A Radically New Method for Hydrogen Storage in Hollow Glass Microspheres
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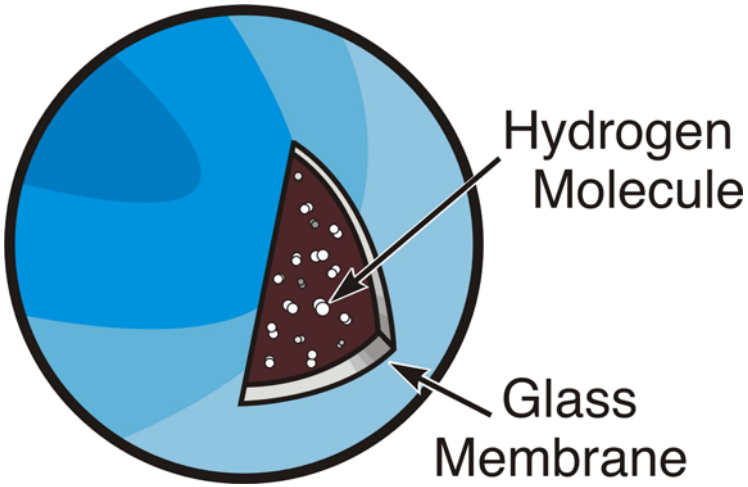
Traditional Applications for HGMS

- Low density fillers for composites with polymers and concrete
- Thermally insulating paint
- Thermally insulating tapes
- Syntactic foams for submersibles
- Oil well drilling
- Targets for laser fusion systems (D/T filled)

Modern Applications for Hydrogen-Filled HGMS

- Hydrogen storage
- Hydrogen separation and purification
- Radiation shielding for manned space flight

