustor. Coal is further supplied by the screw type feeder and air ejector working with air preheated to 550 K. The solid transport ratio of coal mass flow to the transport air mass flow is approx. 2,5.

The coal-air mixture is transported to the distributor in which it is being divided in four streams /with accuracy of approx. 8%/ supplying the four coal injectors. There are two possibilities of injecting coal into the combustor - first with four injectors situated in the inner central cone of the combustor /see Fig.8/ and the second with four injectors situated at the outer periphery of the combustor. The axis of all injectors are arranged at 45 degrees to the tangential direction.

The mass flow of coal is calculated both from the revolutions of the calibrated screw feeder and from the heat balance of the coal, hot transport air and coal-air mixture. The discrepancies are not larger than 6%.

## III. Operating Conditions

### 1. Coal and ash analysis.

In the first experiments coal from the Silesian Region /Bytom mine/ has been used exclusively.

#### Proximate analysis %

Moisture	W <sup>a</sup> 1 - 3,5
Volatile Matter, daf,	30 - 36
Fixed Carbon	61 - 66
Ash A <sup>d</sup>	15,3 - 22,8

#### Ultimate Analysis, daf %

Carbon	80 - 84
Hydrogen	4,5 - 5,5
Sulfur	1,0 - 1,5
Oxygen	8 - 10
Nitrogen	1 - 1,5

#### Ash analysis

SiO <sub>2</sub>	%	43 - 51
Al <sub>2</sub> O <sub>3</sub>		17,4 - 22
Fe <sub>2</sub> O <sub>3</sub>		9 - 11
CaO		4 - 8
MgO		3 - 6
SO <sub>3</sub>		4,2 - 6,4
Na <sub>2</sub> O		0,8 - 1,5
K <sub>2</sub> O		1,5 - 2,7
TiO <sub>2</sub>		1

Coal particles size: 80% through 90  $\mu$ m sieve /170 mesh/ and 95,5% through 200  $\mu$ m sieve /70 mesh/.  
 Heating Value /coal as rec'd/ 23100 - 26700 KJ/kg  
 Characteristic temperatures of ash  
 Initial deformation temperature 1433 K  $\pm$  50

Softening temperature  $1463 \text{ K} \pm 50$   
 Fluid temperature  $1590 \text{ K} \pm 50$

2. Air and oxygen: mass flows and temperatures of preheat.  
 primary air  $0,0556 \text{ kg/sec}$   $550 \text{ K}$   
 secondary air and oxygen  $0,389-0,5 \text{ kg/sec}$   
 $1300-1500 \text{ K}$   
 average temperature of oxidizer  $1100-1300 \text{ K}$   
 air enrichment /by weight/  $45-50\%$   
 additional air  $0,011-0,029 \text{ kg/sec}$   
 $300 \text{ K}$
3. Coal mass flow  $0,11-0,128 \text{ kg/sec}$   
 seed feeding rate  $0,007-0,03 \text{ kg/sec}$
4. Combustion gases rate  $0,5-0,7 \text{ kg/sec}$   
 Combustion gases bleeding  $0,015 \text{ kg/sec}$   
 /by-pass through slag tank/

#### IV. Experimental Results

During 1977-1978 period seven experiments have been carried-out of 3+5 hours of duration. Some experimental results are cited below:

1. Exhaust gas composition /typical/  
 % by volume:  
 $\text{N}_2-49\%$ ;  $\text{O}_2-2+3\%$ ;  $\text{CO}-1\%$ ;  $\text{CO}_2-29\%$ ;  
 $\text{H}_2-1\%$ ;  
 Nitrogen oxides calculated as  $\text{NO}_2$   
 content:  $3,8+5,5 \text{ g/m}^3$   
 /measurements by means of spectrocolorimeter method/.
2. Temperature of the exhaust gases,  
 downstream of sonic nozzle:  
 $2700-2900 \text{ K}$  /measurements by two methods, namely: line reversal of potassium line  $\text{K } 7665 \text{ \AA}$  and absolute intensity of the some line of potassium/.  
 Accuracy  $\pm 50 \text{ K}$ . Maximum temperature has been obtained with  $\alpha = 0,92$ .
3. Pressure fluctuations have been measured by induction pressure transducer. Maximum amplitude of fluctu-

ations was in the range of 2% of the total pressure inside the combustor.

