Forschungszentrum Jülich

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Data Sets of the SANA Experiment 1994–1996

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by

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ABSTRACT

The test facility SANA was installed at the Research Centre Jülich to research on the heat transport mechanisms inside the core of a high temperature gas cooled reactor (HTGR). The test facility consists of a heated pebble bed inside a furnace to simulate the thermal conditions of such a HTGR-core. The experiment demonstrates the possibility to design a non-melting HTGR, even in case of a failure of all heatsinks.

From 1994 to 1996 over 50 steady state tests were carried out. In these experiments all the main parameters of a pebble bed are variated, as pebble material, pebble diameter, gas, heating power and geometry. Due to the wide range of these variations, data base can be used for program validation as for general research on porous media. The data sets of these experiments are presented in this report, including all necessary data for an integral program validation.

Data Sets of the SANA Experiment 1994-1996

By B. Stöcker, H. F. Nießen

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1 Introduction

In the case of an incident with loss of cooling and at the same time pressure loss, which can be regarded as hypothetical, the layout and design of the pebble-bed high temperature reactor (fig. 1) reaches that the afterheat decay can be carried out of the reactor. The hereby occuring temperatures are so low, that they neither lead to a higher release of fission products nor to a damage of the reactor structures. This could be thinkable for common reactor types. The heat transport bases on the at every time available mechanisms as heat transfer, heat radiation and natural convection. Active mechanisms are not necessary for the after heat removal.

1.1 The development of the HTR in the Federal Republic of Germany

The development of the helium-cooled High Temperature Reactor started in the Federal Republic of Germany with the „Arbeitsgemeinschaft Versuchs-Reaktor (AVR)“ located in the area of the Research Centre Jülich. At the beginning of HTR's development stood the reaching of a high thermodynamical efficiency of the secondary steam cycle and the supply of process heat on a high temperature level. With the Thorium-High-

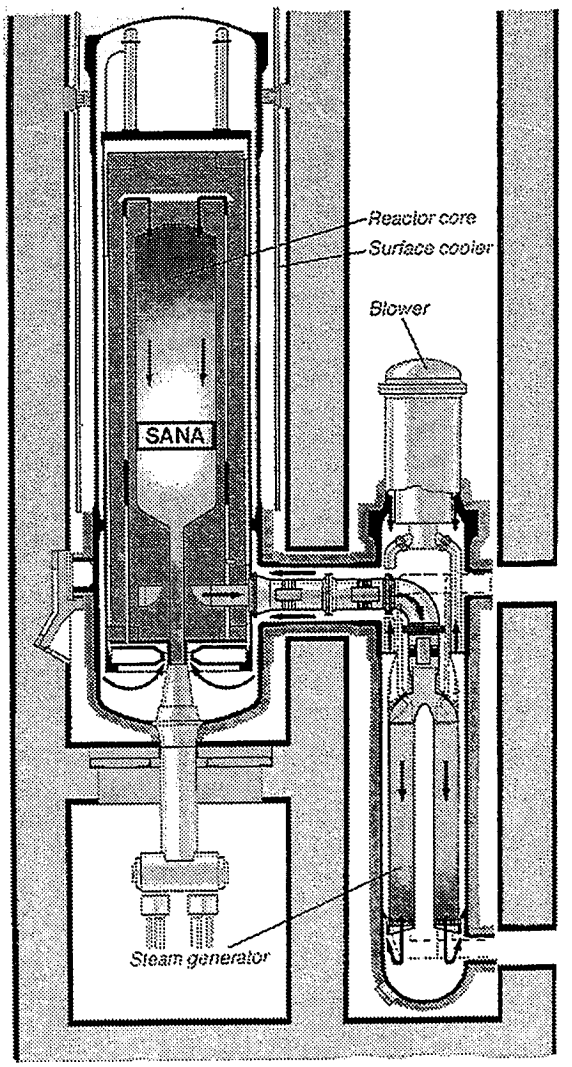


Fig. 1: Schematic plan of a high temperature gas cooled reactor

Temperature Reactor (THTR) in Hamm Uentrop with an electrical power of 300 MW and corresponding 750 MW_{th} the concept of an HTR for power production was realized in an industrial scale technical successfully. Non-technical reasons were decisive for the failing of the THTR, but here we will not take them into consideration. After that the smaller HTR-module with 200 MW_{th} designed by Interatom became more important because of its safety characteristics.

1.2 Description of an HTR at the example of the HTR-Module

The reactor core consists of cylindrical filling of the spherical fuel elements . In normal operation the helium flows through the reactor core under 60 bar. In the steam generator the helium is cooled down from 700 °C to 250 °C. On the secondary side heat conditions (530 °C, 180 bar) are produced as in conventional power plants. For the THTR a steam cycle identical to a coal power plant of the same size situated in the vicinity could be used.

The blower for circulating the cooling gas is situated at the upper end of the steam generator and equalizes a pressure loss of 1,3 bar. It is surrounded by a separate steel pressure vessel and connected with the reactor core by a coaxial duct. This shows by its slender type of construction a height/radius-ratio of approx. 3.1 (height h 0 9,5 m, radius D = 3,0 m) deriving from the previous reactor concepts. This ratio results of an optimization of the heat conducting surface in the case of an incident and neutron loss by leakage under normal operation.

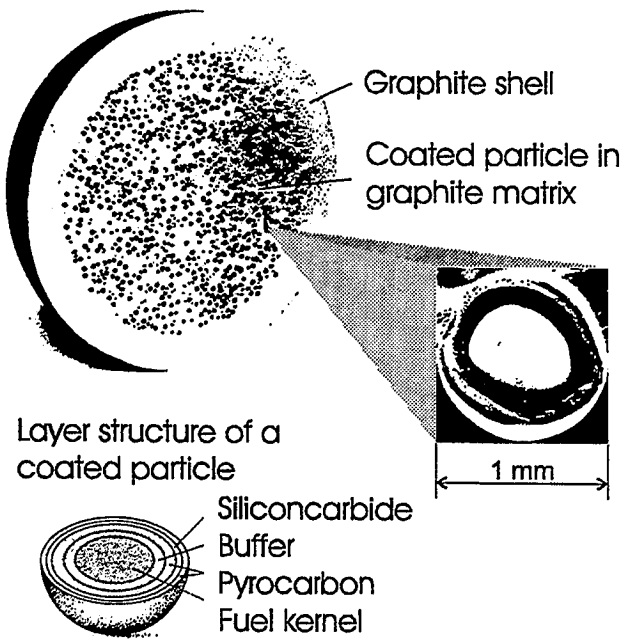


Fig. 2: Fuel element of the HTGR

The reactor core contains approx. 375 000 fuel elements, each with a diameter of 5 cm. Fig. 2 shows the spherical fuel element, a graphite ball, and the embedded „coated particles". The particles are embedded in a graphite matrix. About 10 000 until 20 000 of these particles are in one fuel element. The graphite matrix serves for the moderation of the fast neutrons and is high temperature resistant. Over that graphite has a high specific heat capacity and is able, in the

case of an incident to absorb enormous heat capacities by storing. The reactor core is surrounded by a graphite reflector. In this reflector six reflector rods are provided for the adjustment and hot gas shut-down, for the cold shut-down 18 reflector boreholes are filled with absorber balls. Furthermore, the reactor pressure vessel is protected by the reflector against embrittlement by fast neutrons.

The charging of fuel elements is made from bottom to top. By multiple running through (MEDUL) the fuel elements pass approx. 15 times through the core before reaching the final burn-up of 80 000 MWd/t. Completely burnt-up fuel elements are discharged daily from the reactor and are stored in an intermediate disposal vessel. The same number of fresh fuel elements are charged every day to the reactor with the aid of the charging equipment corresponding to the produced thermal power.

1.3 The inherent safety behaviour of an HTR

Since the revised version of the German Atomic Law in 1994 the company who runs the reactor has to ensure that even in case of heaviest incidents the consequences for the reactor facility remain limited. For the HTR this demand is taken into account by four stability criteria:

1. Nuclear stability
2. Thermal stability
3. Chemical stability
4. Mechanical stability

In the further report only the thermal stability (3.) is explained, since this is the one which is analysed in the SANA experiment.

1.4 Thermal stability

The decay heat has to be removed at any time from the reactor. If all active cooling and emergency cooling systems fail, the occuring heat has to be removed self-acting from the reactor. The reason for this is that no inadmissible temperatures in the fuel elements occur which could lead to a damage of the fuel elements or of the fission products.

A key problem of the reactor safety is the guarantee of a reliable removal of the decay heat, which can be released after the break-off of the chain reaction by decay of the fission products. An easy mathematical description of this time-dependent power release delivers the formulation after Way-Wigner /1/:

$$P_N = P_{th} \cdot 0.0622 \cdot \left(t^{-0.2} - \left(t_0 + t \right)^{-0.2} \right)$$

From this results that immediately after the shut-down of the reactor about 7 % of the thermal power are released. After one hour the fraction of the decay heat is between one and two percentage. The aim of the modern HTR-concepts is, to keep the power density in full load operation (HTR-Module; 3 MW_{th}/m^3) so low, that the arising decay heat can be released over

circuits, radiation and natural convection to the surroundings. Here no unreliable temperatures should appear, which could lead to an essential fission product release. This can be realized in the HTR before a failure happens because of its heat storing amounts of graphite in the core and reflector region and because of the low fission product and structure temperatures compared to the temperature limit of 1 600 °C. The design and layout of an HTR ensure in the case of a failure or incident by natural convection that the maximum temperature does not exceed 1600 °C in the fuel elements.

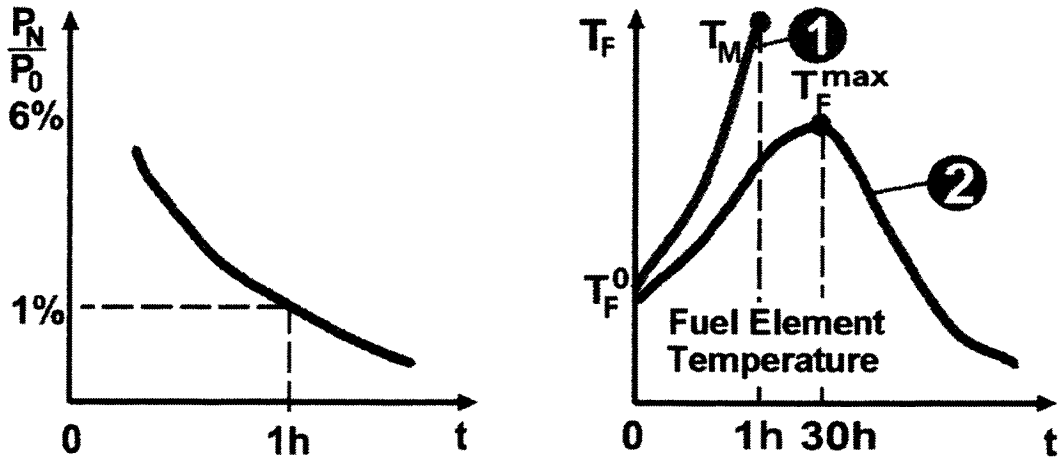


Fig. 3: After being shut down, a reactor produces the after heat P_N (left)
1. Thermal instable reactor: After the failure of all heat sinks the temperature of the fuel increases to the melting point T_M, the core starts melting
2. Thermal stable reactor: Self-acting after heat removal limits the maximum fuel temperature T_F^{max}

2 The experiment SANA

As described in the introduction, the high temperature reactor offers the possibility of a suitable design and dimensions to master heaviest accidents. The produced decay heat is removed safely from the reactor core. The heat transport is based on at any time available mechanisms: heat conduction, heat radiation and natural convection. To confirm this striking safety quality, the considerable heat technical parameters of the self-acting after-heat removal are examined in the experiment SANA (fig. 4), /2/. The tasks of the experiment are:

- Measurement of time dependent three-dimensional temperature distribution.
- Determination of effective heat conductivity as a function of the temperatures in the core structures.
- Evaluation of permitted heat flux densities at different boundary conditions.
- Provision of data sets for the program validation (THERMIX / DIREKT, TINTE).
- Statements concerning natural convection phenomena.

2.1 Structure of the pilot plant

For the examinations in the context of the SANA experiments a bed of graphite pebbles in cylindrical arrangement is selected. The part of the core of the pebble bed reactor has a diameter of 1,5 m as well as a height of 1m. Approximately 9500 graphite pebbles with a diameter of 6 cm in irregular arrangement find space in the volume of 1,77 m^3.

The heat production is carried out in at maximum 4 electrical resistance heating elements which are ordered vertically in the bed. The installed maximum power of 50 kW facilitates a maximum power density of 28 kW/m^3. That means 0,93 % of the full power transferred to the module reactor and corresponds to a time of 3 h to 4 h after admission of the depressurisation accident. To guarantee a considerable radial heat flux, insulation systems limit the bed at the top and the bottom. A schematic plan of the test facility is shown in fig. 5.

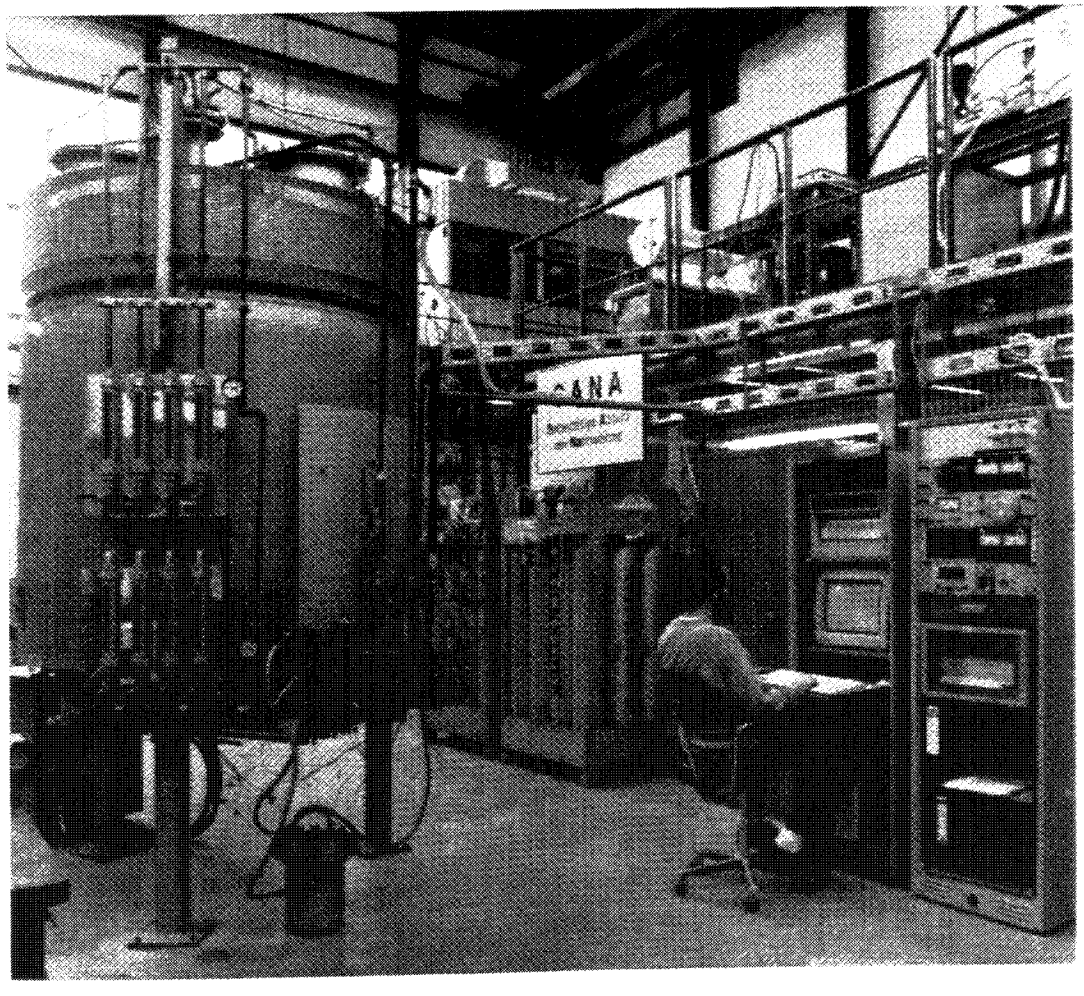


Fig. 4: Photo of the test facility

Thermocouples, which are used for the recording of the temperature profiles, are distributed over the test stand. To prevent corrosion at the graphite installations, the plant is operated among inert gas atmosphere. The heating element connections get cooled with water. The power supply is carried out from the three phase mains. The data acquisition system and the control of the experiments can occur with a personal computer (fig. 6).

SANA main data

Maximum bed temperature	1600 °C
Installed electrical power	50 kW
Diameter of the pebble bed	1,5 m
Height of the pebble bed	1,0 m
Complete height	3,2 m
Pebble diameter	60 mm

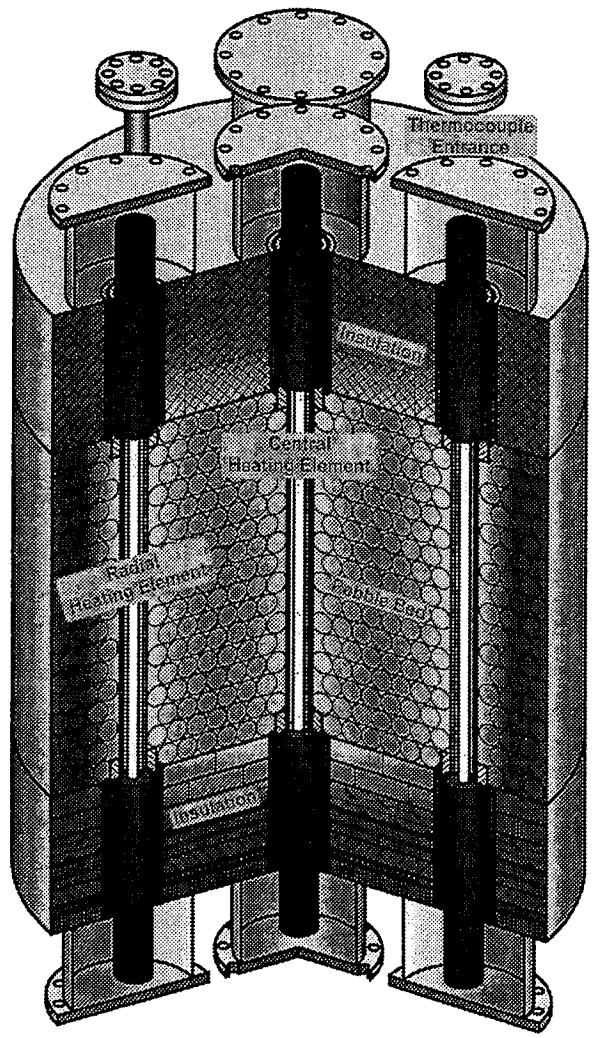


Fig. 5: Schematic plan of the test facility SANA

2.2 Data acquisition system and computer

The thermocouples are connected to a 60 channel hybrid recorder which has a built-in comparison point. The thermoelectric characteristics for a number of common combinations, among this type N and type W, is integrated in the device. It is able to convert the measured thermoelectric voltages to °C and to show them on the display and the built-in printer. For the MoRe elements at first only the recording of the thermoelectric voltage is carried out in the hybrid recorder. A PT100 resistance element is used as an external comparison point temperature. The maximum scanning rate of the recorder lies at 2 seconds. A further hybrid recorder with 30 channels is available to scan the analogue exits of the gas analysis devices as well as the actual value outputs of the thyristor. This recorder works with a maximum scanning rate of 30 channels in 6 seconds.

