solartron mobrey

Precision measurement solutions

7828

Density Transmitter

TECHNICAL MANUAL
78285000

CE

Solartron-Mobrey pursues a policy of continuous development and product improvement. The specification in this document may therefore be changed without notice.

IMPORTANT

HANDLE THE 7828 WITH CARE

DO NOT	drop the transmitter.
DO NOT	use liquids incompatible with materials of construction.
DO NOT	operate the 7828 above its rated pressure**.**
DO NOT	pressure test beyond the specified Test pressure.
ENSURE	all explosion proof requirements are applied
ENSURE	transmitter and associated pipework are pressure tested to 1½ times the maximum operating pressure after installation.
ALWAYS	store and transport the 7828 in its original packaging.

Contents

SECTION 3 - ELECTRICAL INSTALLATION

SECTION 4 - USING ADVIEW

SECTION 5 - CALIBRATION CHECK

SECTION 6 - MAINTENANCE

APPENDIX A - SPECIFICATION

APPENDIX B - CALCULATED PARAMETERS

APPENDIX C - SAFETY CERTIFICATION

APPENDIX D - MODBUS COMMUNICATIONS

1
Introduction

1.1 ABOUT THE 7828 DENSITY TRANSMITTER

1.1.1 WHAT IS IT?

The 7828 Density Transmitter is based on Solartron's proven tuning fork technology. It is an all-welded sensor designed to be mounted directly in-line or into a tank. Density is determined directly from the resonant frequency of the tuning fork immersed in the fluid, and a temperature sensor (PRT) is also fitted within the transmitter.

The transmitter contains integral processing electronics to provide full 'on node' configuration, enabling it to perform a variety of calculations. Two outputs are available:

1. A direct **4-20mA output** giving an output proportional to a user selected process parameter or calculation result, with configurable span, bias, limits and filter options:
   - line density
   - line temperature
   - °API
   - S.G.
   - base density (API)
   - base density (Solartron matrix method)
   - special calculation result.
2. An **RS485(Modbus) interface**, giving access to other measurement results, system information and configuration parameters.

No signal converter is required, which simplifies wiring and enables the 7828 to be connected directly to a plant monitoring and control systems and/or a local indicator.

The 7828 is factory set to perform either API or Matrix referrals. Re-configuration of the 7828's default settings (see Appendix A) is achieved by linking a PC to the Modbus (RS485) connection and running Solartron's ADView software. Once configured, the PC can be removed.

1.1.2 7828 MEASUREMENTS

The 7828 measures the following fluid properties:

- Line Density (Measured in kg/m^3, g/cc, lb/gal, or lb/ft^3)
- Temperature (Measured in **°C** or **°F**)

From these properties, the following are calculated:

- API base density at 15°C, 1.013bar; or at 60°F, 14.5psi
- Base density by the Solartron matrix referral method
- °API
- S.G.
- Special function calculations such as °Brix, °Baume, °Twaddle, % solids, etc.

1.1.3 WHAT IS IT USED FOR?

The 7828 Transmitter is ideally suited to applications where continuous real time measurement of density is required, for example in process control where density is the primary control parameter for the end product, or is an indicator of some other quality control parameter such as % solids or % concentration.

Some examples are:

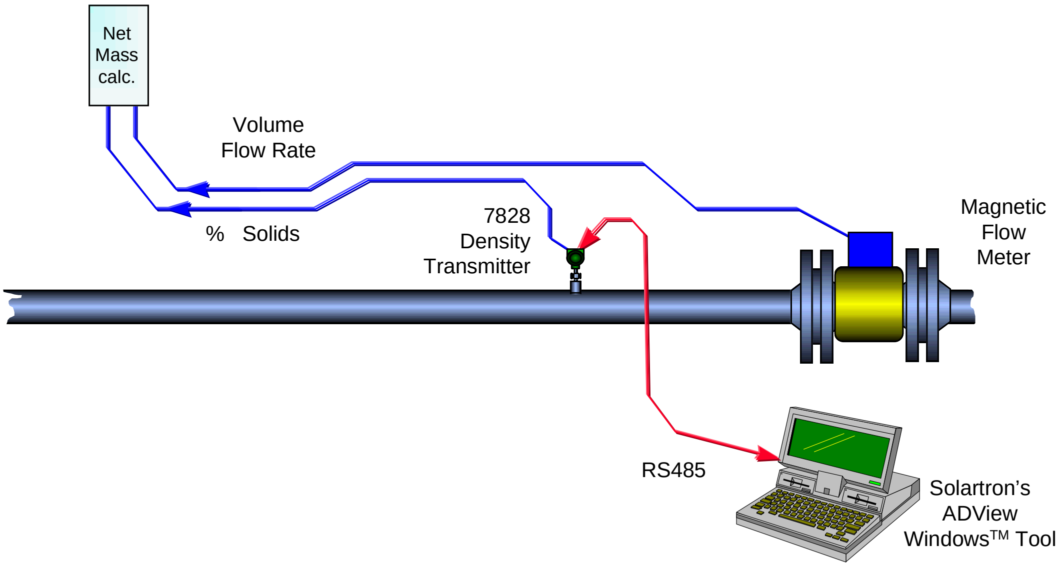
- Blending
- Mixing
- Evaporator control
- End point detection in batch reactions
- Interface detection in continuous separators
- Interface detection in multi-product pipelines

Typical industries include:

- Oil and petrochemical
- Brewing
- Food
- Pharmaceutical
- Minerals processing (clays, carbonates, silicates, etc.

1.1.4 TYPICAL 7828 APPLICATION

Net Mass flowrate calculation



This shows and outline of a typical wet process mineral application where 7828 provides a 4-20mA signal of the %solids determination from the slurry stream. From this signal and the measured volumetric flowrate, net mass flowrate is determined.

The output signal could also be used for %solids control or for net mass flow rate ratio blend control.

The optional RS485/Modbus connection to a PC running ADView can be used for configuration and access to other measured values.

1.2 7828 OPTIONS

A number of options are available for the 7828. They are identified by suffixes appended to the transmitter type number. The table below summarises these. Some of the suffixes are allocated to future developments and the letter code is currently fixed.

Part number			7828	*	*	A	*	A	*	L	*	B	*	*
Wetted parts: materials and finish														
Stem + connections	***Tines***	***Finish***												
316 Stainless Steel	316 Stainless Steel	Standard		**A**										
316 Stainless Steel	316 Stainless Steel	Electro-polished		**C**										
316 Stainless Steel	316 Stainless Steel	PTFE laminated		**F**										
Hastelloy C22	Hastelloy C22	Standard		**E**										
Hastelloy C22	Hastelloy C22	Electro-polished		**D**										
Hastelloy C22	Hastelloy C22	PTFE laminated		**G**										
Monel 400	Monel 400	Standard		**H**										
Monel 400	Monel 400	Electro-polished		**J**										
Monel 400	Monel 400	PTFE laminated		**L**										
Special	Special	Special		**S**										
Sensor electronics														
Standalone (on-node): 4-20mA		BASEEFA EEx d IIC T4			**C**									
Process connections														
2" ANSI 150RF							**A**							
2" ANSI 300RF							**B**							
2" ANSI 600RF							**C**							
2" ANSI 900RF							**D**							
2" ANSI 1200RF							**E**							
2" ANSI 1500RF							**F**							
50mm DIN 2527 RF DN50/PN40							**G**							
50mm DIN 2527 RF DN50/PN100							**H**							
2" Ladish Triclamp (Hygienic)							**J**							
3" Ladish Triclamp (Hygienic)							**K**							
2" IDF (Hygienic)							**L**							
3" IDF (Hygienic)							**M**							
40mm Cone seat compression fitting							**N**							
Special							**S**							
Factory Configuration														
Line density									**A**					
API Base density									**B**					
Matrix base density									**C**					
Factory Calibration type														
Free stream											**A**			
2" boundary (Sch 40)											**B**			
3" boundary (Sch 40)											**C**			
Special											**S**			
Traceability														
None													**A**	
Certificate of materials traceability													**X**	
Manufacturing status			Factory determined											

2
Mechanical Installation

2.1 INTRODUCTION

There are a variety of external factors which affect the ability of the 7828 to operate successfully. In order to ensure that your system works correctly, the effects of these factors must be taken into consideration when designing your installation.

