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PRELIMANARY STUDY TO PREDICTION OF OXIDATION GRAPHITE SHELL FUEL OF HTGRON ATWS CONDITION

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ABSTRACT

PRELIMANARY STUDY TOPREDICTION OF OXIDATION GRAPHITE SHELL FUEL OF HTGRON ATWS CONDITION. One form of fuel HTGR is a sphere shape. Spherical fuel of high temperature gas-cooled reactor (HTGR) is coated in graphite. One of the causes of the weakness of graphite structure is due to graphite degradation. One of the accidents occurring in a high temperature gas cooled reactor(HTGR) type is air in-leakage to the primary systemcalled air ingress. Air ingress is preceded by a pressure drop (D-LOFC) that leads to the degradation of the graphite shell fuel due to chemical reactions between oxygen and graphite at temperatures above 950 ^{0}C and heating reactor core. The events of air ingress occurs in conditions of D-LOFC on the anticipated transient without scram (ATWS). The air ingress is considered as hypothetical scenario. The purpose of this study is to find out the strength of the structure of the graphite shell of HTGR due to oxidation occurring on air ingress-D-LOFC conditions. To determine the effect of oxidation on the integrity of the fuel shell structure, the rate of oxidation is estimated using computational simulations with GRSAC Code. The computational simulationused the data PBMR 400 MWt. The computational simulation is resulted in an oxidation rate of 300 g/min for 60 hours with an ATWS delayed of 2,000 minutes with depressurization for 50 minutes.Fractional weight loss due to oxidation of 0.49 with a time of 125 hours is obviously smaller than the Idaho National Laboratory (INL) results of 0.647.Therefore, strength of the mechanical structure of graphite fuel shell is still in good condition.

Keywords: Shell Graphite, Oxidation rate, Mechanical strength,ATWS, GRSAC code.

ABSTRAK

STUDI AWAL UNTUK MEMPREDIKSI OKSIDASI GRAFIT SHELL BAHAN BAKAR HTGR PADA KONDISI ATWS. *Salah satu bentuk bahan bakar HTGR adalah bentuk bola. Bahan bakar bola tipe reaktor berpendingin gas bersuhu tinggi (HTGR) dibungkus dengan grafit. Salah satu penyebab kelemahan struktur grafit adalah karena degradasi grafit. Salah satu kecelakaan yang terjadi dalam reactor tipe HTGR adalah masuknya udara ke dalam rangkaian system primer yang disebut dengan air ingress. Kecelakaan masuknya udara didahului dengan penurunan tekanan (D-LOFC) yang menyebabkan degradasi bahan bakar grafit shell akibat reaksi kimia antara oksigen dan grafit pada suhu di atas 950^{0}C dan pemanasan teras reaktor. Peristiwa ingress udara terjadi pada kondisi D-LOFC pada transien yang diantisipasi tanpa scram (ATWS).Untuk skenario hipotetis ini, dilakukan pada peristiwa air ingress. Tujuan dari studi ini adalah untuk mengetahui kekuatan struktur mekanik shell grafit HTGR akibat oksidasi yang terjadi pada kondisi air ingress-D-LOFC. Untuk mengetahui dampak oksidasi integritas struktur shell bahan bakar, laju oksidasi diestimasi menggunakan simulasi komputasi dengan GRSAC code. Simulasi komputasi menggunakan data PBMR 400 MWt. Hasil simulasi komputasi diperoleh laju oksidasi sebesar 300g/min selama 60 jam dengan waktu tunda ATWS selama 2000 menit dengan depressurize selama 50 menit. Fraksi kehilangan berat selama oksidasi sebesar 0,49 dengan waktu 120 jam, lebih kecil dari hasil INLyaitu 0,647. Oleh karena itu, kekuatan struktur mekanik shell grafit bahan bakar HTGR masih kondisi baik.*

