

# Water Vapor Concentration Measurement with TDLAS during VHTR

## Steam Ingress

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### Background Information

TDLAS is a non-intrusive, non-perturbative line-of-sight diagnostic technique that can be used to measure steam concentration, temperature, and pressure. A laser beam propagates through a gas and is attenuated if the laser wavelength matches absorption transitions of the gas species (molecules begin to rotate/vibrate). The Beer-Lambert law of absorbance can be used to recover this information. The intensity of transmitted laser light ( $I_t$ ) is proportional to the system dimensions and gas composition:

$$\frac{-dI_v}{I_v} = P \cdot X_{abs}(x) \cdot S_i(T(x)) \cdot \phi_v \cdot dx$$

With  $P$  = total pressure (atm),  $x$  = the local distance along the beam propagation (cm),  $X_{abs}(x)$  = local mole fraction of the absorbing species,  $S_i$  = lineshape function of the transition ( $\text{cm}^{-2}\text{atm}^{-1}$ ),  $T(x)$  = local temperature (K),  $\phi_v$  = lineshape function (cm).

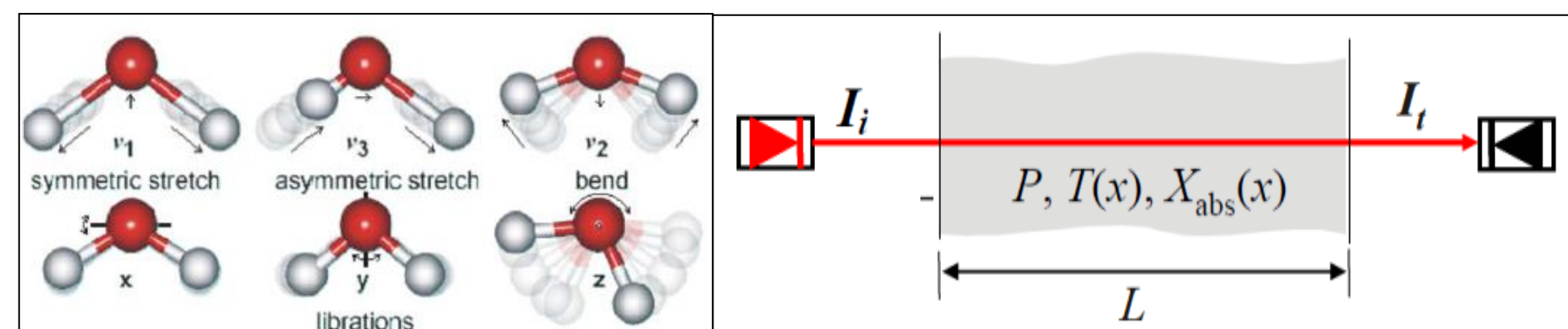


Fig. 1: Main vibrations occurring in water and schematic of absorption measurements

The lineshape depends only on temperature while the lineshape function is dependent on both temperature and pressure. The overall absorption lineshape yields a Voigt profile, which is a convolution of the Gaussian distribution (from random thermal motions of absorbing molecules) and the Lorentzian distribution (from molecular collisions).

