PS Application of Mercury Intrusion Porosimetry in Pore Structure Characterization*

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Abstract

Porosimetry is the measurements of pore size, volume, distribution, density, and other characteristics of a material. Mercury intrusion porosimetry (MIP) has been used in a variety of porous media, including oil/gas reservoir rocks and construction materials, This work is to extend the conventional information from porosimetry, and derive several important pore structure parameters (such as permeability, tortuosity, and conductivity formation factor) from the collected MIP data. The characteristic of pore structure can affect the gas/oil recovery rate significantly, while total porosity could indicate the potential oil/gas storage. We have performed MIP analyses on several samples, including Barnett Shale samples from different depths and difference size fractions, sandstones, and building materials, (concrete, limestone, and brick) Results(both conventional porosimetry and pore structure information) and comparison with literature values will be presented. Considering the difficulty in measuring the permeability of tight rocks like shale, our results are comparable with permeability data in the literature.

References

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Application of mercury intrusion porosimetry in pore structure characterization

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Abstract

Mercury intrusion porosimetry (MIP) has been used to characterize a variety of porous media, including oil/gas reservoir rocks and construction materials. This work is to extend the conventional information from MIP, and derive several important pore structure parameters (such as permeability, tortuosity, and conductivity formation factor).

Theory

1) **Washburn equation (Washburn, 1921) : pore-throat diameter**

$$D = \frac{WASHCON\ \gamma\ (-4cos\theta)}{P}$$

D is the diameter (in **μm**) of the minimum pore intruded by mercury under pressure P (in **psia**);
WASHCON (Washburn constant) is 0.145;
γ is the surface tension (485 dynes/cm);
θ is contact angle (130º).

2) **Katz-Thompson equations (Katz and Thompson, 1986 and 1987) : k and σ/σ_0**

$$k = \frac{1}{226}(L_c)^2\frac{\sigma}{\sigma_0}$$

k is absolute permeability (10^{-12} m^2);
L_c is characteristic length (μm);
σ is the rock conductivity at characteristic length L_c ;
σ_0 is the conductance of brine in the pore space;
σ/σ_0 is **conductivity formation factor.**

$$k = \frac{1}{89}(L_{max})^2\frac{L_{max}}{L_c}\emptyset S(L_{max})$$

L_{max} is pore diameter (μm) at which hydraulic conductance is maximum;
Φ is porosity;
S(Lmax) is the fractional volume of connected pore space composed of pore width of size L_{max} and larger.

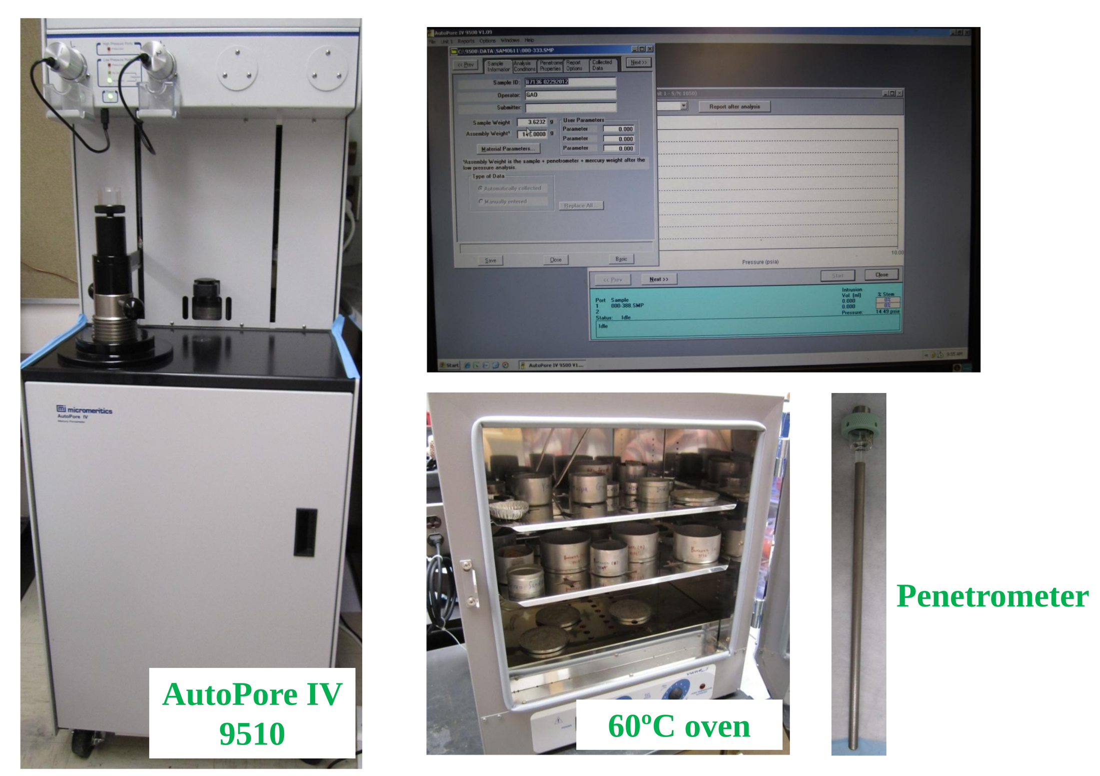
3) **Hager equation (Jörgen Hager, 1998) : tortuosity(τ)**

