# 2. THERMAL DIFFUSIVITY SYSTEM (TDS)

**a. Basic Method**

Apparent thermal diffusivity $\alpha_{app}$ is measured by flow method (monotonic two-side heating of the plate) described in ASTM STP 1320 and ASTM STP 1426 [6, 15]. Apparent thermal diffusivity is determined by measuring the average temperature difference between thermocouples placed near two surfaces of the plate and in the center. Additional thermocouples (for estimation of errors associated with the non-dimensional temperature field) can be arranged near the other surfaces of the specimen. Solution of Fourier equation at heating velocity close to constant gives the simple formula for apparent thermal diffusivity:

$$\propto_{\text{app}} = bX^2/(\upsilon_{+X} + \upsilon_{-X})(1 + \Delta_{\text{y,z}} + \Delta_{\lambda,\text{c}})$$

Here $\upsilon_{+X}$, $\upsilon_{-X}$, etc. are temperature differences between points near the surface and the center of the sample; $b$= d$T$/d$t$ - the heating rate in the center of the sample.

$\Delta_{\text{y,z}}$ – analytical correction to take into account the non-dimensional temperature field calculated on the basis of measurement of temperature differences in the third perpendicular direction;

$\Delta_{\lambda,\text{c}}$ – analytical correction connected with temperature dependence of thermophysical properties and nonlinear heating rate.

Usually, the corrections $\Delta_{\text{y,z}}$ are $\Delta_{\lambda,\text{c}}$ are small and can be defined from control experiments for their estimates.

In addition, testing can be performed according to modified method (for semitransparent materials) described in ASTM STP 1426 [11].

**b. Testing Environment**

The testing environment can be provided according to customer requirements by placing of the measurement cell in a vacuum, atmospheric or hermetically sealed chamber with a chosen gas environment.

**c. Special Features**

Among the specific features of the proposed test method for semitrasparent materals that allows to measure the radiative component of thermal diffusivity $\alpha_{rad}$ one can mention:

- The absorption and the scattering of radiation characteristics are measured;
- The surfaces of standard samples are treated in a special way to stabilise their surface radiative properties;
- Various mathematical models and software are developed depending on mechanisms of radiative heat transfer in homogenous absorbing materials (pure glasses, crystal materials),

absorbing and scattering materials (porous ceramic, foam materials), materials with anisotropic scattering (fiber insulation) etc.;

- At the end of testing the following characteristics of the sample are available:
  - the apparent thermal diffusivity/conductivity,
  - the conductive and radiative thermal diffusivities/conductivities,
  - the characteristics of absorption and scattering of radiation in the specimens.

### d. TDS Description

The TDS consists of a measruing cell, heating/power control system and a computer system with interfacing board and specially developed software (see Fig. 3).