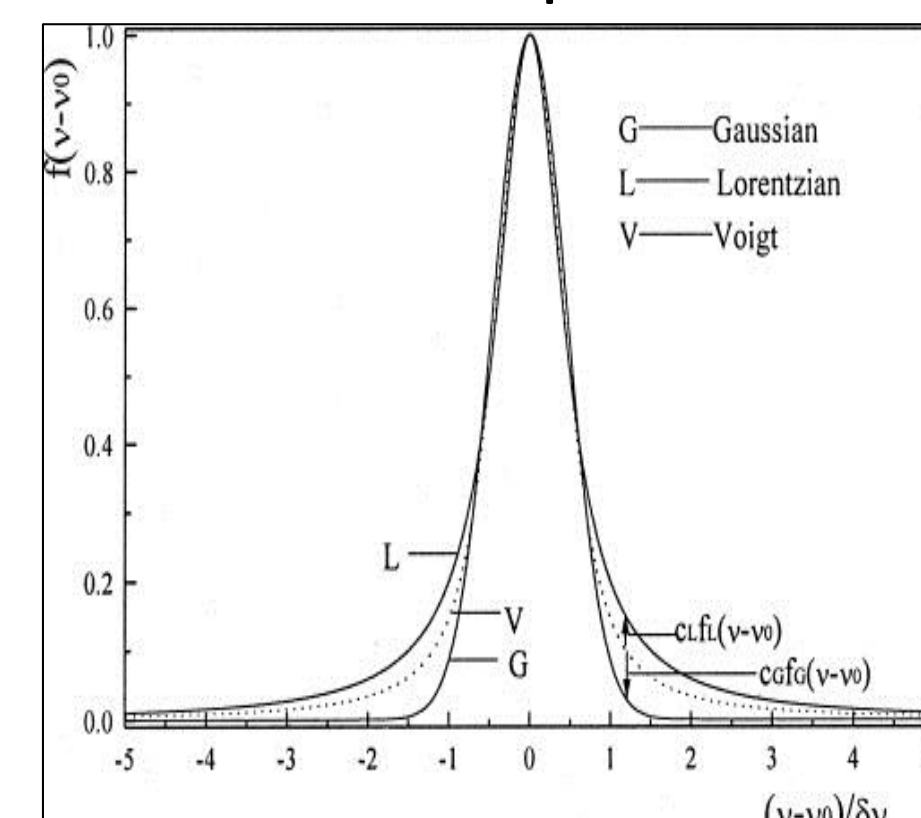


Fig. 2: Comparison of three line profiles with normalized intensity and same width

### HITRAN Absorbance Simulations

A MATLAB code was developed to mine the HITRAN molecular absorption database and perform simulations of absorption to find the best transitions for the VHTR environment ( $P = 0\text{-}35$  psi,  $T = 200\text{-}700^\circ\text{C}$ ,  $[\text{H}_2\text{O}] = \sim 0.01\text{-}0.9$ ,  $x = 8.8$  cm).

