Rod-Type Quench Performance of Nanofluids Towards Developments of Advanced PWR Nanofluids-Engineered Safety Features

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Outline

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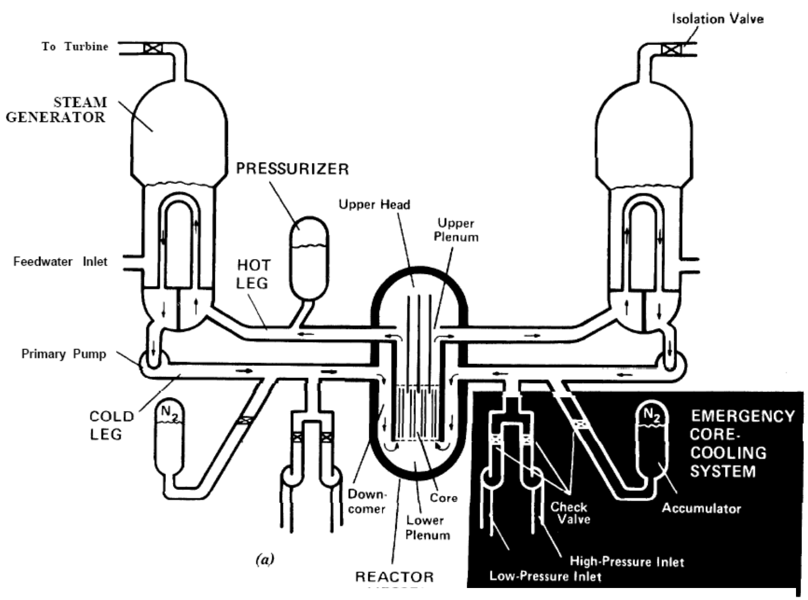
- Nanofluid preparation and properties
- Quench Experiments
- Results and Discussion
- Conclusions

Introduction

- GEN III+ featured with excellent safety performance and competitive power generation cost.
- Safety Concerns for the larger power capacity raised up to the 1500-1800 MWe range.
- Nanofluids as newly engineered coolants are receiving the growing interests for improved heat removal capability.



New Safety Improvement Measure

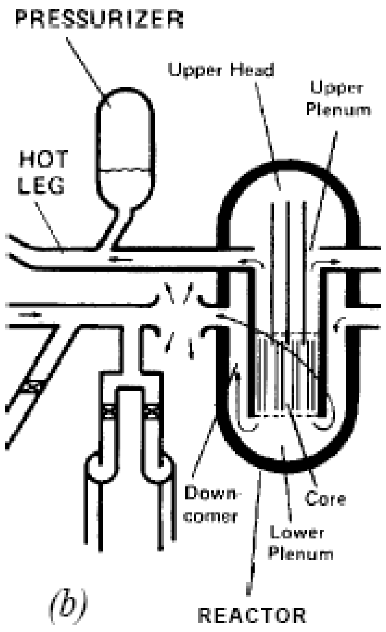
Nanofluid-engineered nuclear safety system

: ***Nanofluid supply system to core (ECCS)*** ***or reactor cavity (IVR-ERVC)***

(*J.C. Vigil, R.J. Pryor, Los Alamos Science*)

Introduction

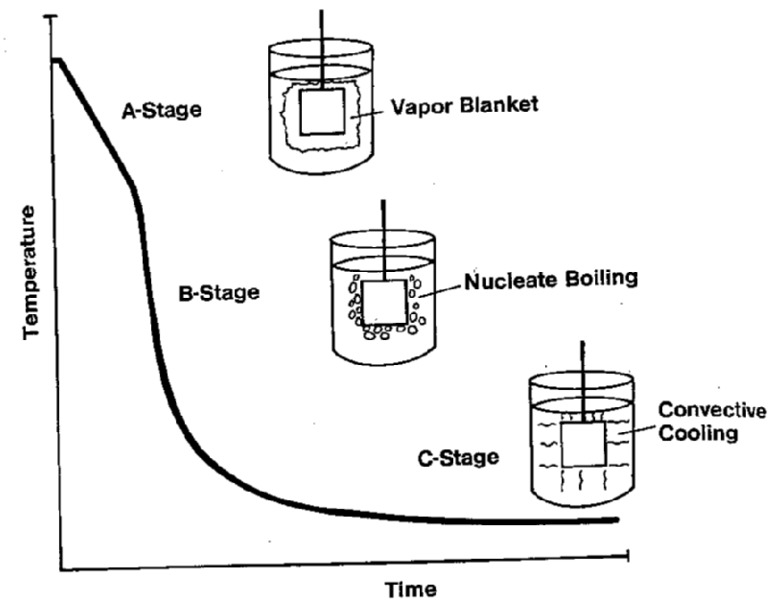
- *For the applicability of nanofluid, quenching performance is required.*
  - *LOCA: the bounding accident threatening nuclear safety*
  - *ECCS: to secure nuclear core can be survived even in the accident*
    - *To meet 10CFR50.46 peak cladding temperature acceptance criteria – cooling*



