# HEXTEQ PROCEDURE

**Procedure: ET HTP 001**



**HEXTEQ**



VALIDATION: To validate this document, the client should request authenticity by sending email to mbowling@eit-international.com quoting the traceable number above.

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**PROCESS PLANT VALIDATION**

| Authorisation | Procedure |
|---|---|
| TM/ QM<br><br>M.K.Bowling | E.T.HTP 001 |

Document Change Control

| ISSUE | Description of change | Date |
|---|---|---|
| 15 | Re written post on-site experiments and major upgrading to equipment in the form of hardware and software | 14.03.2009 |
| 16 | Amended to include reverse testing after field trials show advantages | 28.03.2009 |
| 17 | Amended to include no pressure drop on large units and identification for section on certificate | 11.04.2009 |
| 18 | Input Hexteq Validation page 17 | 02.10.2009 |
| 19 | Attached updated Interim Report Sheet | 08.12.2009 |
| 20 | Incorporating new interim report design | 01.12.2010 |
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**PURPOSE**

1. The purpose of this procedure is to identify the operational methods through HEXTEQ for testing the integrity of plate heat exchangers, whilst in situ, for defects such as cracks and pinholes which may cause cross contamination of the product, due to leakage from the heater, cooler, or non pasteurised side of the heat exchanger, into the adjacent pasteurised side.
2. When using the Hexteq system, minute defects may be detected that are too small to see with visible dye penetrants when the pack is opened (dismantled). This may create major issues for the processor as he would need to identify these defects in order to isolate the defective plates from the good ones. To overcome this problem it is considered that defect diameters > 20 microns shall be cause for rejection. Therefore defects 20 microns and below shall be recorded and tested more frequently until repaired, this is backed up by the University tests that show no leakage from defects below 20 microns, when pressure differentials are under 1 bar. In order to prevent these defects from blocking, it is also recommended that a 5 micron filter is fitted to the inlet of the high pressure side when searching for the said minute defects.
3. Another thing to consider when carrying out in-situ testing is that some cracks close when pressurised. So you may find a crack with dye penetrant when the plate is out of the machine, and not find it when back in the machine and under pressure. This is due to the crack configuration. Dendritic (tree like) cracks for example may have a cross section propagating in many directions and when there is a pressure applied from one side, the two planes are squeezed together and the crack is closed. But when the pressure is increased the crack opens again. This can happen at varying pressures, therefore differential pressures should be as high as possible, but staying within the heat exchanger manufacturers limitations. We recommend between minimum 3 – 10 bar in order to maximise the quality of the test results, and also we recommend testing from both sides where practicable.

**EQUIPMENT MANAGEMENT**

- USE BY QUALIFIED TECHNICIANS ONLY. The Equipment may be used only by your duly qualified employees and strictly in accordance with the use contemplated in this TECHNICAL PROCEDURE.
- You shall keep the Equipment in your sole custody and shall not permit the Equipment to be used in violation of any laws.
- DO NOT REMOVE SERIAL NUMBERS OR COVER COMPANY LOGOS. You may not remove or cover over any serial numbers, tags, nameplates, or identifying logos on the Equipment showing ownership by EIT International .
- EQUIPMENT DAMAGED OR DESTROYED WHILE IN THE FIELD
  AS SOON AS YOU DISCOVER THAT EQUIPMENT IN THE FIELD IS DEFECTIVE, you should notify EIT International Limited of the problem and if necessary return the Equipment to EIT International , freight pre: paid, for evaluation. **DO NOT ATTEMPT TO OPEN OR REPAIR THE EQUIPMENT**. EIT International will make a reasonable effort to repair or replace the Equipment in the shortest amount of time.

**RESPONSIBILITIES**

PROCESSOR RESPONSIBILITIES

- The Processor is responsible for ensuring that the heat exchanger is prepared for test by removing the product and cleaning the internal surface (CIP).
- The Processor must ensure that any permits to work, safety instructions, drawings and any site specific rules are available to the Operator prior to test.
- It is the Processor's responsibility to ensure that any site specific equipment is supplied, also to ensure the safety of the Operator whilst on the Processor's site.
- It is the responsibility of the Processor to clean the heat exchanger, isolate any steam or coolants remove for test, and replace any pipe-work and fittings after testing has been completed.

INSPECTOR RESPONSIBILITIES

- The Qualified Inspector is responsible for carrying out the test method and producing the test reports / Certificates, highlighting any limitations to the Processor.
- The Qualified Inspector shall ensure that he has available clean overalls for each site that is visited and that necessary protective footwear, eye, hand and headgear are available at all times.

- The Qualified Inspector shall ensure that the equipment he is to use is clean, free from dirt, calibrated and maintained in accordance with this procedure prior to leaving for site.
- The Qualified Inspector is also responsible for ensuring that all site requirements, including health and safety and specific site conditions are complied with and work permits must be obtained.
- On leaving site, the Qualified Inspector is responsible for ensuring that the site is left as found and that the Processor's representative has been informed of the test being completed and the results.

**HEXTEQ TEST EQUIPMENT**

THE EQUIPMENT COMPRISES:

- Calibrated Hexteq Intelligent Sensor transmitter unit (see fig 1)
- Flexible hoses to connect heat exchanger outlet adjacent to product side.
- Hexteq Control unit (see fig 8)
- HP unit
- Battery charger unit.
- Suitable transport case.

**SENSOR TRANSMITTER OPERATION**


Fig 1.

**The Remote Hexteq sensor transmitter unit** comprises of an eyelet, inlet pipe, outlet pipes, liquid overflow mechanism, power charging adapter

Instrumentation is provided in the "Electronics Pack", which comprises of various Sensors, process meter and Wireless communications module. Power is supplied by rechargeable battery cells also inside the Electronics Pack.

The unit is powered from a series of high capacity rechargeable batteries and should be charged for 1.5 hours; the charge should last for approximately 10 hours.

The unit has a Auto-Off facility built in, (15 minutes of No logger Comms)


Fig 2.