4. Coal burnt-out. With  $\alpha=1$ , and with residence time for coal particles about 40-60 milliseconds, the unburnt coal amounted to 0,2-1,0%.

#### 5. Seed-slag interaction

Seed was introduced as a water solution of  $\text{K}_2\text{CO}_3$  heated to  $350 \text{ K}$ , under pressure of  $0,6 \text{ MPa}$ .

Injection of seed was secured by two injectors, one situated in axis of the combustor and the second protruding from the side wall of the chamber and injecting against the main flow.

The amount of seed absorbed by the slag was rather high between 15% and 20%.

It is suggested that the main cause of high seed losses is the entrainment of seed droplets /which have not enough time to vaporize/ by the liquid slag layer on the walls of the combustor.

In the Table are presented the chemical compositions of ash and slag from the samples taken in different points of the installation.

Sample 1: ash from the coal, as received

Sample 2: slag from the center of the slag tank

Sample 3: slag from the surface of the slag tank

Sample 4: slag from the bleeding by-pass /fine particles/

Sample 5: slag from the scrubber

TABLE 1.

Sample	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	$\text{CaO}$	$\text{MgO}$	$\text{SO}_3$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	$\text{TiO}_2$	
1	43,7	20,77	10,0	8,11	5,17	6,41	0,8	2,5	1,01	98,47
2	45,74	19,89	9,82	7,03	7,08	0	1,24	8,6	0,9	100,3
3	49,38	21,29	11,96	7,57	4,79	0	0,6	4,2	0,87	100,6
4	33,03	38,04	6,59	12,97	2,68	1,84	1,0	2,45	0,79	99,39
5	39,71	25,3	9,27	8,52	8,14	0	1,2	7,55	1,02	100,71

6. Heat flux to the walls

Typical heat fluxes measured during the runs are as follows:

inlet part of combustor	0,54 MW/m <sup>2</sup>
central " " "	0,44 MW/m <sup>2</sup>
outlet " " "	0,69 MW/m <sup>2</sup>
exhaust part	0,65 MW/m <sup>2</sup>
exhaust of the slag	0,3 MW/m <sup>2</sup>
side injector of seed	1,8 MW/m <sup>2</sup>

During the first 20 minutes of operation they may be higher by 20 - 25% /no slag protection/.

Overall heat losses by cooling are between 14% and 20%.

7. Intensities of heat release, as calculated, are following:

relative to the cross section of combustor:

$$11-12 \frac{\text{MW}}{\text{m}^2 \cdot \text{atm}}$$

density of heat release:

$$15-17 \frac{\text{MW}}{\text{m}^3 \cdot \text{atm}}$$

8. Additional data

Combustion gases by-pass through slag-tank

approx. 2%

Seed rate relative to exhaust gases flow rate 0,3% - 1,0%

Slag removal efficiency 71 - 76%

V. Concluding Remarks

1. Experimental results indicate that stable operation of a one stage coal combustor, directly burning coal, has been achieved during several runs of 4 - 6 hours of duration. The longer runs have been limited only by the capacity of the coal storage devices.
2. The protection of the inner walls by slag layer is highly effective and no damage has been observed after several runs /approx 10 runs/.
3. Heat losses due to cooling of the combustor walls have not exceeded the predicted values and may be reduced to several percents in full scale combustor.
4. The achieved intensity of heat release of the order of  $15-17 \text{ MW/m}^2 \text{ atm} / \sim 50 \text{ MW/m}^3 /$  is very near the required intensity for commercial application.
5. The percentage of seed absorbed by the slag is high, 15% - 20%, it is supposed to be due to the small dimensions of the apparatus.

