Development of Latent Heat Transportation Systems with Various PCM

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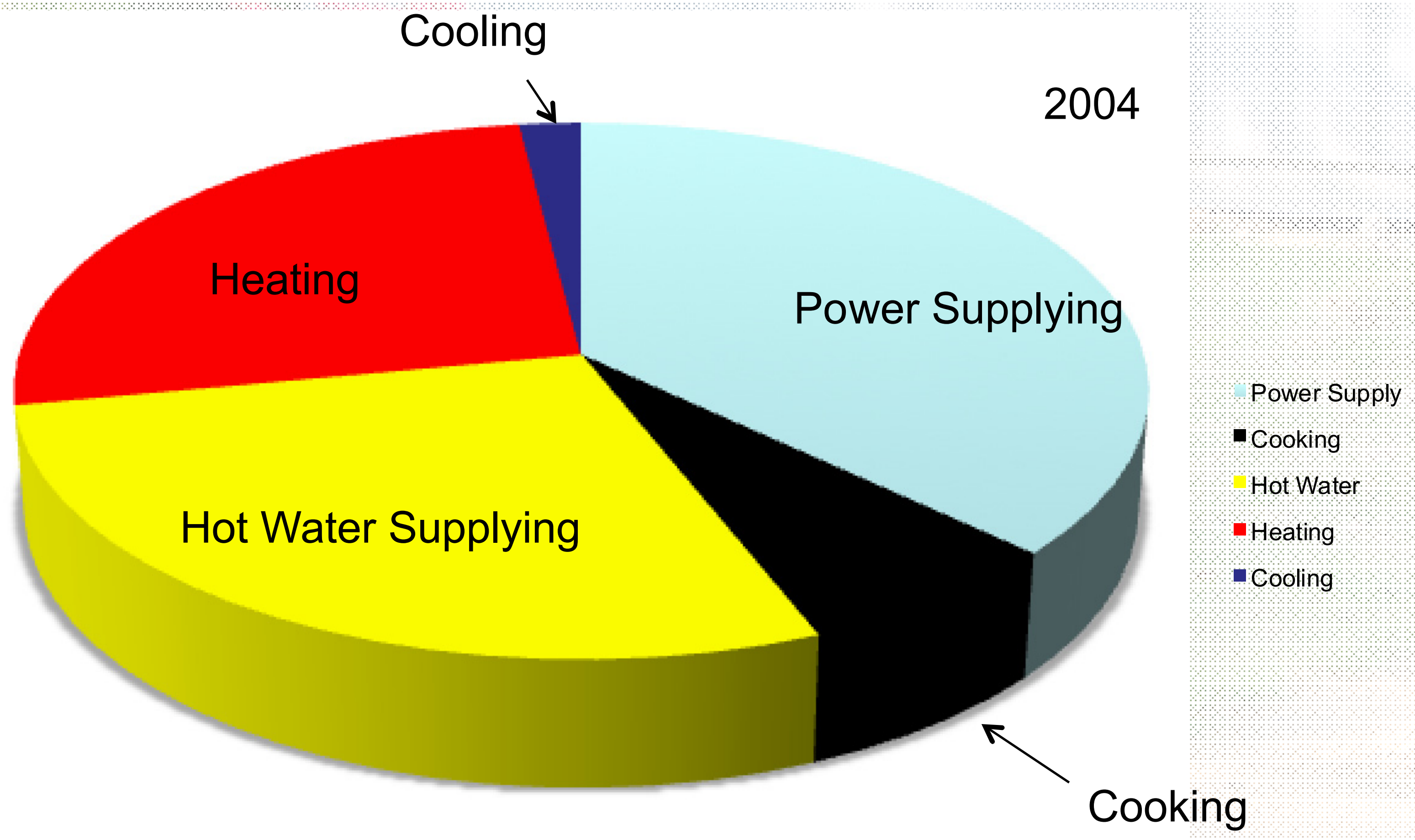
Japanese Energy Consumption in House



Cooling + Heating + Hot Water =Total Thermal Energy – 55%

Thermal Energy Comsumption

Heating/cooling energy consumption
in residential and commercial area in Japan

2.0 EJ(10^{18} J)/year

Exhausted heat from power plants, industries and etc. in Japan

2.5 EJ/year

Unused Thermal Energy

If unused thermal energy can be utilized for heating/cooling systems
as residential and commercial energy source,
we can save 25% CO_2 emissions.

Thermal Gaps between Demand and Suppl y

Time Gap → Latent Heat Thermal Storage

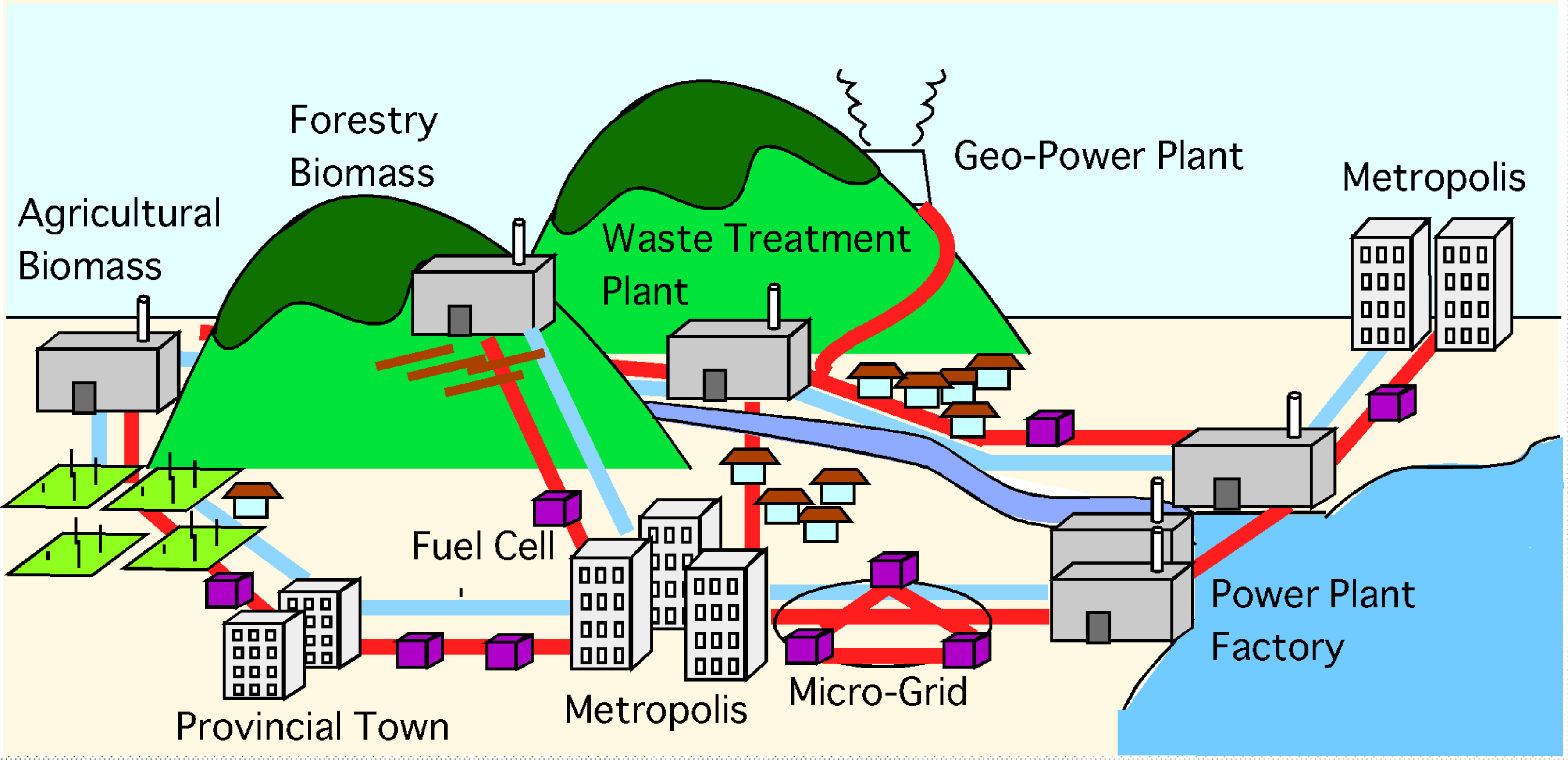
Temperature Gap → Chemical Thermal Storage