The recorders are equipped with a parallel IEEE-488 interface to enable the both direction data exchange and over this with a personal computer which has also an IEC bus interface. The measured data received by the computer can be saved on the built-in hard disk. A serial interface (RS 232) connects the computer with the power giver. The computer can be used for controlling of the heating facilities with it. The imbedding of the measurement hardware into the test stand is represented in fig. 3.

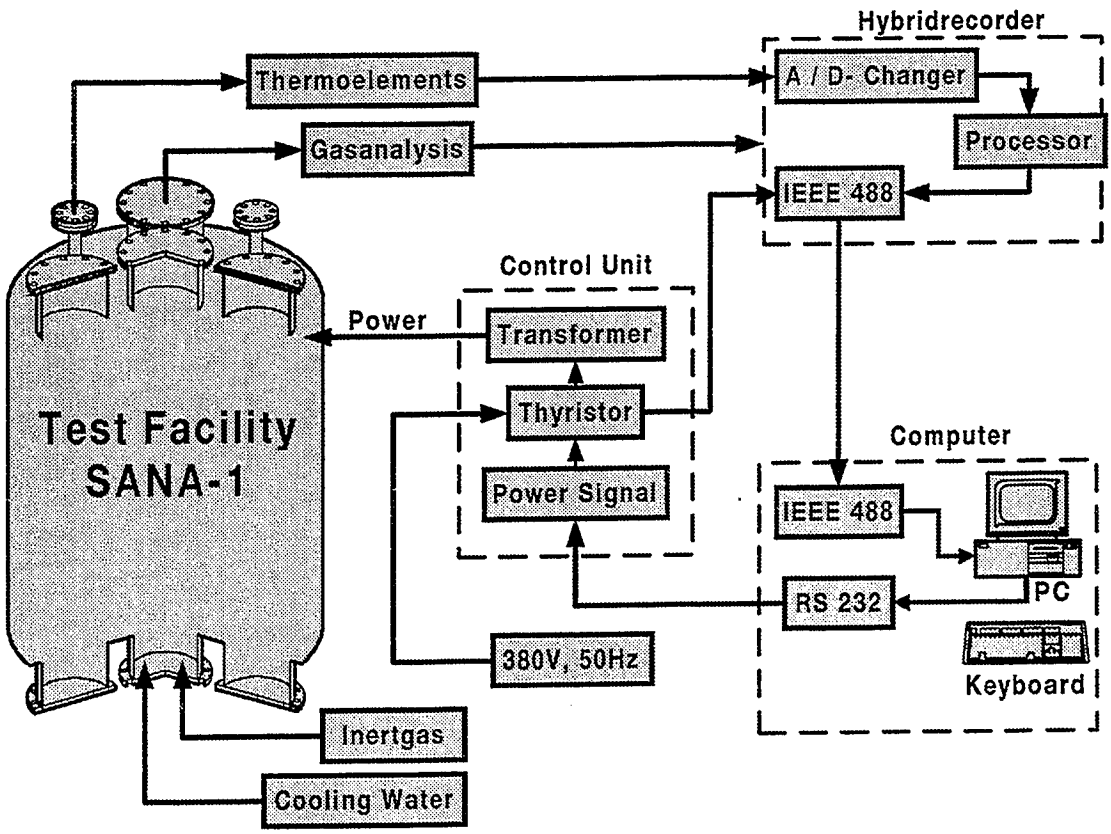


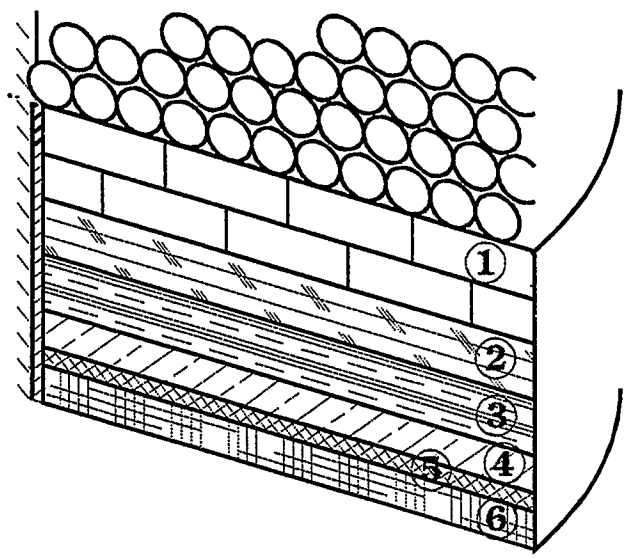
Fig. 6: Flow sheet of electrical power and data

3 Benchmark data

Tests were executed with one or four heating elements in over 22000 hours. Nitrogen (representative for air), helium and argon are used as inert gases. To accomplish the highest temperature region (above of 1200 °C), an insulation is brought in between the vessel wall and the pebble bed at a part of the tests. The influence of natural convection explains the more distinctive vertical arrangement in the temperature layers at the tests with nitrogen in comparison with those with helium. Both, stationary and non steady tests were executed .

The bed is heated by an electrical resistance heater. The heating is executed by a graphite tube with 32 mm outside diameter and attached centrally in the bed. A protection tube of 141mm outside diameter protects the heating tube against the direct touch with the pebbles. The heating element is lasted at the top and the bottom by the connection electrodes, which are also made from graphite. Because of their clearly larger crossways cut area (diameters 80 mm) and therefore clearly lower resistance, only a low heat production has to be removed there. This, by the connection electrodes passed on heat flux, is removed by a water-cooling installed into the cover hoods of the connection electrodes.

To reach this goal the heat flux is removed mainly radial from the bed, it became insulated above and below with different materials (fig. 7). The upper insulation passes CERACHEM-Blanket material from a 400 mm thick layer (data see 5.2). The lower insulation is, because it carries the weight of the bed, built of several layers with various stability and heat conducting properties. These layers are from top to the bottom:



(1) Fire light brick RI 30 B, company Savoie Feuerfest (fireproof), 128 mm thick;
(2) CERAFORM 1000, company Gossler 75 mm thick;
(3) CERAFORM 100, company Gossler 75 mm thick;
(4) THERMOSIL 1100, company Gossler 50 mm thick;
(5) THERMOSIL 1000, company Gossler 25 mm thick;
(6) GOSSLEROC GMP 150, company Gossler 50 mm thick;

Fig. 7: Bottom insulation of the test facility

The whole arrangement is put in a steel vessel which is provided with a touch protective barrier on the outside to avoid injuries by the hot surface. An inert gas atmosphere, either helium, nitrogen or argon, protects the inside graphite materials against corrosion reactions.
The resistance heater is provided with electrical power by the 380V 50 Hz three phase mains. The power is settled about a communication capable thyristor powergiver. The voltage is reduced by a transformer behind the thyristor. At most the current on the secondary side has a value of 1220A. Coated thermocouples of type N (DIN IEC 584) are used for the measuring of the temperature-profiles within the test facility. An example for the arrangement of the thermocouples is shown in the figure.
In addition were measured:

- The pressure in the test stand,
- The pressure in the bottle of gas bundles and in the gas inlet line,
- The gas mass flow,
- The composition of the waste gas,
- Temperatures and flow of the cooling water

A large portion of these measured data was taken and saved by a computer continuously.

3.1 Material data

3.1.1 Pebbles

The tests which are presented in the following chapters are carried out by using a central heating element with 3 types of pebbles:

- electric graphite (60 mm graphite pebbles)
- matrix graphite (30 mm graphite pebbles)
- Al_2O_3 (60 mm aluminium oxide pebbles)

The data of these materials has been estimated by experiments. They are shown in tables 1-3.

Table 1: Material data of electric graphite Sigri AL 2-500 (60 mm graphite pebbles)

	Measurement 3||		**Measurement 4||**	
Temperature [°C]	Density [g/cm^3]	Heat conductivity [W/m K]	Density [g/cm^3]	Heat conductivity [W/m K]
100	1,673	152,3	1,665	158,2
200	1,673	126,0	1,665	127,9
300	1,673	112,8	1,665	105,1
400	1,673	94,9	1,665	94,1
500	1,673	78,9	1,665	82,7
600	1,673	71,2	1,665	74,1
700	1,673	68,1	1,665	68,7
800	1,673	60,5	1,665	62,6
900	1,673	58,0	1,665	57,6
1000	1,673	55,4	1,665	-

Table 2: Material data matrix graphite (30 mm pebbles)

	Measurement 1	
Temperature [°C]	Density [g/cm^3]	Heat conductivity [W/m K]
19	1,632	68,2
96	1,632	64,9
208	1,632	58,2
326	1,632	53,2
405	1,632	50,8
499	1,632	47,7
618	1,632	44,7
726	1,632	41,9
797	1,632	40,4
898	1,632	38,1
987	1,632	36,8
1082	1,632	34,7
1204	1,632	33,4
1301	1,632	32,5

Table 3: Material data Al_2O_3 (65 mm aluminium oxide pebbles)

Probe 1			Probe2		
Temperature [°C]	Density [g/cm^3]	Heat conductivity [W/m K]	Temperature [°C]	Density [g/cm^3]	Heat conductivity [W/m K]
20	3,637	14,6	22	3,637	14,7
103	3,637	12,3	101	3,637	12,4
199	3,637	10,2	199	3,637	10,2
304	3,637	8,7	306	3,637	8,9
409	3,637	7,7	412	3,637	7,8
497	3,637	7,1	497	3,637	7,1
597	3,637	6,6	597	3,637	6,7
700	3,637	6,2	701	3,637	6,3
795	3,637	5,7	797	3,637	5,8
902	3,637	5,4	904	3,637	5,4
1004	3,637	5,1	1004	3,637	5,2
1106	3,637	4,9	1111	3,637	5,0
1203	3,637	4,7	1207	3,637	4,9
1302	3,637	4,4	1306	3,637	4,6

3.1.2 Insulation

The heat conductivity data of the fibre insulation modules at the top are represented in air by the formula:

CERACHEM - Blanket; Fa. Gossler:

$$\lambda_{IOB} = 0{,}0984 - 2{,}02 \cdot 10^{-4} \cdot \vartheta + 4{,}1 \cdot 10^{-7} \cdot \vartheta^2 + 10^{-10} \cdot \vartheta^3;$$

For the bottom insulation the thermal conductivity in air is represented by the following formulas:

Light fire brick RI 30 B; Savoie Feuerfest:

$$\lambda_{IU1} = 0{,}396 + 2{,}46 \cdot 10^{-4} \cdot \vartheta + 2{,}5 \cdot 10^{-7} + 10^{-10} \cdot \vartheta^3;$$

CERAFORM 1000 and CERABORD 100; Gossler:

$$\lambda_{IU2,3} = 0{,}0437 + 7{,}1 \cdot 10^{-5} \cdot \vartheta + 5 \cdot 10^{-8} \cdot \vartheta^2 + 7 \cdot 10^{-11} \cdot \vartheta^3;$$

THERMOSIL 1100; Gossler:

$$\lambda_{IU4} = 0{,}0803 + 4 \cdot 10^{-5} \cdot \vartheta + 7 \cdot 10^{-8} \cdot \vartheta^2;$$

THERMOSIL 1000; Gossler:

$$\lambda_{IU5} = 0{,}041 + 4{,}5 \cdot 10^{-5} \cdot \vartheta + 1{,}1 \cdot 10^{-7} \cdot \vartheta^2 + 5{,}5 \cdot 10^{-11} \cdot \vartheta^3;$$

GOSSLEROC GMP 100; Gossler:

$$\lambda_{IU6} = 0{,}058 + 10^{-6} \cdot \vartheta + 4 \cdot 10^{-7} \cdot \vartheta^2;$$

NOTE: Following KFA–experiments the values for the fibre insulation (layer (6) at the bottom and at the top-insulation) are in helium–atmosphere three times higher than those in air!!!

The amount of heat, which is produced in the heating rod and the connection electrodes are calculated by an estimation of the electrical resistances of heating rod, connection electrodes, transformer and conductors. These values are verified by comparison with the measured electrical currents and displayed in the data sets.

4 The Data Sets

4.1 Data for the stationary tests with long heating element, 60 mm graphite pebbles

The following experimental results are shown:

1. Helium 5, 10, 20, 25, 30, 35 kW nominal heating power 60 mm pebble diameter
2. Nitrogen 5, 10, 20, 25, 30, 35 kW nominal heating power 60 mm pebble diameter

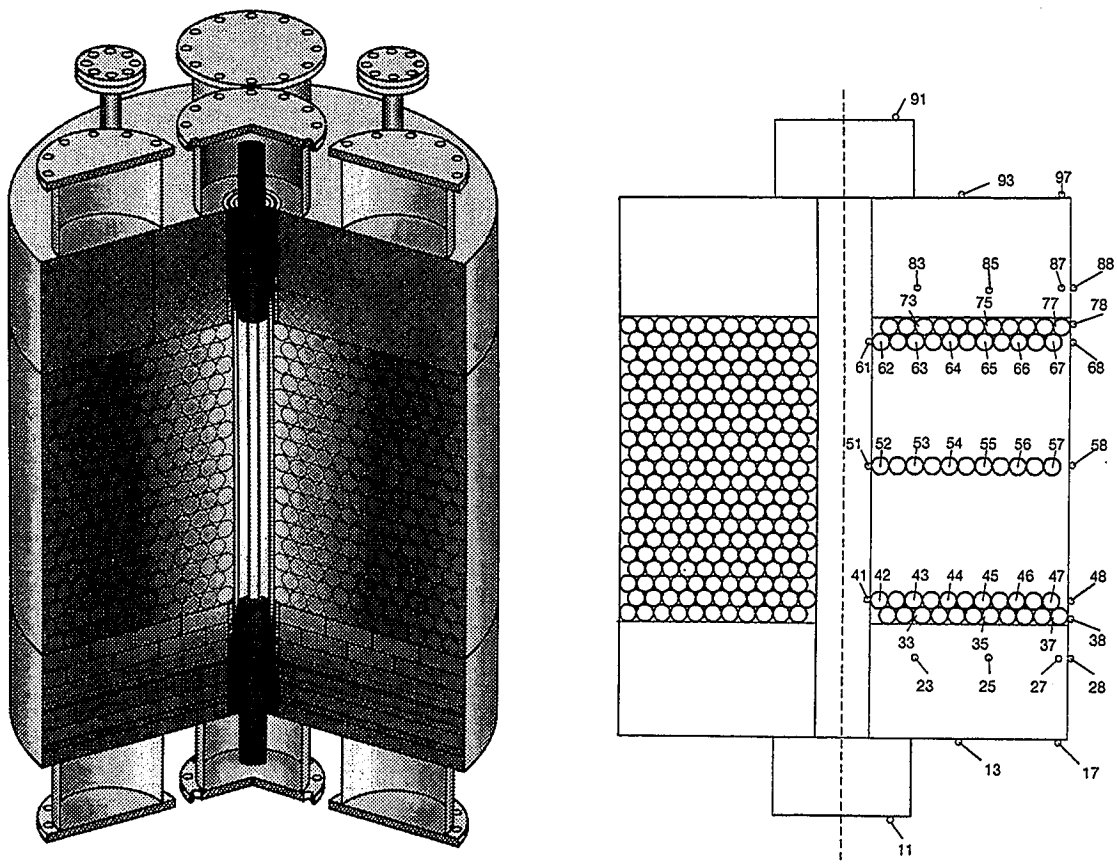


Fig. 8: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

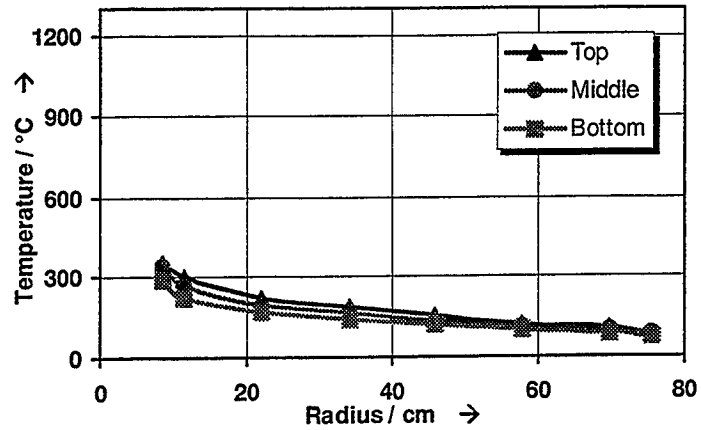
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			32				37	
113			214		118		70	51
97			236		159		99	73
91	359	304	224	187	155	125	105	82
50	344	270	197	166	137	114	99	85
9	291	223	170	138	119	102	85	71
3			164		115		76	62
-13			161		107		63	46
-40			45				20	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		19.11.95
$P_{nominal}$	kW	5,00
$P_{heating\ element}$	kW	4,34
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	0,01
O_2	Vol. %	0,71
$T_{ambient}$	°C	24,9
$T_{dewpoint}$	°C	-48,4

Cooling water:

Top		
T_{inlet}	°C	14,2
T_{outlet}	°C	17,7
Throughput	l/h	155
Bottom		
T_{inlet}	°C	14,6
T_{outlet}	°C	18,1
Throughput	l/h	155



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			40				45	
113			341		188		104	69
97			387		262		151	110
91	565	488	372	311	256	203	168	124
50	552	450	337	284	233	187	157	130
9	491	389	301	240	201	166	132	105
3			290		194		116	89
-13			276		180		92	62
-40			62				22	
Inner pebble layer		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		26.10.95
$P_{nominal}$	kW	10,00
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	0,02
O_2	Vol. %	0,25
$T_{ambient}$	°C	23,0
$T_{dewpoint}$	°C	-44

Cooling water:

Top		
T_{inlet}	°C	16,3
T_{outlet}	°C	21,3
Throughput	l/h	140
Bottom		
T_{inlet}	°C	16,2
T_{outlet}	°C	20,9
Throughput	l/h	140

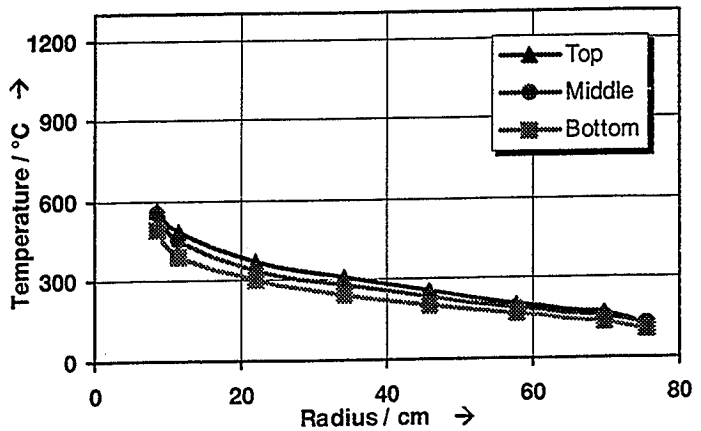


Fig. 9: Stationary tests with long heating element, 60 mm graphite pebbles, helium 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			55				61	
113			530		297		159	100
97			604		415		237	167
91	848	742	587	499	414	327	267	190
50	837	705	558	478	398	317	258	205
9	786	650	525	428	357	291	224	171
3			512		348		193	142
-13			470		315		151	91
-40			89				22	

