Nordic nuclear safety research

NKS-318
ISBN 978-87-7893-398-0

Study and comparison of data on Coolability of Particulate Beds Packed with Irregular Multi-size Particles

Sachin Thakre, Weimin Ma, Sevostian Bechta

Division of Nuclear Power Safety, Royal Institute of Technology (KTH)
Stockholm, Sweden

November 2014

Nordic nuclear safety research

Abstract

Debris bed coolability is one of the important tasks of severe accident research. The key problem to study is, whether decay heat can be completely removed by the coolant ingress into the bed.

Two different types of particles were used to investigate coolability of particulate beds at VTT, Finland. The first type is irregular-shape Aluminum Oxide gravel particles whose sizes vary from 0.25 mm to 10 mm, which were employed in the STYX experiment program (2001-2008). The second type is spherical beads of Zirconium silicate whose sizes vary between 0.8 mm to 1 mm, which were used in the COOLOCE tests (Takasuo et al., 2012) to study the effect of multi-dimensional flooding on coolability. In our earlier study at KTH, the same types of particles were used. POMECO-FL and POMECO-HT facilities were employed to obtain the effective particle diameters and the dryout heat flux of the beds made up to these two types of particles. The work was intended to check the effect of heater's orientation and diameters on the dryout heat flux.

In the present work, the data from COOLOCE are compared with that of POMECO-FL and POMECO-HT. Initially the effective particle diameters obtained from both the experiments are discussed, which is followed by the dryout heat flux comparison. It also includes the discussion over the possible factors (heaters' geometry and porosity) affecting the coolability of the bed.

Key words

Debris bed coolability, Effective particle diameter, Particulate bed, Dryout heat flux

NKS-318
ISBN 978-87-7893-398-0
Electronic report, November 2014
NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark
Phone +45 4677 4041
www.nks.org
e-mail nks@nks.org

Study and comparison of data on Coolability of Particulate Beds Packed with Irregular Multi-size Particles

Final Report from the NKS-R DECOSE activity

(Contract: NKS_R_2012_100)

Sachin Thakre, Weimin Ma and Sevostian Bechta

Division of Nuclear Power Safety (NPS), Royal Institute of Technology (KTH), Stockholm

Contents

1. Introduction

Debris bed coolability is one of the important tasks of severe accident research. The key problem to study is, whether decay heat can be completely removed by the coolant ingress into the bed. An extensive experimental (Li et al., 2012; Lindholm et al., 2006) and analytical work has already been done in order to get insights of the coolability of debris bed. Most of the available experimental data is related to the beds packed with single size (mostly spherical) particles, and less data is available for multi-size/irregular-shape particles. There are several analytical models available, which rely on the mean particle diameter and porosity of the bed in their predictions.

Two different types of particles were used to investigate coolability of particulate beds at VTT, Finland. The first type is irregular-shape Aluminum Oxide gravel particles whose sizes vary from 0.25 mm to 10 mm, which were employed in the STYX experiment program (2001-2008). The second type is spherical beads of Zirconium silicate whose sizes vary between 0.8 mm to 1 mm, which were used in the COOLOCE tests (Takasuo et al., 2012) to study the effect of multi-dimensional flooding on coolability.

In our earlier study at KTH, the same types of particles were used. POMECO-FL and POMECO-HT facilities were employed to obtain the effective particle diameters and the dryout heat flux of the beds made up to these two types of particles. The work was intended to check the effect of heater's orientation and diameters on the dryout heat flux.

