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Laboratory Continuous Furnace for Sintering of UO_2 Pellets

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Abstract

In connection with the Danish fuel-element development programme a laboratory high-temperature continuous furnace for sintering of UO_2 pellets was designed and constructed at the Danish Atomic Energy Commission Research Establishment Risö. The furnace system, which consists of automatic loading and unloading units, a tube furnace and a temperature-regulation unit, is described together with the steps involved in a typical sintering in the furnace. To illustrate the suitability of the system developed, typical densities, density- and diameter tolerances and impurity contents of UO_2 pellets sintered at 1700°C are given, and finally the experience gained during long-time performance of the system is described.

CONTENTS

1. INTRODUCTION

In the production of UO_2 pellets for fuel elements it is important that the pellets can be sintered to close diameter and density tolerances. This can be achieved rather easily in continuous sintering furnaces, where all pellets are sintered in the same manner, whereas the large temperature variation often found in batch furnaces makes it difficult to obtain small tolerances in batch sintering. Financially, the continuous sintering method will probably also be more attractive than the batch method in large-scale production[1] as it may be supposed to require smaller investments in equipment and less manpower. In connection with the Danish fuel-element development programme a laboratory continuous sintering furnace was therefore designed, constructed and tested to evaluate in detail the advantages of continuous sintering of UO_2 pellets. The report describes the general design of this furnace, its operation and performance as well as the densities, diameters and purity of typical pellets sintered in the furnace.

2. GENERAL DESIGN

The system designed is shown in fig. 1. From left to right it consists of the loading system, the furnace and the unloading lift.

2.1. Loading System

The loading system consists of a stoker and a lift carrying the molybdenum boats that contain the pressed pellets to be sintered (see fig. 6). Fig. 1 shows the stoker and the lift in their positions before the furnace, and the general appearance of the two units is shown in fig. 2.

2.1.1. Stoker

The stoker pushing the boats from the lift into the furnace is moved by a rotating endless screw. The speed can be regulated within 20-120 mm/ hour, whereas the speed in the backward direction is fixed and much higher than that in the forward (pushing) direction to minimize the time the boats are at rest.

To avoid breakage or deformation of the boats if their movement is hindered, the stoker rod is placed in a glide bushing in which it will glide backwards if the resistance becomes too great. The backward movement of the stoker rod activates a microswitch that stops the motor driving the endless screw, and the boats are stopped immediately.

2.1.2. Lift

The lift, which contains six compartments for the molybdenum boats, is moved downwards by a rotating endless screw while the furnace is being loaded. When all boats are loaded, this movement can be reversed to bring the lift back to its starting position in which it can again be filled with boats.

The hydrogen from the furnace, which leaves the lift through the compartment in the loading position, is burned at the point where the stoker goes into the lift. To prevent air from being mixed into the hydrogen during the movements of the lift, the compartments above and below the compartment in the loading position are continuously purged with nitrogen.

2.2. Furnace

A cross section of the furnace is seen in fig. 1, and fig. 3 shows the general appearance of the system. The heating element, which consists of an alumina tube wound with molybdenum wire, is suspended in a gas-tight box. Very efficient insulation is provided by alumina powder surrounding the heating element, and near the walls of the box by insulation bricks. In order that a long zone with uniform temperature may be obtained, the distance between the outer windings of the heating element is smaller than that between the central windings. In the present design, a uniform temperature of 1700^{o}C is obtained in the central 20 cm (total wound length 50 cm).

2.3. Unloading Lift

The boats are unloaded from the furnace by means of the lift shown to the right in fig. 1. This lift, which also contains six compartments, works in the same way as the loading lift, except that it is commanded by a photoelectric cell instead of microswitches. After the lift has been filled up with boats, it can be moved to its starting position, where it can be emptied.

The movements of the unloading lift and the stoker are coupled together electrically so that the stoker is stopped while the lift is moving. In this way it is possible to avoid that the boats are pushed into the moving lift, which would damage the boats.