•Blowdown:~15s.
•Bypass/Refill: ~10+~10 sec.
•Reflood

(*J.C. Vigil, R.J. Pryor, Los Alamos Science*)

Fundamental Quenching Test



Nanofluid Preparation and Properties

Table 1. Physical Properties

Sample	pH	k	μ	σ
water	6.45	0.619	1.03	71.39
SiC-water	6.43	0.618	1	71.66

0.001 v% SiC in Water
: No properties changes
Color: light gray

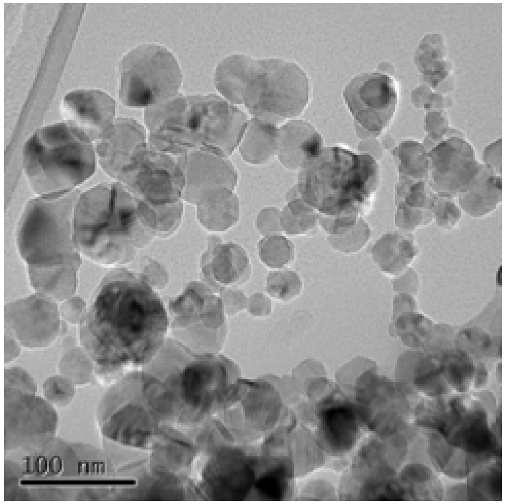


Fig. 1 Morphology of SiC nanoparticles (TEM)

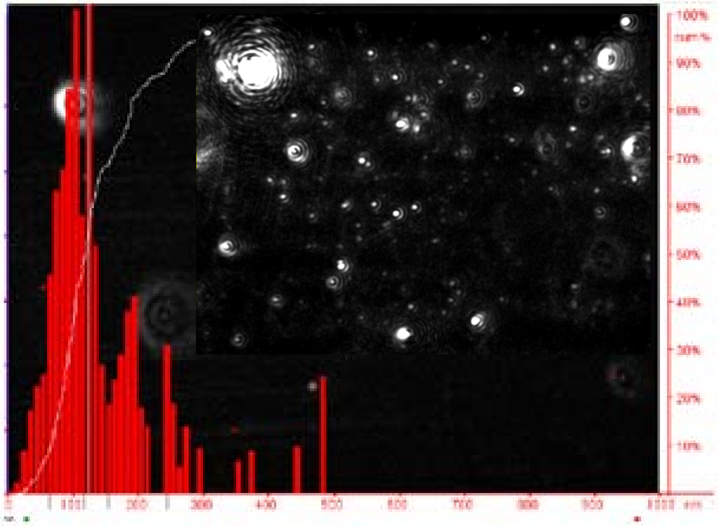


Fig. 2 Brownian Motion and Size distribution in the fluid

- Spherical Shape, 142 nm avg. dia in the dispersion
- Brownian motion in the dispersion

$$Dt = \frac{K_B T}{6\pi\eta r_h}$$

where K_B is Boltzmann's constant, T is temperature and η is viscosity.