6. It now appears entirely feasible to initiate development of a coal combustor of larger scale, for instance 20-50 MW thermal. Development should address combustors with higher slag rejection /special slag removal devices/, better seed homogenization and lower seed absorption by slag. It should be followed by integrated development of the combustor-nozzle-channel system.

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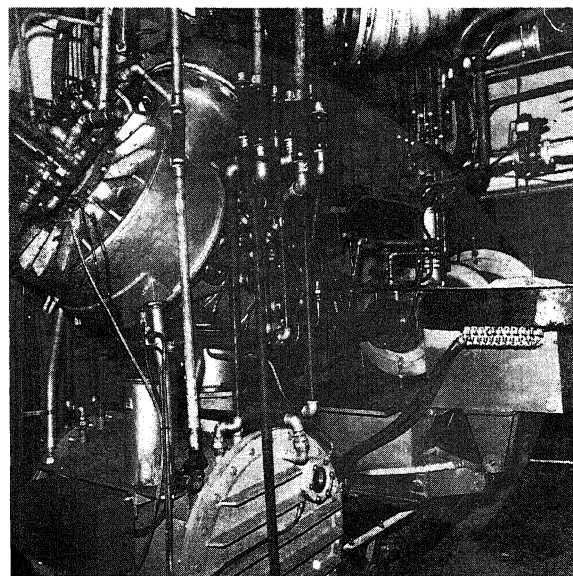