**The Remote Hexteq sensor transmitter unit**

Connect the sensor transmitter to the heat exchanger using the eyelet on top of the housing to suspend it from a suitable load-bearing structure min 1 metre above the highest level of the heat exchanger, and ensure it is level. This is important to maintain accuracy of readings.


Fig 3.

**The Remote Hexteq sensor transmitter unit**

The Inlet attached to the Sensor Transmitter, houses a female quick fit connector which is attached to the outlet of the low pressure side of the heat exchanger via a male quick fit connector attached to a transparent flexible tube.


Fig 4.

**The Remote Hexteq sensor transmitter unit**

Switch **on** the Hexteq Sensor Transmitter unit by pressing the highlighted button for 2 seconds.

Switch **off** the Hexteq Sensor Transmitter unit by pressing the highlighted button for 3 seconds.


Fig 5.

**The Remote Hexteq sensor transmitter unit**

Charger connection highlighted by arrow.

Battery charging should take 1.5 hours between 10 and 30ºC, as cell charging efficiency, Charging outside this range can adversely effect how much charge the cells will hold, deteriorate performance and may also damage the cells.

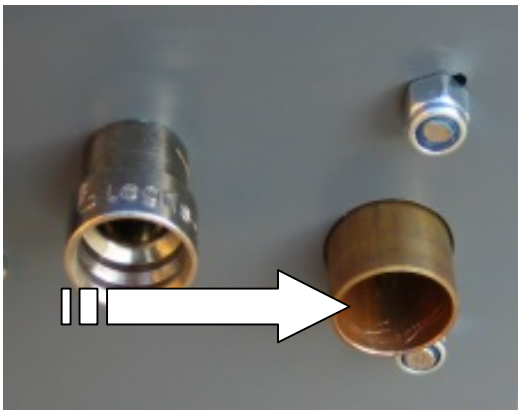


Fig 6.

**The Remote Hexteq sensor transmitter unit**

Outlet pipe highlighted by arrow (twin pipes on SC4 unit).

The Hexteq Sensor Transmitter is primed with water from the low pressure side of the heat exchanger into the inlet of the Hexteq Sensor Transmitter (see fig 3); excess water is then released from the unit through the outlet pipe.


Fig 7.

**The Remote Hexteq sensor transmitter unit**

The Menu Screen.

When initiated the menu screen will display a bar graph showing status of Priming inlet pipe ( **I** ), liquid flow through defect ( **F** ),

Accumulative Flow ( **M** ).


Fig 8.

**Hexteq Control Unit.**

**Power Key**

Power the unit **on** by pressing the I/O button for 2 seconds.

Power the unit **off** by pressing the I/O button for 3 seconds.

This unit will display current date and expiry date.

The menu screen will display Records, Monitor, or Test modes and will communicate with the Sensor Transmitter through Radio Telemetry.


Fig 9.

**Hexteq Control Unit.**

Charger connection and P.C. download connection.

The connection has 2 functions, charging and also connecting the control unit to your P.C for downloading test reports for certificate generation.

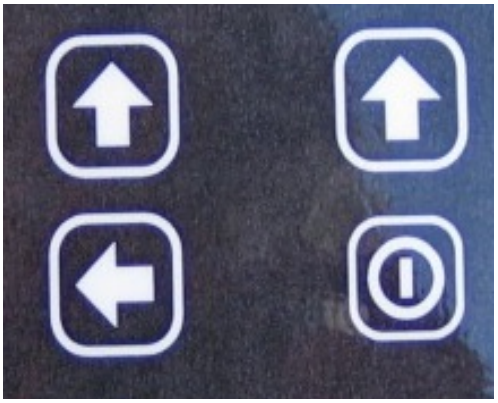
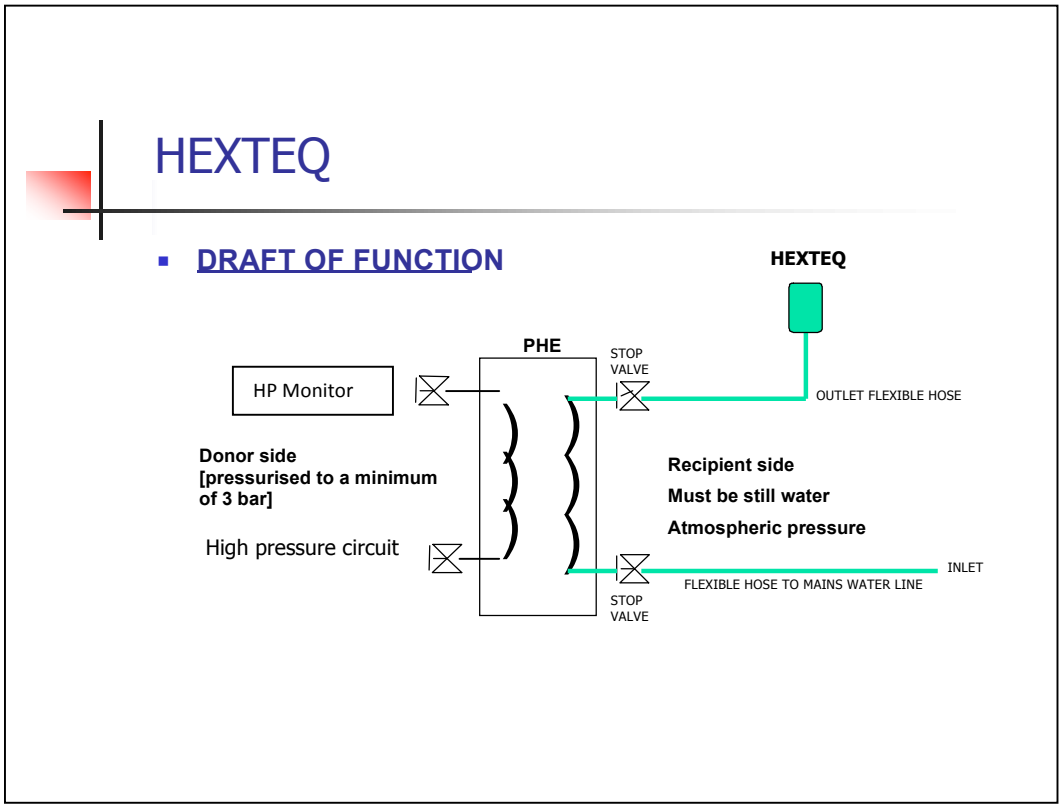


Fig 10.

