Credible Moderation Content

Uranium Oxide Powder and Pellet Systems

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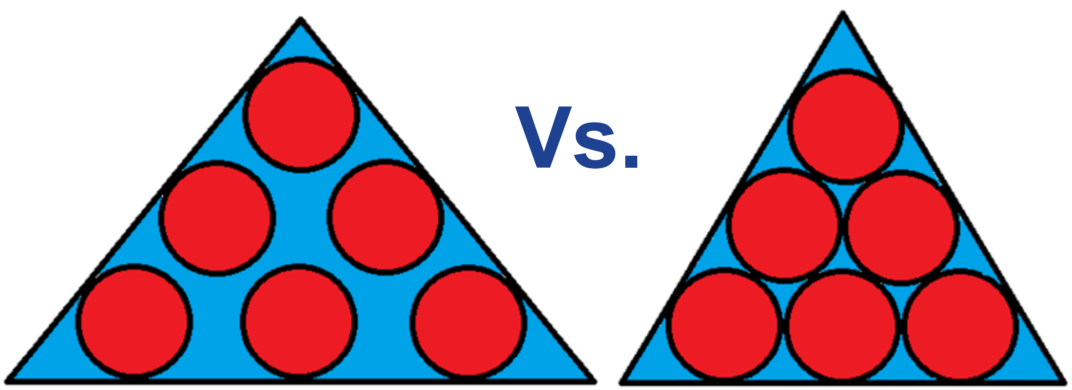
Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

Introduction

Goal

To determine the maximum credible water content in powder or pellet systems of various density and particle size without agitation



e.g., Safety Limit = 30 kg vs. 100 kg

Materials

Material ID	Bulk Density (g/cm^3)	Tap Density (g/cm^3)
UK: UO_2 powder from UF_6 to UO_2 conversion **k**iln	1	1.5
UP: UO_2 **p**re-compacted and granulated powder	2.4	3
UG: UO_2 pellet shavings from dry **g**rinding process	2.4	4.4
U3: U_3O_8 milled powder	1.9	3.5
GP: **G**reen (unsintered) **p**ellets	--	--
SP: **S**intered **p**ellets	--	--

Theoretical Saturation Point

For any UO_2 powder density less than theoretical, voids exist.

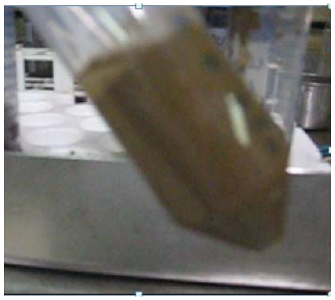
$$Saturation\ Wt.\%\ H_2O = \frac{1 - \frac{\rho_{fuel}}{\rho_{theoretical}}}{1 - \frac{\rho_{fuel}}{\rho_{theoretical}} + \rho_{fuel}}$$

e.g., for ρ_{fuel} = 3 g/cm^3, saturation wt. % = 19.5 %
= maximum credible moderation content without agitation