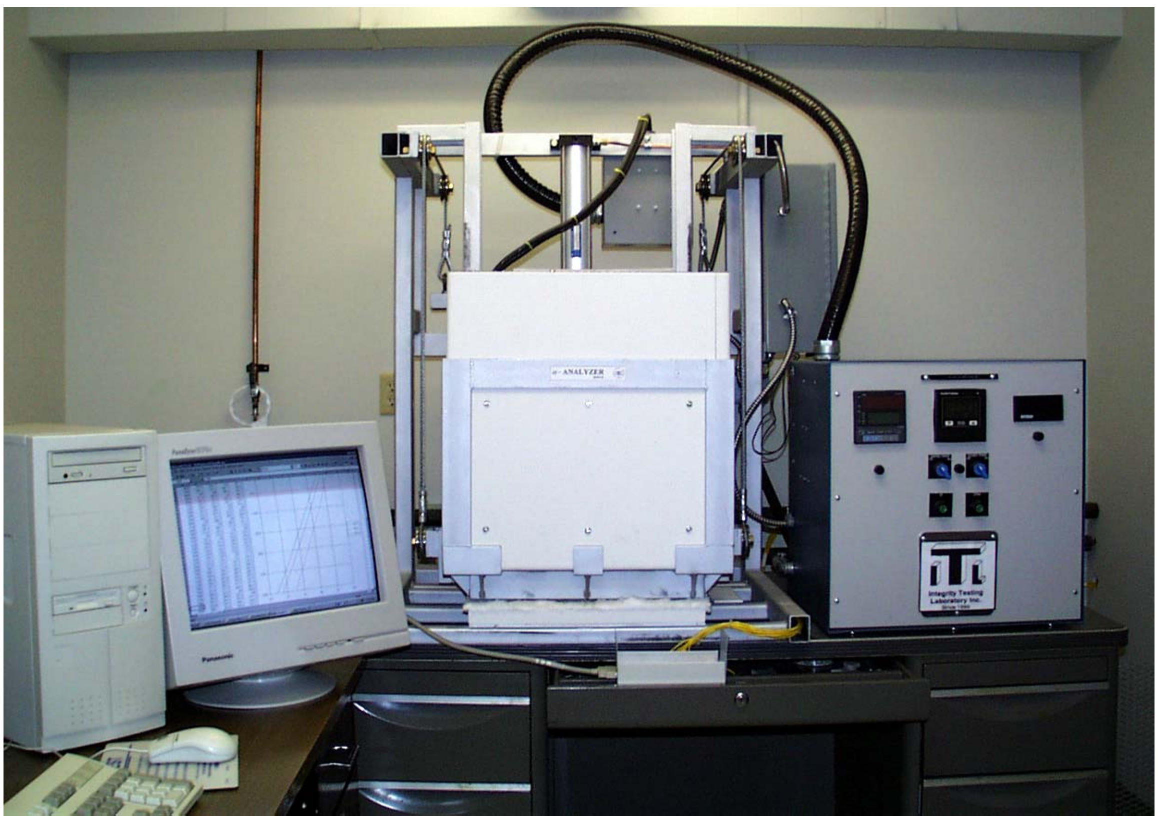

**Figure 3 –** System for measurement of thermal diffusivity at atmospheric gas pressure The ∀A-model is shown.

# TDS Technical Data:

| | |
|---|---|
| *Measurement range* | 0.01-50 $Wm^{-1}K^{-1}$ |
| *Accuracy* | 7 % (will be specified in accordance with the design) |
| *Temperature range:* | 100-1800° C (can be designed for low temperatures, up –150 $^oC$). |
| *Productivity* | The dependence of thermal diffusivity on temperature for one sample in 1-3 hours (depending on the nature of the sample, the number of measurement points and other requirements) |
| *Working environment* | Air, inert gas, vacuum (according to customer specifications). |
| *Sample dimensions* | Plates with thickness 10-35 ×120× 120mm or discs 100-120 mm in diameter |
| *Type of Specimen Phase* | Solids, powders, or liquid |
| *Specimens' Shape* | Can be in the form of plates or discs |
| *Sample preparation* | No polishing or sawing necessary, flat and cylindrical surfaces are acceptable, e.g. groves, drill cores |
| *Geometrical dimensions of measurement cell:* | Standard size 30x30 x30 cm. Note: the geometrical size of the measurment cell can be designed and adjusted according to customer specifications. |
| *Weight* | 150 kg |
| *Control* | Notebook or PC with Windows 95, 98, ME, 2000, NT $^{(TM)}$, steering software with online help functions and |

**e. Application Notes**

Gas pressure has a strong effect on both thermal conductivity and diffusivity *a*. Thermal diffusivities of several types of industrial refractories measured in vacuum using a monotonous heating method at a rate of about $1.5 \cdot 10^3$ K/h, exhibited an abnormal behavior. As can be seen from Figure 4, the thermal diffusivity, *a* of magnesite refractories with porosity Δ=24% measured in vacuum, exceeds the comparable data registered at atmospheric pressure. However, for many materials this phenomenon is absent or less pronounced [1, 4-8] and as was shown [4-8] the physical-chemical processes accompanying the gas transport phenomena across the pores, may be responsible for these effects.