2.4. Temperature Measurement

The temperature is measured with an optical pyrometer, sighted through a window in the unloading lift into the alumina furnace tube. By means of a black body it was ascertained that black-body conditions exist in the middle of the furnace tube, and the pyrometer readings need only be corrected for absorption in and reflections from the window in the unloading lift.

2.5. Electrical Supply

Power is supplied to the furnace from an induction regulator with a maximum output of 100 amp. at 150 V. A servomotor makes it possible to vary the output continuously from zero to full power. About 75 V and 75 amp. are necessary to reach a sintering temperature of $1700^{\circ}C$.

2.6. Temperature Regulation

Because of the positive temperature coefficient of the resistance of the molybdenum heating element, the furnace is self-regulating within $\pm 15^{\circ}C$. For production sintering and for many sintering experiments this variation is not important, and regulation of the furnace temperature is usually not necessary; more strict regulation and programmed heating and cooling can, however, be obtained with the unit shown in fig. 4.

3. OPERATION

A typical sintering process is carried out as follows: After the lift has been filled with boats, the first boat (from the upper compartment) is pushed into the furnace by the stoker. When the stoker has reached the end of its stroke, it is withdrawn automatically; the lift then descends one stage, and the next boat is in position to be pushed in. The boats push each other through the furnace, where sintering takes place, and out into the exit tube, from which they are removed by the unloading lift. The temperature is checked at regular intervals during the sintering, and the power supply to the furnace is adjusted if necessary. At a stoker speed of 60 mm/hour, corresponding to a heating rate of about $100^{\circ}C$/hour, eight boats can be sintered every 24 hours, six during the night and two during the day.

4. PERFORMANCE

The furnace has been at temperature for several years for research sinterings and for small-scale manufacture of UO_2 pellets for irradiation experiments. The only change observed in the system during this time was a slight increase in the power necessary for the maximum sintering temperature to be reached.

Table I, which gives the results obtained in a typical sintering of UO_2 pellets at 1700 °C, shows the densities, diameters and tolerances that can be obtained in the furnace. From the table it will be seen that pellets can be sintered to close density and diameter tolerances. From fig. 5, which shows the microstructure of a typical UO_2 pellet sintered in the furnace, it will also be noted that no other oxide phases (U_4O_9 for instance) are present in the pellets, which indicates that the furnace atmosphere is essentially free from oxygen. That very little excess oxygen is present in the sintered pellets is moreover evident from table II, which also gives the impurity content of pellets sintered in the furnace as well as that of the starting UO_2 powder.

5. CONCLUSIONS

Sintering experiments as well as several manufacturing runs of UO_2 pellets in the furnace showed that:

(1) UO_2 pellets can be sintered in the furnace to close density and diameter tolerances;

(2) pellets of essentially stoichiometric composition can be obtained, which indicates that the furnace atmosphere is practically free from oxygen;

(3) the characteristics of the furnace are not changed even after very long periods at the maximum sintering temperature.

ACKNOWLEDGEMENT

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REFERENCE

1. R. Hauser et A. Porneuf, Frittage industriel de l'oxyde d'uranium en four continu. IAEA Symposium on New Nuclear Materials Including Non-Metallic Fuels, Prague, 1-5 July, 1963, 1, 137.

Table I

Average density and diameter of samples drawn from a typical batch of sintered UO_2 pellets

Sample no.[x]	Average density[xx]	Sample range (density)	Average diameter[xxx]	Sample range (diameter)
	% TD	% TD	mm	mm
1	95.23	0.40	10.216	0.008
2	95.43	0.40	10.196	0.020
3	95.61	0.50	10.194	0.008
4	95.59	0.35	10.191	0.009
5	95.65	0.30	10.191	0.016
6	95.03	0.10	10.208	0.012
Average of all pellets	95.42	0.34		0.012

x Sample size 5 pellets.

xx The densities were determined by buoyancy measurements in water.