Kata kunci: Shell Grafit, laju oksidasi, Kekuatan mekanik, ATWS, Code GRSAC

INTRODUCTION

Experimental power reactor is a type of high-temperature reactor using helium gas as a coolant. One form of high temperature reactor fuel is a spherical fuel element. UO_2 fuel kernel in a matrix containing graphite coated PYC and SiC or ZrC[1-3]. In addition, graphite is relatively inert chemically, thermally highly conductive, have a high heat capacity, easy to make, and has excellent mechanical properties at high temperatures. Therefore, the main component of the terrace as a moderator and reflector of neutrons, fuel element, cladding, as well as in the core structure are designed using graphite material.As discussed by Zhou et al. [1], nuclear grade graphite is widely used as matrix of the spherical fuel elements, thereflectors, and structure material of the HTR-PM. The depresurization and core heat-ups can cause air ingress. Although this is considered to be an 'beyond design base accident' (BDBA), it gets high attention because it can cause oxidation of the reflector graphite and fuel elements so that it can weaken the strength of the structure and decrease the ability of coated particles to maintain the fission product.K. Vierow, K. Hogan, et al discussed about identified for a postulated Loss of Forced Circulation event in a Pebble Bed Modular Reactor[2]. Accidents that occur at high temperature reactor is to have two types; the pressure loss of force coolant (P-LOFC) and depressurize loss of force coolant (D-LOFC) following an accident transients without scram (anticipated transient without scram). Efrida Saragi, et.al has discussed to determine the temperature profile experienced by the fuel on accident scenarios P-LOFC and D-LOFC with ATWS[3].

Anticipated transients without scram (ATWS) accidents are usually follow-on events to LOFC events and involve the control and safety rods, along with the reserve shutdown system (RSS) or small absorber spheres (SAS) not functioning, or with one or more control rods withdrawing at the time of LOFC initiation. Accidents that occur at high temperature reactor are the air ingress or water ingress due to depressurization . After the depressurization stage, it is supposed that air enters the reactor core from the breach due to molecular diffusion and natural circulation of a multi-component gas mixture induced by the distribution of gas temperature and the resulting concentrations in the reactor. Carbon monoxide (CO) and dioxide (CO_2) are produced in the reactor, because the oxygen (O_2) contained in air reacts with the high temperature graphite structures[4-6]. Sign water or water into the main circuit to the terrace will corrode the graphite and accelerated by high temperatures. Chen Zhipeng, et al had discussed rate and severity of the air ingress and potential for oxidation in the 200 MWe Pebble bed Modular High Temperature gas-cooled Reactor (HTR-PM)[4]. One of accidents that occur at high temperature reactor is the air ingress. Liu Peng, et al had discussed on air ingress of the 200 MWe pebble-bed modular [5]. The consequence of air ingress is delayed (delayed entry of air) then depressurization accident occurred at high temperature reactor [5-6]. Therefore, in the case of air ingress conditions on ATWS conditions need to be considered[9-10]. Temperature is an important factor in oxidation process and had a role in the process of degradation due to interaction air with the graphite (air ingress)[12-16]. In 2012, Chang H. Oh, Eung Soo Kim had discussed various water ingress mitigation concept applies to VHTRs that will prevent core damage even in the most extreme scenario[14].

The operating and accident temperatures in the core following a D-LOFC, air ingress could cause significant oxidation. Air ingress into the primary system is a safety concern because of the damage it could cause by oxidizing graphite structures and perhaps other components within the vessel and primary system, and by oxidation damage to the fuel (TRISO particles). The purpose of this study is to predict the strength of the graphite shell of HTGR due to oxidation occurring on D-LOFC conditions.Input data using the data of PBMR 400 MWt. The expected result is the mechanical strength of the graphite due to oxidation on ATWS-DLOFC conditions. The analytical method used is the computational modeling of oxidation rate using GRSAC code [3,6,11,15]. The effect of graphite oxidation on mechanical strength is calculated analytically.

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THEORY

Factors that cause degradation of the graphite structure which is resulted in the weakening of mechanical strength of graphite as shown in Figure 1.