Experimental Saturation Point - Powder

Method 1. Mixing

1. Weigh dry powder
2. Add water and mix
3. Allow to settle
4. Suction free standing water
5. Weigh wet powder

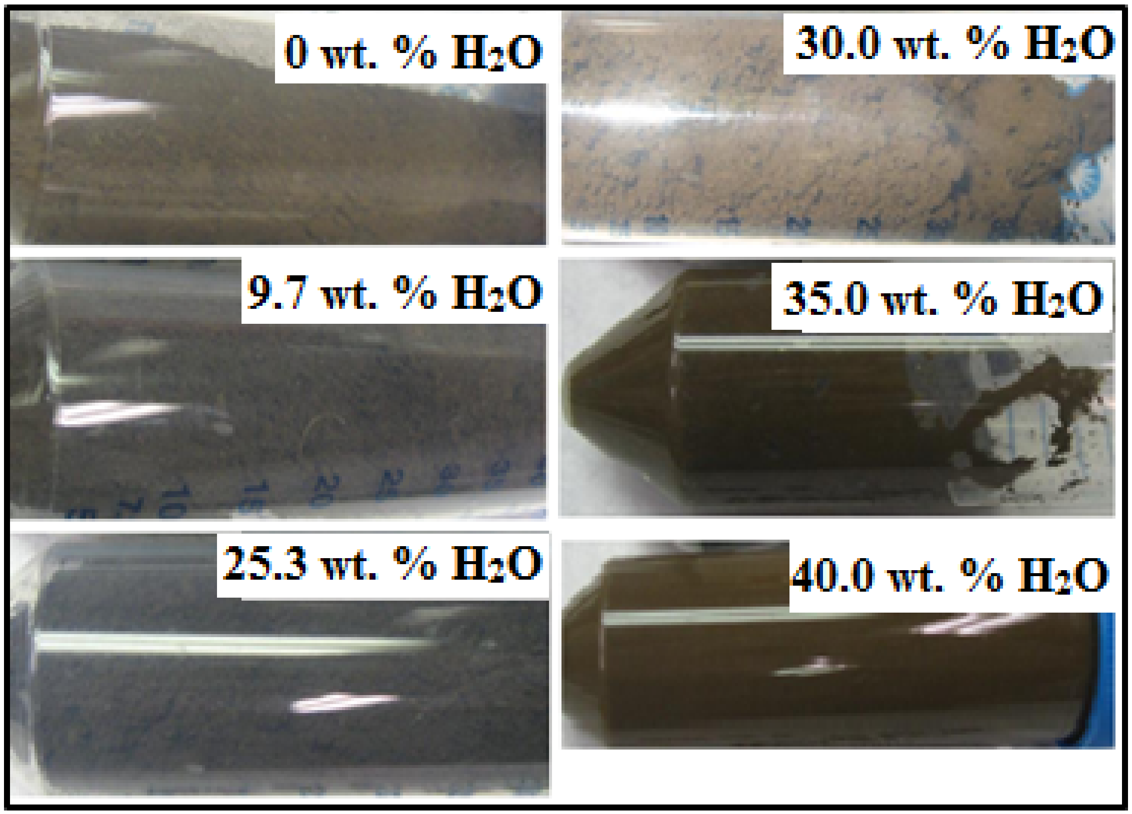


Method 2. No Mixing

1. Slowly pour powder into pan to form a cone
2. Weigh dry powder
3. Slowly add water until no more is absorbed
4. Suction free standing water
5. Weigh wet powder