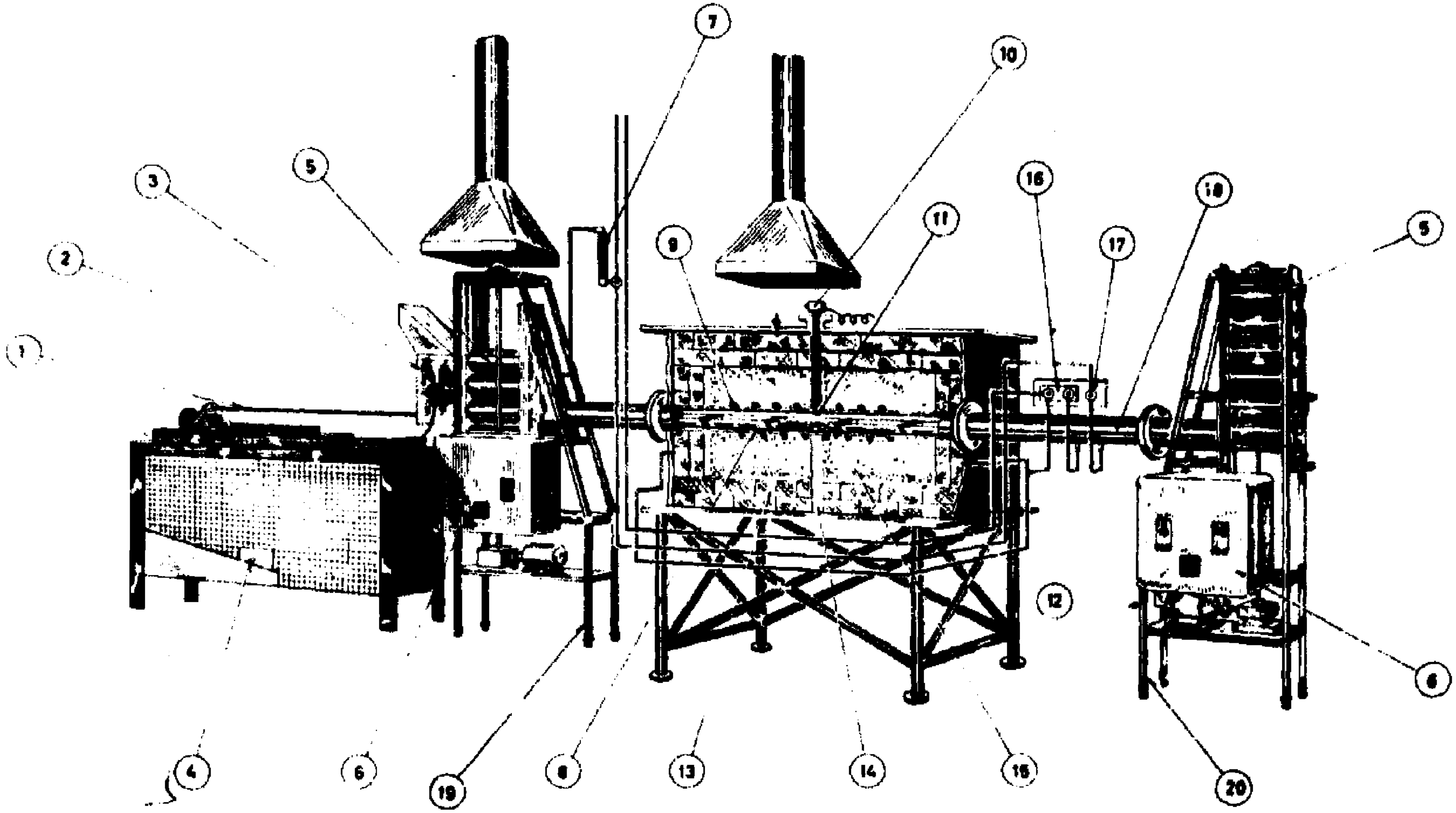
xxx Two diameters were measured on each pellet, at one end and in the middle of the pellet. All measurements in one sample are averaged.