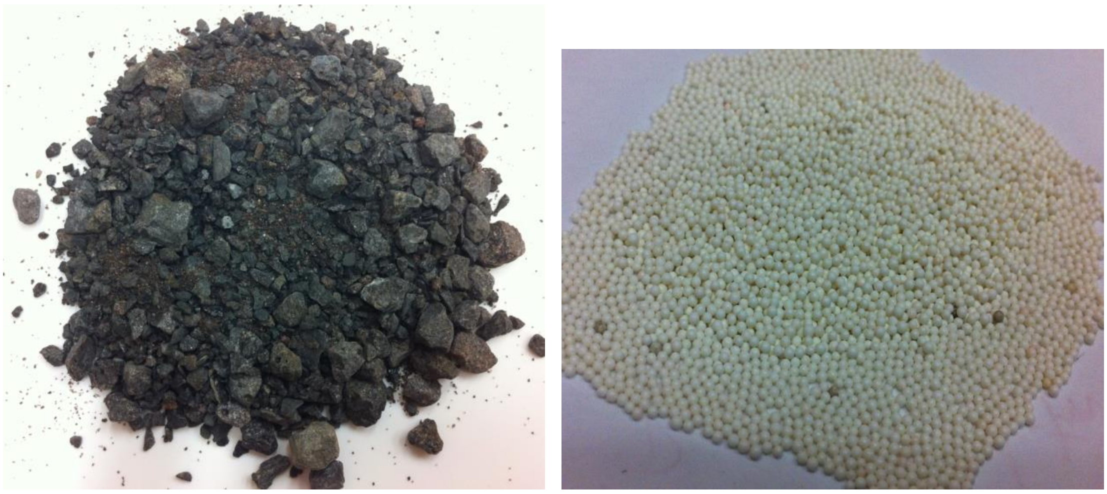
In the present work, the data from COOLOCE are compared with that of POMECO-FL and POMECO-HT. Initially the effective particle diameters obtained from both the experiments are discussed, which is followed by the dryout heat flux comparison. It also includes the discussion over the possible factors (heaters' geometry and porosity) affecting the coolability of the bed.

2. Effective particle diameter

The experiments were carried out on POMECO-FL and POMECO-HT facilities using Bed-1 and Bed-2. The pictures of particles used in Bed-1 and Bed-2 are shown in fig. 3. The mass distribution of Alumina gravels is compared (fig. 4) with the distribution used in STYX experiments. The details of the particulate beds are provided in table 1.

Table 1 Details of the beds.

Bed	Particle type	Density (kg/m^3)	Bed porosity	Particle diameter (mm)
POMECO-FL tests				
Bed-1	Alumina gravels	3900	0.408	0.25-10
Bed-2	Zirconium silicate spheres	4230	0.399	0.8-1
POMECO-HT tests				
Bed-1	Alumina gravels	3900	0.35	0.25-10
Bed-2	Zirconium silicate spheres	4230	0.371	0.8-1



a) b)

Fig. 1. Particles used in experiments (a. used in Bed-1and, b. used in Bed-2).

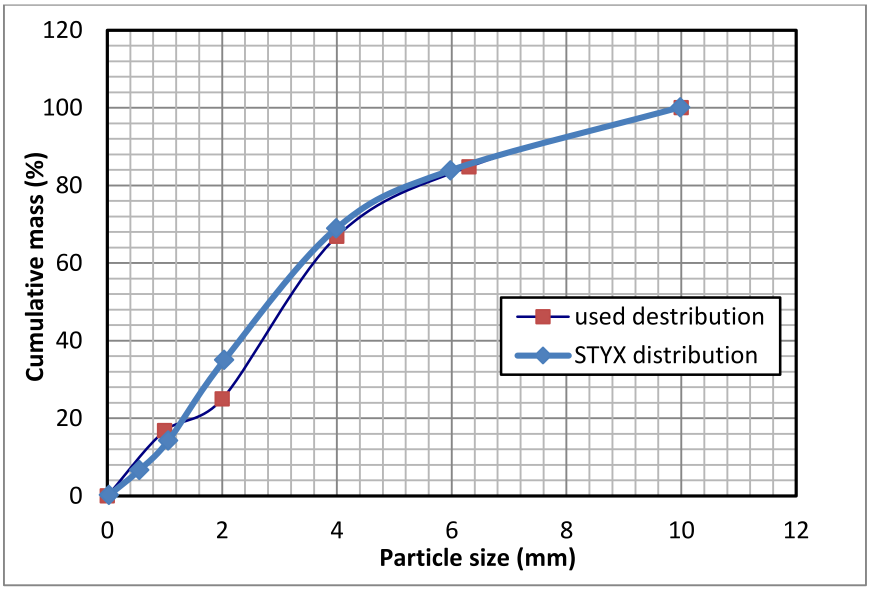


Fig. 2 Alumina gravels particle distribution (compared with Lindholm et al., 2006).

The effective particle diameters of Bed-1 and Bed-2 are found as 0.65 mm and 0.8 mm respectively. Whereas the effective particle diameter for alumina gravel was studied in STYX experiments and found as 0.8 mm. And, for zirconia beads, it is found from the COOLOCE experiments as 0.97 mm. There is little variation in the distribution of the particle size in case of alumina gravels (fig. 2). A slightly higher amount of particles of sizes less than 1 mm may have some effect on the effective particle diameter calculation.