Quench Experiments

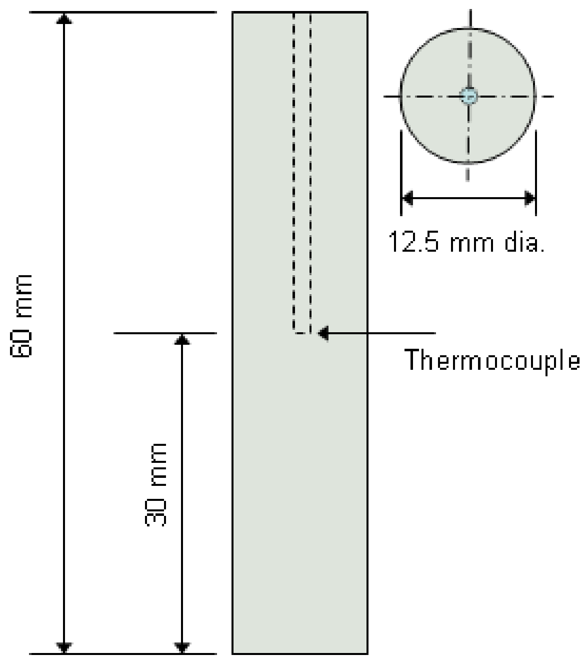


Fig. 3 Drawings of the quench specimen

- Nanofluid quench facility
  - Data acquisition system
  - Furnace
  - Cylinder tank for fluids
  - Thermocouple-connecting rod-coupling cylindrical specimens (Inconel 600)
- Experimental Procedure
  - First, to preheat the quench specimen in the furnace up to 850 °C
  - To quench in 30 °C water and nanofluid
  - While recording temperature history at a frequency of 10 Hz

Results and Discussion

- Centerline temperature histories has been recorded during quenching for water and SiC nanofluid, as well as atmospheric environment

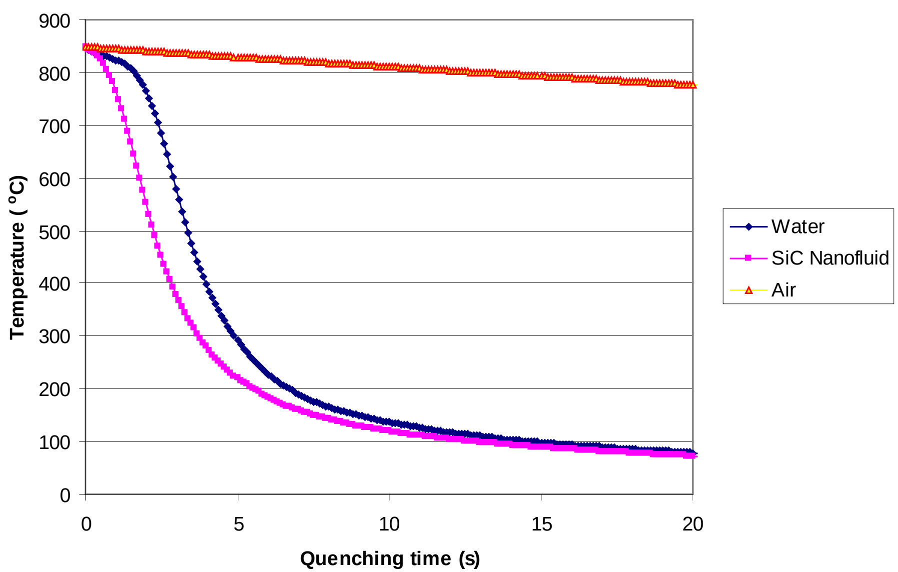


Fig. 3 Temperature history for the quench tests

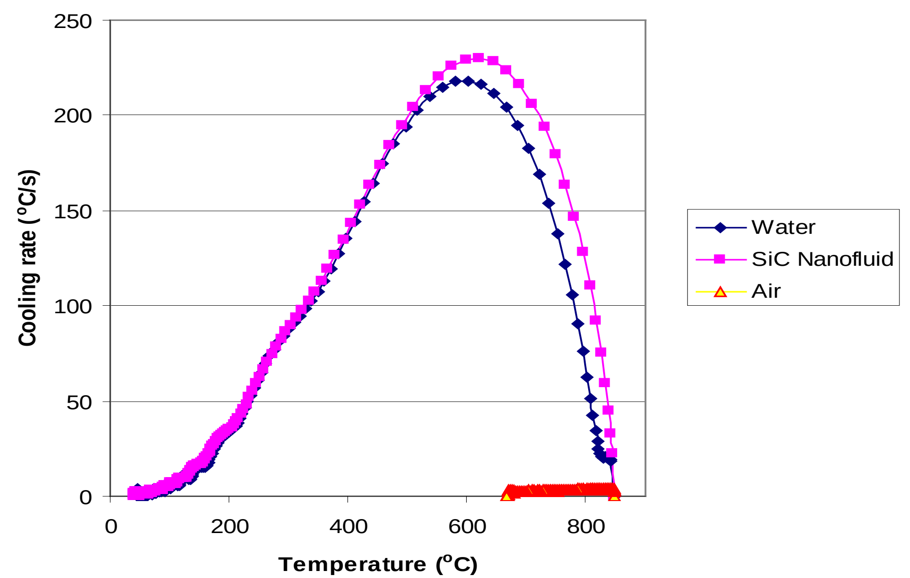


Fig. 4 Comparison of cooling rates vs. temp

- Apparently, SiC nanofluid had a better cooling performance compared to water.