Fig.6 General view of the combustor mounted on slag tank

TEST STAND FOR COAL OR CHAR FIRED MHD-SYSTEM

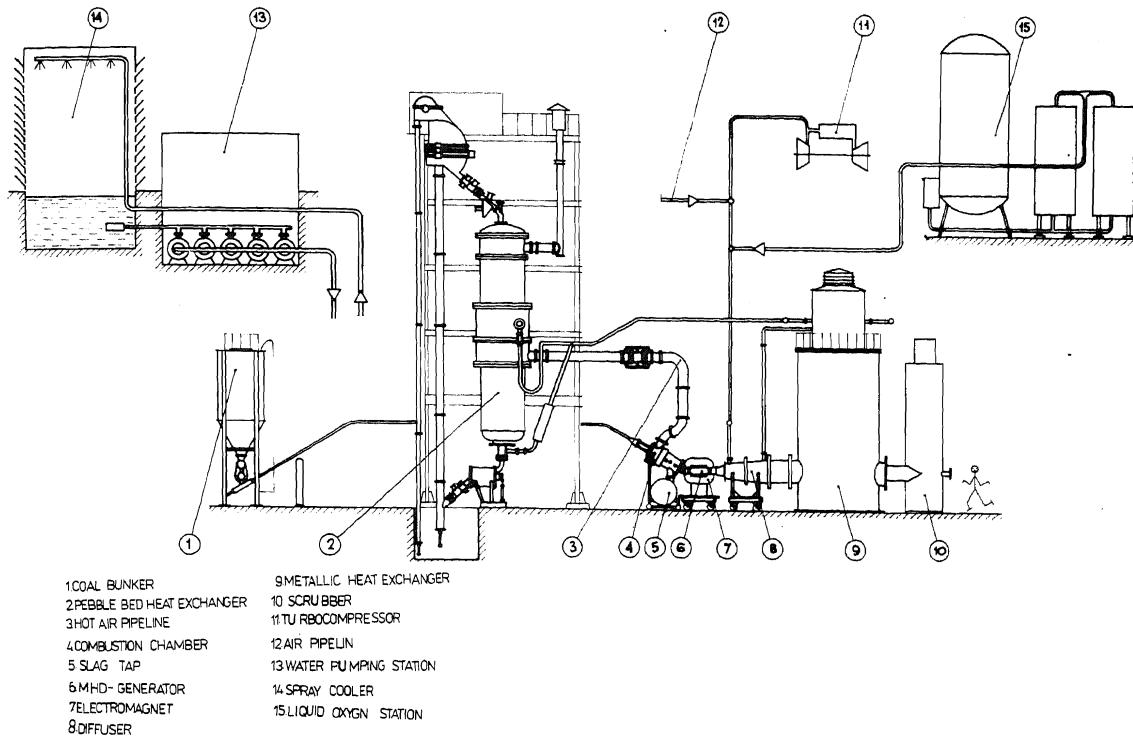


Fig.1

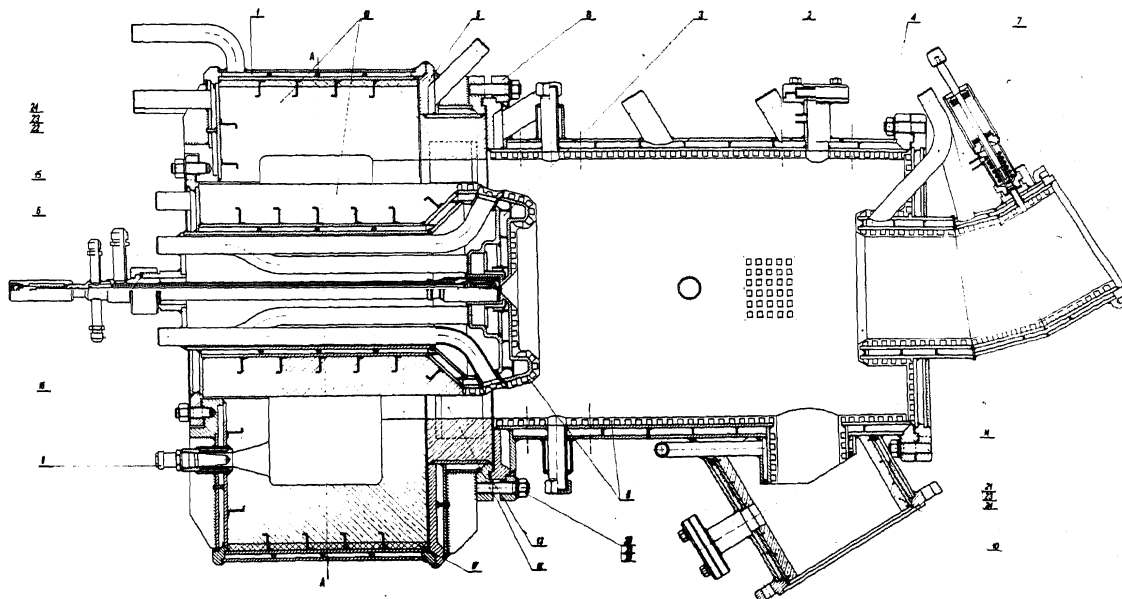


Fig.2 Longitudinal cross-section of combustor

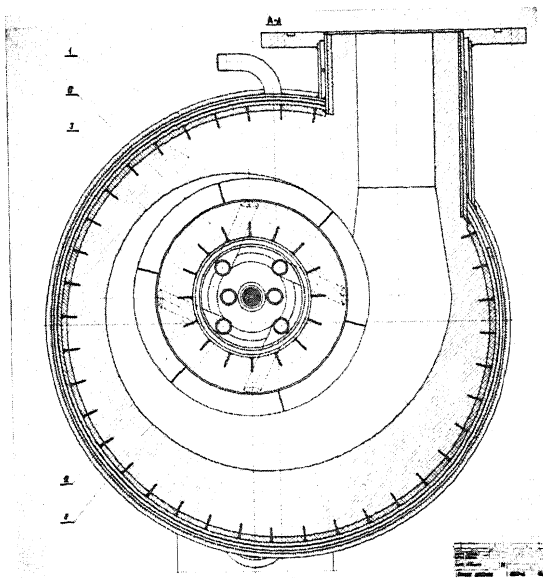


Fig.3 Transversal cross-section at the inlet of the combustor

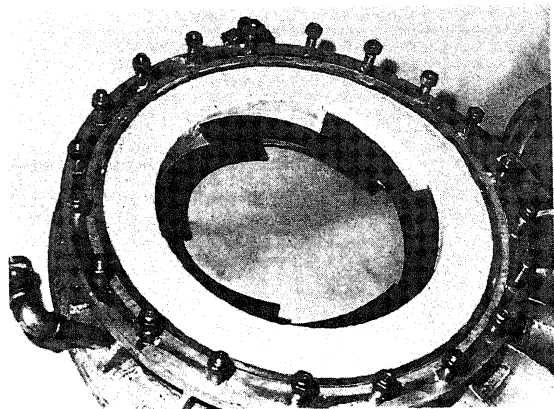


Fig.4 Refractory swirl vanes

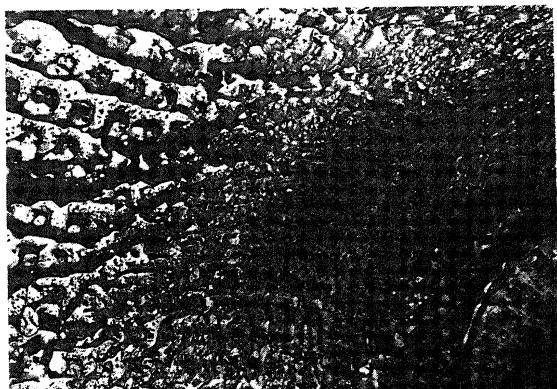