3. Dryout heat flux

The dryout for the Bed-1 is found at 3.59 kW power, which gives the dryout heat flux of 89.9 kW/m^2, under top flooding conditions. The location of dryout inception is found at 96 mm from the bottom which is in the lower half of the bed. Figure 10 shows the comparison of the dryout heat flux with different models. It illustrates that the dryout heat flux calculated from the experiment is slighy higher than those values predicted by the models. Among the comparison, the Lipinski model predicted dryout heat flux closer to the experimental value.

Secondly, the Bed-2 (Zirconium Silicate beads) is prepared for the next test on POMECO-HT facility. Similar to Bed-1, the volume of Bed-2 is 10 liters. The dryout heat flux is found as 161.82 kW/m^2. Figure 12 shows the comparison of dryout heat flux obtained from the experiment with various models, which illustrates that the value is closer to the predictions by Lipinski model and Reed's model.

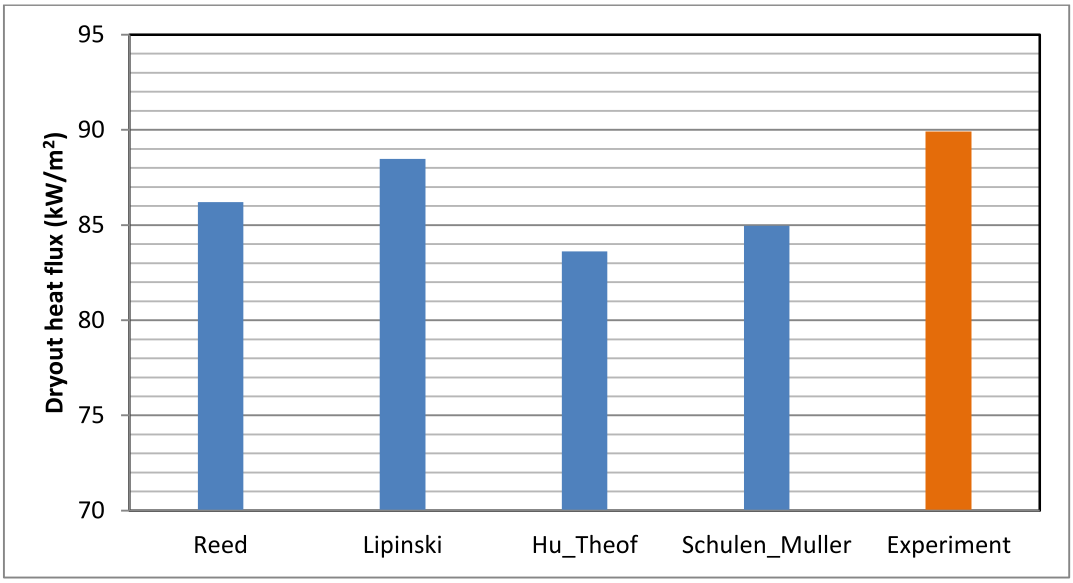


Fig. 3 Comparison of the dryout heat flux in Bed-1 with various models under top flooding conditions.

