TCi User Manual

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1 Introduction

The TCi system provides thermal conductivity and thermal effusivity (thermal inertia) data for a number of material types and states. The key capabilities and benefits of the system include the ability to test:

- Materials ranging from ~ 0 to 100 W/mK in thermal conductivity or 0 – 19000 $W\sqrt{s}/m^2k$ in effusivity.
- Solids, liquids, powders and pastes
- A wide temperature range from –50 to 200℃.
- An accuracy and precision under 5% and 1% respectively. (Stated from 0℃ to 50℃).

The TCi system is engineered to operate in lab environments (including QA/QC labs), for off-line and at-line testing. The base technology is migratable to the production floor and can be integrated into many manufacturing processes as an in-line monitoring and control system (see Mathis ESP product line).

The TCi provides many additional thermo-physical properties by indirect calculation, including:

- Diffusivity
- Heat Capacity, volumetric specific heat
- R-value (insulations)
- Density

A full description of the indirect calculations is provided in Appendix I.

The TCi™ system uses the base platform technology developed by Mathis in 2004/2005 for the pharmaceutical industry, leveraging the solid-state sensor technology as well as associated electronics and improved software.

Keeping true to Mathis' traditional theme of non-destructive testing technology offerings, the TCi maintains the ability to test with little to no sample preparation required, including testing very small samples (approximately the size of a nickel). There are no limitations as to how large a sample can be due to the transient method of measurement the system employs. Testing times are typically within a few seconds and automated testing remains a key convenience. Dual sensor testing is also available for higher testing throughput, as are additional accessories for specific applications.

The TCi platform offers modular expansion of the system's capabilities (e.g. calibration ranges, sensor upgrades, accessories, etc.), and a flexible software architecture that offers the ability to handle control signal interfaces (for automated/integrated systems) and a full, relational database platform for data management.

This operating manual provides in-depth guidance to users in leveraging the TCi for its intended use. It is very important that users invest the time in reviewing the information provided within this document for the safe and effective application of this advanced technology. Upon reviewing the document, should users have any further questions we encourage them to contact their Mathis representative.

1.1 A note on instrument limitations

It should be noted that in applying an instrument such as the TCi in testing a wide variety of materials, material types and temperature ranges, careful consideration should be given to the limitations in performance and/or use of this system under certain conditions. In many cases, the TCi can replace as many as 4 thermal conductivity instruments that traditionally covered the same claimed range of testing. However, in providing an instrument to test such a wide material range, there are some pitfalls that can be encountered and in some circumstances a general research tool like this TCi will not be appropriate (the proverbial square bolt in a round hole).

As such, every attempt is made to provide up-front information on any known limitations of the system and to provide general recommendations that help to ensure the optimal use of the instrument.

Examples of performance constraints that may be encountered and some recommended best practices include:

- Contact with some materials is poor due to the material morphology or a process condition and the fact that the sensor chip surface is not flexible or conforming. Mathis has provided contact agents for solid materials testing and can establish special calibrations for certain materials that are not compatible with liquid contact agents.
- Like all lab instruments, the TCi should be used in a consistent manner to ensure consistent results. The user's test methodology is extremely important and it is recommended users review any new application of the instrument with a Mathis technical support person
- The TCi is designed to withstand the full temperature ranges specified, but has not been calibrated for the entire range given the constraints of available calibration materials and typical requirements for specific Material Groups. Customized calibration of the instrument is possible, either by a Mathis representative or by a user certified for advanced operation of the instrument.
- The TCi is a very sensitive analytical instrument. It is the user's responsibility to provide stable environmental conditions in optimizing the performance of the instrument. As such, the users' test methodology is important to guarantee accurate and consistent results (E.g. Thermal chambers used in sub-zero temperatures may generate frost between the sample and sensor, affecting the results. The user needs to compensate accordingly for these conditions).
- The sensor construction was chosen to meet the optimal combination of test temperature requirements as well as respecting internal design constraints. Some materials of construction may be aggressively affected by contact with certain chemicals – it is necessary to be aware of those chemicals that are known to impact the integrity of the sensor as well as those that have not been tested or determined through literature searches to be safe. Appendix C provides a listing to inform users of these issues and has provided means to test the weakest component, the RTV sealant. Test tabs can be purchased from Mathis for chemical aggression testing, avoiding undue damage to the sensor. Mathis will not take responsibility for damaged sensors due to their exposure to untested or known to be damaging chemicals.
- Testing under compression greater than 15-psig will likely result in a damaged sensor. Special testing conditions requiring higher-pressure ratings can be investigated on an individual basis in contacting a Mathis representative.

The thermal conductivity of the sample material is primarily determined by the direct measurement of the thermal effusivity (thermal inertia) of the material. In rare circumstances, an unacceptable error is evident in testing materials which have a density or heat capacity which are substantially different than the materials applied in the calibration of the system. Section 8.7 Error Analysis explains these issues and Mathis technical support is available to provide further insight if required. Accordingly, testing materials which appropriately fit within the proper Material Group is necessary for accurate results. Material groupings can be further optimized for the specific needs of a user -either by Mathis on a contract basis, or through additional training and software module extension for user calibration capabilities.

Open discussions are recommended on new projects or applications with a Mathis technical support representative in determining whether or not the TCi is an appropriate research tool. In general, the standard configuration of the TCi covers the test requirements of most users.

However, special conditions required by a user can be provided for with customized solutions specific to their needs. Please contact Mathis when considering applications that are not represented in this manual.

Material Testing Summary (taken from section 4):

<table>
<tr><th>Material Type</th><th>Minimum Thickness</th><th>Power Level</th><th>Temperature Range (°C)</th><th>Sample Setup & Preparation</th><th>Contact Agent</th></tr>
<tr><td>Liquids*</td><td>1 mm</td><td>90</td><td>-50 to 192</td><td>Fill 50 mL beaker to 30 mL mark. Place sensor in beaker.</td><td rowspan="3">None</td></tr>
<tr><td>Powders*</td><td>1 mm</td><td>90</td><td>-50 to 192</td><td>Fill 50 mL beaker to 30 mL mark. Place sensor in beaker.</td></tr>
<tr><td>Foams</td><td>2 mm</td><td>90</td><td>-50 to 192</td><td>Place sample on sensor. Place weight on sample.</td></tr>
<tr><td>Composites</td><td>5 mm</td><td>90</td><td>-50 to 192</td><td rowspan="3">Place contact agent on sensor. Place sample on sensor. Place weight on sample.</td><td rowspan="3">-20 to 5°C: 3 drops glycol
5 to 70°C: 3 drops water
70 to 150°C: 3 drops glycerin</td></tr>
<tr><td>Ceramics</td><td>5 mm</td><td>90</td><td>-50 to 192</td></tr>
<tr><td>Metals</td><td>5-12 mm</td><td>125</td><td>-50 to 132</td></tr>
</table>

1.2 TCi Manual Intent

This manual covers the detailed use of the TCi, including the test methods and procedures to use for various types of testing. The manual is primarily directed to explain the operating windows and menus and the detailed steps for day-to-day test setup, display and data collection.

Special accessories and test methods as well as software modules not part of the standard operational package are included separately to those who purchase those items, with appropriate documentation able to be added to this a manual binder as needed. A list of additional modules and accessories available or planned are located in Appendix A.

1.3 TCi System Setup

1.3.1 Checking the items and their condition

The TCi system should typically arrive in a single shipping box. Inspect the box for shipping damage and report this immediately to your shipping department to address with the courier company. Please keep the box where possible for ease of return shipping in the event upgrades or other issues require it. The standard shipping items are listed in the shipping list, typically consisting of:

- Laptop computer
- TCi Controller
- TCi sensor(s)
- TCi Operating manual (software CD inside)
- Contact agent(s)
- Reference material(s)
- TCi sensor base
- Power cable and serial/USB cable

1.3.2 Checking grounded cable and power settings

Note: Power settings are typically changed before shipping for the country destination, however it is always necessary to verify the following proper power setting issues before making connections to the local power grid:

- Check that a properly ***grounded*** cable for your power outlet type is provided. If this is not the case, contact Mathis or your Mathis distribution agent immediately for resolution. ***Do Not Use the TCi in an UNGROUNDED State.***
- Check that the power filter on the rear panel has the setting card appropriate for your voltage level requirements. ***The voltage setting is visible without removal – to change the setting, remove the fuse (fuse puller swings) and pulling the voltage setting card out and flipping or rotating it to the proper setting.***

1.3.3 Making connections

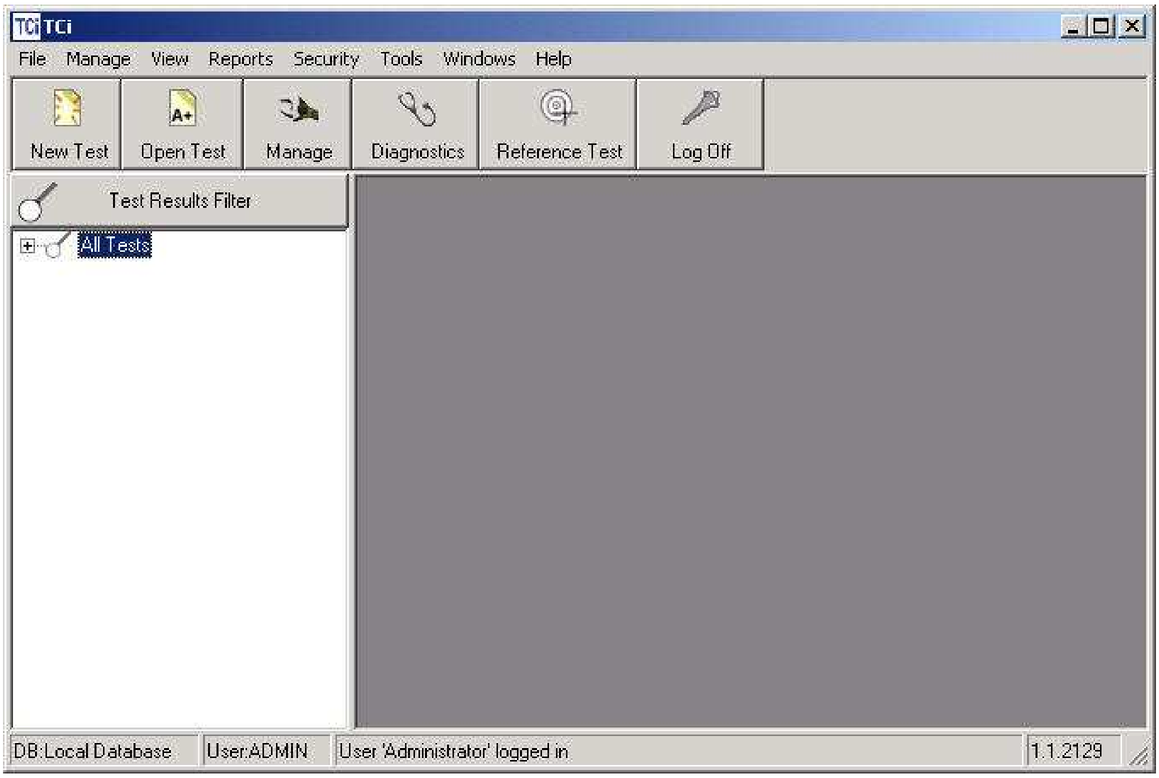
Make the following connections:

- Connect power cable to rear of TCi and into the wall outlet
- Connect power cable to laptop and into the wall outlet
- Connect serial cable to laptop and to rear of TCi
- Connect TCi sensor(s) at rear of TCi – *If you only have one sensor, always use the "Sensor 1" connector location*

1.3.4 Starting up the TCi system

- Turn on the laptop
- Initiate the TCi software by selecting the TCi software icon.
- Proceed to Diagnostics (button located on the main window) - Conduct a system check and material reference check (Refer to sections 7.2.2 and 7.1 of this manual).
- Review the manual for understanding the selection of Material Groups, and general operation.
- Review test procedures, appendices and the SOPs.
- Proceed to testing material samples by following section 4.1.

2 TCi Software Use



The TCi software main window has eight menus, six buttons, test results explorer, and a status bar in addition to the frame, where most windows within the software are displayed.

2.1 Menu Items

The TCi software main menus are located across the top of the main window.

The File menu contains:

New Test – Clicking this option begins a new test. It has the same effect as clicking the New Test button on the toolbar.

Open Test – This option opens the Manage Test Results window. Any set of test results can be opened from there.

Print – This option opens the printer selection window. It is only available when there is a report or table open.

Print Preview – This option shows how the current screen would look if printed. It is only available when there is a report or table open.

Print Setup – This option allows printer options to be selected. It is only available when there is a report or table open.

Log Off –This option logs the current user out and opens the login window.

Change Password – This option opens the Change Password window.

Close – This option is only available when a test or record is open. It closes the active window.

Exit – This option closes the software.

Create Archive – This option allows the records in a database to be stored and a new database created.

The items in the Manage menu open tables containing records of the selected type.

Projects and Materials

Projects - The project describes the common purpose behind a set of tests.

Material Groups - A material group contains all materials with a common characteristic.

Materials - A material is any substance tested.

Calibration

Calibration Methods – Calibration methods detail the timing parameters used in the sensor calibrations.

Calibration Results – All calibration results stored in the database and on sensors connected to the system are listed in this table.

Calibration Material Groups – Calibration materials groups are sets of materials that are used to calibrate the sensors for a type of material or value range. Materials tested using that calibration must be of the same type and fit within the range of thermal effusivity or conductivity values given by the calibration materials.

Calibration Materials – Calibration materials are materials that have stable known thermal values that can be used to calibrate the sensors.

Contact Agents - Contact agents ensure good contact between the sensor surface and solid samples.

Instruments – An instrument is a complete set of TCi hardware, including the controller and sensor(s). The instrument record lists the controller serial number and the instrument family.

Testing

Test Methods – Test methods specify all parameters (other than timing) of the test. A test can be run without materials or material groups being defined, but must have a test method. Timing parameters are set in the calibration method.

Test Results – Test results are displayed in the same format when opened as they are when the test is being performed. Test results can also be found through the test results explorer.

The View menu lists options for the main window. Any of the options can be turned off by clicking them.

Toolbar – The toolbar holds the buttons in the TCi main window.

Status bar – The status bar, located at the bottom of the main window, shows the user logged in and the database being used.

Test Results Explorer – The test results explorer is located on the left of the main window and allows the user to browse the test results by product, material, unit operation, instrument, or user. The test results explorer also has a test results filter button. Keywords can be entered into the filter to search for test results.

The <u>Reports Menu</u> lists the different reports that can be generated in the TCi software

Audit trail Report – The audit trail report lists all activities fitting entered parameters that occur within the software, such as creating records, performing tests, importing and exporting.

Test Report – The test report lists all test results fitting entered parameters.

Reference Material Test Report – The reference material test report gives the results of all reference material tests performed fitting entered parameters.

The <u>Security menu</u> is not visible to users who do not have the permissions required to perform any task related to user or user group management, permissions, or system policies.

System Policies – System policies allow administrators to control user password changes and database connections.

Manage Users – All users must have unique login IDs so that their actions within the software can be documented in the audit trail. Permissions can be granted to users that override group permissions.

Manage User Groups – Membership in a user group grants or limits the permissions a user has to perform actions within the software.

Manage Permissions – Permission default values can be changed in the Manage Permissions window.

The <u>Tools menu</u>

Export

> **Calibration Results** – All calibration results fitting entered parameters are exported to a chosen file type with all attached calibration material and calibration method records.
>
> **Calibration Methods** - All calibration methods fitting the entered parameters are exported to a chosen file type with all attached calibration material records.
>
> **Test Methods** – All test methods fitting entered parameters are exported to a chosen file type with all attached material, project, and calibration method records. Calibration results must be exported separately.
>
> **Test Results** – All test results fitting entered parameters are exported to a chosen file type with all attached test method, material, project, and calibration method records.

Import

> **Calibration Results** – Records from a selected export file are imported.
>
> **Calibration Methods** - Records from a selected export file are imported.
>
> **Test Methods** – Records from a selected export file are imported.

Test Results – Records from a selected export file are imported.

Reference Material Test – A reference material test checks the continued validity of the calibration by comparing the result of the test against the known value of the reference material.

Diagnostics – Diagnostics confirm the functionality of the instrument, test the sensor calibration, and aid troubleshooting. The diagnostics window displays the instrument's status, calibration data, and board inventory.

Change Units of Measure – Metric, Imperial, and CGS units are available for use.

The Windows menu lists all open windows within the software. Clicking one of the listed windows brings that window to the front.

The Help menu lists various ways to open the help file and software information. Topics can be opened by clicking any keyword line or topic title.

Contents – The contents page shows the organisation of the help file.

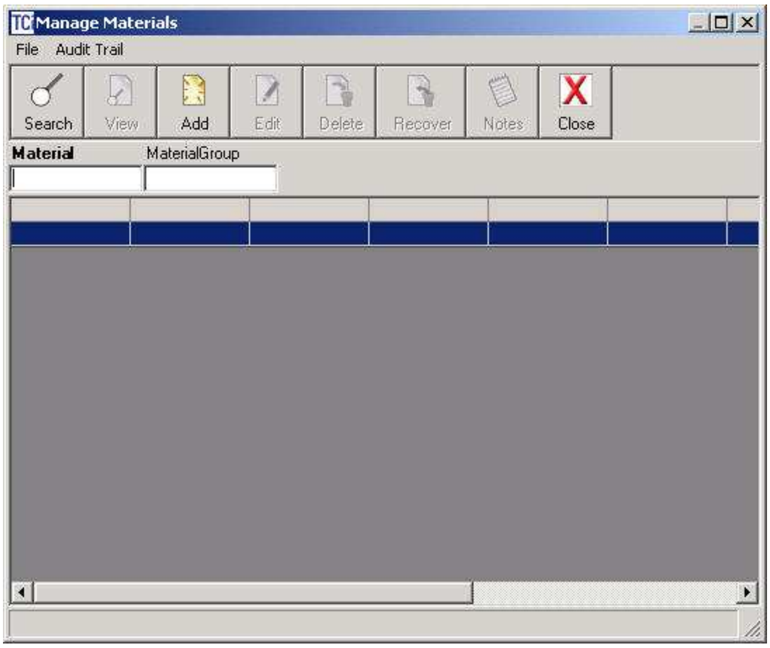
Index – The index lists individual topics and keywords in alphabetical order.

Search – The user enters keywords and a list of topics fitting the entered keywords are displayed.

About – The about window displays version information about the TCi software.

2.2 Table Use

Tables can be opened by clicking a button from the Setup window or by selecting an option from the Manage menu.



The table has File and Audit Trail menus at the top, eight buttons beneath, and fields to enter keywords for searching. The area for table entries takes up the remaining space.

The table is opened with no entries. To display all entries, click the search button. Keywords can be entered to refine the search.

2.2.1 Menus

The menus are positioned along the upper left of the main window. Menu options are grayed out if the user logged in does not have permission to perform the action attached to the menu option.

<u>The Table File menu:</u>

Search – Clicking this option searches the database for all records matching the search keywords. If no keywords have been entered, all records will be returned.

Reset Query – Clicking this option clears the keyword fields.

Reset Grid – Clicking this option resets the column widths in the table (grid).

Print – This option opens the print window to print the table.

Print Preview – This option shows how the table would look printed. There is a print button on the preview so that the table can be printed from there.

Print Setup – This opens the printer options window.

Copy Grid to Clipboard – Clicking this option copies the current table to the clipboard. The table can then be pasted into a spreadsheet program or other document.

Save Rows As – Clicking this option opens a Save window to save the rows as a CSV file, which can then be imported into MS Excel.

View – Once a record has been selected, click this option to open the record. The record also opens if it is double-clicked.

Edit – Select a record and click the Edit option. The information contained in the record can be edited and saved.

Add – Clicking the Add option displays an empty record that can be filled and saved.

Delete – Select a record and click this button to delete it. The record is not permanently deleted but is marked as inactive.

Recover – Recover has two options.

> **Show Deleted Records** – Once this option is clicked, the table displays only deleted records.
>
> **Recover Selected Records** – This option can be used to recover a record once it has been selected. The Recover button can also be clicked.

Notes – Click this button to attach a note to a record. Notes may be attached to test methods, materials, and test results.

Set Default Record – Select a record and click this option. The record will automatically be selected when starting a test.

Close – Clicking this option closes the table.

The Audit trail menu:

Audit trail for all Records – Clicking this option displays the audit trail table. If the Search button is clicked, all entries relating to the current table records are displayed.

Audit trail for selected Records – Clicking this option displays the audit trail table. If the Search button is clicked, all entries pertaining to the selected record are displayed.

2.2.2 Buttons

Search – This button has the same function as the menu option. It searches the database for records fitting the entered keywords, or returns all records if no keywords are entered.

View – Once a record has been selected, click this button to open the record. The record also opens if it is double-clicked.

Add – Clicking the Add button displays an empty record that can be filled and saved.

Edit – Select a record and click the Edit button. The information contained in the record can be edited and saved.

Delete – Select a record and click this button to delete it. The record is not permanently deleted but is marked as inactive.

Recover – Once a record has been deleted, it can be recovered by setting the table to show deleted records, selecting the record, and clicking the recover button.

Notes – Click this button to attach a note to a record. Notes may be attached to test methods, materials, and test results.

Close – Click this button to close the current table.

2.2.3 Table Options

When any row of the table is right-clicked, three options are displayed.

Copy to Clipboard – Clicking this option copies the current table to the clipboard. The table can then be pasted into a spreadsheet program.

Show all Columns – Clicking this option resets the widths of the columns if they have been changed and displays any columns that are hidden by default.

Reset Grid – Clicking this option resets the widths of the columns if they have been changed.

2.2.4 Using the Parameter Fields to Search

Keywords are used to narrow the search for a particular record or set of records. If only part of a keyword is known, use % or * for the remainder of the word. For example: for benzyl compounds, use benz* or benz% to get all results with “benz” as part of the name.

Material groups can be searched by material group name.

Materials can be searched by material group name or material name.

Projects can be searched by project name.

Calibration methods can be searched by calibration method name, instrument family, and calibration parameter (thermal conductivity or effusivity).

Test methods can be searched by test method name, project name, or calibration method.

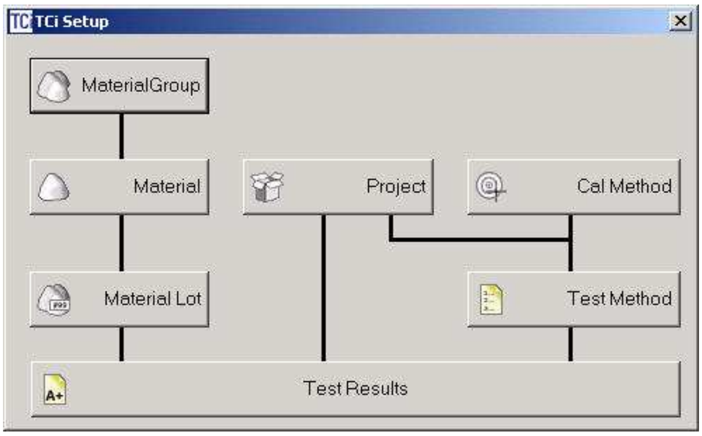
Test results can be searched by test ID, workstation, date range, test method, material, project, or instrument.

Users can be searched by user name or user ID.

User groups can be searched by user group name.

2.3 Record Management

Records can be created, edited, viewed, deleted, and recovered through the tables. The tables can be accessed through the setup window.

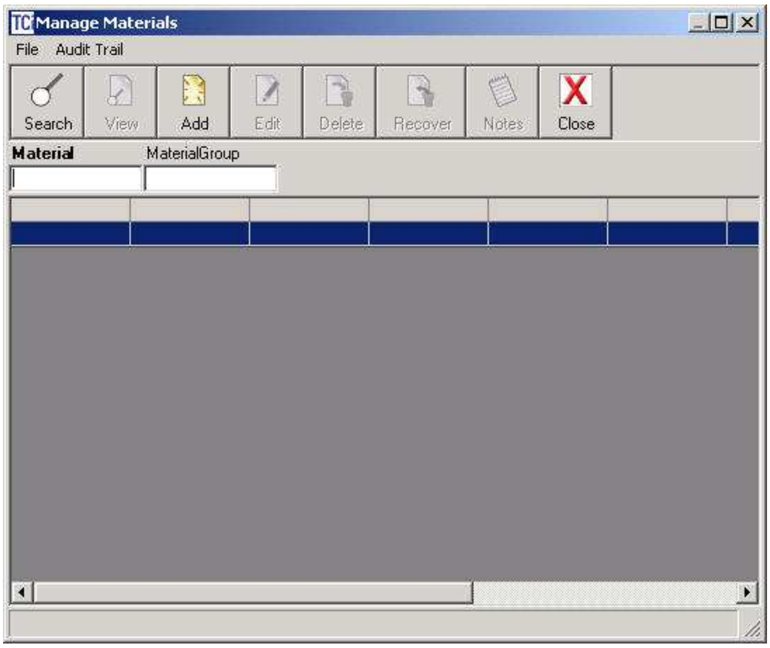


2.3.1 Create a Record

Each individual record type has a different creation process. Record creation is detailed in Chapter 3 and sections 6.3.2 and 6.3.3.

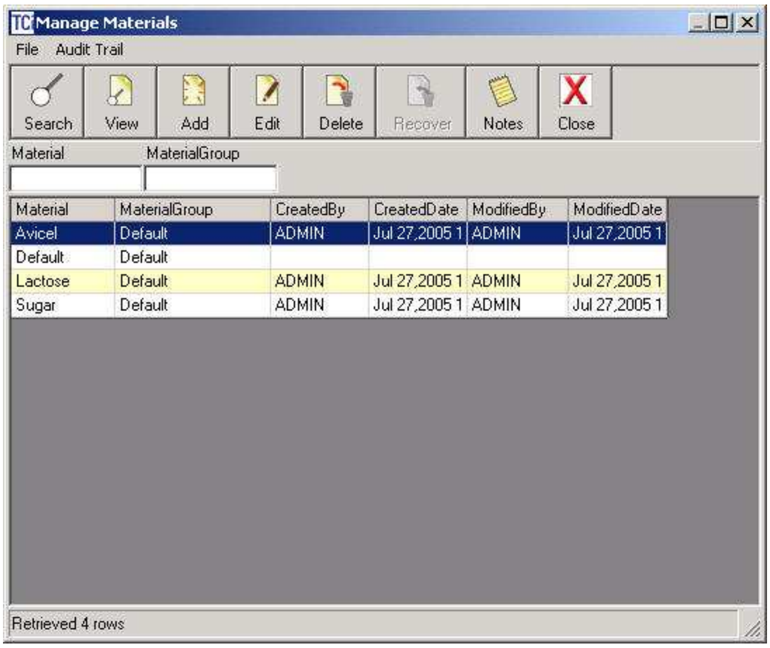
2.3.2 View a Record

Step 1 – Open the record's table.
Select the record type from the Manage menu or click the record type in the Setup window. For example, to open a material click Material in the Setup window.



Step 2 – Enter keywords into the parameter fields.
Information about keywords is given in section 2.2.4.

Step 3 – Click the Search button or press the Enter key.
A list of records fitting the entered parameters is displayed.



Step 4 – Select the desired record.

Step 5 – Click the View button.

2.3.3 Edit a Record

Step 1 – Open the record's table.
Select the record type from the Manage menu or click the record type in the Setup window. For example, to open a material click Material in the Setup window.

Step 2 – Enter keywords into the parameter fields.
Information about keywords is given in section 2.2.4.

Step 3 – Click the Search button or press the Enter key.
A list of records fitting the entered parameters is displayed.

Step 4 – Select the desired record.

Step 5 – Click the Edit button.

Step 6 – Edit the fields as needed.
Any field with a white or blue background can be changed.

Step 7 – Click the Save button.

2.3.4 Delete a Record

Step 1 – Open the record's table.
Select the record type from the Manage menu or click the record type in the Setup window. For example, to open a material click Material in the Setup window.

Step 2 – Enter keywords into the parameter fields.
Information about keywords is given in section 2.2.4.

Step 3 – Click the Search button or press the Enter key.
A list of records fitting the entered parameters is displayed.

Step 4 – Select the desired record.

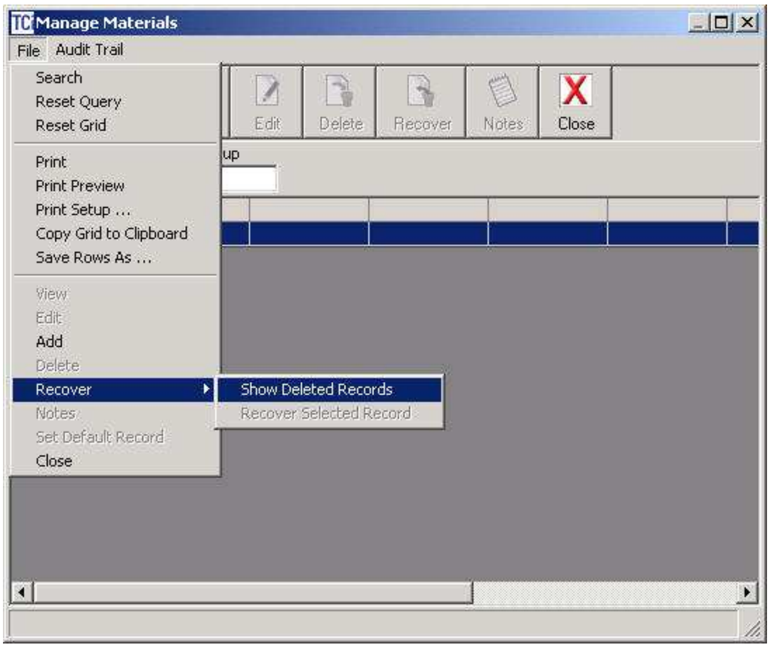
Step 5 – Click the Delete button.