$$wt.\%\ H_2O = \frac{Final\ weight\ - Initial\ weight}{Final\ weight}$$

UK – UO_2 powder from UF_6 to UO_2 conversion kiln



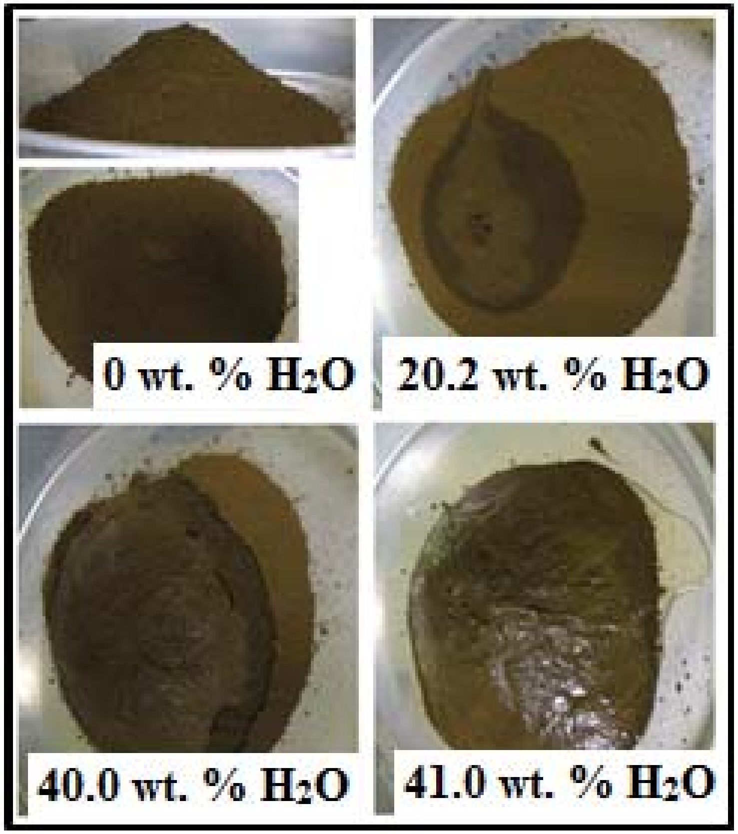
Method 1. Mixing

Experimental Saturation Point
= 33 %

Flowability Point
≈ 40 %

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
1 / 1.5	48 / 37

UK – UO_2 powder from UF_6 to UO_2 conversion kiln



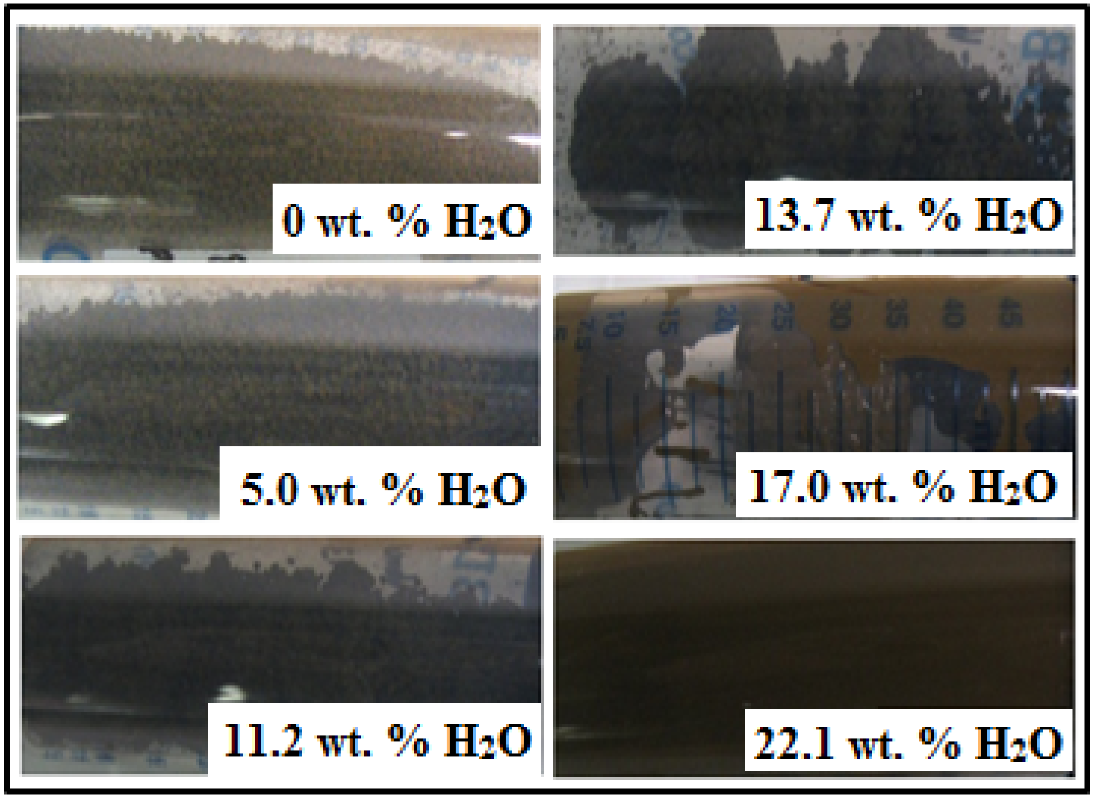
Method 2. No Mixing

Experimental Saturation Point = 40 %

Does not become flowable

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
1 / 1.5	48 / 37

UP – UO_2 pre-compacted and granulated powder