There are two main aspects to consider:

1. The **accuracy and repeatability** of the measurements;
2. The **relevance** of the measurements to the **overall purpose** of the system.

Factors which may adversely affect **accuracy and repeatability** include:

- The presence of gas or bubbles within the fluid being measured
- Non-uniformity of the fluid
- The presence of solids as contaminants
- Fouling of the transducer
- Temperature gradients
- Cavitation and swirls caused by valves or discontinuities in the pipework
- Operating at temperatures below the wax point of crude oils
- The measured fluid being unrepresentative of the main flow.

In some applications, absolute accuracy is less important than repeatability. For example, in a system where the control parameters are initially adjusted for optimum performance, and thereafter only checked periodically.

The term **achievable accuracy** can be used to describe a measure of the product quality that can be realistically obtained from a process system. It is a function of measurement accuracy, stability and system response. High accuracy alone is no guarantee of good product quality if the response time of the system is measured in tens of minutes, or if the measurement bears little relevance to the operation of the system. Similarly, systems which require constant calibration and maintenance cannot achieve good achievable accuracy.

Factors which may adversely affect the **relevance** of the measurements could include:

- Measurement used for control purposes being made too far away from the point of control, so that the system cannot respond properly to changes;
- Measurements made on fluid which is unrepresentative of the main flow.

This chapter has the following sections:

Section 2.2 - The importance of boundary and viscosity effects

Section 2.3 - Mechanical details for mounting and installing 7828

Section 2.4 - Optimising measurement accuracy and repeatability

Section 2.5 - Commissioning the system

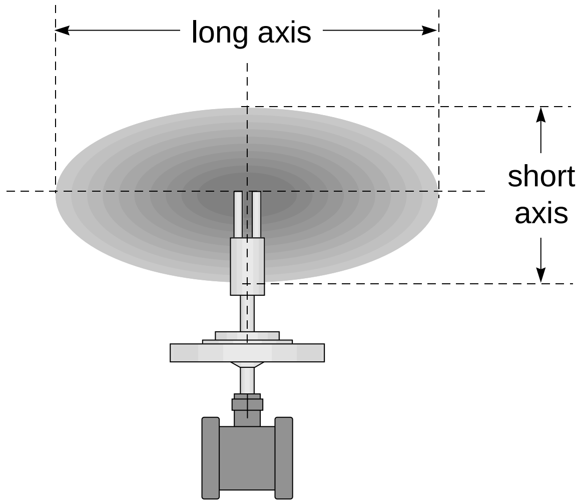
2.2 BOUNDARY AND VISCOSITY EFFECTS

Unlike Solartron's tube density sensors, the tines of the 7828 are not totally enclosed. The walls of the pipe or tank in which the transmitter is installed will introduce boundaries to the fluid flow, and this will have an effect on the calibration of the sensor. To overcome this, Solartron calibrate the 7828 under a variety of pre-defined conditions corresponding to the installation and pipe schedule. This condition is selected when ordering the 7828, so that, by calibrating the sensor under the same boundary conditions as the installation, the need for additional on site calibration is eliminated.

2.2.1 BOUNDARY EFFECTS

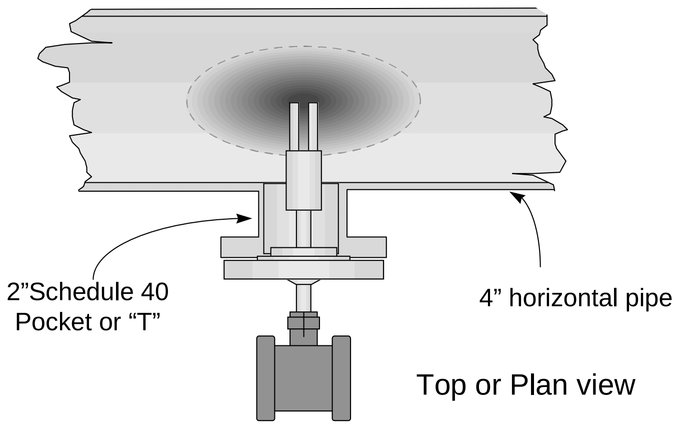
Any insertion device or transducer can only measure the properties of the fluid within the region of fluid to which it is sensitive.