**Hexteq Control Unit.**

If the IO button is pressed at the same time as left arrow button, you will be given the option to remove one or all records. Follow on screen instructions to enable this function. Once removed, records cannot be reinstated.



**TEST METHOD. IF POSSIBLE, TEST HEAT EXCHANGER FROM BOTH SIDES**

**HP side = High Pressure Side. LP side = Low Pressure side.**

**Liquid static on High Pressure side**

It is the client's responsibility to ensure that the heat exchanger is removed from service and all pipe-work is disconnected from the heat exchanger in order to allow the Qualified Inspector to connect the multi-fit adaptors to the inlet and outlet of both sides under examination. When testing is completed, the client shall re-connect the heat exchanger to the service pipe-work.

It is the Qualified Inspector's responsibility to connect stop valves and filters to all above fittings and then to connect the Hexteq unit to one side and a suitably pressurised water supply to the adjacent side.

**L.P. Side** - Connect adapters to the inlet and outlet of the low pressure side of the heat exchanger to enable fitting of flexible hoses. Ensure that the outlet has shut-off valve fitted at the end of the flexible tube, and the inlet side has valve fitted close to heat exchanger.

Fill the low pressure side with tap water from the inlet end and hang the flexible hose from the outlet end above the highest level of the heat exchanger + 1-2 Metres and slowly open and close the valve on the outlet end. This will ensure that any air pockets are removed from the system by using back pressure to force out the air. When this is done and this side is under pressure, close both valves off.

**H.P. Side** - Connect adapters to the inlet and outlet of the high pressure side of the heat exchanger to enable fitting of flexible hoses. Ensure that the outlet has shut-off valve fitted at the end of the flexible tube and the HP unit is connected, and the inlet side has valve fitted close to heat exchanger.

Fill the high pressure side with tap water from the inlet end and hang the flexible hose from the outlet end above the highest level of the heat exchanger + 1-2 Metres and slowly open and close the valve on the outlet end. This will ensure that any air pockets are removed from the system by using back pressure to force out the air. When this is done and this side is under pressure MIN 3 BAR, close both valves off.

**L.P. Side – Slowly open the valve on the outlet located at end of tube on the LP side.** This will release the pressurised water from this side of the heat exchanger, holding the end level with the top of S/Tx unit, then wait for the flow to stop, then open the valve slightly on the inlet side of low pressure side, then when you observe a very slow flow, connect this end of the hose to the inlet of the S/Tx unit. Observe a very low flow released from the sensor transmitter outlet pipe, then close the valve, stopping the flow. The S/Tx unit should be 1 – 2 metres above the highest level of the heat exchanger, and have the capability to be raised and lowered as required.
Water temperature shall ideally be between 10 and 20 degrees C. Power on Hexteq unit into Monitor mode and wait for stabilisation of the system. If you are unable to stabilise due to liquid flowing from Hexteq outlet, and HP pressure dropping the heat exchanger has failed with major defect. We advise highest achievable pressure differential for the test. Sometimes, if the heat exchanger has a very large volume, there will be no pressure drop when leakage is evident from the outlet of the low pressure side. This can be expressed by the extended time needed to increase the pressure on the high pressure side, this can be similar to the time needed to drop the pressure when leakage is evident. More evidence that simply pressure testing a heat exchanger does not find leaks in large units.

There may be a stabilisation period of a few minutes where liquid temperatures fluctuate, and the liquid expands and contracts. After this period, observe the inlet pipe level in the monitor mode and wait until stabilisation before instructing the Sensor Transmitter to go into Test Mode. If the inlet level drops slightly, lower the height of the Hexteq unit until level stabilises, keep the unit above highest level on exchanger.

When the above procedure has been completed, it is then time to reverse the test conditions by changing the HP side to become the LP side and vice versa. The reason for this is due to cracks that close when the plates are forced together at contact points on the LP side, then become open when the pressures are reversed. In order to complete this procedure there needs to be valves inserted onto **all** adaptors.

**The Control Unit**
Power On/Off
Power the unit on, by pressing the 1/0 Button for 2 seconds.
You will be greeted with a sign-on screen.

e.g.1 (Logger Date within Expiry Date)
Hexteq
Easytest

e.g.2 (Logger Date outside Expiry Date)
Hexteq
Easytest

| | |
|---|---|
| Exp Date: 01Jan'06 | EXPIRED: 01Jan'06 |
| Batt: 5.4V f/w:1.0 | Batt: 5.4V f/w:1.0 |

If the unit has 'Expired' then return the unit to EIT International for re: calibration.

Press the 1/0 Button for 3 seconds to power off.

GPS (Global Positioning System)
The unit is equipped with a GPS Satellite Communication module. There should be 2 ticks visible when the Control unit is powered on and at least 1 tick to ensure fix for test location on report.

Menu Screen
The Menu Screen shows the current Time and Date and gives the user two soft key options.

1) Records

2) Mon/Test

Records State
Each Test result can be referred to by its allocated serial number and the Time and Date of test.

The Control unit can hold 80 Test results.

A Record length can be from 1 to 300 samples @ 1 sample per second.

A 'Mean' value is displayed in the Record Viewed.

Use the soft keys to scroll through the Records.

Test/Monitor
This Screen shows the current Battery Voltages for the Control Unit and also for the Sensor Transmitter Unit. The user has two soft key options.

2.1) Test

2.2) Monitor

NB: Whether in Test or Monitor mode. The Measurement reading will be 'Absolute' in the RESET condition and 'Differential' whilst calculating.