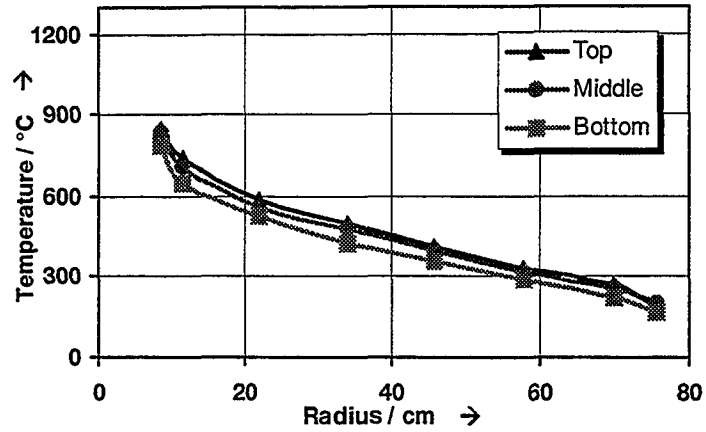
Protecting tube | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		16.11.95
$P_{nominal}$	kW	20,00
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0,01
O_2	Vol. %	2,05
$T_{ambient}$	°C	27,0
$T_{dewpoint}$	°C	-8,1

Cooling water:

Top		
T_{inlet}	°C	16,5
T_{outlet}	°C	24,6
Throughput	l/h	155
Bottom		
T_{inlet}	°C	16,7
T_{outlet}	°C	26,4
Throughput	l/h	155



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			61				67	
113			604		340		182	113
97			690		479		269	192
91	952	838	672	574	479	382	312	220
50	945	806	646	558	469	375	304	239
9	899	754	619	509	428	348	268	201
3			606		418		229	166
-13			550		374		177	104
-40			98				23	

Protecting tube | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		30.10.95
$P_{nominal}$	kW	25,04
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,23
O_2	Vol. %	0,27
$T_{ambient}$	°C	27,2
$T_{dewpoint}$	°C	-40

Cooling water:

Top		
T_{inlet}	°C	16,8
T_{outlet}	°C	27
Throughput	l/h	155
Bottom		
T_{inlet}	°C	17,2
T_{outlet}	°C	26,0
Throughput	l/h	155

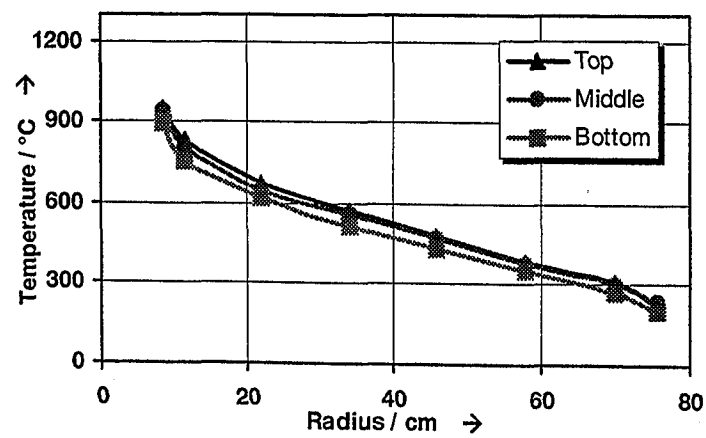


Fig. 10: Stationary tests with long heating element, 60 mm graphite pebbles, helium 20 kW (top) and 25 kW (bottom) nominal heating power

Temperatures:

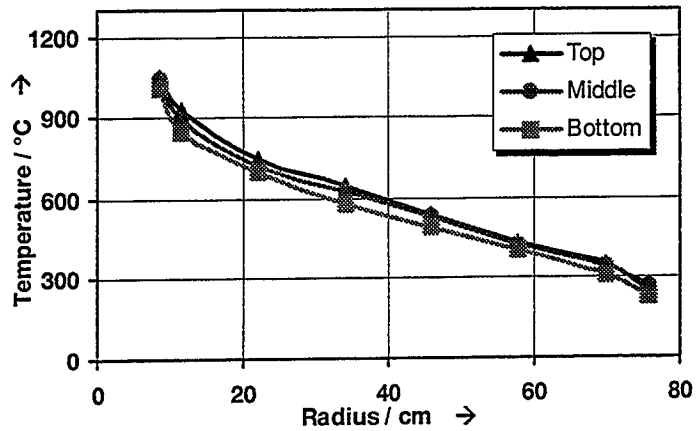
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			67				74	
113			678		388		206	126
97			768		538		310	216
91	1052	926	749	644	540	432	352	247
50	1047	894	724	629	531	427	345	268
9	1012	850	700	579	489	401	308	229
3			688		479		262	188
-13			624		426		199	113
-40			105				21	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		06.11.95
$P_{nominal}$	kW	30,10
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,7
O_2	Vol. %	0,26
$T_{ambient}$	°C	26,0
$T_{dewpoint}$	°C	-48,4

Cooling water:

Top		
T_{inlet}	°C	14,7
T_{outlet}	°C	26,8
Throughput	l/h	155
Bottom		
T_{inlet}	°C	15,3
T_{outlet}	°C	25,5
Throughput	l/h	155



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			74				81	
113			752		432		231	141
97			850		599		349	245
91	1151	1016	827	715	603	485	398	279
50	1148	987	806	704	600	486	393	303
9	1119	948	788	658	560	461	356	264
3			777		551		303	215
-13			701		486		229	128
-40			116				23	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		03.11.95
$P_{nominal}$	kW	35,02
$P_{heating\ element}$	kW	32,02
$P_{elektrode}$	kW	1,94
CO_2	Vol. %	0,5
O_2	Vol. %	0,25
$T_{ambient}$	°C	26,0
$T_{dewpoint}$	°C	-44

Cooling water:

Top		
T_{inlet}	°C	15,6
T_{outlet}	°C	29,6
Throughput	l/h	160
Bottom		
T_{inlet}	°C	15,9
T_{outlet}	°C	27,8
Throughput	l/h	160

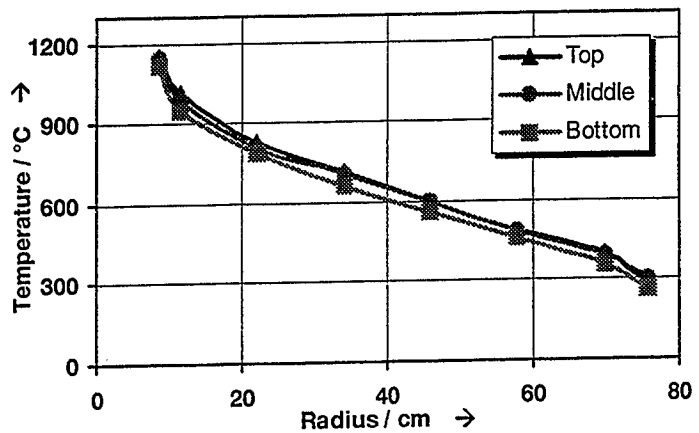


Fig. 11: Stationary tests with long heating element, 60 mm graphite pebbles, helium 30 kW (top) and 35 kW (bottom) nominal heating power

Temperatures:

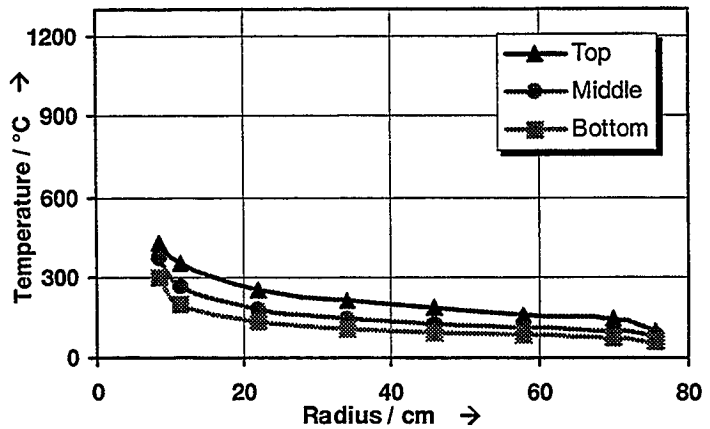
Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			28				38	
113			276		158		96	60
97			287		213		159	94
91	430	356	254	214	187	163	148	101
50	377	271	179	151	130	116	104	85
9	305	200	133	107	94	85	75	61
3			124		91		69	53
-13			139		90		57	41
-40			42				22	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		23.11.95
$P_{nominal}$	kW	5,05
$P_{heating\ element}$	kW	4,34
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	0
O_2	Vol. %	2,11
$T_{ambient}$	°C	25,3
$T_{dewpoint}$	°C	-8,1

Cooling water:

Top		
T_{inlet}	°C	10,8
T_{outlet}	°C	14,6
Throughput	l/h	160
Bottom		
T_{inlet}	°C	10,8
T_{outlet}	°C	14,5
Throughput	l/h	160



Temperatures:

Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			39				49	
113			443		268		153	85
97			470		347		243	144
91	648	563	435	370	315	269	232	156
50	593	465	323	263	220	188	165	125
9	497	344	228	175	147	128	108	84
3			214		141		97	70
-13			232		139		78	51
-40			59				24	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		12.10.95
$P_{nominal}$	kW	10,03
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	0,04
O_2	Vol. %	-0,04
$T_{ambient}$	°C	26,3
$T_{dewpoint}$	°C	-31,5

Cooling water:

Top		
T_{inlet}	°C	17,1
T_{outlet}	°C	22
Throughput	l/h	190
Bottom		
T_{inlet}	°C	16,9
T_{outlet}	°C	21,0
Throughput	l/h	190

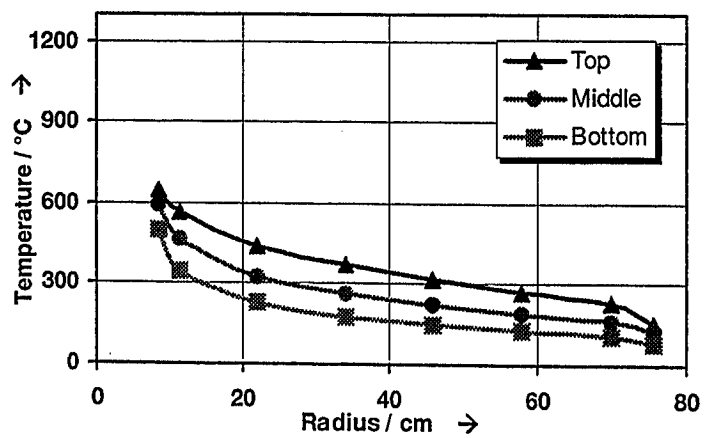


Fig. 12: Stationary tests with long heating element, 60 mm graphite pebbles, nitrogen 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

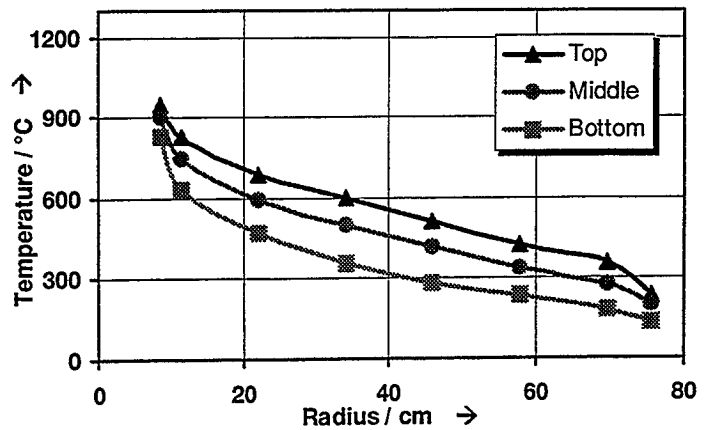
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			47				60	
113			659		405		222	116
97			713		535		352	214
91	947	831	684	598	514	425	357	233
50	904	749	591	499	416	336	275	199
9	826	636	474	357	284	234	185	135
3			451		271		163	108
-13			451		271		127	70
-40			81				22	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		27.11.95
$P_{nominal}$	kW	20,00
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0,24
O_2	Vol. %	0,05
$T_{ambient}$	°C	25,6
$T_{dewpoint}$	°C	-45,5

Cooling water:

Top		
T_{inlet}	°C	13,8
T_{outlet}	°C	21,1
Throughput	l/h	160
Bottom		
T_{inlet}	°C	14,2
T_{outlet}	°C	22,6
Throughput	l/h	160



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			57				72	
113			743		467		258	133
97			801		604		390	247
91	1042	930	774	680	587	488	411	270
50	1013	859	696	598	507	407	328	236
9	946	763	600	465	370	296	231	163
3			580		357		198	129
-13			560		351		156	82
-40			90				24	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		16.10.95
$P_{nominal}$	kW	24,97
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,49
O_2	Vol. %	-0,07
$T_{ambient}$	°C	29,5
$T_{dewpoint}$	°C	-34,5

Cooling water:

Top		
T_{inlet}	°C	16,6
T_{outlet}	°C	25
Throughput	l/h	185
Bottom		
T_{inlet}	°C	16,8
T_{outlet}	°C	24,0
Throughput	l/h	185

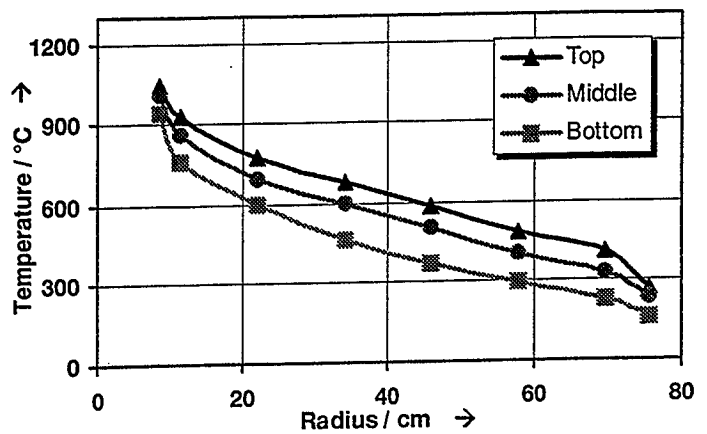


Fig. 13: Stationary tests with long heating element, 60 mm graphite pebbles, nitrogen 20 kW (top) and 25 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			60				76	
113			815		523		288	145
97			877		663		424	272
91	1141	1014	850	750	649	539	452	297
50	1118	953	784	682	582	470	377	269
9	1071	877	709	566	458	366	282	194
3			692		446		240	152
-13			665		433		189	93
-40			101				24	

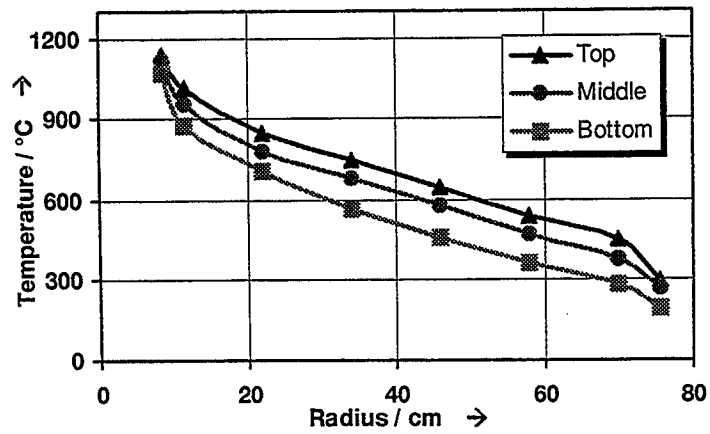
Protecting tube | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		19.10.95
$P_{nominal}$	kW	30,02
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,58
O_2	Vol. %	-0,08
$T_{ambient}$	°C	26,2
$T_{dewpoint}$	°C	-43,5

Cooling water:

Top		
T_{inlet}	°C	16,5
T_{outlet}	°C	25,4
Throughput	l/h	190
Bottom		
T_{inlet}	°C	16,2
T_{outlet}	°C	25,0
Throughput	l/h	190



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			65				80	
113			900		575		316	155
97			961		721		465	296
91	1250	1105	929	821	713	591	492	322
50	1251	1051	871	765	658	536	426	301
9	1225	986	812	663	544	438	331	226
3			798		534		282	176
-13			768		512		221	103
-40			112				22	

Protecting tube | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		30.11.95
$P_{nominal}$	kW	34,99
$P_{heating\ element}$	kW	32,02
$P_{elektrode}$	kW	1,94
CO_2	Vol. %	0,53
O_2	Vol. %	0,03
$T_{ambient}$	°C	26,0
$T_{dewpoint}$	°C	-46,5

Cooling water:

Top		
T_{inlet}	°C	13,4
T_{outlet}	°C	25,8
Throughput	l/h	160
Bottom		
T_{inlet}	°C	14,3
T_{outlet}	°C	28,4
Throughput	l/h	160

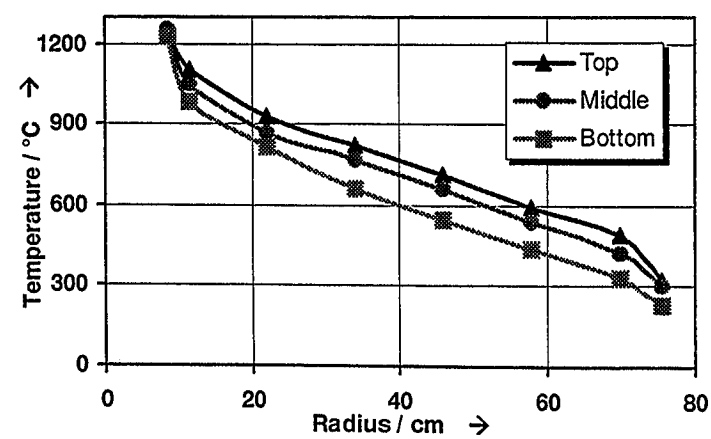


Fig. 14: Stationary tests with long heating element, 60 mm graphite pebbles, nitrogen 30 kW (top) and 35 kW (bottom) nominal heating power