Results and Discussion

- The measured time durations required to reduce the centerline temperature up to a fixed temperature and values of cooling rate at max. and 300 ^{o}C are shown in Table 2.

Table 2. Measured quenching time to drop to a temperature and cooling rates (CR)

	water	*SiC-water*	*air*
Max. CR	*218.05*	*230.01*	*4.04*
Temp. at Max. CR	*585.05*	*613.58*	*833.34*
Time to 600 ^{o}C	*2.91*	*1.79*	*-*
Time to 400 ^{o}C	*3.98*	*2.84*	*-*
Time to 200 ^{o}C	*6.7*	*5.52*	*-*

Results and Discussion

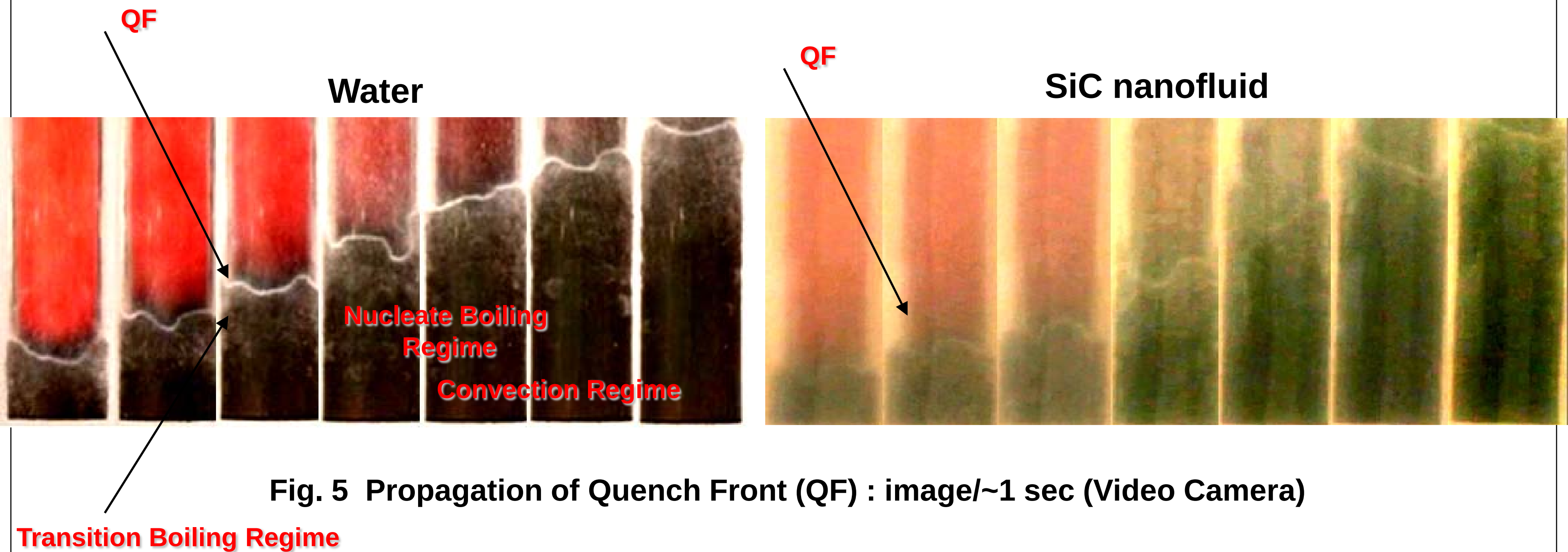


Fig. 5 Propagation of Quench Front (QF) : image/~1 sec (Video Camera)

