Sensitivity of Oxide ABR Transient Response with τ

Chris Keckler

June 8, 2017

After the optimal ARC design for the 1000 MWth oxide-fuelled ABR was chosen through parametric analysis (see [1]), the sensitivity of the design to the ARC heat transfer constant, τ, was examined. Through COMSOL multiphysics finite element simulations, the time constant for heat transfer from the primary coolant to the ARC upper reservoir fluid was optimized down to 1.3 s [2]. This is accomplished through the use of an annular upper reservoir designed specifically for the fuel assembly present in ABR cores. Using $\tau = 1.3$ s, it was determined that no oscillations are induced into the system response to the ULOHS, UTOP, and ULOF transient scenarios. The purpose of this study was to determine if the transient response utilizing the optimal ARC design is particularly sensitive to the τ parameter. This was done by modifying the input decks for the three transients to have longer time constants in 0.5 s increments from 1.3 s up through 4.8 s – nearly a 4x increase. The results of this sensitivity study for the three transients are presented below.

1 ULOHS

Figure 1 shows the peak coolant temperatures with time of each ULOHS simulation for all τ values on a single plot. Because each simulation gives very nearly the same values throughout the transient for all values of τ, it is difficult to distinguish between the different cases. Similarly, Figure 2 shows both the reactivity introduced from the ARC system as well as the net reactivity throughout the ULOHS transient for all values of τ. Again, virtually no difference is seen between the different SAS runs, and the lines essentially completely overlap. Even when τ is brought up to 20 s (not depicted), the difference in transient performance is minimal. No instabilities are formed - rather the temperature and ARC reactivity behavior is simply shifted by about 15 seconds in the transient phase of the simulation, but the maximum and asymptotic temperatures remain the same. These results indicate that the ULOHS scenario with the optimal ARC system implemented is very insensitive to the heat transfer time lag between coolant and ARC reservoir. This favorable behavior is likely due to the monotonicity and smoothness of temperature and reactivity changes in a ULOHS scenario.

2 UTOP

Figure 3 shows the peak coolant temperatures with time of each UTOP simulation for all τ values on a single plot. It is seen that the increasing τ value has a slight impact on the results and introduces some small oscillations, although the difference in temperatures between models is less than 1 C. All oscillations induced by the increased τ are less than 1 C in magnitude and do not grow. There is no clear trend with increasing τ, and overall the results of the increased time lag are not safety significant. Figure 4 shows similar behavior for the reactivity during the transient. Detailed evaluation of the ARC reactivity shows that small oscillations of less than \$0.01 are present with some values of τ. The small oscillations are triggered by the abrupt end to the rod withdrawal, which makes for a non-smooth reactivity component, and are present even in the case of very small τ. As with the temperature behavior, these oscillations persist for longer in some cases than others, but no trend exists where the oscillations continue to grow with further increasing τ. None of the examined τ values introduce oscillations into the UTOP response of any significance, and the maximum and asymptotic temperatures are unaffected.
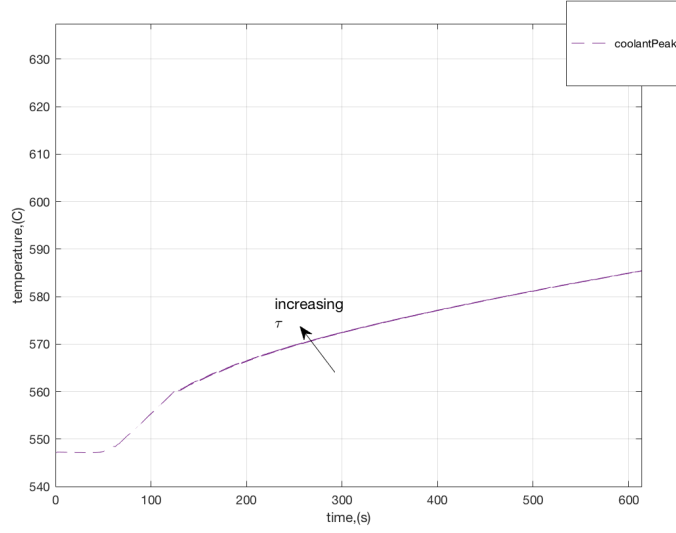
Figure 1: Peak coolant temperature in the oxide ABR ULOHS scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.
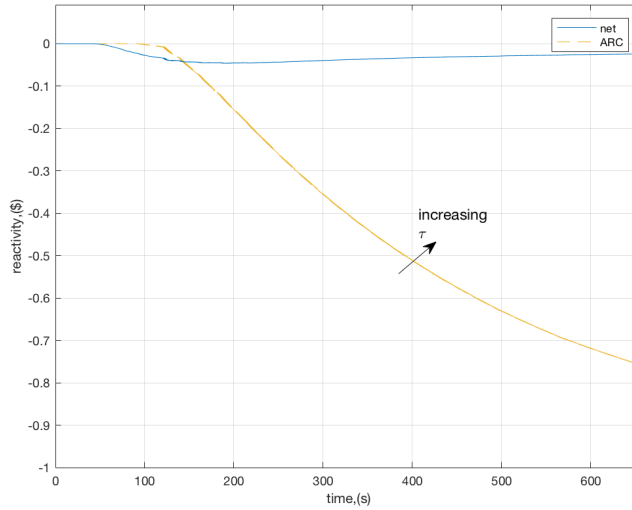