4.2 Data for the stationary tests with short heating element on the top side, 60 mm graphite pebbles

1. Helium 5, 10, 20, 25 kW nominal heating power
2. Nitrogen 5, 10, 20, 25 kW nominal heating power

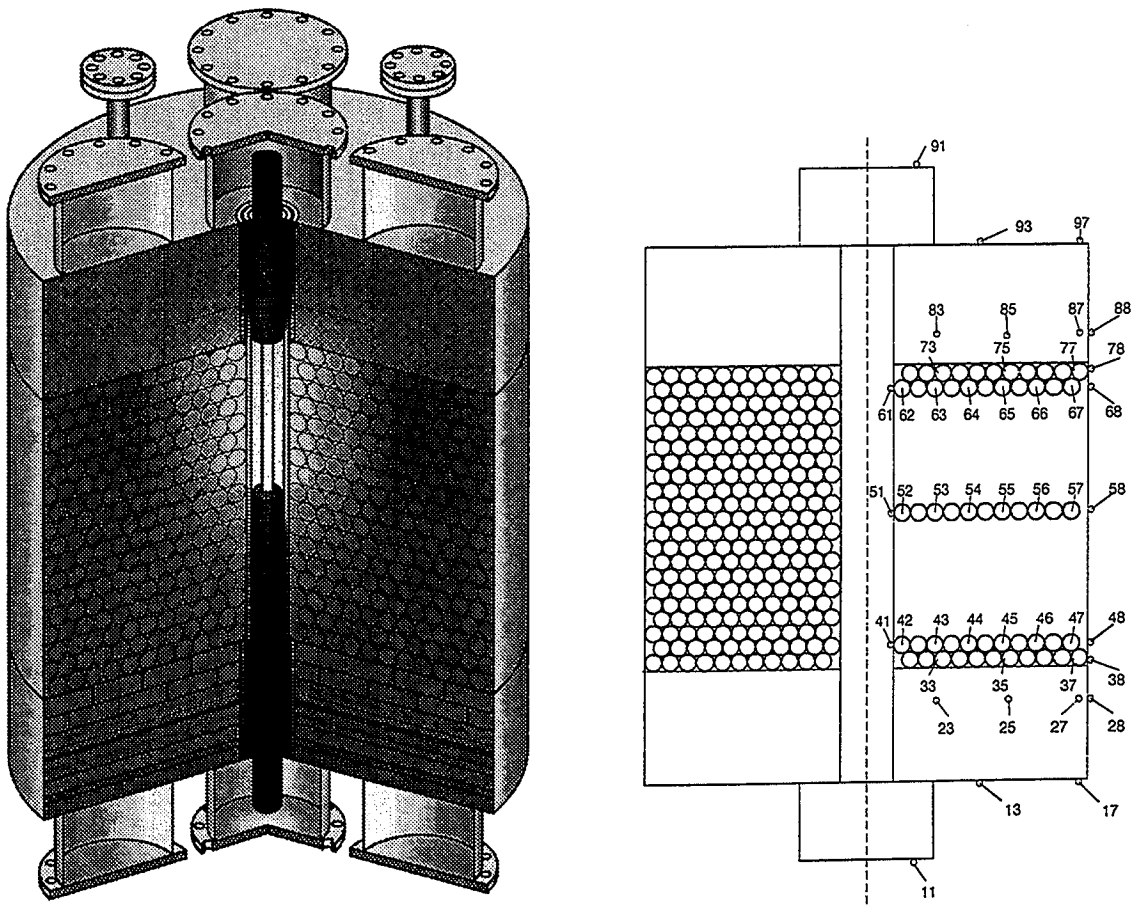


Fig. 15: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

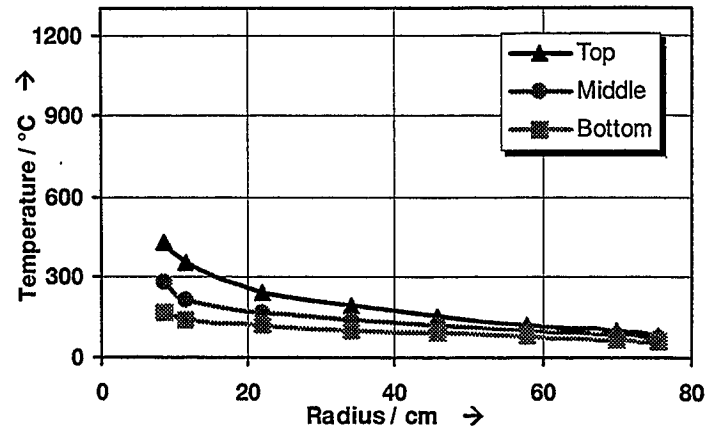
Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			32				35	
113			249		125		70	49
97			275		163		100	73
91	432	357	245	194	156	123	103	80
50	285	217	166	140	119	101	88	76
9	167	139	119	104	93	83	70	61
3			115		91		64	53
-13			111		83		54	41
-40			38				31	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		24.01.95
$P_{nominal}$	kW	4,99
$P_{heating\ element}$	kW	3,7
$P_{elektrode}$	kW	0,86
CO_2	Vol. %	-0,01
O_2	Vol. %	999,99
$T_{ambient}$	°C	26,0
$T_{dewpoint}$	°C	-21,5

Cooling water:

Top		
T_{inlet}	°C	11,2
T_{outlet}	°C	15,9
Throughput	l/h	145
Bottom		
T_{inlet}	°C	12,0
T_{outlet}	°C	14,1
Throughput	l/h	145



Temperatures:

Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			42				46	
113			408		209		110	62
97			462		282		162	113
91	698	591	429	343	274	211	171	126
50	489	387	302	249	209	171	145	120
9	277	237	205	177	156	135	111	91
3			198		151		98	78
-13			185		137		79	56
-40			30				40	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		11.01.96
$P_{nominal}$	kW	10,04
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	-0,01
O_2	Vol. %	2
$T_{ambient}$	°C	24,6
$T_{dewpoint}$	°C	-14,6

Cooling water:

Top		
T_{inlet}	°C	12,3
T_{outlet}	°C	19,2
Throughput	l/h	190
Bottom		
T_{inlet}	°C	13,1
T_{outlet}	°C	17,3
Throughput	l/h	190

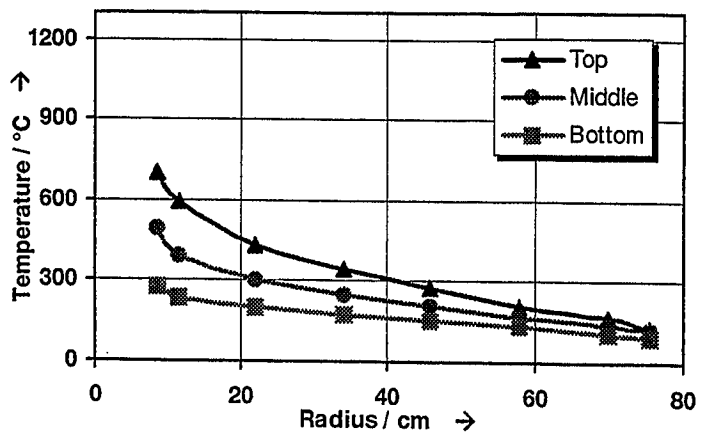


Fig. 16: Stationary tests with short heating element on the top side, 60 mm graphite pebbles, helium, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

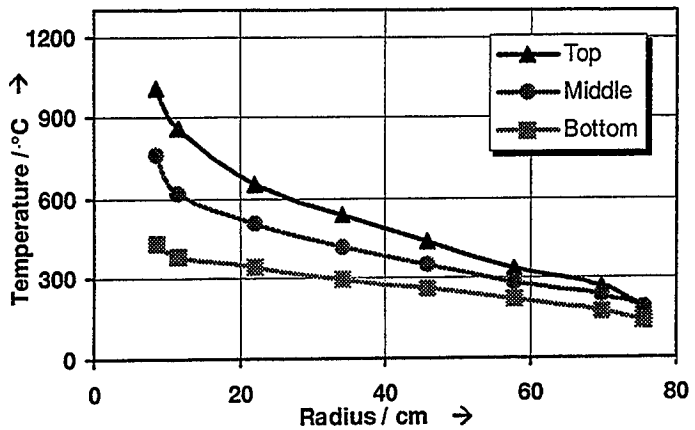
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			56				58	
113			613		323		164	99
97			695		441		247	168
91	1012	860	655	539	435	337	269	190
50	761	622	503	420	352	282	233	186
9	431	382	341	297	261	222	177	140
3			330		252		154	117
-13			298		223		119	78
-40			78				52	

Gas and power data:

Date		18.01.96
$P_{nominal}$	kW	20,05
$P_{heating\ element}$	kW	16,17
$P_{elektrode}$	kW	2,78
CO_2	Vol. %	0,55
O_2	Vol. %	-999,99
$T_{ambient}$	°C	24,2
$T_{dewpoint}$	°C	-47,6

Cooling water:

Top		
T_{inlet}	°C	11,7
T_{outlet}	°C	21,8
Throughput	l/h	155
Bottom		
T_{inlet}	°C	12,4
T_{outlet}	°C	19,3
Throughput	l/h	155



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			62				65	
113			696		369		188	112
97			786		506		284	194
91	1130	963	744	618	503	391	312	219
50	874	721	590	497	419	335	273	216
9	504	453	411	359	314	265	208	162
3			398		305		179	134
-13			357		267		137	86
-40			81				54	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		15.01.96
$P_{nominal}$	kW	25,00
$P_{heating\ element}$	kW	20,34
$P_{elektrode}$	kW	3,43
CO_2	Vol. %	-0,01
O_2	Vol. %	2,04
$T_{ambient}$	°C	24,3
$T_{dewpoint}$	°C	-14,1

Cooling water:

Top		
T_{inlet}	°C	7,7
T_{outlet}	°C	20,3
Throughput	l/h	150
Bottom		
T_{inlet}	°C	8,7
T_{outlet}	°C	17,4
Throughput	l/h	150

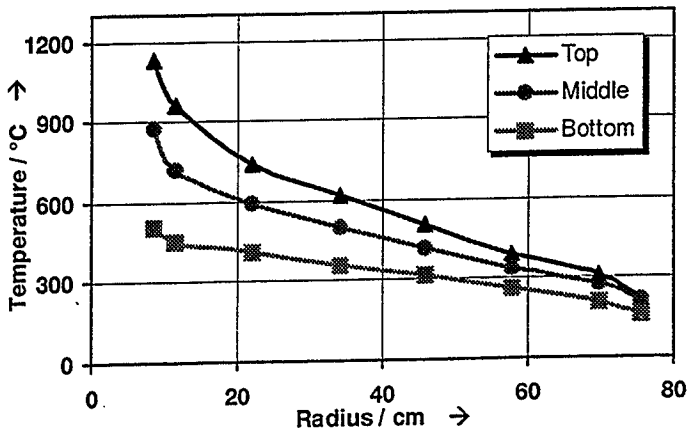


Fig. 17: Stationary tests with short heating element on the top side, 60 mm graphite pebbles, helium, 20 kW (top) and 25 kW (bottom) nominal heating power

Temperatures:

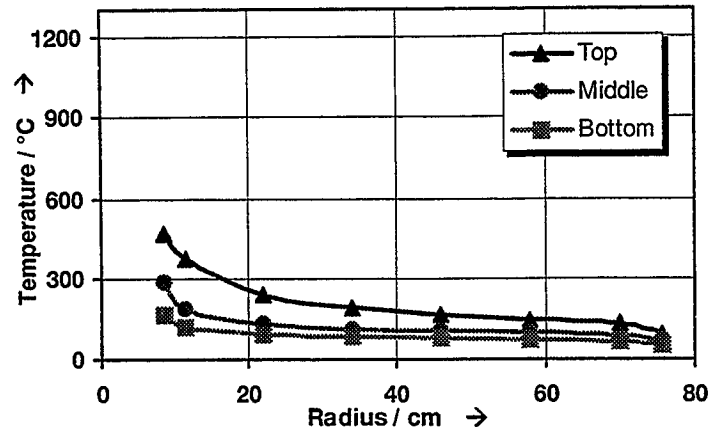
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			30				37	
113			296		158		93	58
97			293		201		149	88
91	469	374	242	196	169	148	134	94
50	293	192	135	116	107	96	90	75
9	166	123	96	85	78	72	64	54
3			92		76		59	47
-13			97		73		50	38
-40			149				31	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		21.12.96
$P_{nominal}$	kW	5,00
$P_{heating\ element}$	kW	3,7
$P_{elektrode}$	kW	0,86
CO_2	Vol. %	0
O_2	Vol. %	2,06
$T_{ambient}$	°C	28,3
$T_{dewpoint}$	°C	-14,1

Cooling water:

Top		
T_{inlet}	°C	11,8
T_{outlet}	°C	16
Throughput	l/h	165
Bottom		
T_{inlet}	°C	12,4
T_{outlet}	°C	14,3
Throughput	l/h	165



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			41				48	
113			491		273		150	83
97			511		351		243	142
91	750	633	457	370	308	258	226	151
50	492	347	247	204	181	163	146	114
9	267	198	152	131	118	107	93	74
3			144		114		85	63
-13			150		108		68	47
-40			54				37	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		11.12.95
$P_{nominal}$	kW	10,02
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	-0,01
O_2	Vol. %	2,11
$T_{ambient}$	°C	28,2
$T_{dewpoint}$	°C	-14,1

Cooling water:

Top		
T_{inlet}	°C	14,8
T_{outlet}	°C	22,5
Throughput	l/h	130
Bottom		
T_{inlet}	°C	15,6
T_{outlet}	°C	19,5
Throughput	l/h	130

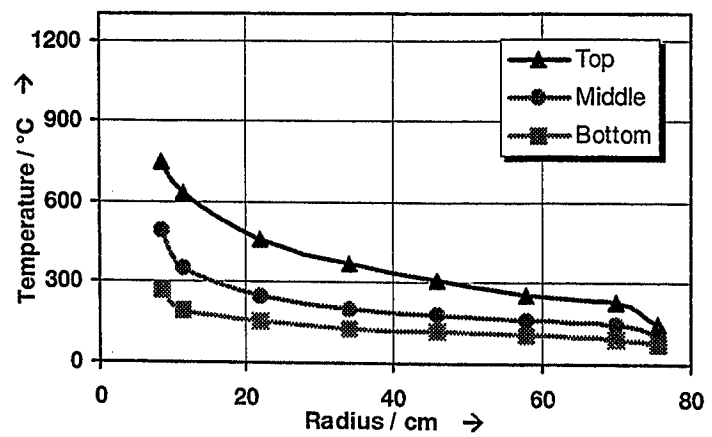


Fig. 18: Stationary tests with short heating element on the top side, 60 mm graphite pebbles, nitrogen, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

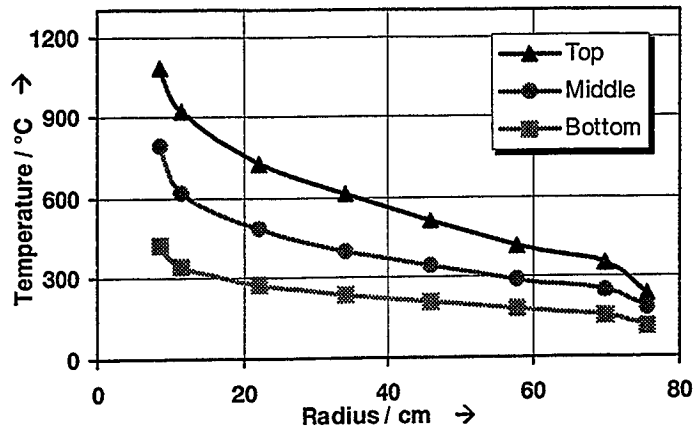
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			53				63	
113			734		428		229	118
97			775		546		356	217
91	1082	923	726	613	514	420	353	233
50	793	616	486	400	343	288	247	184
9	425	341	278	237	207	183	154	117
3			265		199		137	95
-13			264		189		106	66
-40			73				48	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		18.12.95
$P_{nominal}$	kW	20,00
$P_{heating\ element}$	kW	16,17
$P_{elektrode}$	kW	2,78
CO_2	Vol. %	0,36
O_2	Vol. %	0,04
$T_{ambient}$	°C	28,0
$T_{dewpoint}$	°C	-49

Cooling water:

Top		
T_{inlet}	°C	13,5
T_{outlet}	°C	22,7
Throughput	l/h	160
Bottom		
T_{inlet}	°C	13,6
T_{outlet}	°C	19,2
Throughput	l/h	160



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			57				68	
113			825		496		265	130
97			871		620		400	246
91	1204	1029	823	704	593	484	403	265
50	921	732	593	496	423	349	291	211
9	506	419	350	295	255	218	180	134
3			333		245		158	106
-13			325		230		122	71
-40			83				50	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		14.12.96
$P_{nominal}$	kW	24,99
$P_{heating\ element}$	kW	20,34
$P_{elektrode}$	kW	3,43
CO_2	Vol. %	0,38
O_2	Vol. %	0,05
$T_{ambient}$	°C	28,4
$T_{dewpoint}$	°C	-50,9

Cooling water:

Top		
T_{inlet}	°C	12,9
T_{outlet}	°C	23,9
Throughput	l/h	165
Bottom		
T_{inlet}	°C	14,1
T_{outlet}	°C	20,2
Throughput	l/h	165

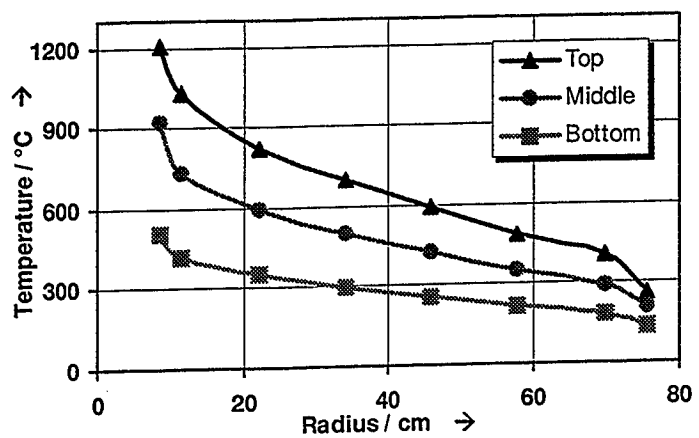


Fig. 19: Stationary tests with short heating element on the top side, 60 mm graphite pebbles, nitrogen, 20 kW (top) and 25 kW (bottom) nominal heating power

