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# Effect of Sintering Atmosphere on the Microstructure of High $Gd_2O_3$ $UO_2$ Nuclear Fuel

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## 1. Introduction

In light water reactors, electrical energy is generated through nuclear fission within $UO_2$-based fuel pellets. At the beginning of the fuel cycle, excess reactivity must be effectively controlled to ensure safe and stable operation. To suppress this excess reactivity, burnable absorbers (BAs) are incorporated directly into the fuel matrix. Among various BA materials, gadolinium (Gd) is widely used due to its high neutron absorption cross section and chemical compatibility with $UO_2$ [1].

Recent trends in nuclear fuel development emphasize high-burnup operation, extended fuel cycles, and advanced reactor systems such as small modular reactors (SMRs). In particular, boron-free core concepts eliminate soluble boron from the coolant, thereby simplifying reactor systems and enhancing maintainability. The absence of soluble boron consequently increases reliance on integral burnable absorbers within fuel pellets. Furthermore, the move toward higher U-235 enrichment beyond conventional limits requires increased burnable absorber content to maintain appropriate reactivity margins.

Despite these advantages, incorporating high amounts of $Gd_2O_3$ into $UO_2$ fuel introduces fabrication challenges. Increasing $Gd_2O_3$ content alters defect chemistry and diffusion behavior during sintering, often leading to reduced densification and modified pore evolution. These microstructural changes directly affect the structural stability and performance reliability of the fuel [2,3].

The role of oxygen potential during sintering has been recognized as a key factor governing densification behavior in $UO_2$-based fuels. Yuda and Une [4] investigated the initial sintering behavior of $UO_2$–(5,10 wt%)$Gd_2O_3$ compacts under controlled oxygen potentials and reported that variations in oxygen potential significantly affected shrinkage behavior and densification kinetics through changes in diffusion coefficients. Similarly, Song et al. [5] analyzed $UO_2$–$Gd_2O_3$ pellets sintered under different atmospheric conditions and demonstrated that oxygen potential influences pore evolution and final sintered density through defect-chemical mechanisms.

However, most previous investigations focused on low to intermediate $Gd_2O_3$ contents. Systematic studies addressing the role of sintering atmosphere in high-content solid-solution fuels remain limited. Therefore, this study investigates the effect of sintering atmosphere on the densification behavior of 17 wt% $Gd_2O_3$ $(U,Gd)O_2$ solid-solution nuclear fuel.

## 2. Experimental & Results

In this study, 17 wt% $Gd_2O_3$ $(U,Gd)O_2$ fuel pellets were fabricated, and the effect of sintering atmosphere on densification behavior was investigated. Green pellets were prepared by uniaxial pressing under identical forming conditions to minimize variations in initial density. Sintering was conducted at 1730 °C for 4 hours, while the $CO_2$ content in the sintering atmosphere was adjusted to 1, 3, and 5 vol% to control the oxygen potential. The density of the sintered pellets was evaluated using Archimedes' principle.

Fig. 1 shows photographs of the green and sintered pellets. All samples maintained uniform geometry after pressing, and no macroscopic cracks or structural defects were observed after sintering. Dimensional shrinkage during sintering confirmed effective densification.

Fig. 2 presents the relative density (%TD) of the sintered pellets as a function of $CO_2$ concentration in the sintering atmosphere. A gradual increase in relative density was observed as the $CO_2$ content increased from 1 vol% to 5 vol%, with the highest density obtained at 5 vol% $CO_2$.

Optical microscopy confirmed the absence of macroscopic defects and indicated a homogeneous solid-solution structure. Slight variations in pore distribution and morphology were observed depending on the sintering atmosphere, with a more uniform pore distribution under higher $CO_2$ conditions.

X-ray diffraction analysis verified the formation of a single-phase $(U,Gd)O_2$ solid solution in all samples, with no detectable residual $Gd_2O_3$ phase. Minor shifts in diffraction peak positions were observed between different atmospheric conditions, suggesting variations in lattice defect structure associated with changes in oxygen potential.

The densification trend observed within the present $CO_2$ range is consistent with previously reported behavior in the low oxygen potential regime. Unlike higher $CO_2$ ratios reported in earlier studies, the present experimental range (1–5 vol%) remained within the densification-favorable region.

These results demonstrate that control of the sintering atmosphere plays an important role in governing densification behavior and microstructural evolution in high-content $Gd_2O_3$ nuclear fuels.

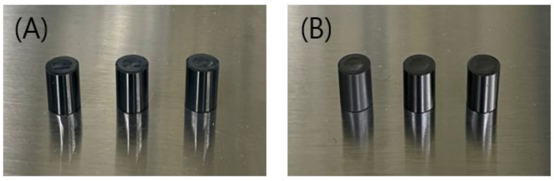

Fig. 1. Photographs of (A) green pellets and (B) sintered pellets containing 17 wt% $Gd_2O_3$ $(U,Gd)O_2$.

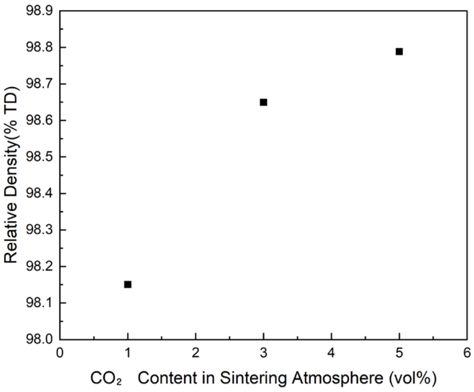

Fig. 2. Relative density of 17 wt% $Gd_2O_3$ $(U,Gd)O_2$ pellets as a function of $CO_2$ concentration in the sintering atmosphere.

## 4. Conclusions

This study investigated the effect of sintering atmosphere on the densification behavior of 17 wt% $Gd_2O_3$ $(U,Gd)O_2$ nuclear fuel pellets. All fabricated pellets maintained structural integrity after sintering at 1730 °C for 4 hours, forming a single-phase solid solution without detectable residual $Gd_2O_3$.

Relative density increased systematically with increasing $CO_2$ concentration in the sintering atmosphere, with higher $CO_2$ conditions promoting enhanced densification. These findings indicate that oxygen potential during sintering significantly influences densification behavior in high-content gadolinia fuels.

The results suggest that controlled adjustment of $CO_2$ concentration can serve as an effective process parameter for optimizing fabrication conditions of high-content burnable absorber nuclear fuels.

## ACKNOWLEDGEMENT

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