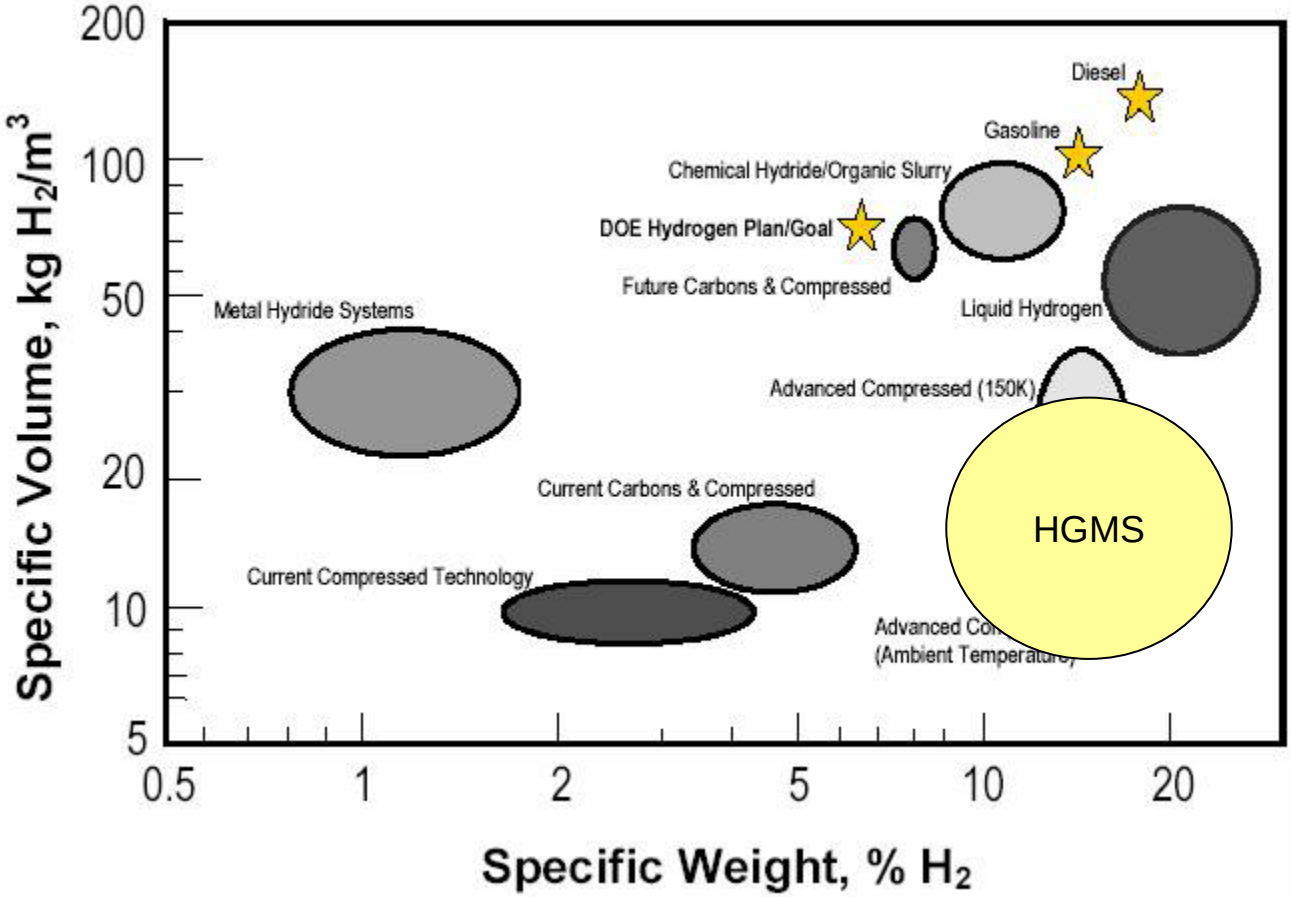
Advantages of HGMS

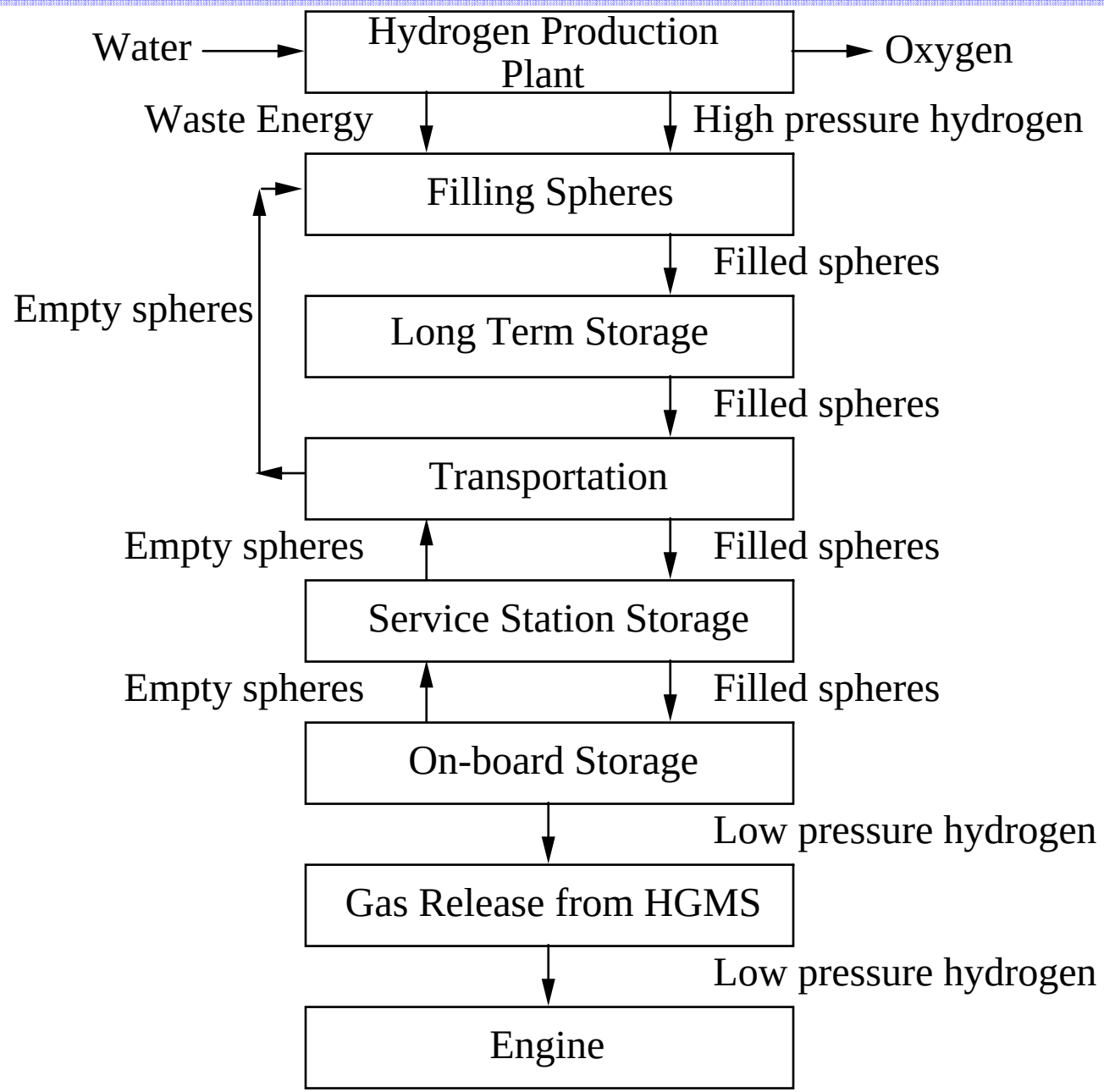


HYDROGEN-FILLED HOLLOW GLASS MICROSPHERE

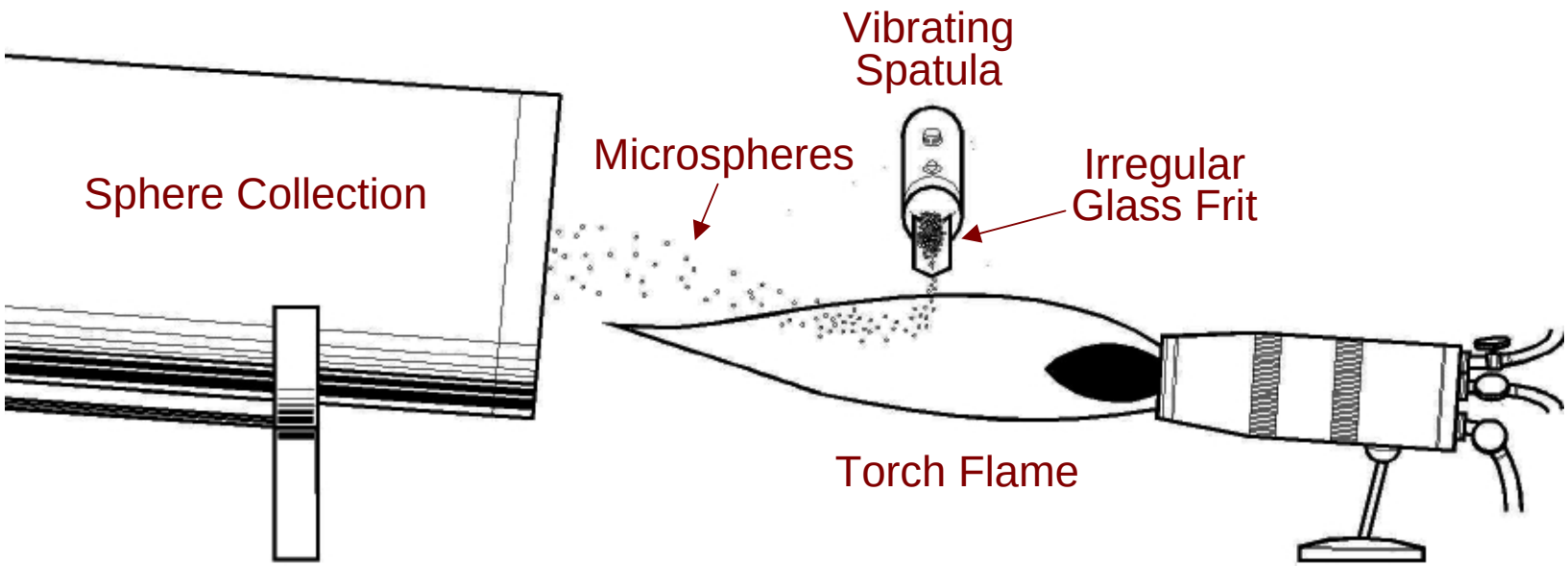
- Cheap, plentiful raw materials
- Established technology
- Made from recycled glass
- Readily used for many cycles
- Light-weight
- High strength (high pressure)
- Safety
- Flow like liquids
- High separation ratio ($>10^6$)
- High H_2/volume
- Low mass/H_2 content

Storage Densities



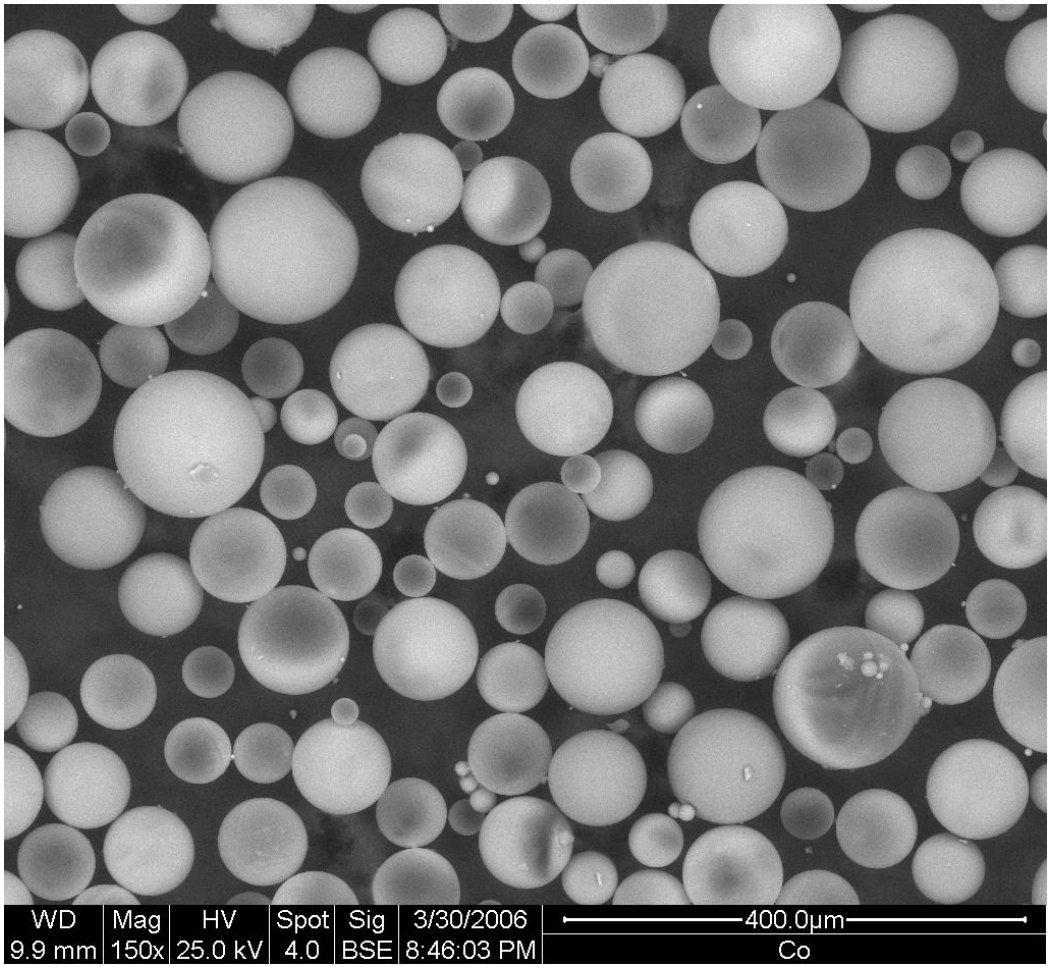

Water
Hydrogen Production Plant
Oxygen
Waste Energy
High pressure hydrogen
Filling Spheres
Filled spheres
Empty spheres
Long Term Storage
Filled spheres
Transportation
Empty spheres
Filled spheres
Service Station Storage
Empty spheres
Filled spheres
On-board Storage
Low pressure hydrogen
Gas Release from HGMS
Low pressure hydrogen
Engine

Hollow Glass Microsphere Production

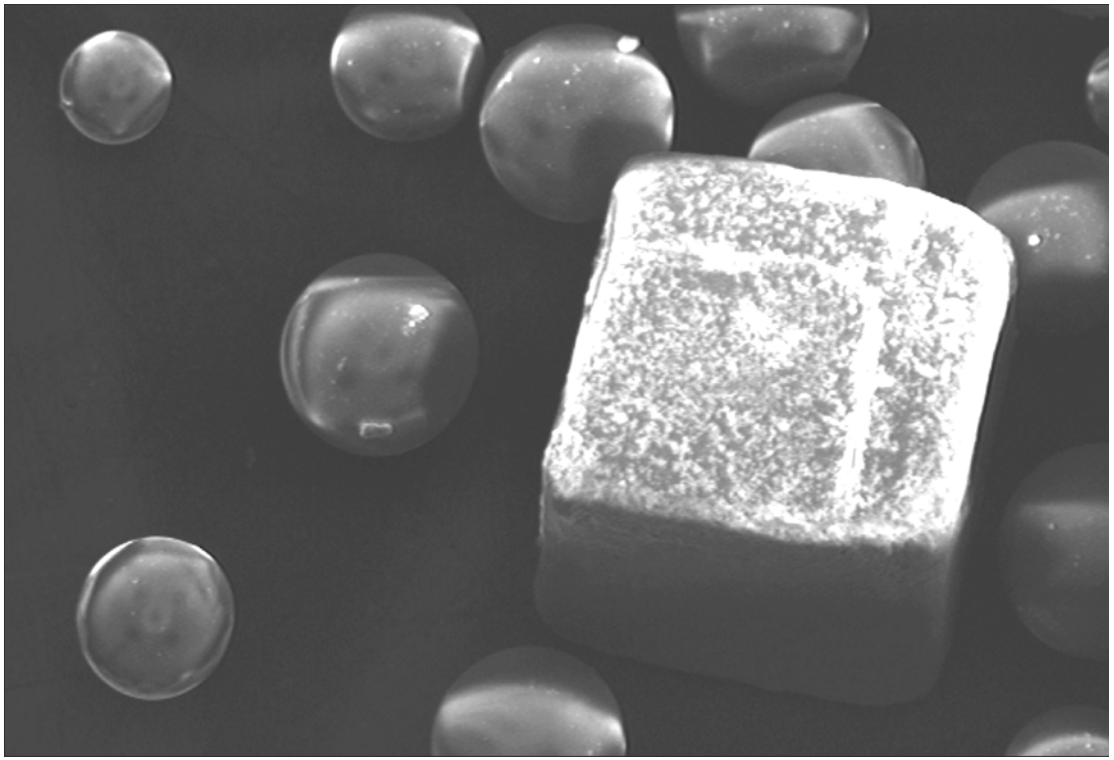


Flame spraying method for producing microspheres

ESEM Micrograph of GL – 1394 (CoO)