4.3 Data for the stationary tests with short heating element on the bottom side, 60 mm graphite pebbles

1. Helium 5, 10, 20, 25 kW nominal heating power
2. Nitrogen 5, 10, 20, 25 kW nominal heating power

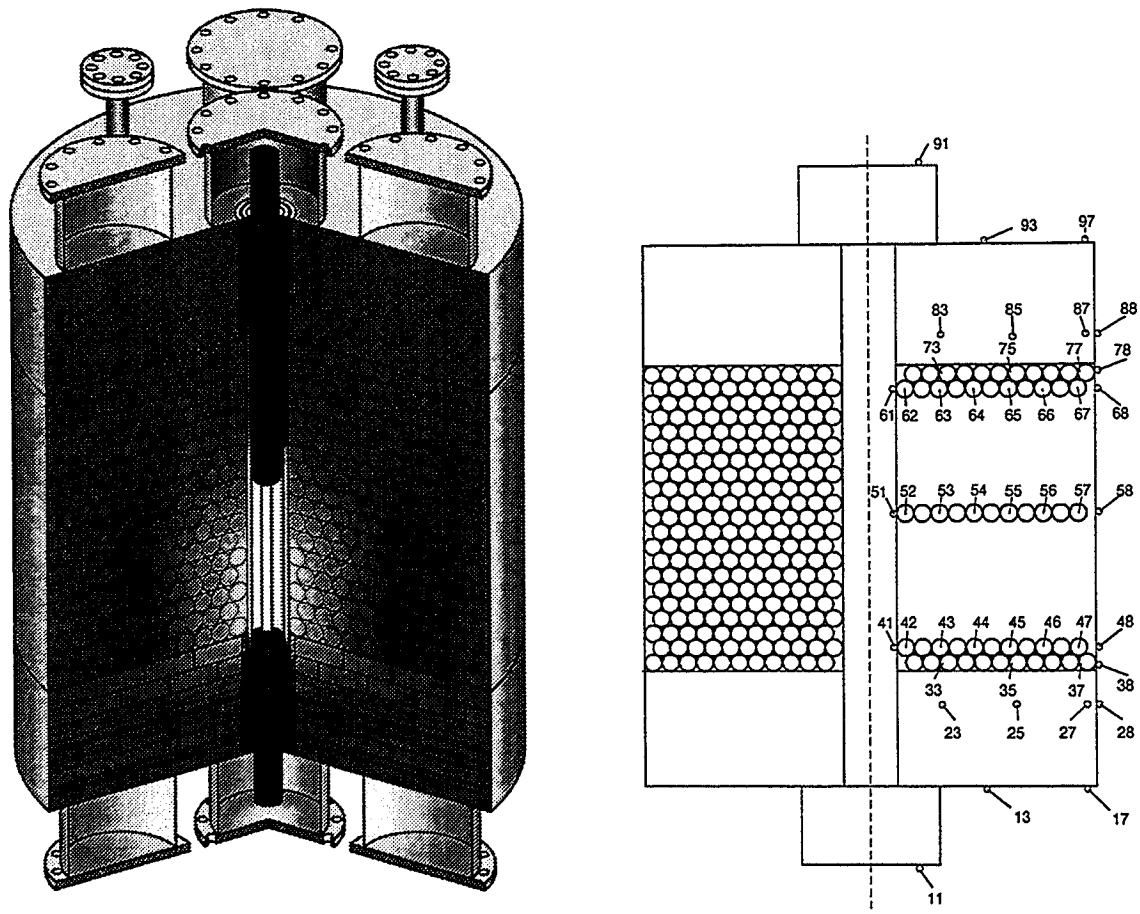


Fig. 20: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

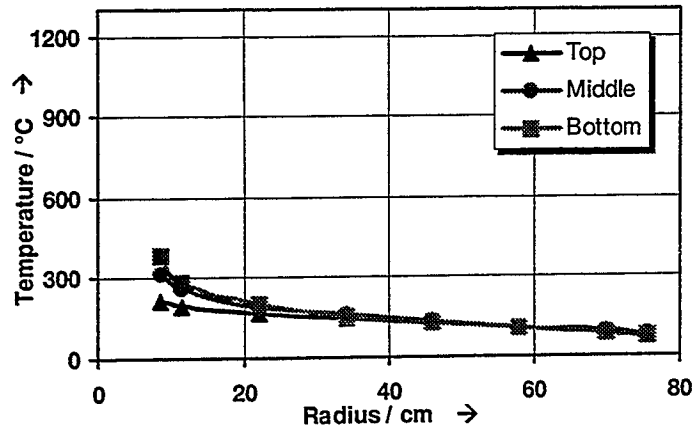
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			28				36	
113			147		94		61	47
97			173		129		87	66
91	213	198	168	149	129	108	93	74
50	319	264	191	162	135	111	96	82
9	385	280	199	154	128	108	89	73
3			192		124		80	64
-13			194		120		66	48
-40			50				34	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		12.02.96
$P_{nominal}$	kW	4,99
$P_{heating\ element}$	kW	3,7
$P_{elektrode}$	kW	0,86
CO_2	Vol. %	-0,02
O_2	Vol. %	1,99
$T_{ambient}$	°C	24,5
$T_{dewpoint}$	°C	-16,5

Cooling water:

Top		
T_{inlet}	°C	12,6
T_{outlet}	°C	15,8
Throughput	l/h	145
Bottom		
T_{inlet}	°C	13,0
T_{outlet}	°C	17,3
Throughput	l/h	145



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			34				43	
113			233		149		89	64
97			280		211		135	97
91	338	317	277	247	214	174	144	109
50	525	447	332	283	231	183	151	123
9	651	498	364	277	222	178	137	108
3			354		215		120	92
-13			339		205		97	64
-40			70				43	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		01.02.96
$P_{nominal}$	kW	10,01
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	-0,02
O_2	Vol. %	2,01
$T_{ambient}$	°C	26,3
$T_{dewpoint}$	°C	-19,5

Cooling water:

Top		
T_{inlet}	°C	9,4
T_{outlet}	°C	14,2
Throughput	l/h	150
Bottom		
T_{inlet}	°C	10,0
T_{outlet}	°C	16,9
Throughput	l/h	150

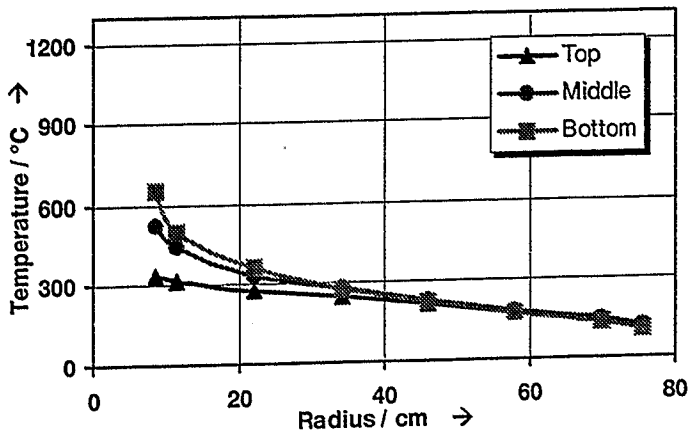


Fig. 21: Stationary tests with short heating element on the bottom side, 60 mm graphite pebbles, helium, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

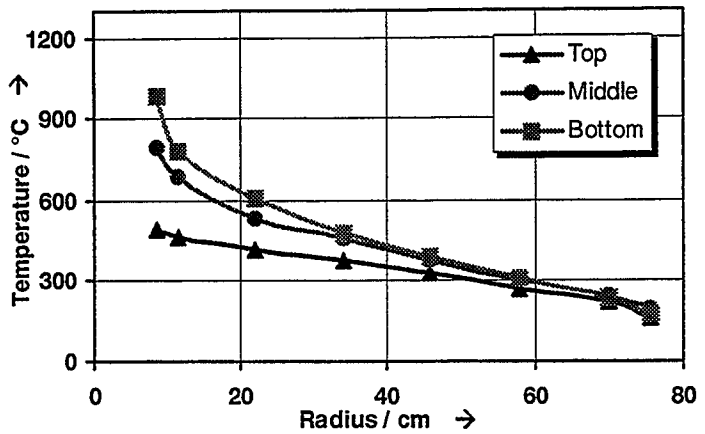
Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			44				53	
113			344		222		129	86
97			418		320		200	140
91	493	468	419	379	329	270	222	160
50	794	689	530	460	380	303	246	193
9	986	779	607	478	389	310	235	175
3			595		380		201	146
-13			555		352		158	92
-40			98				55	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		08.02.96
$P_{nominal}$	kW	20,01
$P_{heating\ element}$	kW	16,17
$P_{elektrode}$	kW	2,78
CO_2	Vol. %	-0,02
O_2	Vol. %	999,99
$T_{ambient}$	°C	24,3
$T_{dewpoint}$	°C	-21

Cooling water:

Top		
T_{inlet}	°C	11,4
T_{outlet}	°C	18,4
Throughput	l/h	150
Bottom		
T_{inlet}	°C	12,0
T_{outlet}	°C	23,0
Throughput	l/h	150



Temperatures:

Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			51				63	
113			393		256		149	100
97			477		368		230	162
91	557	531	480	435	380	314	257	185
50	896	783	611	536	448	359	290	225
9	1123	896	709	568	467	375	283	210
3			699		459		241	175
-13			647		418		188	109
-40			113				64	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		05.02.96
$P_{nominal}$	kW	25,00
$P_{heating\ element}$	kW	20,34
$P_{elektrode}$	kW	3,43
CO_2	Vol. %	0,43
O_2	Vol. %	-999,99
$T_{ambient}$	°C	27,7
$T_{dewpoint}$	°C	-40,5

Cooling water:

Top		
T_{inlet}	°C	10,3
T_{outlet}	°C	19,2
Throughput	l/h	160
Bottom		
T_{inlet}	°C	11,2
T_{outlet}	°C	24,5
Throughput	l/h	160

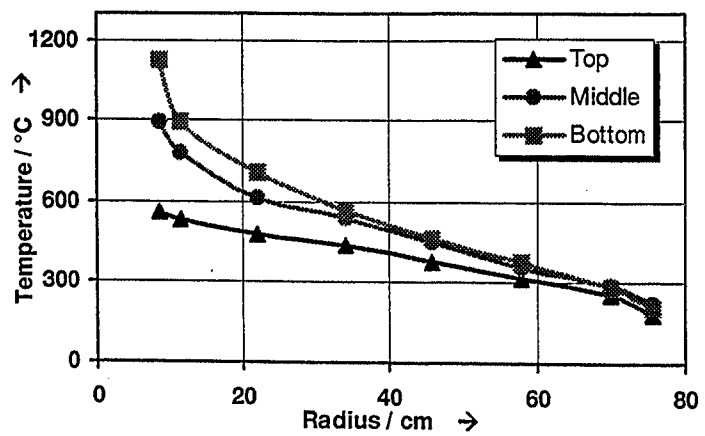


Fig. 22: Stationary tests with short heating element on the bottom side, 60 mm graphite pebbles, helium, 20 kW (top) and 25 kW (bottom) nominal heating power

Temperatures:

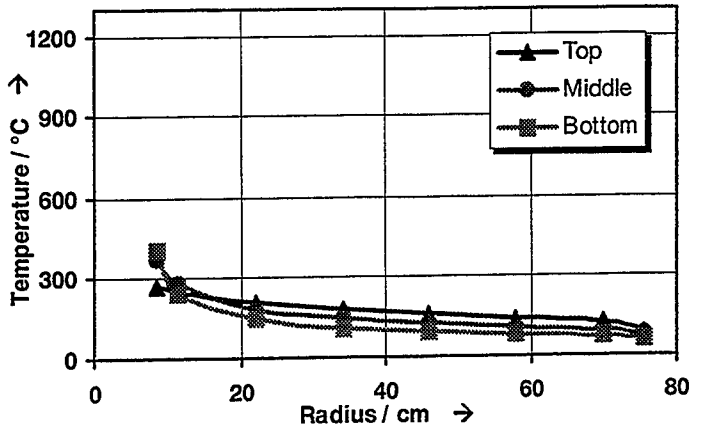
Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			26				34	
113			200		132		82	53
97			224		179		136	83
91	269	252	210	185	164	143	128	89
50	370	285	185	148	126	109	97	78
9	404	245	145	108	93	82	71	58
3			132		89		65	50
-13			160		90		53	37
-40			46				30	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		04.03.96
$P_{nominal}$	kW	5,01
$P_{heating\ element}$	kW	3,7
$P_{elektrode}$	kW	0,86
CO_2	Vol. %	-0,02
O_2	Vol. %	2,09
$T_{ambient}$	°C	22,2
$T_{dewpoint}$	°C	-18

Cooling water:

Top		
T_{inlet}	°C	12,5
T_{outlet}	°C	15,6
Throughput	l/h	140
Bottom		
T_{inlet}	°C	12,9
T_{outlet}	°C	16,7
Throughput	l/h	140



Temperatures:

Radius [cm]→ / Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			33				44	
113			324		219		130	76
97			374		304		219	131
91	428	411	364	327	288	246	213	141
50	615	503	354	284	231	191	163	123
9	690	454	283	199	160	137	113	87
3			258		152		102	72
-13			294		157		81	51
-40			65				38	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		20.02.96
$P_{nominal}$	kW	10,01
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	0
O_2	Vol. %	2,06
$T_{ambient}$	°C	26,8
$T_{dewpoint}$	°C	-16,1

Cooling water:

Top		
T_{inlet}	°C	11
T_{outlet}	°C	15,9
Throughput	l/h	140
Bottom		
T_{inlet}	°C	11,9
T_{outlet}	°C	17,9
Throughput	l/h	140

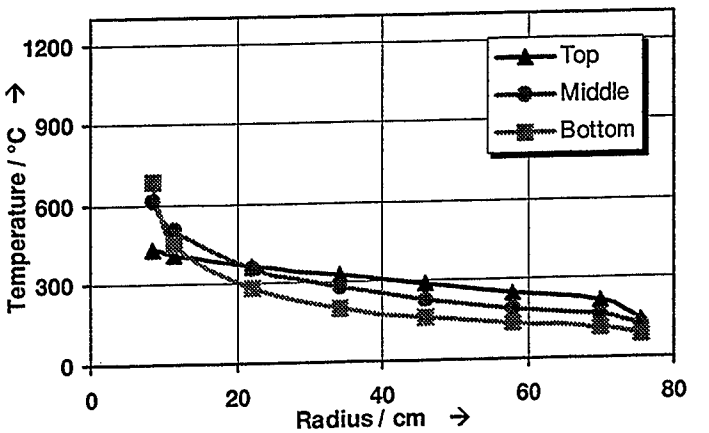


Fig. 23: Stationary tests with short heating element on the bottom side, 60 mm graphite pebbles, nitrogen, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

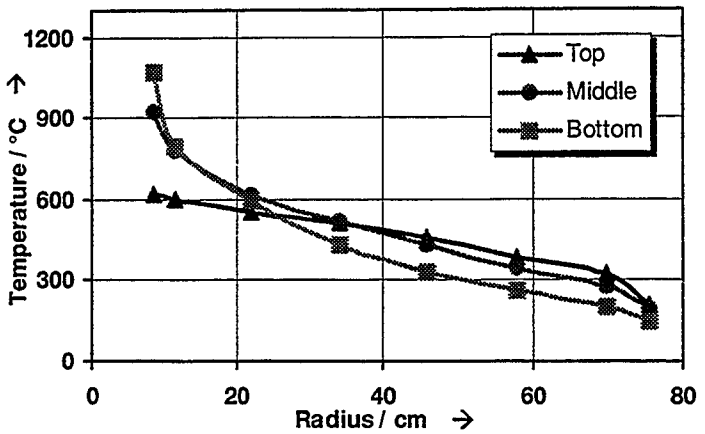
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			43				59	
113			479		336		195	107
97			555		459		315	192
91	621	600	554	509	455	384	322	210
50	925	785	613	522	432	342	274	197
9	1073	792	590	433	332	263	203	146
3			567		316		177	117
-13			575		328		141	75
-40			93				50	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		27.02.96
$P_{nominal}$	kW	20,07
$P_{heating\ element}$	kW	16,17
$P_{elektrode}$	kW	2,78
CO_2	Vol. %	0,33
O_2	Vol. %	-999,99
$T_{ambient}$	°C	27,5
$T_{dewpoint}$	°C	-48,1

Cooling water:

Top		
T_{inlet}	°C	10,5
T_{outlet}	°C	17,7
Throughput	l/h	155
Bottom		
T_{inlet}	°C	11,2
T_{outlet}	°C	22,0
Throughput	l/h	155



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			49				66	
113			534		373		216	119
97			621		515		349	215
91	693	669	622	575	516	435	363	235
50	1046	890	709	615	517	410	322	227
9	1229	921	717	548	424	330	249	173
3			699		411		213	137
-13			694		412		169	85
-40			106				54	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		23.02.96
$P_{nominal}$	kW	24,96
$P_{heating\ element}$	kW	20,34
$P_{elektrode}$	kW	3,43
CO_2	Vol. %	0,19
O_2	Vol. %	-999,99
$T_{ambient}$	°C	30,4
$T_{dewpoint}$	°C	-45,5

Cooling water:

Top		
T_{inlet}	°C	11,2
T_{outlet}	°C	20,1
Throughput	l/h	145
Bottom		
T_{inlet}	°C	12,4
T_{outlet}	°C	25,3
Throughput	l/h	145

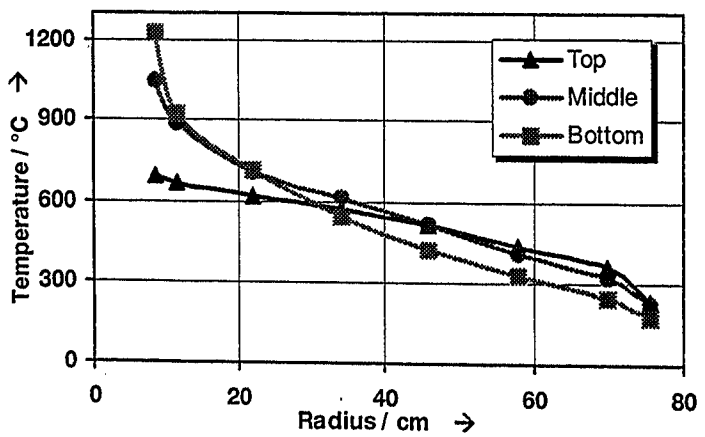


Fig. 24: Stationary tests with short heating element on the bottom side, 60 mm graphite pebbles, nitrogen, 20 kW (top) and 25 kW (bottom) nominal heating power

4.4 Data for the stationary tests with short heating element on the bottom side and a gas plenum above the pebble bed, 60 mm graphite pebbles