2.3.5 Recover a Record

Step 1 – Open the record's table.
Select the record type from the Manage menu or click the record type in the Setup window. For example, to open a material click Material in the Setup window.

Step 2 – Click the File menu in the table.

Step 3 – Click the Show Deleted Records option from the Recover submenu.



Step 4 – Select the record to be recovered.

Step 5 – Click the Recover button.

Step 6 - Click the Show Deleted Records option from the Recover submenu to display the undeleted records.

2.4 Printing

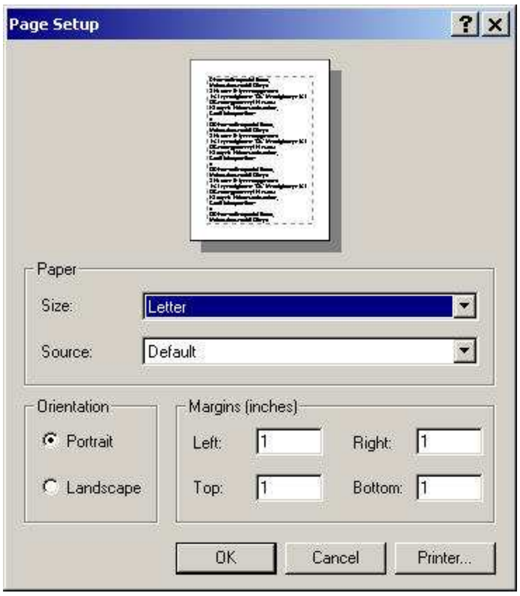
Test reports, tables, records, and results screens can be printed. A printer must be installed before anything can be printed.

Step 1 - Click the File menu.

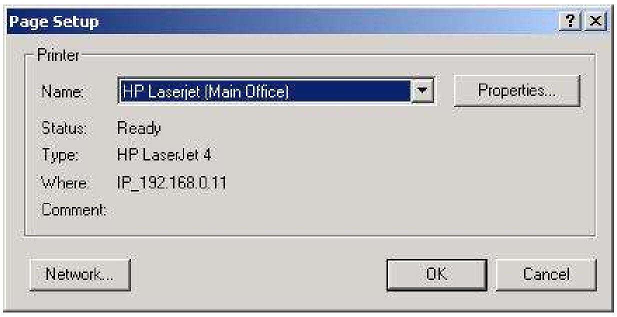
Step 2 - Click Print.
If the print option is grayed out, the screen cannot be printed.

View a preview of the screen, table, report, or record by clicking the Print Preview option in the file menu. The screen, table, report, or record can be printed form the preview screen.

Change the print options by clicking Print Setup from the File menu.



Click the Printer button to select a printer (if multiple are available) or to see the printer's status.



Step 3 – Click the OK button.

3 Records

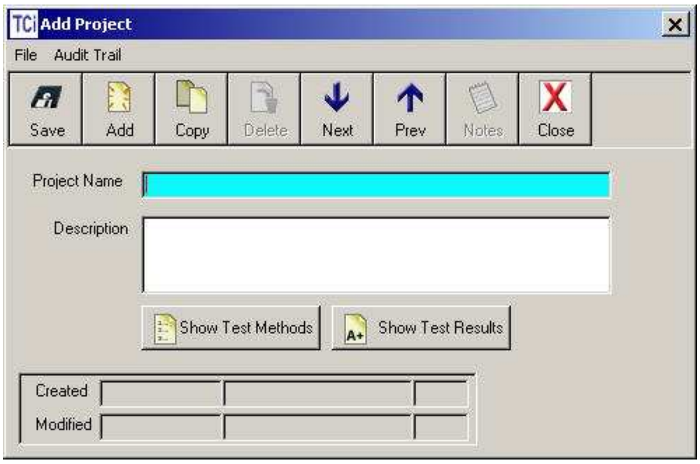
The following section describes how to use and generate the different types of records which support the data generated from testing.

3.1 Project

A project describes the common purpose behind a set of tests. Using this field allows you to separate data for easy reference and future quick access. Projects are not necessary to run tests. A default project is included in the TCi software and is all that is required to perform a test. As more data is collected, the project can be used to filter data.

Step 1 – Open the Project table.

Step 2 – Click the Add button.



Step 3 – Enter the project name.
The project name indicates the purpose or common theme to the tests attached to it.

Step 4 – Enter a description (optional).

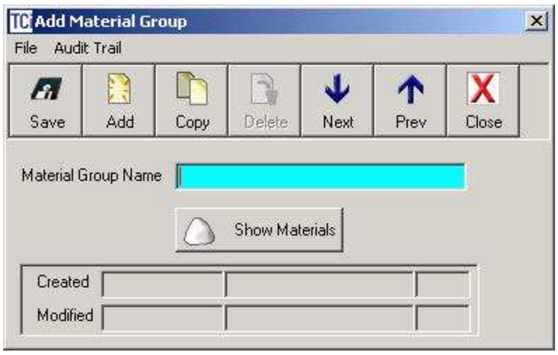
Step 5 – Click the Save button.

3.2 Material Group

A material group contains all materials with a common characteristic. Material groups are not necessary to run tests. A default material group is included in the TCi software and is all that is required to perform a test.

Step 1 – Open the material group table.

Step 2 – Click the Add button.



Step 3 – Enter the material group name.
Use the material group name to indicate the common characteristic of the materials to be attached to the group. For example: lubricants, powders, liquids, or the material name (if different grades are to be included in the group).

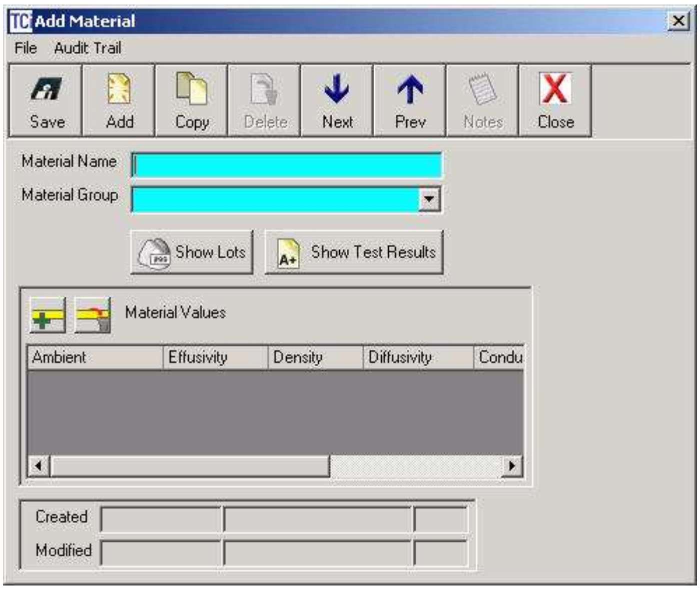
Step 4 – Click the Save button.

3.3 Material

A material is any substance tested. All tests on a particular material can be easily found by searching for the material name. Entering a material name is not necessary to run a test. The value of that test is put at risk if this information is not entered either before or after the test is conducted. A default material name is included in the TCi software and is all that is required to perform a test. As more data is collected, the material name can be used to filter data. However, a material name must be specified to allow calculation of indirect values.

Step 1 – Open the material table.

Step 2 – Click the Add button.



Step 3 – Enter the material name.
If multiple grades of the material are in use, indicate the grade in the material name. Do not specify the material lot as this is covered separately (section 3.4).

Step 4 – Select a material group.
If no group is selected, the material group is set to the default material group by the software.

Step 5 – Click the Add Material Values button (optional).

Step 6 – Enter material properties (optional).
Enter a temperature, then the effusivity, density, diffusivity, heat capacity, and the source of the values. Not all values must be entered. When values are entered, indirect values (diffusivity, heat capacity, R-value, and depth of penetration) can be calculated. Heat capacity and diffusivity can be entered, or calculated if sufficient information is entered.

For diffusivity, density and heat capacity must be entered.

For heat capacity, density must be entered.

The R-value and depth of penetration can be calculated without additional values.

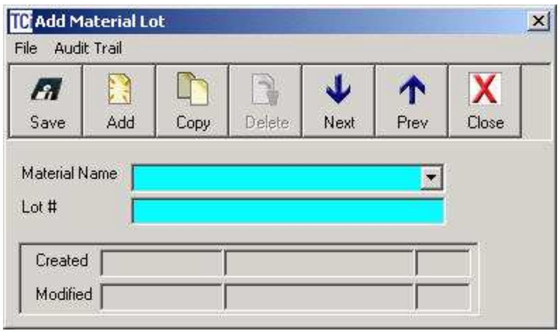
Step 7 – Click the Save button.

3.4 Material Lot

A material lot differentiates between different batches of the same material.

Step 1 – Open the material lot table.

Step 2 – Click the Add button.



Step 3 – Select a material.

Step 4 – Enter the lot number.
Each lot number for a material must be unique.

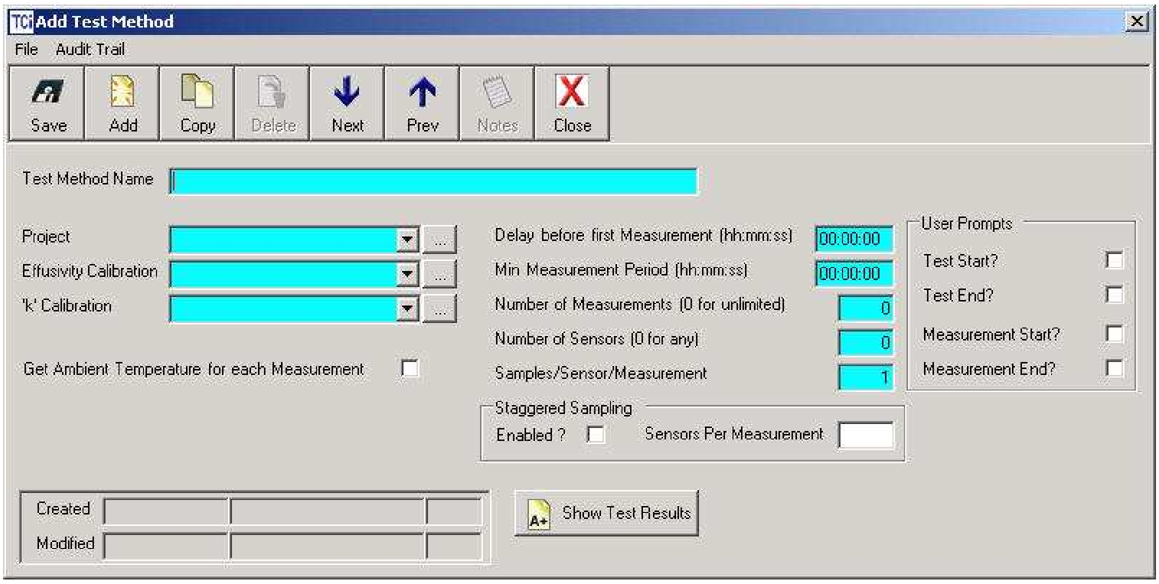
Step 5 – Click the Save button.

3.5 Test Method

A test method describes the parameters of a test: what type of measurements to take (thermal conductivity or effusivity), when to take measurements, how many measurements to take. Unlike the records discussed previously, the test method is required and must be selected before a test with any parameters other than the default can be performed.

Step 1 – Open the test method table.

Step 2 – Click the Add button.



Step 3 – Enter a name for the test method.
The test method name describes the purpose of the test. Use very broad or specific names as the tests require. If a test method is to be used to monitor thermal conductivity of a specific material in a process, urethane foam after a curing process for example, an appropriate name would be "Urethane Foam – k after Curing." If the purpose of the test is more general, powder effusivity for example, an appropriate name would be "Powder Effusivity" or 'General – Powder Effusivity."

Step 4 – Select a project.

Step 5 – Select an effusivity or thermal conductivity calibration method.
The method determines the parameters used in the test.

Step 6 – Click the Get Ambient Temperature for Each Measurement checkbox (Optional).
Check this option only if the temperature is expected to be changing during the test.

Step 7 – Enter the delay before the first measurement (optional).
If no delay is entered, measurements begin immediately upon the beginning of the test.

Step 8 – Enter the minimum measurement period (optional).
A minimum measurement period is used to limit the measurements to a set cycle. A period of 10 minutes means that each sensor will take its measurement(s) every ten minutes. If a period is not specified, the measurements are taken upon completion of the cooling time.

Step 9 – Enter the number of measurements to be taken.
If zero is entered, measurements will be taken until the test is stopped by the user.

Step 10 – Enter the number of sensors to be used.
If zero is entered, any number of sensors can be selected when beginning a test.

Step 11 – Enter the number of samples per sensor per measurement.
This is the number of times the sensor fires during a single measurement interval.

Step 12 – Click the checkbox to enable staggered sampling, if desired.

When staggered sampling is enabled, a set number of sensors fire each rotation until all sensors have been used. Without staggered sampling all of the sensors fire on a single rotation.

Step 13 – Select the prompts to be displayed.

Step 14 – Click the Save button.

3.6 Contact Agents

The TCi sensor surface is made of a solid material. It can measure liquids, powders, and pastes by direct contact with these materials. However, when it comes in contact with solids, there is always a contact resistance. Using a contact agent minimizes the contact resistance. For optimal performance and convenience, Mathis has built into each factory calibration the error corrections for the material groups provided with the following contact agents as listed. ***Not using a contact agent when testing with these material groups will likely result in less than optimal results.***

Three standard contact agents are currently offered with the TCi system: Water, Glycol, and Glycerin. Contact agents have correction factors to prevent them from negatively affecting measurements.

Material Type	Contact Agent	
Liquids	None	
Powders		
Foams		
Composites	-20 to 5℃	3 drops glycol
Ceramics	5 to 70℃	3 drops water
Metals	70 to 150℃	3 drops glycerin*

*Use glycerin when conducting large auto test sequences testing as the water may evaporate.

The best contact agent available is water, since it has relatively high thermal conductivity (~0.6 W/mK), low viscosity, and is easy to apply and clean.

At temperatures lower than 5°C and higher than 70°C a different contact agent is needed.

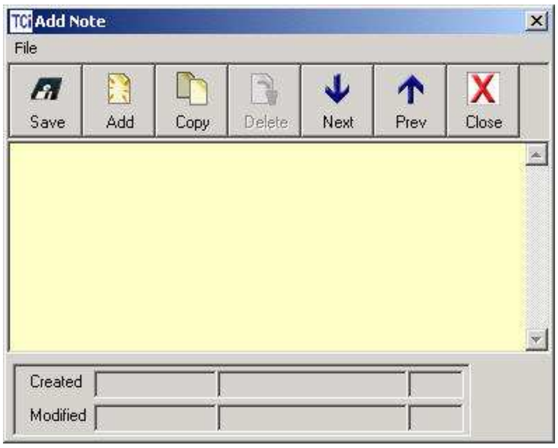
3.7 Notes

Notes can be attached to any other record in the TCi software. They are accessible through the Notes button on most records.

Step 1 - Open a record.
Notes can be attached to material, project, and test method records.

Step 2 - Click the Notes button.
The notes table is displayed.

Step 3 - Click the Add button.



Step 4 - Enter the note.
The note can be up to 200 characters long.

Step 5 - Click the Save button.

4 Testing

In general, testing with the TCi system is intended to be fast. It can directly measure thermal conductivity or effusivity. It can indirectly measure diffusivity, heat capacity, the R-Value, or depth of penetration.

Material Type	Minimum Thickness	Power Level	Temperature Range (°C)	Sample Setup & Preparation	Contact Agent
Liquids*	1 mm	90	-50 to 192	Fill 50 mL beaker to 30 mL mark. Place sensor in beaker.	None
Powders*	1 mm	90	-50 to 192	Fill 50 mL beaker to 30 mL mark. Place sensor in beaker.	
Foams	2 mm	90	-50 to 192	Place sample on sensor. Place weight on sample.	
Composites	5 mm	90	-50 to 192	Place contact agent on sensor. Place sample on sensor. Place weight on sample.	-20 to 5°C: 3 drops glycol 5 to 70°C: 3 drops water 70 to 150°C: 3 drops glycerin*
Ceramics	5 mm	90	-50 to 192		
Metals	5-12 mm	125	-50 to 132		

*Note: For lower sample volumes, other accessories are available – see Appendix A or contact Mathis for more information.

Note: When testing materials, especially high conductivity materials, ***use fabric gloves to minimize heat transfer from your hands to the tested materials***. High conductivity materials will quickly absorb heat from your hands, and will create a temperature gradient, which may affect the results.

4.1 General Procedure

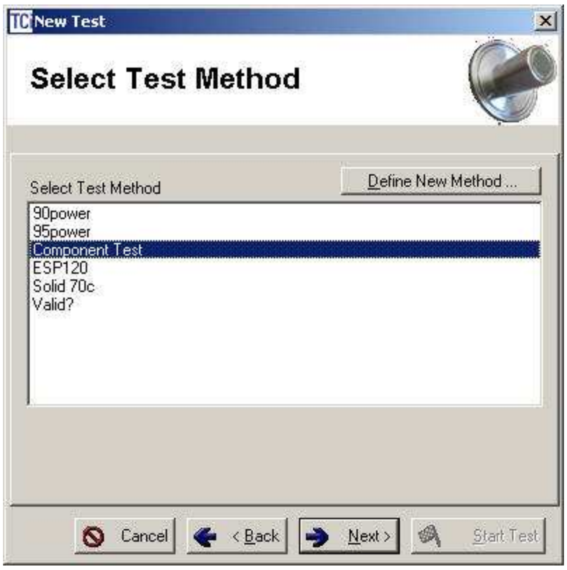
Step 1 – Prepare the materials to be tested.
Specifics of material preparation are given in the following sections. Wear gloves while handling materials to avoid thermal contamination.

Step 2 – Position the material on the sensor.
Specifics on sensor positioning are given in the following sections.

Step 3 - Click the New Test button on the toolbar.
Alternately, click the New Test option in the file main menu.

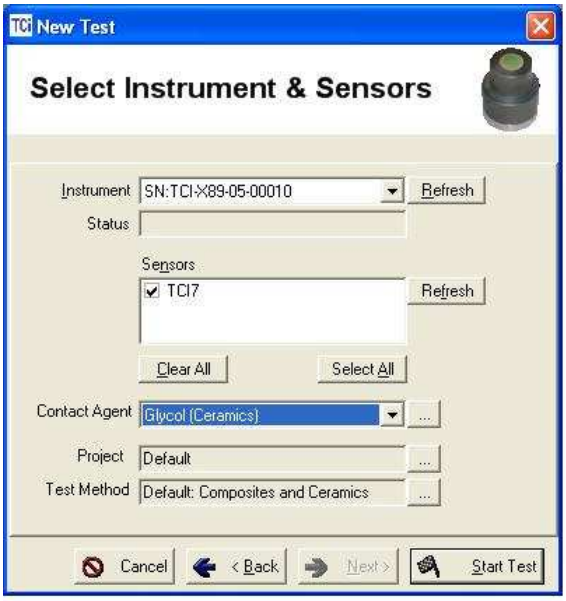
Step 4 - Select the project.

Step 5 – Click the Next button.



Step 6 - Select the test method to be used.
A test method describes the parameters of a test: what type of measurements to take (thermal conductivity or effusivity), when to take measurements, and how many measurements to take. Select a test method that uses a calibration method with the calibration material group and power level appropriate to the test material. Power levels are discussed in the following sections.

Step 7 – Click the Next button.



Step 8 – Select the instrument.

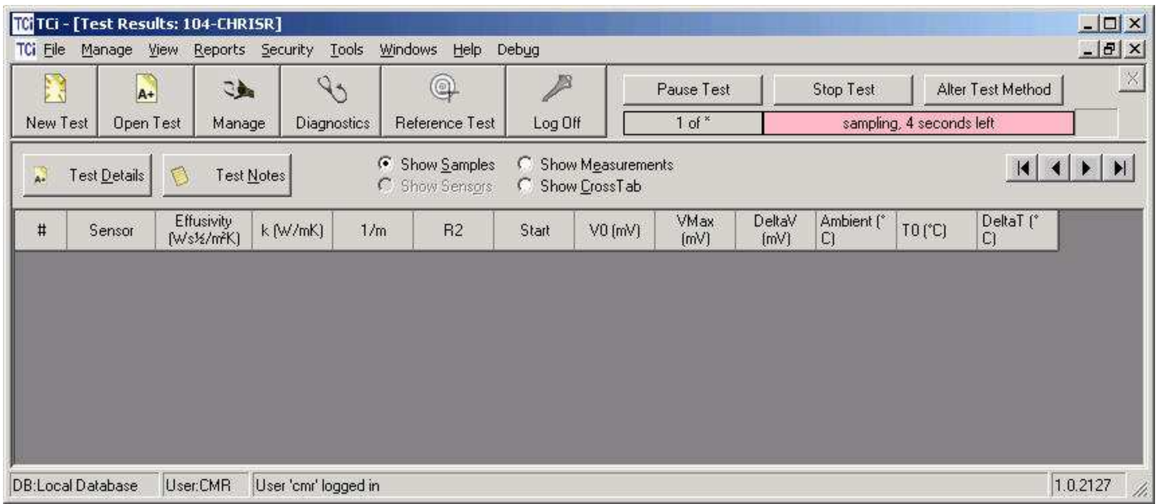
Step 9 – Select the sensors.

Step 10 – Select the contact agent.
See the table in section 4 for a guide to contact agents. Detailed background is located in section 8.

Step 11 – Click the Start Test button.

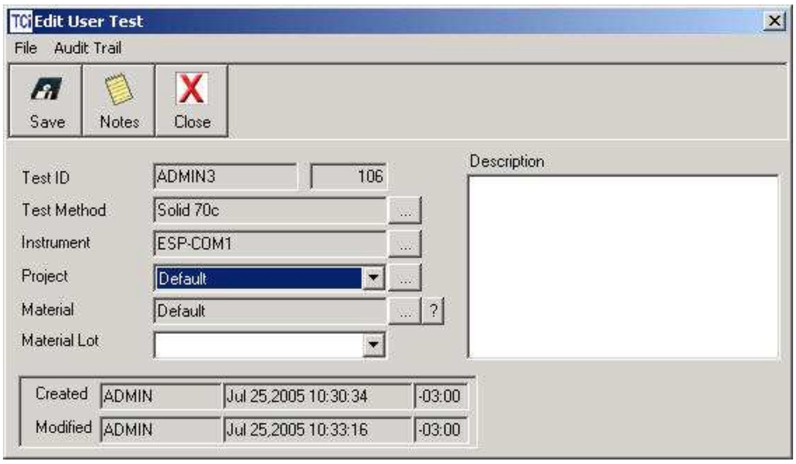
The test results table is displayed. The test can be paused or stopped by clicking the appropriate button at the top of the test window. The samples are displayed as they are taken.

View the measurements by clicking the Show Measurements option at the top of the test window. Multiple measurements can be taken during a sample.



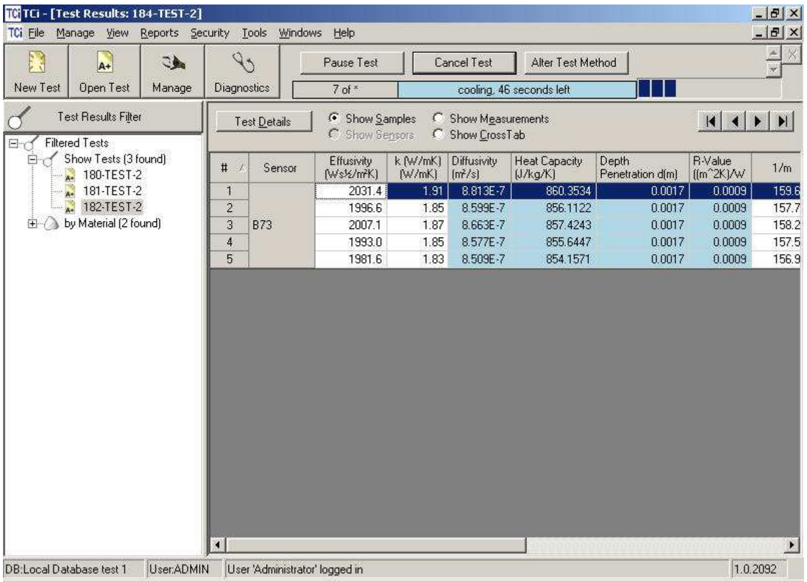
If any cell is red, the measurement is not valid. Repeat the measurement. Check the R^2 value for each measurement. If the R^2 value is less than 0.999, the measurement is not valid. Ensure that the sensor is on a stable surface and that the material and sensor are in good contact. An orange cell means that the thermal conductivity or effusivity value is outside of the acceptable range.

Step 12 – Click the Test Details button.



Step 13 – Click the ? button beside the material drop-down menu.

Step 14 – Select a material.
The derived values are displayed on the test results table if the material has a density value entered.



4.2 Foam Testing

Foam samples are frequently fragile and must be handled with care. Do not use thermal interface materials as they are difficult to clean off the foam. Foams use a power level of 90. Foam samples must be a minimum of 2 mm thick to test.

Note on caring for foam samples: Always keep foams samples free of dirt or other substances which will affect the foam results. Inspect before testing for dents or other forms of compression damage. Store samples carefully to avoid such damage.

Step 1 – Place the sample on the sensor.
Handle the sample with gloves to prevent thermal contamination.

Step 2 – Carefully place a weight on the sample.
The 500 gram weight (supplied by Mathis Instruments Ltd.) provides consistent pressure and keeps the sample in good contact with the sensor surface.

Step 3 – Perform the test.

4.3 Powder Testing

Powders require a power level of 90. The sensor and weight must be applied carefully to provide consistent compaction of the powder. There must be at least 1 mm of powder against the sensor surface for testing.

Step 1 – Fill the 50 mL beaker to the 30 mL mark with the powder sample.

Step 2 – Place the sensor in the beaker so the sensor surface is in contact with the powder.

Step 3 – Place the weight on the sensor.

Step 4 – Perform the test.

4.4 Solid Testing

Solids include composites, ceramics, metals, and any other non-foam solid materials such as wood, polymers, and glass.

The power level depends on the nature of the solid. The power level for tests on low thermal conductivity materials such as polymers, ceramics, and wood should be 90 . The power level for tests on high thermal conductivity materials such as metals should be 125. Composites and ceramics must be at least 5 mm thick for testing. Metals must be at least 9 mm.

When testing a material that is a solid but is not a composite, ceramic, or metal use the table in section 8.2 to guess the appropriate test method to use. Test the material and compare it's thermal conductivity or effusivity to the ranges listed. If the value is within the range, the selected test method was the correct one. If the value id lower or higher than the range, retest the material with a test method with a lower or higher range as needed.

Note on solid materials care: Be aware of the surface condition you are testing when testing solids. A smooth presentation to the sensor face will result in more consistent data. Damage (e.g. pitting, cracks etc.) will be detected if placed over the testing area of the sensor. Polymers often creep (slow deformation) at room temperature so should be placed in a consistent and safe position to avoid damage or uneven surfaces. Reference materials should be used in the same manner all the time and test the same location to ensure the highest possible consistency in results.

Step 1 - Spread a small quantity of contact agent on the sensor surface.
Contact agents include water, Glycol, or glycerin.

Use three drops of glycol contact agent when testing at temperatures below 5ºC.

Use three drops of water as the contact agent when testing at temperatures between 5 and 70ºC.

Use three drops of glycerin as the contact agent when testing at temperatures between 70 and 150ºC or when testing for long periods of time.

Test contact agents on materials before testing with them to ensure that the contact agent does not dissolve, warp or otherwise damage the material. Omit the contact agent if it can damage the sample.

Step 2 - Place the sample on the sensor.

Step 3 - Carefully place a weight on the sample.
If the sample is heavier than 500 grams, the weight should not be used. The sensor chip is fragile and can be damaged if the sample and weight are not placed carefully.

Step 4 – Perform the test.

4.5 Liquid Testing

Liquid testing requires a power level of 90. There must be at least 1 mm of liquid for testing (an approximation only, due to varying viscosities and resultant convective effects on the test).

Step 1 – Pour 30 mL of the sample liquid into a 50 mL Pyrex beaker.

Step 2 - Place the sensor into the beaker.
Slowly slide the sensor into the liquid at a slight angle so that bubbles do not form on the sensor's surface. If the liquid is a highly viscous material, waiting may help to ensure stability if bubbles are entrained in the sample.

Step 3 – Perform the test.

4.6 Indirect Property Calculations

Several properties can be determined indirectly from test results using the TCi software. The derived properties are displayed in the results grid of a test. Below are the theoretical base calculations that are used for the software calculations.

Diffusivity is determined from the equation:

$$\alpha = \frac{k}{\rho Cp} \text{ [m}^2\text{/s]}$$

Where α is the diffusivity, k is the thermal conductivity, ρ is the density, and Cp is the heat capacity. The density must be entered for this value to be calculated. The heat capacity can be entered or calculated if the density has been entered.

Heat Capacity is determined from the equation:

$$C_p = \frac{e^2}{k\rho} \text{ [J/kg·K]}$$

Where Cp is the heat capacity, e is the effusivity, k is the thermal conductivity, and ρ is the density. The density must be entered for this value to be calculated. Both thermal conductivity and effusivity calibrations must be available for this value to be calculated.