Fig.5 Pattern of slag layer covering the inside wall of the combustor

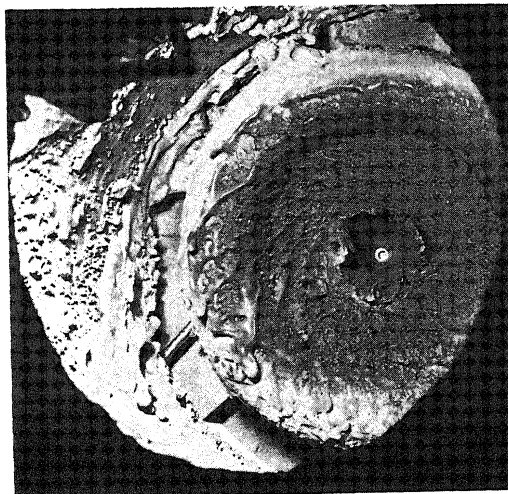


Fig.7 View of the inside of the combustor after run

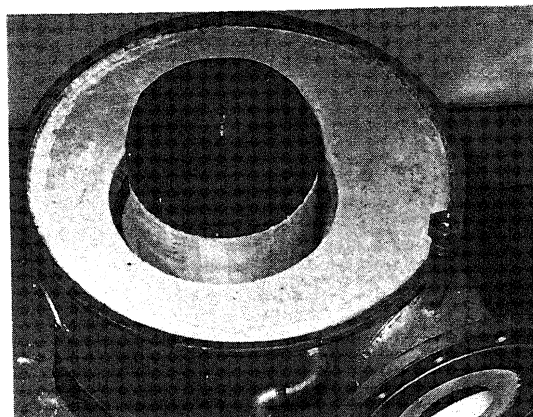


Fig.8 Inlet internal part of the combustor. Two, of four, coal injectors are visible

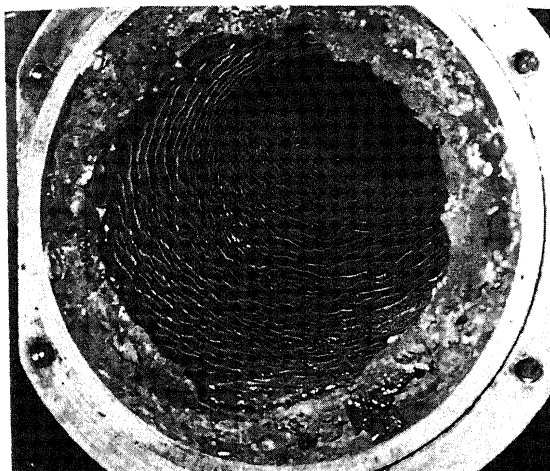


Fig.9 View of the outlet of exhaust gases from the combustor. Effect of some residual swirl is clearly visible