Figure 1. Root causes of air-ingress accident [17,19]

As shown in the middle of Fig. 1, the weakening of the graphite structure is caused by (1) oxidation, and (2) high temperature. The root cause of these conditions originates from the temperature and molecular mass differences between the inside and outside of the reactor vessel[14-15]. The oxygen is the main reactant. Graphite oxidation cannot occur without air ingress. Oxidation (air inlet) is the reaction of oxygen with graphite depending on the temperature.The model for heat exchange from the coolant to the adjacent solid node at temperature Ts is used exponential approach method [16].

$$T_{co} = T_{ci} + (T_s - T_{ci})\ (1 - e^{-hA/WC_p}) \tag{1}$$

where;

T_{ci} is the coolant inlet temperature
$T_{co}$is the coolant outlet temperatures
T_s is temperature of surface
W is helium mass flow, kg/s
C_p is helium specific heat
h is heat transfer coefficient
A is cross section of the core ,m^2

The chemical reaction that occurs is: C + xO_2→yCo + z CO_2 [4],[15-16]. The oxidation rates and structural failure are greatly affected by how fast the air ingresses. The high temperature in the reactor accelerates the graphite oxidation because the oxidation reaction exponentially increases with temperature according to the Arrhenius model. The purpose of this study was to determine the mechanical strength due to oxidation of the graphite. Effect of graphite oxidation to the mechanical strength by the following equation[4];

$$\frac{S}{S_o} = \exp\ (-10x) \tag{2}$$

where; x = fractional weight loss due to oxidation
S = tensile strength

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METHODOLOGY

The high temperature reactor is postulated on the condition anticipated transients without scram (ATWS). Postulations accident is the inclusion of air into the primary circuit and toward the reactor core (referred to air ingress). The calculation of the rate of oxidation of graphite using GRSAC code. Stages of the process undertaken to determine of oxidation rate using GRSAC code as follows. The first process is to select a scenario of an accident, and type of fuel. The second process is to provides input data. Input data on GRSAC code design consists of eight categories Nuclear design, core layout design, primary cooling design, graphite prop.& materials oxidation, reactor cavity design, vessel design, fuel element design. Design arrangement of fuel for the reactor core using GRSAC code as shown in Figure 2. . The third process is ATWS. The ATWS condition requires time delayed scram and on D-LOFC accident conditions is select to depressurization.

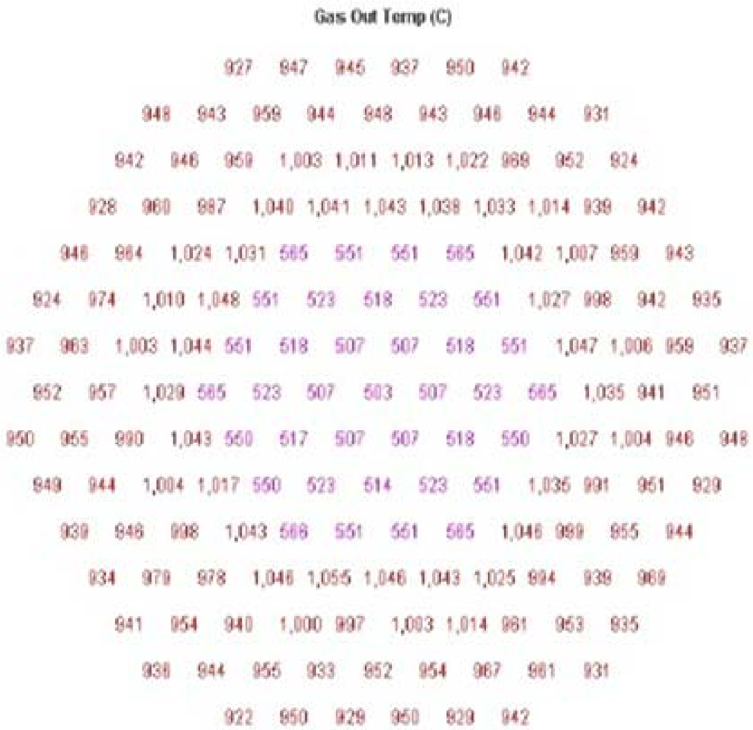

Figure 2. Display fuel arrays using GRSAC [1,3,15,16]