Table II

Purity of UO_2 powder and UO_2 pellets sintered in the continuous sintering furnace. Impurities in powder taken from suppliers' specifications (max. values)

Element	Impurity content in UO_2 powder (ppm on U-basis)	Impurity content in UO_2 pellets (ppm on U-basis)
B	0.08	0.1
Cd	0.07	10
Cr	1	1
Cu	1	1
Mg	3	1
Mo	2	2
Pb	1	1
V	6	1
Zn	20	5
Fe	30	1
Mu	2	0.1
Ni	5	1
Si	30	1
Al	35	1
Excess oxygen %	2.08	2,0065

CONTINUOUS SINTERING FURNACE



1 STOKER
2 FLAME CONTROL
3 FLAME SHIELD
4 SPEED REGULATION
5 COMPARTMENTS FOR BOATS
6 ELECTRIC REGULATION UNIT
7 FLOW METER FOR PURGING GAS
8 ALUMINA TUBE
9 MOLYBDENUM HEATING ELEMENT
10 THERMOCOUPLE
11 ALUMINA TUBE (BLACK BODY)
12 ALUMINA POWDER
13 INSULATING BRICKS
14 ALUMINA SUPPORT TUBE
15 MOLYBDENUM BOATS WITH PELLETS
16 HYDROGEN VALVES
17 NITROGEN VALVE
18 EXIT TUBE
19 LIFT FOR LOADING
20 LIFT FOR UNLOADING

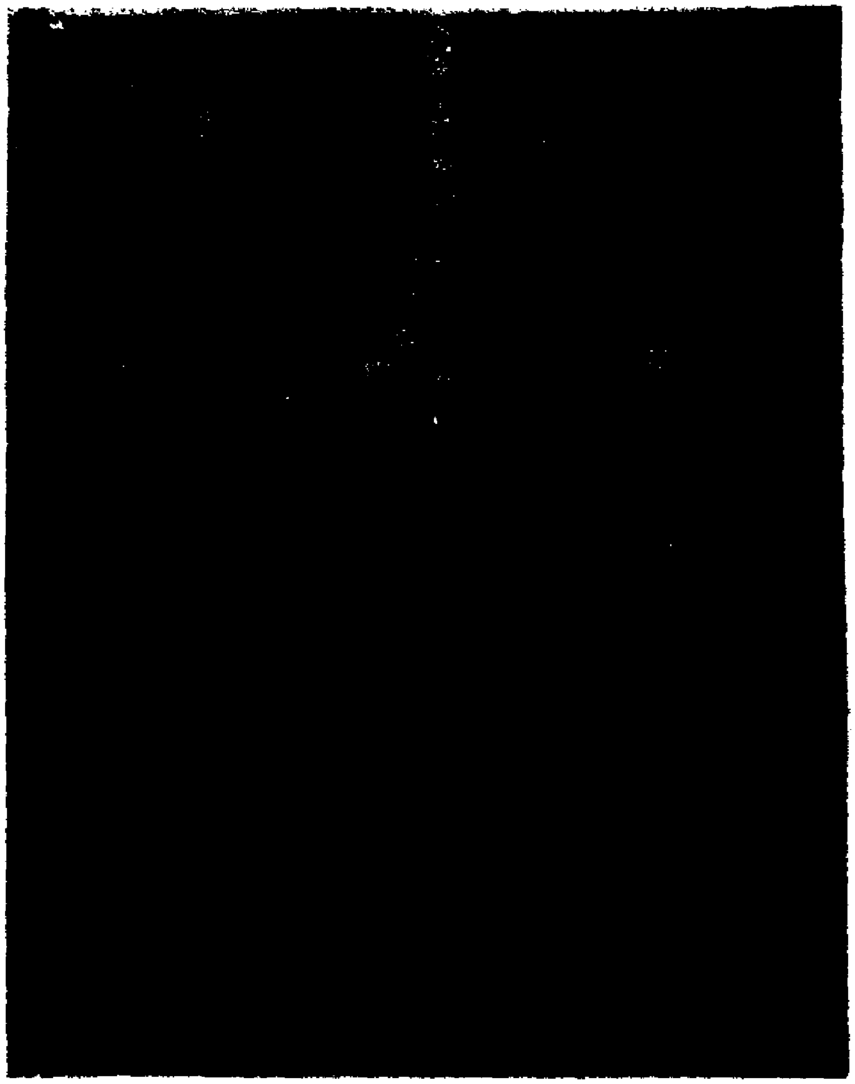


Fig. 2. Loading system consisting of stoker and lift. The system is shown in its position before the furnace.