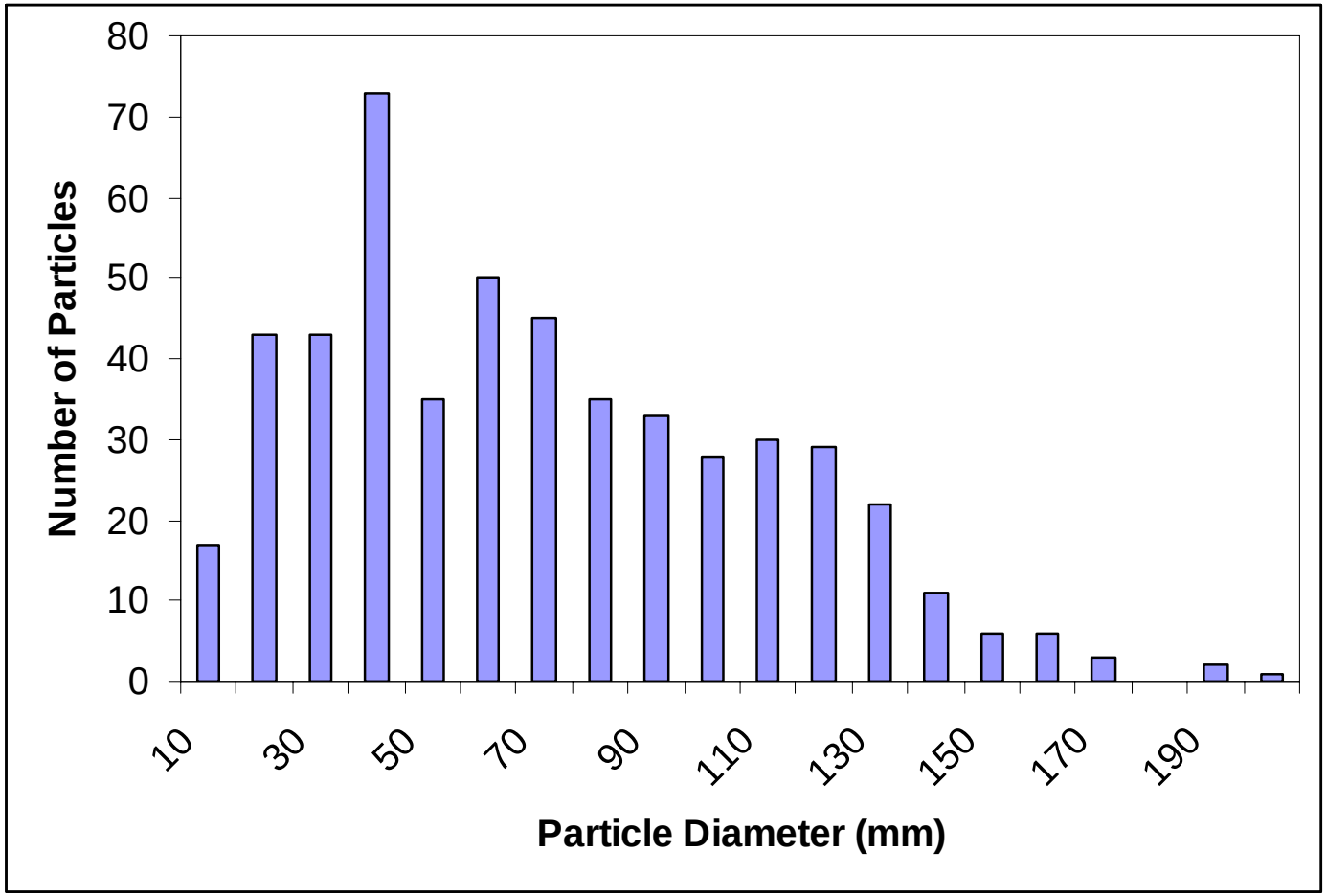
Hollow Glass Microspheres



Compositions

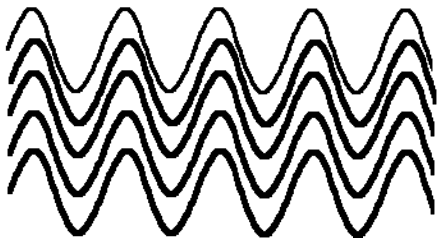
GL – 1404	**Undoped**
GL – 1402	**Amber – 0.2 wt% FeO**
GL – 1386	**5 wt% FeO**
GL – 1391	**5 wt% NiO**
GL – 1394	**5 wt% CoO**

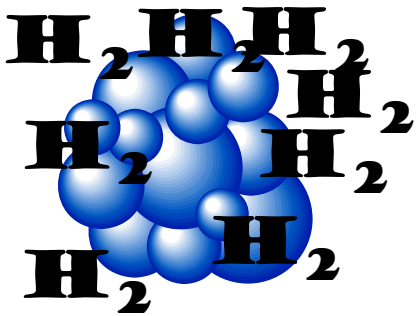
Particle Size Distribution for GL – 1386 (FeO)



What is Photo – Induced Outgassing?