Test
Before Proceeding to a test ensure the following:

2.1.1) A 'Fix' on your Location needs to have been made before proceeding (one or two ticks should be seen in the bottom right hand corner).

2.1.2) The Sensor Transmitter unit is switched on and a communications 'Link' has been established between The Sensor Transmitter unit and Control Unit.

2.1.3) The Sensor Transmitter unit has been 'Primed' i.e. the non-pressurized circuit is filled with water and the The Sensor Transmitter unit is vertical (hanging straight). The pressurized circuit also needs to have water of the same temperature as that of the non-pressurized circuit.
I.e. Both circuits are flushed with tap water until the exiting water is the same temperature as the supply.
2.1.4) The Pressurized circuit needs to be pressurized (Min 3 bar).

A test may now commence.

2.1.5) after the Test button is pressed there will be up to 10 sec delay while the system initializes (RESET). The system now waits (30 seconds) for a 'Trigger flow'. If a 'Trigger flow' does not occur, then a logging session will continue. Meaning either No Flow, or a very small Flow. In this case the calculated Flow may be a little inaccurate. The user should refer to the logged data for an accurate flow reading.

NB: If the Control Units memory is full. A test can not happen.
If the flow is too great. Then the unit will never initialize.
If air bubbles or the inlet level drops, then the test will cease.
To Abort a Test. Press all non-power keys.

Monitor
Putting the system in monitor mode allows the user to see if the unit is primed or not. Also a dummy test run can be observed

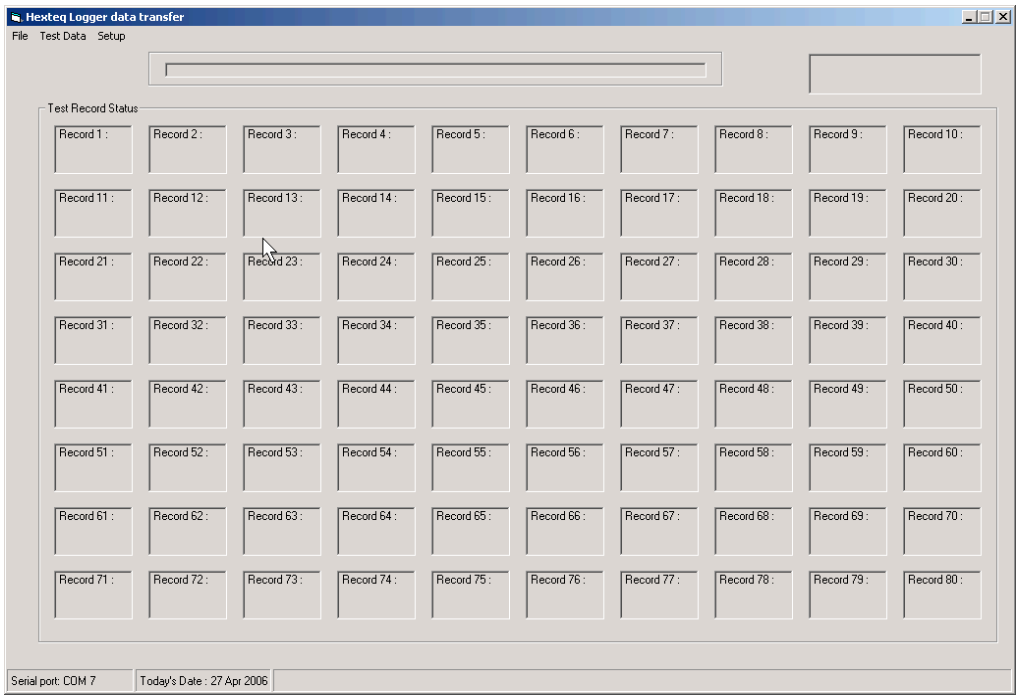
When Priming. The inlet level will rise and then settle. Continue to allow water into the The Sensor Transmitter unit until the Measurement reading starts to increase. The Sensor Transmitter unit is now primed.
In the RESET condition there will be no flow measured.
USB Connection
To upload the test data the USB connector should be plugged into the Control Unit.
The records can be read and saved or deleted.
The internal clock can also be adjusted here.

**Uploading of Test Data from the Hexteq Control Unit to a PC**

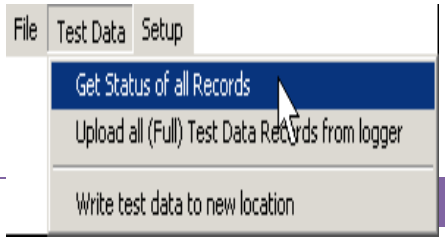
The Hexteq Control Unit contains a non-volatile memory with a capacity for up to 80 test results. The supplied PC application for Hexteq data upload communicates with the Control Unit via a USB lead. The supplied USB lead is a custom item with a special plug because the waterproof connector on the logger is shared between USB and the battery charger connection.

Once the software is correctly installed, the Control Unit should show 'USB CONNECTED' on the LCD when switched on. The PC should recognise the Control Unit as a Virtual Com Port device, and allocate it a Virtual Com Port number. This can be confirmed by looking at the PC 'device manager' window, and opening the Com Port list. As a test, by disconnecting and re-connecting the Control Unit on the USB port, one should see the Virtual Com Port (with the allocated number) disappear and reappear.