Nitrogen 5, 10 kW nominal heating power

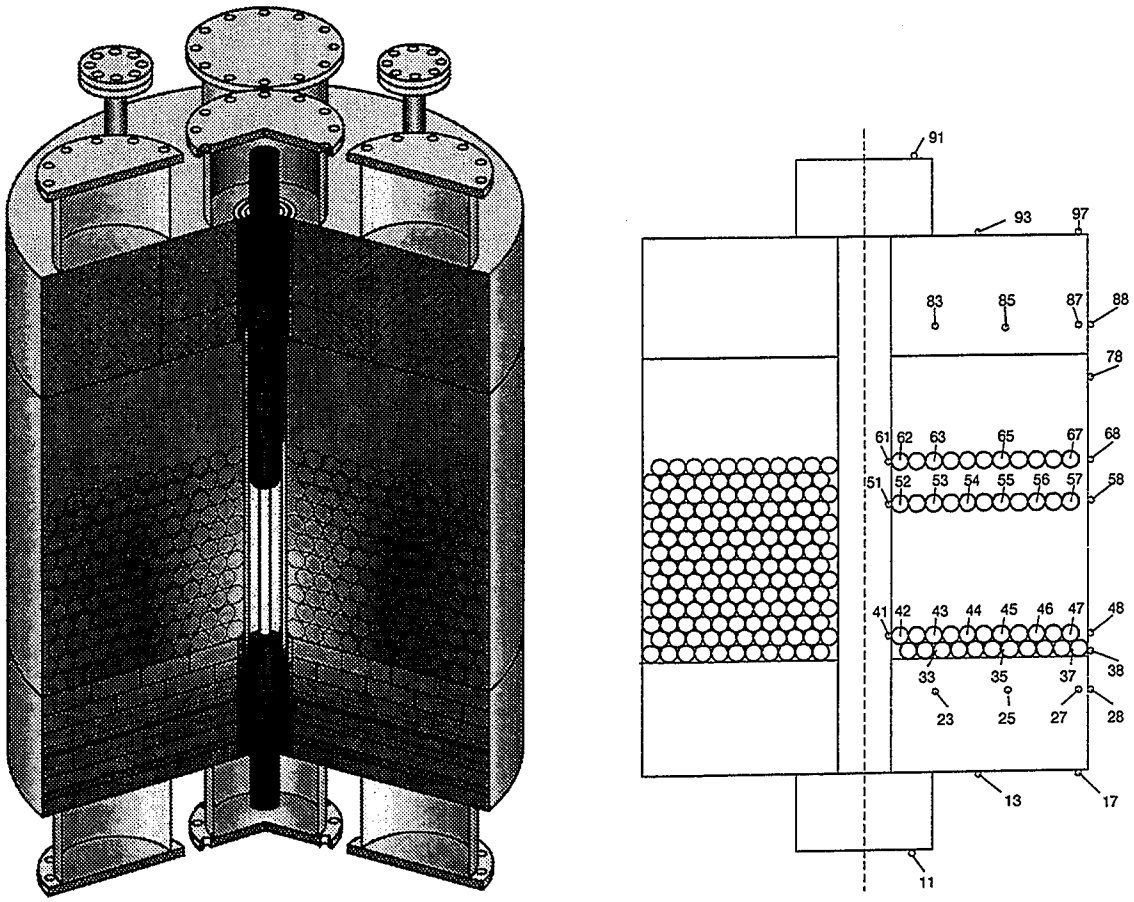


Fig. 25: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

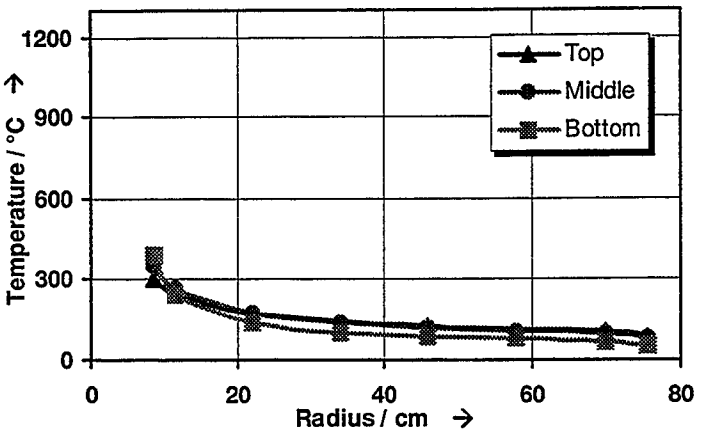
Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			30				37	
113			162		104		74	55
91			0		0		0	82
63	301	242	176	0	126	0	107	87
50	349	270	174	140	120	109	99	79
9	390	244	139	103	89	79	68	56
3			129		84		63	49
-13			156		87		53	40
-40			52				34	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		17.09.95
$P_{nominal}$	kW	5,01
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	0,04
O_2	Vol. %	-0,01
$T_{ambient}$	°C	25,4
$T_{dewpoint}$	°C	-39,5

Cooling water:

Top		
T_{inlet}	°C	19,2
T_{outlet}	°C	22,2
Throughput	l/h	190
Bottom		
T_{inlet}	°C	19,0
T_{outlet}	°C	23,6
Throughput	l/h	190



Temperatures:

Radius [cm]→ Height [cm]↓	6,5	10	22	34	46	58	70	75,6
140			34				44	
113			244		161		111	77
91			0		0		0	126
63	451	386	302	0	208	0	169	135
50	552	455	315	251	207	179	158	120
9	637	439	262	182	145	125	103	80
3			244		137		93	67
-13			276		144		75	50
-40			71				40	
Protecting tube		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		17.09.95
$P_{nominal}$	kW	9,98
$P_{heating\ element}$	kW	7,84
$P_{elektrode}$	kW	1,5
CO_2	Vol. %	0,14
O_2	Vol. %	-0,06
$T_{ambient}$	°C	23,2
$T_{dewpoint}$	°C	-40

Cooling water:

Top		
T_{inlet}	°C	18,4
T_{outlet}	°C	22,6
Throughput	l/h	190
Bottom		
T_{inlet}	°C	18,1
T_{outlet}	°C	25,4
Throughput	l/h	190

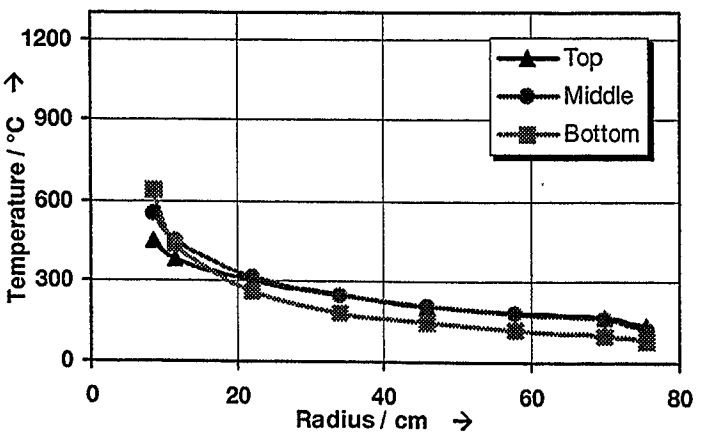


Fig. 26: Stationary tests with short heating element on the bottom side, 60 mm graphite pebbles, gas plenum above the pebble bed, nitrogen, 20 kW (top) and 25 kW (bottom) nominal heating power

4.5 Data for the stationary tests with long heating element, 30 mm graphite pebbles

In the following some results are presented for benchmark calculations:

1. Helium 5, 10, 15, 20, 25, 30 kW nominal heating power 30mm pebble diameter
2. Nitrogen 5, 10, 15, 20, 25, 30 kW nominal heating power 30mm pebble diameter

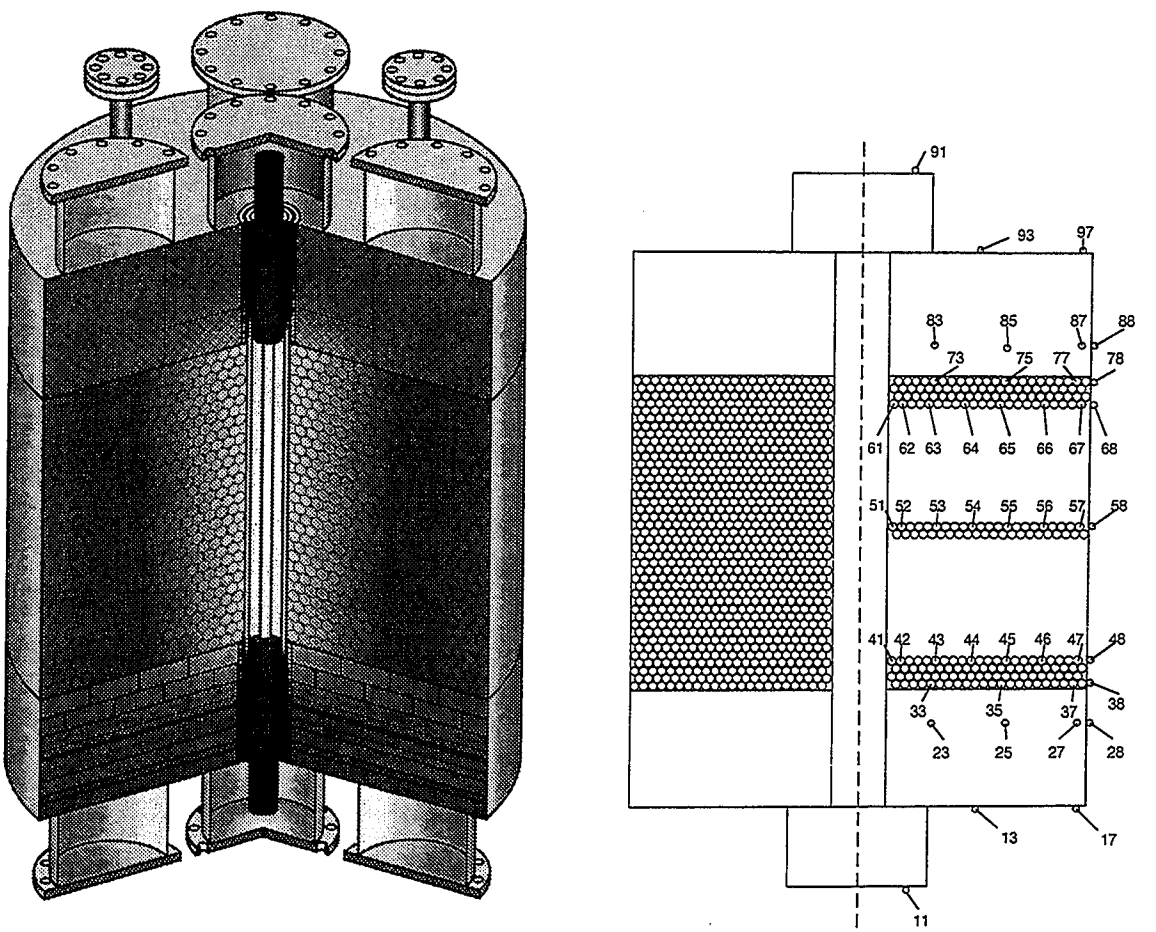


Fig. 27: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

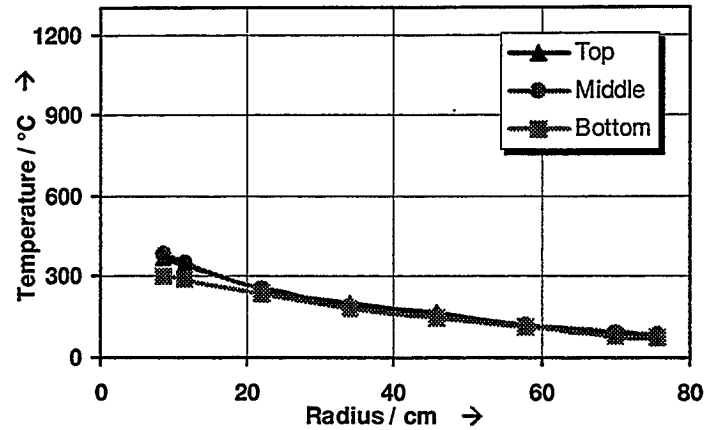
Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			33				34	
113			235		121		68	47
98,5			260		179		90	71
91	373	343	258	205	165	123	94	79
50	381	350	257	189	156	123	96	84
9	300	286	233	182	146	115	83	73
1,5			222		136		86	63
-13			206		132		68	48
-40			49				35	
inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		11.04.96
$P_{nominal}$	kW	5,04
$P_{heating\ element}$	kW	4,34
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	-0,01
O_2	Vol. %	2,08
$T_{ambient}$	°C	25,5
$T_{dewpoint}$	°C	-13,6

Cooling water:

Top		
T_{inlet}	°C	15,2
T_{outlet}	°C	19,5
Throughput	l/h	100
Bottom		
T_{inlet}	°C	15,9
T_{outlet}	°C	19,5
Throughput	l/h	100



Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			45				43	
113			382		199		104	63
98,5			430		299		141	106
91	606	559	429	344	277	203	149	119
50	614	573	435	324	265	203	153	131
9	508	488	402	316	251	193	132	112
1,5			384		233		137	94
-13			347		223		104	67
-40			72				46	
inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		18.04.96
$P_{nominal}$	kW	10,00
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	-0,01
O_2	Vol. %	2,08
$T_{ambient}$	°C	26,5
$T_{dewpoint}$	°C	-15,1

Cooling water:

Top		
T_{inlet}	°C	18,9
T_{outlet}	°C	28,3
Throughput	l/h	110
Bottom		
T_{inlet}	°C	19,6
T_{outlet}	°C	26,7
Throughput	l/h	110

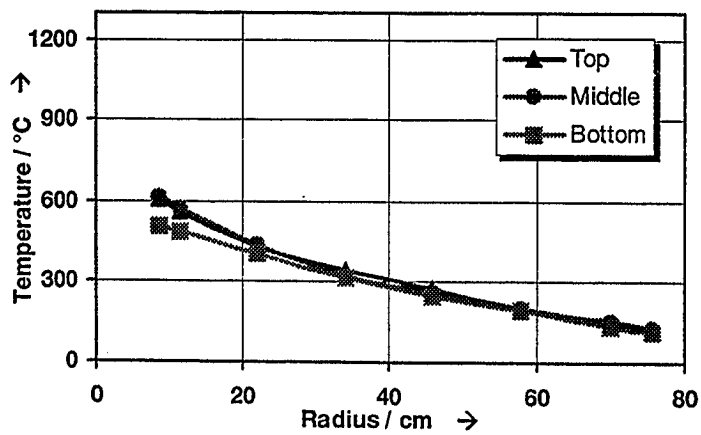


Fig. 28: Stationary tests with long heating element, 30 mm graphite pebbles, helium, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			54				49	
113			490		258		132	76
98,5			553		388		181	133
91	768	711	553	447	362	265	193	151
50	778	729	567	430	352	269	199	167
9	668	642	536	427	340	260	174	144
1,5			516		317		182	119
-13			457		297		133	81
-40			88				54	

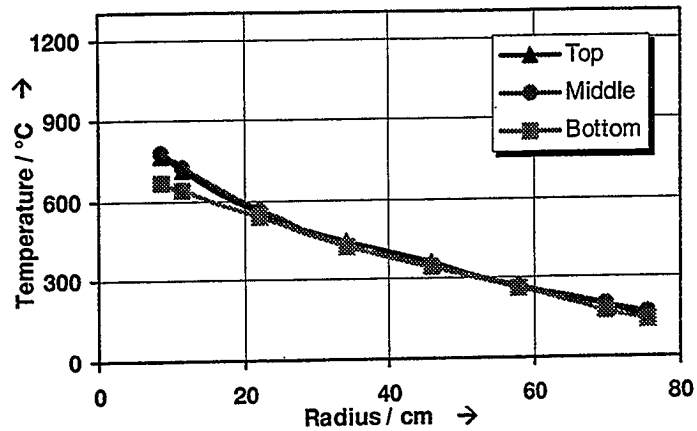
Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		15.04.96
$P_{nominal}$	kW	15,05
$P_{heating\ element}$	kW	13,51
$P_{elektrode}$	kW	0,9
CO_2	Vol. %	-0,01
O_2	Vol. %	2,09
$T_{ambient}$	°C	27,2
$T_{dewpoint}$	°C	-16,1

Cooling water:

Top		
T_{inlet}	°C	20,3
T_{outlet}	°C	34,5
Throughput	l/h	90
Bottom		
T_{inlet}	°C	21,2
T_{outlet}	°C	32,1
Throughput	l/h	90



Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			57				52	
113			592		316		159	87
98,5			669		476		222	161
91	912	848	670	547	445	326	236	183
50	920	866	687	530	437	333	245	203
9	808	782	659	531	427	327	216	177
1,5			637		398		227	144
-13			562		369		162	94
-40			97				58	

Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		25.04.96
$P_{nominal}$	kW	20,02
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0,58
O_2	Vol. %	0,07
$T_{ambient}$	°C	25,5
$T_{dewpoint}$	°C	-46,6

Cooling water:

Top		
T_{inlet}	°C	16,6
T_{outlet}	°C	30,2
Throughput	l/h	115
Bottom		
T_{inlet}	°C	17,5
T_{outlet}	°C	28,8
Throughput	l/h	115

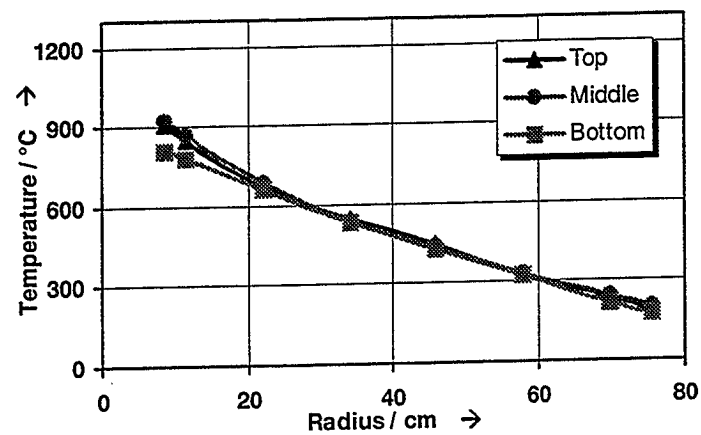


Fig. 29: Stationary tests with long heating element, 30 mm graphite pebbles, helium, 15 kW (top) and 20 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			72				67	
113			686		373		189	107
98,5			771		558		266	191
91	1037	966	772	637	524	389	283	217
50	1046	988	796	624	520	399	294	241
9	935	906	772	630	512	395	262	213
1,5			749		480		275	174
-13			656		438		194	112
-40			111				68	

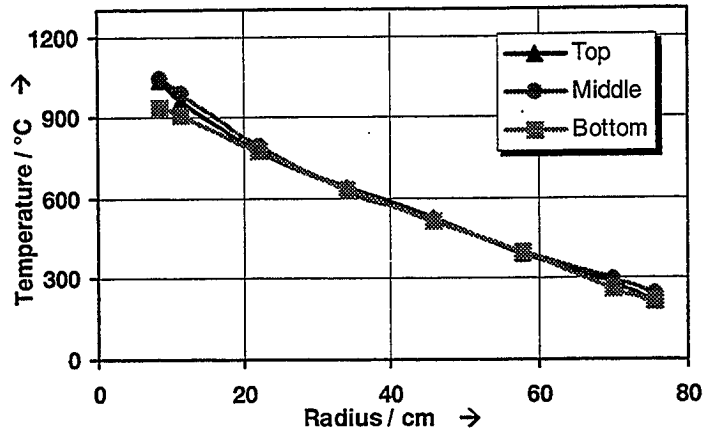
Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		22.04.96
$P_{nominal}$	kW	25,04
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,36
O_2	Vol. %	0,09
$T_{ambient}$	°C	33,0
$T_{dewpoint}$	°C	-36,3

Cooling water:

Top		
T_{inlet}	°C	19,5
T_{outlet}	°C	36,4
Throughput	l/h	120
Bottom		
T_{inlet}	°C	20,2
T_{outlet}	°C	33,1
Throughput	l/h	120



Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			78				69	
113			778		425		214	115
98,5			866		632		300	215
91	1155	1076	867	719	594	442	320	243
50	1159	1096	890	705	590	454	332	269
9	1045	1014	869	715	584	452	298	240
1,5			846		548		313	194
-13			738		497		218	122
-40			119				71	

Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		29.04.96
$P_{nominal}$	kW	30,01
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,38
O_2	Vol. %	0,09
$T_{ambient}$	°C	30,0
$T_{dewpoint}$	°C	-38,5

Cooling water:

Top		
T_{inlet}	°C	17,2
T_{outlet}	°C	36,6
Throughput	l/h	145
Bottom		
T_{inlet}	°C	18,2
T_{outlet}	°C	33,1
Throughput	l/h	145