$$k = \frac{\rho}{24\tau^2(1+\rho V_{tot})}\int_{\eta=r_c,min}^{\eta=r_c,max}\eta^2 f_V(\eta)d\eta$$

ρ is material density;
V_{tot} is total pore volume;
τ is tortuosity which is defined as the ratio of actual distance traveled (l_e) to shortest distance (l) (τ >1):
$\int_{\eta=r_c,min}^{\eta=r_c,max}\eta^2 f_V(\eta)d\eta$ is pore volume distribution by pore size;
$f_V(r_c)=dV(r_c)/dr_c$, from MIP;

Materials

- Barnett shale (Blakley) from different depths (7109 ft, 7136 ft, 7169 ft, 7199 ft, 7219 ft)
- Building materials (concrete, limestone, red brick)
- Berea sandstone and Indiana sandstone



Results

1) Barnett shale

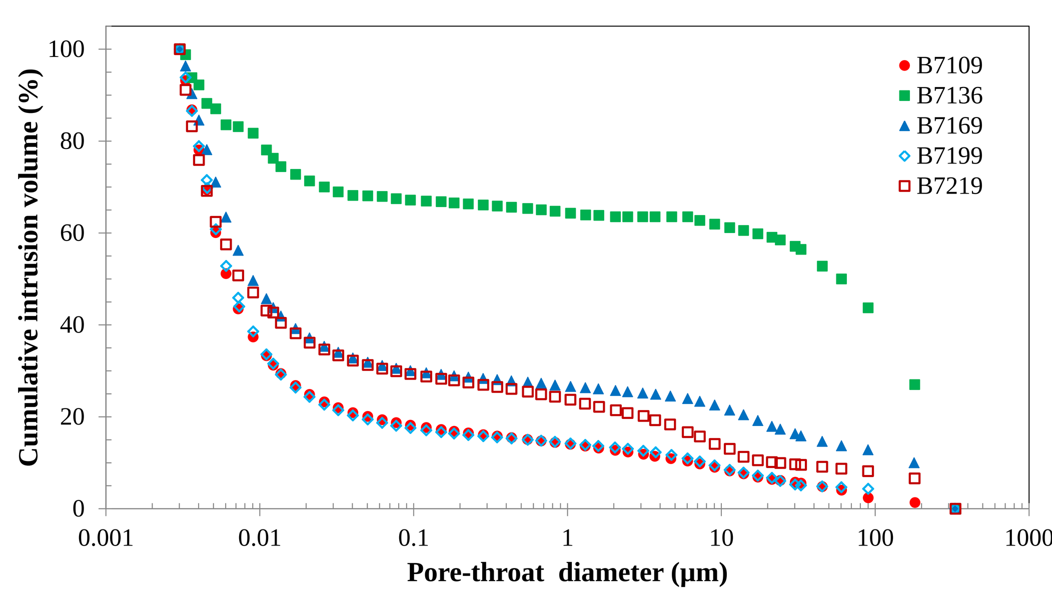


Figure 1. Cumulative intrusion volume (%)vs. pore-throat diameter for Barnett shales.