Method 1. Mixing

Experimental Saturation Point = 19 %

Flowability Point ≈ 35 %

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
2.4 / 3	25 / 19

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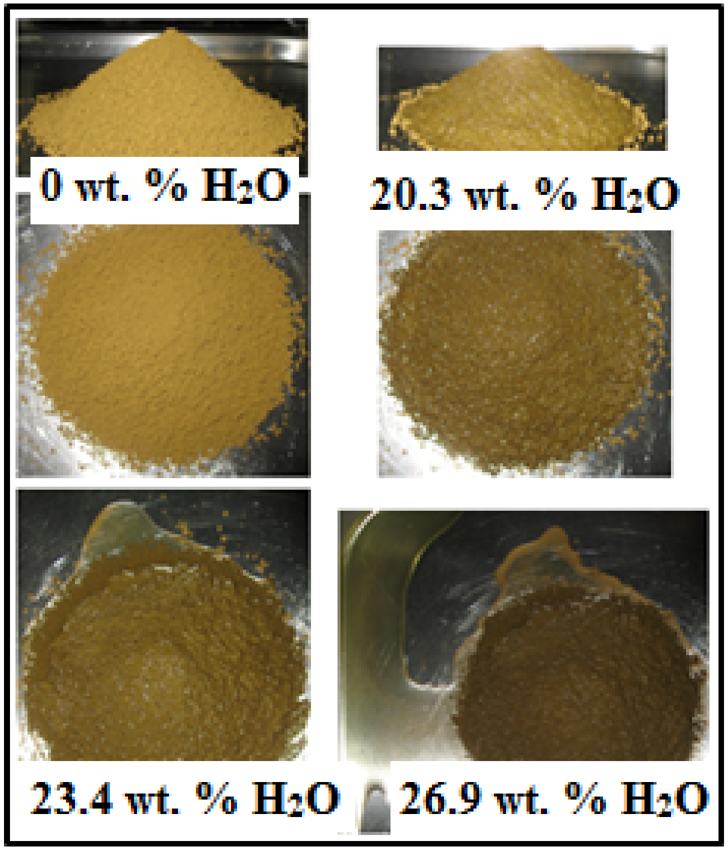
UP – UO_2 pre-compacted and granulated powder



Method 2. No Mixing

Experimental
Saturation Point
= 22 %

Does not become flowable

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
2.4 / 3	25 / 19

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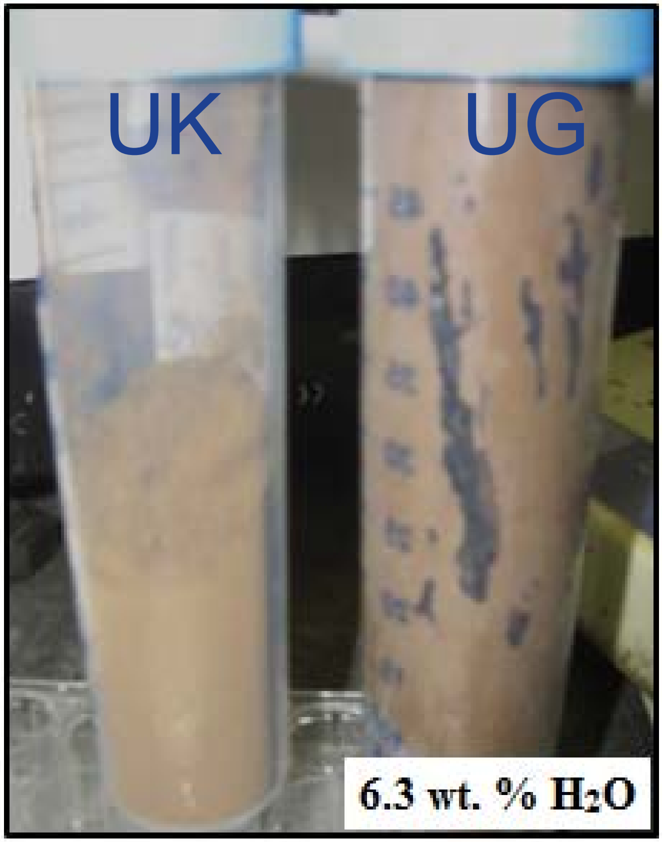
UG – UO_2 pellet shavings from dry grinding process



