

ROTARY CASCADE RETORT FURNACE FOR THE MANUFACTURE OF
HTR FUEL ELEMENT KERNELS

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PDF - S. VILJOEN 30/10/2006

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ABSTRACT

The production of nuclear fuels requires in all cases thermal / thermochemical treatments for different processes such as calcining, debinding, reduction, sintering or coating. Especially the sintering process is usually done in pusher or walking beam furnaces under considerably high temperatures.

Even if such furnaces have proven to be reliable and have been used in the industry for many years, there is still room for improvement in view of reliability and product quality by using a different furnace design for the production of HTR fuel element kernels.

The rotary cascade retort furnace consists of an inclined tube which is supported on both ends. Inside of the tube mold shaped parts (cascades) are installed. The bottom of these mold shaped parts is equipped with an aperture which leads the fuel kernels to the subsequent section. As the apertures are shifted by a certain angle from one mold shaped part to the other, the fuel kernels are gently guided to the next section (like a cascade) when the tube is rotating. The residual share of the bottom of the mold shaped parts is slightly more than 50 %. This avoids a bypass for the fuel kernels and it acts as a radiation shield for heat insulation purposes.

As a result, this arrangement leads to an optimized intermixture of the agitated fuel kernels in one section but avoids the intermixture with the neighbor section in the cascade. Further, a well-defined flow of fuel kernels along the furnace is achieved.

These are the most important premises for the desired uniform quality distribution of the fuel kernels and

for the prevention of crack formation in the fuel kernels during the subsequent heat treatment process.

Since the tube diameter can be kept far below the specified critical diameter of 168 mm for fuel kernels, the rotating tube furnace is inherently safe against a possible accumulation of a critical mass.

REQUIREMENTS FOR THE PRODUCTION OF FUEL KERNELS

The fuel kernels of the spheres for the HT-PBMR are microspheres made of uranium oxide (UO₂) of low enriched uranium, with a diameter of 500 μ m.

The kernels are manufactured in a gel precipitation process.

The kernels are heat treated (dried, calcined, reduced and sintered) after dropping and washing. During heat treatment the kernels shrink considerably. Consequently, the kernels are highly strained due to the stress caused by the shrinking (Fig. 1)

Shrinking of Kernels after Shaping

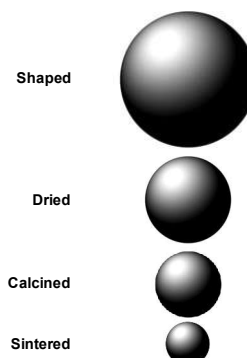


Figure 1

The gel structure of the UO₂-kernels is very complex. Furthermore, the valence of the uranium changes from 6 to 4 during heat treatment, leading to a transformation in the crystal lattice. This causes additional internal stress on the UO₂-kernels. The complex gel structure and the change in valence is UO₂-specific and does not apply to Thorium Oxide ThO₂. (Fig. 2)

