DOES SOUND REALLY SLOW DOWN IN POROUS ABSORBERS?
How much? and Does it matter?

Sound waves in air are adiabatic. That means that the compressions and rarefactions of air experience no loss to heat. In order for that to happen, the temperature has to be able to vary along with pressure and density.
When sound waves go through a porous absorber however, the presence of the fibers or cell walls restrict changes in temperature. Air trapped in fibrous absorber is approximately isothermal. That means that instead of the sound wave being an adiabatic compression of air, now it's an isothermal compression. Isothermal compression requires energy exchange with the environment, which means that sound energy gets lost as heat to the fibers or cell walls.

There's also a secondary effect. Sound waves cause the air to move back and forth slightly. Gases next to a solid surface usually have what's called a "No-slip Boundary Condition" which means that the air right next to the surface is stuck to that surface. Within a short distance from that surface (called the viscous penetration depth) any air that tries to move will do work on the surface, and thus give up energy. You can think of this action as basically being "sound friction." And because the fibers of fiberglass are solid, there is a lot of air trapped within the viscous penetration depth of a strand.

It is true that sound moves slower in air trapped in fiberglass than in normal air (because it's isothermal). This is historically interesting because the concept of isothermal/adiabatic compression for sound waves didn't exist in Sir Isaac Newton's time, and he famously miscalculated the speed of sound around 280 m/s (918.6352 ft/s), instead of 332 m/s (1089.239 ft/s) – at sea level and 0˚C, 32˚F.
So, his original formula would have been correct for air trapped in a porous absorber.

Background and speed of sound formula:

The Concept of Isothermal Change and Adiabatic Change

A change in volume of gas carried out at a constant temperature of a gas is called isothermal change.
A change in volume of a gas carried with a change in the temperature of a gas is called adiabatic change.
The velocity of sound in air (or in other gases) can be expressed as

$$c = \sqrt{\frac{kp}{\rho}}$$

Therefore;

$$c = \sqrt{kRT}$$

where

c = sound velocity (m/s, ft/s)
k = ratio of specific heats (adiabatic index, isentropic expansion factor)

Gas	Ratio of Specific Heat - *k* -
Air, Standard - Isothermic	1
Air, Standard - Adiabatic	1.4

p = pressure (Pa, psi)
R = 286.9 (J/kg K) = 1,716 (ft lb/slug ˚R) = individual gas constant specific for air
T = absolute temperature (K, R); 273.15 ˚K, or 491.69 ˚R

Therefore;
c = 331.23 m/s or 1086.85 ft./s (Adiabatic Change)

For Isothermal Change (in porous fiber), we replace the Ratio of Specific heat of 1.4 with 1.0 and the resulting speed is:
c = 279.94 m/s or 918.55 ft./s

You can do this yourself using my Reflections-Boundaries-Mass spreadsheet, tab; "Speed of Sound" and tab; "Trap depths & related calcs". You can download it from my resources page.

This is a change of **15.4%** in the speed of sound. The resonant frequency shift due to this change in speed through a depth of 24" or 609.6 mm of fiber is from 282.1 Hz to 239.6 Hz. This is a change of 42.5 Hz! (at sea level, 21˚C) NOTE: The frequency of a sound wave entering the absorber does not change, only the resonant frequency of the absorber.

I have argued with a colleague that, overall, this doesn't change any of our fundamental calculations. However, I could be wrong.

Let's look at this:
The 'average' small control room probably has a room volume in the range of 54 cubic meters or 1909 cubic feet. With dimensions of **L = 487.0 cm, W = 379.0 cm, H = 293.0 cm** or L = 191.7", W = 149.2", H = 115.4". Let's assume that there is a full 8" or 20 cm of trapping on 5 surfaces, which is a lot! - And far more than the average 'panel' buildout.

The total treatment volume is 12.89 cubic meters, 455.2 cubic feet.
The total air volume is 41.18 cubic meters, 1454.25 cubic feet.

The sound traveling through the air alone (sea level, 21˚C) will travel at 343.96 m/sec or 1128.46 ft/sec while the other 31% of the volume travels slightly slower (**15.4%**) due to the isothermal change in the fiber. The results are more complicated since the floor is not treated and the dimensions are not the same.

The length mode is longer and has a smaller percentage of fiber; 4463.6 mm air to 406.4 mm of fiber. The width mode is 3383.6 mm air to 406.4 mm of fiber, and the height mode is 2726.8 mm air to 203.2 mm fiber. The percentages of isothermal change are as follows: Length = 9.1%, Width = 12%, and Height = 7.4%. (from here on, it's all in metric – but I hope you get the idea)
So, only in the percentages of space shown above will the speed of sound slow by 15.4% on average.