For practical reasons it is helpful to consider the sensitive or ***effective region*** for the transmitter as an three-dimensional ellipse centred on the tips of the tines with its long axis aligned with the direction in which the tines vibrate, as shown below. The 7828 is insensitive to the properties of the fluid outside this region.

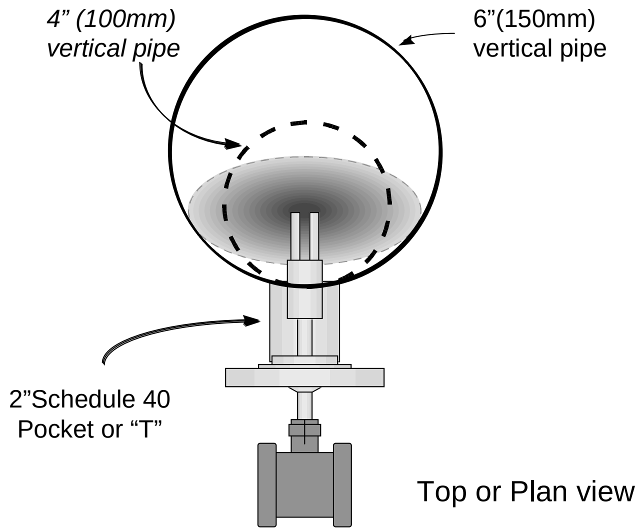


If part of this volume is taken up by the pipework or fittings there is said to be a boundary effect; i.e. the intrusion of the pipe walls will alter the calibration.

The diagram below illustrates the 7828 installed in a pocket on the side of a 4" (100mm) horizontal pipe line (viewed from *above*). The *effective region* is completely enclosed within the pipe line and thus is completely fluid.

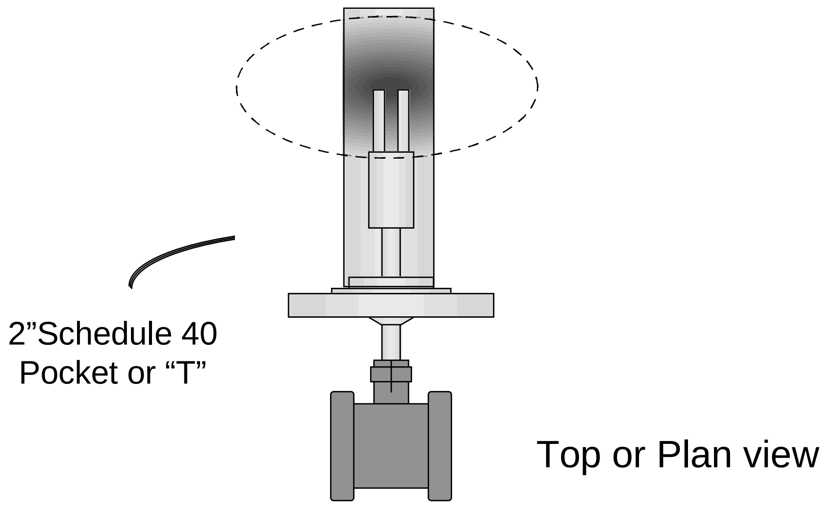


This next view shows other pipe outlines superimposed:



The smaller circle represents a 4" vertical pipe, which intersects the *effective region*. The 6" (150mm) pipe is the smallest pipe diameter to completely enclose the *effective region* when the pipe is vertical. Thus smaller pipe diameters can lead to a variety of different geometries which would each require a separate calibration.