Gel Precipitation of Microspheres for Preparation of UO₂ and ThO₂ Fuel Kernels

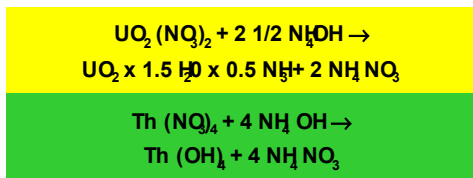


Figure 2

SINTER FURNACES OF TODAY

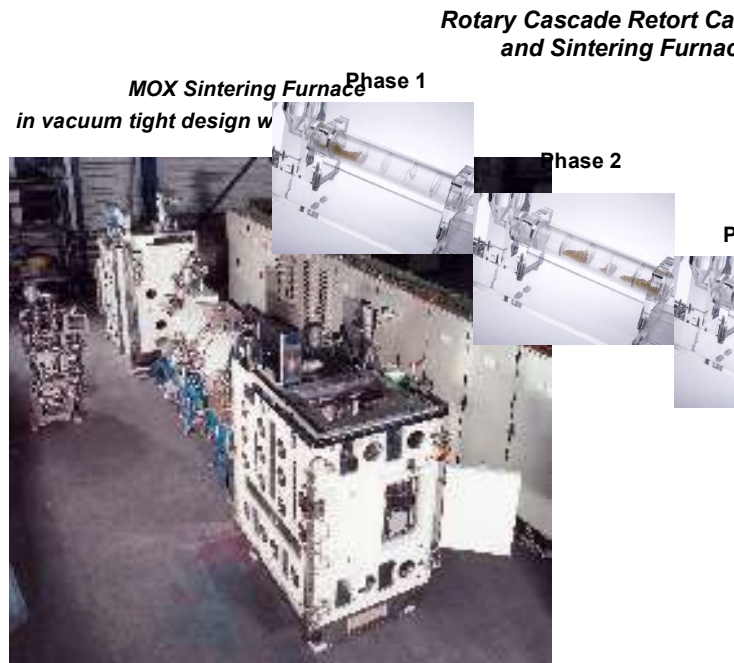
The state of the art furnaces for today's production of nuclear fuels are batch furnaces (horizontal or vertical) for small capacities. Larger production volumes are sintered either in pusher furnaces or walking beam furnaces. These two designs have proven their reliability in the industry for many years. Fig. 3 shows a pusher furnace for UO₂ pellets in an "open design".



Sintering Furnace for UO₂ Pellets

Figure 3

Fig. 4 shows a pusher furnace for MOX-pellets in a



vacuum-tight design with a continuous pusher unit.

Figure 4

These furnaces are thermally insulated by a special ceramic brick lining, with molybdenum heaters. The pellets are stacked on boats which are pushed through the furnace and have to be transported back in a closed loop to the entrance side of the furnace after being unloaded.

In addition to the described furnace types a number of rotary retort furnaces for calcining, reduction from U_3O_8 to UO_2 or hydrofluorizing UO_2 to UF_4 are available in the market.

Our company (ALD / Degussa) has outstanding experience in designing and manufacturing all kind of such furnaces (Fig. 5).

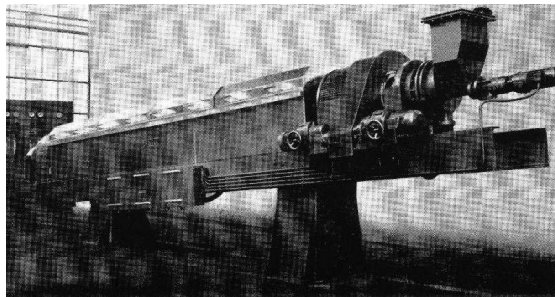


Figure 5

REQUIREMENTS FOR HTR FUEL ELEMENT KERNELS

The performance of heat treatment which is required to produce crack-free UO_2 -kernels in sufficient quality must meet high standards. (Fig. 6)

UO_2 Fuel Kernels Surface Appearance

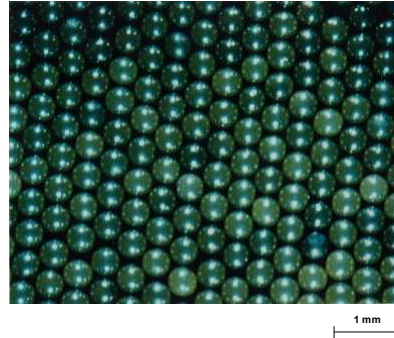


Figure 6

To meet these standards a smooth movement of the kernels during calcining, reducing and sintering has proven to be a great advantage.

We (ALD) have designed a cascade rotary retort furnace for calcining, reducing and sintering of fuel kernels for HT-PBMR spheres which was also tested in a model with dummy material. The furnace is designed for argon-hydrogen atmosphere and a max. temperature of approx. 1700 °C.