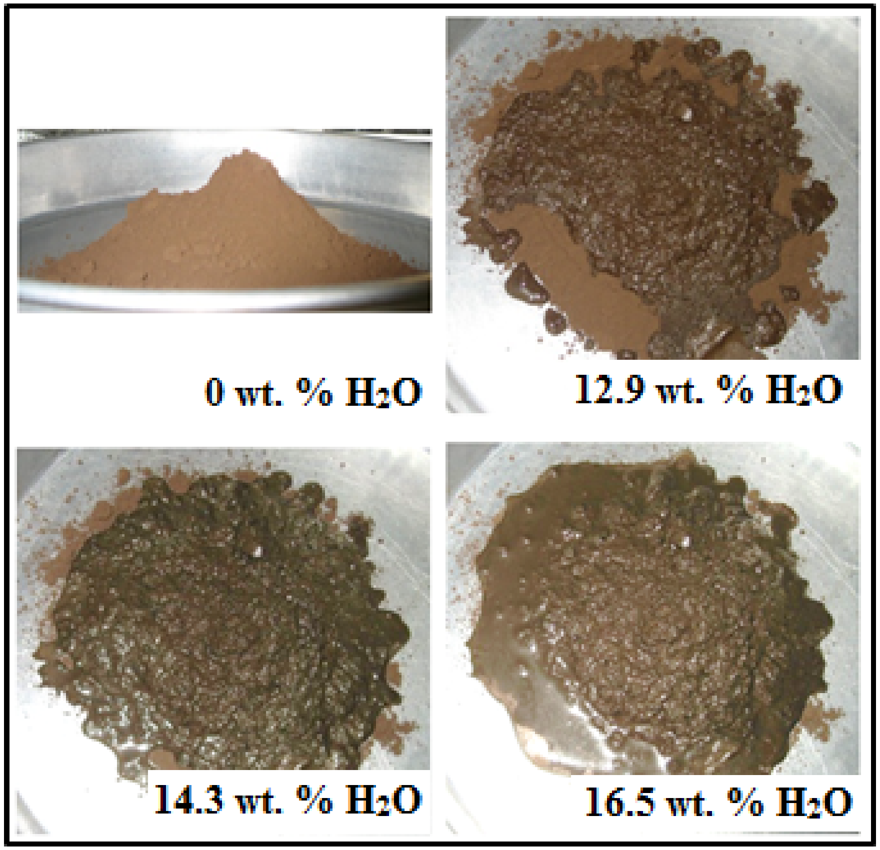
Method 1. Mixing

Experimental Saturation Point = 13 %

Flowability Point ≈ 20 %

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
2.4 / 4.4	25 / 12

UG – UO_2 pellet shavings from dry grinding process



Method 2. No Mixing

Experimental
Saturation Point
= 18 %

Flows when tipped

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
2.4 / 4.4	25 / 12

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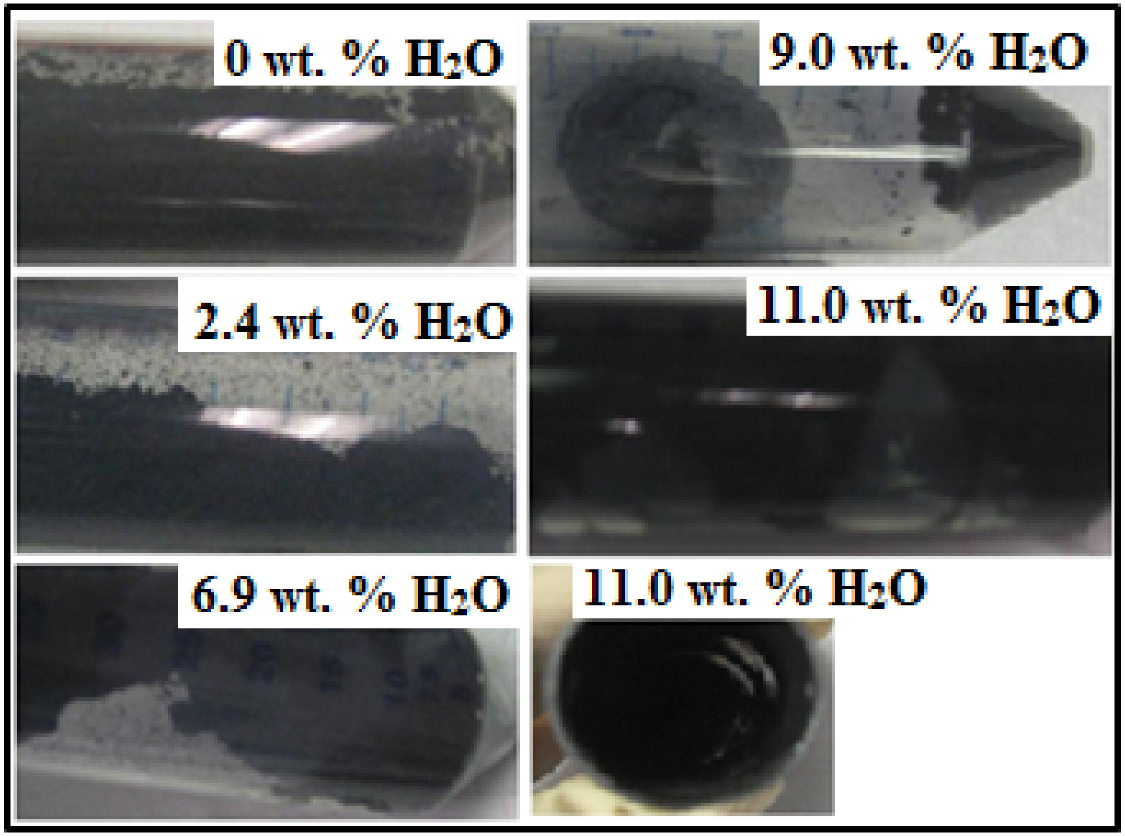
U3 – U_3O_8 Milled Powder