An alternative condition is shown in the next diagram where the side pocket is extended until it passes completely through the *effective region* producing a "core":



From this, it would appear that almost every installation requires a separate in situ calibration - a very undesirable situation. The problem is resolved by providing standard calibration geometries which can be used in all pipe work configurations and thereby allow the factory calibration conditions to be reproduced in the process. These standard geometries are described in section 2.3.

2.2.2 VISCOSITY EFFECTS

The 7828 can be affected by the viscosity of the fluid surrounding it. This is manifested in two ways:

1. An error in the density measurement, due to the effect of viscosity on the vibration of the fork tines;
2. In T-piece installations, where the 7828 is retracted into a pocket away from the main fluid flow, high viscosity impedes the flushing of fluid near the tines. This may mean that, if a step change in density occurs, the fluid being measured will not representative of the fluid in the main flow, and the density response time may be extended significantly.

A summary of these effects and the action to be taken to minimise them is given below:

Viscosity range	***Remedy***
<u>*T-piece installations only:*</u>	
Less than 100cP:	None required
Greater than 100cP:[1]	Density measurements may be unpredictable; use flow-through chamber or free stream installation
<u>*All other installations:*</u>	
Up to 500cP	None required
500 to 20,000cP steady:	Perform simple on-site calibration to derive density offset adjustment (see Calibration section)
500 to 20,000cP variable:	
- where changes in density and viscosity are correlated:	Perform three-point on-site calibration to derive revised K0, K1 and K2 factors - consult Solartron
- where there is little or no correlation between viscosity and density:	Consult Solartron for advice.
Above 20,000cP	Density measurements may be unpredictable

[1] *Where the main flow is greater than 1.5m/s and there is no waxing present, the T-piece installation can be used for viscosities not exceeding 250cP.*

2.3 STANDARD INSTALLATIONS

To overcome the need for in-situ calibration for every installation, three 'standard' installations are proposed. If an installation conforms to one of these standards, the factory calibration of the 7828 is valid, and in-situ calibration unnecessary. The three installations are summarised below.