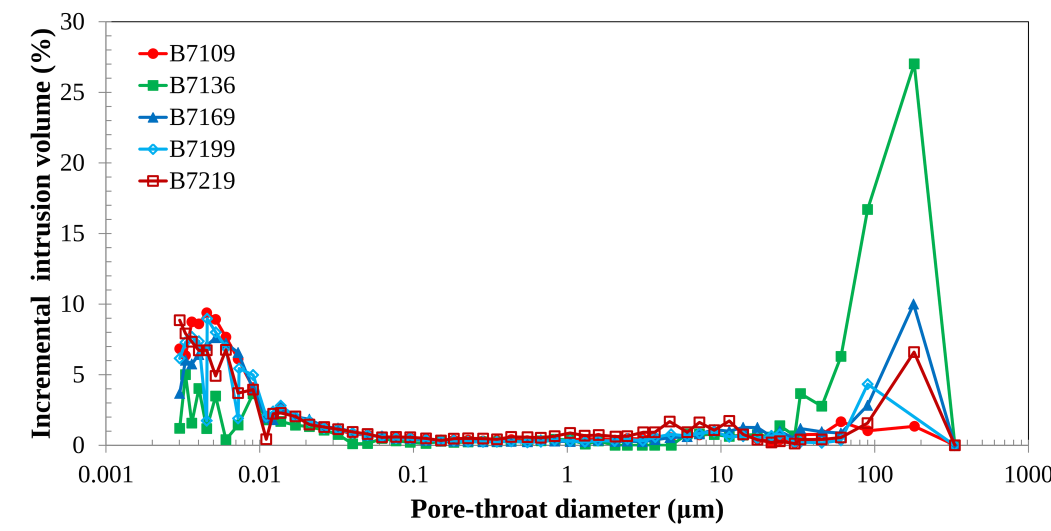


Figure 2. Incremental intrusion volume (%) vs. pore diameter for Barnett shales.

Table 1. MIP results for Barnett shale from different depths.

Depth (ft)	Porosity (%)	Permeability (mD)	Conductivity formation factor (σ/σ_0)	Tortuosity	Stem volume used * (%)
7109	4.32	4.24E-06	0.073	--	49
7136	**1.04**	**1.22E-06**	**0.021**	**41877.43**	**13**
7169	2.88	2.61E-06	0.036	27324.81	38
7199	5.96	6.93E-06	0.077	8749.44	55
7219	2.61	2.57E-06	0.028	21388.85	28

* Data are reliable when stem volume used is between 25% and 90%.