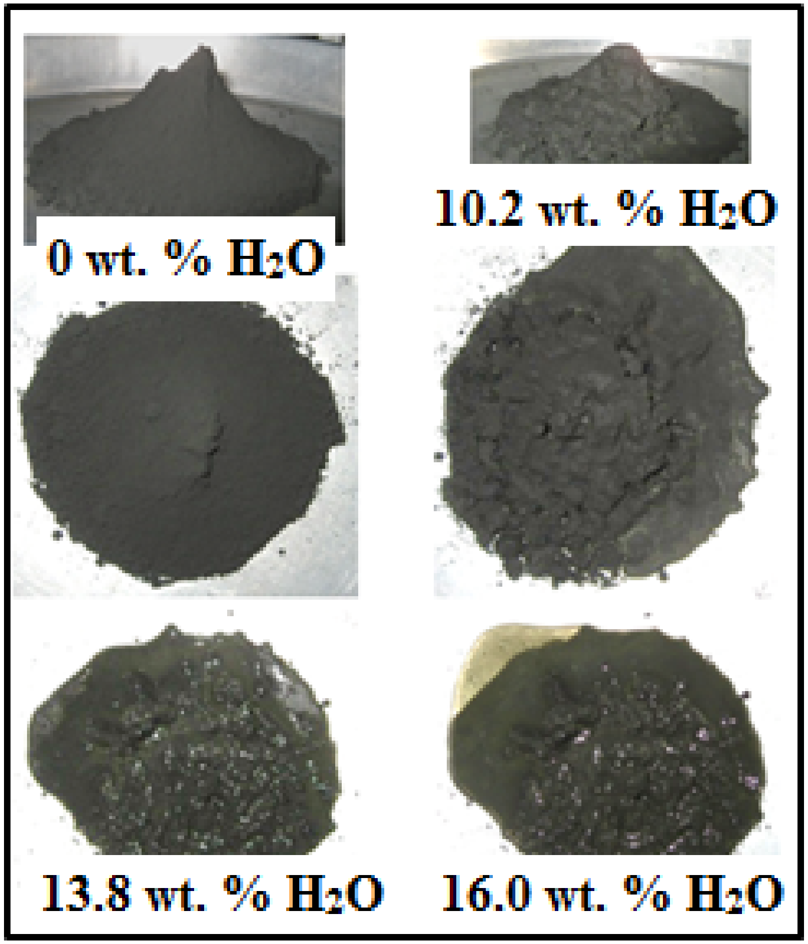


Method 1. Mixing

Experimental Saturation Point = 14 %

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
1.9 / 3.5	29 / 14

U3 – U_3O_8 Milled Powder



Method 2. No Mixing

Experimental Saturation Point
= 13 %

Does not become flowable

Bulk / Tap Density (g/cm^3)	Bulk / Tap Theoretical Saturation Point
1.9 / 3.5	29 / 14