Spatial Gap → Latent Heat Transportation

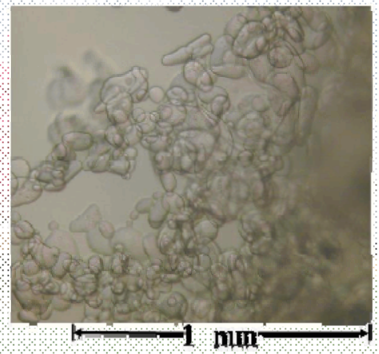
↓

Thermal Gap Solution

Thermal Grid



Latent Heat Transportation



High Heat Density

about 3 times higher than water

Flow Rate Reduction 1/3

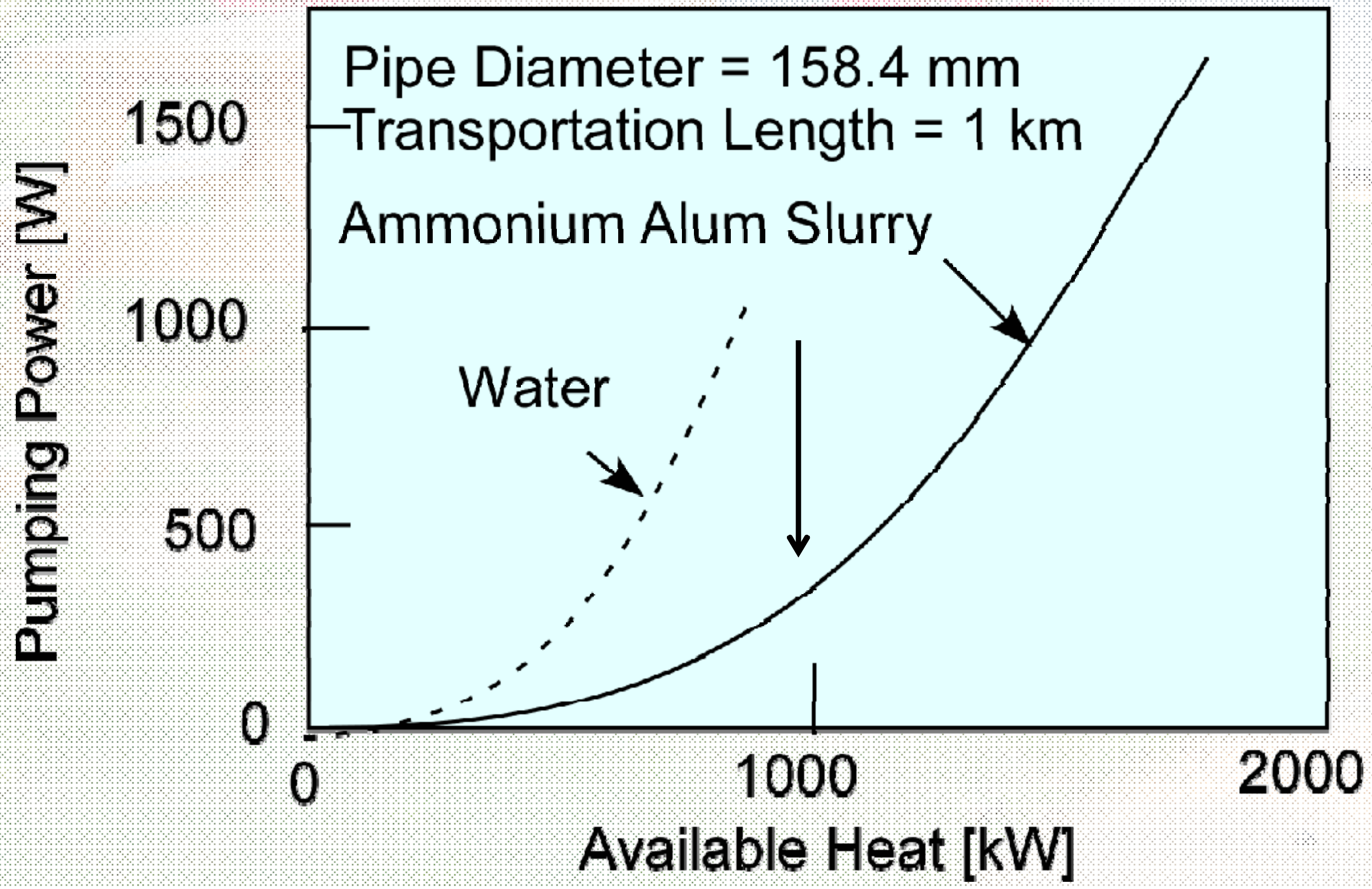
Saving Pumping Enegy

Temperature Sustainability

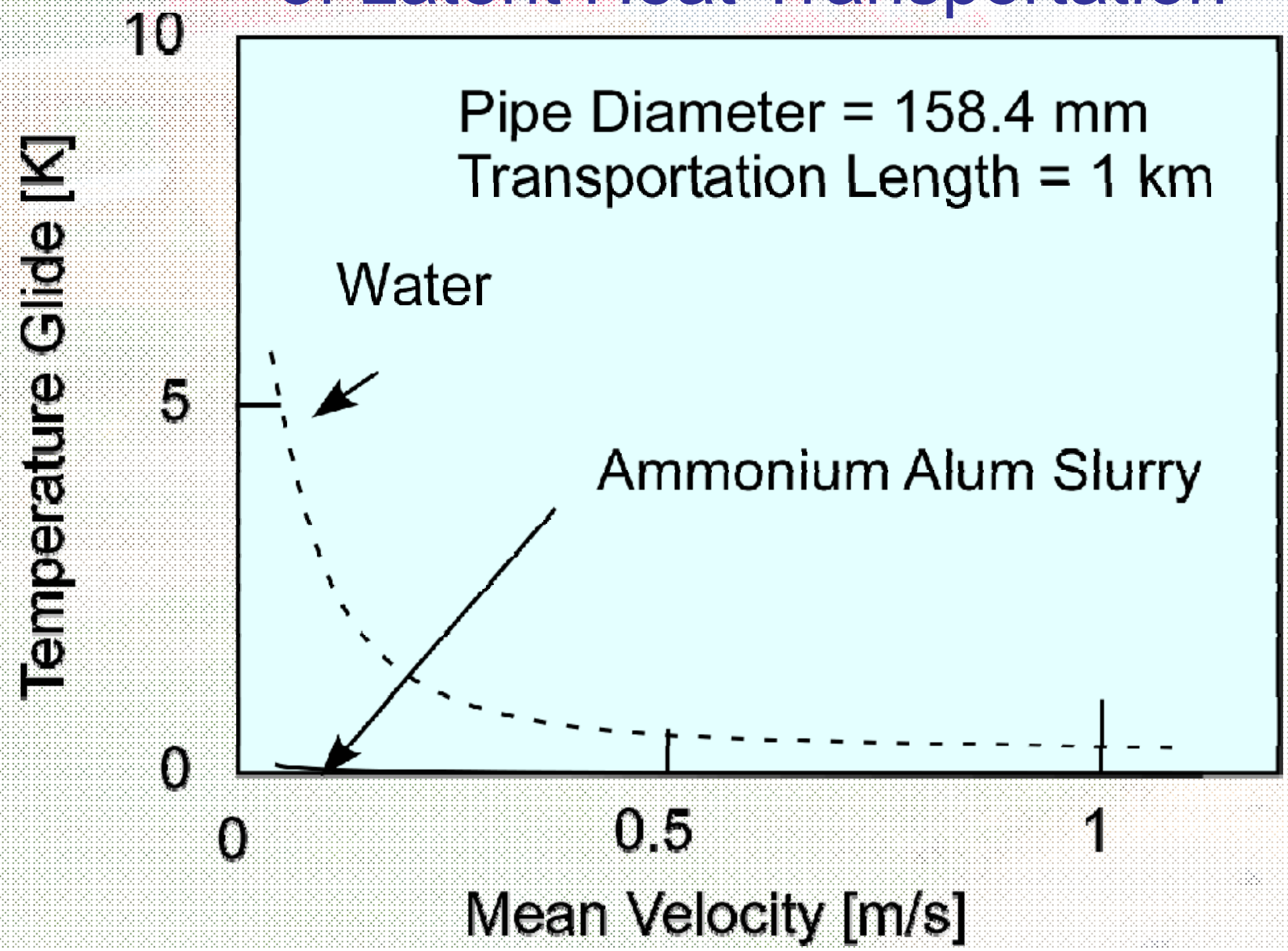
Heat Transfer = Heat Transfer Coefficient x Heat Transfer Area x Temperature Difference

High Heat Transfer

Flow Rate Reduction of Latent Heat Transportation



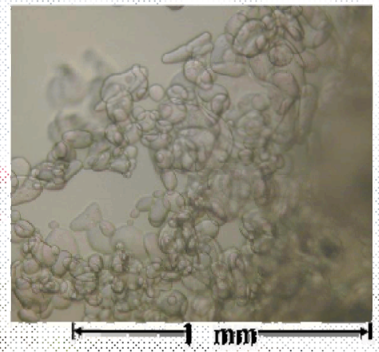
Temperature Sustainability of Latent Heat Transportation



Phase Change Materials for Latent Heat Transportation

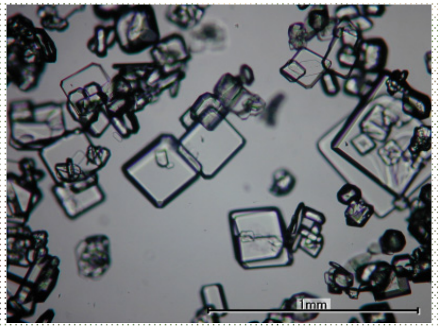
Ice/Water Slurries

- Cheap
- 0 ^{o}C



Clathrate Hydrate Slurries

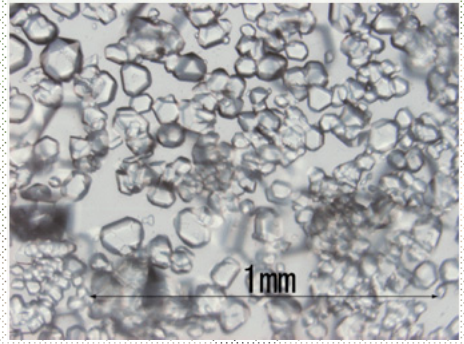
- trimethylolethane (TME)
- tetra-n-butylammonium bromide (TBAB)
- 10 to 15 ^{o}C