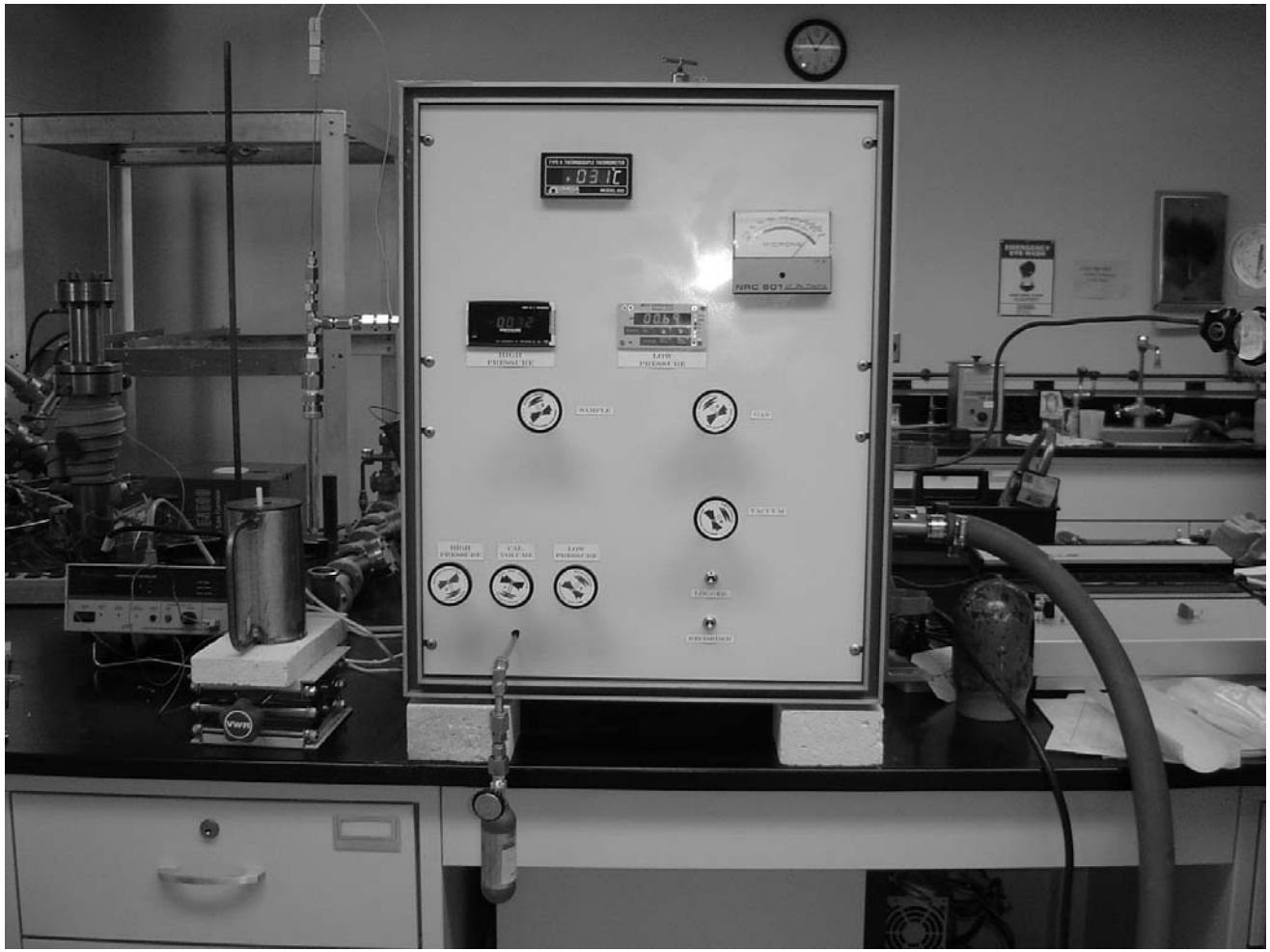
250 W Infrared Light Bulb



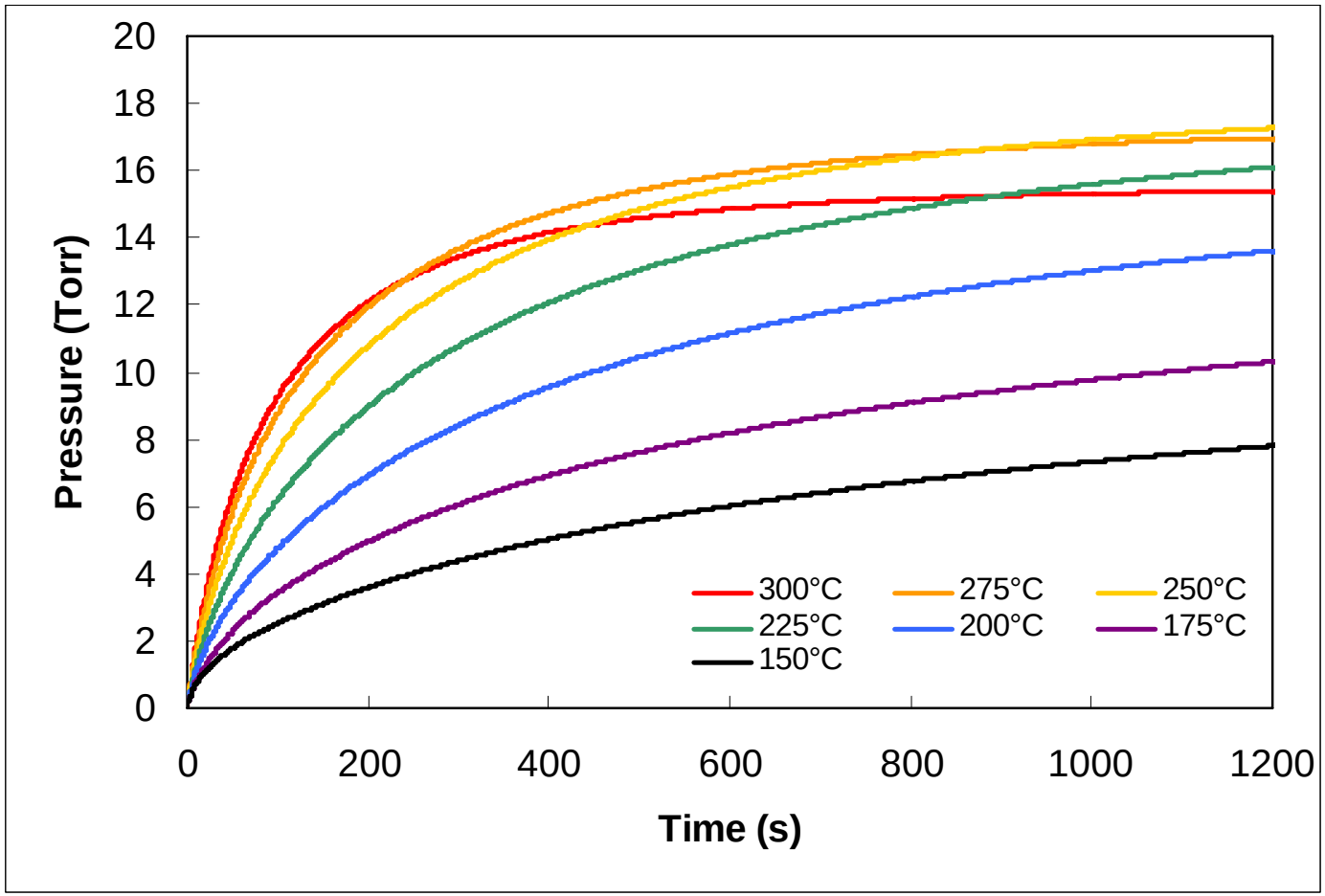


Hollow Glass Microspheres

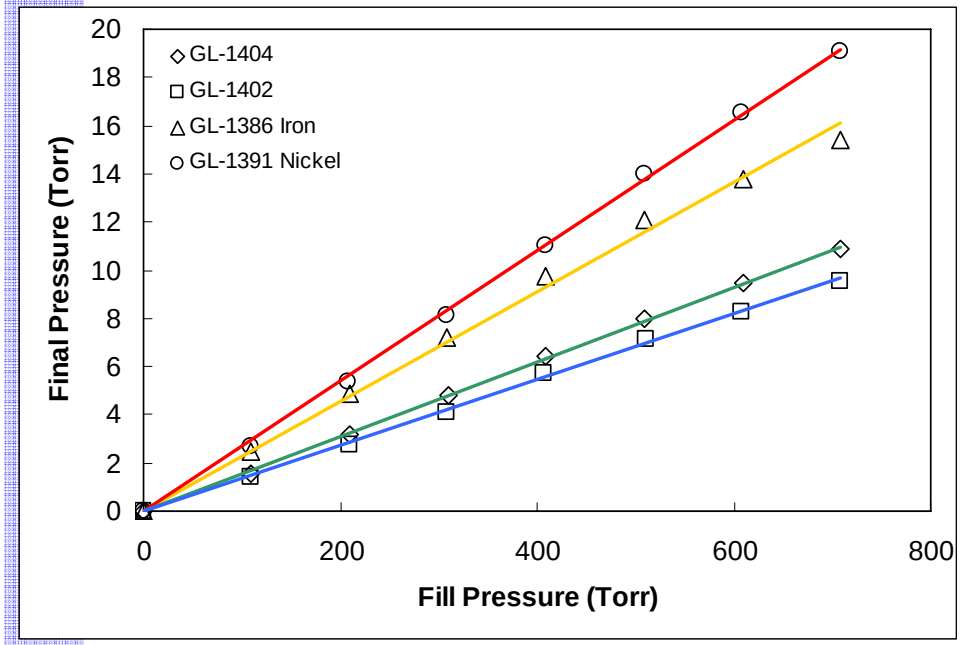
PVT Measurement System



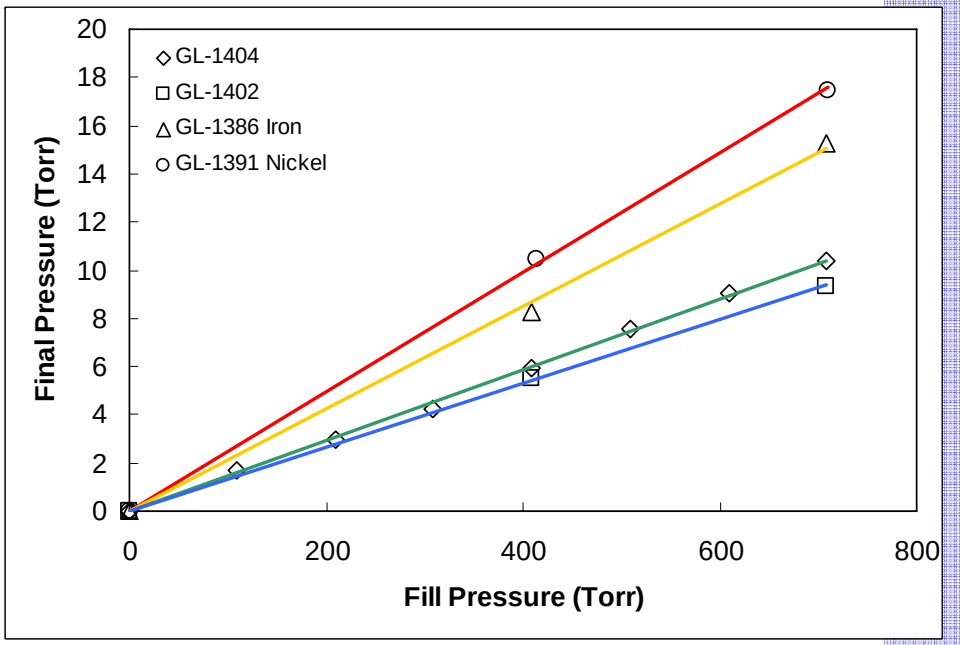
Helium Outgassing Curves for GL – 1386 (FeO)