Figure 2: ARC and net reactivity in the oxide ABR ULOHS scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.

3 ULOF

Figure 5 shows the peak coolant temperatures with time of each ULOF simulation for all τ values on a single plot. As τ is increased, small oscillations in the coolant peak temperature are introduced in the early phase of the transient (i.e. < 500 s). These oscillations do not become significantly larger as τ is increased, and none of them grow as the transient progresses. The oscillations which are present due to the transition from forced to natural circulation at 700 s are not impacted significantly by the increased τ. Furthermore, as τ is increased, the peak coolant temperatures at later stages in the transient actually slightly decrease. This is due to a cancelling effect within the reactivity feedbacks, which ends up dampening the net reactivity response and keeping the reactor state at a lower net reactivity for longer during the early transient phase, which later shows through as a slightly lower temperature at the asymptotic state. This is depicted in Figure 6. The change with increasing τ is likely easier to see in the ULOF than the other transients due to the low
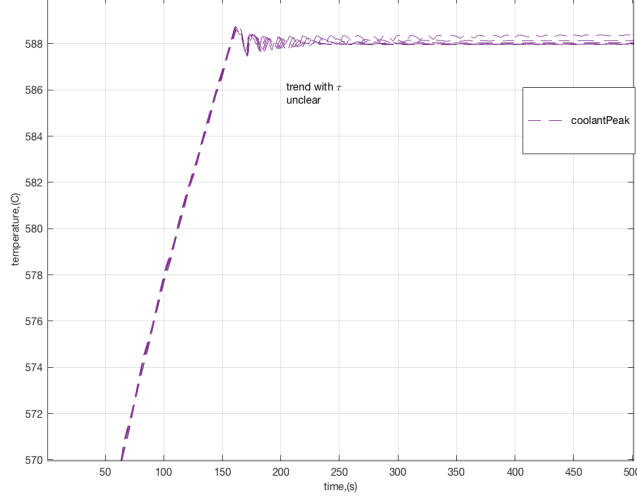
Figure 3: Peak coolant temperature in the oxide ABR UTOP scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.
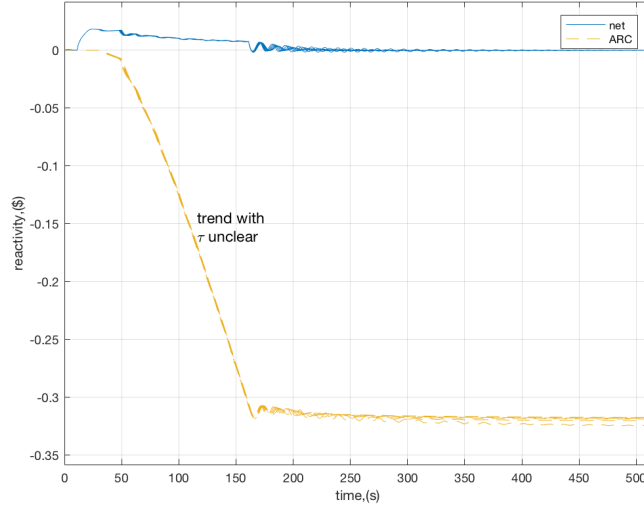

Figure 4: ARC and net reactivity in the oxide ABR UTOP scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.

flow conditions, which makes τ up to 5x larger than the nominal full-flow value. This very long time delay allows for more heat transfer from the oxide fuel to the coolant, which allows the coolant temperature to change more as the ARC reservoir is slowly heating up. This makes the different cases easier to differentiate from each other.