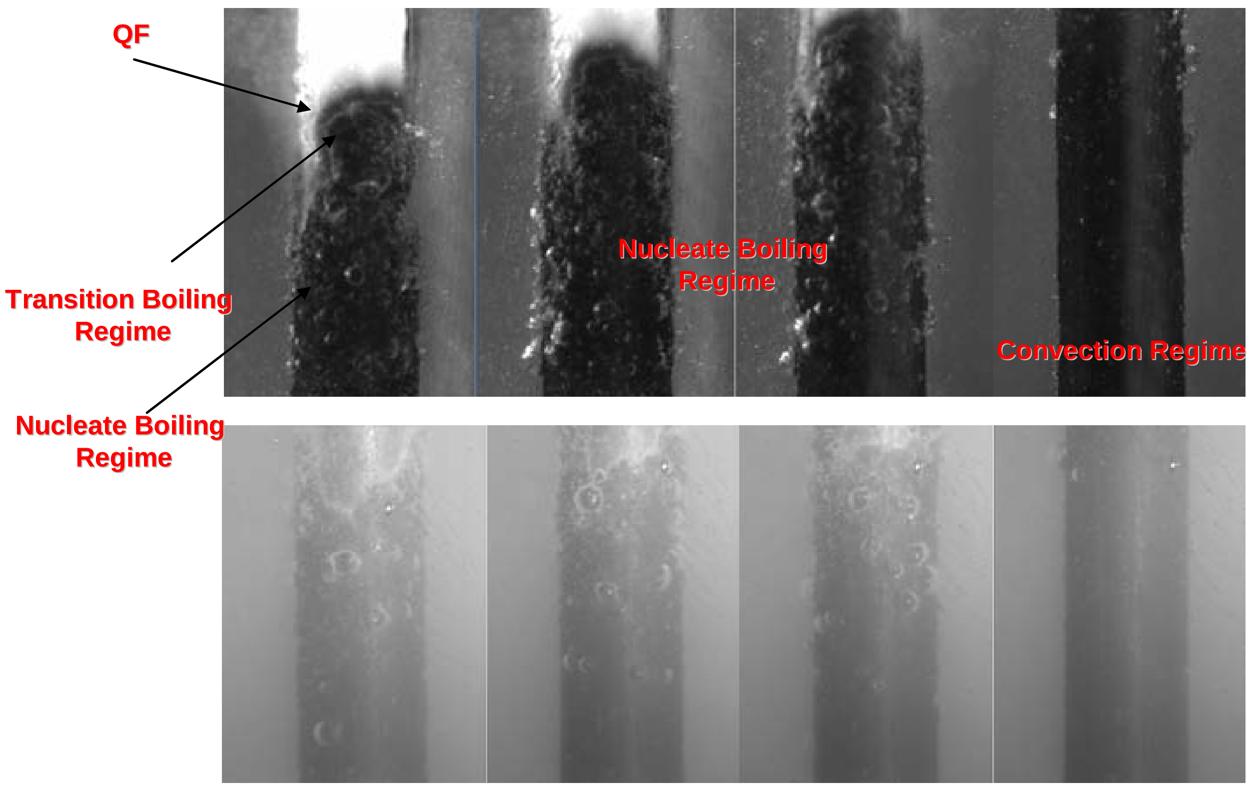
- Rewetting is the re-contact of liquid with a hot surface of overheated fuel rods. A quench front (QF) is defined as the edge of the contact area, which is advancing by progressive cooling of the surface.
- Rewetting phenomena are essential to physically understand the effects of nanoparticles/naofluids resulting in change of the cooling rate.
- Quench Front (QF) the max velocity of ~9 mm/sec in both water and SiC nanofluid
- The progression of the QF is axial-conduction-controlled typically and heat transfer mode of transition boiling most likely controls the propagation of the QF
- Apparently, no outstanding difference of QF propagation mechanisms are shown.

Results and Discussion

Duffey and Pothouse(1973) correlation says that simply if nanofluid has higher heat transfer coefficient than water in QF and higher Leidenfrost temp., we can expect that quench velocity would be increased. But not quite clear in this nanofluid maybe due to its low concentration without the physical properties changes.

For *Bi*»1,

$$u_{QF}^{-1} = \frac{\pi \rho C k}{2 h_{QF}} \cdot \frac{(T_w - T_s)}{(T_L - T_s)}$$



(a) water

(b) SiC nanofluid

Summary

- This paper provides the first insight to a rod-type quenching performance and phenomena of nanofluids as a preliminary report.
- A more systematic study of the effect of fluid temperature, nanomaterials and concentration on the quenching efficiency is underway.

- Mechanistic changes expected from using nanofluid as a new coolant of an ECCS can be suggested as follows;

  - **improved heat transfer coefficient of nanofluids in QF**
  - **improved thermal dissipation accelerating QF**
  - **locally nonuniform cooling in nanofluids**
  - **rupture of vapor blanket/film due to turbulence enhancement**
  - **improved radiation heat transfer of nanofluids**
  - **improved surface wettability by nanoparticles**