2) Building materials

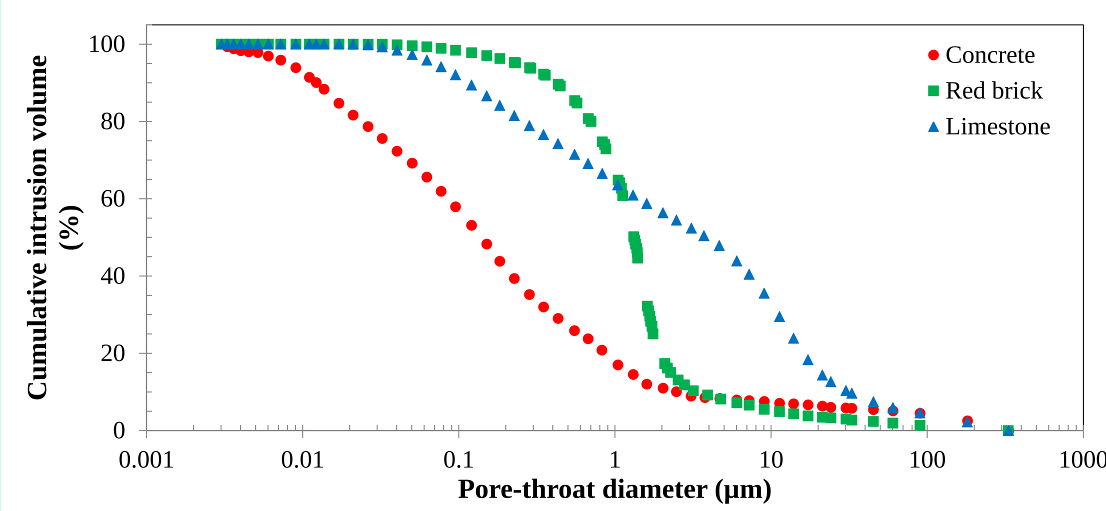


Figure 3. Cumulative intrusion volume (%) vs. pore-throat diameter for building materials.

Table 2. MIP results for building materials.

Sample	Porosity (%)	Permeability (mD)	Permeability from references (mD)	Conductivity formation factor (σ/σ_0)	Tortuosity	Stem volume used (%)
Concrete	20.81	3.00E-02	10^{-2}-10^{2} [a]	0.297	329.14	55
Red brick	21.19	3.19E+00	6-39[b]	0.369	16.25	30
Limestone	14.51	1.28E+02	2-27[c]	0.226	5.08	40

[a] Picandet et al. (2009).
[b] Bentz et al. (2000).
[c] Boving and Grathwohl (2001).

3) Indiana sandstone and Berea sandstone

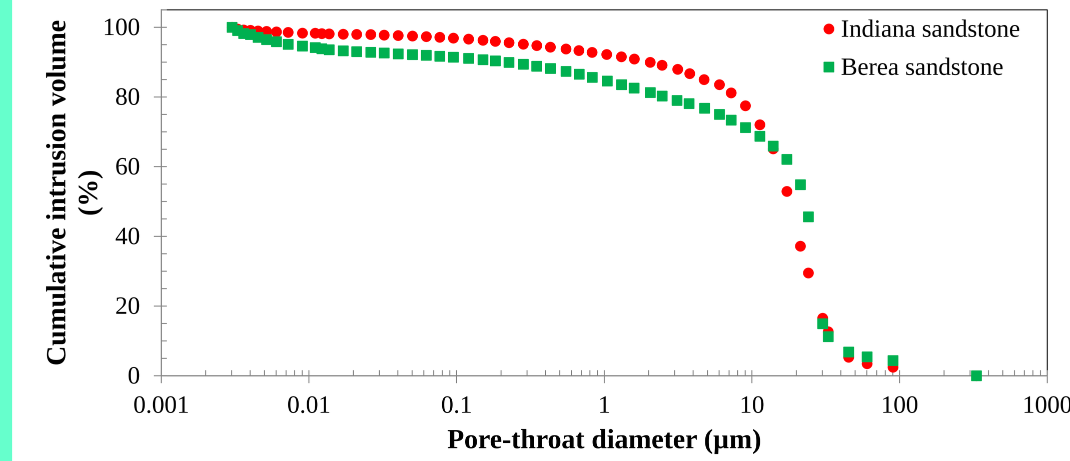


Figure 4. Cumulative intrusion volume (%) vs. pore-throat diameter for Indiana sandstone and Berea sandstone.

Table 3. MIP results for Indiana sandstone and Berea sandstone.

Sample	porosity (%)	permeability (mD)	N_2 permeability (mD)	Conductivity formation factor (σ/σ_0)	Tortuosity	Stem volume used (%)
Berea sandstone	24.85	1344	910	0.521	1.98	60
Indiana sandstone	16.75	364	180	0.276	2.80	31

Conclusions

1) **Permeability values of the Barnett shale samples are in nano-Darcy. Among them, 7,136 ft sample has the lowest k and Φ values.**
2) ***k*** **values for three types of building materials are comparable with literature values.**
3) **Tortuosity is inversely related to permeability.**
4) **MIP can provide porosity, pore-size distribution, formation factor, and tortuosity for a range of porous media.**

Several cited References

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