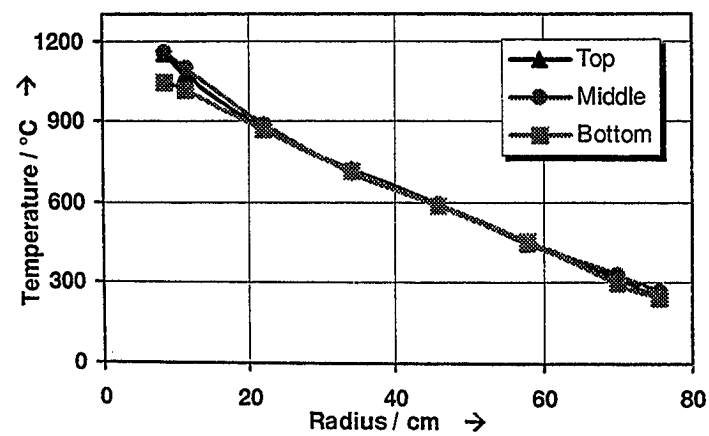


Fig. 30: Stationary tests with long heating element, 30 mm graphite pebbles, helium, 25 kW (top) and 30 kW (bottom) nominal heating power

Temperatures:

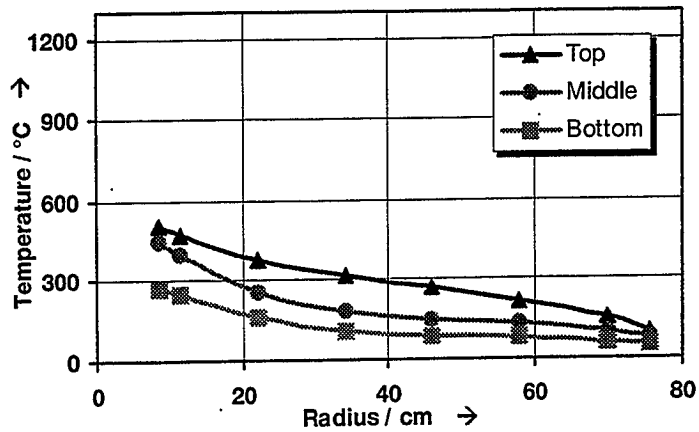
Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			32				37	
113			362		215		116	57
98,5			395		316		175	92
91	508	469	374	318	270	217	152	101
50	443	397	257	180	151	134	103	83
9	272	246	160	110	90	79	62	54
1,5			141		82		60	46
-13			164		89		51	37
-40			46				32	
inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		08.04.96
$P_{nominal}$	kW	5,04
$P_{heating\ element}$	kW	4,34
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	-0,01
O_2	Vol. %	2,1
$T_{ambient}$	°C	26,7
$T_{dewpoint}$	°C	-14,1

Cooling water:

Top		
T_{inlet}	°C	15
T_{outlet}	°C	20
Throughput	l/h	140
Bottom		
T_{inlet}	°C	16,0
T_{outlet}	°C	19,0
Throughput	l/h	140



Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			39				45	
113			538		325		168	35
98,5			592		471		245	133
91	756	705	579	498	422	331	227	148
50	710	660	489	353	285	234	166	127
9	516	482	346	226	166	134	95	80
1,5			310		145		93	65
-13			310		161		75	49
-40			62				39	
inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		22.03.96
$P_{nominal}$	kW	9,99
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	0,18
O_2	Vol. %	-0,1
$T_{ambient}$	°C	27,3
$T_{dewpoint}$	°C	-29,5

Cooling water:

Top		
T_{inlet}	°C	14,9
T_{outlet}	°C	20,3
Throughput	l/h	165
Bottom		
T_{inlet}	°C	14,6
T_{outlet}	°C	19,5
Throughput	l/h	165

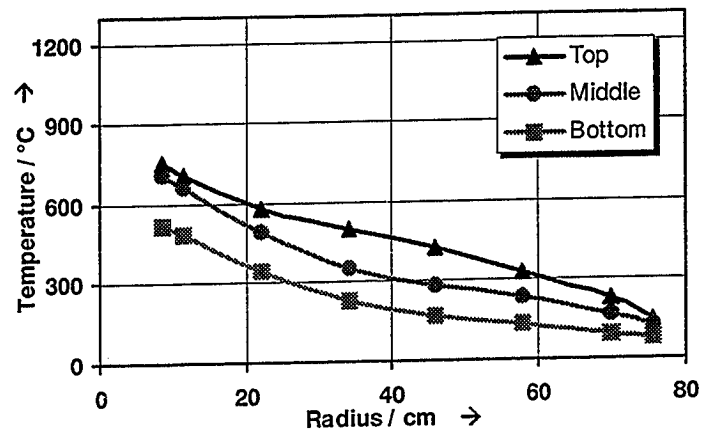


Fig. 31: Stationary tests with long heating element, 30 mm graphite pebbles, nitrogen, 5 kW (top) and 10 kW (bottom) nominal heating power

Dateiname: sn15o113	Temperaturen:

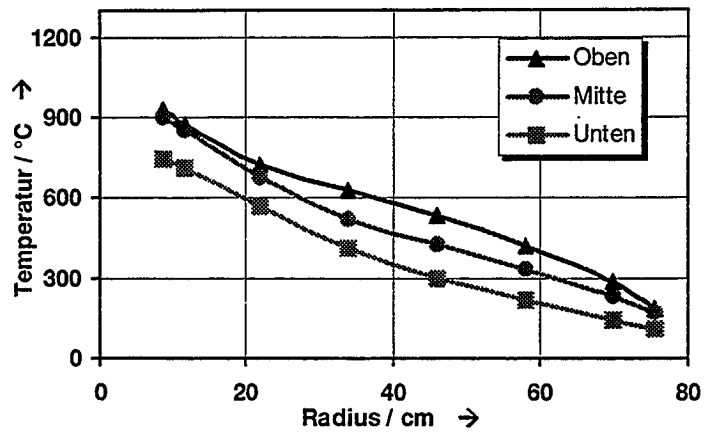
Meßgas- und Leistungsdaten :

Datum		29.03.96
P_{Brutto}	kW	15,01
$P_{Heizelement}$	kW	13,51
$P_{Elektrode}$	kW	0,9
CO_2	Vol. %	0,29
O_2	Vol. %	-999,99
$T_{Umgebung}$	°C	29,8
$T_{Taupunkt}$	°C	-42

Kühlwasser:

Deckel		
$T_{Eintritt}$	°C	13,8
$T_{Austritt}$	°C	22,2
Durchsatz	l/h	130
Boden		
$T_{Eintritt}$	°C	14,5
$T_{Austritt}$	°C	22,2
Durchsatz	l/h	130

Radius [cm]→ Höhe [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			47				51	
113			671		415		212	89
98,5			734		584		302	164
91	925	870	727	628	537	419	286	184
50	902	852	677	523	429	335	231	170
9	745	711	569	410	295	217	141	111
1,5			535		254		140	88
-13			499		282		111	62
-40			77				45	
Erste Kugelschicht		Kugelschüttung			Isolation		Ofenoberfläche	



Temperatures:

Gas and power data:

Date		25.03.96
$P_{nominal}$	kW	20,04
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0
O_2	Vol. %	999,99
$T_{ambient}$	°C	28,1
$T_{dewpoint}$	°C	-14,6

Cooling water:

Top		
T_{inlet}	°C	15,7
T_{outlet}	°C	25,8
Throughput	l/h	140
Bottom		
T_{inlet}	°C	16,3
T_{outlet}	°C	25,7
Throughput	l/h	140

Radius [cm]→ Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			53				55	
113			770		473		241	99
98,5			841		669		340	189
91	1055	996	836	725	622	484	331	213
50	1044	991	809	644	536	415	283	205
9	906	873	731	567	429	306	186	142
1,5			702		376		187	111
-13			640		389		147	75
-40			90				51	
Inner pebble layer		Pebble Bed			Insulation		Vessel surface	

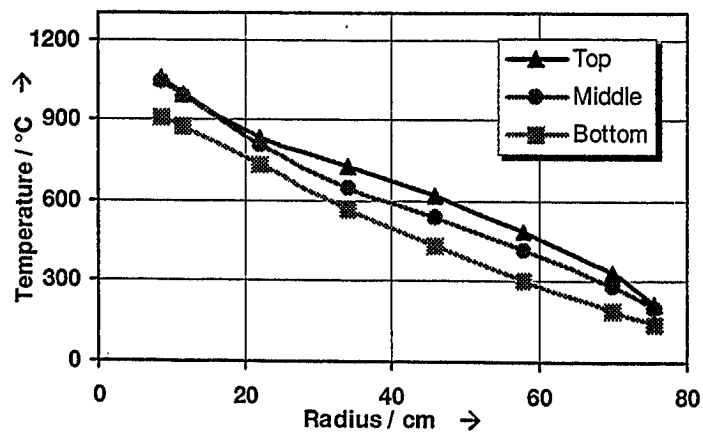


Fig. 32: Stationary tests with long heating element, 30 mm graphite pebbles, nitrogen, 15 kW (top) and 20 kW (bottom) nominal heating power

Temperatures:

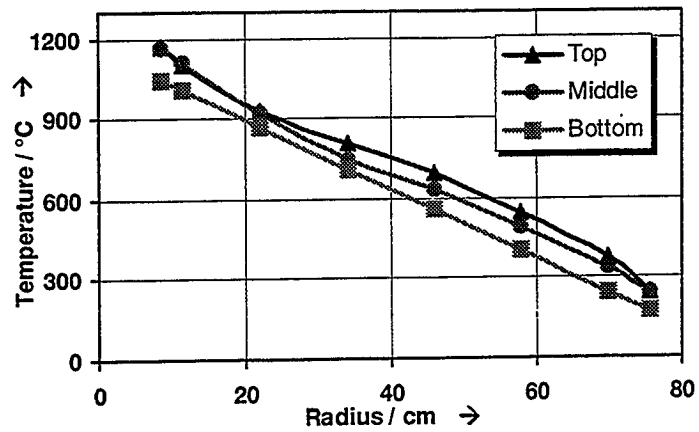
Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			59				60	
113			870		543		277	109
98,5			937		745		383	213
91	1171	1106	933	810	697	544	375	241
50	1165	1110	922	749	633	492	338	240
9	1043	1011	869	705	558	406	240	177
1,5			844		505		246	138
-13			770		503		189	89
-40			101				56	
inner pebble layer		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		02.04.96
$P_{nominal}$	kW	25,00
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,47
O_2	Vol. %	-999,99
$T_{ambient}$	°C	29,1
$T_{dewpoint}$	°C	-37

Cooling water:

Top		
T_{inlet}	°C	12,5
T_{outlet}	°C	24,6
Throughput	l/h	135
Bottom		
T_{inlet}	°C	13,9
T_{outlet}	°C	24,7
Throughput	l/h	135



Temperatures:

Radius [cm]→ / Height [cm]↓	8,5	11,5	22	34	46	58	70	75,6
140			68				67	
113			960		589		299	122
98,5			1026		816		419	238
91	1296	1207	1023	889	767	600	416	270
50	1269	1208	1019	840	717	561	390	276
9	1153	1122	979	816	666	502	302	217
1,5			958		617		313	171
-13			875		599		235	106
-40			116				63	
inner pebble layer		Pebble Bed			Insulation		Vessel surface	

Gas and power data:

Date		03.05.96
$P_{nominal}$	kW	30,03
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,34
O_2	Vol. %	0,01
$T_{ambient}$	°C	30,5
$T_{dewpoint}$	°C	-42,1

Cooling water:

Top		
T_{inlet}	°C	16,8
T_{outlet}	°C	36,8
Throughput	l/h	115
Bottom		
T_{inlet}	°C	17,9
T_{outlet}	°C	32,4
Throughput	l/h	115

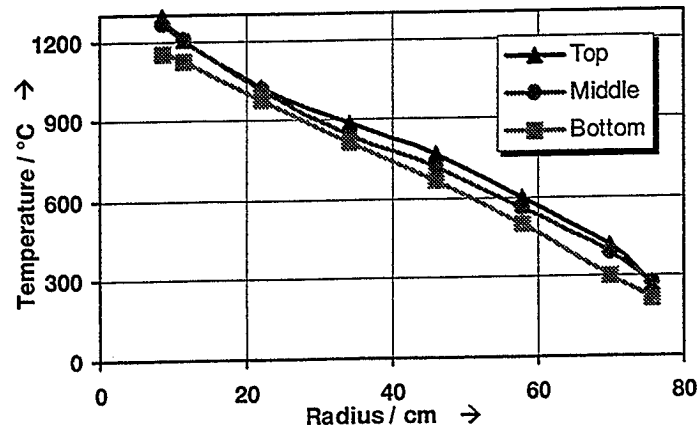


Fig. 33: Stationary tests with long heating element, 30 mm graphite pebbles, nitrogen, 25 kW (top) and 30 kW (bottom) nominal heating power

4.6 Data for the stationary tests with long heating element, 65 mm aluminium oxide pebbles (Al_2O_3)

In the following some results are presented for benchmark calculations:

1. Helium 5, 10, 15, 20, 25, 30 kW nominal heating power
2. Nitrogen 5, 10, 15, 20, 25, 30 kW nominal heating power

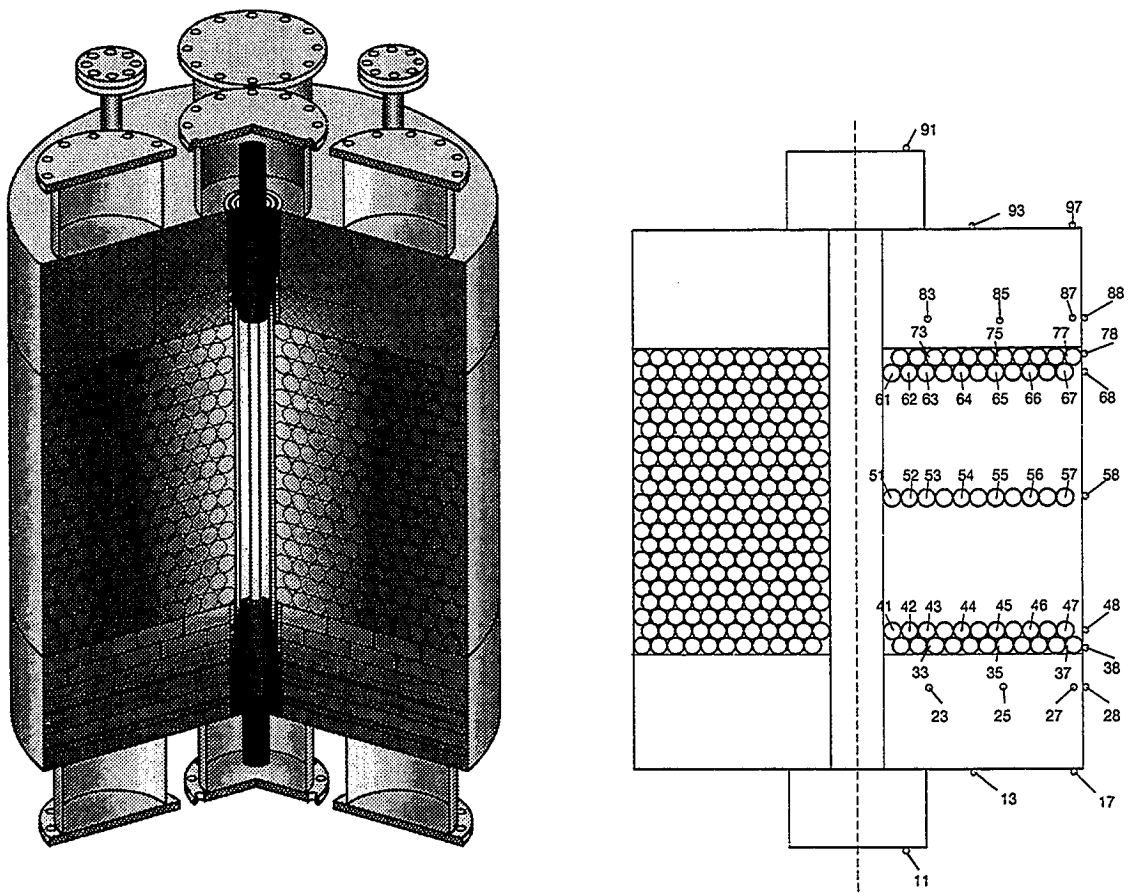


Fig. 34: Schematic plan (left) and arrangement of the thermocouples (right)

Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			40				39	
113			295		169		95	60
97			338		234		147	91
91	424	362	316	253	216	169	137	99
50	375	307	244	191	150	131	106	83
9	278	212	177	126	98	81	70	59
3			163		97		64	51
-13			171		96		53	42
-40			51				35	

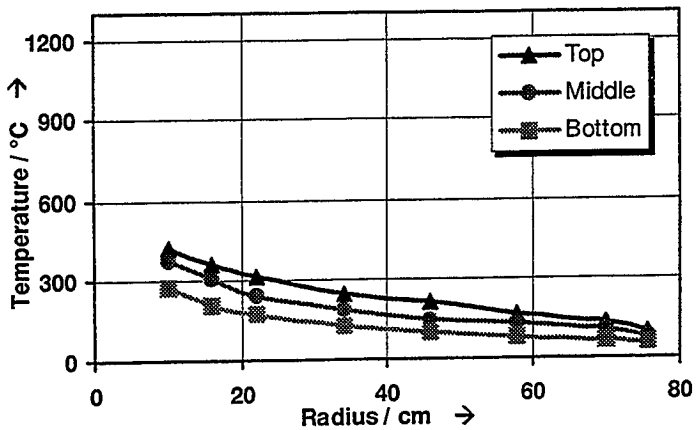
inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		08.07.96
$P_{nominal}$	kW	4,96
$P_{heating\ element}$	kW	4,33
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	0
O_2	Vol. %	
$T_{ambient}$	°C	25,3
$T_{dewpoint}$	°C	-42,5

Cooling water:

Top		
T_{inlet}	°C	19,3
T_{outlet}	°C	24,6
Throughput	l/h	120
Bottom		
T_{inlet}	°C	19,9
T_{outlet}	°C	23,7
Throughput	l/h	120



Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			51				48	
113			451		256		137	81
97			521		358		217	129
91	658	570	497	400	337	258	204	142
50	620	521	427	333	257	217	167	124
9	486	397	335	235	170	133	110	86
3			312		170		98	72
-13			303		168		78	55
-40			69				43	

inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		01.07.96
$P_{nominal}$	kW	9,97
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	-0,02
O_2	Vol. %	
$T_{ambient}$	°C	27,7
$T_{dewpoint}$	°C	-37,5

Cooling water:

Top		
T_{inlet}	°C	18,6
T_{outlet}	°C	27
Throughput	l/h	120
Bottom		
T_{inlet}	°C	19,5
T_{outlet}	°C	25,8
Throughput	l/h	120

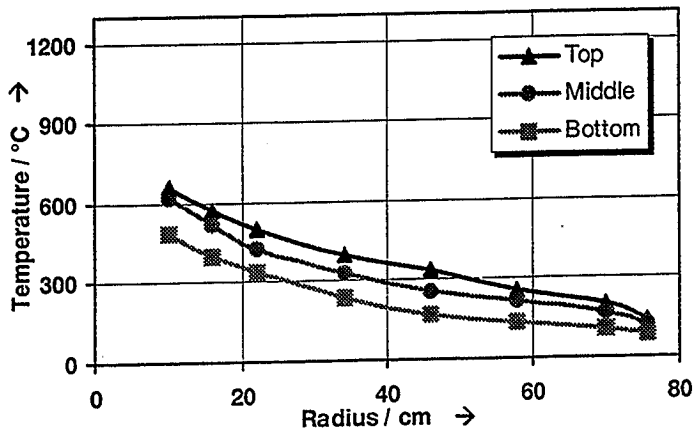


Fig. 35: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, helium, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			66				63	
113			585		333		174	101
97			673		457		268	163
91	841	748	673	525	437	329	256	180
50	818	701	590	466	363	299	226	166
9	679	588	511	370	266	203	161	122
3			485		271		143	100
-13			440		257		112	75
-40			89				55	