TME hydrates

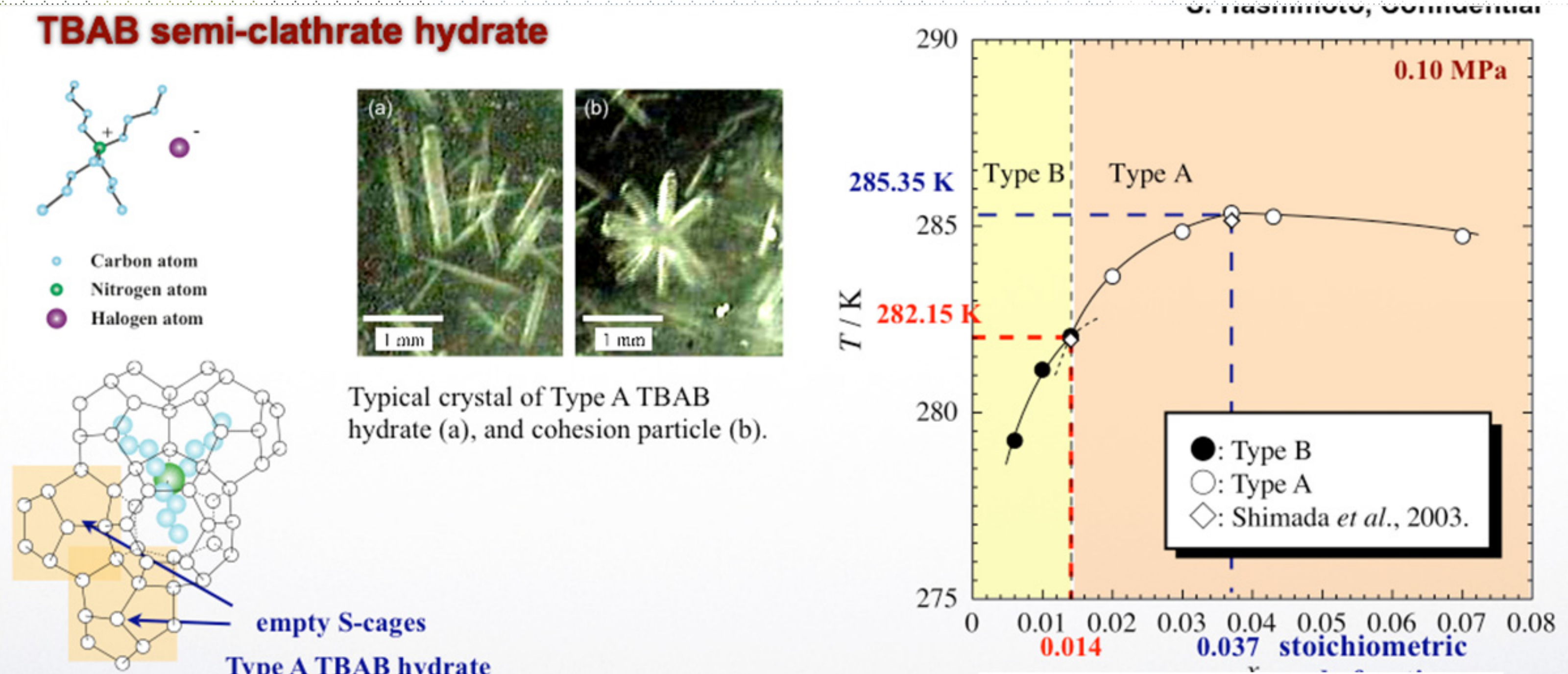
Inorganic Hydrate Slurries

- ammonium alum
- disodium hydrogen phosphate
- 30 to 90 ^{o}C



Ammonia Alum hydrates

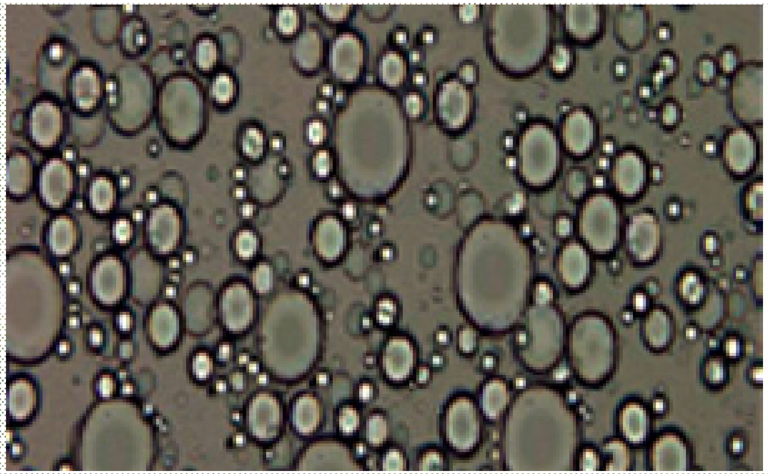
TBAB Hydrate Slurries



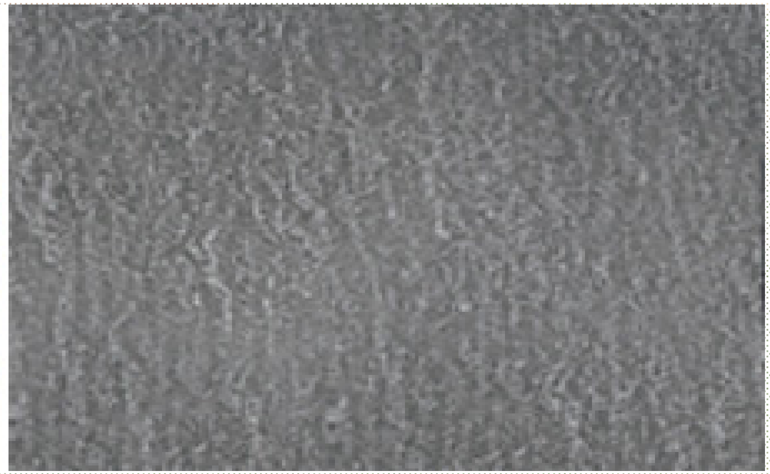
JFE Engineering

Emulsions of Tetra-Decane

tetradecane $C_{14}H_{30}$



Normal emulsification

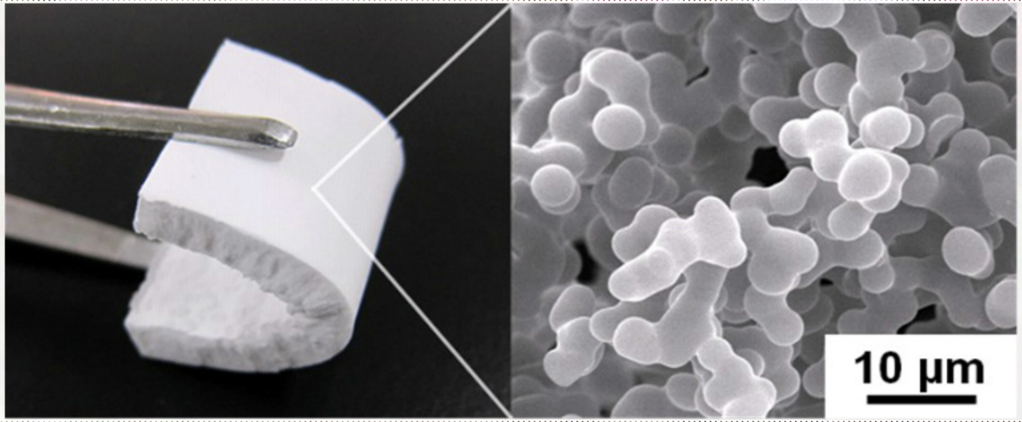


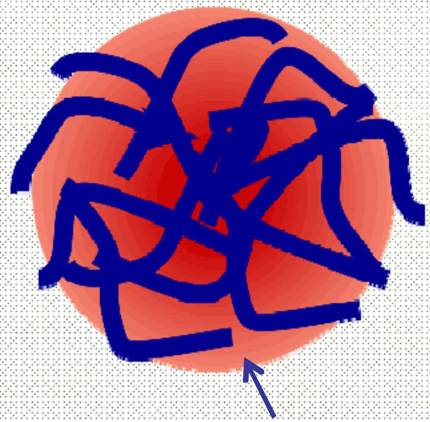
Nano-emulsion

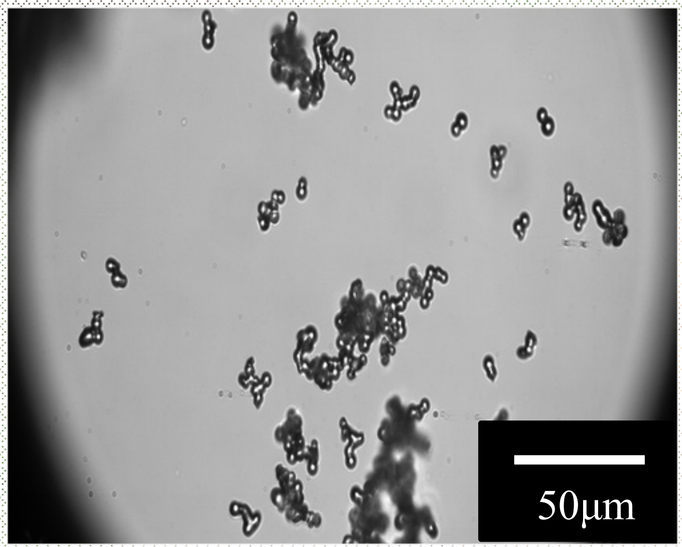