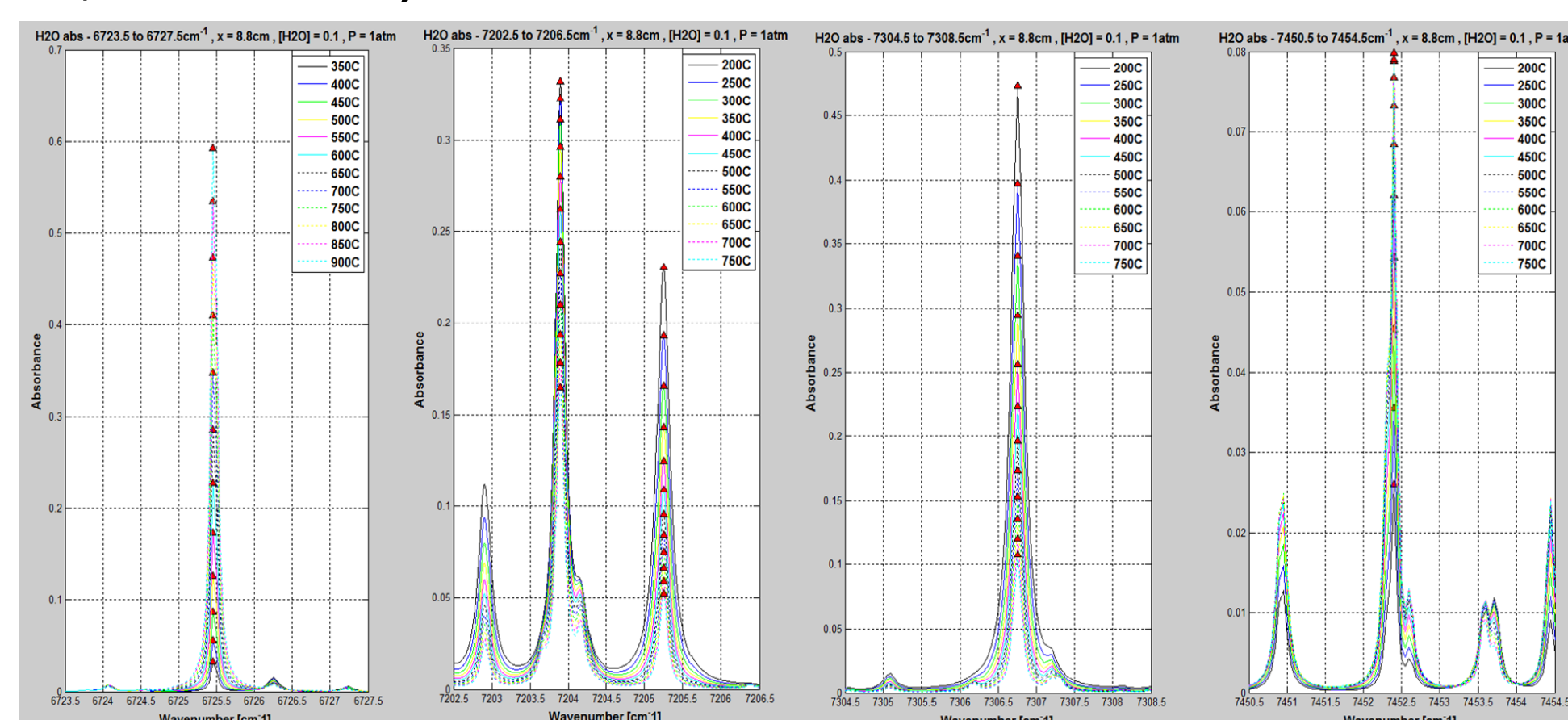


Fig. 3: Absorbance simulations of the four wavelengths selected by line selection process

### Objective

Very-high-temperature reactors (VHTR) utilize a graphite-moderated, helium-cooled design that has the ability to provide outlet temperatures in excess of  $700^\circ\text{C}$ . Safety and structural integrity concerns have led to extensive accident condition investigations. Steam generator heat-exchange tube rupture accidents (SGTR) can lead to increased reactor core steam density, which can cause chemical corrosion of graphite structural supports and fuel elements. It is important to be able to computationally model the propagation of steam throughout the nuclear reactor core, but more experimental data is needed to validate such CFD codes. The primary objective of this project is to instrument a  $1/8^{\text{th}}$  scaled experimental VHTR, designed by The Ohio State University, with tunable diode laser absorption spectroscopy (TDLAS) equipment to map how water vapor propagates through the test facility's bundle configuration via concentration changes.

### Experimental Design

- The OSU VHTR test facility can be seen in figure 4. Concentration measurements will be taken between adjacent graphite rods in the lower plenum of the reactor. Instrumentation rods capable of launching/catching a laser beam will be coupled with high temperature fiber optics to deliver light to the desired rod locations so that steam propagation can be tomographically mapped.
- Distributed feedback lasers (DFB) are fiber coupled, CW lasers that have the ability to be rapidly scanned (5kHz+) over small wavelength ranges ( $\sim 0.25$  nm) by modulating current. Due to the dynamic environment encountered during VHTR steam ingress and the narrow tuning range of DFB lasers, it was necessary to multiplex four DFB's together to cover the array of possible concentrations, temperatures, and pressures.



Fig. 6: DFB mounts, Mux/Demux system, DAQ, and laser current/temperature controller