Let us ONLY consider the Axial components.
This room is at sea level and 21˚C or 70˚F.
The Primary Axial modes (resonances) of this room are: **L = 35.3 Hz, W = 45.4 Hz, H = 58.7 Hz**

Taking into consideration the isothermal affect of the fiber which will shift the speed sound lower during its presence in the fiber and changing the resonant character of the space to the following:

LENGTH	Length of travel	Time (S)
In Air	4.46 meters	0.012977241 S
In Fiber	0.41 meters	0.001391495 S
Total time		0.014368736 S
		34.80 Hz
WIDTH		
In Air	3.38 meters	0.009837305 S
In Fiber	0.41 meters	0.001391495 S
Total time		0.011228800 S
		44.53 Hz
HEIGHT		
In Air	2.73 meters	0.007927758 S
In Fiber	0.20 meters	0.000695747 S
Total time		0.008623506 S
		57.98 Hz

The Primary Axial modes (resonances) of this room are changed by: **L = 0.5 Hz, W = 0.87 Hz, H = 0.72 Hz**. These differences are well within the range of 'Q' provided by an assortment of tuned traps.

These theoretical/calculated results confirm my personal experiences in our many rooms, yet my colleague **does** have a valid point for rooms with very, very deep trapping. As it is, most builds and even my BNE builds will not exhibit any noticeable errors from modeling to real-world measurements and therefore I stand by what I have said before:

It doesn't affect much and therefore doesn't matter for most applications.

There has been talk about an additional parameter, Tortuosity, which is the ratio of the average path length a wavelet in air takes when it flows through a material to the average path length the wavelet takes without the material (fiber) present. "Tortuosity, as the name suggests, is a measure of how tortuous the air paths are within the absorbent, and this influences the amount of absorption produced." - Acoustic Absorbers and Diffusers by D'Antonio & Cox. Tortuosity is used when measuring the effectiveness or usefulness of a porous absorber for a particular purpose. It will not, as far as I know, noticeably change the speed of sound at different frequencies as some have stated. While it is true that the frequency of a wave remains same when it moves from one medium to another, but it's wavelength and speed do change with refractive index, which is different for different media.

The speed of a sound wave in air is also very close to constant for all frequencies that are **human-audible**. For example, the speed of light in vacuum is constant regardless of the frequency. However, when light interacts with a refraction (prism) the speed changes per frequency. This is also true of sound waves refracting and the source of pleasant diffusion. This refraction DOES occur in a porous absorber or fiber. That's why they are so good at absorption.

A sound frequency is set by the oscillating body which sets up the sound waves. The speed of the wave(s) is determined by the elastic/inertial properties of the medium and the wavelength is then given by λ.

$$\lambda = \frac{v}{f}$$

As a practical example, think about an orchestra. If v did vary with f, the sounds from the different instruments would reach your ears at different times. The result would not be very musical.

<u>If you would like to test this, listen to your favorite music through 24" of glass wool or rock wool.</u> If you hear weird sounds, dissonance, and other unpleasantries due to the speed of sound changing per frequency, I am wrong. But if what you hear is **attenuated** per frequency – most at the high frequencies and less at the low frequencies, my math, theory, and experience is correct. ☺

For more information see - http://www.physicsclassroom.com/class/sound/Lesson-2/The-Speed-of-Sound

Also, please note that I write my papers and articles for the 'studio owner' and 'musician'. This is NOT a treatise for advance frequency analysis nor for use under water or in volcanos or other industrial applications. i.e.; 0 – 15 Hz and 20 kHz – Gama rays.

Opinion: {This is very similar to the claim that the electrical 'skin-effect' in wiring is a 'thing' for audio frequencies. When, in fact, it is only important at microwave frequencies. See where I'm going? I'm trying to get you guys through the valley of bullshit that so often drowns the novice. Let's do what works and quit splitting hairs.}

So, again I say: **It doesn't affect much and therefore doesn't matter for our applications**.

It is very important to be open to change when doing research and in the process of writing this paper, I was actually WANTING to be proven wrong. <u>Many thanks to my colleague that pushed me to do this research</u>. I truly enjoy a challenge, especially one which would challenge my presumptions, prejudices, and experience. I encourage all who read this to look further for the truth. Challenge and be skeptical. Question everything.
Now, I must get back to work.

- John H. Brandt