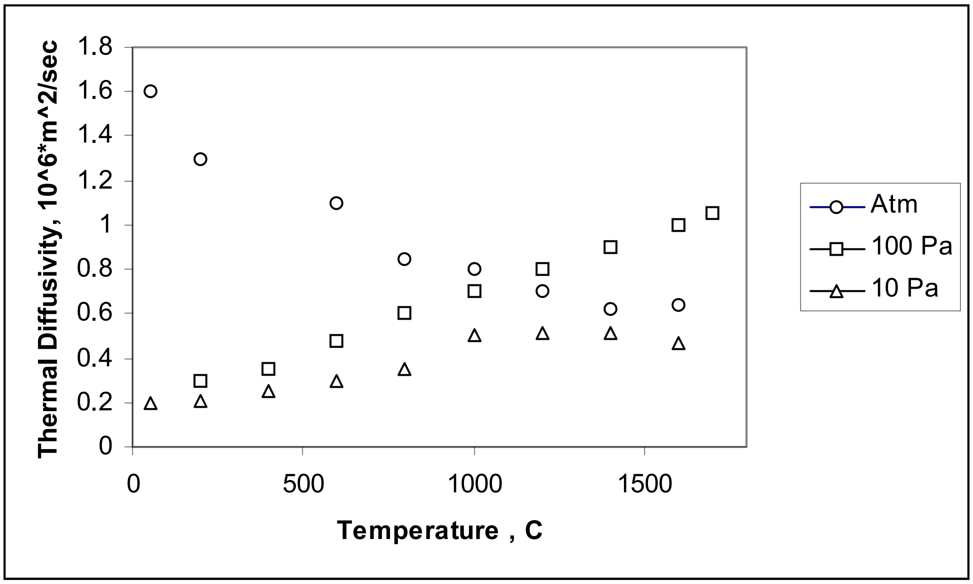


**Figure 4** –Thermal diffusivity of magnesite refractories in Nitrogen at atmospheric pressure and in vacuum [1].

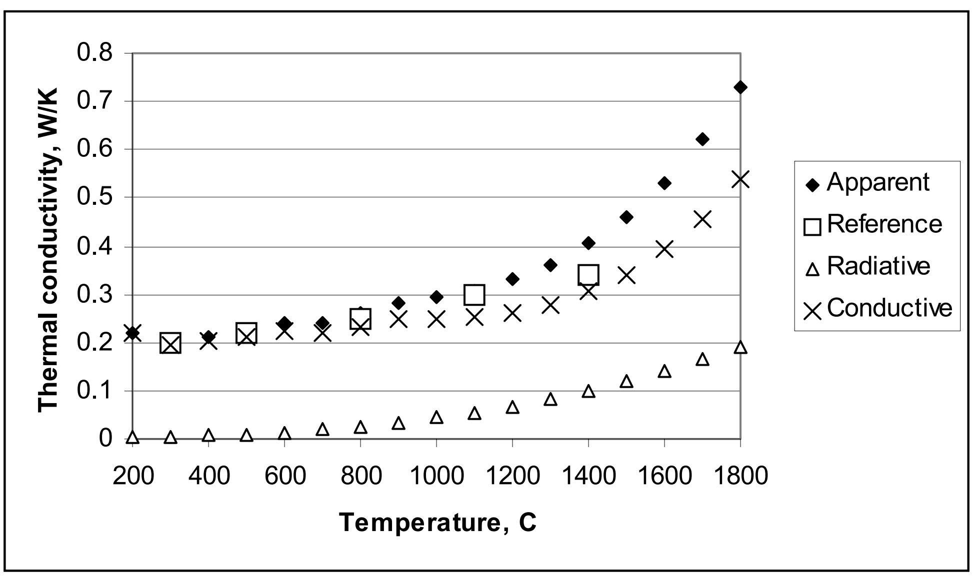


**Figure 5** – Apparent, radiative and true conductive thermal conductivities of a *fiber alumina insulation* with porosity 84% (ASTM STP 1426, 2002 [10]). Reference data is taken from ZIRCAR's catalog.

Another example showing the results of measurement of the radiative and conductive components of the apparent thermal diffusivity/conductivity is presented in Fig. 5. Such measurements are unique and are offered only by ITL Inc. [9-11]. The conductive component of thermal conductivity is a real property of the material and does not depend on heat boundary conditions. This component can be used for more accurate heat transfer calculations when radiative component is significant. NOTE: In this conditions application of ASTM Standards is limited or forbidden.

**f. Advantages**

**TDS is fast:**

- The temperature dependence for one sample can be measured in 2 –3 hours.

Note: Most of the experimental data for refractories and high temperature insulation in the temperature range above 1400 °C were determined by this method. The obtained data is at the basis for a large number of Standard Reference Data, and Reference Books.

**TDS is easy to use:**

- the measurements are controlled by a PC or laptop computer.
- User-friendly software with online help functions.

**TDS can use a variety of sample forms and shapes:**

- no polishing, works on various types of surfaces.

**TDS can measure semitransparent to IR radiation materials**