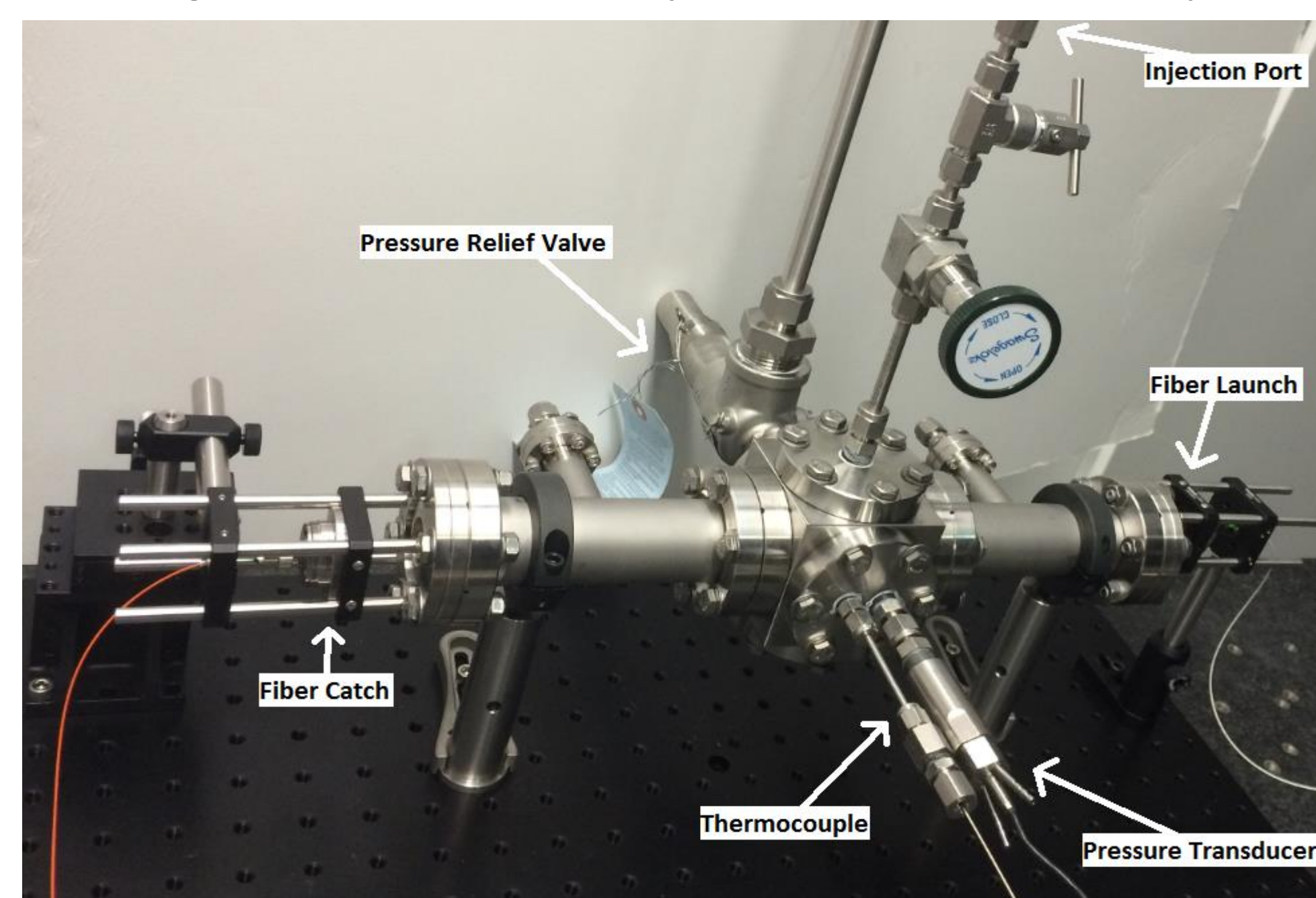


Fig. 7: Three-chamber heated pressure vessel used for controlled environment testing