Phase change temperature : 5.9°C

Latent heat : 229kJ/kg

Transportation System of Tetra-Decane with Super-Hydrophobic Marshmallow Gel



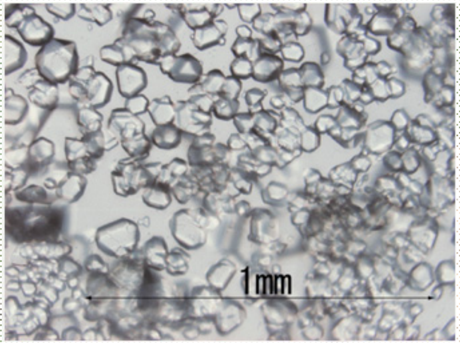




Inorganic Hydrates for High Temperature

Inorganic Hydrates	Phase Change Temperature °C	Latent Heat kJ/kg
$Na_2SO_4 \cdot 10H_2O$	32.4	192
$Na_2HPO_4 \cdot 10H_2O$	36.4	251
$Ca(NO_3)_2 \cdot 4H_2O$	43	247
$NaCH_3COO \cdot 3H_2O$	58	281
$Ba(OH)_2 \cdot 8H_2O$	78	142
$KAl(SO_4)_2 \cdot$12H2O	92.5	197
$AlNH_4(SO_4)_2 \cdot 12H_2O$	94.5	251