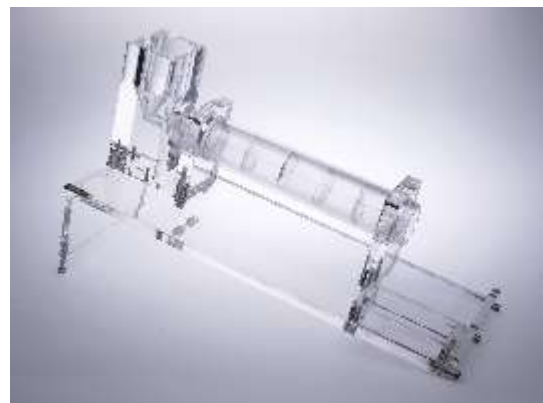
DESIGN AND FUNCTION OF THE ROTARY CASCADE RETORT FURNACE

The rotary retort furnace consists of an inclined retort which is supported on both ends. Inside of the retort a cascade of crucibles is installed.

The model of the furnace is shown in Fig. 7.

Fig. 7

Rotary Cascade Retort Calcining and Sintering Furnace



The crucibles and the retort are made from molybdenum. The bottom of these crucibles is

provided with an opening which leads the fuel kernels to the next section. As the openings are shifted to a certain angle from one crucible to the next, the fuel kernels are gently guided to the next section (like a cascade, see Fig. 8) when the retort is rotating.

Figure 8

Three rounded barriers with a height of approx. 1 mm on the inner wall of the cascade keep the kernels in a constant rolling motion and keep them from sliding on the cascade's inner wall. The remaining part of the bottom of the crucibles is slightly more than 50 %. This prevents the fuel kernels to pass through all crucibles at one time. It also serves as a radiation shield for thermal insulation.

As a result this arrangement leads to an optimized mixture of fuel kernels in one section and avoids mixing with the next section of the cascade. Furthermore, a well-defined flow of fuel kernels along the furnace is achieved.

These are the most important features of the fuel kernels' required uniform distribution and the prevention of crack formation in the fuel kernels during the heat treatment process.

In the inside of the retort which is 100 mm in diameter and 2200 mm long, 20 crucibles with a volume of approx. 850 ml each can be installed. Assuming the volume of one crucible is filled to 1/3 with particles and the packing density of the particles is 50 Vol. %, it is possible to produce approx. 18 kg heavy metal, which is equivalent to 20 kg UO₂-kernels in this furnace per day (24 hours). These figures were based on a geometric density of the calcined particles of approx. 2,8 g/cm³ and a rotational speed of 30 minutes for one rotation of the retort. For a cycle time of 12 hours for the kernels the total weight content of the UO₂-kernels in the furnace is 10 kg. The specified level of enrichment of 7,8 % on U-235 results in a total content of approx. 700 g U-235 in the furnace.

This value clearly ranges below the admissible value of 1000 g. Therefore, the specified furnace is inherently safe regarding criticality.

Further to all of these improvements there is no risk for boat jamming or to build up a critical mass of fuels. There is also no longer a need to transport the pusher trays/boats in a circle, as the rotary cascade retort furnace works without such equipment.

As an option to the reduction and sintering furnace it is also possible to build a calcining furnace. Since the maximum calcination temperature of 300 °C is considerably lower, stainless steel should be used as material for the rotary retort and the crucibles.

SUMMARY

The production of nuclear fuels require a number of thermal treatments of pellets or kernels. These processes have proven reliable and are well-established in the industry. The requirements to ensure the process parameters and the treatment results are sufficiently met with the furnace designs used nowadays. To further improve product quality, especially of the HTR fuel element kernels, a gentle movement of these parts during sintering is necessary. The described Rotary Cascade Retort Furnace offers a lot of improvements by ensuring constant and high product quality. The furnace design also offers a very simplified system.

REFERENCES

- [1] Degussa-Brochure "Sinter Furnaces for Nuclear Applications"
- [2] Patent DE 10204166B4, "Process for the production of the fuel kernels for HTR fuel elements by continuous roll-over of the kernels during calcining and reduction/sintering in a rotary cascade retort furnace and design of such furnace", 2004
- [3] Pictures from ALD's records