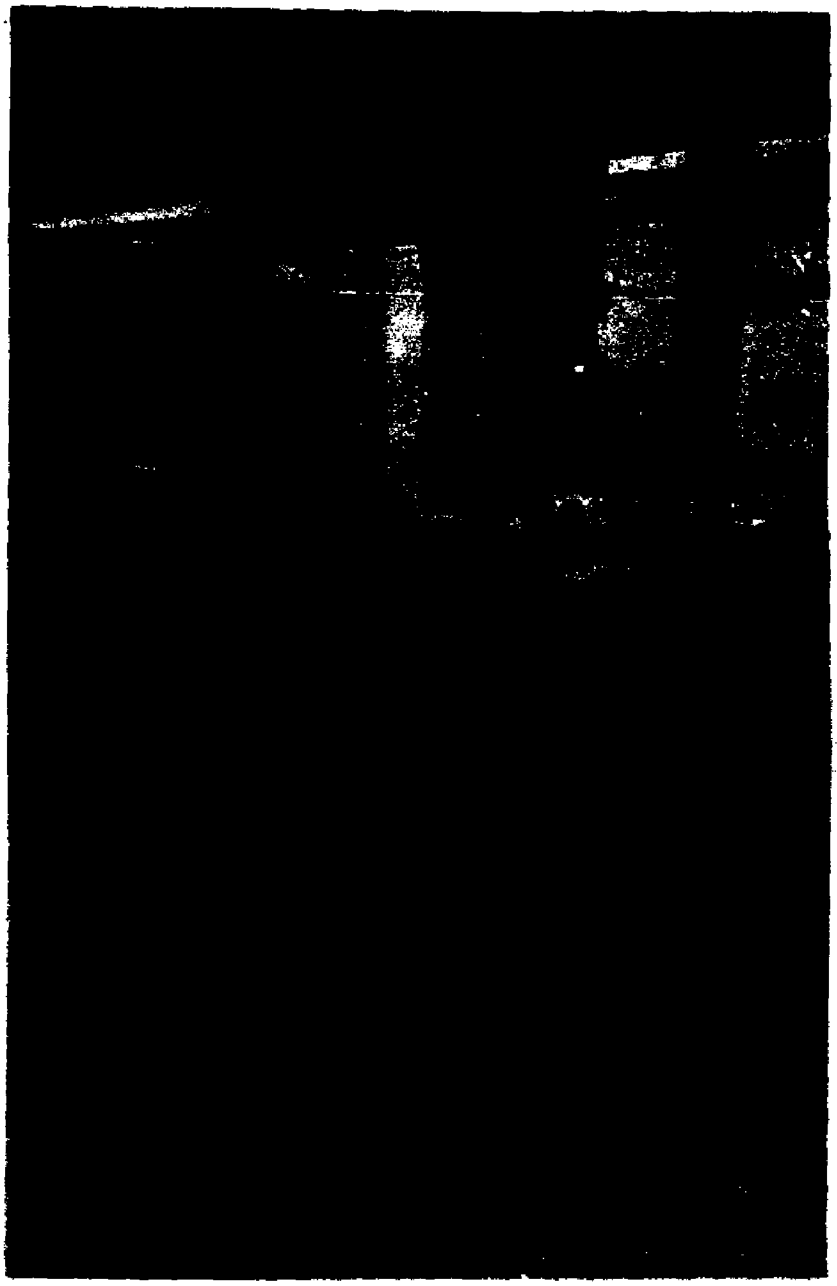


Fig. 3. Sintering furnace seen from the exit end.