Ammonia Alum Particles



High Solubility in Water → Solidification In Room Temperature

Control Hydrate Fraction

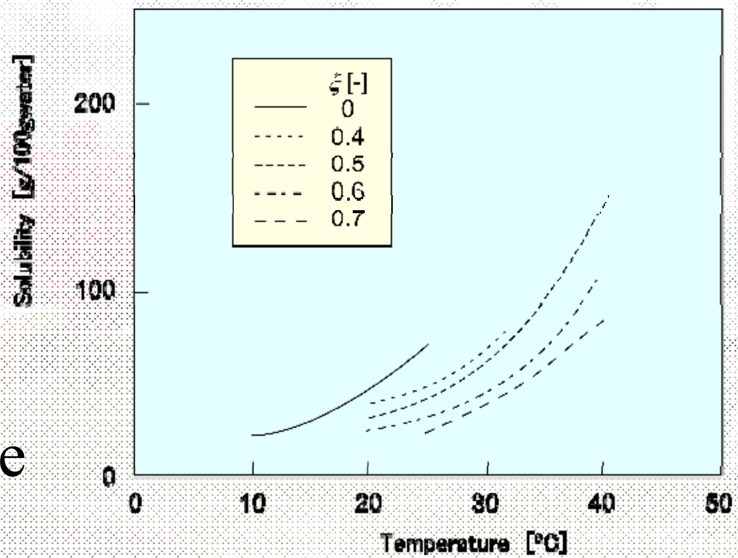
Solubility Control

Disodium Hydrogen Phosphate

Mixture Solvent

Water +Ethylene Glycol

x = EG Conc. in the Mixture

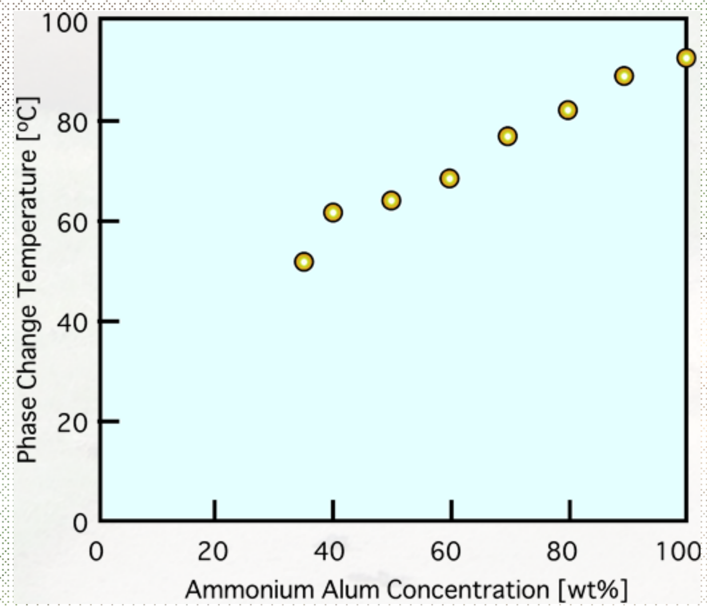


Concentration Control

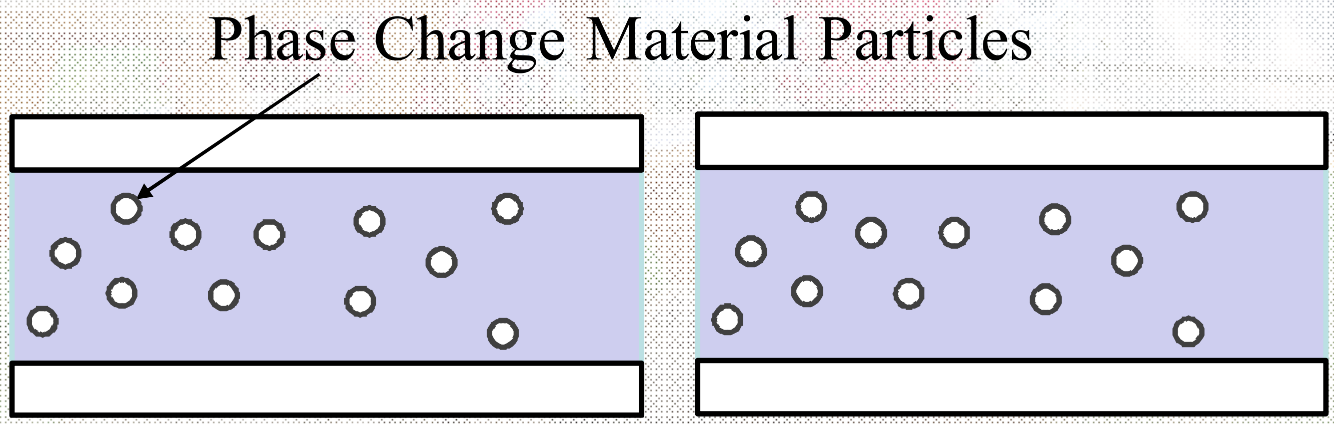
Ammonia Alum

Target Temperature 51°C

Hydrate Fraction 12wt%



Problems on High Temperature Latent Heat Transportation

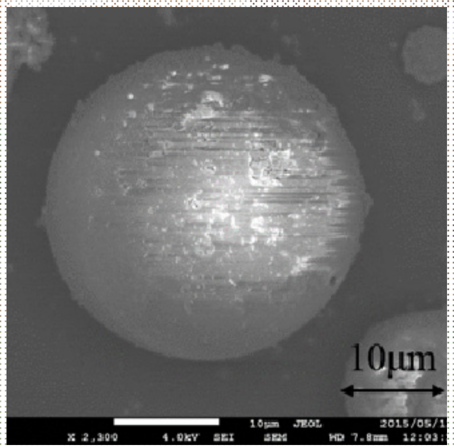


Particles grow

Adhesion

Pipe Blocking

Silica Hard Shell Micro-Capsules (HSMC) Containing Phase Change Materials



Silica has
- high stabilities
  on Temperature
  on Mechanical Stress
  on Chemical Materials
- Low Adhesion Energy
  on Metals