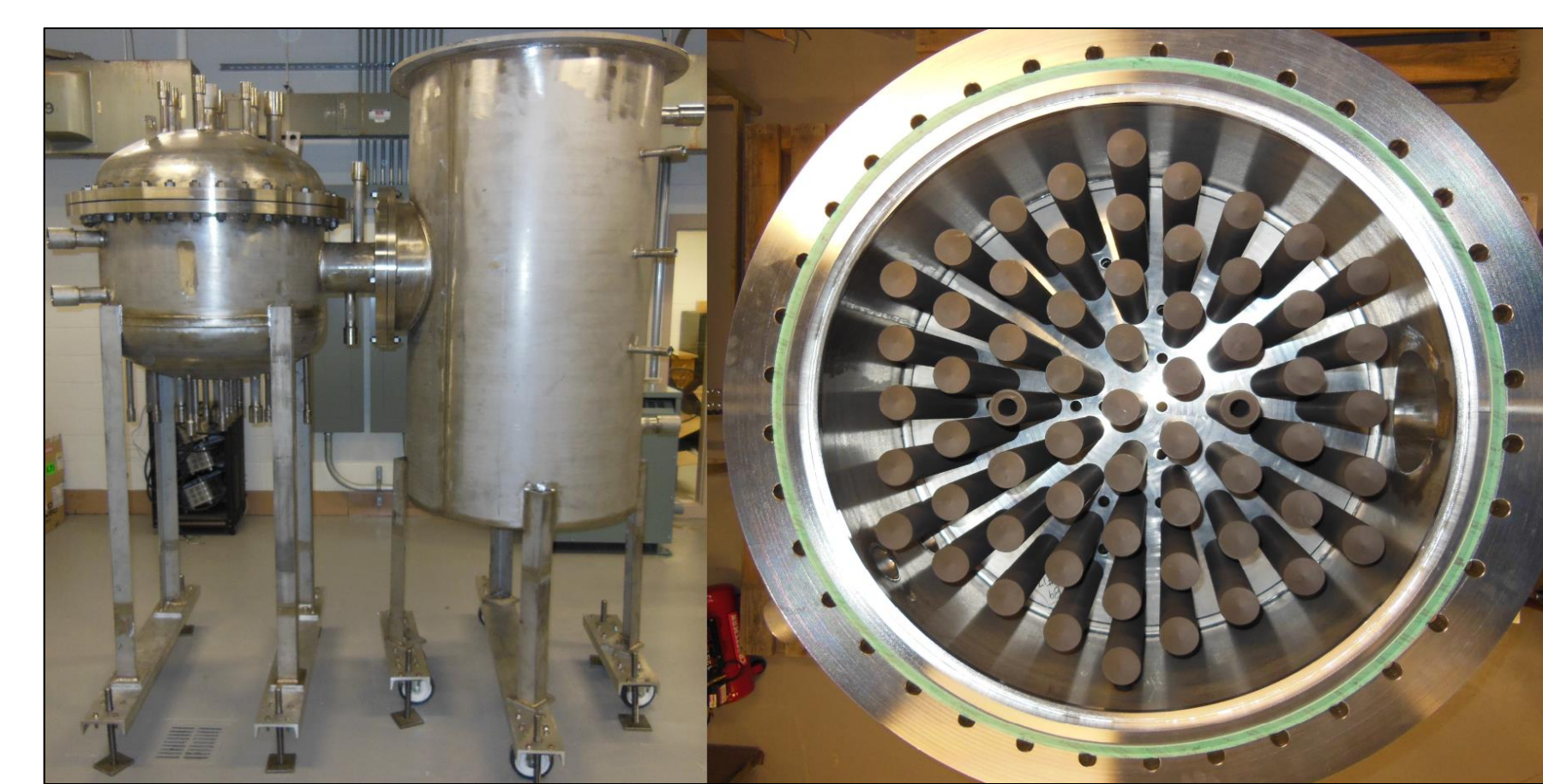


Fig. 4: OSU VHTR experimental test facility (left) and look at graphite rod configuration in lower plenum (right)