Relationship Between Final and Applied Pressure



Helium



Hydrogen

Outgassing Curve Analysis for PVT Measurements

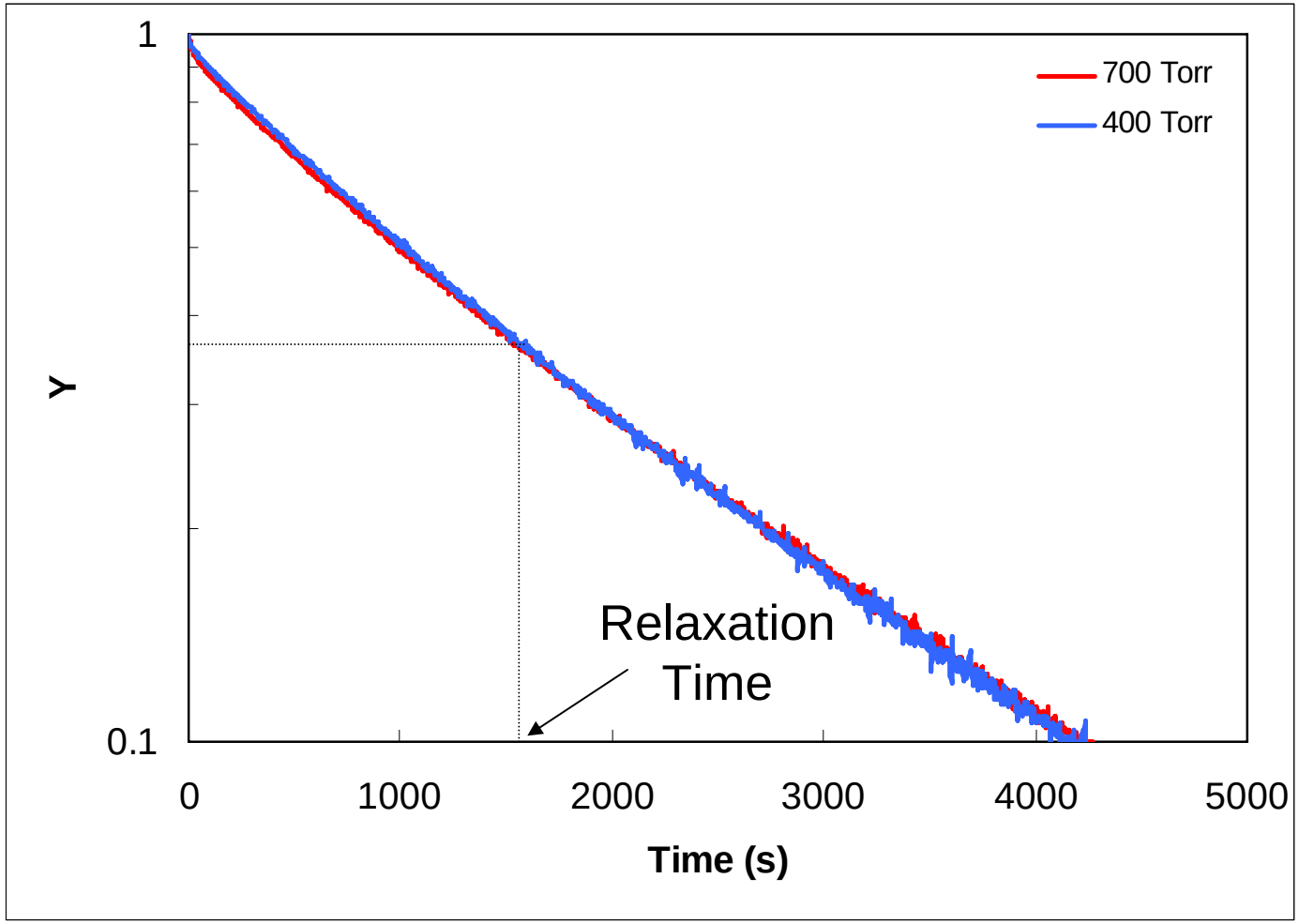
$$\frac{dP_2}{dt} = -\frac{1}{\tau}\left[-\left(\frac{\alpha+1}{\alpha}\right)P_2^{\infty} + \left(\frac{\alpha+1}{\alpha}\right)P_2\right]$$

$$\alpha = V_2/V_1$$

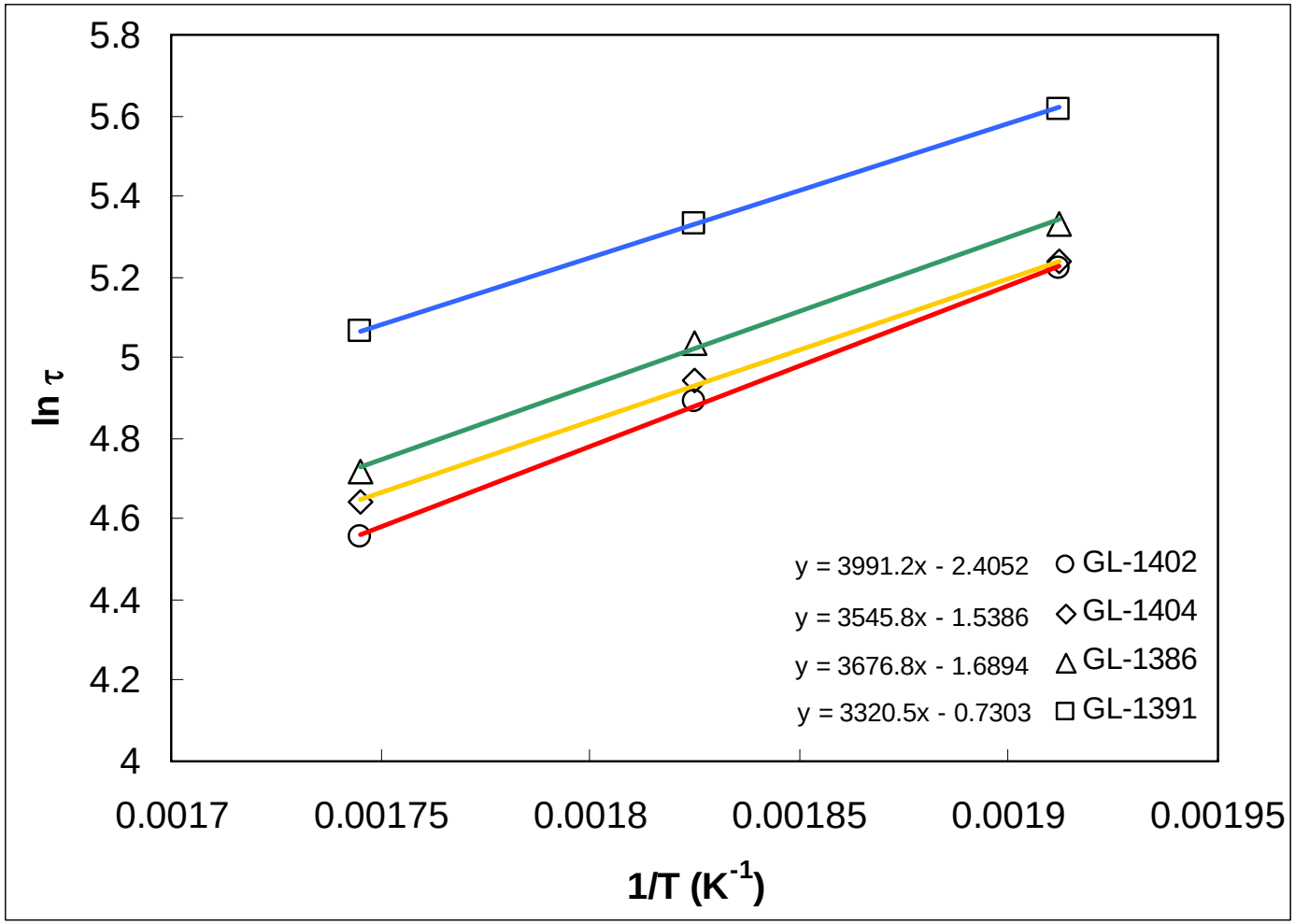
$$\tau = \frac{(r-l)l}{3RTK}$$

$$Y = \left(1 - \frac{P_2}{P_2^{\infty}}\right) = \exp\left[-\left(\frac{\alpha+1}{\alpha}\right)\frac{t}{\tau}\right]$$