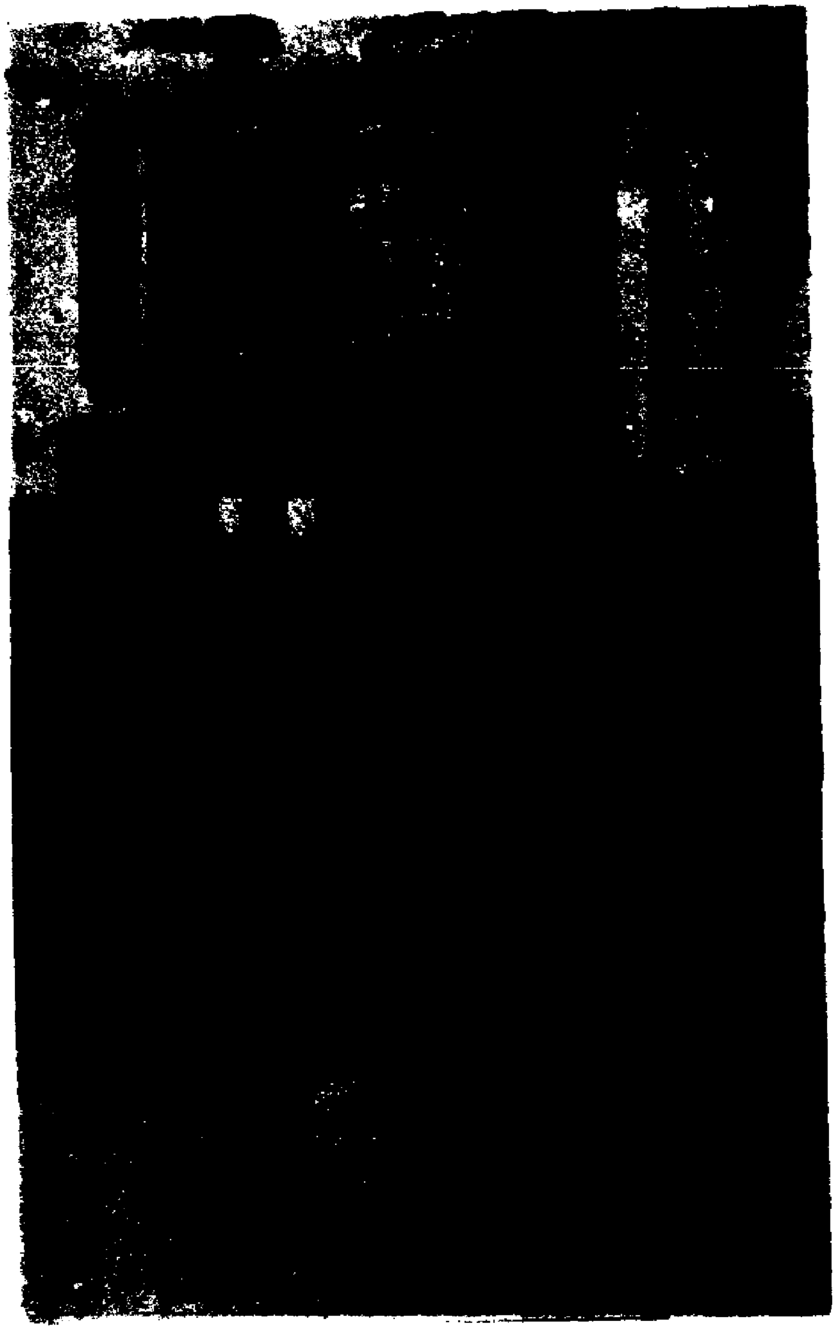


Fig. 4. Temperature regulation unit. The transformer is seen below the cupboard.

Fig. 5. Microstructure of a UO_2 pellet sintered in the furnace. The pellet was prepared from Degussa UO_2 powder.

Fig. 6. Molybdenum boat with UO_2 pellets sintered in the furnace.