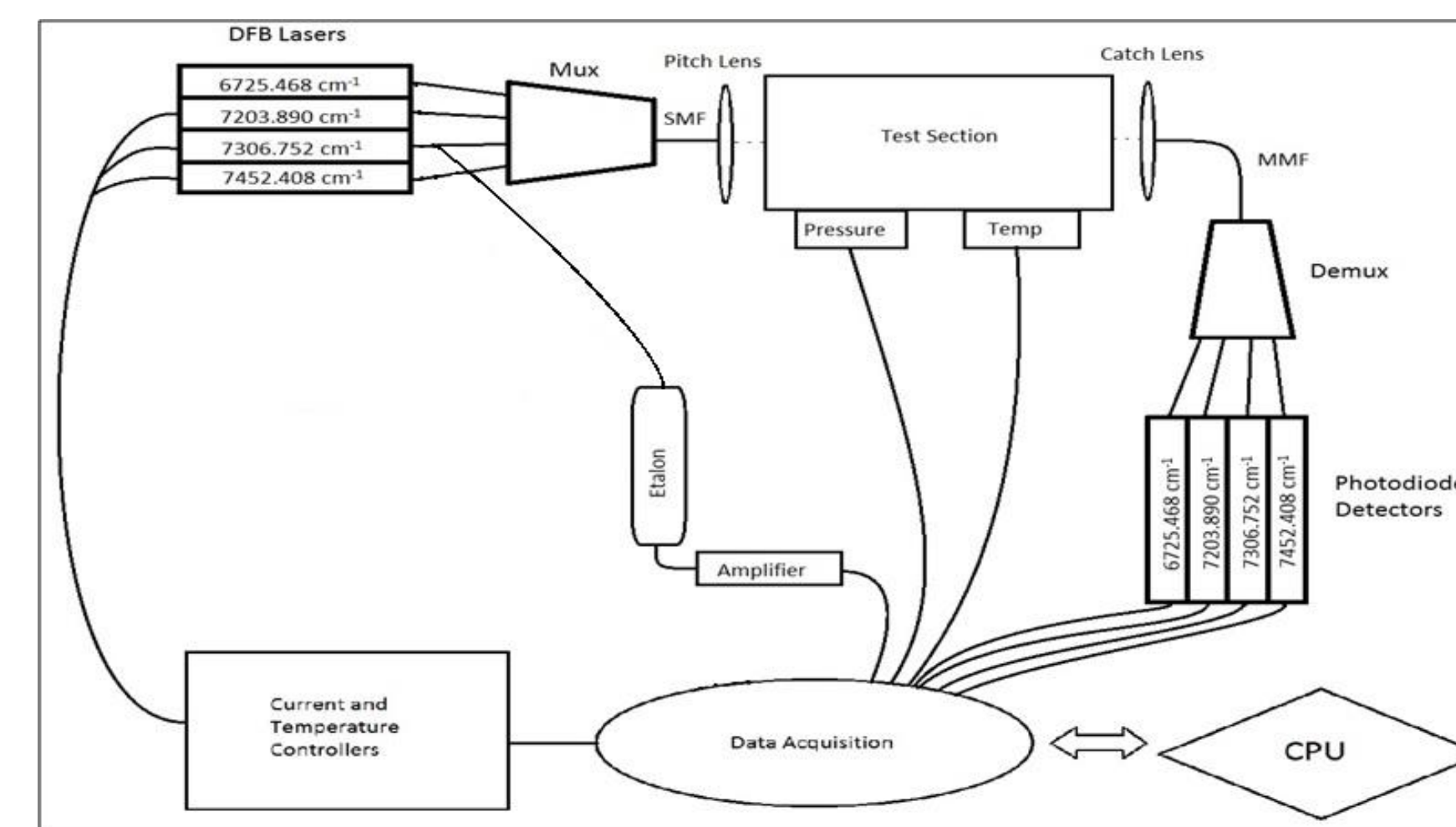


Fig. 5: Diagram of experimental setup

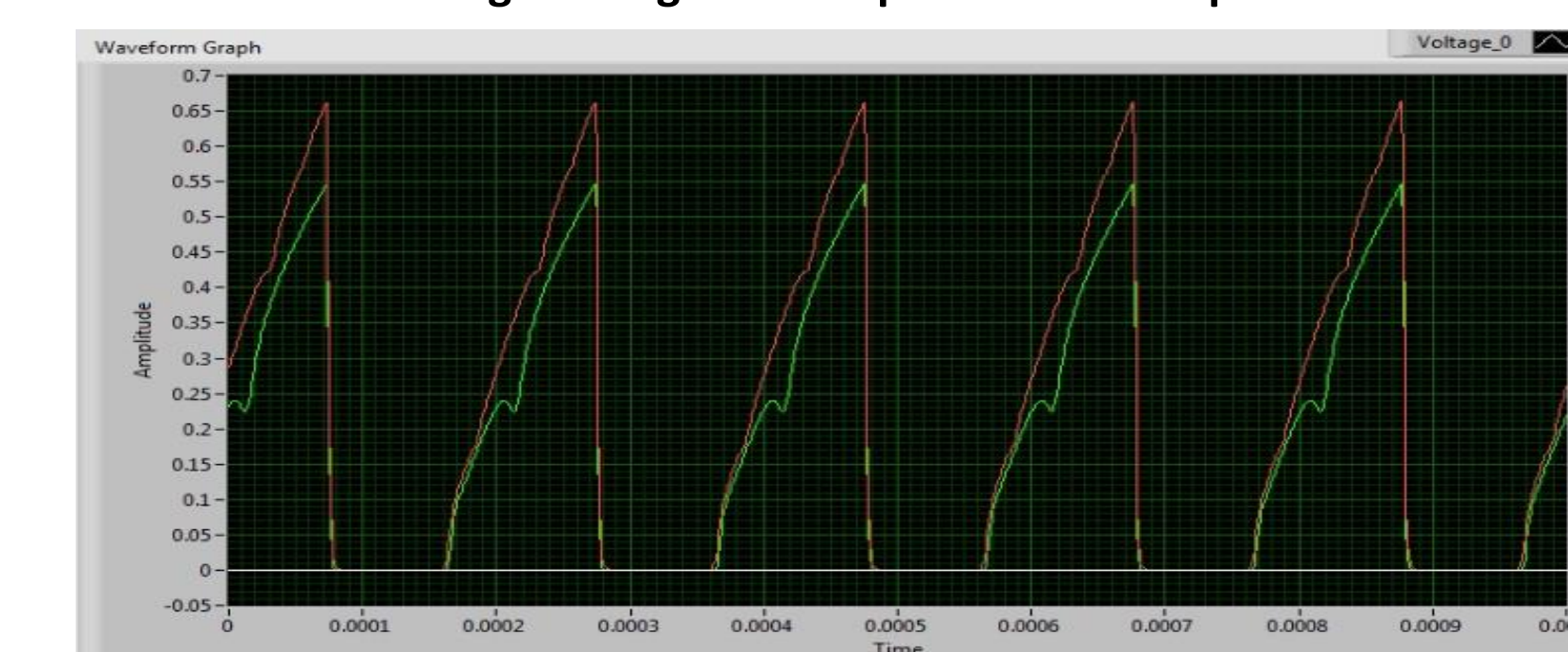


Fig. 8: LabVIEW screenshot of raw transmission data @  $35^\circ\text{C}$ ,  $[\text{H}_2\text{O}] \sim 0.0275$ ,  $P = 1$  atm, and  $x = 7.5$  cm