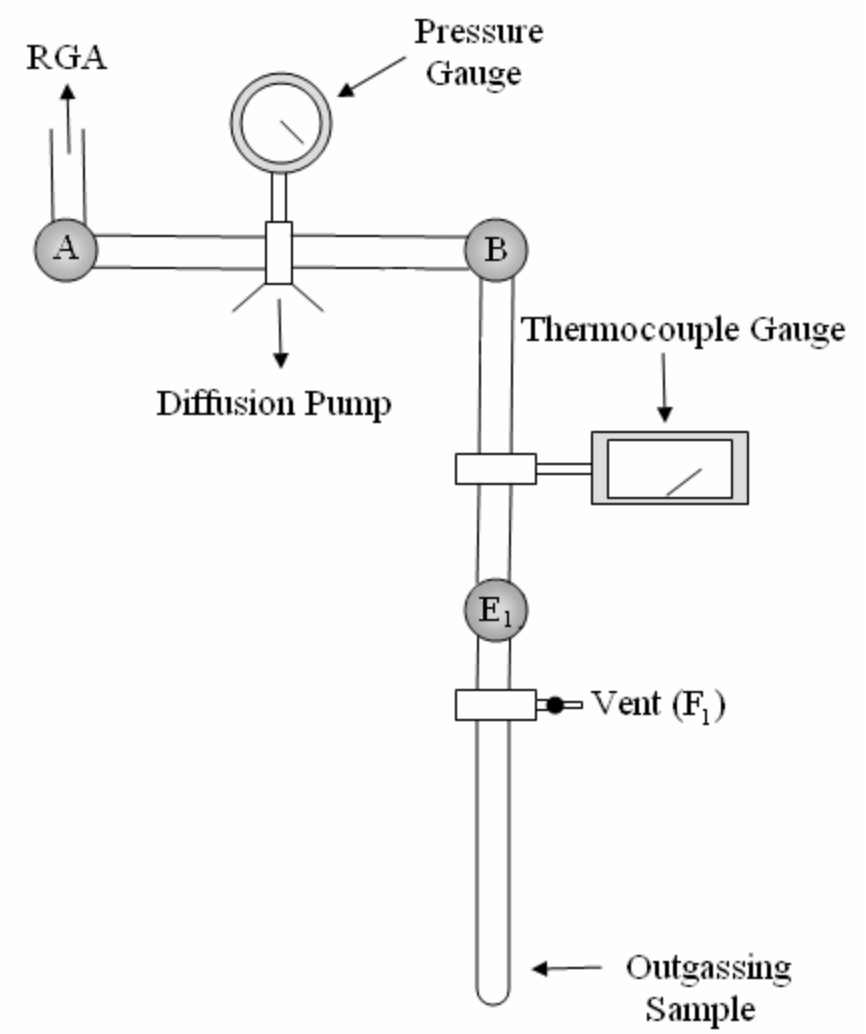
Hydrogen Outgassing Curve



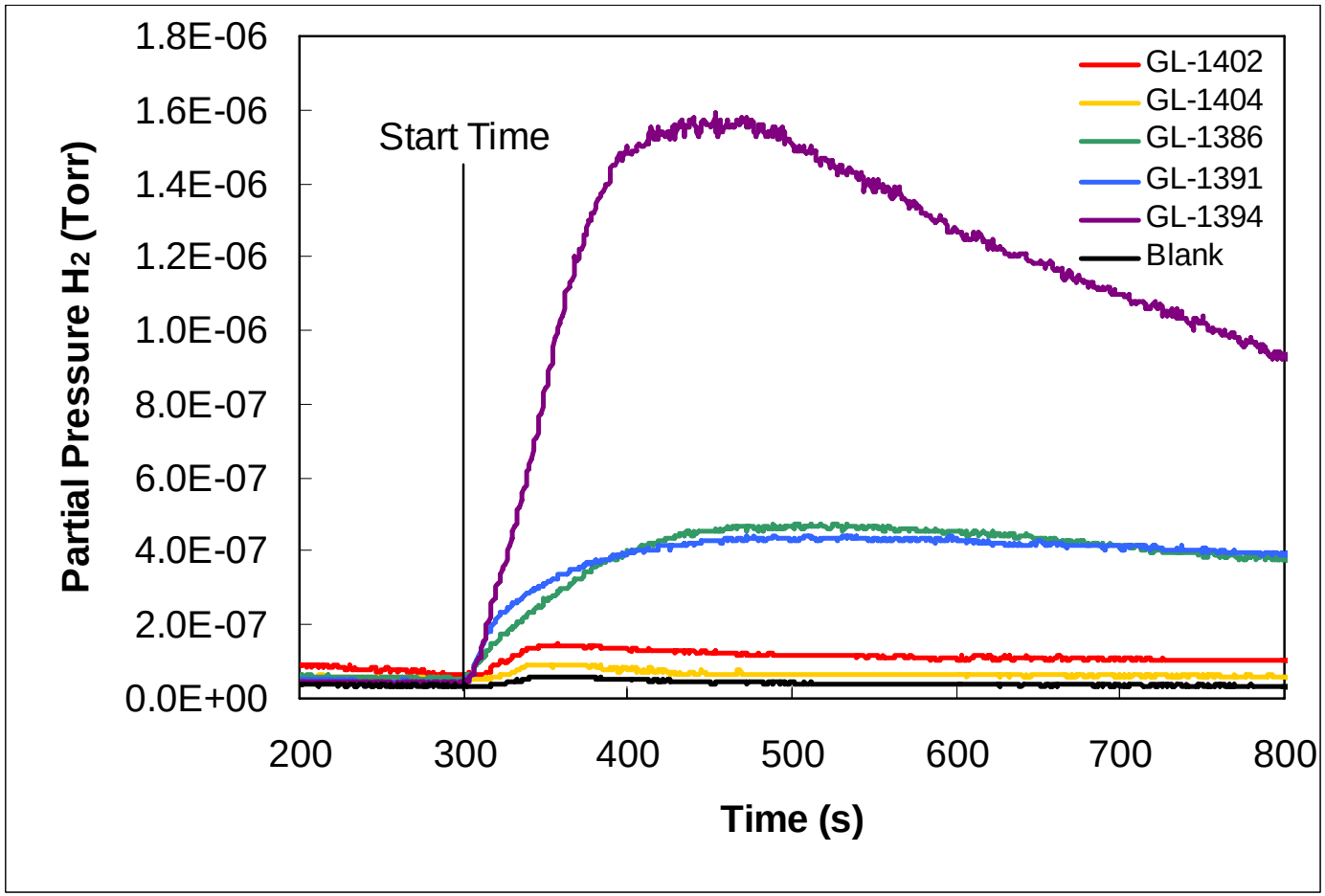
Arrhenius Plot of Relaxation Times



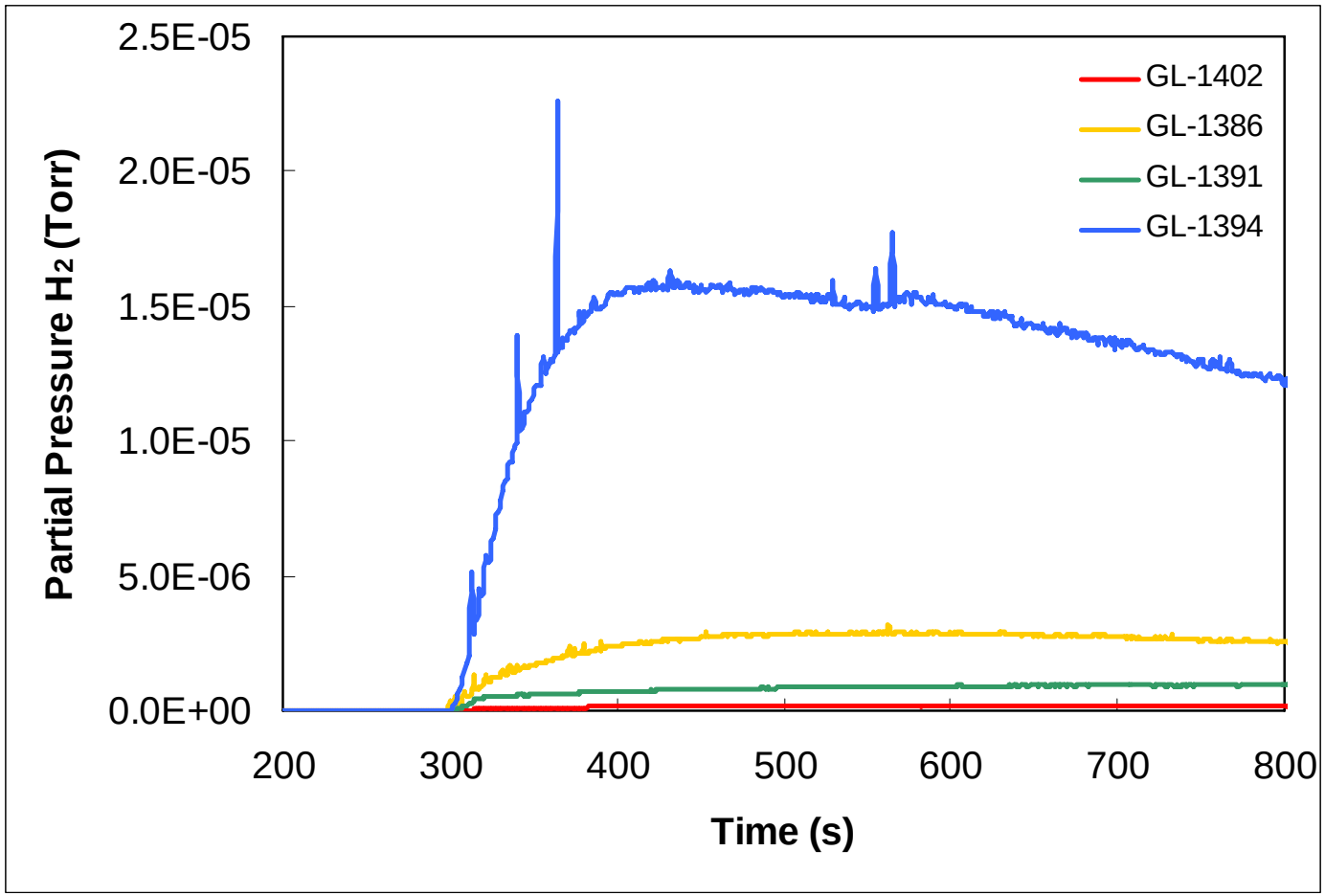
Residual Gas Analyzer



Lamp Outgassing Curves for HGMS Loaded to 700 Torr



Lamp Outgassing Curves for HGMS Loaded to 1500 psi



1500 psi = 77,572.4 Torr

Lamp vs. Furnace H_2 Outgassing Curves for GL – 1394 (CoO)