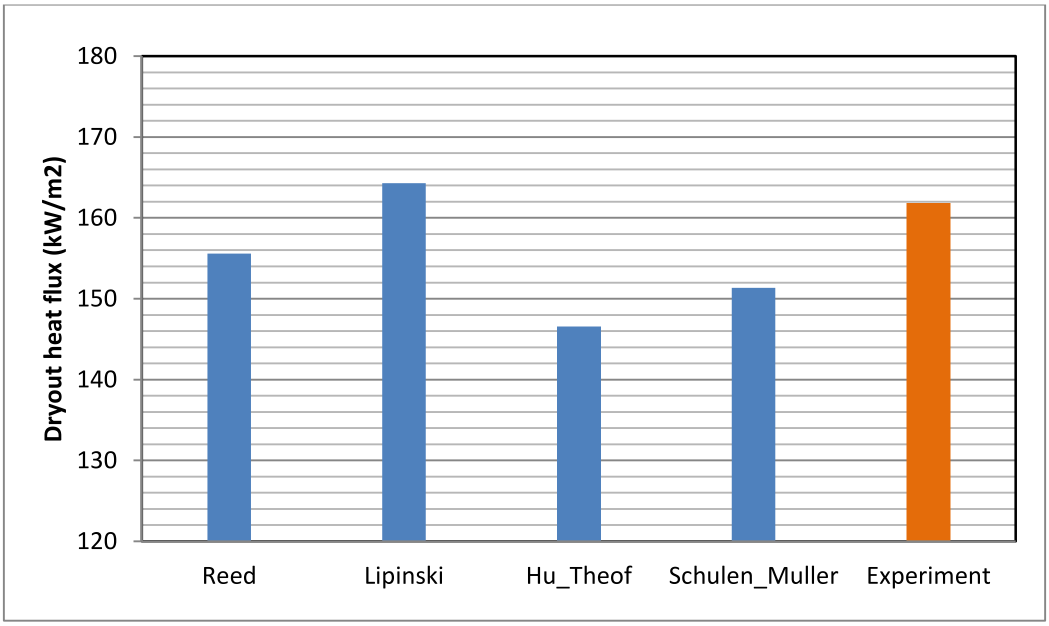


Fig. 4 Comparison of the dryout heat flux in Bed-2 with various models under top flooding conditions.

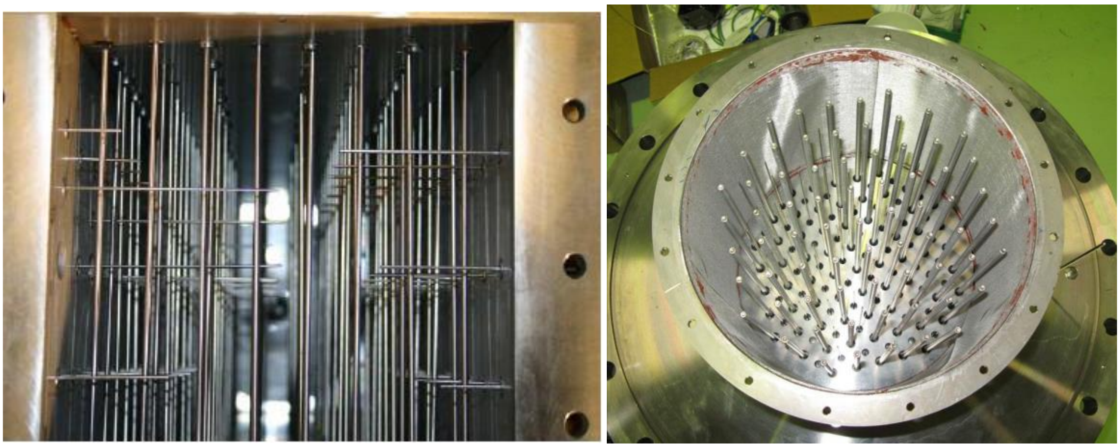
Table 2- Comparison of dryout heat flux from different experiments.

Particles	Bed porosity (POMECO-HT, KTH),	Bed porosity (COOLOCE, VTT)	Dryout heat flux (POMECO-HT, KTH), (kW/m^2)	Dryout heat flux (COOLOCE, VTT), (kW/m^2)
Alumina gravel	0.35	0.39	89.9	171
Zirconia beads	0.371	38-40	161.82	270

Table 2 shows the dryout heat flux comparison for the two types of beds obtained from the experiments carried out on two different test facilities; POMECO-HT at KTH, Sweden and COOLOCE at VTT, Finland. Comparing the dryout heat flux values it is found that experiments performed at COOLOCE facility gave higher dryout heat fluxes than at POMECO-HT facility. However, the dryout heat flux values from POMECO-HT compared with the one dimensional dryout models in fig. 3-4 shows that the values are closely predicted by the Lipinski model.

There may be many factors responsible for the difference in values found from the experiments. The process of filling particulate beds can affect the porosity of the bed which may change its coolability. From the table 2 we can see that the porosities of the beds at COOLOCE facility are higher than that of at POMECO-HT. For Alumina gravels bed it is significantly higher. And it is known that the more porous beds are comparatively more coolable. This may be the factor that helped to enhance the dryout heat flux in COOLOCE experiments.