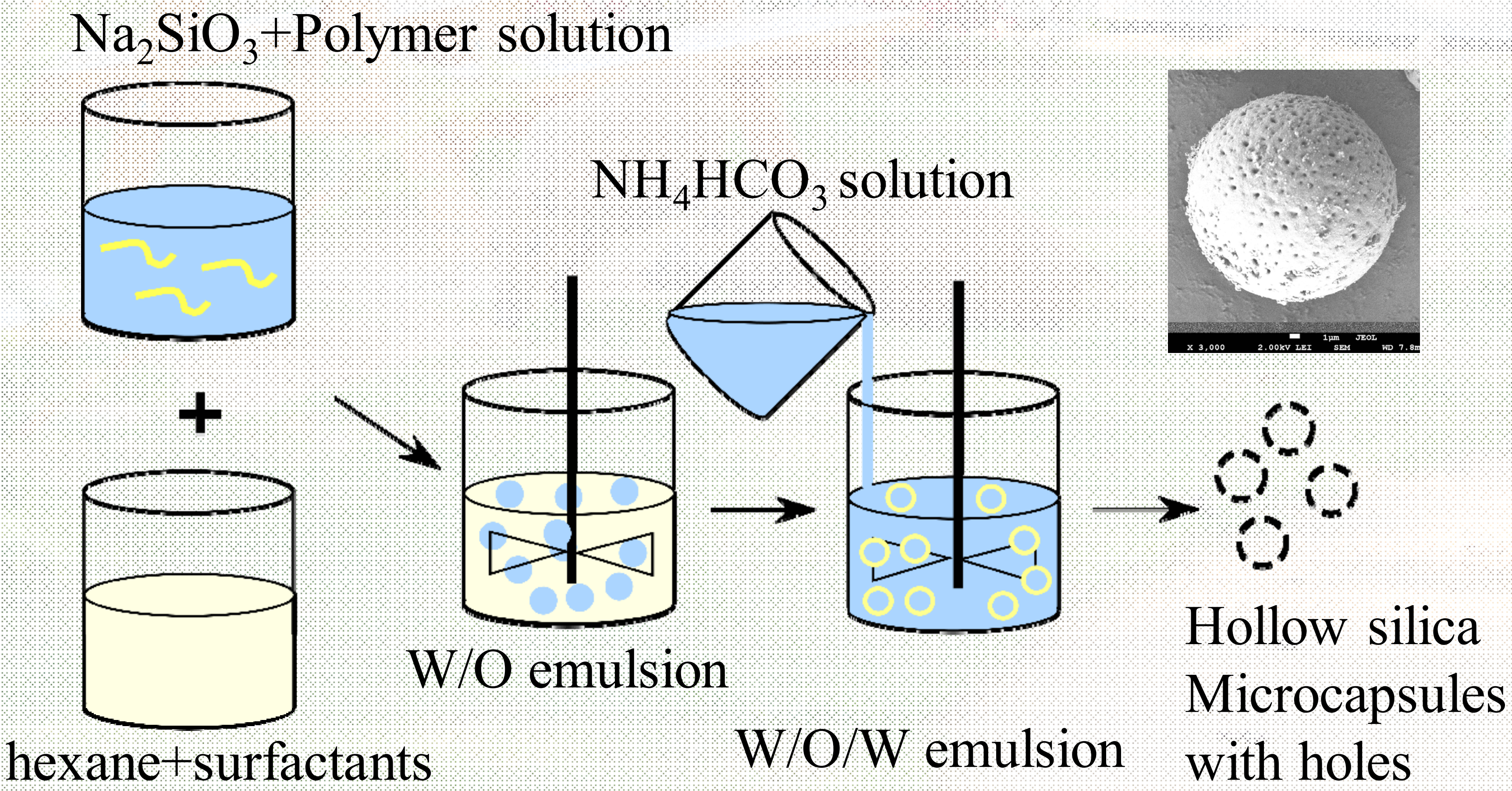
Hidema et al. Int. Heat Mass Trans. 2015

Promising Capsule-Shell Material for Containing PCMs

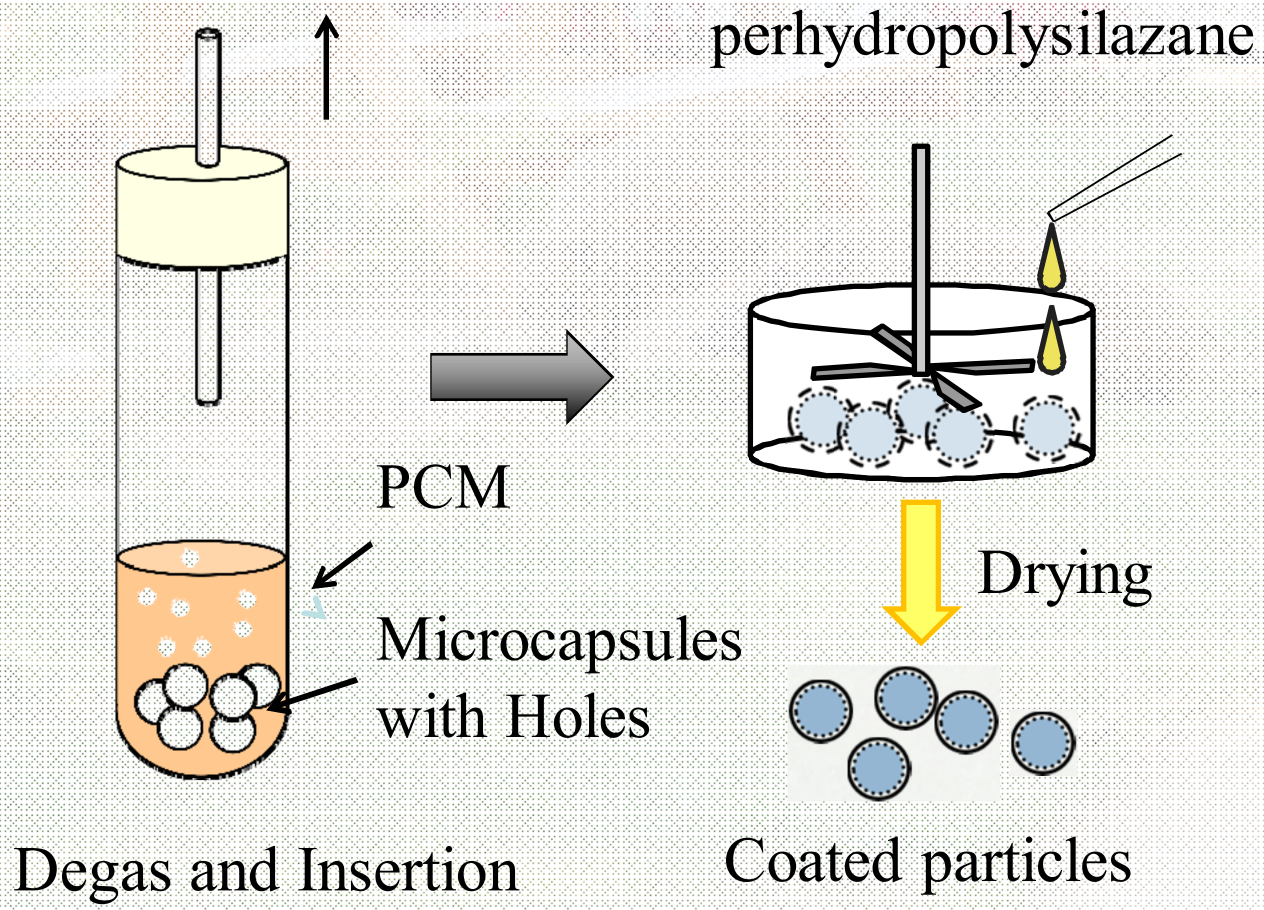
Toyoda et al. Chem. Lett. 2014
Tamaru et al. Proc. ICR2015