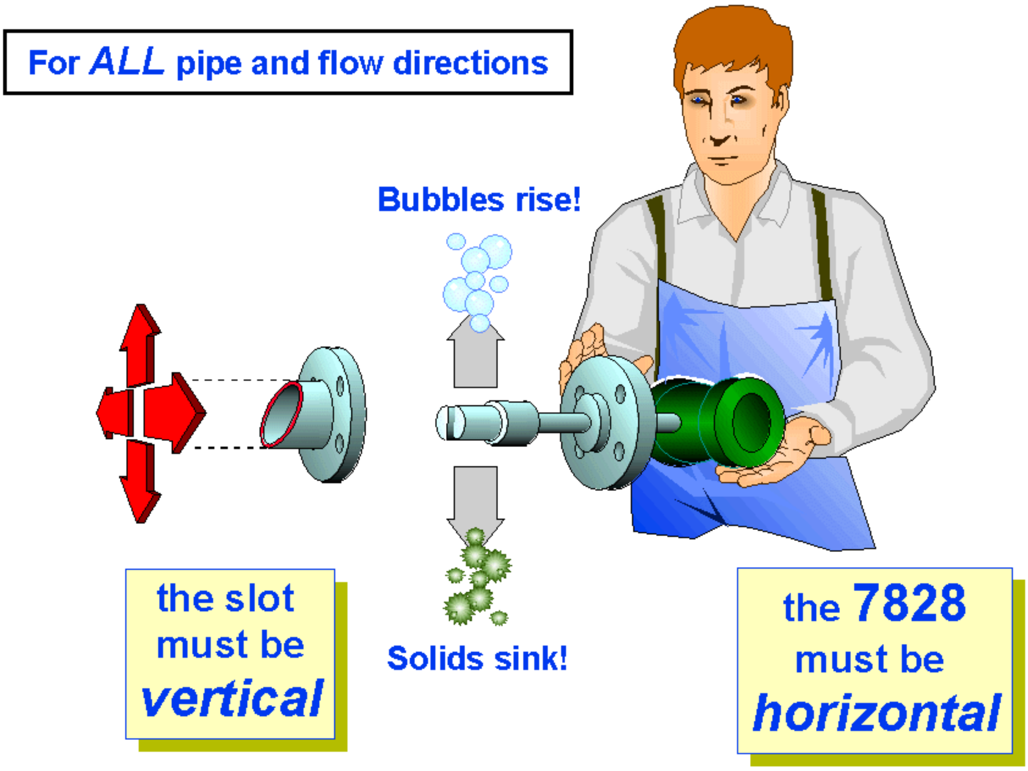
Standard installation	***Free stream***	***T-piece*** ***(2in or 3in dia., pipe or weldolet)***	***Flow-through chamber***
Description	7828 tines project directly into the main fluid flow	7828 tines are contained in a side pocket off the main flow, recessed by 25.4mm (1in.).	7828 tines are contained in a flow-through chamber in which fluid is circulated from the main flow
Flow rate	0.3 to 0.5 m/s *(0.98 to 1.6 ft/s)* at the 7828	0.5 to 3 m/s *(1.6 to 9.8 ft/s)* at main pipe wall	10 to 30 l./min (2.6 to 8 US gal./min)
Viscosity limits	Up to 20 000cP	Up to 100cP (250cP in some cases)	Up to 20 000cP
Temperature	-50 to 200°C (-58 to 392°F)	-50 to 200°C (-58 to 392°F)	-50 to 200°C (-58 to 392°F)
Main flow pipe size	100mm (4") horizontal 150mm (6") vertical, or larger	50mm (2") or larger	Any
Advantages	• simple installation in large bore pipes • ideal for clean fluids and non-waxing oils	• simple installation in large bore pipes • ideal for clean fluids and non-waxing oils	• adaptable installation to any diameter main pipe and for tank applications • ideal for flow and temperature conditioning • fast response
Drawbacks	Not suitable: • for low or unstable flow rates • for small bore pipes	Not suitable: • for dirty fluids or slurries • for low or unstable flow rates • where step changes in viscosity can occur • for small bore pipes • where temperature effects are significant	• careful system design required to ensure representative measurement • frequently requires the use of a pump

For tank installations, always consult Solartron.

2.3.1 7828 ORIENTATION

For Free-stream and T-piece installations, it is essential that the 7828 is always orientated with the transducer horizontal and the slot between the tines vertical.

This is irrespective of the pipe line orientation, and helps to prevent the trapping of bubbles or solids on the transducer.



> **Note:** All drawings and dimensions given in the following sections are derived from detailed dimensional drawings. They are given here for planning purposes only. Before commencing fabrication, reference should always be made to the current issue of the appropriate drawings - contact Solartron for details.

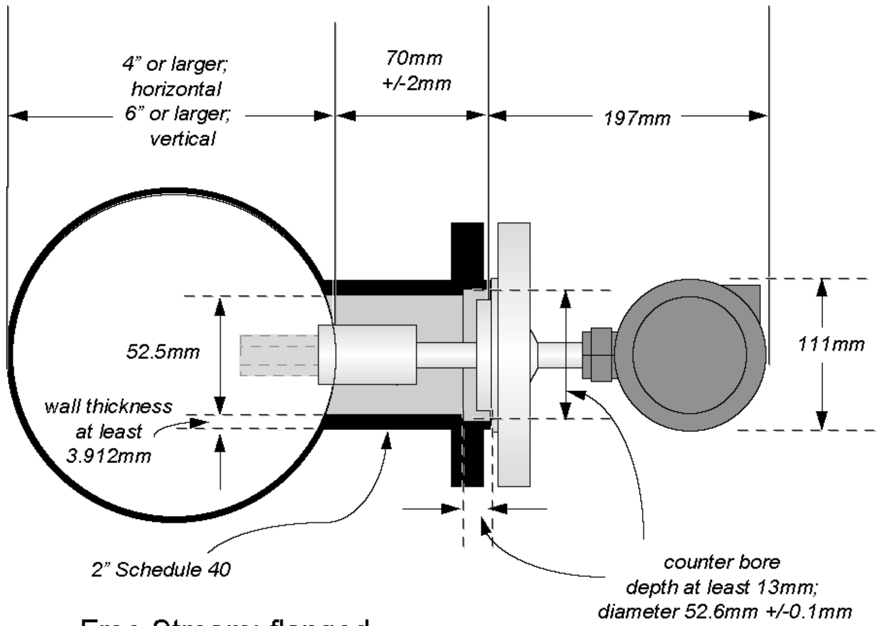
2.3.2 FREE STREAM INSTALLATION - FLANGED FITTING