The R-value is determined from the equation:

$$R = \frac{l}{k} \ [\mathrm{m^2K/W}]$$

Where k is the thermal conductivity and l is the material thickness (the depth of penetration). This property is only applicable to insulative materials.

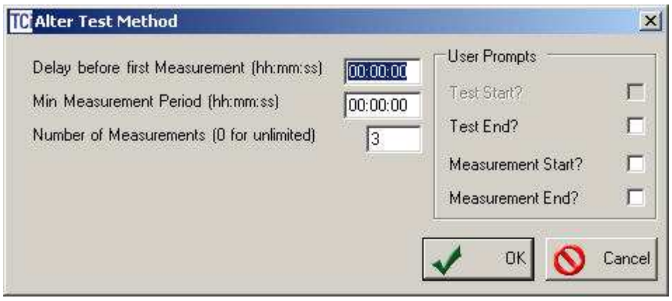
The depth of penetration is determined form the equation:

$$d = (4\alpha t)^{1/2} \ [\mathrm{m}]$$

Where α is the diffusivity, and t is the test time from the thermal conductivity calibration. The thermal diffusivity, heat capacity, or density must be entered for this value to be calculated.

4.7 Altering the Test Method During the Test

The test method can be altered during the test by clicking the Alter Test Method button at the top of the test window. Changes made to the test method in this window last only for the duration of the test. The test method record is not altered.



4.8 Changing the Units of Measurement

Imperial, SI, and CGS units are available for use. Note that this feature requires restarting the software.

Step 1 – Select Change Units of Measure from the Tools menu.

Step 2 – Select the units from the drop-down list.

Step 3 – Click the OK button.

Step 4 – Log out and restart the software.

4.9 Auto Testing

Multiple repeated tests can be performed in the same manner as standard tests. Create a test method with the desired interval between tests.

Step 1 – Open the test method table.

Step 2 – Click the New button.

Step 3 – Enter the test method name.

Step 4 – Select the project and calibration method.

Step 5 – Enter the minimum measurement period.
The measurement period is the interval between tests beyond the cooling time. The time must be entered in hh:mm:ss format (for a period of ten minutes, enter 00:10:00). Leave the field empty if tests can be performed as soon as the cooling time is complete.

Step 6 – Enter the number of measurements.
For unlimited measurements, enter 0.

Step 7 – Enter the number of sensors.
Enter 0 for any number of sensors.

Step 8 – Enter the number of samples/sensor/measurement.
This is the number of times each sensor fires during an interval. If one sensor is left for a long test, multiple samples can be taken in each interval so an r.s.d. can be calculated for each interval.

Step 9 – Select the user prompts.
Do not turn on the measurement prompts.

Step 10 – Click the Save button.

Step 11 – Prepare the sample.

Step 12 – Perform the test.

5 Data Analysis techniques and practices

5.1 Opening a Test

An opened test appears the same as a test being performed with the exception of the test control button field, which is not displayed.

Step 1 - Click the Open Test button on the toolbar/in the main menu.

Step 2 - Enter keywords into the query fields and click the OK button.
Once the test is open, the project and material information can be edited.

5.2 Using Excel for Added Analysis Power

A trial version of MS Excel or MS Office is supplied with each unit. Test data can be copied to Excel by copying to the clipboard or exporting to a CSV file that can be then imported to Excel. See section 5.6 for information on exporting and importing.

5.2.1 Copying to the Clipboard

Step 1 – Open the desired table or test results.

Step 2 – Right-click an entry in the table.

Step 3 – Select the Copy Grid to Clipboard option.

Step 4 – Paste the table into Excel.

5.3 Overlaying Measurements/Tests

Individual samples can be overlaid on a voltage time chart. Overlaying samples allows a deviation point to be found.

Step 1 - Open the test results table.

Step 2 – Open the desired test

Step 3 – Right-click on one measurement.

Step 4 – Select the Show Voltage Chart or Overlay Voltage Chart option.

Step 5 – Right-click a second measurement.

Step 6 – Select the Overlay option.

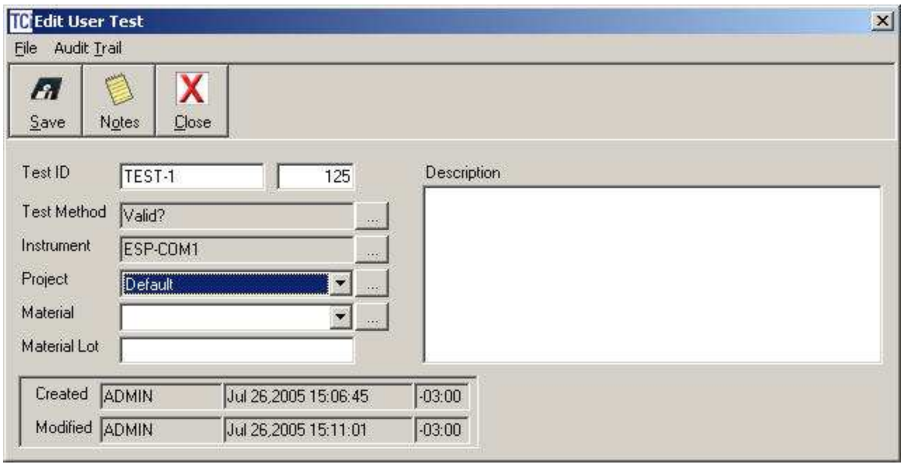
5.4 Editing a Test

The project, material, and material lot of a test can be edited after the test has been performed.

Step 1 – Open the test results table.

Step 2 – Open the desired test.

Step 3 – Click the Test Details button at the top of the window.
View the details of the test method, instrument, project, and material by clicking the **…** button.



Step 4 – Edit any details with a white or blue background.

Step 5 – Enter a description (optional).

Step 6 – Click the Save button.

5.5 Reports

Reports can be generated for the audit trail, tests, the activity, and reference material tests.

Step 1 - Select the desired type of report from the report menu.

Step 2 - Enter keywords into the query fields and click the OK button.
Entries for the audit trail report can be searched by user ID, date range and audit code. A date range must be entered to be able to search.

Entries for the test report can be searched by test ID, workstation, date range, and sensor serial number.

Entries for the reference material test report can be searched by test number and date range.

Step 3 – Click the Report button.
The report can be saved, printed, or exported by clicking the appropriate buttons. Reports can be exported into XLS, RTF, DOC, or PDF files.

5.6 Exporting and Importing

Records can be transferred between databases and computers by exporting and importing XML files. Test results, calibration results, and test methods can be exported and imported. All attendant records with the exception of calibration results (when exporting test methods or test results) and notes are exported and imported with the test results, calibrations, or test methods. The two computers must have very close, if not the same versions of the software for importing and exporting files to work properly. If different database versions are in use, contact Mathis Instruments Ltd. for a database upgrade.

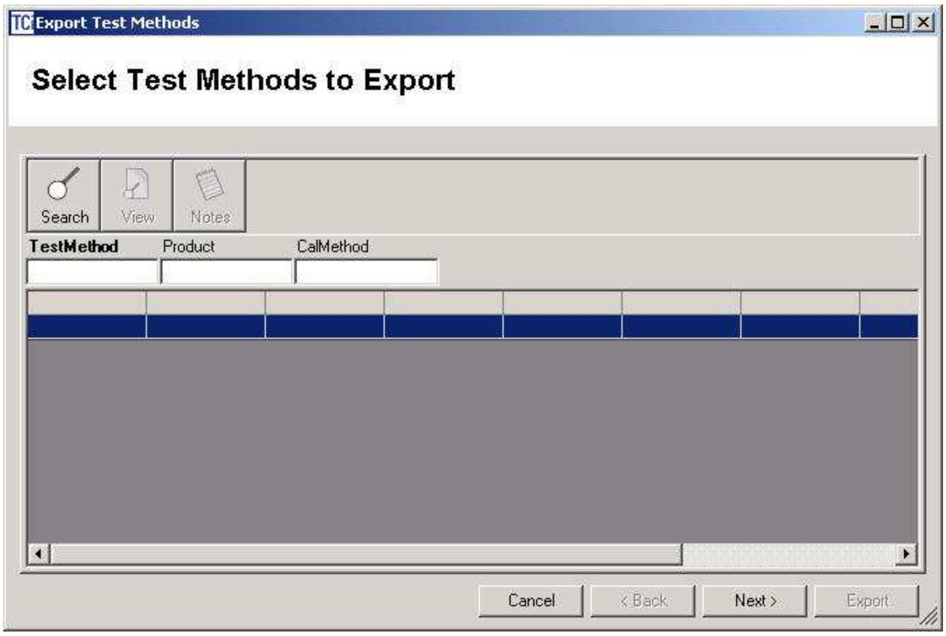
Calibration material and calibration method records are exported with calibration results.

Material, project, and calibration method records are exported with test methods. Calibration results must be exported separately.

Test method, material, project, and calibration method records are exported with test results.

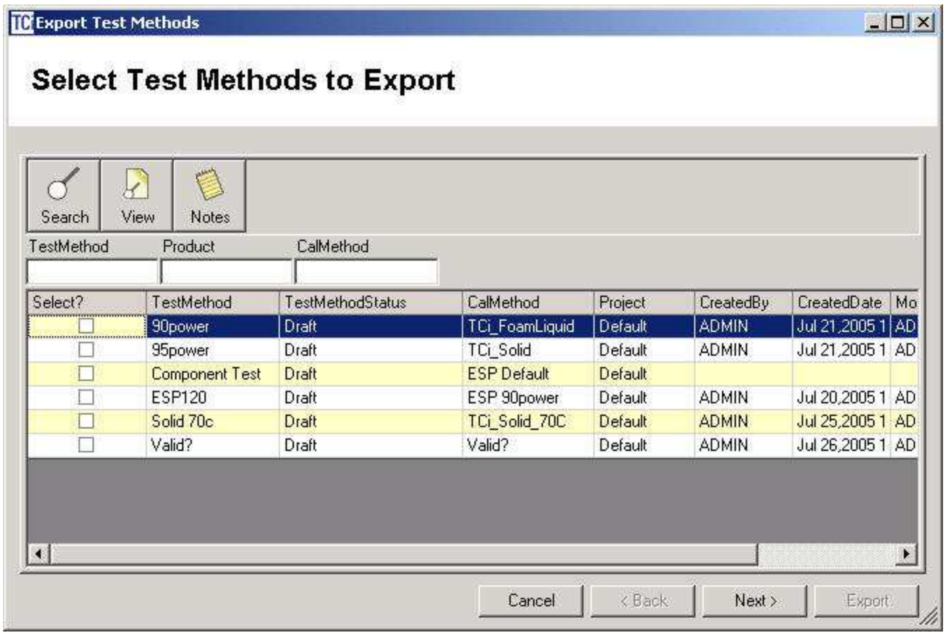
5.6.1 Export

Step 1 – Select the type of file to export from the Tools menu.



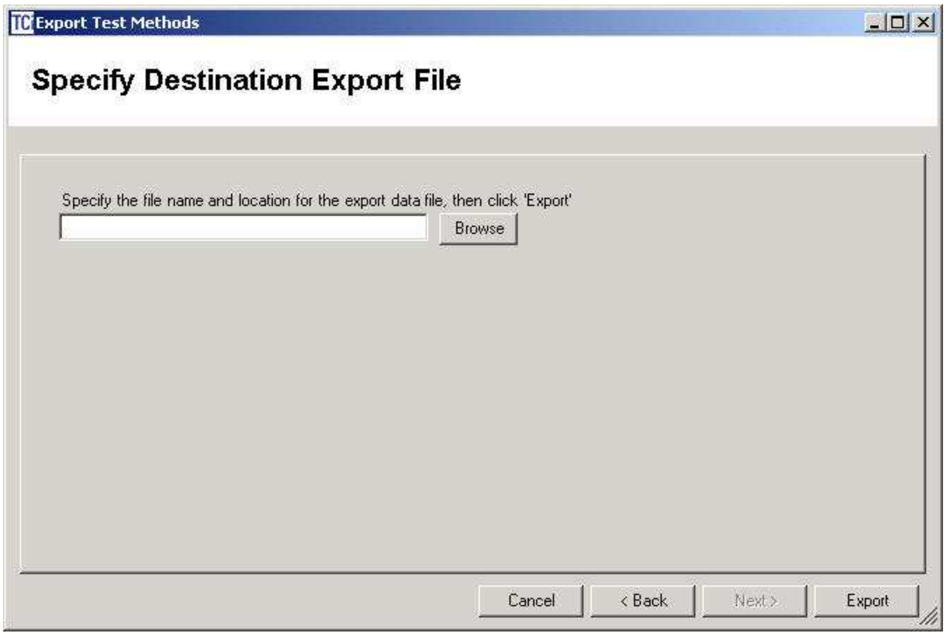
Step 2 – Enter keywords in the parameter fields.

Step 3 – Click the Search button or press the Enter key.



Step 4 – Select the records to export from the displayed list.

Step 5 – Click the Next button.

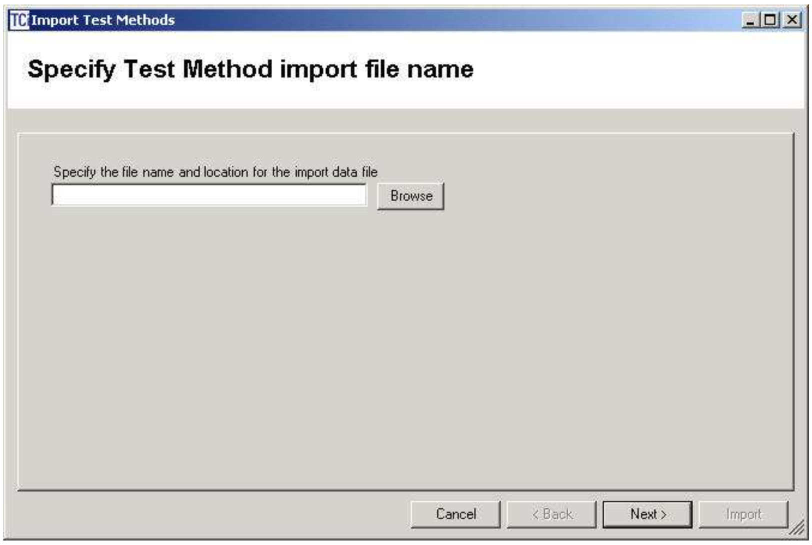


Step 6 – Select a destination for the export file.

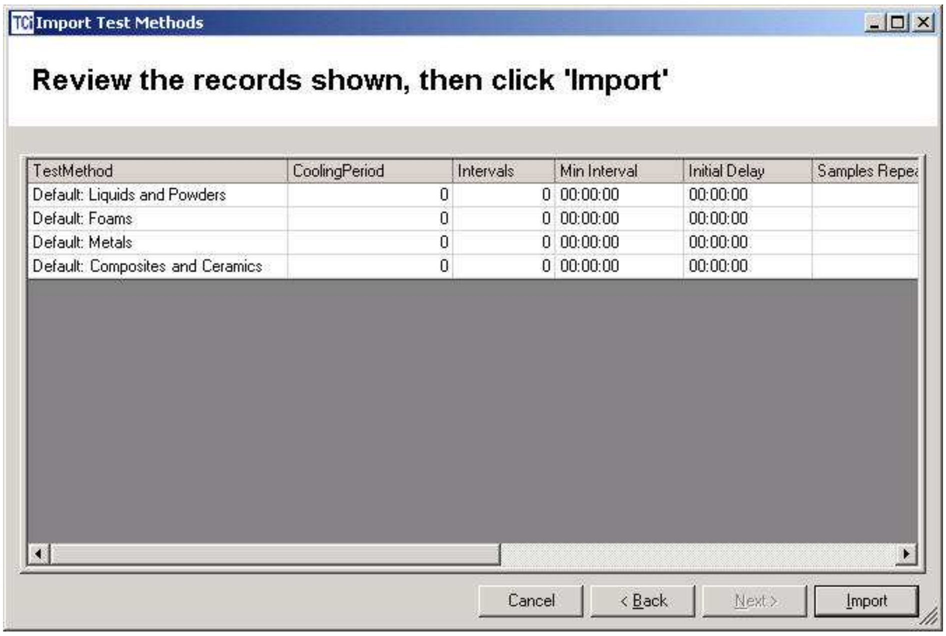
Step 7 – Click the Export button.

5.6.2 Import

Step 1 – Select the type of record to import from the Tools menu.



Step 2 – Select the file to import.
All records contained in the file are displayed.



Step 3 – Click the Import button.

6 Software Setup and Maintenance

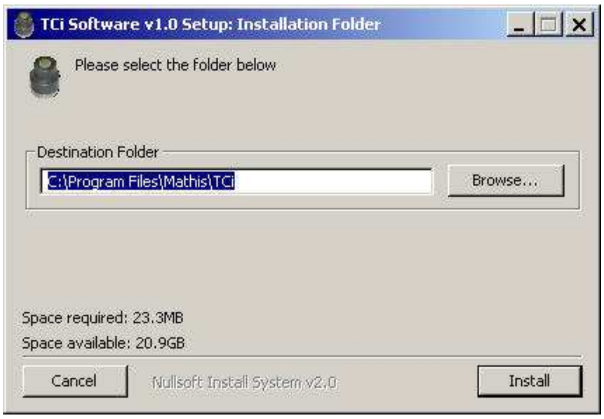
6.1 Setup

If multiple TCi instruments are used within the same company, a network database is advised instead of using a local database. SQL Server or Oracle and a TCP/IP connection over a fast Ethernet network are required for multiple systems to be connected.

The database of a previous software version may not be compatible with a new version of software. If there are database errors after installation of a new version of software, contact Mathis instruments.

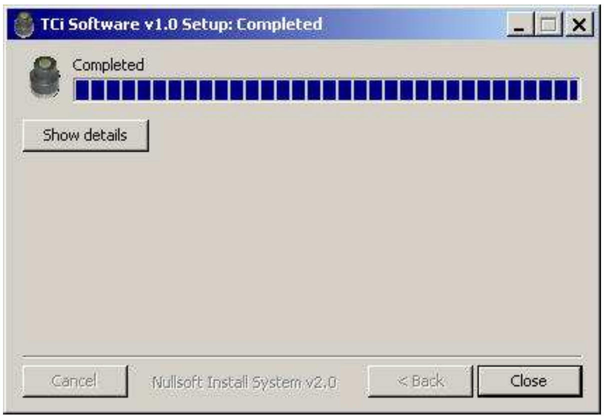
Step 1 – Ensure that any previous versions of the software have been uninstalled.

Step 2 – Double-click the TCi setup.exe icon.



Step 3 – Click OK or enter a new file location.

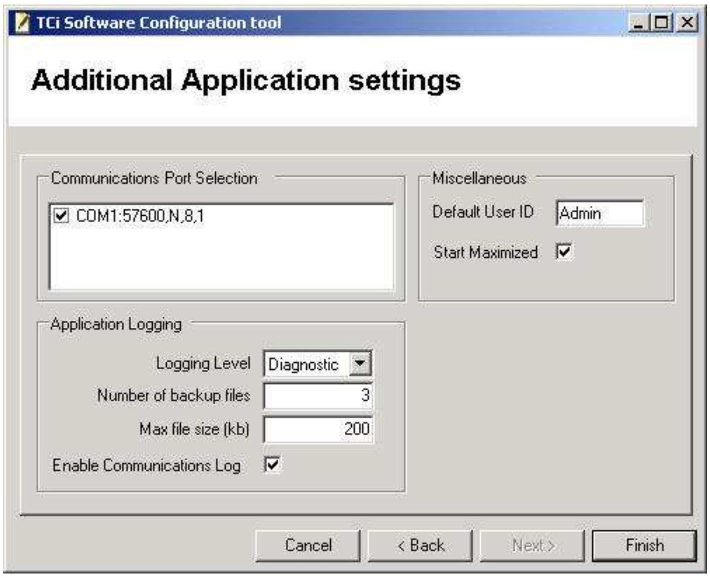
Step 4 – Click the Install button.



Step 5 – Click the close button.

Express Configuration

Step 6 – Click the Next button.



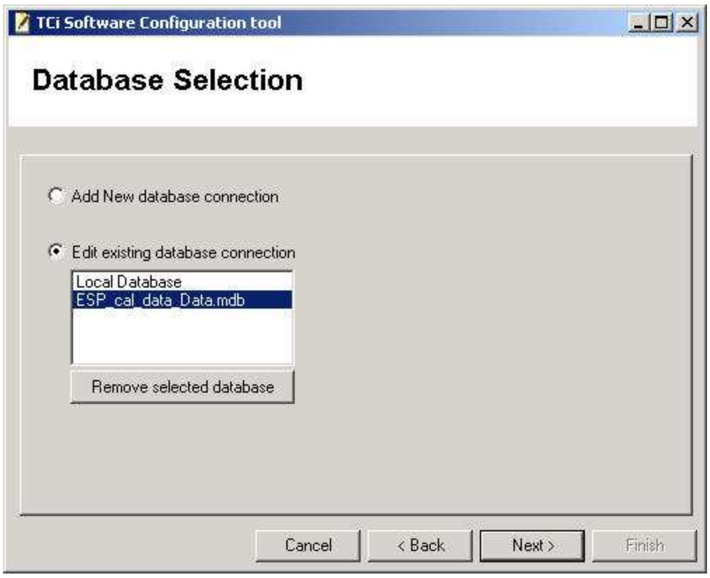
Step 7 – Change the COM port if required.

Step 8 – Click the Finish button.

Custom Configuration (to add or modify the database connection).

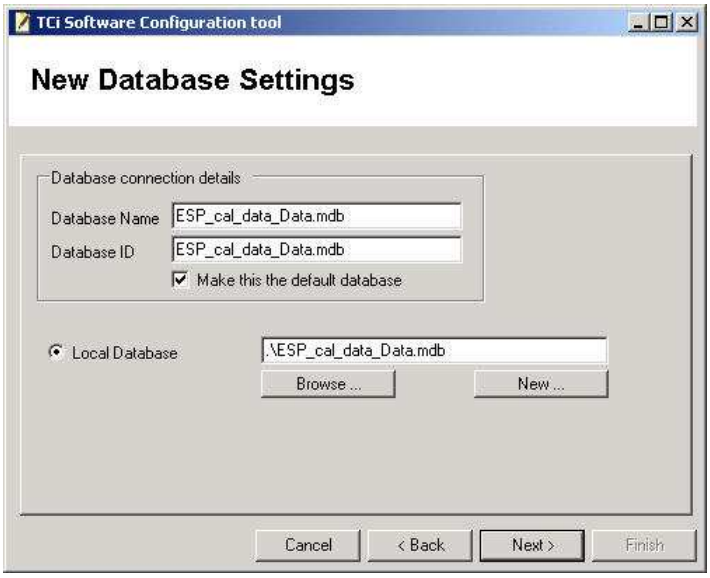
Step 6 – Select the custom configuration option.

Step 7 – Click the Next button.



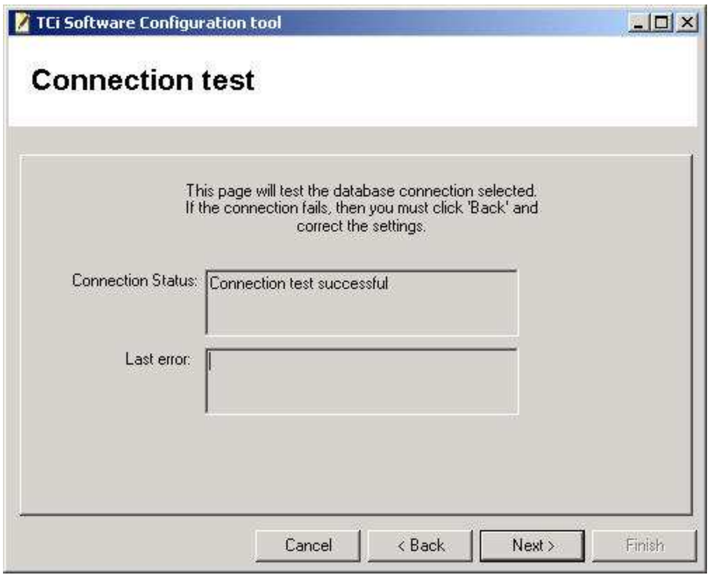
Step 8 – Select a database or create a new database.

Step 9 – Click the Next button.



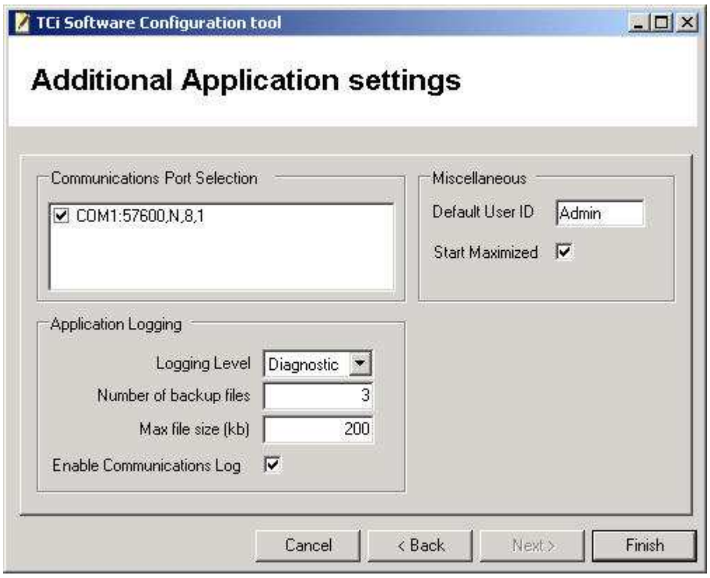
Step 10 – Enter database details or select the local database.

Step 11 – Click the Next button.



Step 12 – Check that the connection was successful.

Step 13 – Click the Next button.



Step 14 – Select the COM port the TCi unit is connected to.

Step 15 – Change the default User ID for login.

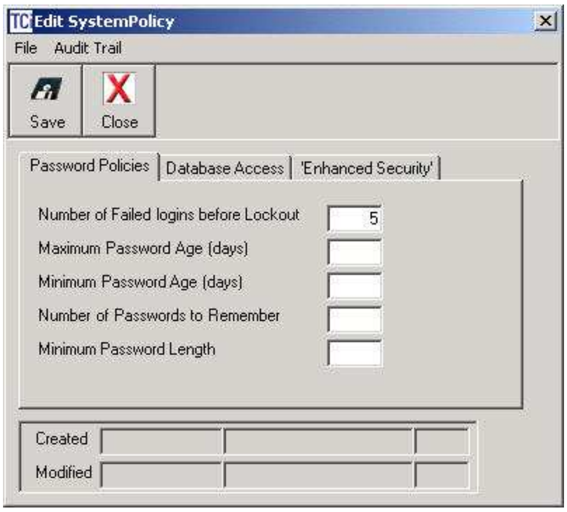
Step 16 – Click the Finish button.

6.2 System Policies

System policies allow administrators to enforce security practices on users.

Step 1 – Open the system policies window.

Click the System Policies option on the Security menu.



Step 2 – Set the number of failed login attempts.
If a user enters the wrong password more than the set number of times, their account is locked and they cannot login. An administrator must reactivate their account before they can login. Instructions for reactivating a locked account are given in section 6.3.4.

Step 3 – Set the maximum password age (in days).
The next time the user attempts to login after the password expires, they will be required to change their password. Instructions for changing a password are given in section 6.4.

Step 4 – Set the minimum password age.
If the password has been in use for less than the set time, it cannot be changed. The minimum password age restriction is used to prevent users from cycling their passwords quickly.

Step 5 – Set the number of passwords to remember.
As long as a password is in memory, it cannot be reused.

Step 6 – Set the minimum password length.
A length of zero means that any number of characters can be used as a password.

Step 7 – Click the Database Access tab.

Step 8 – Set the database access.
There are three options available for database user login as shown above. In the first, a single database is used for all users. In the second, users are connected to different databases depending on the first group listed in their profile. In the third option, each user is connected to a specific database.

Step 9 – Click the Enhanced Security tab.

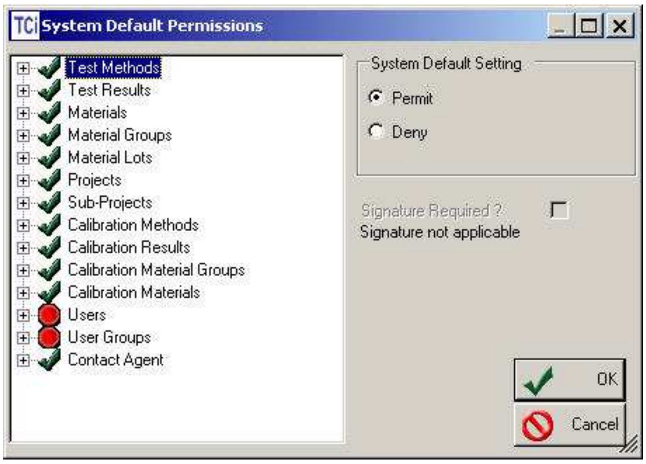
Step 10 – Activate enhanced security (optional).
The enhanced security option enforces database security. No records in the database can be altered or deleted. Once the enhanced security is activated, it cannot be turned off without replacing the database. A new database can be created and used without turning on the enhanced security. Multiple databases can be used, some secure and some unsecured.

6.3 Manage Users and User Groups

6.3.1 Permissions

Permissions allow users to perform actions within the software. The default values of the permissions are provided in appendix G. The values of the permissions can be changed for individual users and groups or the default values can be changed. Information on editing the permission values for users and user groups is given in sections 6.3.2 and 6.3.3.
The default values can be changed by following these instructions:

Step 1 – Open the permission window.
Click the Manage Permissions option from the Security main menu.