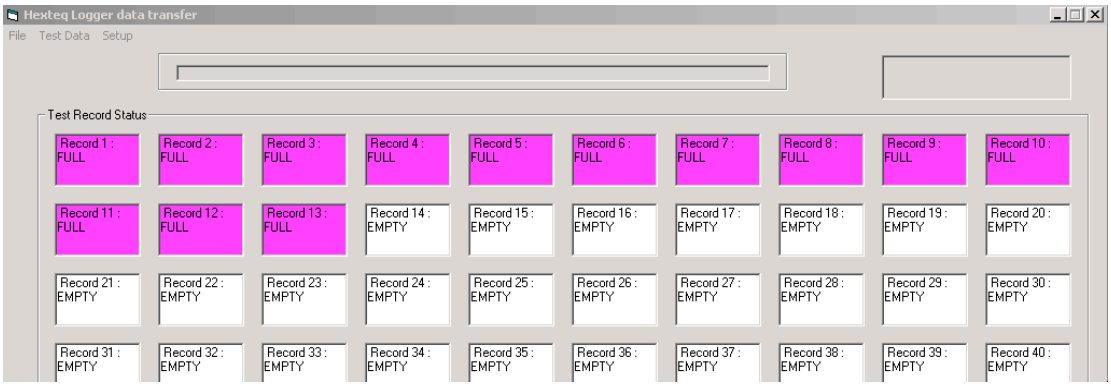
When the Hexteq Test Data Upload program is run, the main screen will be witnessed, as shown below:



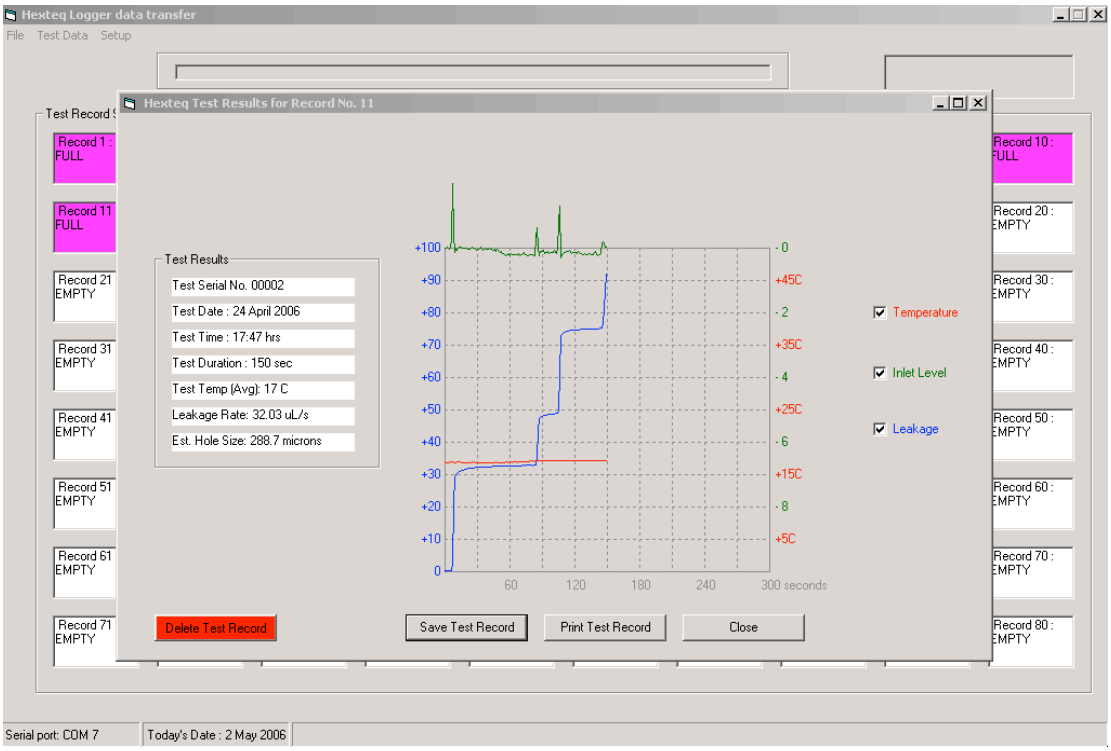

If you want to find out the status of all test records in the Control Unit (how many are empty, and how many are full), select 'Get Status of all Records' from the Test Data menu header, as shown:



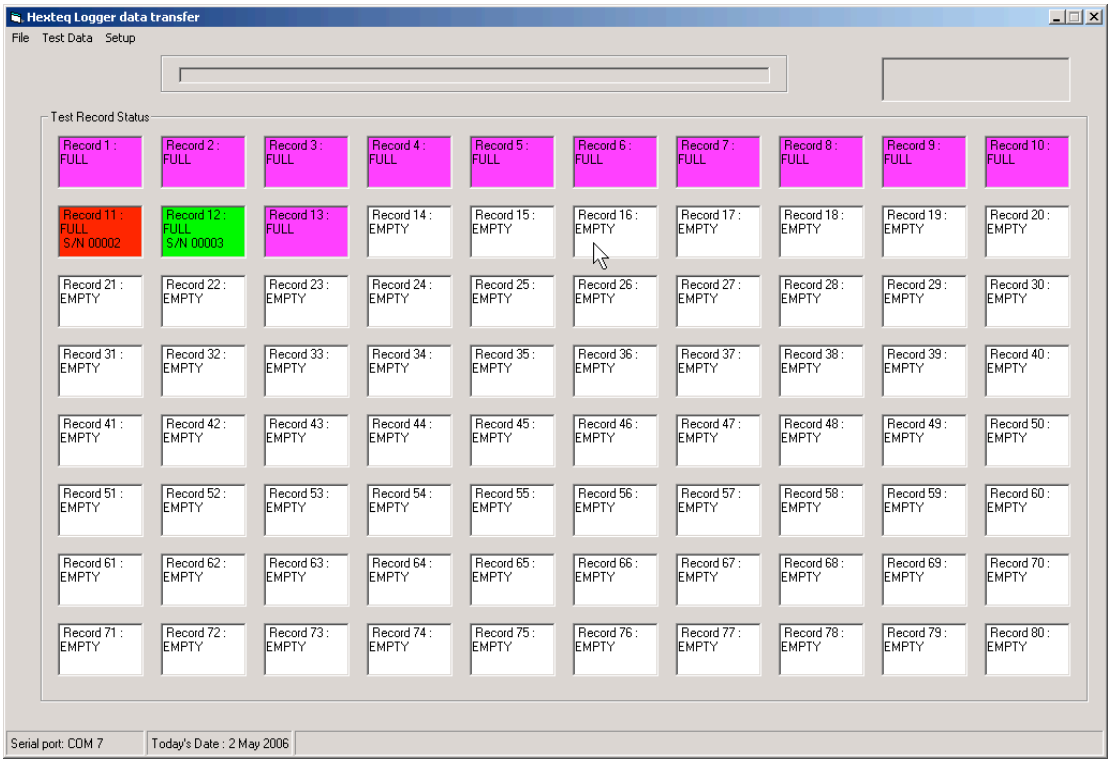
An example of a Get Status command is show below for a Control Unit which currently holds 13 Full test data records. The colour coding can be seen as purple for a Full data record, and white for an Empty one.