Conditions:

Flow:	0.3 to 0.5m/s (at the transducer)
Viscosity limit:	Up to 20 000cP
Temperature:	-50°C to 200°C

Note that the thermal mass of the flanges may affect the response time of the transducer to temperature changes.

The view shown below is schematic to show the dimensions of the side pocket, which is fabricated by the end user.



Free Stream; flanged

The pocket can be fabricated with 2” schedule 40, 80 or 160 tube without affecting the calibration.

Counter bore the pocket to a minimum depth of 13mm and diameter 52.6 ±0.1mm to locate the 7828 centrally.

Weld neck or slip-on flanges may be used, according to the flange rating selected. However, for higher rated flanges, only slip-on flanges may give the necessary clearances.

2.3.3 FREE STREAM INSTALLATION - WELDOLET

This is the preferred option where temperature variations are a critical factor. The reduced thermal mass of the weldolet's taper-lock fitting renders it more able to track rapid changes in temperature.

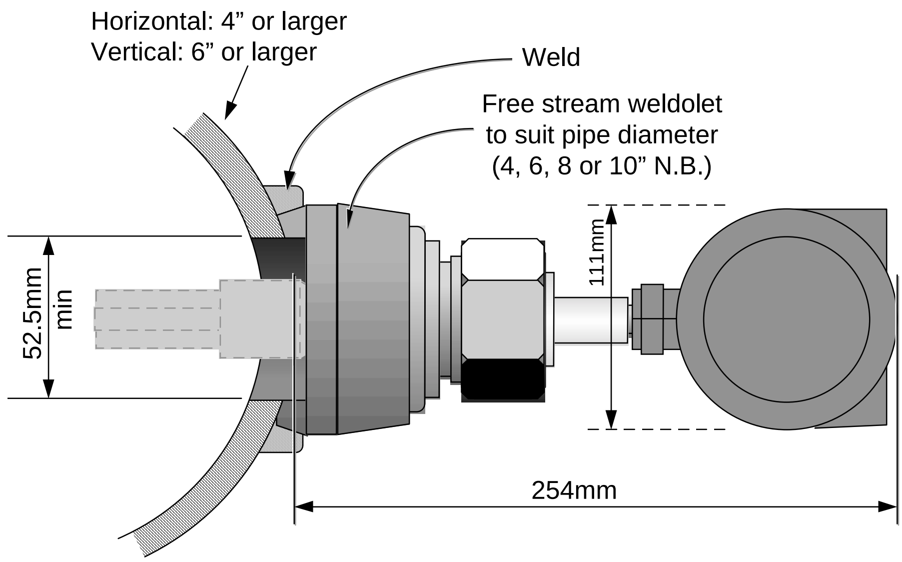
Conditions:

Flow:	0.3 to 0.5m/s (at the transducer)
Viscosity limit:	Up to 20 000cP
Temperature:	-50°C to 200°C

The weldolet has a 1.5" taper lock fitting, and is supplied to be welded on 4", 6", 8" or 10" pipelines. Use of the weldolet ensures that the tines of the 7828 are orientated correctly and are fully inserted into the fluid stream.

Before fitting the weldolet, the pipeline must be bored through at 52.5mm diameter to accept the viscometer. The weldolet must be welded to the pipeline concentrically with the pre-bored hole.

The view shown below is schematic to show the relevant dimensions.