Step 2 – Open a permission group by clicking the box with the plus symbol in it.
Alternately, if all permissions in the group are to be set to the same value, select the group and set the value.

Step 3 - Select a permission.

Step 4 – Edit the permission value by clicking Permit or Deny.
The checkmark means the permission is set to Permit by default. The red circle means the permission is set to Deny by default.

Step 5 – Repeat steps 2-4 as needed.
Close a permission group by clicking the box with the minus sign in it.

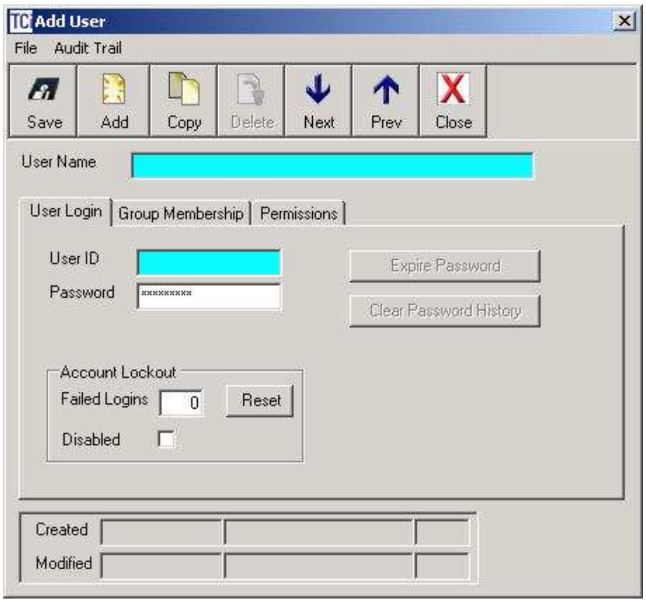
Step 6 – Click the OK button.

6.3.2 Users

Every user has a profile or record within the TCI software. The profile has a unique login ID that allows the user's actions within the system to be limited and tracked. Activities are limited by the permissions the user has, as set in the user's profile. All actions by users are logged in the audit trail. User profiles can be edited, copied, deleted, and recovered in the same manner as other records.

Step 1 – Open the user table.

Step 2 – Click the Add button.



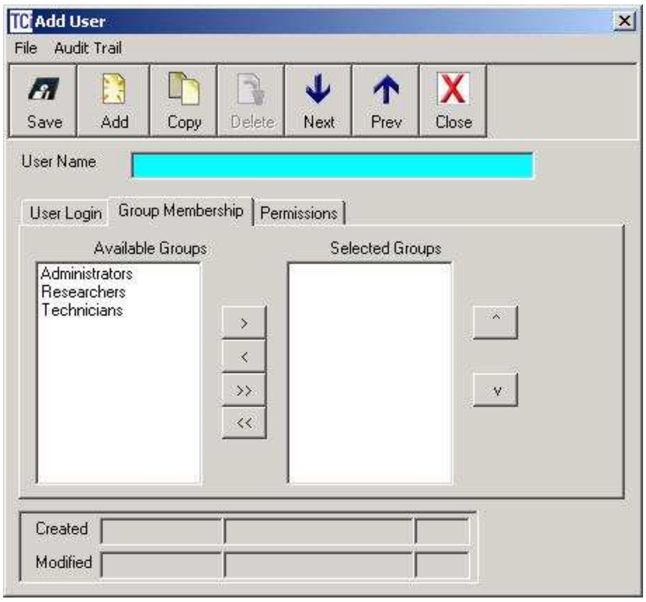
Step 3 – Enter the user's name.

Step 4 – Enter the user's ID.
Every user ID must be unique. Even if a user profile has been deleted, since no records can be permanently deleted, the user ID still cannot be re-used.

Step 5 – Enter the user's password.

Step 6 – Set the number of login failures permitted.

Step 7 – Click the Group Membership tab.

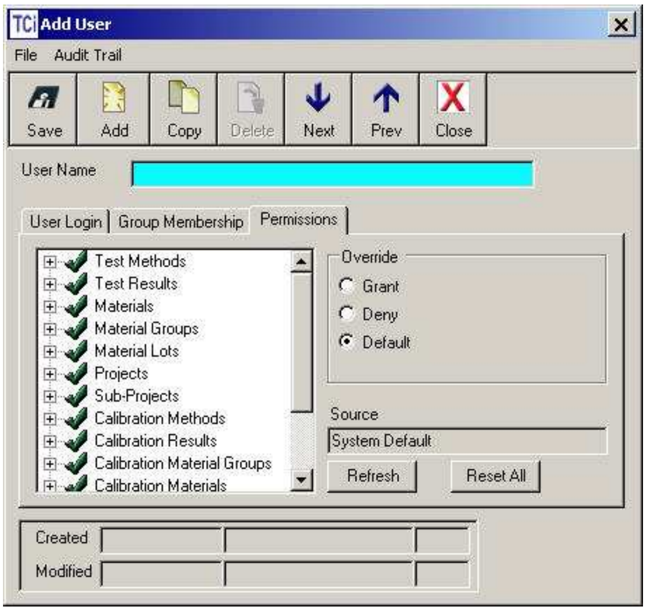


Step 8 – Select any group the user should be a part of and click the > button (optional).

Step 9 – Order the groups in the Selected Groups list.
The order of the groups in the selected groups list is significant. The permissions of groups higher in the list overrule the permissions of lower groups. Permissions of the user overrule permissions from the group(s). An exception occurs when a permission is left set to default. If a permission is set to Default in the user's profile, it can be overruled if a group the user belongs to has a value of Permit or Deny for that permission. Default values can always be overruled by a group lower in the list.

Select each group and use the up and down arrow keys to position it in the correct order. If the user is a member of the Administrator group, it should be at the top of the list.

Step 10 – Click the permissions tab.



Step 11 – Change the permission values if necessary.
Any permission with a value of Default can be overruled by permission values set in groups to which the user belongs. If there are actions the user must or must not be able to perform, set their values to Permit or Deny.

Step 12 – Click the Save button.

6.3.3 Groups

User groups allow administrators to quickly set permissions for large numbers of users who perform the same actions within the TCi software. Users added to a group have the permissions of that group. User groups can be edited, copied, deleted, and recovered in the same manner as other records. There are four groups pre-loaded in the TCi software: Mathis User, Administrator, Researcher, and Technician. These groups can be managed in the same manner as any other group created within the system.

The Mathis User group contains and is only used by Mathis employees. It is present to allow setup and maintenance of the system.

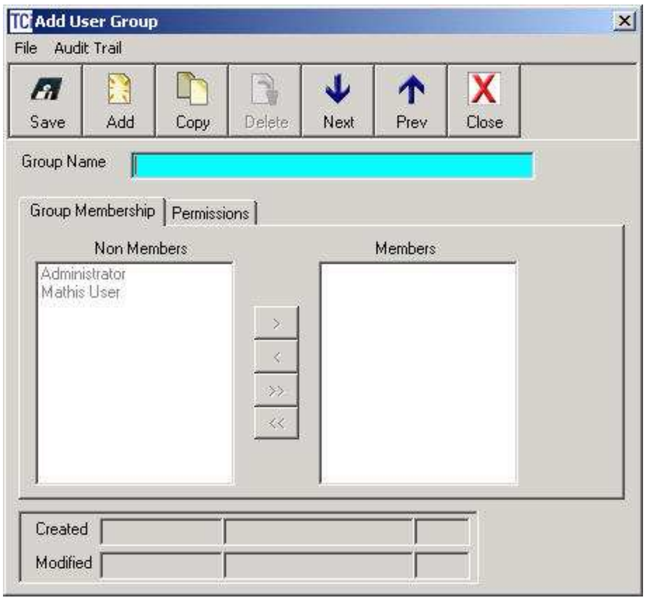
The Administrator group is for users who will use the software to manage users and perform system maintenance but will not be testing or performing diagnostics.

The Researcher group is for users who can perform any action within the software. Researchers can create test methods and any other records, perform tests, and perform diagnostics.

The Technician group is for users who perform tests, run diagnostics, and generate reports.

Step 1 – Open the user group table.

Step 2 – Click the Add button.



Step 3 – Enter the group name.

Step 4 – Select users for the group and click the > button.

Step 5 – Click the Permissions tab.

Step 6 - Change the permission values as needed.
Any permission with a value of Default can be overruled by permission values set in other groups to which the user belongs. If there are actions the users of the group must or must not be able to perform, set their values to Permit or Deny. Permit or Deny values of a group can only be overruled by Permit or Deny values in groups higher in the list of groups in which the user is a member or by the user's permissions set in their profile.

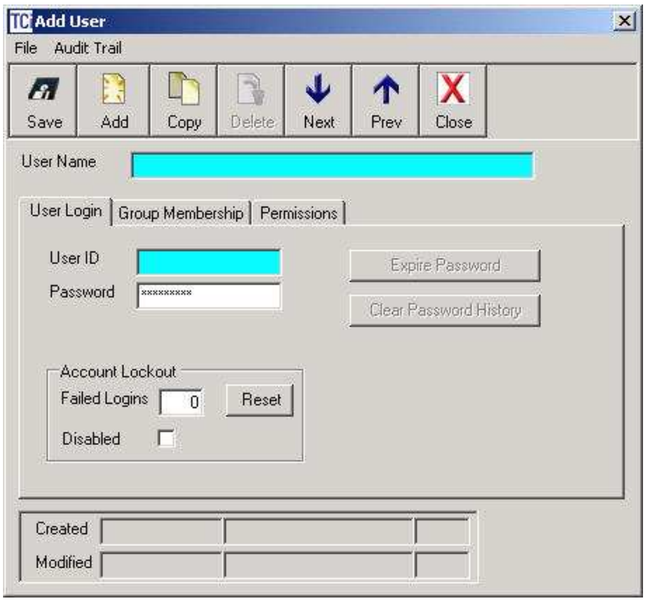
Step 7 – Click the Save button.

6.3.4 Reactivating a Locked Account

Only an administrator can re-activate a locked account.

Step 1 – Open the user table.
Select Manage Users from the Security menu.

Step 2 – Open the user's profile.



Step 3 – Click the Reset button in the Account Lockout box.

Step 4 – Click the Save button.

6.3.5 Clear Password History

Step 1 – Open the user table.

Step 2 – Select the user's record.

Step 3 – Click the Clear Password History button.

6.4 Change Password

User password changes can be periodically necessary, depending on the level of security set by the administrator. The administrator can set a maximum password age. Once a password hits the maximum age, the user must change their password the next time they log in. The change password window is displayed when they log in.

Step 1 – Click the Change Password option in the file main menu.

Step 2 – Enter the current password.

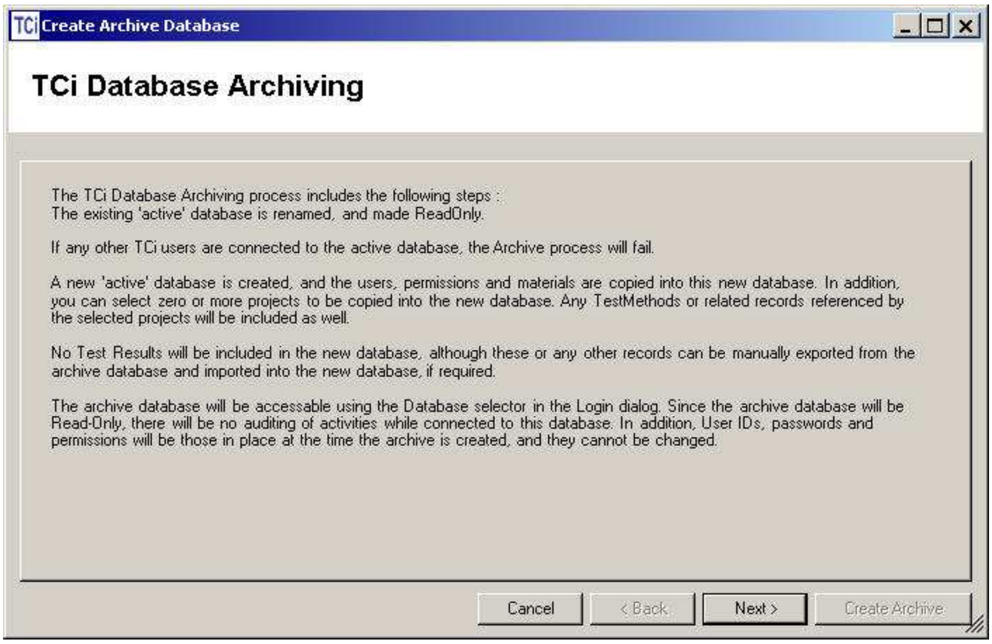
Step 3 – Enter the new password.

Step 4 – Confirm the new password by entering it again.

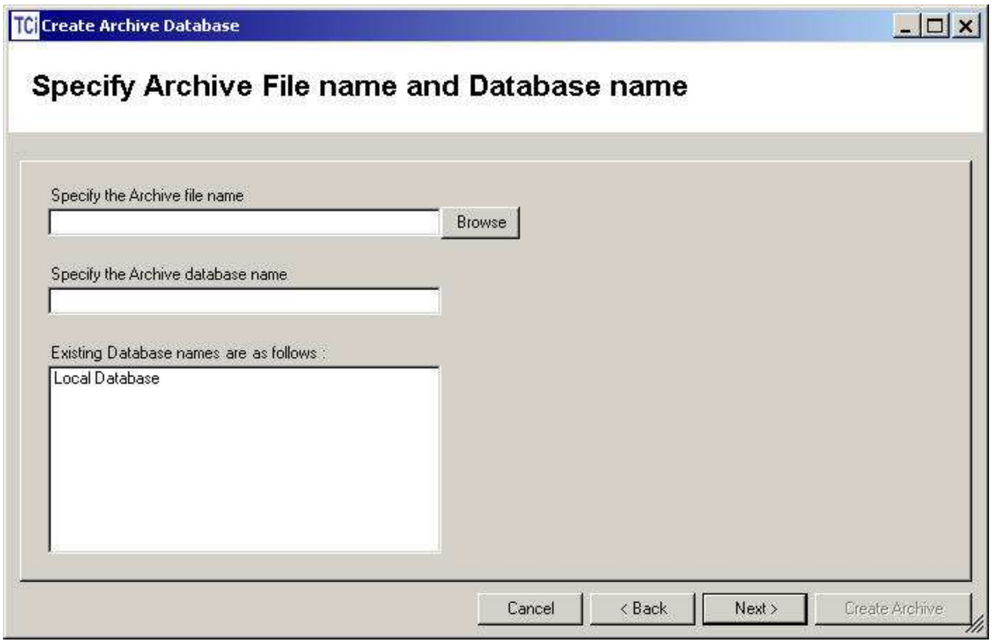
6.5 Archiving

All users except the administrator creating the archive must be disconnected from the database to allow the archive to be successfully created.

Step 1 – Click Create Archive from the File menu.



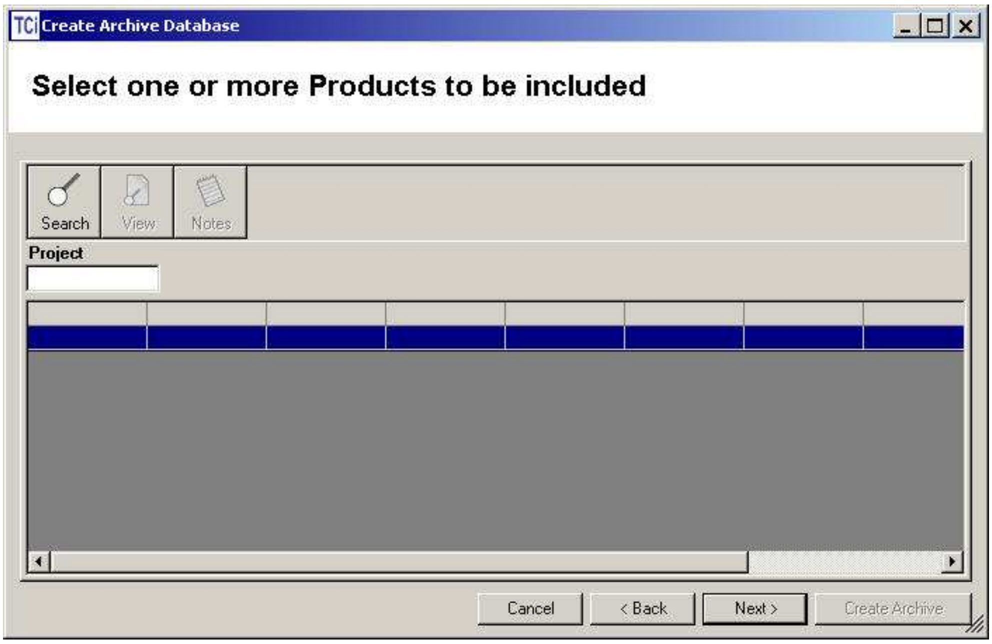
Step 2 – Click the Next button.



Step 3 – Enter the archive file name.

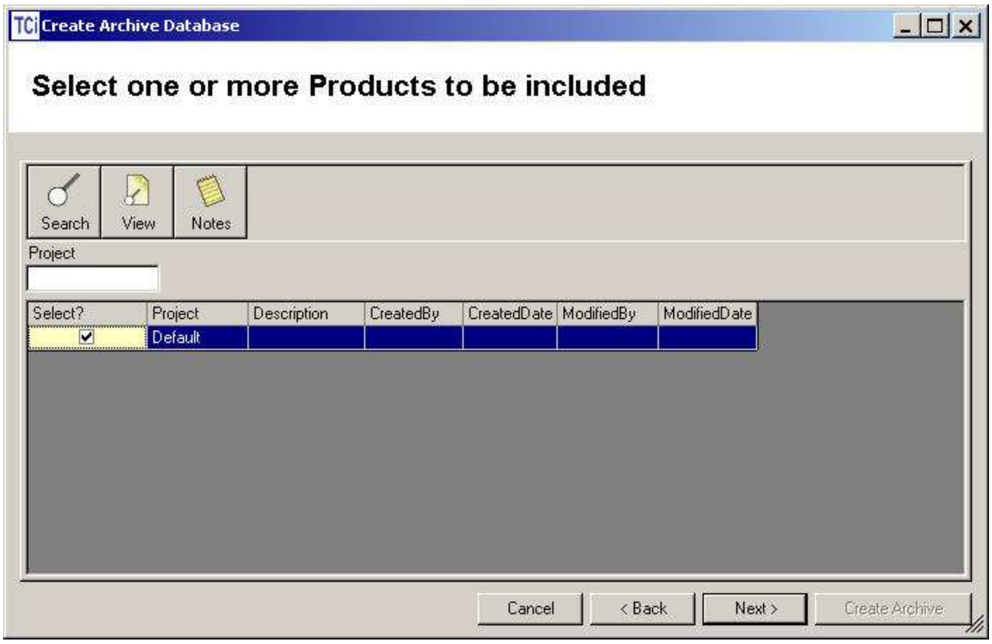
Step 4 – Enter the archive database name.

Step 5 – Click the Next button.



Step 6 – Search for project records to archive.
Click the Search button to view all available projects. All records attached to the project record are added to the archive as well.

Step 7 – Click the Next button.



Step 8 – Select the Projects to add to the archive.

Step 9 – Click the Next button.

Step 10 – Click the Create Archive button.

7 System Calibration and Maintenance

7.1 Calibration

Mathis personnel conduct factory calibrations and the system is shipped ready for use. If a new sensor is received after shipment, the calibration results for that sensor must be imported from an XML file sent by Mathis Instruments Ltd.

Multiple calibrations can be included with different test times and power levels, depending on the requirements of the user.

The calibration can be confirmed by performing a reference material test with PDMS, Laf 6720, Pyroceram, or Phosphor Bronze. The instructions for performing a reference material test are given in section 6.5.1.

User calibration capabilities are available for advanced, trained users. See Appendix A for details.

7.1.1 Import Calibration Results

Step 1 – Select Calibration Results from the Tools Import menu.

Step 2 – Click the Browse button and locate the XML file.

Step 3 – Select the XML file.

Step 4 – Click the Import button.

7.1.2 Calibration Method

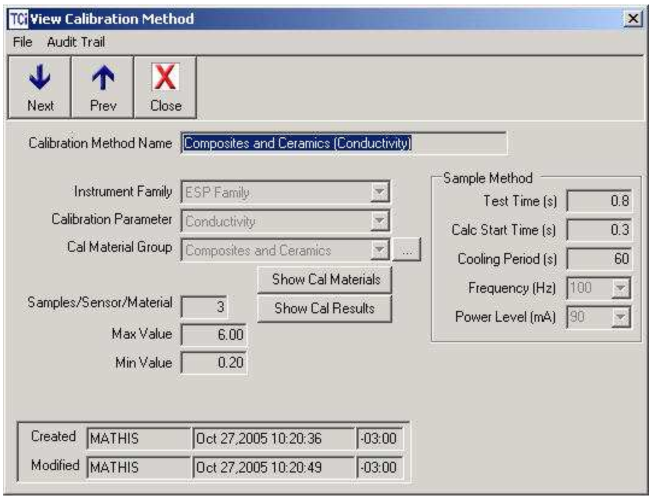
Calibration methods contain the parameters used to calibrate sensors, including calibration type (thermal conductivity or effusivity), test time, start time, cooling time, power level, and calibration material group. Calibration methods cannot be altered or deleted in the same manner as other records. They can be viewed in the same manner as other records.

The test time is the time during which voltage is applied to the sensor.

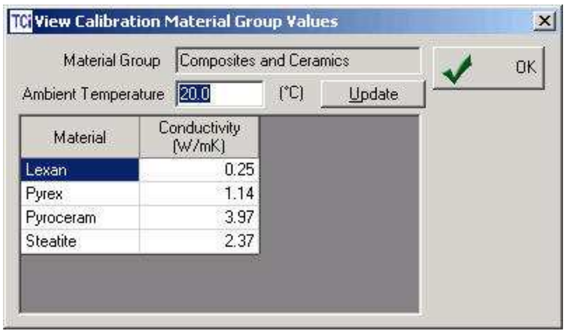
The start time is the time into a test after which the data is used for calculations.

The cooling time is the time the sensor requires to cool down after a measurement is taken. No further measurements can be taken by a sensor during the cooling time.

The power level is the amount of voltage applied to the sensor. Use lower power levels when testing powders, foams, liquids, composites, and ceramics and higher power levels when testing metals.



The thermal conductivity values of the calibration materials used by the method may be viewed by clicking the Show Cal Materials button.



7.2 Diagnostics

Diagnostics confirm the functionality of the instrument, test the sensor calibration, and aid troubleshooting. The diagnostics window displays the instrument's status, calibration data, and board inventory.

7.2.1 Reference Material Test

Use the reference material test to confirm that the sensor's calibrations are still valid. There are four available reference materials depending on which calibrations were purchased: PDMS, Laf 6720, Pyroceram, and Phosphor Bronze.

Calibration Material Group	Reference Material
Liquids and Powders	PDMS
Foams	Laf 6720
Composites and Ceramics	Pyroceram
Metals	Phosphor Bronze

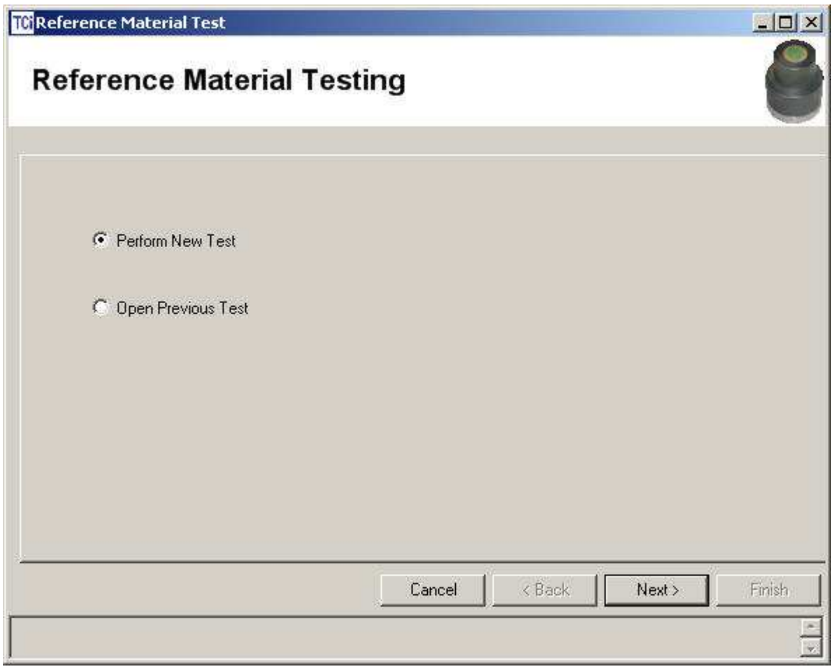
Step 1 – Prepare the reference material and sensor.

PDMS - Pour 30 mL of PDMS into a 50 mL beaker. Allow the PDMS to settle for two hours prior to the reference material test. Slowly slide the sensor surface into the PDMS at an angle to prevent bubbles from forming on the sensor surface.

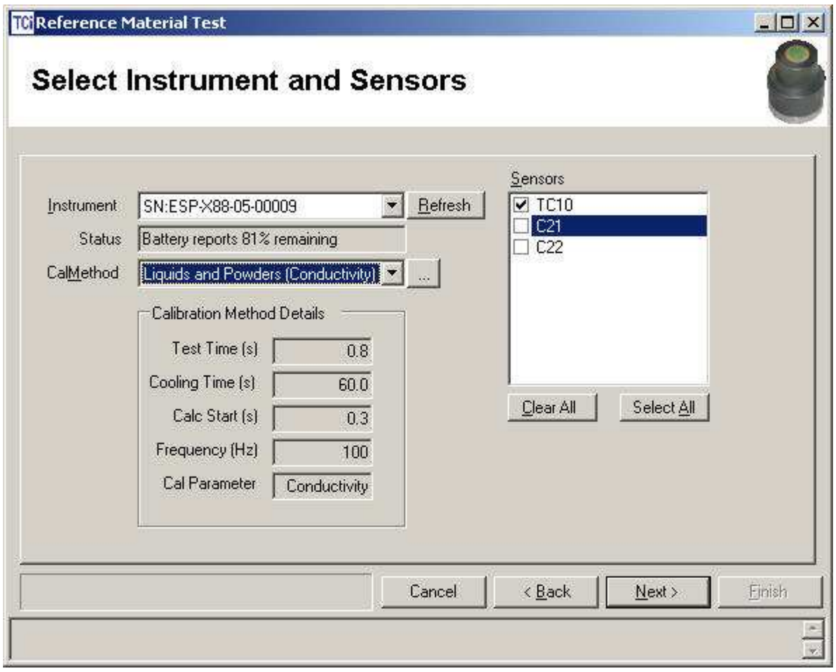
Laf 6720 - Place the sample on the sensor and place a weight on the sample to ensure good contact.

Pyroceram and Phosphor Bronze - Place the required amount of contact agent on the sensor surface (-20 - 5 C - three drops of Glycol, 5 - 70 C three drops of water, 70 - 150 C or for long term tests three drops of glycerin). Place the sample on the sensor and place the weight on the sample to ensure good contact.

Step 2 - Click Reference Material Test from the Tools menu.
Leave the Perform New Test option selected.



Step 3 - Click the Next button.

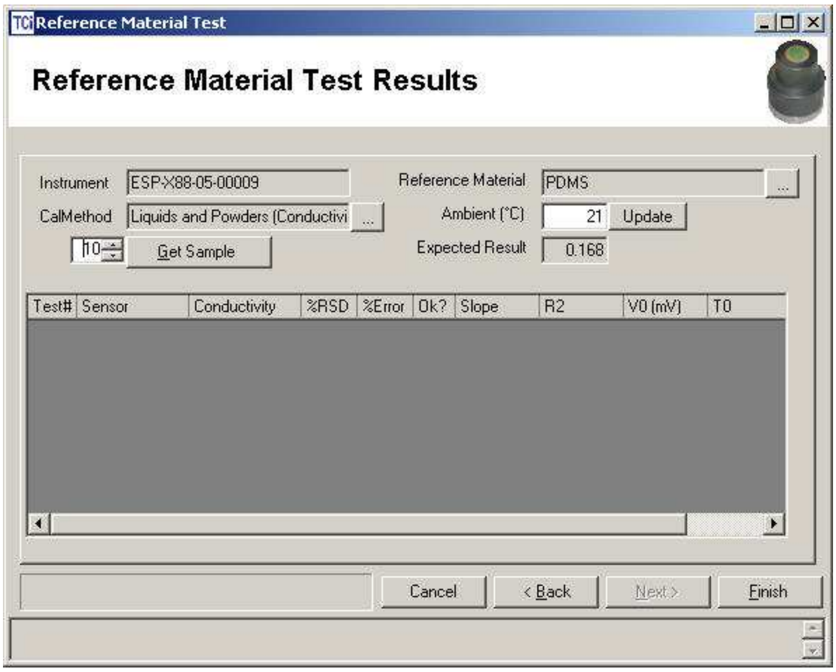


Step 4 - Select an Instrument.

Step 5 – Select the calibration method.
The reference material to be used is determined by the calibration material group specified in the calibration method selected.

Step 6 – Select the sensor(s) to be used.