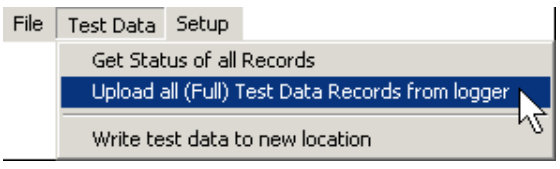

Clicking on the Empty records causes no action to be taken, as there is no data to be uploaded. Clicking on a Full (purple) record will cause the data for that full record to be uploaded and the data shown on the Results screen, as below:



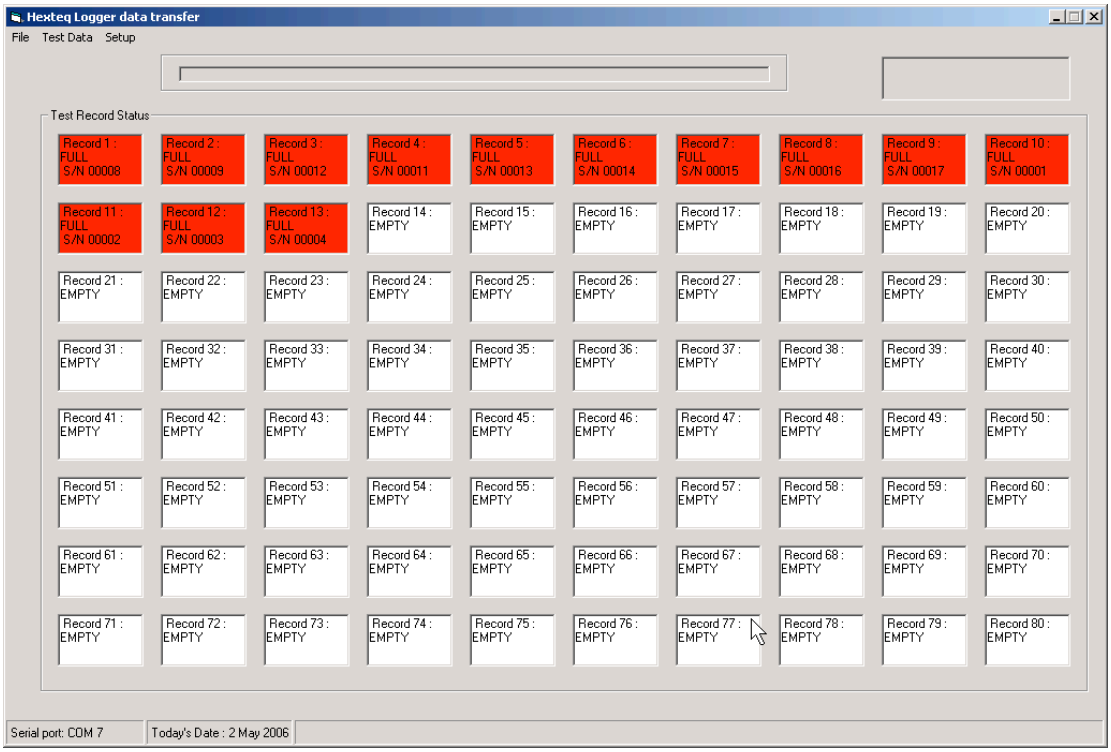
From the Results screen, the Test Record can be saved, printed or deleted. It is not necessary to do any of those things at this stage, because they can be done later. For now, we can just close the Results window, and we will again see the main screen display, but this time the Test Record colour has changed to Red. This indicates that the Test data has been loaded to the PC but not yet saved to disk. Clicking again on the red Test Record will open the results screen, this time much quicker because the Test Result data is already uploaded to the PC. The screen shot below shows the main screen which has had the Status of all Records loaded, then the Full Test Data for Records 11 and 12 loaded, but only Record 12 has been saved to disk: in this case it is colour-coded green, whereas Record 11 stays as red because although it has been uploaded it has not been saved to disk.



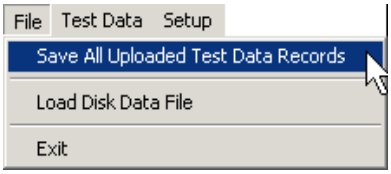

Instead of accessing individual Test Records, one can instead just tell the program to Upload All Full records from the Test Data menu. This is the simplest option for the user, but it takes longer as all the Records have to be loaded in full. If you only need one or two Records from a logger which contains many test results, it is quicker to access them individually.