Powder Summary

Material ID	Density Bulk / Tap (g/cm^3)	Theoretical Saturation Point Bulk / Tap	Experimental Saturation Point with Mixing (σ)	Experimental Saturation Point No Mixing	Experimental Flowability Point with mixing
UK	1 / 1.5	48 / 37	33	40	40
UP	2.4 / 3	25 / 19	19	22	35
UG	2.4 / 4.4	25 / 12	13	18	20
U3	1.9 / 3.5	29 / 14	14	13	19

Experimental Saturation Point - Pellets

Method

1. Weigh empty beaker (M_1)
2. Fill beaker to top with water and weigh (M_2)
3. Pour pellets into beaker and weigh (M_3)
4. Add water to fill beaker to top and weigh (M_4)

Assume: density of water = 1

$$V_{beaker} = M_{2,\ beaker\ +\ water} - M_{1,\ beaker}$$

$$V_{water} = M_{4,\ wet\ pellets} - M_{3,\ dry\ pellets}$$

$$V_{fuel} = V_{beaker} - V_{water}$$

$$\frac{W}{F} = \frac{V_{water}}{V_{fuel}}$$

$$wt.\%\ H_2O = \frac{M_{4,\ wet\ pellets} - M_{3,\ dry\ pellets}}{M_{4,\ wet\ pellets}}$$

Sintered Pellets

Beaker Size (mL)	100	250	500	1200
W/F (σ)	0.85 (0.01)	0.79 (0.03)	0.72 (0.003)	0.66 (0.02)
wt. % H_2O (σ)	7.6 (0.1)	6.6 (0.1)	6.3 (0.1)	5.9 (0.1)

Zou and Yu (1996) predicted a W/F range of 0.59-0.86 for random packing of equilateral cylinders.

wt. % H_2O left after water is drained off = 3.0 (0.4) %

Green Pellets

Beaker Size (mL)	100	250	500	1200
W/F (σ)	1.40 (0.25)	1.05 (0.04)	0.82 (0.03)	0.92 (0.08)
wt. % H_2O (σ)	17.0 (1.2)	13.9 (0.2)	12.0 (0.3)	12.0 (0.3)

It is recommended to use wt. % H_2O for porous material such as green pellets. The measured volume of pellets is underestimated when water is absorbed into the pellet. $V_{fuel} = V_{beaker} - V_{water}$

Wt. % H_2O left after water is drained off = 8.2 (0.5) %

Conclusion

Powder with mixing:

- saturation point = f(tap density)
- flowability = f(tap density, bulk density, particle size dist.)

Powder without mixing:

- saturation point = f(tap density, bulk density, particle size dist.)

Sintered pellets

- In a container (≥ 1.2 L): wt. % H_2O = 5.9 % (W/F = 0.66)
- After draining: wt. % H_2O = 3.0 %

Green pellets

- In a container (≥ 1.2 L): wt. % H_2O = 12.0 %
- After draining: wt. % H_2O = 8.2 %

Recommendations

The bulk density of a powder may be conservatively used to limit the credible moderation content and increase the mass or geometry subcritical limit.

The flowability of a powder may be used to determine maximum credible moderation content for various accident scenarios, e.g., holdup in a HEPA filter.

Recommendations

The maximum credible water content of randomly packed pellets may be used to increase the mass or geometry subcritical limits.

Safe Mass Limits for Sintered Pellets

Geometry	12" Reflection (W/F = Optimal)	12" Reflection (W/F = 1)
Sphere	36	178
Hemisphere	41	191

The water content remaining on pellets after draining may be used to represent the water layer that would form under various accident conditions, e.g., a spill of pellets on a floor with simultaneous sprinkler activation.

Future Work

- Powder behavior with other moderators (e.g., oil, pore former, lubricant)
- Distribution of water within powder as a function of powder density and water content
- W/F for pellets stacked in a pellet boat (i.e., not randomly packed)