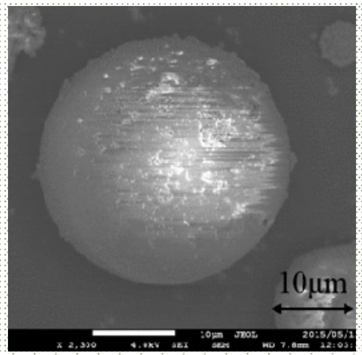
Process –
Hollow Silica Microcapsules with Fine Holes

Virtudaso et al., Mater. Lett., 2011



Process –
Inserting Materials and Coating

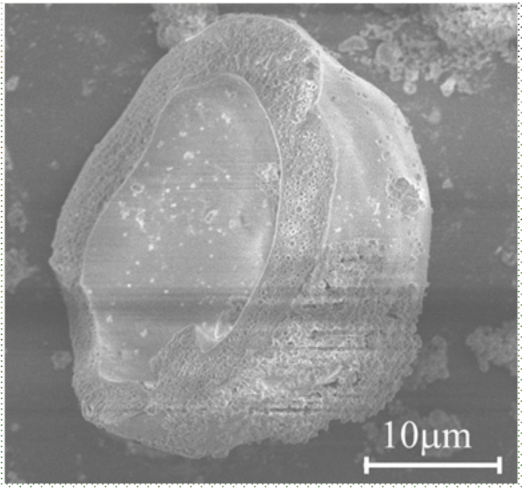


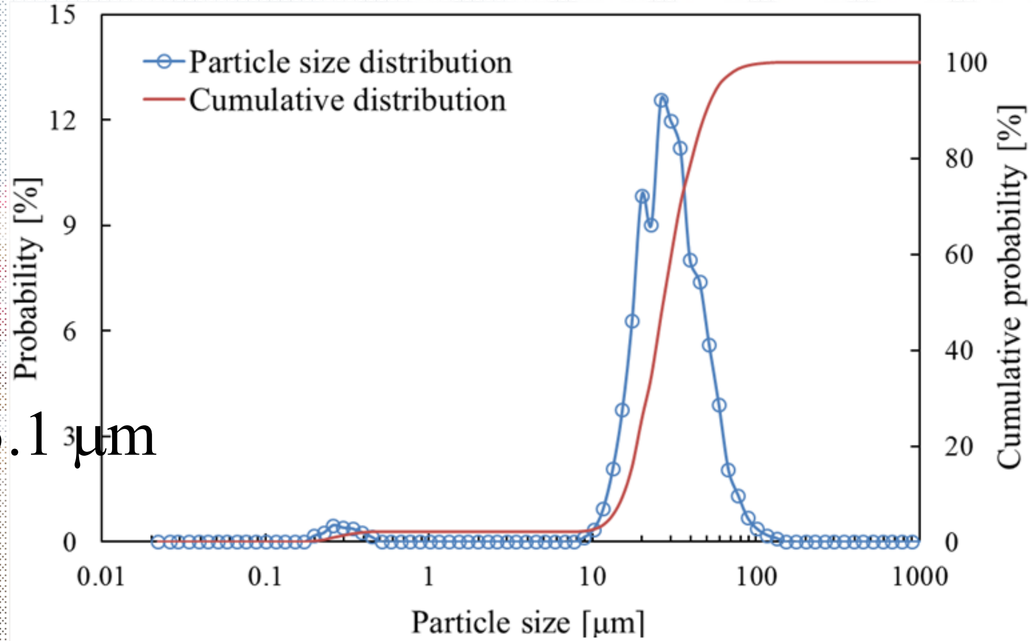


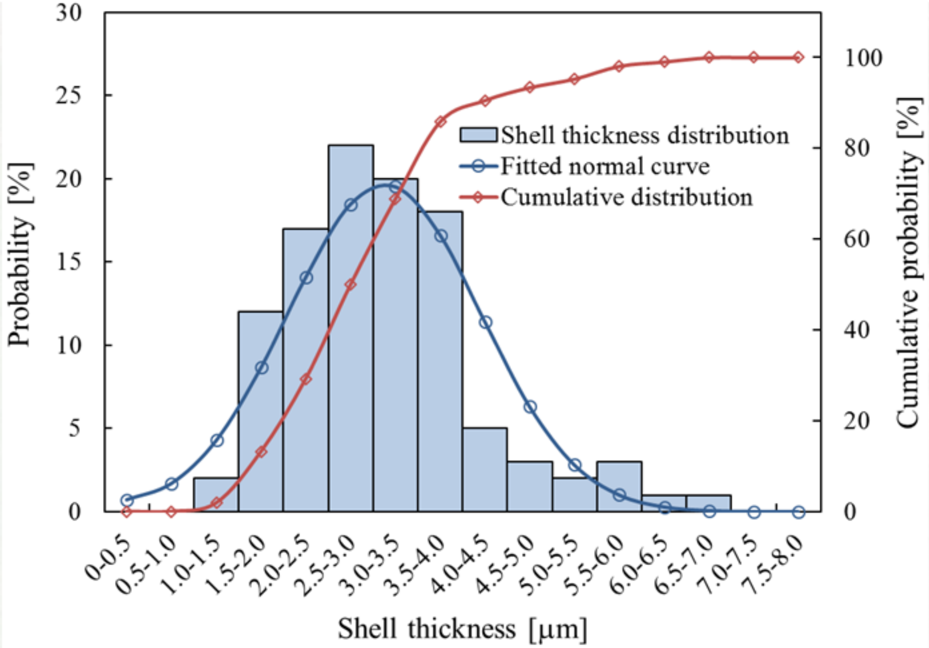
Size of HSMC

Mean Diameter: 24.8μm
Mean Shell Thickness
: 3.1 μm

Void Fraction : 42.4vol%



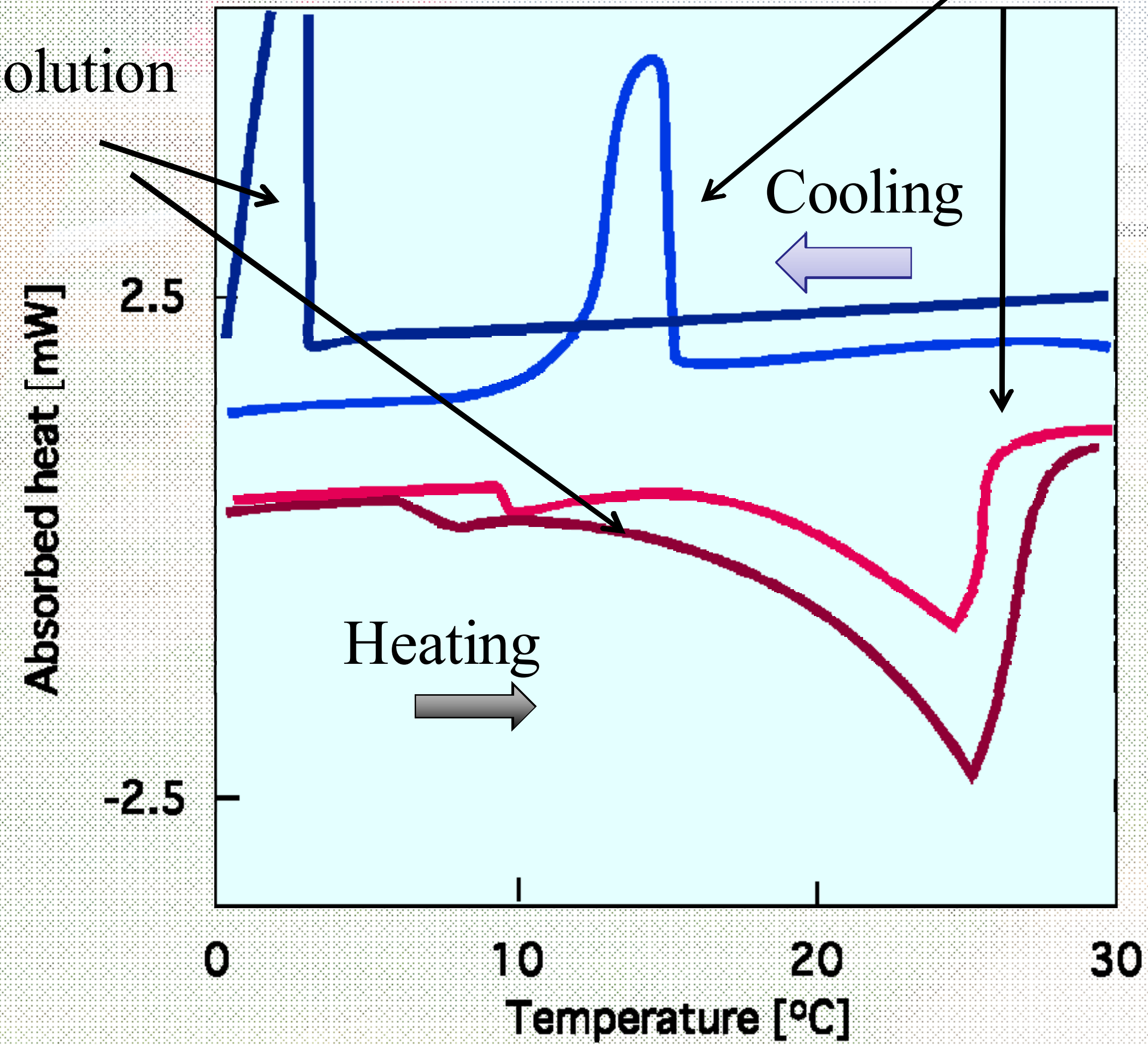


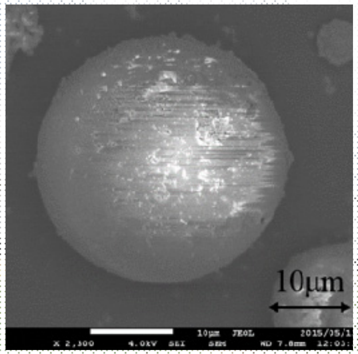


Absorbed/Desorbed Heat

Encapsulated TME Solution

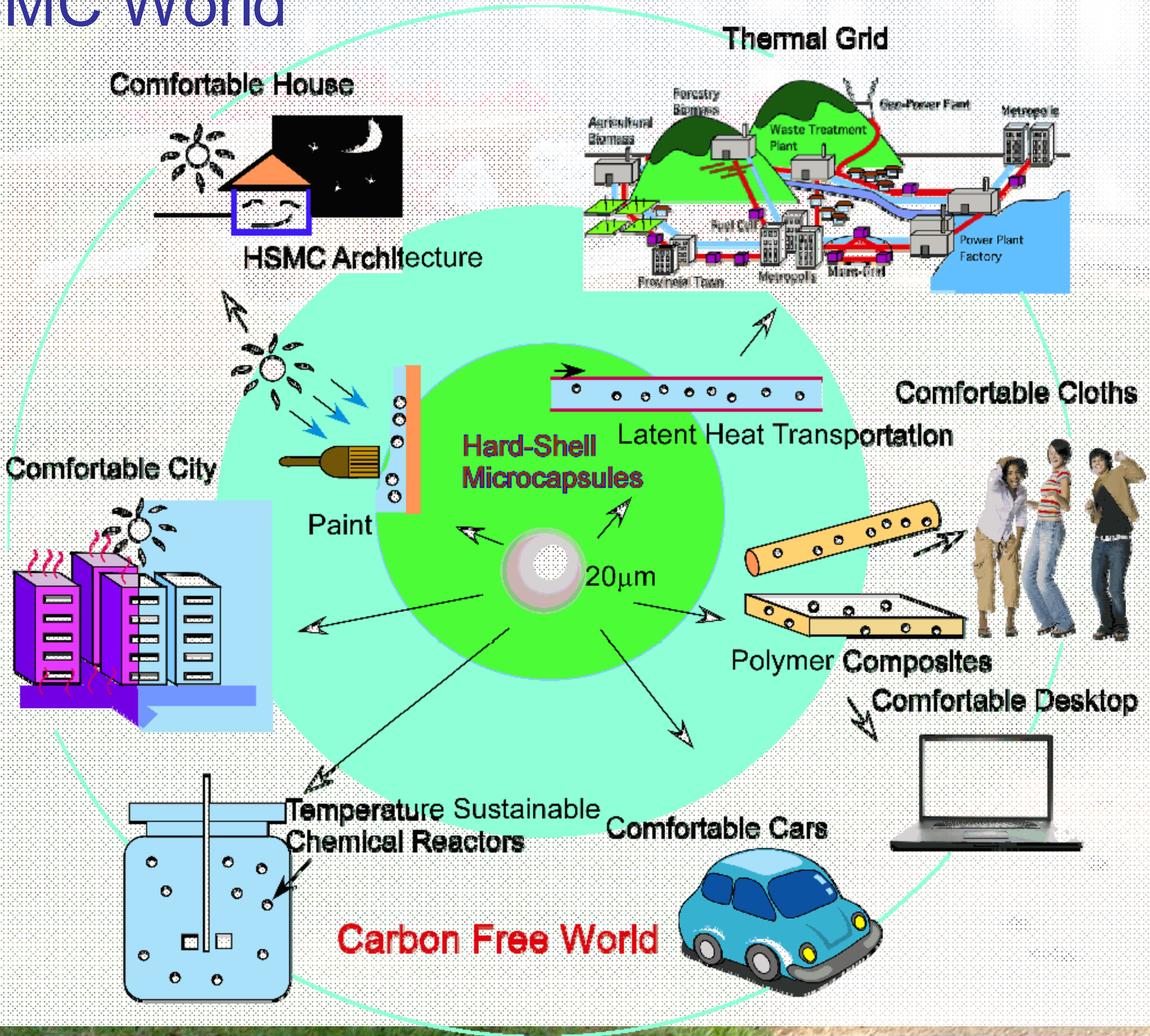
TME Solution





Supercooling Depression Effect

HSMC World


Thermal Grid
Comfortable House
HSMC Architecture
Forestry Biomass
Agricultural Biomass
Waste Treatment Plant
Geo-Power Plant
Metropolis
Fuel Cell
Power Plant Factory
Provincial Town
Metropolis
Main Grid
Comfortable Cloths
Latent Heat Transportation
Hard-Shell Microcapsules
Comfortable City
Paint
20μm
Polymer Composites
Comfortable Desktop
Temperature Sustainable Chemical Reactors
Comfortable Cars
Carbon Free World

Conclusions

Hard-Shell Micro-Capsules (HSMC) is a promising material for encapsulating Phase Change Materials

Thermal Gap solution