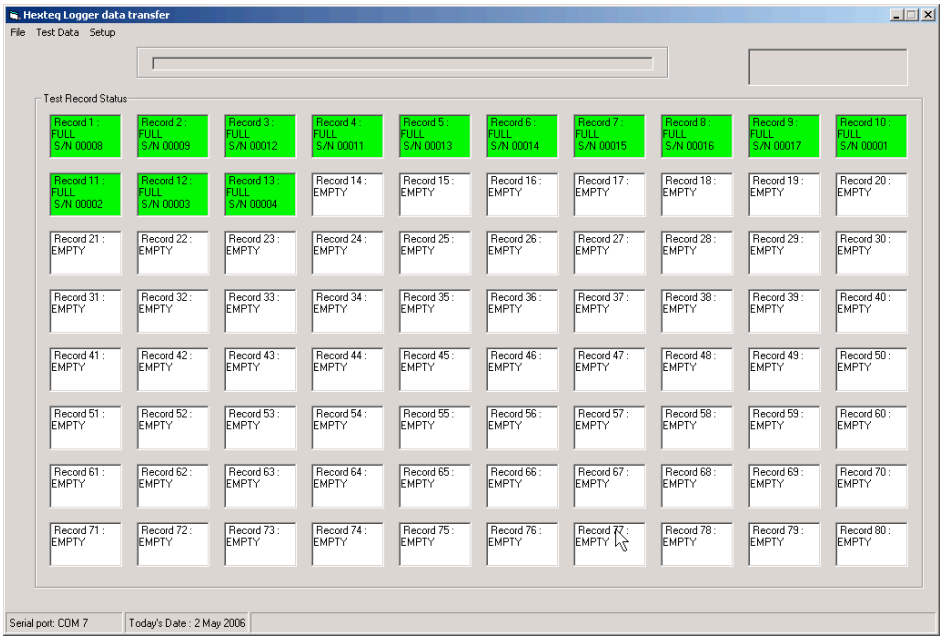
The resulting screen would then be as below, with all Full Records shown loaded but not yet saved, and therefore shown in red.




Once the Test Records are loaded, they can be saved in one operation also, by going to the File menu and selecting the 'Save All' command as shown:




The result of Saving All to disk will be that all the Test Records are saved to disk, and all the Records are shown colour-coded in green, accordingly.




Control Unit Charging

The Control Unit contains 4 x 'AA' High Capacity rechargeable batteries.
The Charger should be connected for at least 1.5 hours.

Charged batteries should last at least 8 Hours. The Control Unit has a Auto-Off facility (15 mins of no key presses).

**Sensor Transmitter Unit**

The Sensor Transmitter has one inlet pipe and two outlets.

The inlet is the one with the connector.

**Power**

Power on the unit by pressing the push switch near the inlet pipe for 2 seconds.
To turn off unit press switch for 3 seconds. (The unit has a 15 min Auto Power Off, after losing communications with a Control Unit).

When the unit is Powered a sign-on screen will greet you.

e.g. 1 (Stx)

Hexteq
Easytest
Exp Date: 01Jan'06
Batt: 5.4V f/w:1.0

If the Control Unit doesn't establish a comms link with a Logger within 15 seconds, then the unit will go into standby.

Expiry Date

If the Sensor Transmitter receives data indicating that the date is past that of the Expiry date, the unit will display the Expiry screen. e.g. "Expired: 01Jan'06". And the unit should be returned for calibration.

Operation

As long as a link between a Control Unit and Sensor Transmitter Unit is 'within expiry date' the Sensor Transmitter Unit will display a bar graph indicating the internal processes and readings.

M: = Measurement (accumulative flow)
F: = Flow (liquid flowing through defect in real time)
I: = Inlet Status of the priming tube (inlet pipe)

If the Control Unit is in any screen, apart from Test or Monitor. The Sensor Transmitter will be in RESET mode.
When RESET is seen the Measurement reading will be 'Absolute'.

When RESET is not seen the Measurement is 'Differential'.

Sensor Transmitter Charging
The Sensor Transmitter contains 4 x 'AA' High Capacity rechargeable batteries.
The Charger should be connected for at least 1.5 hours.

Charged batteries should last at least 10 Hours. The Sensor Transmitter has an Auto-Off facility (15 mins of no Control Unit comms).

**DETERMINING IF THE HEAT EXCHANGER HAS FAILED**

The following criterion determines if the heat exchanger has failed the Hexteq test;

- Minimum test pressure of > 3 bar not achieved, possibly due to poor seals (gaskets).
- Any consistent rise during test period showing defect diameter > 20 microns.
- If there is a defect below 20 microns, the client shall be offered more frequent testing in order to monitor the defect for propagation into the rejectable defect zone > 20 microns.
- If any consistent rise is observed over the period of the test, the test is to be repeated for the same period with no differential pressure. Then the high pressure is to be re-set to the original condition for the same period. The test results are to be evaluated as follows;
- If during the second period, there is no rise, and during the third period there is a significant rise, then the pack has failed.
- If during the second period, there is a rise, then the complete test is to be re-started, as this would indicate unacceptable pressure fluctuations and spurious indications.

**REPORTING**

- On completion of the test, the test results shall be recorded for certificate generation.
- The Master Certificate confirming the test results shall be produced by the Hexteq Operator, and posted to the client, containing the following information;
- Hard copy of the test data.
- Client, contact, location.
- Order number, Job number, Test Procedure.
- Heat exchanger make, Type, Serial number, test restrictions. Identification of sides tested then reversed, for example "Hot HP" means HP on Hot service side, and "Product HP" means High Pressure on Product side.
- Operator, date, signature.

**OPERATORS ACTIONS AFTER HEXTEQ REJECTION OF HEAT EXCHANGER**

The client is to be informed of the rejection and given the following options;

- Acceptance by the client of additional work required.
- The client is to be offered a Hexteq re- test after any dismantling of defective plates.

**CALIBRATION**

- Calibration of the Hexteq equipment is carried out annually in accordance with the requirements of the EIT International System quality management. The items requiring calibration are;
- The Hexteq Control Unit / Sensor Transmitter Unit / High Pressure unit.

**OPERATOR QUALIFICATIONS AND TRAINING**

- All Operators shall be trained and examined for the tests they are to perform. The Operator shall be assessed through examination with a pass / fail.
- The period of validity is 12 months from the examination date. Re: qualification is the responsibility of the Operator, who shall apply in writing to EIT International , 4 weeks prior to the expiry date. Failure to re: qualify will result in withdrawal of certification. Additional training shall be given where techniques or operational procedures have been changed.
- Each Operator will be issued with a certificate showing the level of qualifications attained.

**REFERENCES**

- BSEN ISO9001 - Model for quality assurance in design / development / production / installation and servicing.