The heaters' geometry may also affect the dryout heat flux of a particulate bed. In these type of experiments where the bed is artificially heated may have some unavoidable factors affecting the coolability of the bed. In POMECO-HT facility the bed is heated by the 3 mm diameter cartridge heaters which are horizontally inserted into the test section from sides (fig. 5a). And, these are arranged in the form of layers at fixed interval of heights. On the other hand, the heaters are vertically inserted from the bottom into a cylindrical test section of COOLOCE (fig. 5b). These are also the cartridge heaters having 6 mm diameter (bigger than POMECO-HT heaters). These arrangements may have different water ingress pattern during cooling of the bed due to its horizontal and vertical orientation. There is a possibility that the vertically oriented heaters may form a channel following its edge, which helps to release the steam upwards through it and enhance the coolability of a bed.



a) b)

Fig. 5Arrangement of heaters into a test section, a) POMECO-HT test section, b) COOLOCE test section.

4. Concluding remarks

The results from tests carried out on the POMECO-FL and POMECO-HT facility using a bed packed with alumina gravels and zirconia beads are compared with that of COOLOCE tests.

Initially, the effective particle diameters of the gravel particles and the zirconia beads calculated from the POMECO-FL experiments are compared with that of COOLOCE experiments.

Secondly, the dryout heat fluxes measured on the POMECO-HT facility using the same particulate beds are compared with the COOLOCE results. The possible factors responsible for the change in the values of dryout heat flux are explained.

5. Acknowledgement

This study is supported by the research programs of APRI8, ENSI and NKS. The discussions with the MSWI team members at KTH are acknowledged. NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

6. Disclaimer

The views expressed in this document remain the responsibility of the author(s) and do not necessarily reflect those of NKS. In particular, neither NKS nor any other organization or body supporting NKS activities can be held responsible for the material presented in this report.

7. References

Li, L.X., Ma, W.M., Thakre, S., 2012, "An Experimental Study on Pressure Drop and Dryout Heat Flux of Two-Phase Flow in Packed Beds of Multi-Sized and Irregular Particles", *Nuclear Engineering and Design,* 242, 369-378.

Lindholm, I., Holmström, S., Miettinen, J., 2006. Dryout heat flux experiments with deep heterogeneous particle bed, *Nuclear Engineer and Design*, 236, 2060–2074.

Takasuo, E., Holmström, S., Kinnunen, T., Pankakoski, P., 2012. The COOLOCE experiments investigating the dryout power in debris beds of heap-like and cylindrical geometries, *Nuclear Engineer and Design,* 250, 687-700.

Title	Study and comparison of data on Coolability of Particulate Beds Packed with Irregular Multi-size Particles
Author(s)	Sachin Thakre, Weimin Ma, Sevostian Bechta
Affiliation(s)	Division of Nuclear Power Safety, Royal Institute of Technology (KTH), Stockholm, Sweden
ISBN	978-87-7893-398-0
Date	November 2014
Project	NKS-R / DECOSE
No. of pages	9
No. of tables	2
No. of illustrations	5
No. of references	3

Abstract

Debris bed coolability is one of the important tasks of severe accident research. The key problem to study is, whether decay heat can be completely removed by the coolant ingress into the bed.

Two different types of particles were used to investigate coolability of particulate beds at VTT, Finland. The first type is irregular-shape Aluminum Oxide gravel particles whose sizes vary from 0.25 mm to 10 mm, which were employed in the STYX experiment program (2001-2008). The second type is spherical beads of Zirconium silicate whose sizes vary between 0.8 mm to 1 mm, which were used in the COOLOCE tests (Takasuo et al., 2012) to study the effect of multi-dimensional flooding on coolability. In our earlier study at KTH, the same types of particles were used. POMECO-FL and POMECO-HT facilities were employed to obtain the effective particle diameters and the dryout heat flux of the beds made up to these two types of particles. The work was intended to check the effect of heater's orientation and diameters on the dryout heat flux.

In the present work, the data from COOLOCE are compared with that of POMECO-FL and POMECO-HT. Initially the effective particle diameters obtained from both the experiments are discussed, which is followed by the dryout heat flux comparison. It also includes the discussion over the possible factors (heaters' geometry and porosity) affecting the coolability of the bed.

Key words: Debris bed coolability, Effective particle diameter, Particulate bed, Dryout heat flux

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4041, e-mail nks@nks.org, www.nks.org