On enter data for cavity reactor is as follows. Reactor cavity design are required data i.e. shield cooler/reactor cooling cavity system (RCCS) area, reactor cavity effective, cavity wall thickness, vault (cavity) volume, air flow into vault, temperature inlet RCCS, flow RCCS coolant, air ingress chimney (on or off), chimney height. In P-LOFC accidents condition, air ingress chimney flag is off. The D-LOFC accidents condition is ON because this condition had occurred loss of coolant (leaked)[3],[16]. The ATWS condition requires time delayed scram and on D-LOFC accident conditions is select to depressurization. Air ingress is preceded by a depressurization accident. Anticipated transients without scram (ATWS) accidents are usually follow-on events to LOFC events and involve the control and safety rods, along with the reserve shutdown system (RSS) or small absorber spheres (SAS) not functioning, or with one or more control rods withdrawing at the time of LOFC initiation. The standard ATWS option in GRSAC is for no negative reactivity insertion, and involves checking the Delayed Scram box in the Programmed Inputs screen in addition to the other inputs as appropriate for the LOFC case[17]. The delay time for a scram to occur can be entered as a preprogrammed scram time, or set as a very large number to ensure that a scram is avoided throughout the entire run**.** The onset of air ingress is assumed to begin immediately, 2000 minutes (h) and 2500 minutes[15-16] with depressurization time of 50 minutesand 100 minutes. For the simulation data using the data input PBMR 400MWt as shown in Table 1. And input data on GRSAC code using Table 1.The result of program in graphical using a postprocessor program on GRSAC software.

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Table 1. Operating Parameters of PBMR 400 MWt[1],[3-6],[14], [15-24].

Parameter	Units	Value
Core full (rated) power	MW(t)	400
RPF decay heat smear factor	dl	0.9
Fraction of refl. heat full power	dl	0.021
Side refl. bypass flow fraction	dl	0.13
Center refl. bypass flow fraction	dl	0.05
Core (active) outer diameter	m	3.7
Core (active) height	m	11
Central reflector diameter	m	2
Initial primary pressure	MPa	9
Initial total mass flow	Kg/s	192.5
RCCS (water) cooling flow	Kg/s	20
RCCS cooling T-inlet	^{o}C	28
Core inlet temp	^{o}C	496
Core outlet temp	^{o}C	900
Ambient air temperature	^{o}C	32
Outlet reflector height	m	1.5
Inlet reflector height	m	1.5
Side reflector outer diameter	m	5.7
Vessel inside diameter	m	6.2
Vessel thickness	m	0.2
Inlet plenum height	m	1
Outlet plenum height	m	1
RCCS emissivity	dl	0.75
Reflector emissivity	dl	0.8
Vessel inside emissivity	dl	0.8
Vessel outside emissivity	dl	0.75
Core barrel inner diameter	m	5.76
Bed void mean value	dl	0.383
core pressure drop	MPa	0.31

RESULTS AND DISCUSSION

Oxidation will cause degradation of the graphite structure, and increase the local load (stress). Internal oxidation between oxygen and graphite will invade the pore structure of graphite resulted in the weakening of mechanical strength. The results of computational simulation on D-LOFC condition are obtained the fuel temperature, the rate of oxidation of graphite on air ingress conditions. The temperature dependence of oxidation behavior for the graphite was investigated using GRSAC code. The model for heat exchange from the coolant to the adjacent solid node at temperature of surface used equation 1. The result of the calculation using equation 1. as shown in Fig.3.From Fig. 3, the graphite shell fuel temperature began to rise and reached a maximum temperature at 1650 ^{o}C within 40 hours and then dropped until 1320 ^{o}C within 100 hours. The increase of temperature is caused of loss of forced helium flow and loss of coolant (leak).When temperature of the shell fuel is higher than 600 °C, oxygen was almost dissipated by the structure of graphite [18,26]. This can occur because, at this temperature, good chemical reactivity and significantly increase the pore diffusion.