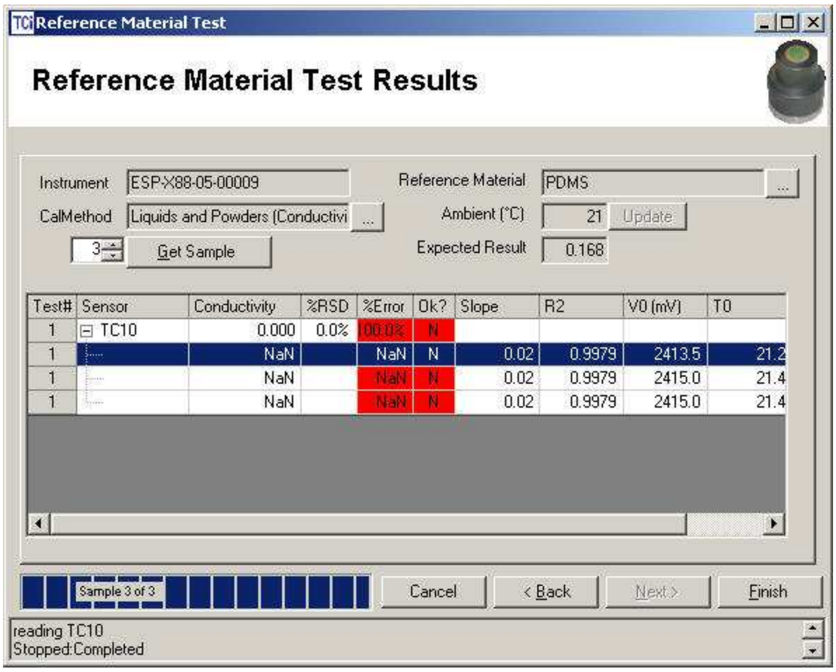
Step 7 - Click the Next button.



Step 8 - Enter the ambient temperature.

Step 9 – Click the Update button beside the Ambient Temperature field.

Step 10 - Click the Get Sample button.
The result is displayed. All results should be within 5% of the predicted value (displayed under the reference material name). If the result is in a red cell, the diagnostic has failed. If the diagnostics fail, a new calibration may need to be performed. Contact Mathis Instruments Ltd. for troubleshooting.



Step 11 - Click the Finish button.

<u>PDMS Cleaning Procedure</u>
Treat the sensors' surfaces very gently when cleaning.

Step 1 - Wipe down the sensor with mineral oil on KimWipes.

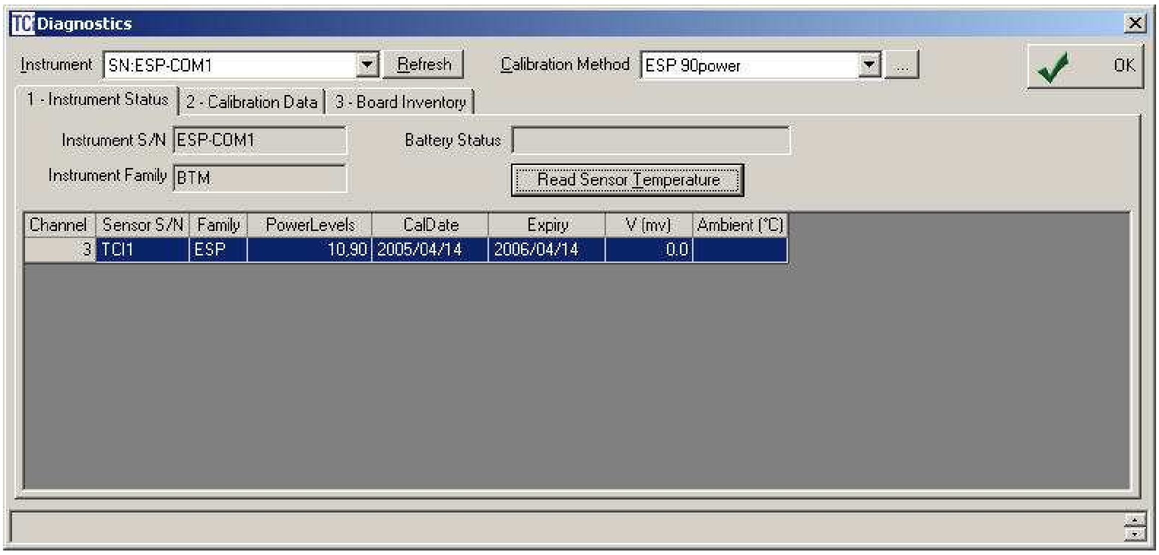
Step 2 - Wash the sensor with soap and water.

Step 3 - Wipe down the sensor with isopropyl alcohol.
The isopropyl alcohol removes any possible bacteria from the sensor for FDA regulated labs.

7.2.2 System Checks

Step 1 – Open the diagnostics window.
Click the Diagnostics button on the toolbar.

The first tab, labeled Instrument Status, contains information about the instrument.

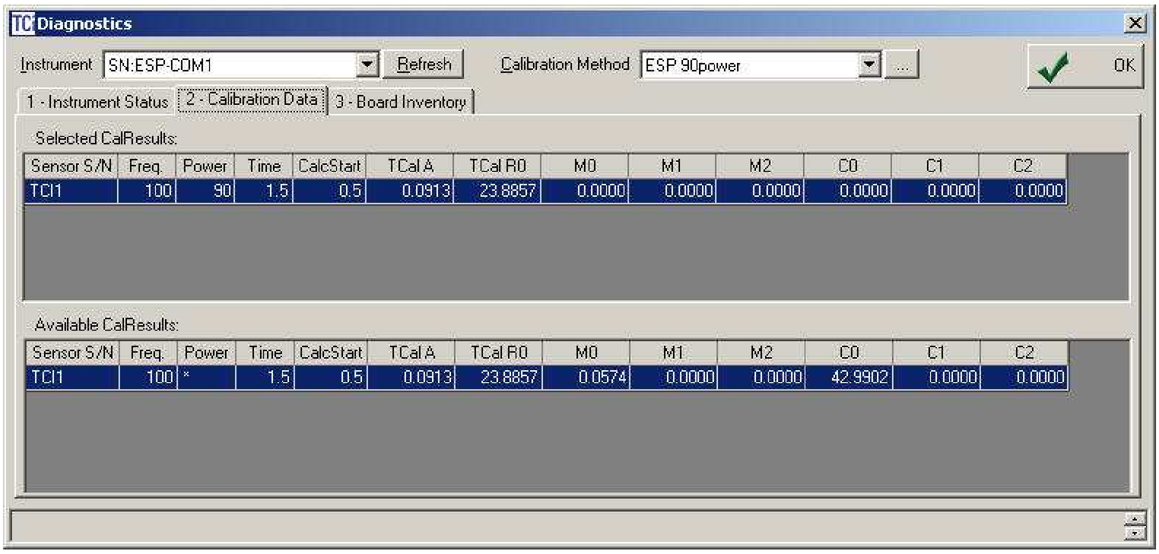


Step 2 – Click the Read Sensor Temperature button.
The reading is displayed in the ambient temperature column of the table.

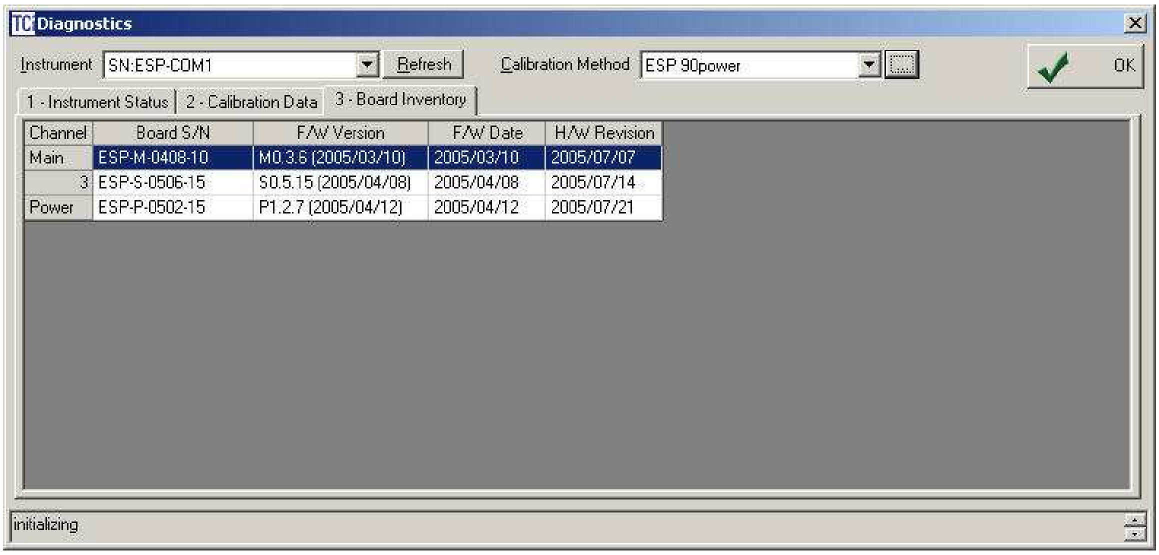
Step 3 – Click the Calibration Data tab.

Step 4 – Select a calibration method.
The calibration method drop-down list is located at the top of the diagnostics window.

Calibration results for the selected calibration method are displayed in the top table. All calibration results in the database are listed in the bottom table.



Step 5 – Click the Board Inventory tab.
The board inventory tab lists all circuit boards in the instrument. Their serial numbers, firmware versions, the date they were programmed, and hardware versions are listed.



7.3 Cleaning Procedure

This procedure provides general guidelines for cleaning the TCi system.

Warning: Prior to cleaning - shut down the control unit and disconnect the power plug at the outlet.

The TCi system is comprised of a controller, sensors and cables. Different parts of the system tolerate different cleaning materials and methods. Please follow these guidelines to ensure proper operation of the TCi system.

Warning: The sensor is sealed and can sustain immersion in water for a time. However, for a longer life span it is not recommended to maintain the sensors immersed in liquids. Do not spray high-pressure liquids on the sensor surface.

Note: Keep the protective caps on when transporting or storing the sensors. Shut off the controller power before disconnecting the sensors.

The materials of construction are detailed in Appendix E. Of the various materials used in the sensor, Torlon, glass, and RTV cannot tolerate certain cleaning agents, and the sensor chip is ceramic and can be broken. For a simple cleaning process, please refer to Table 1. A complete chemical list is available in Appendix C in the event other cleaning agents are required to remove sample residue.

TCi Sensor Cleaning:
Step 1 - Wipe the Torlon/Stainless sensor shell with a KimWipe or equivalent to remove material residues. Avoid scratching any surfaces.

Step 2 - Clean the sensor surface with a swab dipped in a cleaning agent per the table below. Allow the sensor to dry. Apply isopropyl alcohol to the sensor surface and wipe off with a KimWipe.

Table 1: Simple cleaning recommendations

Cleaning Agent	Controller Unit	Cables	Sensor
Water	✓	✓	✓
Soap and Water	✓	✓	✓
Isopropyl Alcohol	✓	✓	✓

TCi Controller Cleaning: Wipe the control unit down with a damp cloth.
Warning: Do not spray any liquid on the control unit. The control unit is sealed against light dust but is not sealed against liquids. It can be damaged if sprayed with liquids.

Resistance to Materials:

The chemical resistance chart in appendix C provides a list of chemicals that can be used if the simple cleaning recommendation for the sensors is not appropriate. If you wish to use materials not listed, contact Mathis Instruments for an RTV test kit.

7.4 Troubleshooting

7.4.1 General Information required

If problems are encountered in the TCi software, please send a detailed explanation of the problem, the expected result, and steps to reproduce the problem. The details should be in a doc file with a screen capture of the error message and a screen capture of the Help About dialog. Place the doc file in a zip file with the following files from the TCi program files folder:

1. TCi.log
2. TCi_Data.mdb (if you are using a local access database)
3. TCi_COM#.log (# is the Com port number of the com port the TCi controller is plugged into on the computer)

7.4.2 Troubleshooting List

<u>Low on Memory Error</u>
Low on memory errors occur when the TCI software is using a lot of memory, for example doing a search of a large database with no parameters. Wait for the function to complete. If using an SQL server, the server may have timed out.

<u>My test was aborted or interrupted and now I cannot locate the data.</u>
Tests are created in a deleted state and that status is not changed until the test is completed. To locate the test data:

Step 1 - Select Test Results from the manage menu.

Step 2 - Select Show Deleted Records from the Recover submenu of the File menu.

Step 3 - Select the record.

Step 4 - Click the Recover button.

Step 5 - Click Show Deleted Records from the File menu to show active records again.

Instrument not Found
The instrument driver does not recognise a controller with no sensor connected as an instrument. If a "No instrument found" error is displayed, check to make sure that sensors are attached to the controller.

Importing and exporting across timezones
Import/Export does not work when the source and destination are in different time zones. Set the time zone of the destination machine to the time zone of the source. This will allow the import. After the import, the time zone can be changed back.

My import failed because there was a record of the same name in the new database
Rename the record in either the old or the new database and re-try the import. To rename the record, either edit the record and change it's name or, if the record is signed, make a copy of the record and change it's name. Then delete the old copy. This should allow the record to be imported into the new database.

My test results import failed
If a draft test method is edited to belong to another product after a user test has been performed with the product the test method was originally attached to, the new product can not be exported which will cause the Import to fail. There is at present no solution for this problem.

I tried to export/import a large number of records and the import failed
There is a maximum number of files that can be imported, based on the max length of an SQL command. 100 tests will export and import successfully. If an import with more records fails, try importing a smaller number. Performance will also be slower when importing or exporting a large number of records.

The notes did not import
Notes are exported with the records they are attached to but are not imported. There is no solution for this problem at present. Notify Mathis Instruments Ltd. and provide details to help isolate the problem.

An imported record now is attributed to a different user than the creator
A record is connected to a UserID. The installation on the new computer can also have a user with that UserID. The record is now connected to that user. There is no solution at present for this problem as user information cannot be exported or imported.

Is it an error to import a record twice?
No, a record can be imported multiple times as long as the record is not changed in the old or new database. When a record is imported again it is compared to the record of the same name and, when found to be identical, is removed from the list of files to be imported. Once all other records in the import file are checked, the import is indicated as a success. However, the records that are identical to those already present will not be listed in the grid of files imported.

I opened a record to edit it and now I cannot save it.
If two users have the same record open for editing, only one of them can save it. The second person to save will receive an error stating that the record cannot be saved.

I changed the order of the groups in a user's record and the change was not saved.
When the order of groups is changed, the change is not always saved. There is a work-around for this problem: remove all groups from the list, save the record, and then re-add the groups in the correct order.

8 Theory of Operation

8.1 TCi Calibrations

8.1.1 Sensor temperature calibration

This section explains the relationship between the sensor's change in temperature, ΔT, its resistance ΔR and its voltage drop ΔV, and how to calculate ΔT from TCR (temperature coefficient of resistivity) calibration parameters.

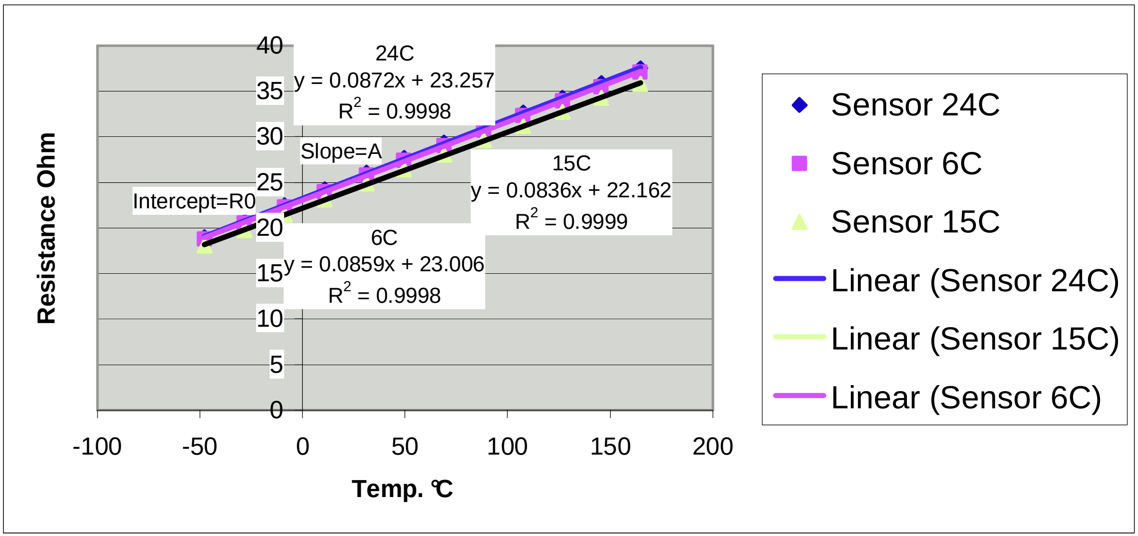
The TCR calibration is calibration of sensor resistance versus temperature, and is given in this equation (assuming perfect linearity):

$$R(T) = R_0 + A \cdot T \qquad (1)$$

Where:

R(T) = resistance of sensor at a given temperature (Ohm)
R_0 = resistance of sensor at 0ºC (Ohm)
T = temperature (ºC)
A = slope (Ohm/ºC)

Example of TCR calibration:



Range of *A* ~0.05 – 0.15 Ohm/ºC for this sensor design Range of R_0 ~20 – 25 Ohm

The slope *A* is equal to:

$$A = R_0 \cdot TCR \qquad (2)$$

Where: *TCR* = Temperature Coefficient of Resistivity, assumed to be constant over the measured temperature range.

Notes:

1. **The slope depends on sensor resistance in general, and on R_0 in particular. Therefore, even if 2 sensors have the same *TCR*, their temperature calibration lines will still have different slopes if their resistance at a given temperature is not the same.**

2. **The higher slope, the more sensitive the sensor is. In other words, higher *TCR* and higher sensor resistance will provide higher sensitivity.**

For platinum used in the sensor, the *TCR* is approximately 0.0037 $^{o}C^{-1}$, or 0.37% for each ºC.

To calculate the surface temperature of the sensor from (1) we use:

$$T = \frac{R(T) - R_0}{A} \qquad (3)$$

The resistance may be measured directly by the electronics (using very low current and short time to avoid sensor heating), or calculated from the initial voltage, V_0, or from the applied power *P* (if applied power is the same for all sensors).

$$R = \frac{V_0}{I} \qquad (4)$$

$$R = \frac{V_0^{\ 2}}{P} \qquad (5)$$

Where *R* is the measured sensor resistance at the said temperature, I is the current and *P* is the power.

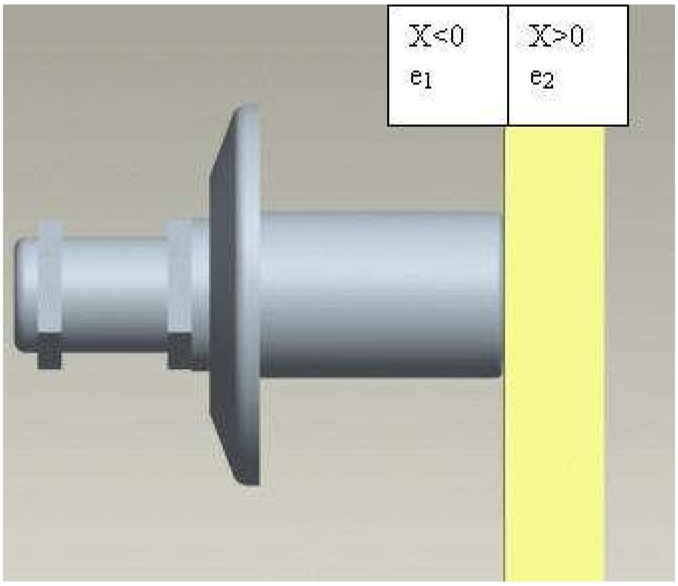
Software calibration parameters: *A; R_0*

8.1.2 Basic multi-point effusivity calibration

The heat equation with a constant supply of heat per sec per volume *G'* is given below:

$$c\rho \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + G' \qquad (6)$$

Assume two semi-infinite media in contact with heat generated at the interface at a constant rate per unit area per unit time. Further assume that the effusivity sensor represents one medium, and the other medium is the tested material, and both are at the same temperature and in equilibrium after contact between them has been established. The solution of equation (6) follows these expressions:



$$\Delta T_1(x,t) = \frac{2G\sqrt{t}}{e_1 + e_2} ierfc \frac{|x|}{2\sqrt{\alpha_1 \cdot t}} \text{ for } x < 0,\ t > 0 \quad (7)$$

$$\Delta T_2(x,t) = \frac{2G\sqrt{t}}{e_1 + e_2} ierfc \frac{x}{2\sqrt{\alpha_2 \cdot t}} \text{ for } x > 0,\ t > 0 \quad (8)$$

Where:

ΔT = change in sensor surface temperature (ºC)
G = power flux supplied to sensor (W/m^2)
t = time measured from start of process (sec)
e_1 = equivalent effusivity of sensor ($\sqrt{k_1 \cdot c_1 \cdot \rho_1}$, $\frac{W\sqrt{s}}{m^2k}$)
e_2 = effusivity of measured material ($\sqrt{k_2 \cdot c_2 \cdot \rho_2}$, $\frac{W\sqrt{s}}{m^2k}$)
α_1 = equivalent diffusivity of sensor, m^2/s
α_2 = diffusivity of measured material, m^2/s

Assumption: Both sensor and measured material are in equilibrium and at the same temperature when the measurement starts.

If no contact resistance exists at the interface, $T_1(x=0,t) = T_2(x=0,t)$ at all points with $x = 0$. For $x = 0$ equations (7) and (8) are reduced to:

$$\Delta T(x=0,t) = \frac{2G\sqrt{t}}{e_1 + e_2} \cdot 0.5642 = \frac{1.1284G\sqrt{t}}{e_1 + e_2} \quad (9)$$

In the previous section we saw the connection between sensor temperature and resistance. The resistance change of the sensor is:

$$\Delta R(t) = R(t) - R(t=0) = A \cdot \Delta T(x=0,t) \qquad (10)$$

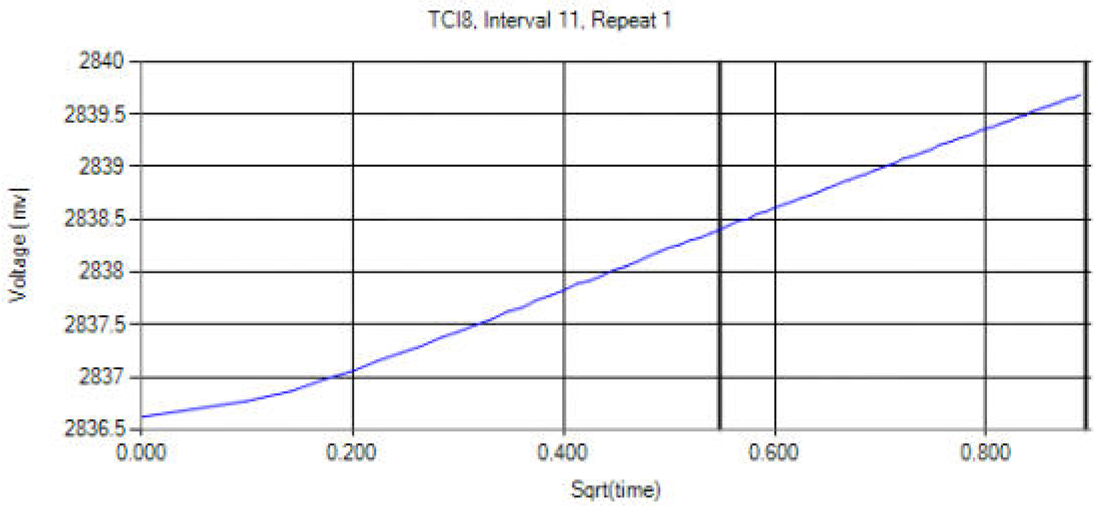
And the voltage change on the sensor is:

$$\Delta V(t) = I \cdot \Delta R(t) = I \cdot A \cdot \Delta T(x=0,t) \qquad (11)$$

Using equation (9) we can write:

$$\Delta V(t) = \frac{1.1284 I \cdot A \cdot G\sqrt{t}}{e_1 + e_2} \qquad (12)$$

Example of voltage versus $\sqrt{t}$ measurement:



Equation (12) can be written (in the linear zone) as:

$$\Delta V = m\sqrt{t} \qquad (13)$$

Where *m* is the slope,

$$m = \frac{1.1284 I \cdot A \cdot G}{e_1 + e_2} \quad (V/\sqrt{s}) \qquad (14)$$

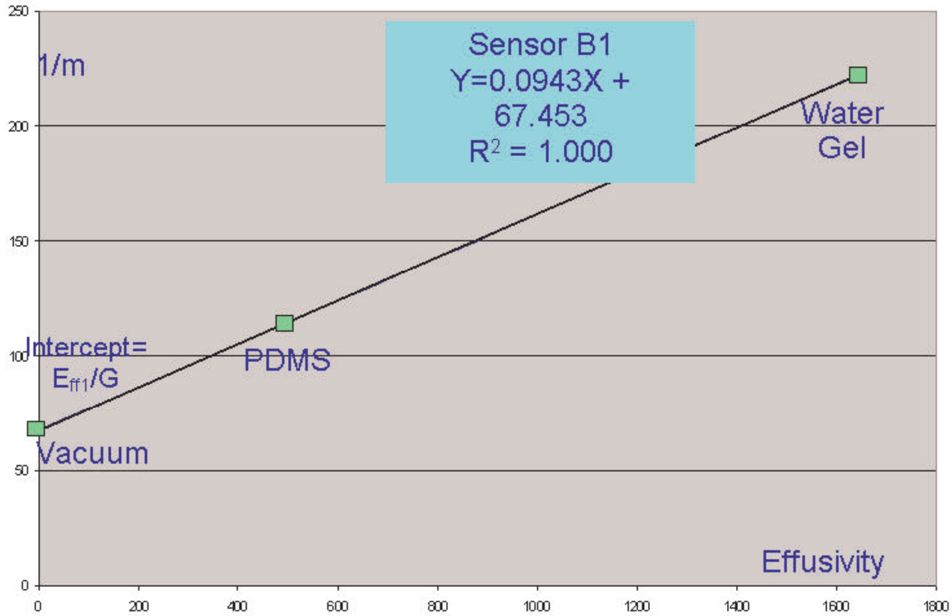
$$\frac{1}{m} = \frac{e_1 + e_2}{1.1284 I \cdot A \cdot G} \quad (\sqrt{s}/V) \qquad (15)$$

If e_2 is 0, i.e. sensor response is measured in vacuum, then:

$$\frac{1}{m}(vacuum) = \frac{e_1}{1.1284 I \cdot A \cdot G} \qquad (16)$$

The figure (e_1/IAG) is a sensor/system figure of merit, and depends only on sensor characteristics and supplied power, and may be used for calibration.

Example of sensor effusivity calibration curve using vacuum and other materials is given below. The calibration line shows very good linearity.



The calibration line can be written as:

$$\frac{1}{m} = M \cdot e_2 + C \qquad (17)$$

Where *M* is the slope of the effusivity calibration and is equal to:

$$M = \frac{1}{1.1284 I \cdot A \cdot G} \quad (m^2 \cdot {}^\circ C / W \cdot Amp \cdot \Omega) \qquad (18)$$

And *C* is:

$$C = \frac{e_1}{1.1284 I \cdot A \cdot G} \quad (\sqrt{s}/V) \qquad (19)$$

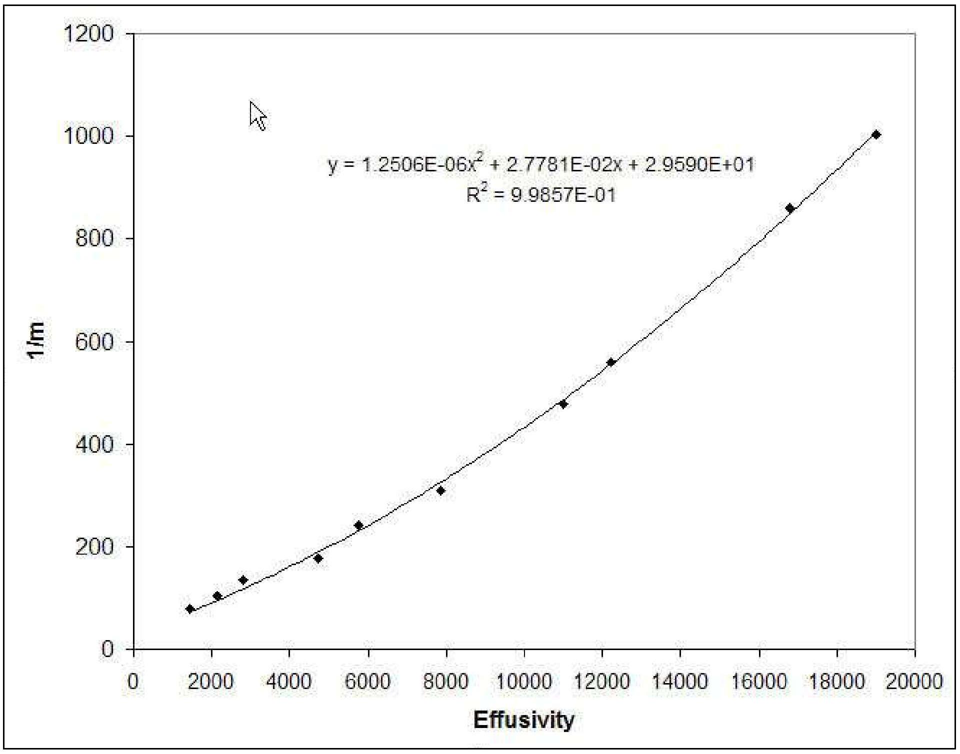
C is the *1/m* value for vacuum.

$$\frac{C}{M} = e_1 \qquad (W\sqrt{s}/m^2\,{}^\circ C) \qquad (20)$$

e_1, sensor effusivity can be calculated from (20).