For the ULOF, a previous study by Qvist et al. has examined the sensitivity of the ARC response to the heat transfer time delay between coolant and ARC reservoir [3]. Qvist et al. investigated the size magnitude of oscillations induced by having an increasing mass of steel between the fuel and the ARC upper reservoir (effectively a longer time delay for heat transfer) and found that oscillations can be avoided for a particular τ if the equilibrium temperatures following the ULOF transient are allowed to be high enough. Qvist et al. found that the equilibrium coolant temperatures should be 725 C to avoid oscillations, no matter the τ. The current study agrees with these previously reported results, as the asymptotic coolant temperature

3

for the oxide ABR core with the optimal ARC design installed is roughly 710 C. This is close to the values reported by Qvist et al., and supports the result that the transient ULOF performance is rather insensitive to τ.
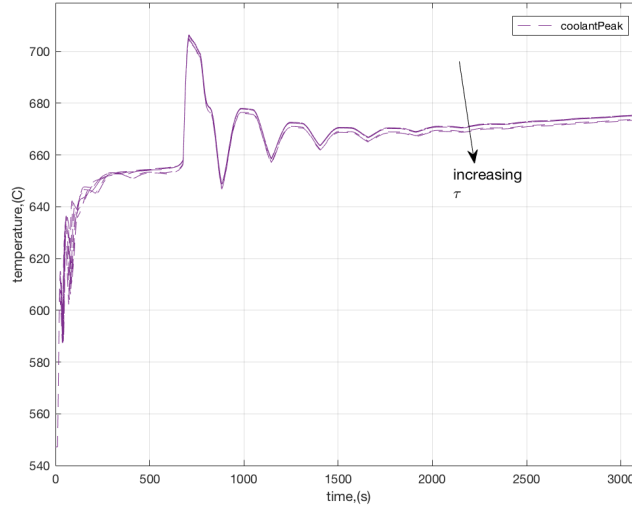

Figure 5: Peak coolant temperature in the oxide ABR ULOF scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.
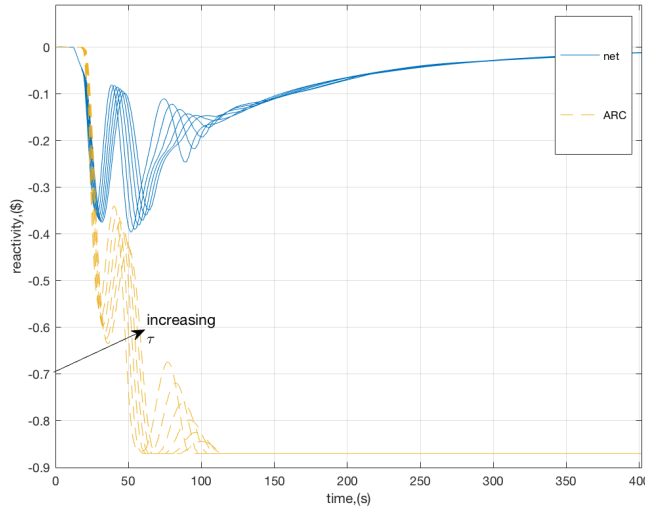

Figure 6: ARC and net reactivity in the oxide ABR ULOF scenario for $\tau = [1.3, 1.8, 2.3, 2.8, 3.3, 3.8, 4.3, 4.8]$ s.

4   Conclusions

This study examined the sensitivity of the transient ULOHS, UTOP, and ULOF behavior of the ARC-equipped oxide ABR with increasing heat transfer lag from the primary coolant to the ARC upper reservoir. From the sensitivity study it is concluded that the response with the optimal ARC design chosen in [1] is not sensitive τ. Almost no difference is seen in the ULOHS with increasing τ. Very small differences are seen

with increasing τ for the UTOP and ULOF scenarios, but these differences do not introduce any notable unstable behavior and are not detrimental to safety. Therefore it is concluded that the physical design of the ARC upper reservoir should not be severely constrained to obtain a small τ, and significant margin in the geometric design exists for minimizing the additional pressure drop and ensuring structural integrity.

References

[1] C. Keckler, S. Qvist, T. Fanning, M. Fratoni, E. Greenspan. "SAS4A/SASSYS-1 Simulation of ARC System in Oxide ABR for Improved Safety Margin," ANS Winter Conference, Washington DC, 2017.

[2] S. Qvist, C. Hellesen, R. Thiele, A. Dubberley, M Gradecka, E. Greenspan. "Autonomous Reactivity Control (ARC) - Principles, geometry and design process," Nuclear Engineering and Design (2016).

[3] S. Qvist, C. Hellesen, M Gradecka, A Dubberley, T. Fanning, E. Greenspan, "Tailoring the response of Autonomous Reactivity Control (ARC) systems," Annals of Nuclear Energy (2016).