Based on the temperature profile shown in Fig. 3, the oxidation rate can be calculated using GRSAC code and the results are shown in Fig. 4.From Fig. 4, the rate of oxidation decreases slightly and then increases slowly until it reaches the level of the highest oxidation and finally down. Oxidation will occur air ingress. Air ingress caused degradation of the graphite shell fuel due to chemical reactions between oxygen and graphite.In Figure 4.a, the oxidation rate obtained on ATWS condition with Air ingress - DLOFC of 298 grams/min. The oxidation rate shown in Figure 4.a. is greater than that shown in Figure 4.b. This suggests that the rate of oxidation is affected by depressurization time. A faster depressurization time will result in material degradation. Based on the oxidation rates shown in Fig. 4, oxidation percentages versus times can be calculated as shown in Fig. 5.

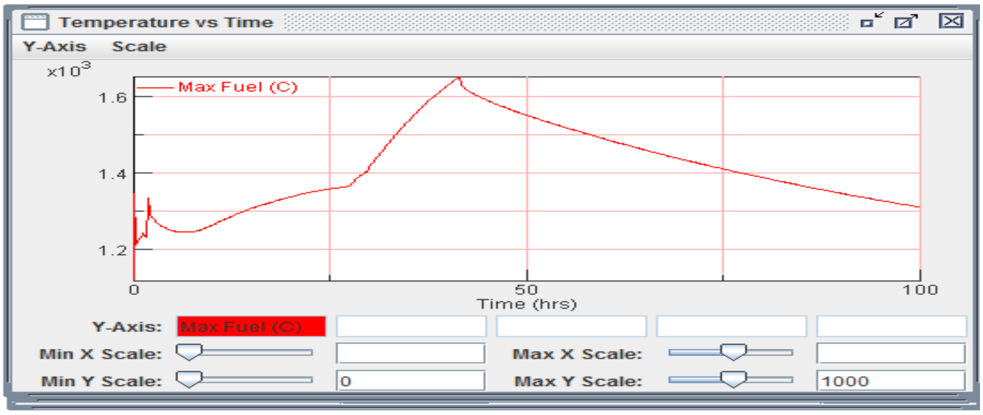
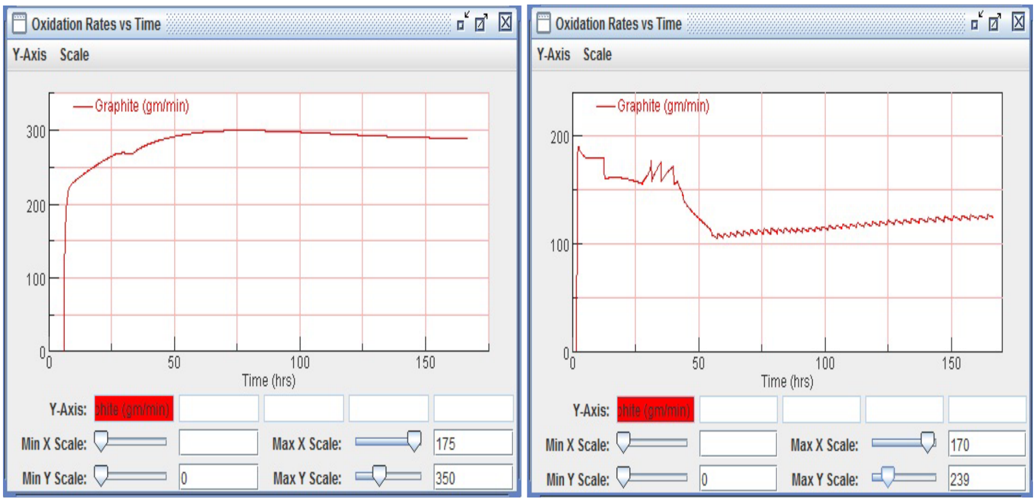