In practice, for high effusivity (high k) materials equation (13) is inaccurate, because the heat flows also laterally and the one- dimensional heat flow assumption is no longer satisfied. Equations (13), (14) and (15) are only approximate.

A better representation of this case can be achieved by a second order polynomial approximation. Example of sensor effusivity calibration curve using metals is given below.



This curve can be mathematically described (instead of (17)) as:

$$\frac{1}{m} = M_2 \cdot e_2{}^2 + M_1 \cdot e_2 + C \qquad (21)$$

Where M_2 and M_1 describe the curve of the effusivity calibration and are proportional to:

$$M_1 \propto \frac{1}{I \cdot A \cdot G} \qquad (m^2 \cdot {}^\circ C / W \cdot Amp \cdot \Omega) \qquad (22)$$

And C is the same expression as in (17), i.e. *1/m* value for vacuum.

Equation (21) is deducted empirically.

Note: to minimize *C* one needs to minimize sensor effusivity. This is an important conclusion for the error analysis below.

To calculate the effusivity of the measured materials we solve the polynomial equation (21) for e_2:

$$e_2 = \pm\sqrt{\frac{1/m}{M_2} + \frac{M_1{}^2}{4M_2{}^2} - \frac{C}{M_2}} - \frac{M_1}{2M_2} \qquad (23)$$

Where *1/m* is the inverse of the voltage versus √t slope measured for this material, and M_1, M_2 & *C* are the curve coefficients and intercept of the effusivity calibration curve for that sensor. Use + if $M_2>0$, use – if $M_2<0$. If $M_2 = 0$ then the equation (17) applies.

Software cal parameters: M_2; M_1; *C*. $C=C(T)$ and is further broken down to C_0, C_1 and C_2 as a function of temperature, see below. Also note that *C* will be different at different power levels.

Range of typical on sensor power). $M_1 = 0.03 – 0.06$ ($m^2 \cdot °C / W \cdot Amp \cdot \Omega$) for the TCi sensor (depends

$C = 25 – 60$ ($\sqrt{s}/V$) (depends on temperature and sensor power).

8.2 Material groups and power levels

The wide range of effusivity and *k* requires grouping of materials with similar behavior and effusivity/k range, and operation of the TCi sensor at different power levels. Each group of materials has its own calibration curve, which is of course affected by the power level.

The table below summarizes the material groups and their attributes.

Material group	Eff range W√s/m²K	k range W/mk	Temp. range, °C	Minimum Thickness	Power level	Comments
Liquids & powders • Vacuum • PDMS* • Water gel	0-1660	0-0.6	0≤T≤100	1 mm	Low	No contact agent
Foams • 2704 • 2706 • 2710 • 2720*	50-200	0.04-0.09	0≤T≤ 60	2 mm	Low	No contact agent
Composites & ceramics • Lexan • Pyrex • Steatite • Pyroceram*	500-3,000	0.2-4.0	-20≤T≤200	5 mm	Low	
Metals • Titanium • SS • Sapphire • Phosphor bronze* • Brass	4,500-19,000	6-110	-20≤T≤200	5-12 mm	High	

Notes:

1. *** means reference material for that group.**
2. **Low power, 90 mA.**
3. **High power, 125 mA.**
4. **All groups use start time 0.3s and stop time 0.8s.**

8.3 Contact agent

The TCi sensor has a solid and hard surface. When measuring solids, there will always be some contact resistance, which may significantly affect the results. The quality of heat transfer depends on many parameters such as type of material, surface quality, etc.

To overcome this problem we use a contact agent (CA). The best CA available is water, since it has relatively high thermal conductivity (~0.6 W/mK), low viscosity, and is easy to apply and clean. Water can be used in a limited temperature range though, from ~5°C to ~70°C. Calibrations of solids (except foams) are all done with water.

At temperatures lower than 5°C and higher than 70°C a different CA is needed. Any such material will have a lower thermal conductivity than water. And since calibrations are done only at room temperature with water (and automatically corrected at other temperatures), there is a need to correct for the contact resistance. This correction factor (CF) may be constant over the entire range of materials, or may have a simple relationship with regard to the measured *1/m*.

For example, *CF=a*(1/m)+b*. If a=1.1 and b=0.3, and the measured *1/m*=100, then the corrected *1/m* to be used for the calculation of effusivity and *k* would be 110.3 (*1/m* is automatically corrected by software).

Presently, 2 CAs other than water are used, glycol for low temperature (down to -20°C) and glycerin for high temperature (up to +150°C). Hopefully, in future only one CA would be specified for the complete temperature range, thus no CF would be needed.

Correction factors for low temperature (<5°C):

Group	Contact Agent	Correction Factor, CF
Ceramics and Composites	Glycol	a=+1.02, b=0 (+2% flat)
Metals	Glycol	a=+1.05, b=0 (+5% flat)

Correction factors for high temperature (>70°C):

Group	Contact Agent	Correction Factor, CF
Ceramics and Composites	Glycerin	a=+1.0, b=0 (+0% flat)
Metals	Glycerin	a=+1.06, b=0 (+6% flat)

Note: foams and liquids do not need a CA, and therefore no CF.

8.4 Thermal Conductivity (*k*) Calibration

Calibration and measurements of *k* are based on same data acquired for effusivity. The same separation into material groups and power levels, and contact agents apply for *k* as well.

The algorithm to calibrate and calculate *k* is the *m**, which is outlined in US Patent 6,676,287 B1. It uses an iterative process to calibrate the sensor against measured materials with known thermal conductivity. The calibration process generates a value called m*, such that:

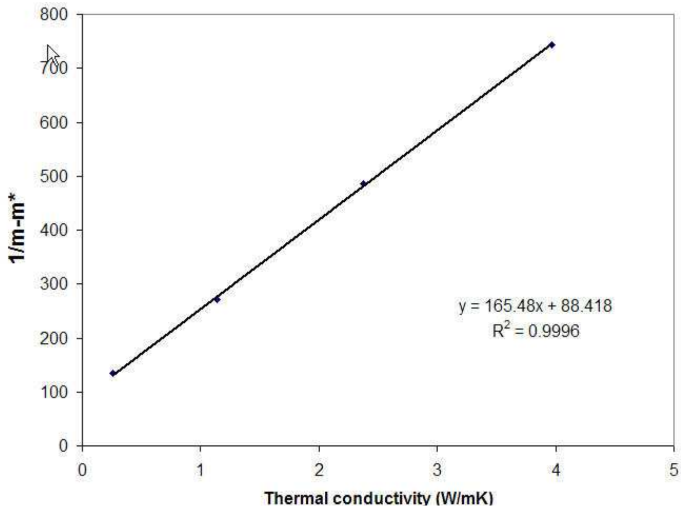
A typical *k* calibration has this form:

$$\frac{1}{m-m^*} = Slope \cdot k + Intercept \qquad (24)$$

m^* is found by an iterative process during calibration. To calculate *k* use:

$$k = \frac{\frac{1}{m-m^*} - Intercept}{Slope} \qquad (25)$$

Each group of materials has a different *k* calibration for room temperature. With automatic power correction and *C(T)* correction (see below), this calibration can be also used for different temperatures. The CA correction factor is used for *k* calculations as well. The calibration curves for *k* are all linear. Example is given below.



<u>Limitation</u>

The method for measuring *k* requires different calibration curves for materials with dissimilar thermo physical properties. For instance, it is necessary to calibrate solids and liquids separately, and use the applicable calibration when measuring a certain material. Measuring a liquid with a calibration made for solids, or vice versa, will generate a wrong result. Additionally, certain materials may exhibit an anomaly relative to others. Those materials normally have different effusivity to conductivity ratio than the materials used for calibration. For instance, carbon has high conductivity like high *k* metals, but its volumetric heat capacity is much smaller than metals with similar thermal conductivity.

8.5 Temperature Considerations in Effusivity Calibration

As seen above, M_2, M_1 and C are required for effusivity calibration at a given set of conditions. How do these parameters change in temperature?

Equation (22) suggests that M_2 and M_1 will remain constant in temperature as long as the denominator is constant. Since

$$G = \frac{I^2 R}{SensorArea} \qquad (26)$$

It turns that

$$M_1 \propto \frac{SensorArea}{I \cdot A \cdot I^2 R} = \frac{SensorArea}{A \cdot (I^3 \cdot R)} \qquad (27)$$

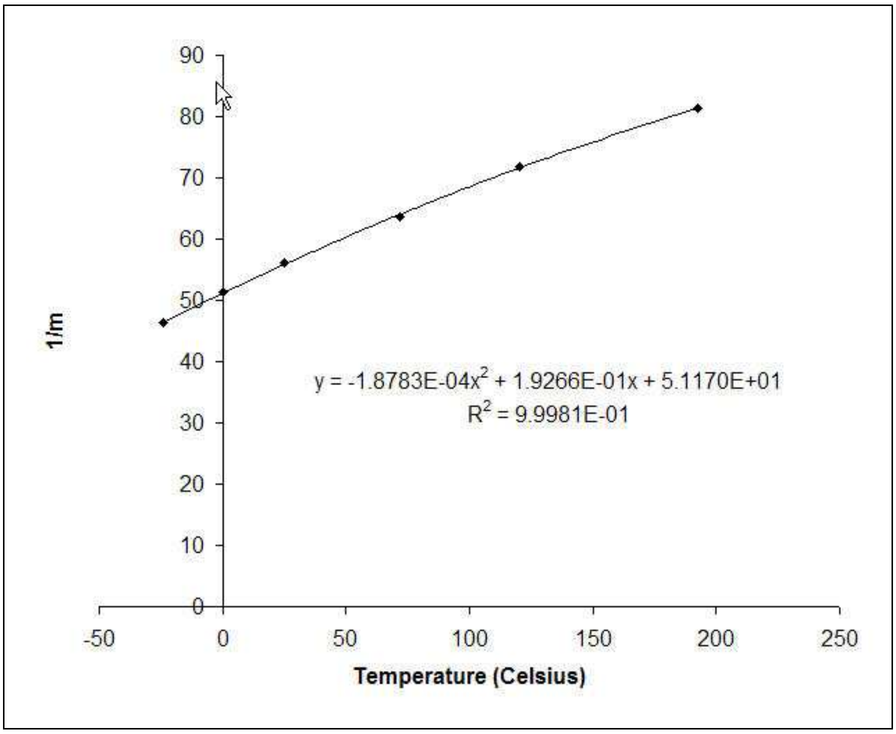
The *SensorArea* and *A* are constant in the temperature range of interest. Therefore, if the product $(I^3 R)$ is kept constant, M_2 and M_1 will remain constant over the whole temperature range.

The same analysis applies also to *C*, since *C* has the same denominator in equation (19). The sensor equivalent effusivity, e_1, may change with temperature though, as it depends on the sensor materials and construction. Experiments show that *C* can be approximated by a 2nd order polynomial in a wide range of temperature. The function *C(T)* is deducted empirically.

$$C = C_0 + C_1 \cdot T + C_2 \cdot T^2 \qquad (28)$$

Note: *C(T)* and its 3 coefficients are different at different power levels. This entails that *C(T)* has to be measured at all power levels used.

The figure below shows this relationship of one of the TCi sensors measured between -30°C and +200°C in vacuum.



Conclusions:

1. The parameters M_2 and M_1 of the effusivity calibration of the sensor over temperature range are constant as long as the current supplied to the sensor may be corrected to compensate for change in its resistance, such that (I^3R) remains constant. It is enough to measure M_2 and M_1 at one temperature only.
2. The intercept *C* grows monotonously with rising temperature and needs to be measured at a few temperature points to determine its equation (3 parameters).

8.6 Temperature considerations in k *calibration*

In conductivity calibration, because the Intercept is determined by the iteration process, it does not always have a real meaning except for the mathematical purpose. The correction of the sensor changing effusivity in temperature cannot be done on the Intercept, as it is done for effusivity.

One way of doing that is to correct *1/m* with the *C(T)* data. Suppose the *k* calibration is done at 25°C. At any other temperature T, C_T=C(T). Let's define:

$$\Delta C = C_T - C_{25}$$

ΔC may be positive (T>25°C) or negative (T<25°C). And m_{25} and m_T are the measured slopes of the material under test at 25°C and T°C, respectively.

To calculate *k* use:

$$k = \frac{\frac{1}{m^{'} - m^{*}} - Intercept}{Slope}$$ in *W/mK*

Where

$$m' = \frac{1}{1/m_T - \Delta C}$$ in *V/√s*

Is the corrected slope for temperature T.

For example, suppose a material under test has $1/m_{25}$=150 *√s/V* and $1/m_{70}$=160 *√s/V*, and the *k* calibration has these parameters: *Slope*=100 *√smK/WV*, *Intercept*=90 *√s/V* and m^*=0.0015 *V/√s*.

Calculation of *k* at 25°C is:

$$k_{25} = \frac{\frac{1}{m - m^{*}} - Intercept}{Slope} = \frac{\frac{1}{1/150 - 0.0015} - 90}{100} = \frac{\frac{1}{0.005166} - 90}{100} = \frac{193.55 - 90}{100} = 1.035$$

W/mK.

Calculation of *k* at 70°C is:

From the *1/m* Vs. temperature graph above, C_{25}=32 and C_{70}=36. Hence ΔC=+4 *√s/V*.

$$m' = \frac{1}{1/m_T - \Delta C} = \frac{1}{1/m_{70} - \Delta C} = \frac{1}{160 - 4} = \frac{1}{156}$$

$$k_{70} = \frac{\frac{1}{m^{'} - m^{*}} - Intercept}{Slope} = \frac{\frac{1}{1/156 - 0.0015} - 90}{100} = \frac{\frac{1}{0.0049} - 90}{100} = \frac{203.65 - 90}{100} = 1.136$$

W/mK.

Without correction the calculated *k* would be:

$$k_{70} = \frac{\frac{1}{m - m^{*}} - Intercept}{Slope} = \frac{\frac{1}{1/160 - 0.0015} - 90}{100} = \frac{\frac{1}{0.00475} - 90}{100} = \frac{210.52 - 90}{100} = 1.20$$

W/mK.

Notes:

1. **For *k* calculation, the *C(T)* must correspond to the applicable power level.**
2. **This correction is most effective for low *k* materials**

8.7 Error analysis

8.7.1 General

There are in general 2 types of errors (sometimes called uncertainty) – offset and variation. Offset errors affect the accuracy of the measurement while the variation affects the repeatability.

Errors in effusivity and conductivity measurements have four significant sources: variations in the tested material, quality of contact between sensor and tested material, errors from equipment and errors from calibration (offset only).

8.7.2 Material

Variations in tested material will change the heat transfer characteristics. A good example is humidity content in powders. Water has much higher effusivity than most powders, and therefore change in humidity content will drastically change the measured effusivity and conductivity. Another example is material variation due to ambient temperature. Material variation is not treated as a measurement error, but rather as the measured characteristic. The user should be attentive to material variations when considering measured results.

8.7.3 Contact

The quality of contact between the sensor surface and the tested material is critical to having accurate and repeatable measurements. Powders, liquids and creams usually create a good contact with the sensor, but it is not always the case with solids.

As indicated earlier, all solids (except for foams) require a contact agent. Water is a good material and is used between 5°C and 70°C. It normally would create a uniform thin layer, and given its relative high conductivity, its contribution to variation will be small. The user must be careful to avoid any air bubbles, as those affect the heat transfer between the sensor and tested material.

Contact agents other than water may vary more, and some errors in the range of a few percentage points may be expected, specifically at low temperature where the viscosity increases. The software corrects for the contact quality of the recommended contact agents (mentioned earlier as CF) whenever they are used.

Note: the surface of the tested material must be smooth. Rough surface finish will create an affective thick layer of contact agent, and will add to the total error budget.

8.7.4 Equipment

Equipment errors may originate from variations in the current source due to changes in environment temperature, short term and long term drifts, change in sensor resistance (and hence supplied power) during the transient measurement and change in sensor resistance (and hence supplied power) due to initial sensor temperature. Additional errors may come from the voltage measurement circuitry.

To evaluate the error from the change in sensor resistance during a transient, assume a ~1 degree Celsius change in sensor temperature (~1.0 s transient) for the range of materials used with the system. The platinum wire of the sensor has a TCR of 0.0037 °C^{-1}. During the transient, the sensor resistance changes 0.37%, and the power supplied to the sensor changes by the same amount. However, since the calibration of the sensor is performed in exactly the same manner as the measurement of the tested material, this error is calibrated out for most practical cases, leaving a very small residual error of less than 0.1%.

As mentioned earlier, the power supplied to the sensor is automatically corrected at the beginning of each sampling, to the extent of the precision of the current source. Additionally, offset errors due to the effusivity of the sensor are corrected to a large extent, though at low and high temperatures there will be larger offset error than at room temperature, where calibration is done. The estimated error contribution may be a few additional percentage points at temperatures below 0°C and above 50°C.

8.7.5 **Calibration**

The TCi calibration curves are based on various sets of materials, which were tested for conductivity and volumetric heat capacity by other methods and equipment. The measured values of those materials are used for the TCi calibration curves. Since these values may have accuracy errors of a few percentage points, these errors are naturally transferred to the TCi sensor.

The overall accuracy of the TCi is estimated at 5% between 0°C and 50°C, and up to 10% above or below that temperature range. The variation is typically 1-2% (%RSD calculated from at least 10 consecutive samples, at 0°C to 50°C).

The following mathematical analysis refers to variation in effusivity measurements, inflicted by variation of the current between different measurements in any given set of measurements. The analysis is limited to those cases where the calibration is linear, but intuitively it also applies to 2nd order effusivity equations.

It is assumed that the sensor and tested material are in equilibrium and at the same temperature at the beginning of the set of measurements, and thus the sensor resistance, *R*, is identical for all measurements. It is further assumed that effusivities of sensor and measured material don't change during the measurement.

From (14) $m = \dfrac{1.1284 I \cdot A \cdot G}{e_1 + e_2}$ we can write the variance in *m* as:

$$\Delta m = \frac{1.1284 A \cdot (I \cdot \Delta G + G \cdot \Delta I)}{e_1 + e_2} \qquad (32)$$

And the relative variance as:

$$\frac{\Delta m}{m} = \frac{\dfrac{1.1284 A \cdot (I \cdot \Delta G + G \cdot \Delta I)}{e_1 + e_2}}{\dfrac{1.1284 I \cdot A \cdot G}{e_1 + e_2}} = \frac{I \cdot \Delta G + G \cdot \Delta I}{I \cdot G} = \frac{\Delta G}{G} + \frac{\Delta I}{I} \qquad (33)$$

Since *G* is proportional to I^2 (*R* is assumed constant from one measurement to another):

$$\frac{\Delta m}{m} = \frac{3\Delta I}{I} \qquad (34)$$

The relative variance in slope *m* ideally is triple the relative variance in current *I*. Intuitively this is understood, since a stable current source will provide stable voltage measurements.

Note: equation (34) ignores second order errors.

It is generally known that:

$$\left|\Delta(\frac{1}{m})\right| = \left|(\frac{1}{m^2})\cdot\Delta m\right| \tag{35}$$

And therefore:

$$\frac{\Delta(1/m)}{1/m} = \frac{\Delta m}{m} \tag{36}$$

The relative variance in *1/m* is the same as the relative variance in *m*.
From (17) we can calculate the variance in e_2 as (*C* is assumed constant for the set of measurements):

$$\Delta e_2 = \frac{\Delta(1/m)}{M} \tag{37}$$

And the relative variance as:

$$\frac{\Delta e_2}{e_2} = \frac{\Delta(1/m)}{M} \Big/ \left(\frac{1/m - C}{M}\right) = \frac{\Delta(1/m)}{1/m - C} \tag{38}$$

If *C* =0, i.e. sensor effusivity is 0, then:

$$\frac{\Delta e_2}{e_2} = \frac{\Delta(1/m)}{1/m} = \frac{\Delta m}{m} = \frac{3\Delta I}{I} \tag{39}$$

In an ideal case where the sensor effusivity is 0, the relative variance in measured effusivity is triple the relative variance of the supplied current. However, in reality *C* is always a positive number as can be seen from equation (19), and therefore the relative variance in measured effusivity is always higher than the relative variance in *m* or *1/m*.

Conclusions:

1. Lower sensor effusivity will reduce *C*, and this in turn will reduce the variance in measured effusivity. This is evident from equation (38).
2. Low effusivity materials will produce higher *m* and lower *1/m* than high effusivity materials. Therefore, the relative variance of measured effusivity is expected to be higher for low effusivity materials.

The first conclusion proposes that it is desired to design the sensor such that it has minimum effusivity. This principle is intuitively understood (in terms of sensitivity and consumed power) and in fact has been an important factor in the sensor design.

Appendices

Appendix A: System Components and Accessories

Standard Components

- TCi Control unit
- TCi Software
- TCi Sensor
- TCi Sensor base
- TCi Manual
- Laptop
- TCi weight (brass, standard 500g)
- Pyrex beaker (50mL) – for standard liquid and powder testing
- *Reference material kit (box) – LAF 6720 foam, Pyroceram, Phosphor bronze, PDMS (liquid)
- *Contact Agents (250 mL) – Glycerin, Glycol
- Power cable
- Serial cable with USB adapter

* Note that clients can order a base package with one material range and will receive the appropriate reference material and contacts agents.

Accessories

- Handle (available upon customer request
- Special Powder and liquid testing sensor (for small volumes)
- Paste (specify, size)
- Additional TCi sensor
- Travel Case (Pelican style)
- RTV test tabs and SOP – for user-based testing of chemical aggression towards the sensor RTV seal
- Upright sample testing accessory – used for larger sample placement when testing upright.

Services

- Sample testing
- Chemical aggression testing
- Special calibration services – Mathis can provide calibration ranges specific to a clients application
- Advanced training – Users with a very broad range of materials and applications are encouraged to get advanced training on the use of the TCi.
- Special application developments – Mathis' experience can be used to create new test methods for new materials or processes.
- Testing migration services – Mathis can provide consulting to migrate off-line testing to on-line processes, including on-line process control

Planned Accessories (please inquire as to the status)

- Thin Film Sensor package – allows for testing thin film materials, includes an additional sensor, fixturing and reference material(s)
- User calibration software module – Allows advanced, trained users the ability to create/modify some calibration parameters

Thermal chamber integrated control package – Mathis will be offering a turn-key control package for their recommended Tenney thermal chamber, which can also be modified for use with other thermal chambers. This system will allow one sample to be auto tested through a series of temperatures in a hands-free manner.

Appendix B: TCi System Specifications

Overview:

The TCi is a state of the art thermal property characterization instrument based on the modified hot wire technique. The TCi sensor is optimally engineered for the testing of liquids and powders, but can also test solid materials. The system enables testing of a wide range of thermally conductive materials, ranging from foams to metals. Some of the points of difference that differentiate the TCi from other thermo-physical testing technologies are its rapid, non-destructive test method, greater ease-of-use and the overall sample flexibility it offers users.

Construction:

- TCi system consists of PC (or laptop), Controller assembly, sensor(s) and software
- Tests solids, pastes, liquids and powders
- Number of sensors: 1 or 2 (optional)

Performance:

- Thermal conductivity range: 0-100 W/mK
- Effusivity range: 0-19,000 W√s/m^{2}k
- Accuracy, typically:
  - 5% for 0°C to 50°C
  - 10% for -20°C to 0°C and 50°C to 200°C
- Precision, typically:
  - 1.0%[1] RSD for 0°C to 50°C
  - 1.5% RSD for -20°C to 0°C and 50°C to 200°C
- Cooling time: 60 sec typically

Environmental – Operating:

- Operating temperature:
  - o Controller +15°C to +28°C
  - o Sensor -20°C to 200°C
- Relative humidity: 90% non-condensing

Environmental – Non-operating:

- Storage: temperature –40°C to +70°C, relative humidity up to 95% non-condensing
- Temperature shock: -20 °C to +30 °C
- Mechanical shock: typical transportation

Calibration:

- Sensor is factory calibrated. No user calibration required.
- Calibration data is verified prior to sensor operation.

Input power:

- 110-230 VAC 50-60Hz

Certifications:

- FCC
- CE
- CSA

Reliability:

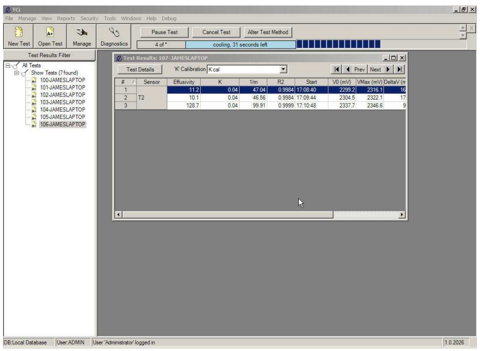
- MTBF (mean time between failures) ≥ 4,000 hours
- Extensive BIT procedure (built-in testing)
- System assemblies are interchangeable and field replaceable.

Safety and failure protection:

- Sensor and tested material protected against temperature rise of more than 10°C
- Maximum voltage drop on sensor is 5 VDC
- Auto shutdown procedure

User Interface Software:

- Windows® based software interface
- Full relational database with import/export capabilities
- Easy export to Excel
- Fully configurable test methods
- Multiple graphical and tabular display options
- Provides direct, indirect (calculated) and user input capabilities for a number of thermal physical properties including:
  - Thermal Effusivity (direct)
  - Thermal Conductivity (indirect)
  - Thermal Diffusivity (indirect/ input)
  - Heat Capacity (indirect/input)
  - Density (indirect/input)



[1] Precision is defined as the %RSD of a test of 10 consecutive measurements

TCi Sensor Specifications

Overview:

The TCi is a state of the art thermal property characterization instrument based on the modified hot wire technique. The TCi sensor is optimally engineered for the testing of liquids and powders, but can also test solid materials. The system enables testing of a wide range of thermally conductive materials, ranging from foams to metals. Some of the points of difference that differentiate the TCi from other thermo-physical testing technologies are its rapid, non-destructive test method, greater ease-of-use and the overall sample flexibility it offers users.

Construction:

- Sealed against dust and liquids by an RTV (silicone based) sealant between Torlon™housing and sensor chip.
- Housing is made of Torlon
- Chip surface is made of alumina (96% aluminum oxide) with a thin sealing glass layer (DuPont P/N 5415A, screen printable, laser trimmable, airfired G1 glass encapsulant)

Cleaning and Compatibility:

- Immune to cleaning agents such as detergents and isopropyl alcohol.
- Compatible with acidic liquids
- For full material compatibility and cleaning procedure see operating manual

Performance:

- Thermal conductivity range: 0-100 W/mK
- Effusivity range: 0 – 19,000 W√s/m^2k
- Accuracy, typically:
  - o 5% for 0°C to 50°C
  - o 10% for –20℃ to 0℃ and 50℃ to 200℃.
- Precision, typically:
  - o 1.0%[2] for 0°C to 50°C
  - o 1.5% RSD for -20℃ to 0℃ and 50℃ to 200℃.
- Cooling time: 60 sec typically

Environmental – Operating:

- Operating Temperature Sensor head: -20°C to +200°C
- Relative humidity: up to 95% non-condensing
- External pressure: up to 1 atm (14.7 PSIG)
- External low pressure or vacuum

Certifications:

- FCC
- CE
- CSA

Environmental – Non-operating:

- Storage: temperature up to 70°C, relative humidity up to 95% non-condensing
- Temperature shock: -20°C to +30°C
- Mechanical shock: typical transportation

Calibration:

- Sensor is factory calibrated. Calibration data is stored in the database.
- Calibration data is verified prior to sensor operation.
- Sensors are interchangeable and field replaceable.

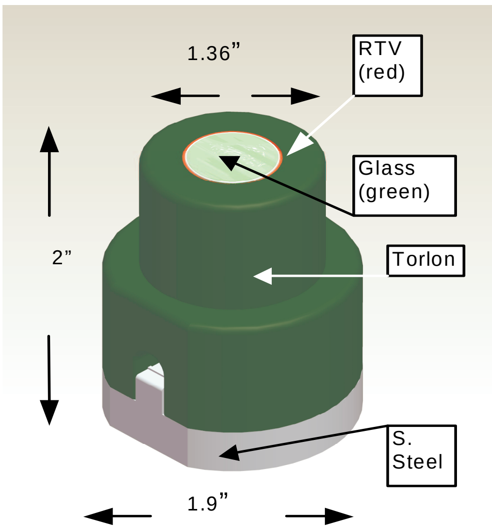
Reliability:

- Mean time between failures (MTBF) ≥ 10,000 hours for a typical operation profile.

- **Safety and failure protection:**
- Material under evaluation will not experience a surface temperature rise during a test of more than 10°C (typically 0.2°C to 2.0°C).
- Maximum voltage drop on sensor is 5V DC.

Customization:

- Sensor housing can be customized on request.



[2] Precision is defined as the %RSD of a test of 10 consecutive measurements.

Appendix C: Chemical Resistance Data

If there is uncertainty as to the safety of using a chemical with the TCi sensor, test the chemical with a tab of RTV before using it with the sensor. RTV is the weakest part of the sensor's construction and will likely react most strongly to any chemical. Place a tab in a beaker and cover the tab with the chemical. Leave the tab for several hours or overnight. If the tab is unaffected by the chemical, it should be safe to use with the sensor.

There are two types of TCi sensor – sensors with Torlon shells and sensors with full stainless steel shells. The sensors with Torlon shells are have different chemical resistance than sensors with stainless steel shells.