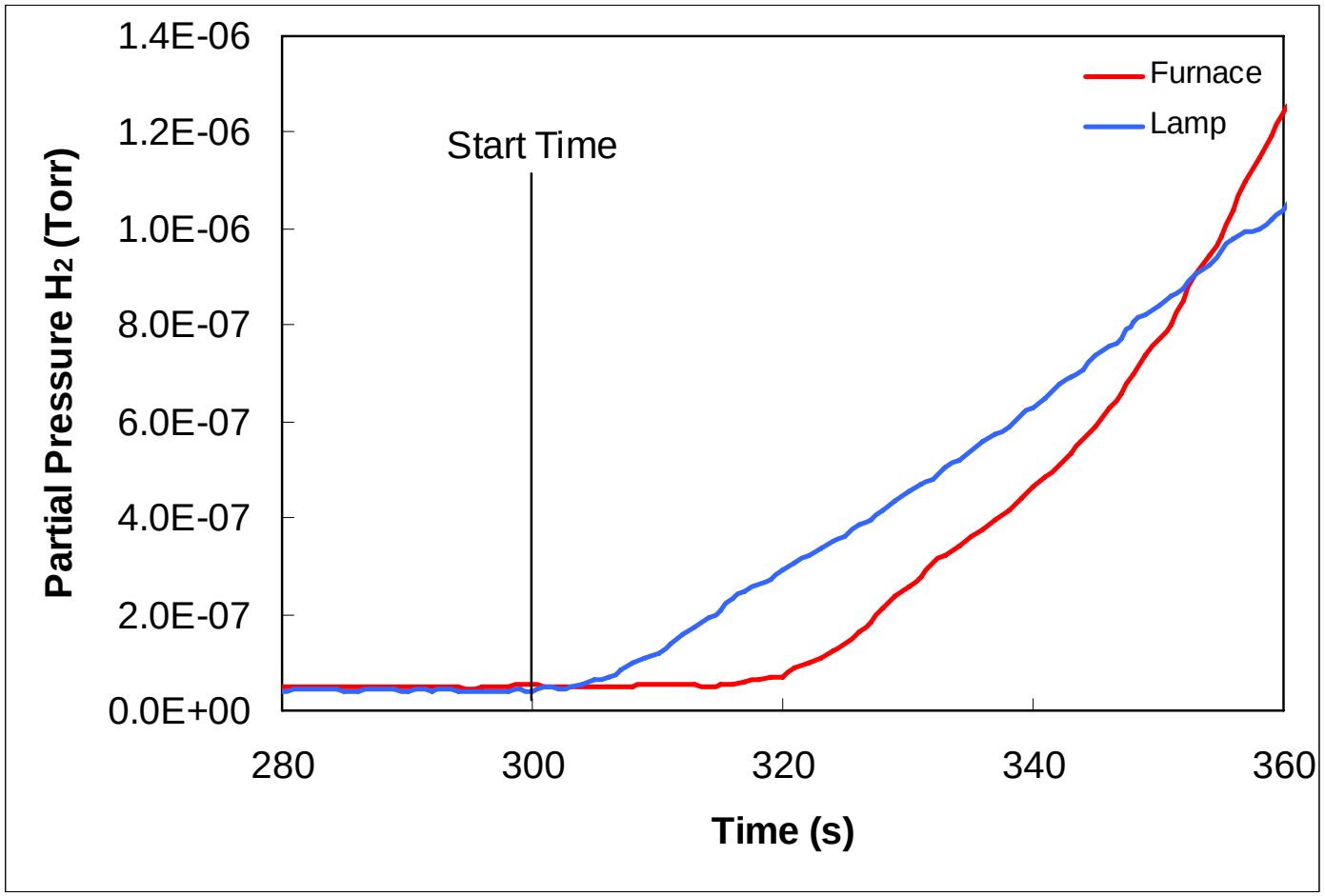
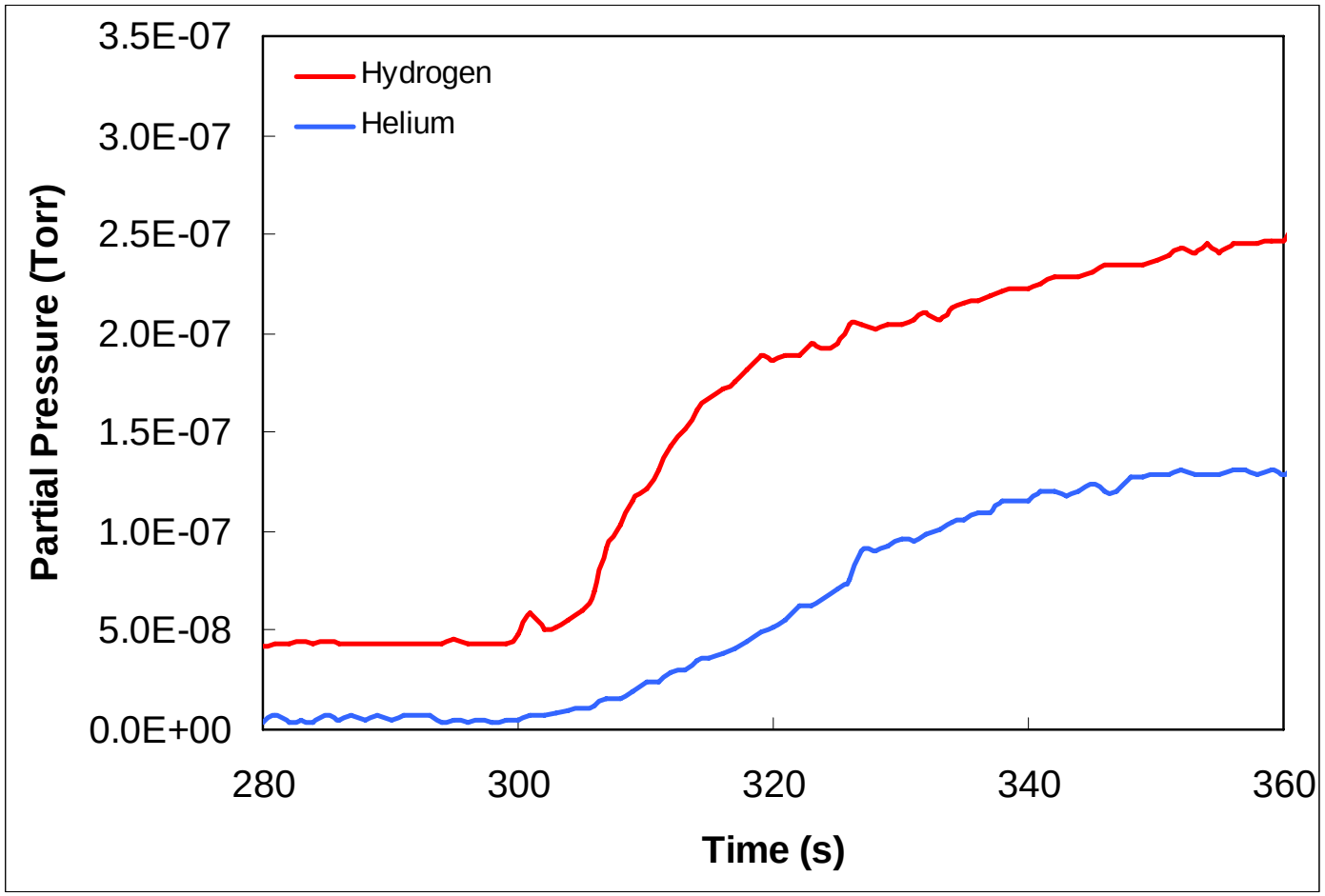
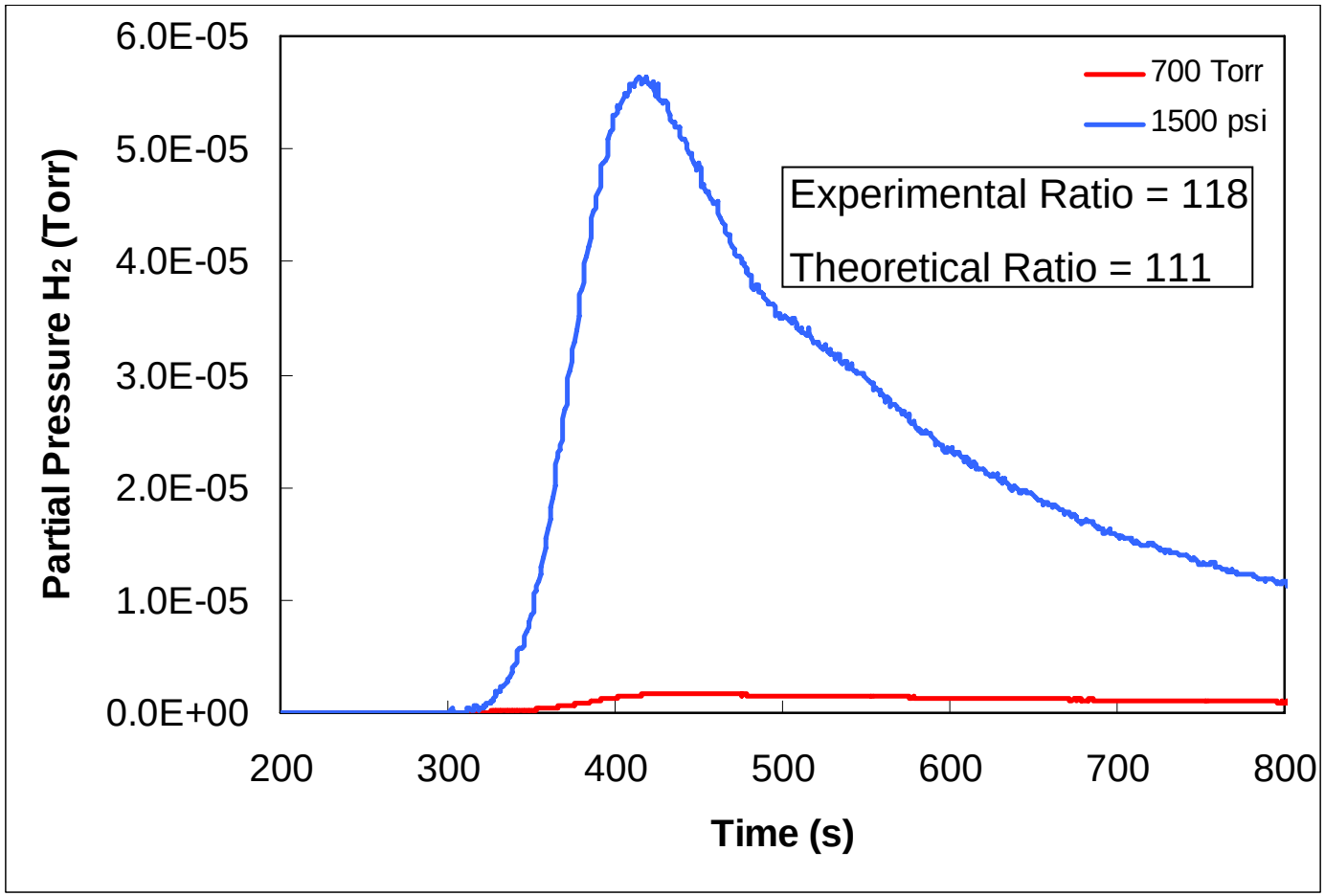
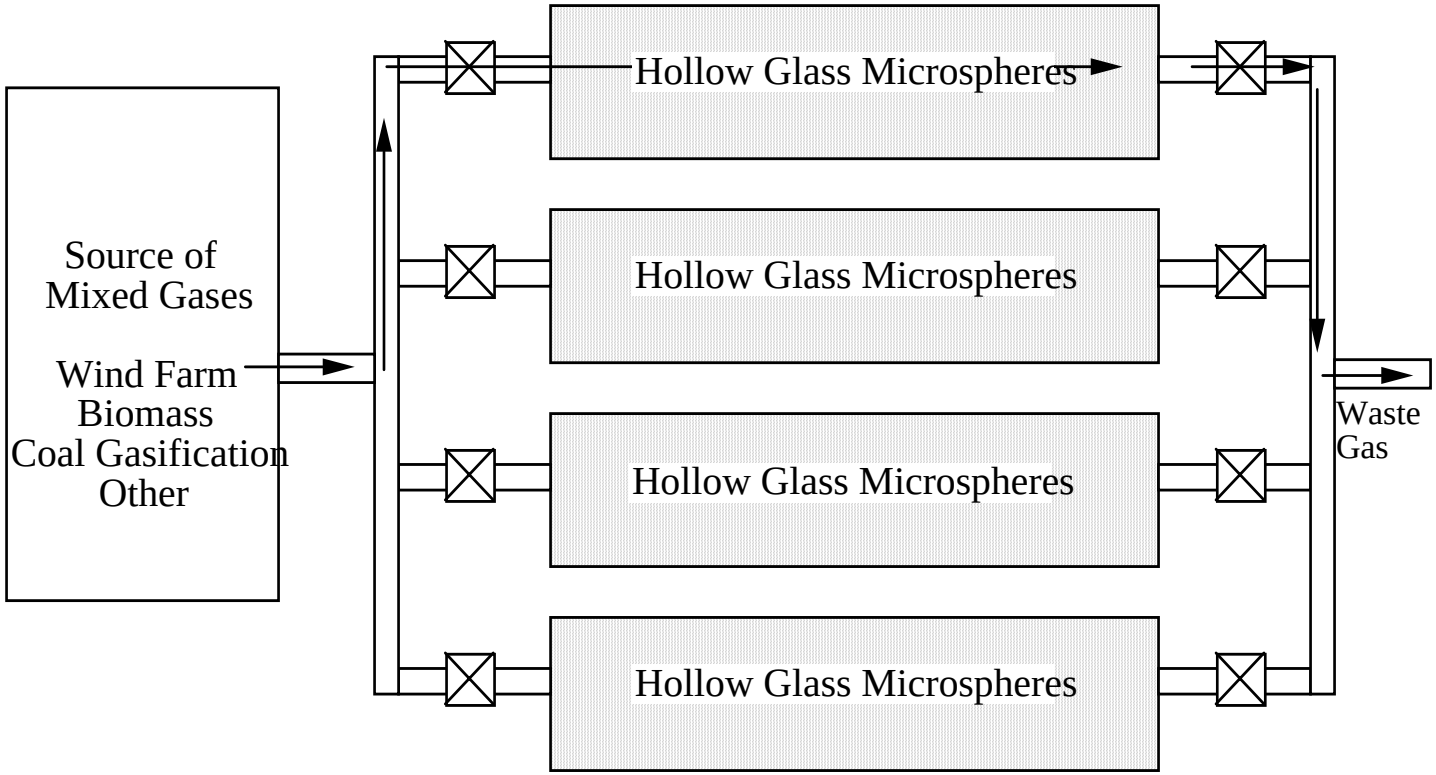