- A three-chamber heated pressure vessel (figure 7) has been constructed to verify our selected transitions and to gain more experience with the technique before moving to VHTR testing. This test section is equipped with fused-silica viewports and has the ability to be injected with a known water vapor concentration, heated to  $426^\circ\text{C}$ , and pressurized to 35 psi. The end chambers can be vacuumed and act as heat sinks to protect the current fiber launch/collection system from high temperatures while minimizing ambient water vapor absorption.

### Preliminary Results/Discussion

Some preliminary data has been acquired at low temperature ( $<100^\circ\text{C}$ ) in a non-sealed environment to verify DFB wavelength selection (DFB2 =  $7204\text{cm}^{-1}$  and DFB3 =  $7306\text{cm}^{-1}$ ) as well as aid in data analysis code development. In order to simulate a laser intensity profile with no absorption, a polynomial curve fit is applied to the raw transmission data. The data points included in the polyfit are only from locations with no beam attenuation. Once the zero absorption baseline is established, the difference between the transmission data and the zero baseline is taken and divided by the zero baseline to get a time based experimental absorption percentage. The absorption percentage data points were fit with a Gaussian profile to extract the peak.

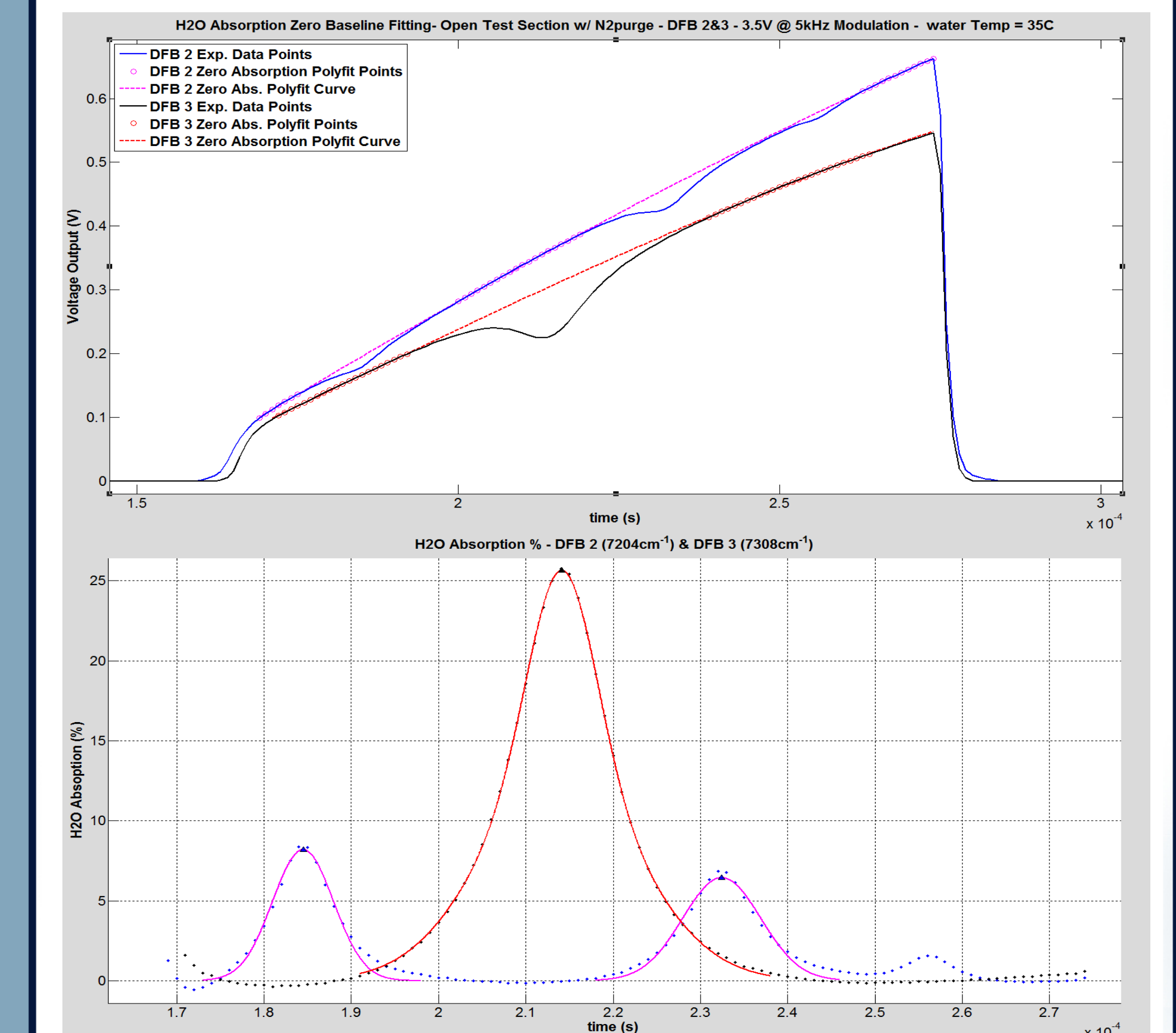


Fig. 9: Zero-absorption baseline polyfit (top) and experimental absorption percent with Gaussian fits for peak extraction

A temperature ratiometry was performed on these peaks for transitions with opposite temperature/lineshape dependencies. The steeper (more accurate) ratio, R13, yielded a ratio mean of 3.0329893 and a temperature determination of  $36.94^\circ\text{C}$  (percent error = 5.54%) based on a decay fit to simulated absorption ratios. Additionally, the  $\text{H}_2\text{O}$  concentration was estimated at 0.0275 based on HITRAN absorption simulations.

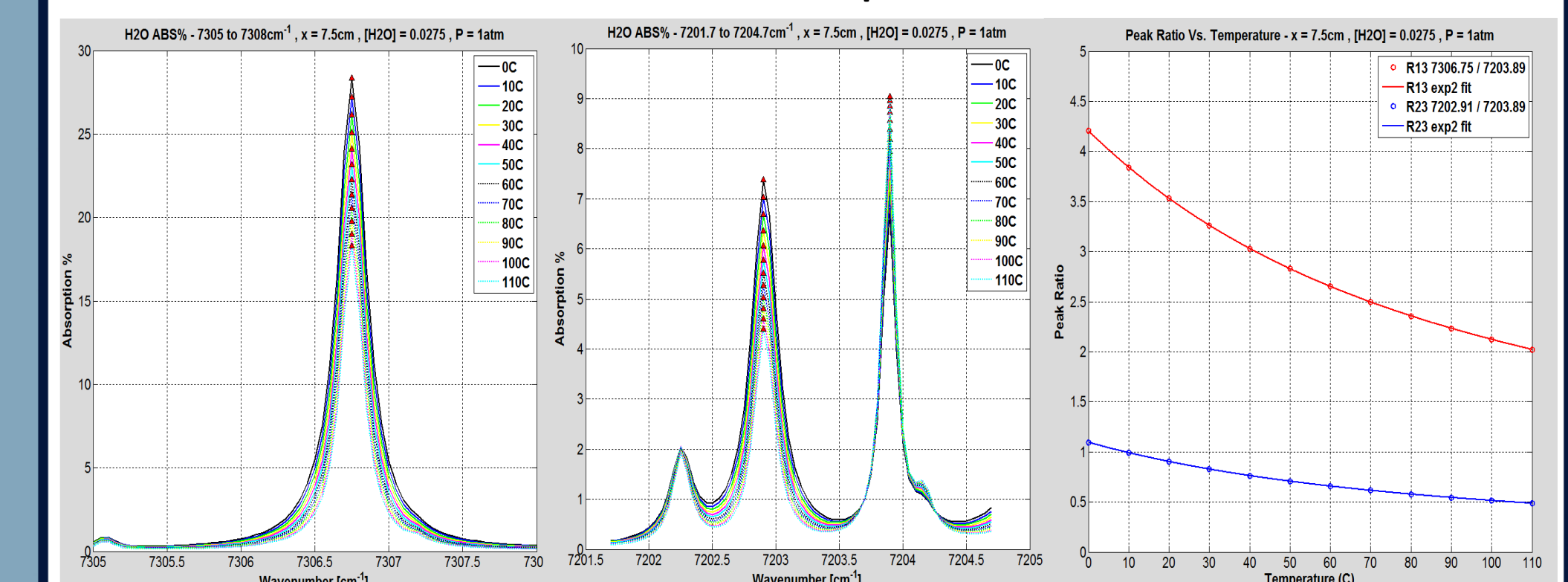


Fig. 10: HITRAN temperature ratiometry simulation