The following chemicals are safe to use with the Stainless Steel TCi sensors:

Acetaldehyde
Acetamide
Acetic Acid, 80%
Acetic Acid, Glacial
Acetone
Acetylene
Alconox
Aluminum Chloride
Aluminum Nitrate
Aluminum Potassium Sulfate, 10%
Aluminum Potassium Sulfate, 100%
Aluminum Sulfate
Alums
Amines
Ammonia, 10%
Ammonia Nitrate
Ammonium Hydroxide
Ammonium Nitrate
Ammonium Phosphate, Monobasic
Ammonium Phosphate, Tribasic
Ammonium Sulfate
Aniline
Arochlor 1248
Arsenic Acid
Avicel Microcrystalline Cellulose
Barium Chloride
Barium Hydroxide
Barium Nitrate
Barium Sulfate
Barium Sulfide
Beer
Beet Sugar Liquids
Benzoic Acid
Bleach
Body Wash
Borax
Boric Acid
Brine
Butanol (Butyl Alcohol)
Butter
Buttermilk
Butyl Amine
Butyl Phthalate
Calcium Bisulfite
Calcium Carbonate
Calcium Chloride
Calcium Hydroxide
Calcium Hypochlorite
Calcium Nitrate
Calcium Oxide
Calgon
Carbon Monoxide
Carbon Dioxide (dry)
Carbon Dioxide (wet)
Carbonated Water
Carbonic Acid
Castor Oil
Cider
Citric Acid
Clorox (Bleach)
Coconut Oil
Cod Liver Oil
Coffee
Cold Cream
Copper Cyanide
Copper Sulfate 5%
Copper Sulfate >5%
Corn Oil
Cottonseed Oil
Cough Syrup
Cupric Acid
Cyanic Acid
Detergents
Detergents, Laundry
Diethylamine
Diethylene Glycol
Dow 200
Dowtherm SR-1
Ethanolamine
Ethyl Acetate
Ethylene Diamine
Epsom Salts (Magnesium Sulfate)
Ethanol
Ethylene Glycol
Ferric Sulfate
Formaldehyde 100%
Formic Acid
Gelatin
Glucose
Glue, P.V.A.
Glycerin
Glycolic Acid
Grape Juice
Hair Mousse
Hexanol
Honey
Hydraulic Oil (Petro)
Hydraulic Oil (Synthetic)
Hydrazine
Hydrogen Peroxide, 10%
Hydrogen Peroxide, 30%
Hydrogen Peroxide 50%
Hydrogen Peroxide 100%
Isopropanol
Lactic Acid

Lard
Latex
Lead Acetate
Lead Nitrate
Liquinox
Linoleic Acid
Linseed Oil
Lithium Chloride
Lye: Sodium Hydroxide
Lye: Calcium Hydroxide
Magnesium Hydroxide
Magnesium Sulfate (Epsom salts)
Malic Acid
Methanol (Methyl Alcohol)
Methyl Alcohol, 10%
Milk
Mineral Oils
Monoethanolamine
Mustard
Natural Gas
Nickel Sulfate
Octanol
Oxalic Acid (cold)
Ozone
Oil, Engine
Peanut Oils
Photographic Developer
Phthalic Acid
Polydimethylsiloxane
Potassium Bicarbonate
Potassium Bromide
Potassium Chlorate
Potassium Chloride
Potassium Cyanide Solutions
Potassium Dichromate
Potassium Nitrate
Potassium Sulfate
Potassium Sulfide
Propanol
Propylene Glycol
Rosins
Rum
Salt Brine (NaCl saturated)
Sea Water
Shampoo
Shampoo, Dandruff
Shaving Cream
Silica Gel
Silicone
Silicone Oil
Silicone Grease
Silver Nitrate
Soap Solutions
Sodium Bicarbonate
Sodium Bisulfite
Sodium Borate (Borax)
Sodium Carbonate (Soda Ash)
Sodium Chloride
Sodium Cyanide
Sodium Hydroxide, 10%
Sodium Metaphosphate
Sodium Perborate
Sodium Silicate
Sodium Sulfate
Sodium Sulfite
Sodium Tetraborate
Sodium Thiosulfate (hypo)
Soybean Oil
Stannous Chloride
Starch
Stearic Acid
Sugar
Sugar (liquids)
Sulphate (liquors)
Sulfur
Sulphur Dioxide
Sulphur Dioxide (dry)
Sulphur Trioxide (dry)
Tanic Acid
Tanning Liquors
Toothpaste
Transformer Oil
Trisodium Phosphate
Urea
Vegetable Juice
Vinegar
Water, Acid, Mine
Water, Distilled
Water, Fresh
Water, Salt
Weed Killers
Whiskey and Wines
White Liquor (Pulp Mill)
Zinc Chloride
Zinc Sulfate

The following chemicals are not safe to use with Stainless Steel shell TCi Sensors (Chemicals considered unsafe due to lack of information on one or more components are marked with *):

Acetate Solvent
Acetic Acid
Acetic Anhydride
Acetophenone
Acetyl Chloride (dry)
Acrylonitrile
Aluminum Chloride, 20%
Aluminum Fluoride
Aluminum Hydroxide
Ammonia, Anhydrous
Ammonia, Liquid*
Ammonium Carbonate
Ammonium Chloride
Ammonium Persulfate
Ammonium Phosphate, Dibasic
Amyl Acetate
Amyl Alcohol
Amyl Chloride
Anderol L-774
Aniline Oil
Aniline Hydrochloride
Ansul Ether
Antifreeze
Antimony Trichloride
Aqua Regia (80% HCl, 20% HNO_3)
Aromatic Hydrocarbons
Askarel
Asphalt
ASTM #1*
ASTM #3
ASTM Fuel A
ASTM Fuel B
ASTM Fuel C
ASTM Fuel D
Auto Transmission Fluid
Barium Carbonate
Barium Cyanide*
Benzaldehyde
Benzene
Benzene Sulfonic Acid
Benzine
Benzol
Benzophenone
Brake Fluid (Non-petroleum)*
Bromine
Bromobenzene

Bunker Oil
Butadiene
Butane
Butyl Carbitol
Butyl Ether
Butylacetate
Butylaldehyde
Butylene
Butyric acid
Calcium Bisulfate
Calcium Bisulfide
Calcium Sulfate
Carbitol*
Carbitol Acetate
Carbolic Acid (Phenol)
Carbon Bisulfide
Carbon Disulfide
Carbon Tetrachloride
Cellosolve
Chassis Grease
Chlordane
Chlorine Water
Chlorine, Anhydrous Liquid
Chlorine (dry)
Chloroacetic Acid
Chloroacetone
Chlorobenzene (Mono)
Chlorobenzol
Chlorobromomethane
Chloroform
Chlorosulfonic Acid
Chrome Plating Solution*
Chromic Acid 55
Chromic Acid 10%
Chromic Acid 30%
Chromic Acid 50%
Copper Chloride
Copper Nitrate
Cream*
Creosote
Creosote Oil
Cresols
Cresylic Acid
Crude Oil
Cyclohexane
Cyclohexanol
Cyclohexanone
Decalin
Denatured Alcohol*
Diacetone
Diacetone Alcohol
Dibutyl Amine
Dichloro Aniline
Dichlorobenzene
Dichloro Butane
Dichloroethane
Diethyl Ether
Diesel Fuel
Dimethyl aniline
Dimethyl Ether
Dimethyl Formaldehyde
Dimethyl Formamide*
Dimethyl Terephthalate
Dioctyl Phthalate
Dioxane
Diphenyl
Diphenyl Oxide
Dow Corning 550*
Dow Gard*
Dowtherm A & E
Elco 28*
Ethane
Ether
Ethyl Benzene
Ethyl Benzoate
Ethyl Cellulose*
Ethyl Chloride
Ethyl Ether
Ethyl Merlaptan
Ethylene Bromide
Ethylene Chloride
Ethylene Chlorohydrin
Ethylene Dichloride
Ethylene Oxide
Fatty Acids
Ferric Chloride
Ferric Nitrate
Ferrous Chloride
Ferrous Sulphate
Fluoboric Acid
Fluorine
Fluosilicic Acid
Formaldehyde 40%
Freon® 11
Freon 12
Freon 22
Freon 113
Freon TF
Fuel Oils
Furan resin
Furfural
Furfuryl Alcohol
Fyrquel*
Gallic Acid
Gasoline (high Aromatic)
Gasoline, leaded, ref.
Gasoline, unleaded
Grease
Heptane
Hexaldehyde*
Hexane
Home Heating Oil*
Hydrobromic Acid 20%
Hydrobromic Acid 100%
Hydrochloric Acid 20%
Hydrochloric Acid 37%
Hydrochloric Acid 100%
Hydrochloric Acid, Dry Gas
Hydrocyanic Acid
Hydrocyanic Acid (Gas 10%)
Hydrofluoric Acid 20%
Hydrofluoric Acid 50%
Hydrofluoric Acid 75%
Hydrofluoric Acid 100%
Hydrofluosilicic Acid 20%
Hydrofluosilicic Acid 100%
Hydrogen Gas
Hydrogen Sulfide (aqua)
Hydrogen Sulfide (dry)
Hypoid Gear Lube
Ink
Iodine
Isooctane
Iso Phorone
Isopar
Isopropyl Acetate
Isopropyl Ether
Jet Fuel (JP3, JP4, JP5)
Kerosene
Ketones
Lacquer Thinner
Lacquer
Lead Sulfamate
Ligroin
Lime*
Lubricants
Lye: Potassium Hydroxide
Magnesium Carbonate*
Magnesium Chloride
Magnesium Nitrate*
Malathion
Maleic Acid
Manganese Sulphate
Melamine
Mercuric Chloride (dilute)
Mercuric Cyanide
Mercury*
Meter-Cresol
Methacrylic Acid

Methane
Methyl Acetate
Methyl Acetone*
Methyl Acrylate
Methyl Bromide*
Methyl Butyl Ketone
Methyl Cellosolve
Methyl Chloride
Methyl Ethyl Ketone
Methyl Ethyl Ketone Peroxide
Methyl Isobutyl Ketone
Methyl Isopropyl Ketone
Methyl Methacrylate
Methylamine*
Methylene Chloride
Mineral Spirits
Molasses*
Monovinyl Acetylene*
Naphtha
Naphthalene
Naphthenic Acid
Neatsfoot Oil*
Nickel Chloride
Nitrating Acid <15%
Nitric Acid 5-10%
Nitric Acid 20%
Nitric Acid 50%
Nitric Acid Concentrated
Nitrobenzene
Nitromethane
Nitropropane
Nitrous Acid*
Octane
Oleic Acid
Oleum 25%
Oleum 100%
Olive Oils
Orange Oils
Oronite 8200
Palmitic Acid
Paraffin*
Pentane
Perchloric Acid
Perchloroethylene
Petrolatum
Petroleum
Petroleum Ether
Phenol 10%
Phenol (Carbolic Acid)
Phosphoric Acid (crude)
Phosphoric Acid >40%
Phosphoric Acid <40%
Photographic Solutions*
Phthalic Anhydride*
Picric Acid
Pine Oil
Potash (Potassium Carbonate)*
Potassium Chromate
Potassium Ferrocyanide
Potassium Hydroxide (Caustic Potash)
Potassium Permanganate
Propane (liquefied)
Propyl Acetate
Propylene
Pydraul
Pyranol
Pyridine
Pyrogallic Acid
Rapeseed Oil
SAE10W30*
Salad Dressings
Salt (Sodium Chloride)
Shellac (Bleached)*
Shellac (Orange)*
Skydrol
Skydrol 500
Sodium Acetate
Sodium Bisulfate
Sodium Chlorate
Sodium Chromate
Sodium Fluoride
Sodium Hydrosulfite
Sodium Hydroxide 50%
Sodium Hydroxide 80%
Sodium Hypochlorite <20%
Sodium Hypochlorite 100%
Sodium Metasilicate*
Sodium Nitrate
Sodium Peroxide
Sodium Polyphosphate
Sodium Sulfide
Sorghum*
Sovasol
Stannic Chloride
Stoddard Solvent
Styrene
Sulphur Chloride
Sulphur Hexafluoride
Sulphur Trioxide
Sulphuric Acid <10%
Sulphuric Acid 10-75%
Sulphuric Acid 75-100%
Sulphuric Acid (cold Concentrated)
Sulphuric Acid (hot Concentrated)
Sulphurous Acid
Tar*
Tartaric Acid
Tetrachloroethane
Tetrachloroethylene
Tetrahydrofuran
Tetralin
Tidewater Oil*
Tin Salts
Toluene (Toluol)
Tomato Juice*
Trichloroacetic Acid
Trichloroethane
Trichloroethylene
Tricresylphosphate
Triethylamine*
Turbine Oil
Turpentine
UCDN 50HB280X*
Univis J-43
Urine*
Varnish
Vinyl Acetate
Wheat Germ Oil*
White water (Paper Mill)*
Wood Oil
Xylene
Zinc Hydrosulfite*

The following chemicals are safe to use with the Torlon Shell TCi sensors:

Acetaldehyde
Acetamide
Acetone
Acetic Acid, 80%
Alconox
Aluminum Chloride

Aluminum Sulfate
Ammonia Nitrate
Ammonium Nitrate
Ammonium Phosphate, Monobasic
Aniline
Avicel Microcrystalline Cellulose
Barium Chloride
Barium Sulfate
Barium Sulfide
Beer
Bleach
Body Wash
Brine
Butanol (Butyl Alcohol)
Butyl Amine
Butyl Phthalate
Carbonated Water
Calcium Chloride
Calcium Hypochlorite
Clorox (Bleach)
Coffee
Cold Cream
Cough Syrup
Detergents
Detergents, Laundry
Diethylamine
Dow 200
Dowtherm SR-1
Epsom Salts (Magnesium Sulfate)
Ethanol
Ethyl Acetate
Ethylene Glycol
Formaldehyde 100%
Gelatin
Glucose
Glycerin
Hair Mousse
Honey
Hydrogen Peroxide, 10%
Hydrogen Peroxide, 30%
Isopropanol
Lactic Acid
Lead Acetate
Liquinox
Magnesium Chloride
Magnesium Sulfate (Epsom salts)
Methanol (Methyl Alcohol)
Methyl Alcohol, 10%
Milk
Mineral Oils
Oil, Engine
Peanut Oils
Polydimethylsiloxane
Potassium Bicarbonate
Potassium Bromide
Potassium Chloride
Potassium Dichromate
Salt Brine (NaCl saturated)
Sea Water
Shampoo
Shaving Cream
Silica Gel
Silicone
Silicone Oil
Silicone Grease
Silver Nitrate
Soap Solutions
Sodium Bicarbonate
Sodium Bisulfite
Sodium Carbonate (Soda Ash)
Sodium Chloride
Sodium Sulfate
Starch
Sugar
Sugar (liquids)
Sulfur
Sulfur Dioxide
Sulfur Dioxide (dry)
Toothpaste
Transformer Oil
Vinegar
Water, Distilled
Water, Fresh
Water, Salt
Whiskey and Wines

The following chemicals are not safe to use with Torlon Shell TCi Sensors (Chemicals considered unsafe due to lack of information on one or more components are marked with *):

Acetate Solvent
Acetic Acid
Acetic Acid, Glacial
Acetic Anhydride
Acetophenone
Acetyl Chloride (dry)
Acetylene
Acrylonitrile
Aluminum Chloride, 20%
Aluminum Fluoride
Aluminum Hydroxide
Aluminum Nitrate
Aluminum Potassium Sulfate, 10%
Aluminum Potassium Sulfate, 100%
Alums
Amines
Ammonia, 10%
Ammonia, Anhydrous
Ammonia, Liquid*
Ammonium Carbonate
Ammonium Chloride
Ammonium Hydroxide
Ammonium Persulfate
Ammonium Phosphate, Dibasic
Ammonium Phosphate, Tribasic
Ammonium Sulfate
Amyl Acetate
Amyl Alcohol
Amyl Chloride
Anderol L-774
Aniline Oil
Aniline Hydrochloride
Ansul Ether
Antifreeze
Antimony Trichloride
Aqua Regia (80% HCl, 20% HNO_3)
Arochlor 1248
Aromatic Hydrocarbons
Arsenic Acid*
Askarel
Asphalt
ASTM #1*
ASTM #3
ASTM Fuel A
ASTM Fuel B
ASTM Fuel C
ASTM Fuel D
Auto Transmission Fluid
Barium Carbonate

Barium Cyanide*
Barium Hydroxide
Barium Nitrate
Beet Sugar Liquids*
Benzaldehyde
Benzene
Benzene Sulfonic Acid
Benzine
Benzoic Acid
Benzol
Benzophenone
Borax
Boric Acid*
Brake Fluid (Non-petroleum)*
Bromine
Bromobenzene
Bunker Oil
Butadiene
Butane
Butter
Buttermilk*
Butyl Carbitol
Butyl Ether
Butylacetate
Butylaldehyde
Butylene
Butyric acid
Calcium Bisulfate
Calcium Bisulfide
Calcium Bisulfite*
Calcium Carbonate
Calcium Hydroxide
Calcium Nitrate
Calcium Oxide*
Calcium Sulfate
Calgon*
Carbitol*
Carbitol Acetate
Carbolic Acid (Phenol)
Carbon Bisulfide
Carbon Dioxide (dry)
Carbon Dioxide (wet)
Carbon Disulfide
Carbon Monoxide*
Carbon Tetrachloride
Carbonic Acid*
Castor Oil*
Cellosolve
Chassis Grease
Chlordane
Chlorine Water
Chlorine, Anhydrous Liquid
Chlorine (dry)
Chloroacetic Acid
Chloroacetone
Chlorobenzene (Mono)
Chlorobenzol
Chlorobromomethane
Chloroform
Chlorosulfonic Acid
Chrome Plating Solution*
Chromic Acid 55
Chromic Acid 10%
Chromic Acid 30%
Chromic Acid 50%
Cider
Citric Acid*
Coconut Oil*
Cod Liver Oil
Copper Chloride
Copper Cyanide
Copper Nitrate
Copper Sulfate 5%
Copper Sulfate >5%
Corn Oil*
Cottonseed Oil*
Cream*
Creosote*
Creosote Oil
Cresols
Cresylic Acid
Crude Oil
Cupric Acid*
Cyanic Acid*
Cyclohexane
Cyclohexanol
Cyclohexanone
Decalin
Denatured Alcohol*
Diacetone
Diacetone Alcohol
Dibutyl Amine
Dichloro Aniline
Dichlorobenzene
Dichloro Butane
Dichloroethane
Diethyl Ether
Diesel Fuel
Diethylene Glycol
Dimethyl aniline
Dimethyl Ether
Dimethyl Formaldehyde
Dimethyl Formamide*
Dimethyl Terephthalate
Dioctyl Phthalate
Dioxane
Diphenyl
Diphenyl Oxide
Dow Corning 550*
Dow Gard*
Dowtherm A & E
Elco 28*
Ethane
Ethanolamine
Ether
Ethyl Benzene
Ethyl Benzoate
Ethyl Cellulose*
Ethyl Chloride
Ethyl Ether
Ethyl Merlaptan
Ethylene Bromide
Ethylene Chloride
Ethylene Chlorohydrin
Ethylene Diamine
Ethylene Dichloride
Ethylene Oxide
Fatty Acids
Ferric Chloride
Ferric Nitrate
Ferric Sulfate
Ferrous Chloride
Ferrous Sulphate
Fluoboric Acid
Fluorine
Fluosilicic Acid
Formaldehyde 40%
Formic Acid
Freon® 11
Freon 12
Freon 22
Freon 113
Freon TF
Fuel Oils
Furan resin
Furfural
Furfuryl Alcohol
Fyrquel*
Gallic Acid
Gasoline (high Aromatic)
Gasoline, leaded, ref.
Gasoline, unleaded
Glue, P.V.A.*
Glycolic Acid*
Grape Juice
Grease
Heptane
Hexaldehyde*
Hexane

Hexanol*
Home Heating Oil*
Hydraulic Oil (Petro)
Hydraulic Oil (Synthetic)
Hydrazine
Hydrobromic Acid 20%
Hydrobromic Acid 100%
Hydrochloric Acid 20%
Hydrochloric Acid 37%
Hydrochloric Acid 100%
Hydrochloric Acid, Dry Gas
Hydrocyanic Acid
Hydrocyanic Acid (Gas 10%)
Hydrofluoric Acid 20%
Hydrofluoric Acid 50%
Hydrofluoric Acid 75%
Hydrofluoric Acid 100%
Hydrofluosilicic Acid 20%
Hydrofluosilicic Acid 100%
Hydrogen Gas
Hydrogen Peroxide 50%
Hydrogen Peroxide 100%
Hydrogen Sulfide (aqua)
Hydrogen Sulfide (dry)
Hypoid Gear Lube
Ink
Iodine
Isooctane
Iso Phorone
Isopar
Isopropyl Acetate
Isopropyl Ether
Jet Fuel (JP3, JP4, JP5)
Kerosene
Ketones
Lacquer Thinner
Lacquer
Lard
Latex*
Lead Nitrate
Lead Sulfamate
Ligroin
Lime*
Linoleic Acid
Linseed Oil
Lithium Chloride*
Lubricants
Lye: Potassium Hydroxide
Lye: Sodium Hydroxide
Lye: Calcium Hydroxide
Magnesium Carbonate*
Magnesium Hydroxide
Magnesium Nitrate*
Malathion
Maleic Acid
Malic Acid
Manganese Sulfate*
Melamine
Mercuric Chloride (dilute)
Mercuric Cyanide
Mercury*
Meter-Cresol
Methacrylic Acid
Methane
Methyl Acetate
Methyl Acetone*
Methyl Acrylate
Methyl Bromide*
Methyl Butyl Ketone
Methyl Cellosolve
Methyl Chloride
Methyl Ethyl Ketone
Methyl Ethyl Ketone Peroxide
Methyl Isobutyl Ketone
Methyl Isopropyl Ketone
Methyl Methacrylate
Methylamine*
Methylene Chloride
Mineral Spirits
Molasses
Monoethanolamine
Monovinyl Acetylene*
Mustard*
Naphtha
Naphthalene
Naphthenic Acid
Natural Gas*
Neatsfoot Oil*
Nickel Chloride
Nickel Sulfate
Nitrating Acid <15%
Nitric Acid 5-10%
Nitric Acid 20%
Nitric Acid 50%
Nitric Acid Concentrated
Nitrobenzene
Nitromethane
Nitropropane
Nitrous Acid*
Octane
Octanol*
Oleic Acid
Oleum 25%
Oleum 100%
Olive Oils
Orange Oils
Oronite 8200
Oxalic Acid (cold)
Ozone
Palmitic Acid
Paraffin*
Pentane
Perchloric Acid
Perchloroethylene
Petrolatum
Petroleum
Petroleum Ether
Phenol 10%
Phenol (Carbolic Acid)
Phosphoric Acid (crude)
Phosphoric Acid >40%
Phosphoric Acid <40%'
Photographic Developer
Photographic Solutions*
Phthalic Acid
Phthalic Anhydride*
Picric Acid
Pine Oil
Potash (Potassium Carbonate)*
Potassium Chlorate
Potassium Chromate
Potassium Cyanide Solutions
Potassium Ferrocyanide
Potassium Hydroxide (Caustic Potash)
Potassium Nitrate
Potassium Permanganate
Potassium Sulfate
Potassium Sulfide*
Propane (liquefied)
Propanol*
Propyl Acetate
Propylene
Propylene Glycol
Pydraul
Pyranol
Pyridine
Pyrogallic Acid
Rapeseed Oil
Rosins*
Rum*
SAE10W30*
Salad Dressings*
Salt (Sodium Chloride)
Shampoo, Dandruff*
Shellac (Bleached)*
Shellac (Orange)*
Skydrol

Skydrol 500
Sodium Acetate
Sodium Bisulfate
Sodium Borate (Borax)
Sodium Chlorate
Sodium Chromate
Sodium Cyanide*
Sodium Fluoride
Sodium Hydrosulfite
Sodium Hydroxide, 10%
Sodium Hydroxide 50%
Sodium Hydroxide 80%
Sodium Hypochlorite <20%
Sodium Hypochlorite 100%
Sodium Metaphosphate*
Sodium Metasilicate*
Sodium Nitrate
Sodium Perborate
Sodium Peroxide
Sodium Polyphosphate
Sodium Silicate*
Sodium Sulfide
Sodium Sulfite
Sodium Tetraborate*
Sodium Thiosulfate (hypo)*
Sorghum*
Sovasol
Soybean Oil*
Stannic Chloride
Stannous Chloride
Stearic Acid
Stoddard Solvent
Styrene
Sulfate (liquors)
Sulfur Chloride
Sulfur Hexafluoride
Sulfur Trioxide
Sulfur Trioxide (dry)
Sulfuric Acid <10%
Sulfuric Acid 10-75%
Sulfuric Acid 75-100%
Sulfuric Acid (cold Concentrated)
Sulfuric Acid (hot Concentrated)
Sulfurous Acid
Tanic Acid
Tanning Liquors
Tar*
Tartaric Acid
Tetrachloroethane
Tetrachloroethylene
Tetrahydrofuran
Tetralin
Tidewater Oil*
Tin Salts
Toluene (Toluol)
Tomato Juice*
Trichloroacetic Acid
Trichloroethane
Trichloroethylene
Tricresylphosphate
Triethylamine*
Trisodium Phosphate*
Turbine Oil
Turpentine
UCDN 50HB280X*
Univis J-43
Urea
Urine*
Varnish
Vegetable Juice
Vinyl Acetate
Water, Acid, Mine
Weed Killers*
Wheat Germ Oil*
White Liquor (Pulp Mill)*
White water (Paper Mill)*
Wood Oil
Xylene
Zinc Chloride
Zinc Hydrosulfite*
Zinc Sulfate

Appendix D: Replacement Parts

Sensors
Paste

Appendix E: Materials of Construction

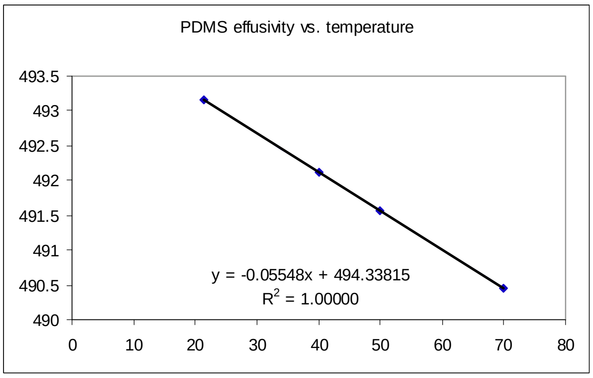
The sensor is constructed from passivated 316 stainless steel, RTV (silicone), green glass, silicon, and Torlon.

Appendix F: PDMS Reference Material

Reference Material - PDMS

PDMS (DiMethyl PolySiloxane Silicone Fluid, Clear Co Products Company), was selected as the reference material because of the following characteristics:

- Stable effusivity and conductivity as function of temperature and is on-hygroscopic
- Reproducible intimate contact versus powders or solid materials
- Meets FDA specifications
- Viscosity 10,000 Cs eliminates convection.
- HMIS Health, Flammability and Reactivity ratings of zero (0) – MSDS available
- Available cleaning SOP
- Fully characterized over the entire working temperature range
- Appropriate effusivity (nominal 493 $Ws^{1/2}/m^2K$) and thermal conductivity (0.168 W/mK)
- Value traceable to NIST



Format: Supply of PDMS with sufficient material to last one month of daily testing (if desired). Alternatively, if monthly reference material checking is conducted the supply should last a year.

Testing setup: The reference material beaker is provided for testing one sensor at a time. The PDMS should be placed into the beaker and allowed to sit to avoid testing air bubbles entrained in the liquid (from pouring). The PDMS can then be kept in the testing container indefinitely (cover with saran wrap or other cover to keep dust or particulate out of the - topping it up periodically as the sensor removal will deplete the liquid over time. Gently slide the sensor into the beaker at a slight angle to prevent bubbles from forming on the sensor surface. Bring the material to be tested in contact with the sensor. The heating and guarding elements of the sensor must be completely covered by the material. Material handling should be minimized. Ideally, the sensor is placed onto the material in its original container.

After testing, clean each sensor using mineral oil first, then soap and water, let dry and then apply isopropyl alcohol to remove final residues.

Acceptance criteria: The effusivity of the reference material must fall within 5% of the stated value. Acceptable criteria limits can exceed 5% if effusivity results are used in a relative rather than absolute manner. In that case, the acceptance criterion is that the relative standard deviation between multiple effusivity readings of the reference material must be below 2%. If the effusivity of the reference material falls outside of the acceptance range, the following actions can be taken:

- Confirm that the reference material is in firm contact with the sensor(s).
- Confirm that the reference material is fresh (if applicable).