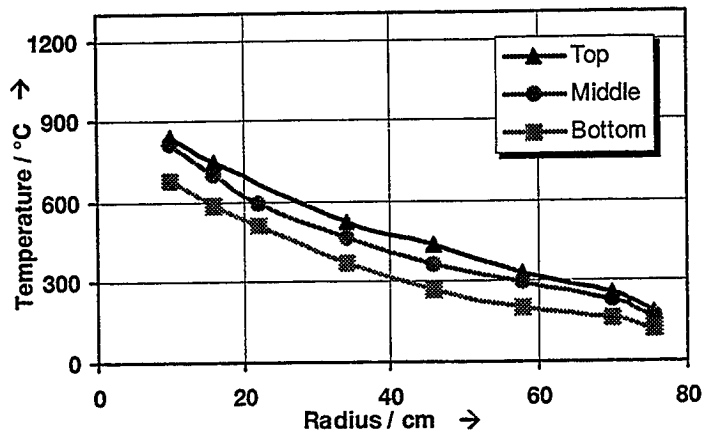
Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		23.07.95
$P_{nominal}$	kW	15,00
$P_{heating\ element}$	kW	13,51
$P_{elektrode}$	kW	0,9
CO_2	Vol. %	-0,02
O_2	Vol. %	
$T_{ambient}$	°C	36,6
$T_{dewpoint}$	°C	-38,5

Cooling water:

Top		
T_{inlet}	°C	21,9
T_{outlet}	°C	34,1
Throughput	l/h	110
Bottom		
T_{inlet}	°C	22,8
T_{outlet}	°C	32,4
Throughput	l/h	110



Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			66				57	
113			683		382		194	105
97			787		532		308	179
91	992	876	763	619	512	386	293	202
50	990	856	732	580	458	370	273	193
9	857	762	675	505	365	273	209	147
3			648		377		184	118
-13			575		349		139	81
-40			96				51	

Inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		25.06.96
$P_{nominal}$	kW	19,99
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0,02
O_2	Vol. %	0
$T_{ambient}$	°C	23,7
$T_{dewpoint}$	°C	-41

Cooling water:

Top		
T_{inlet}	°C	19,6
T_{outlet}	°C	32,2
Throughput	l/h	115
Bottom		
T_{inlet}	°C	20,6
T_{outlet}	°C	32,0
Throughput	l/h	115

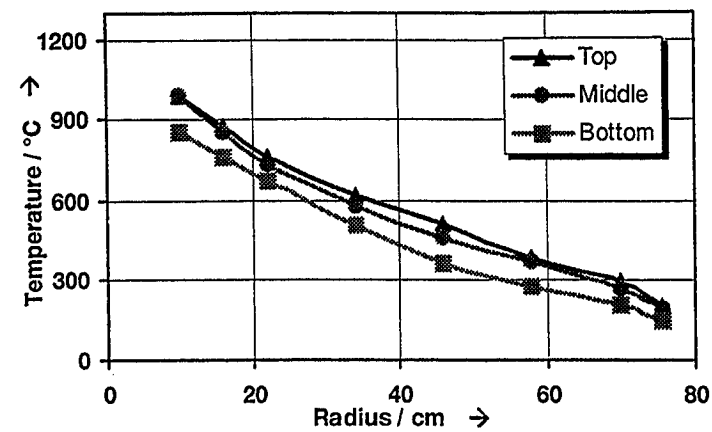


Fig. 36: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, helium, 15 kW (top) and 20 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			74				62	
113			792		444		222	116
97			905		610		351	202
91	1134	1009	879	715	592	445	335	229
50	1144	995	859	684	547	437	321	224
9	1007	911	816	622	456	342	257	177
3			789		475		227	141
-13			690		431		167	93
-40			106				57	

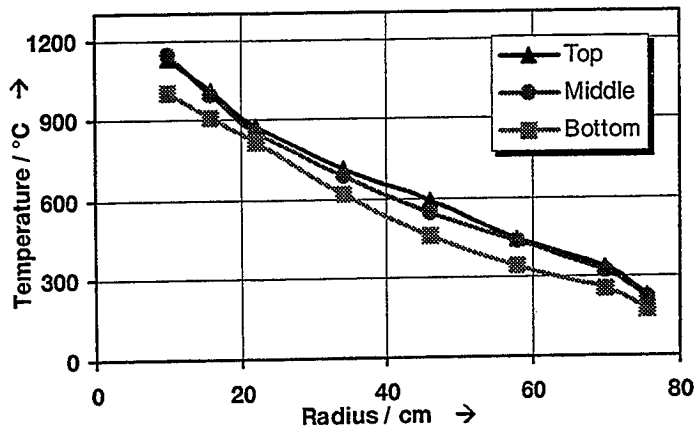
inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		21.06.96
$P_{nominal}$	kW	25,00
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,02
O_2	Vol. %	0
$T_{ambient}$	°C	23,0
$T_{dewpoint}$	°C	-38,5

Cooling water:

Top		
T_{inlet}	°C	19,3
T_{outlet}	°C	33,8
Throughput	l/h	120
Bottom		
T_{inlet}	°C	20,0
T_{outlet}	°C	33,0
Throughput	l/h	120



Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			91				78	
113			911		516		261	138
97			1036		700		401	241
91	1292	1160		828	684	516	388	268
50	1304	1142	996	803	652	517	382	266
9	1163	1068	969	754	563	427	321	222
3			942		590		284	177
-13			815		524		211	117
-40			125				71	

inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		12.07.96
$P_{nominal}$	kW	30,00
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,01
O_2	Vol. %	0
$T_{ambient}$	°C	33,0
$T_{dewpoint}$	°C	-34

Cooling water:

Top		
T_{inlet}	°C	20,8
T_{outlet}	°C	40,8
Throughput	l/h	110
Bottom		
T_{inlet}	°C	21,9
T_{outlet}	°C	40,2
Throughput	l/h	110

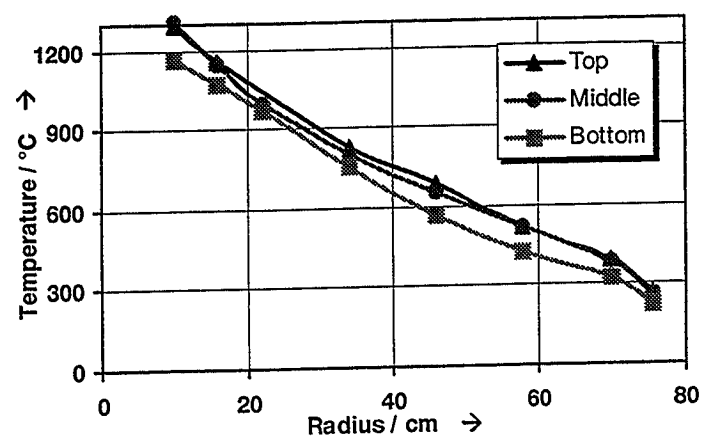


Fig. 37: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, helium, 25 kW (top) and 30 kW (bottom) nominal heating power

Temperatures:

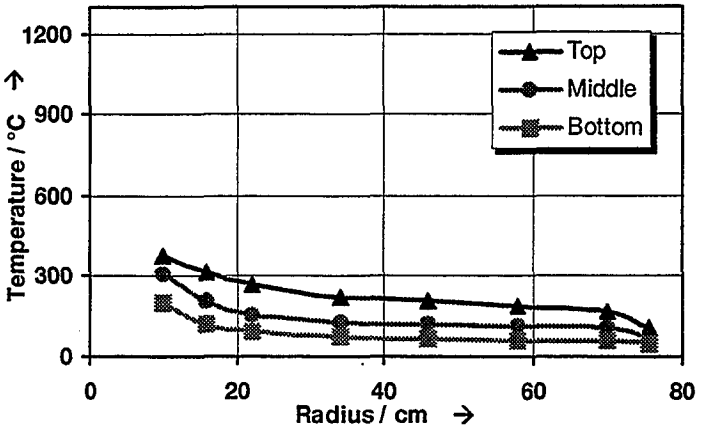
Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			33				38	
113			303		180		109	63
97			319		233		182	98
91	378	314	270	223	210	186	168	105
50	307	211	152	127	118	117	106	76
9	203	119	94	72	66	62	58	48
3			86		63		52	41
-13			116		65		43	34
-40			44				31	
Inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		03.06.96
$P_{nominal}$	kW	5,02
$P_{heating\ element}$	kW	4,33
$P_{elektrode}$	kW	0,34
CO_2	Vol. %	0
O_2	Vol. %	
$T_{ambient}$	°C	27,0
$T_{dewpoint}$	°C	-29,5

Cooling water:

Top		
T_{inlet}	°C	17,6
T_{outlet}	°C	22,8
Throughput	l/h	105
Bottom		
T_{inlet}	°C	18,4
T_{outlet}	°C	21,8
Throughput	l/h	105



Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			47				52	
113			496		304		176	91
97			537		392		288	155
91	640	550	482	397	362	306	268	168
50	530	402	302	240	211	203	179	123
9	359	235	181	130	114	105	97	75
3			163		108		87	61
-13			207		113		68	48
-40			65				41	
Inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		10.06.96
$P_{nominal}$	kW	10,01
$P_{heating\ element}$	kW	8,91
$P_{elektrode}$	kW	0,62
CO_2	Vol. %	-0,02
O_2	Vol. %	
$T_{ambient}$	°C	33,2
$T_{dewpoint}$	°C	-29

Cooling water:

Top		
T_{inlet}	°C	21,7
T_{outlet}	°C	33,3
Throughput	l/h	85
Bottom		
T_{inlet}	°C	22,8
T_{outlet}	°C	29,0
Throughput	l/h	85

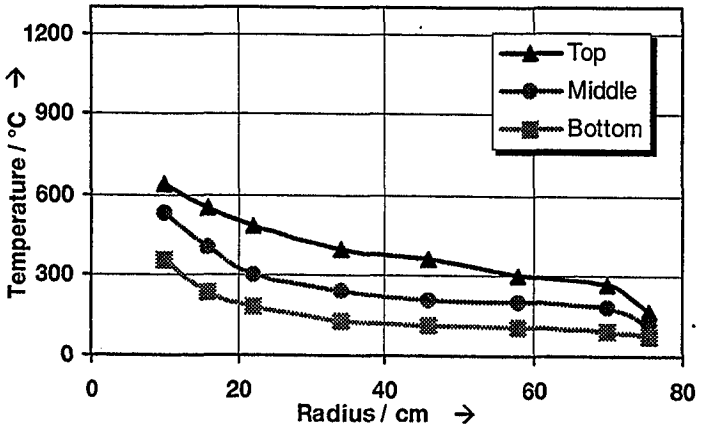


Fig. 38: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, nitrogen, 5 kW (top) and 10 kW (bottom) nominal heating power

Temperatures:

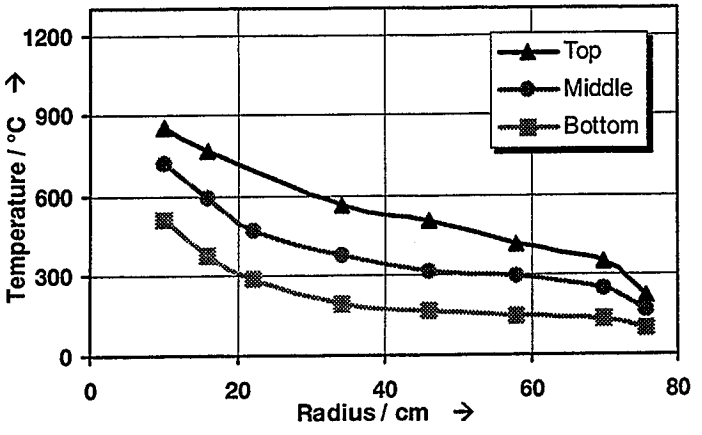
Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			57				62	
113			673		425		237	116
97			729		538		373	206
91	857	769	702	568	507	415	351	224
50	723	596	474	375	316	293	250	167
9	513	374	291	199	167	150	136	101
3			257		158		121	80
-13			309		167		91	60
-40			79				48	
Inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		20.07.96
$P_{nominal}$	kW	15,00
$P_{heating\ element}$	kW	13,51
$P_{elektrode}$	kW	0,9
CO_2	Vol. %	-0,02
O_2	Vol. %	
$T_{ambient}$	°C	36,1
$T_{dewpoint}$	°C	-39,5

Cooling water:

Top		
T_{inlet}	°C	21,6
T_{outlet}	°C	33
Throughput	l/h	110
Bottom		
T_{inlet}	°C	22,6
T_{outlet}	°C	30,3
Throughput	l/h	110



Temperatures:

Radius [cm]→ / Height [cm]↓	10	16	22	34	46	58	70	75,6
140			58				59	
113			789		496		273	123
97			858		627		430	234
91	1015	909	804	673	595	485	402	255
50	898	742	596	469	389	351	291	190
9	649	490	384	251	199	175	157	110
3			342		189		138	84
-13			390		202		99	59
-40			83				46	
Inner pebble layer	Pebble Bed				Insulation		Vessel surface	

Gas and power data:

Date		14.06.96
$P_{nominal}$	kW	20,01
$P_{heating\ element}$	kW	18,12
$P_{elektrode}$	kW	1,17
CO_2	Vol. %	0,02
O_2	Vol. %	0
$T_{ambient}$	°C	26,5
$T_{dewpoint}$	°C	-34,5

Cooling water:

Top		
T_{inlet}	°C	20
T_{outlet}	°C	31,7
Throughput	l/h	115
Bottom		
T_{inlet}	°C	20,9
T_{outlet}	°C	28,8
Throughput	l/h	115

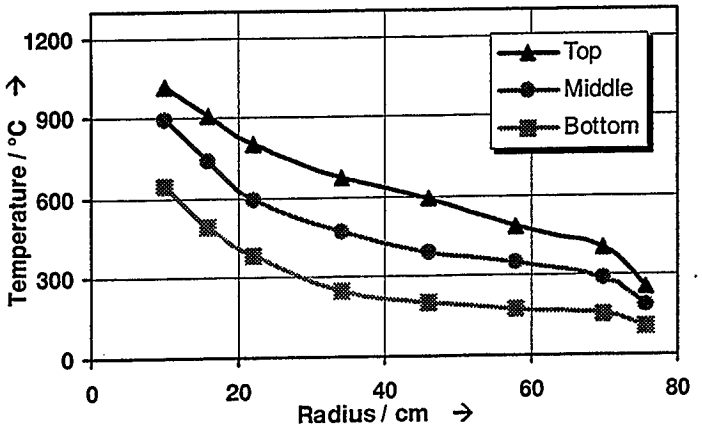


Fig. 39: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, nitrogen, 15 kW (top) and 20 kW (bottom) nominal heating power

Temperatures:

Radius [cm]→ Height [cm]↓	10	16	22	34	46	58	70	75,6
140			68				67	
113			909		578		316	141
97			986		724		486	268
91	1166	1054	938	794	695	561	455	292
50	1075	914	761	604	497	433	348	226
9	824	665	542	356	265	224	195	135
3			491		256		171	102
-13			523		274		124	71
-40			97				53	

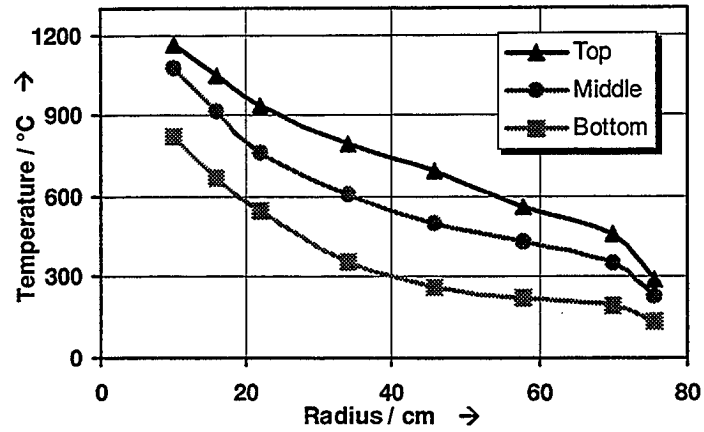
inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		20.06.96
$P_{nominal}$	kW	25,00
$P_{heating\ element}$	kW	22,74
$P_{elektrode}$	kW	1,43
CO_2	Vol. %	0,02
O_2	Vol. %	0
$T_{ambient}$	°C	29,4
$T_{dewpoint}$	°C	-36,5

Cooling water:

Top		
T_{inlet}	°C	22
T_{outlet}	°C	36,1
Throughput	l/h	115
Bottom		
T_{inlet}	°C	22,9
T_{outlet}	°C	33,4
Throughput	l/h	115



Temperatures:

Radius [cm]→ Height [cm]↓	10	16	22	34	46	58	70	75,6
140			77				77	
113			1043		667		362	161
97			1129		827		545	306
91		1222		926	804	643	514	331
50	1265	1094	934	755	623	528	414	266
9	1014	872	739	499	357	289	244	166
3			684		351		213	124
-13			686		374		156	83
-40			114				59	

inner pebble layer | Pebble Bed | Insulation | Vessel surface

Gas and power data:

Date		16.07.96
$P_{nominal}$	kW	30,00
$P_{heating\ element}$	kW	27,42
$P_{elektrode}$	kW	1,65
CO_2	Vol. %	0,01
O_2	Vol. %	0
$T_{ambient}$	°C	30,9
$T_{dewpoint}$	°C	-40,5

Cooling water:

Top		
T_{inlet}	°C	20,7
T_{outlet}	°C	39
Throughput	l/h	110
Bottom		
T_{inlet}	°C	21,5
T_{outlet}	°C	37,0
Throughput	l/h	110

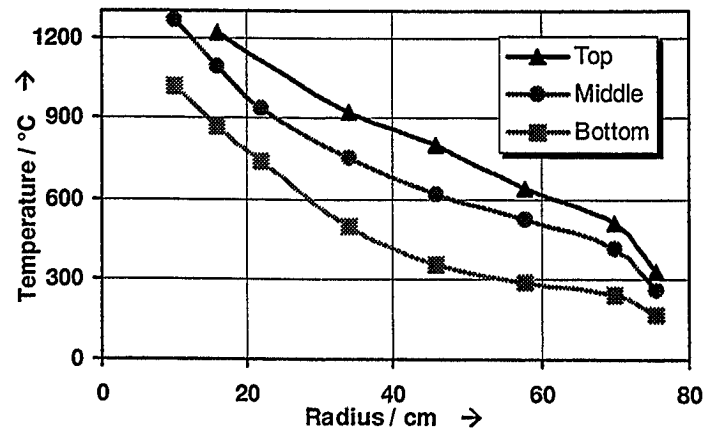


Fig. 40: Stationary tests with long heating element, 65 mm aluminium oxide pebbles, nitrogen, 25 kW (top) and 30 kW (bottom) nominal heating power

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