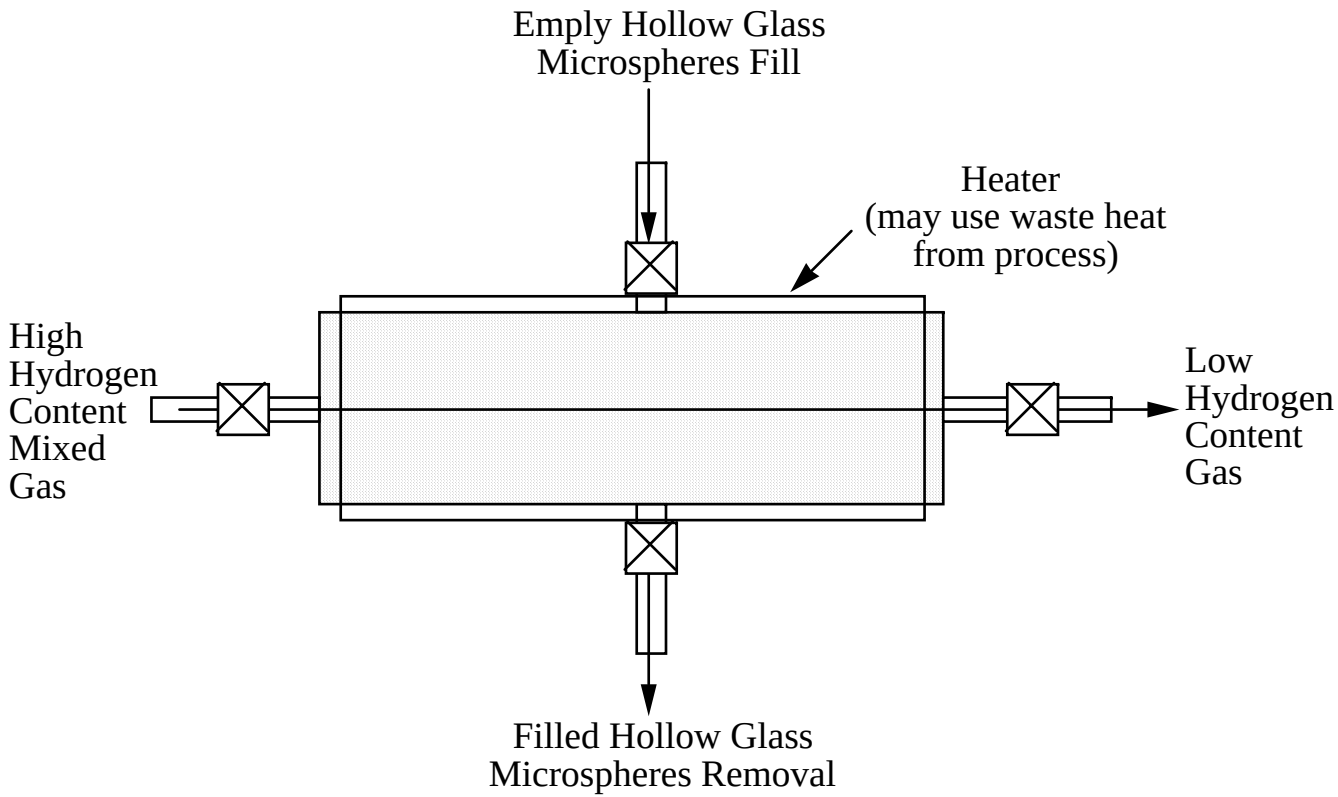
Photo-induced Outgassing of He/H_2 Mixture From GL – 1391 (NiO)



Effect of Fill Pressure on Thermal Outgassing Curves for GL – 1386 (FeO)




Source of
Mixed Gases
Wind Farm
Biomass
Coal Gasification
Other
Hollow Glass Microspheres
Hollow Glass Microspheres
Hollow Glass Microspheres
Hollow Glass Microspheres
Waste
Gas


Emply Hollow Glass
Microspheres Fill
Heater
(may use waste heat
from process)
High
Hydrogen
Content
Mixed
Gas
Low
Hydrogen
Content
Gas
Filled Hollow Glass
Microspheres Removal

Conclusions

- Hollow glass microspheres have many attractive features as a H_2 storage medium.

- Photo-enhanced outgassing of H_2 from HGMS is significantly faster than conventional heating.

- Discovery of the photo-enhanced diffusion effect increases the potential for HGMS to make a major impact on H_2 storage and generation on demand.

- Additional possibilities for use of HGMS for separation of H_2 from mixed gas streams and for purification of mixed gases to yield very high purity H_2 exist. These applications increase the attractiveness of this method for hydrogen storage.

Presentations to Date

- Fabienne C. Raszewski, Mathew M. Hall and James E. Shelby, "Thermal and Photo-Induced Outgassing of Hollow Glass Microspheres," GOMD meeting ACerS, Greenville, SC, May, 2006.

- James E. Shelby and Mathew M. Hall, "Separation, Purification, and Storage of Hydrogen in Hollow Glass Microspheres," GOMD meeting ACerS, Greenville, SC, May, 2006.

- James E. Shelby and Mathew M. Hall, "Novel Applications of Hydrogen-Filled Hollow Glass Microspheres," University Conference on Glass, Penn. State U., June, 2005. (invited)

- Matthew M. Hall and James E. Shelby, “Hollow Glass Microspheres for Hydrogen Gas Storage,” NHA Annual Hydrogen Conference, Mar. 2005, Washington, DC. (invited)

- Matthew M. Hall, Scott T. Misture, and James E. Shelby, “Glass as an Enabling Material for the Hydrogen Economy,” GOMD meeting ACerS, Cocoa Beach, FL, Nov. 2004.