PDMS Material Safety Data Sheet

Product Identification: Pure Silicone Fluid (standard viscosities 50, 100, 200, 350 (food grade), 500, 1,000, and 10,000 cSt)

CLEARCO PRODUCTS CO. INC
3430-G PROGRESS DR
BENSALEM, PA 19020
Telephone: 1 (800) 533 5823

Emergency Telephone Number
CHEM-TEL: 1 (800) 255 3924

Date Prepared: 01/10/04

SECTION II: HAZARDOUS INGREDIENTS / IDENTITY INFORMATION

Ingredient Description	% Weight	CAS Number	ACGIH PPM	TLV MG/M3	ACGIH PPM	STEL MG/M3	OSHA PPM	PEL MG/M3	SARA 313
Polydimethylsiloxane	100%	63148-62-9	N/E	N/E	N/E	N/E	N/E	N/E	N/E

HMIS RATING

FLAMMABILITY 0 REACTIVITY 0 HEALTH 0 *0 - Minimal*

SECTION III: PHYSICAL / CHEMICAL CHARACTERISTICS

Boiling Point	>450℉ /232℃
Specific Gravity (H_2O=1)	.953
Vapor Pressure (20℃)	Negl. MMHG
Vapor Density (Air = 1):	Negl.
Evaporation Rate (EE=1)	<1
Melting Point	N/A
Solubility In Water (20℃)	Insoluble
Solubility in Organic Solvent	Soluble in Toluene
Appearance & Odor:	Clear colorless liquid – Odorless

SECTION IV: FIRE AND EXPLOSION HAZARD DATA

Flash Point (Method Used)	>400℉ / 204℃ by PMCC
Flammable Limits:	LEL: No Data UEL: No Data

Extinguishing Medium: All standard firefighting media
Special Fire Fighting Procedures: None Known

SECTION V: REACTIVITY DATA

Stability:	Stable
Conditions to Avoid:	None
Hazard Polymerization:	Will Not Occur
Incompatabilities:	None

Hazardous Decomposition / Combustion: Carbon Monoxide Carbon Dioxide

SECTION VI: HEALTH HAZARD DATA

Acute Signs / Effects of Overexposure:	
Eye Contact:	Can Cause Mild Eye Irritation
Skin Contact:	None Known
Inhalation:	None Known
Medical Conditions Aggravated:	None Known
Other:	None Known
Chronic Effects of Overexposure:	None Known

Emergency and First Aid Procedures:	
Ingestion:	None Known
Skin:	Wash with soap and water
Inhalation:	None Known
Eyes:	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention if irritation persists.

This product or one of its ingredients 0.1% or more is not listed as a carcinogen or suspected carcinogen by NTP, IARC, or OSHA.

SECTION VII: PRECAUTIONS FOR SAFE HANDLING AND USE

Spill Response: Wipe, scrape, or soak up in an inert material and put in a container for disposal. Wash walking surfaces with detergent and water to reduce slipping hazard.

Disposal Method: Disposal should be made in accordance with Federal, State, and Local regulations. Incineration recommended in approved incinerator according to Federal, State, and Local regulations.

SECTION VIII: PROTECTION AND PRECAUTIONS

Ventilation:	None Known
Respiratory Protection:	None Known
Eye and Face Protection:	Safety Glasses
Protective Gloves:	None Known
Other Protective Equipment:	None Known
Precautions to be Taken in Handling and Storage:	None Known
Engineering Controls:	None Known

SECTION IX: DEPARTMENT OF TRANSPORTATION DATA

DOT Proper Shipping Name:	None
DOT Hazard Class:	None
DOT Labels:	None
UN/NA Number:	None
Placards:	None

Export:	None
EPA Hazard Waste:	None
Sara Hazard Class:	None
WHMIS Hazard Class:	No Known WHMIS Class
CPSC Classification:	None
Transportation Class:	None
RID (OCTI):	None
ADR (ECE):	None
RAR (IATA):	None

DISCLAIMER

Information presented herein has been compiled from information provided to us by our suppliers and other sources considered to be dependable and is accurate and reliable to the best of our knowledge and belief but is not guaranteed to be so. We make no warranty as to the results to be obtained in using any material and since conditions of use are not under our control, we must necessarily disclaim all liability with respect to the use of any material supplied by us.

PDMS Sensor Cleaning Procedure

Treat the sensor surface very gently when cleaning.

Step 1 - Wipe down the sensor with mineral oils on KimWipes.

Step 2 - Wash the sensor with soap and water.

Step 3 - Wipe down the sensor with isopropyl alcohol.

Appendix G: Permission Default Values

Permission Group	Sub Group	2nd Sub Group	Default Value
Test Methods	Add Test Method		Permit
	Edit Test Method	Edit Draft Test Method	Permit
		Edit Released Test Method	Permit
	Delete Test Method		Permit
	Recover Test Method		Permit
	Release Test Method		Permit
	Execute Test Method	Execute Draft Test Method	Permit
		Execute Released Test Method	Permit
		Alter Test Method while Executing	Permit
	Import Test Methods		Deny
	Export Test Methods		Permit
	Test Method Notes	Add Test Method	Permit
		Edit Test Method	Permit
		Delete Test Method	Permit
		Recover Test Method	Permit
Test Results	Release Test Results		Permit
	Approve Test Results		Permit
	Delete Test Results		Permit
	Import Test Results		Deny
	Test Result Notes	Add Test Result Notes	Permit
		Edit Test Result Notes	Permit
		Delete Test Result Notes	Permit
		Recover Test Result Notes	Permit
Materials	Add Materials		Permit
	Edit Materials		Permit
	Delete Materials		Permit
	Recover Materials		Permit
Material Groups	Add Material Groups		Permit
	Edit Material Groups		Permit
	Delete Material Groups		Permit
	Recover Material Groups		Permit
Material Lots	Add Material Lots		Permit
	Edit Material Lots		Permit
	Delete Material Lots		Permit
	Recover Material Lots		Permit
Projects	Add Projects		Permit
	Edit Projects		Permit
	Delete Projects		Permit
	Recover Projects		Permit
Control Signals	Add Control Signals		Deny
	Edit Control Signals		Deny
	Delete Control Signals		Deny
	Recover Control Signals		Deny
Calibration Methods	Add Calibration Methods		Deny
	Edit Calibration Methods		Deny
	Delete Calibration Methods		Permit

Permission Group	Sub Group	2^{nd} Sub Group	Default Value
	Recover Calibration Methods		Permit
	Execute Calibration Methods		Deny
	Perform One-Point Correction		Permit
	Import Calibration Methods		Deny
	Export Calibration Methods		Permit
	Calibration Method Notes	Add Calibration Method Notes	Permit
		Edit Calibration Method Notes	Permit
		Delete Calibration Method Notes	Permit
		Recover Calibration Method Notes	Permit
Calibration Results	Edit Calibration Results		Permit
	Delete Calibration Results		Permit
	Recover Calibration Results		Permit
	Release Calibration Results		Permit
	Import Calibration Results		Deny
	Export Calibration Results		Permit
Calibration Material Groups	Add Calibration Material Groups		Deny
	Edit Calibration Material Groups		Deny
	Delete Calibration Material Groups		Deny
	Recover Calibration Material Groups		Deny
Calibration Materials	Add Calibration Materials		Deny
	Edit Calibration Materials		Deny
	Delete Calibration Materials		Deny
	Recover Calibration Materials		Deny
Users	Add Users		Deny
	Edit Users		Deny
	Delete Users		Deny
	Recover Users		Deny
User Groups	Add User Groups		Deny
	Edit User Groups		Deny
	Delete User Groups		Deny
	Recover User Groups		Deny

Appendix H: CE Certification

1 DECLARATION OF CONFORMITY

Supplier Name: Mathis Instruments Ltd.

Supplier Address: 21 Alison Blvd.
Fredericton, New Brunswick
Canada
E3C 2N5

Declares under our sole responsibility that the following product

Product Name: TCi – Thermal Property Analyzer
Model#: X-89

Conforms to the following normative European and International Standards

Normative:
Standards EN 61010
EN 61326 : 1997 + Amendments A1:1998 & A2:2001, Class A

Following the provisions of the normative European Council Directives

EMC Directive 89/336/EEC (including amendments)
Low Voltage Directive 73/23/EEC (amended by 93/68/EEC)
R&TTE Directive 1999/5/EC

Product conformance to cited product specifications is based on sample (type) testing, evaluation, or assessment at Nemko Canada, Inc. located in Ottawa, Canada. Accepted by EU or FCC Notified and Competent Bodies.

Nancy Mathis

Nancy Mathis
President

Mathis Instruments Ltd.
21 Alison Blvd.
Fredericton, NB
E3C 2N5

Tel#: (506) 457-1515, Fax#: (506) 462-7210

Appendix I: Units and Conversions

Basic symbols and dimensions:

	MKS (SI)	CGS	Imperial
Thermal Conductivity	*k* (*W/mK*)	*k* (*cal/s°C*)	*k* (*Btu/hr/ft/°F*) or (*Btu*in/hr/ft² °F*)
Thermal Diffusivity	α (m^2/s)	α (cm^2/s)	α (-)
Heat Capacity	*Cp* (*J/kg/K*)	*Cp* (*cal/g/°C*)	*Cp* (*Btu/lb/°F*)
Density	ρ (kg/m^3)	ρ (g/cm^3)	ρ (lb/ft^3)
Energy	*J* (*Joules*)	*J* (*Joules*)	*Btu* (*British Thermal Units*)
Energy Rate (Watts)	*W = J/s* (*Watts*)	*W*	*Btu/min*
Change in absolute Temperature	*K (Kelvin)*	*°C*	*°F*
Time	*s (seconds)*	*s(seconds)*	*hr, min*
Effusivity	*e* ($W\cdot s^{1/2}/m^2/K$)	*e* ($cal\cdot s^{1/2}/cm^2/K$)	*e* ($Btu/hr^{1/2}/ft^2/°F$)
Thickness	*l(m)*	*l(cm)*	*l(ft)*
Depth of Penetration	*d(m)*	*d(cm)*	*d(ft)*

Conversions

Thermal conductivity: *1 W/mK* = *0.002389 cal/s°C*
= *0.5785 Btu/hr/ft/°F*
= $6.942\ Btu\cdot in/hr/ft^2/°F$

Thermal Diffusivity: $1\ m^2/s$ $=1000000\ mm^2/s$
$=10000\ cm^2/s$

Heat Capacity: $1\ J\cdot K/kg$ $=2.388\times10^{-4}\ cal/g/°C$
$=2.391\times10^{-4}\ Btu/lb/°F$

Density: $1\ kg/m^3$ $=0.01\ g/cm^3$
$=0.06243\ lb/ft^3$

Energy: *1 J* *=0.23885cal*
$=9.4782\times10^{-4}\ Btu$

Energy Rate (Power): *1 J/s(W)* *=0.056869 Btu/min*

Change in Temperature: *1 K* *=1°C*
=1.8°F

Temperature: *°C to °F* *°F = 1.8 °C + 32*

Time: *1 s* *=0.01667 min*

		=2.778 hr
Effusivity:	1 W· $s^{1/2}/m^2/K$	=2.388x10^{-5} cal· $s^{1/2}/cm^2/K$ =8.946x10^{-4} Btu/$hr^{1/2}/ft^2/°F$
Length:	1 m	= 100 cm = 3.2808 ft

Calculation of Thermal Diffusivity:

$$\alpha = \frac{k}{\rho Cp}$$

$$\alpha = \frac{W/mK}{kg/m^3 \cdot J/kgK} = \frac{J/s/m}{m^3 \cdot J} = \frac{m^2}{s}$$

The user must enter the density and Cp for this calculation.

Calculation of Heat Capacity:

$$e = \sqrt{k\rho C_p}$$

$$e^2 = k\rho C_p$$

$$C_p = \frac{e^2}{k\rho}$$

$$C_p = \frac{\left(W \cdot s^{1/2}/m^2/K\right)^2}{W/mK \cdot kg/m^3} = \frac{\left(J^2/s^2\right)\cdot s/m^4/K^2}{\left(J/s\right)/mK \cdot kg/m^3} = \frac{\left(J/s\right)\cdot s/m^4/s}{K \cdot kg/m^4} = \frac{J}{kgK}$$

User must enter the density for this calculation

Calculation of R-value (RSI):

$$R = \frac{l}{k}$$

$$R = \frac{m}{W/mK} = \frac{K \cdot m^2}{W}$$

The user must enter the thickness of material for this calculation

Depth of Penetration:

$$d = \left(4\alpha t\right)^{1/2}$$

$$d = \left(\frac{m^2}{s}s\right)^{1/2} = m$$

Where the time is the test time.

Appendix J: Contact Agents

MSDS - Glycerin

SECTION 1 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MSDS Identification:
Key: 96127
Name: Glycerol, 99+%

Catalog Numbers:
AC158920000, AC158920010, AC158920025, AC158920200, AC158920250

Synonyms:
Glycerol; 1,2,3-Propanetriol; Glyceritol; Glycic Alcohol; 1,2,3-Trihydroxypropane; 1,2,3-Propanetriol

Company Identification (Europe):
Acros Organics BVBA
Janssen Pharmaceuticalaan 3a
2440 Geel, Belgium

Company Identification (USA):
Acros Organics
One Reagent Lane
Fairlawn, NJ 07410

For information in the US, call:
800-ACROS-01

For information in Europe, call:
+32 14 57 52 11

Emergency Number, Europe:
+32 14 57 52 99

Emergency Number, US:
201-796-7100

For CHEMTREC assistance, call:
800-424-9300

For International CHEMTREC assistance, call:
703-527-3887

SECTION 2 - COMPOSITION, INFORMATION ON INGREDIENTS

CAS#	Chemical Name	%	EINECS#	Haz Symbols	Risk Phrases
56-81-5	Glycerol	99.0	200-289-5		

Hazard Symbols: None Listed.

Risk Phrases: None Listed.

SECTION 3 - HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Appearance: Clear liquid. Caution! This is expected to be a low hazard for usual industrial handling. May cause eye, skin, and respiratory tract irritation.

Target Organs: None known.

POTENTIAL HEALTH EFFECTS

Eye: May cause eye irritation.

Skin: May cause skin irritation. Low hazard for usual industrial handling.

Ingestion: Ingestion of large amounts may cause gastrointestinal irritation. Low hazard for usual industrial andling. May cause headache.

Inhalation: Low hazard for usual industrial handling. Inhalation of a mist of this material may cause respiratory tract irritation.

Chronic: No information found.

SECTION 4 - FIRST AID MEASURES

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. If irritation develops, get medical aid.

Skin: Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.

Ingestion: Never give anything by mouth to an unconscious person. Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water. Get medical aid if irritation or symptoms occur.

Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid if cough or other symptoms appear.

Notes to Physician: Treat symptomatically and

SECTION 5 - FIRE FIGHTING MEASURES

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion. Use water spray to keep fire-exposed containers cool. Vapors may be heavier than air. They can spread along the ground and collect in low or confined areas. Containers may explode when heated.

Extinguishing Media: Use water spray to cool fire-exposed containers. Use agent most appropriate to extinguish fire. Use water spray, dry chemical, carbon dioxide, or appropriate foam.

Autoignition Temperature: 400 deg C (752.00 deg F)

Flash Point: 193 deg C (379.40 deg F)

Explosion Limits, lower: 1.1

Explosion Limits, upper: Not available.

NFPA Rating: (estimated) Health: 0; Flammability: 1; Instability: 0

SECTION 6 - ACCIDENTAL RELEASE MEASURES

General Information: Use proper personal protective equipment as indicated in Section 8.

Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Remove all sources of ignition. Provide ventilation.

SECTION 7 - HANDLING AND STORAGE

Handling: Wash thoroughly after handling. Wash hands before eating. Use with adequate ventilation. Avoid contact with eyes, skin, and clothing. Keep container tightly closed. Avoid ingestion and inhalation. Wash clothing before reuse.

Storage: Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. No special precautions indicated.

SECTION 8 - EXPOSURE CONTROLS, PERSONAL PROTECTION

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate ventilation to keep airborne concentrations low.

EXPOSURE LIMITS

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Glycerol	10 mg/m3	none listed	15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

OSHA Vacated PELs:

Glycerol: 10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

PERSONAL PROTECTIVE EQUIPMENT

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to minimize contact with skin.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Liquid

Color: Clear

Odor: faint odor

pH: Not available.

Vapor Pressure: .0025 mm Hg @ 5

Vapor Density: 3.17 ($H2O$=1)

Evaporation Rate: Not available.

Viscosity: Not available.

Boiling Point: 290 deg C

Freezing/Melting Point: 20 deg F

Decomposition Temperature: 290 C

Solubility in water: Miscible in water. Insol. in chloroform,

Specific Gravity/Density: 1.4746

Molecular Formula: C3H8O3

Molecular Weight: 92.0542

SECTION 10 - STABILITY AND REACTIVITY

Chemical Stability: Stable.

Conditions to Avoid: Incompatible materials, ignition sources, excess heat.

Incompatibilities with Other Materials: Not available.

Hazardous Decomposition Products: Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide.

Hazardous Polymerization: Will not occur.

SECTION 11 - TOXICOLOGICAL INFORMATION

RTECS#:

CAS# 56-81-5: MA8050000

LD50/LC50:

CAS# 56-81-5: Draize test, rabbit, eye: 126 mg Mild; Draize test, rabbit, eye: 500 mg/24H Mild; Draize test, rabbit, skin: 500 mg/24H Mild; Inhalation, rat: LC50 = >570 mg/m3/1H; Oral, mouse: LD50 = 4090 mg/kg; Oral, rabbit: LD50 = 27 gm/kg; Oral, rat: LD50 = 12600 mg/kg; Skin, rabbit: LD50 = >10 gm/kg.

Carcinogenicity:

Glycerol - Not listed by ACGIH, IARC, or NTP.

Epidemiology:

No information available.

Teratogenicity:

No information available.

Reproductive Effects:

No information available.

Neurotoxicity:

No information available.

Mutagenicity:

No information available.

Other Studies:

No data available.

SECTION 12 - ECOLOGICAL INFORMATION

Ecotoxicity:

56-81-5:LC50 (96 Hr.) rainbow trout = 50-67 mg/L; 12 degrees CLC50 (96 Hr.) goldfish = >5000 mg/L

SECTION 13 - DISPOSAL CONSIDERATIONS

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

RCRA P-Series: None listed.

RCRA U-Series: None listed.

SECTION 14 - TRANSPORT INFORMATION

US DOT

No information available

Canadian TDG

No information available.

SECTION 15 - REGULATORY INFORMATION

US FEDERAL

TSCA

CAS# 56-81-5 is listed on the TSCA inventory.

Health & Safety Reporting List

None of the chemicals are on the Health & Safety Reporting List.

Chemical Test Rules

None of the chemicals in this product are under a Chemical Test Rule.

Section 12b

None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule

None of the chemicals in this material have a SNUR under TSCA.

SARA

CERCLA Hazardous Substances and corresponding RQs

None of the chemicals in this material have an RQ.

SARA Section 302 Extremely Hazardous Substances

None of the chemicals in this product have a TPQ.

SARA Codes

CAS# 56-81-5: chronic.

Section 313

No chemicals are reportable under Section 313.

Clean Air Act:

This material does not contain any hazardous air pollutants. This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.

Clean Water Act:

None of the chemicals in this product are listed as Hazardous Substances under the CWA. None of the chemicals in this product are listed as Priority Pollutants under the CWA. None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:

None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

Glycerol can be found on the following state right to know lists: Pennsylvania, Minnesota, Massachusetts.

California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols: Not available.
Risk Phrases:
Safety Phrases:
S 28A After contact with skin, wash immediately with plenty of water.
S 37 Wear suitable gloves.
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

WGK (Water Danger/Protection)

CAS# 56-81-5: 0

Canada

CAS# 56-81-5 is listed on Canada's DSL List. This product has a WHMIS classification of D2B.
CAS# 56-81-5 is not listed on Canada's Ingredient Disclosure List.

SECTION 16 - ADDITIONAL INFORMATION

MSDS Creation Date: 7/20/1999 **Revision** #3 **Date:** 3/18/2003

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no way shall the company be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if the company has been advised of the possibility of such damages.

MSDS – Glycol

SECTION 1 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MSDS Identification:
Key: 09400
Name: Ethylene glycol

Catalog Numbers:
AC146750000, AC146750010, AC146750025, AC146750250, AC295530000, AC295530010, AC295530025, AC410010000, AC410010010, AC410010040, AC410010200, S79007, S80005, S800051, S93233, BP230-1, BP230-4, E177-20, E177-4, E178-1, E178-200, E178-4, E178-500, E178J4, E1844, S800052, ZZE1785C15

Synonyms:
1,2-Dihydroxyethane; 1,2-Ethanediol; Ethylene alcohol; Ethylene dihydrate.

Company Identification:
Fisher Scientific
1 Reagent Lane
Fairlawn, NJ 07410

For information, call:
201-796-7100

Emergency Number:
201-796-7100

For CHEMTREC assistance, call:
800-424-9300

For International CHEMTREC assistance, call:
703-527-3887

SECTION 2 - COMPOSITION, INFORMATION ON INGREDIENTS

CAS#	Chemical Name	%	EINECS#	Haz Symbols	Risk Phrases
107-21-1	Ethylene glycol	>95	203-473-3		

Hazard Symbols: XN

Risk Phrases: 22

SECTION 3 - HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Appearance: clear, colorless liquid. Warning! Hygroscopic (absorbs moisture from the air). May cause kidney damage. May cause central nervous system effects. May cause cardiac disturbances. Harmful or fatal if swallowed. May cause eye, skin, and respiratory tract irritation.

Target Organs: Kidneys, heart, central nervous system.

POTENTIAL HEALTH EFFECTS

Eye: May cause moderate eye irritation.

Skin: May cause skin irritation. Low hazard for usual industrial handling.

Ingestion: May cause nausea and vomiting. Toxicity follows 3-stage progression. (1) involves central nervous system effects including paralysis of eye muscles, convulsions, and coma. Metabolic acidosis and cerebral swelling may also occur. (2) involves cardiopulmonary system with symptoms of hypertension, rapid heart beat, and possible cardiac failure. (3) involves severe kidney abnormalities including possible renal failure.

Inhalation: May cause respiratory tract irritation. Heated or misted substance may cause headache, irregular eye movements, and possible coma.

Chronic: May cause kidney injury.

SECTION 4 - FIRST AID MEASURES

Eyes: Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid immediately. Do NOT allow victim to rub eyes or keep eyes closed.

Skin: Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.

Ingestion: If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid immediately.

Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid if cough or other symptoms appear.

Notes to Physician: Ethanol may inhibit methanol metabolism.

SECTION 5 - FIRE FIGHTING MEASURES

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Vapors may be heavier than air. They can spread along the ground and collect in low or confined areas.

Extinguishing Media: In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam. Water or foam may cause frothing. Use agent most appropriate to extinguish fire.

Autoignition Temperature: 410 deg C (770.00 deg F)

Flash Point: 111 deg C (231.80 deg F)

Explosion Limits, lower: 3.20 vol %

Explosion Limits, upper: 15.30 vol %

NFPA Rating: (estimated) Health: 2; Flammability: 1; Instability: 0

SECTION 6 - ACCIDENTAL RELEASE MEASURES

General Information: Use proper personal protective equipment as indicated in Section 8.

Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Provide ventilation.

SECTION 7 - HANDLING AND STORAGE

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Use with adequate ventilation. Avoid contact with eyes, skin, and clothing. Avoid ingestion and inhalation.

Storage: Store in a cool, dry, well-ventilated area away from incompatible substances.

SECTION 8 - EXPOSURE CONTROLS, PERSONAL PROTECTION

Engineering Controls: Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.

EXPOSURE LIMITS

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Ethylene glycol	100 mg/m3 Ceiling (aerosol only)	none listed	none listed

OSHA Vacated PELs:

Ethylene glycol: No OSHA Vacated PELs are listed for this chemical.

PERSONAL PROTECTIVE EQUIPMENT

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Liquid

Color: clear, colorless

Odor: odorless

pH: Not available.

Vapor Pressure: .05 mm Hg @ 20 deg C

Vapor Density: 2.1 (air=1)

Evaporation Rate: Not available.

Viscosity: 21cP @ 20 deg C

Boiling Point: 195 deg C @ 760 mm Hg

Freezing/Melting Point: -13 deg C

Decomposition Temperature:

Solubility in water: Soluble.

Specific Gravity/Density: 1.1200g/cm3

Molecular Formula: $C_2H_6O_2$

Molecular Weight: 62.06

SECTION 10 - STABILITY AND REACTIVITY

Chemical Stability: Stable at room temperature in closed containers under normal storage and handling conditions.

Conditions to Avoid: Moisture, excess heat.

Incompatibilities with Other Materials: Chlorosulfonic acid, dimethyl terephthalate, oleum, phosphorus pentasulfide, silvered-copper wire, sodium hydroxide, sulfuric acid, titanium butoxide. Causes ignition at room temperature with chromium trioxide, potassium permanganate, and sodium peroxide. Causes ignition at 100C with ammonium dichromate, silver chlorate, sodium chloride, and uranyl nitrate.

Hazardous Decomposition Products: Carbon monoxide, carbon dioxide.

Hazardous Polymerization: Has not been reported.

SECTION 11 - TOXICOLOGICAL INFORMATION

RTECS#:

CAS# 107-21-1: KW2975000

LD50/LC50:

CAS# 107-21-1: Draize test, rabbit, eye: 500 mg/24H Mild; Draize test, rabbit, eye: 100 mg/1H Mild; Draize test, rabbit, eye: 0.012 ppm/3D; Draize test, rabbit, eye: 1440 mg/6H Moderate; Oral, mouse: LD50 = 5500 mg/kg; Oral, rat: LD50 = 4700 mg/kg; Skin, rabbit: LD50 = 9530 uL/kg.

Carcinogenicity:

Ethylene glycol -

Not listed by ACGIH, IARC, or NTP.

Epidemiology:

No data available.

Teratogenicity:

An expert panel convened by the NTP's Center for the Evaluation of Risks to Human Reproduction concluded 2/13/03 that developmental and reproductive risks stemming from exposure to the chemicals propylene glycol and ethylene glycol are negligible.

Reproductive Effects:

No data available.

Neurotoxicity:

No data available.

Mutagenicity:

No data available.

Other Studies:

Please refer to RTECS KW2975000 for additional information.

SECTION 12 - ECOLOGICAL INFORMATION

Ecotoxicity:

Fish: Rainbow trout: LC50 = 41000 mg/L; 96 Hr.; UnspecifiedFish: Bluegill/Sunfish: LC50 = 27500-41000 mg/L; 96 Hr.; UnspecifiedFish: Goldfish: LC50 = 27500-41000 mg/L; 96 Hr.; UnspecifiedWater flea LC50 = 46300 mg/L; 48 Hr.; UnspecifiedBacteria: Phytobacterium phosphoreum: EC50 =620 mg/L; 30 minutes; Microtox testGoldfish LD50= >5000mg/L/24Hr Guppies LC50= 493,000ppm/7D Shrimp (salt water) LC50= >100ppm/48Hr

SECTION 13 - DISPOSAL CONSIDERATIONS

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

RCRA P-Series: None listed.

RCRA U-Series: None listed.

SECTION 14 - TRANSPORT INFORMATION

US DOT

Shipping Name: Not regulated Hazard Class: UN Number: Packing Group:

Canadian TDG

Shipping Name: Not Regulated Hazard Class: 0 UN Number: UN Packing Group:

USA RQ: CAS# 107-21-1: 5000 lb final RQ; 2270 kg final RQ

SECTION 15 - REGULATORY INFORMATION

US FEDERAL

TSCA

CAS# 107-21-1 is listed on the TSCA inventory.

Health & Safety Reporting List

None of the chemicals are on the Health & Safety Reporting List.

Chemical Test Rules

None of the chemicals in this product are under a Chemical Test Rule.

Section 12b

None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule

None of the chemicals in this material have a SNUR under TSCA.

SARA

CERCLA Hazardous Substances and corresponding RQs

CAS# 107-21-1: 5000 lb final RQ; 2270 kg final RQ

SARA Section 302 Extremely Hazardous Substances

None of the chemicals in this product have a TPQ.

SARA Codes

CAS# 107-21-1: acute, chronic.

Section 313

This material contains Ethylene glycol (**CAS#** 107-21-1, 95%),which is subject to the reporting requirements of Section 313 of SARA Title **III** and 40 CFR Part 372.

Clean Air Act:

CAS# 107-21-1 is listed as a hazardous air pollutant (HAP). This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.

Clean Water Act:

None of the chemicals in this product are listed as Hazardous Substances under the CWA. None of the chemicals in this product are listed as Priority Pollutants under the CWA. None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:

None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

Ethylene glycol can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.
California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols: XN Risk Phrases:
R 22 Harmful if swallowed.
Safety Phrases:

WGK (Water Danger/Protection)

CAS# 107-21-1: 0

Canada

CAS# 107-21-1 is listed on Canada's DSL List. This product does not have a WHMIS classification.
CAS# 107-21-1 is listed on Canada's Ingredient Disclosure List.

SECTION 16 - ADDITIONAL INFORMATION

MSDS Creation Date: 5/12/1999 **Revision** #4 **Date:** 1/26/2004

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no way shall the company be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if the company has been advised of the possibility of such damages.

Appendix K: Disclaimer

While the information contained herein is believed to be reliable, the manufacturer makes no representations as to the reliability of the results the buyer or User will achieve. No statements or recommendations herein are to be construed as representations applicable to the particular application of the User or buyer or as inducements to infringe upon any relevant patent, now or hereafter in existence.

Under no circumstances shall the manufacturer be liable for incidental, consequential or other damages from alleged negligence, breach of warranty or condition, strict liability or any other legal theory, arising out of the manufacture, sale, use or handling of the product or products referred to herein.

The sole remedy of the buyer and the sole liability of the manufacturer for any claims shall be limited to the buyer's purchase price of the product which is subject of the claim or the amount actually paid for such product, whichever is less.

Technical advice furnished by the seller shall not constitute a warranty or condition, statutory or otherwise, which is expressly disclaimed, all such advice being given and accepted at the buyer's risk.

The data and results set forth herein are based on laboratory work and do not necessarily indicate results that the buyer or User will attain. Full-scale testing and product performance is the responsibility of the buyer and User.

Any discrepancy between this disclaimer and the warranty through the distributor of this product, the warranty shall prevail.