**ASSOCIATED DOCUMENTS**

- Operator qualification Certificate and training program.
- Calibration and certification of Hexteq equipment.
- Hexteq Validation documents.
- Hexteq Interim Report sheet
- Hexteq Test Certificate
- Set-up Procedure for the client to make the heat exchanger ready for Test

**HEXTEQ VALIDATION DOCUMENT**

Testing of Hexteq Heat Exchanger Leak Detection System.

For

EIT International
Biopharma House,
Winnall Valley Road
Winchester
SO23 0LD, UK
Tel: +44 (0)1962 841092
enquiries@eit-international.com

**Introduction.**

A Hexteq Satcomm 3 heat exchanger leak detection system was supplied for testing by EIT International , of the above address.

The requirement of the test programme was to assess the accuracy and repeatability of hole size determination when the equipment was attached to a heat exchanger circuit containing a simulated leak in the form of a nozzle of known aperture size.

The Hexteq leak detection kit is a portable test system designed to assess the integrity of plate: pack heat exchangers and consists of three items of equipment. The inlet meter measures the real time inlet manifold pressure for the duration of the test. The flow rate measuring device measures the flow of fluid through the leak from the high pressure to the low pressure side of the heat exchanger. Water from the low pressure side is fed via a tube into the unit, initially filling an inlet pre: chamber. When the unit is primed with sufficient fluid, the water passes into a secondary measurement chamber which then fills to a set volume before automatically dumping the charge and restarting the fill cycle. The sensitivity of the measuring system is such that the magnitude of this flow rate can be only a few microlitres per second.

Each test is controlled by the hand held test process controller and data acquisition unit. This component also collects the data from the measuring head and the pressure meter at the end of each test and calculates the flow rate, from which and estimation of the hole size is also made. The data acquisition unit can store data from up to 80 separate tests before requiring download. All three items of electronic equipment are linked by wireless communication for data transfer and a GPS unit is also included to provide positional information for each individual test. At the end of a test programme the results are uploaded to a computer via a USB link for final processing.

**Method.**

A test circuit was assembled to simulate a faulty heat exchanger consisting of a number of heat exchanger elements held within a suitable manifold. A series of nozzles, each with a laser: drilled hole of different nominal size were used to represent the actual leak. A high pressure water supply produced via a hand pump was applied to one side of the heat exchanger and the resulting egress from the nozzle, plumbed in parallel with the heat exchanger, was fed to the Hexteq flow rate measuring system via the heat exchanger open side circuit to simulate service conditions. The equipment as set: up for testing is shown in figures 1 to 4.

A number of combinations of differing inlet pressures and nozzle sizes were tested in order to assess the repeatability and hole size estimation accuracy of the test system.

Further verification of the hole sizes in the test nozzles used was carried out using images produced in a scanning electron microscope, these images incorporating a scale bar for direct measurement of aperture size.

Nozzles with 100um, 50um, and 25um apertures were used for the tests and an inline filter was incorporated into the circuit to minimize the risk of partial or complete blockage of the test nozzles. All nozzles were ultrasonically cleaned and blown through with compressed air prior to use.

Each of the other three nozzles were tested at 5, 3 and 1 bar inlet pressure. The suitability of the hole size calculation formula embedded in the software of the test equipment was also assessed. A minimum of three tests were carried out for any one set of conditions.

**Results.**

At the end of the test programme all results were uploaded to a computer and the flow rate charts containing all relevant test data were printed off. The estimated hole sizes for each test were extracted from the test charts and are shown in table 1 along with the calculated flow rates and start and finish test pressures. Copies of all the test charts are included at the end of this report.

Images of the apertures in the three test nozzles used during the course of this programme are shown in figures 5 to 7. These were taken using a JEOL 6310 scanning electron microscope after the tests were completed. The hole size (or an estimate of) can be determined by reference to the scale bar shown in each image. It can be seen that although the 100 micron aperture appears clear, there is significant disruption to the profile of both the 50 and the 25 micron nozzles. It is noted that the 25 micron nozzle gave some of the most consistent results during use but that no flow was observed when the 1 bar tests were started despite two attempts at cleaning. For this reason, no further tests were carried out at this lowest pressure.

**Discussion.**

From the data shown in table 1 it can be seen that the repeatability of measured values within any one test group is good but the estimated hole sizes do not always match with the stated nominal hole size. The main reason for this apparent discrepancy in actual and calculated hole size in some of the test condition groups probably lies in the susceptibility of the test nozzles to partial flow restriction by particles within the water circuit. Examples of the nozzle apertures directly after testing, as shown in the SEM images, show clearly the potential for blockage to have an impact on these measured values.

The required objective of this test programme was to assess the repeatability of test results and estimate of measured hole size under a range of different operating conditions. The results show that given a set of stable flow conditions the measured values are consistent but that in some instances the measured aperture size does not match the stated nominal nozzle size. However, given that the test nozzles are very susceptible to partial blockage it ca be assumed that the actual flow rates used to calculate the nominal hole size have all been accurately and consistently determined by the test equipment. The embedded formula for calculating the size of the aperture is based on flow through a uniformly round aperture, a condition unlikely to be encountered in a corroded heat exchanger cell. This approach does however give a good first estimation of the likely size of aperture present and the sensitivity of the equipment to flow of any kind is a first and most important step to determining whether or not a fault exists.

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20th February 2007.

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| Client: | Address: |
| Client contact: | Client Order: |
| Job number: | Test date: |
| Inspector: | Test Procedure: |
| Risk assessment: Low Medium High (delete as appropriate) | Equipment Serial Number: |
| **EXAMINATION PARAMETERS AND RESULT:** | |
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| HOURS | **MONDAY** | **TUESDAY** | **WEDNESDAY** | **THURSDAY** | **FRIDAY** | **SATURDAY** | **SUNDAY** |
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| **TRAVELLING** | | | | | | | |
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| Inspector: | Signature: | Date: |
| Client: | Signature: | Date: |