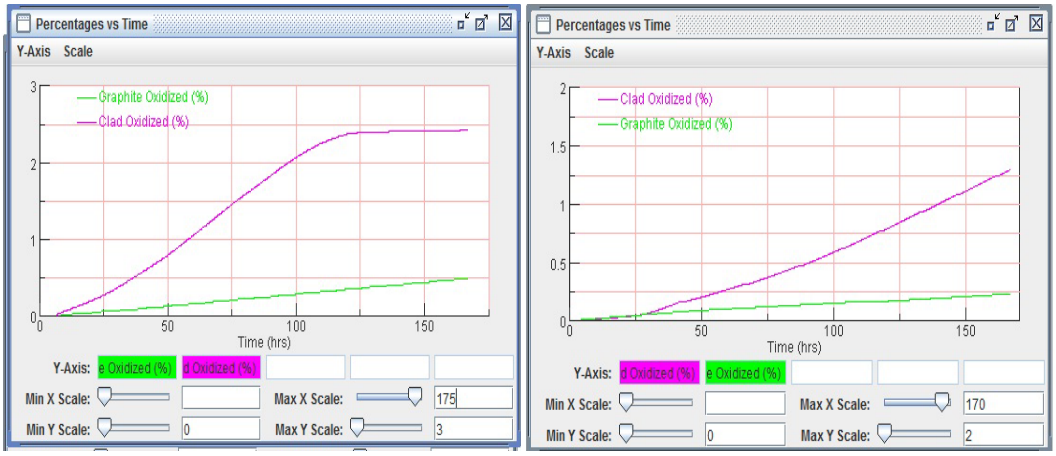
Figure 3. Fuel temperature vs time with delayed ATWS conditions for 2500 minuteson D-LOFC condition



(a) (b)

Figure 4. The rate of graphite oxidation predictions versus time on condition ATWS.

a) For 2000 minutes with a depressurization (t) for 50 minutes
b) For 2500 minutes with a depressurization (t) for 100 minutes



(a) (b)

Figure 5. Fractional weight loss due to oxidationversus time on condition ATWS

a. For 2000 minutes with a depressurization (t) for 50 minutes
b. For 2500 minutes with a depressurization (t) for 100 minutes.

Figure 5 shows that fractional losses due to oxidation occur most at a delayed time of 2000 minutes with a depressurization of 50 minutes. This is due to the rapid depressurization time. Compared to the results obtained in the previous study using Langmuir formulation which generated the oxidized graphite percentage of 2.89% [5]. The total oxidized graphite on cladding is only 2.4% by GRSAC and 2.89% by Langmuir formulation [23-24].The experiments result by INL [25-26], the average weight loss ratio for fracture of IG-110 is 0.647.The maximum weight loss ratio at 125 h is 0.49 with depressurization of 50 minutes which is obviously smaller than the Idaho National Laboratory (INL) results. It can be concluded that the nuclear grade graphite would not fracture and the structure.

Based on the fractional weight loss shell graphite as shown in Fig. 5, effect of graphite oxidation to mechanical forces using the equation 2 as shown in Table 2. For the preliminary calculation on the component subjected to external loads, it may be conservatively assumed that any portion of graphite that oxidized [24].

Table 2. Effect oxidations on material strength

Delayed times (minutes)	Depressurization times (minutes)	Max temperature fuel (^oC)	Fractional weight loss due to oxidation (%)	S/So
2500	100	1650	0,22	0,1108
2000	50	1496	0,49	0,006738

CONCLUSION

The oxidation effect of the graphite material is still small (S / So = 0.006738), and the greatest weight loss during depressurization during 50 minutes of 1.55 kg for reactor core. The maximum weight loss ratio at 125 h is 0.49 with depressurization of 50 minutes which is obviously smaller than the Idaho National Laboratory (INL) results. The oxidation rate occurs at high temperatures under ATWS conditions with rapid depressurization. Structural failure is strongly influenced by oxidation and high temperatures. The oxidation reaction increases exponentially with temperature according to the Arrhenius model. Therefore, despite the absorption of air currents, the reactor fuel cladding will not release the radioactive material to the environment because the mechanical strength of the graphite fuel structure is still good.

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