Free stream: 1.5” Swagelok fitting

The installation will conform generally to Schedule 40 pressure ratings. The weldolet fabrication is rated to 100 Bar at ambient temperature.

Note: Correct installation and pressure testing of the fitting is the responsibility of the user.

2.3.4 T-PIECE INSTALLATION

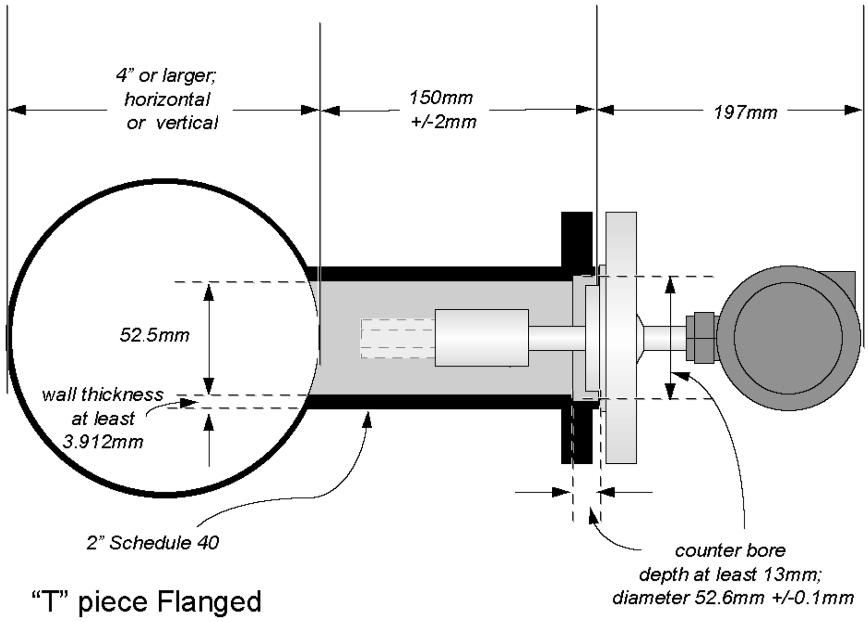
Conditions:

Flow:	0.5 to 3.0m/s (at the main pipe wall)
Viscosity:	Up to 100cP, or 250cP under some conditions (See section 2.2.2)
Temperature:	-50°C to 200°C

The thermal mass of the flanges may affect the response time of the transducer to temperature changes.

Flow velocity at the pipe wall and fluid viscosity must be within the limits shown to ensure that the fluid within the pocket is constantly refreshed. This installation will not respond as rapidly as the free-stream installation to step changes in viscosity.

The view shown is schematic to show the dimensions of the side pocket, which is fabricated by the end user.



"T" piece Flanged

The pocket geometry ***must be*** consistent with 2" schedule 40 tube in both internal diameter and minimum wall thickness, i.e.:

internal diameter:	52.5mm
minimum wall thickness:	3.192mm

Alternatively, schedule 80 or 160 tube may be used, but this affects the calibration, and must therefore be specified when ordering the sensor.

Counter bore the pocket to a minimum depth of 13mm and diameter 52.6 ±0.1mm to locate the 7828 centrally.

Weld neck or slip-on flanges may be used, according to the flange rating selected. However, for higher rated flanges, only slip-on flanges may give the necessary clearances.

For normal flow conditions (up to 3m/s at the pipewall), the tines should be retracted 25mm from the main pipe wall. For higher flow rates, increase this by 10mm for every 1m/s increase in main flow rate.

For **hygienic applications**, normal 2" hygienic tube is too thin for this application; (it can vibrate in sympathy with the fork, causing measurement errors). Use 3" hygienic tube and fittings instead, or fabricate hygienic fittings with the same wall thickness and internal diameter as those shown in the diagram above.

2.3.5 T-PIECE WELDOLET INSTALLATION

This is the preferred option where temperature variations are a critical factor. The reduced thermal mass of the weldolet's taper-lock fitting renders it more able to track rapid changes in temperature.

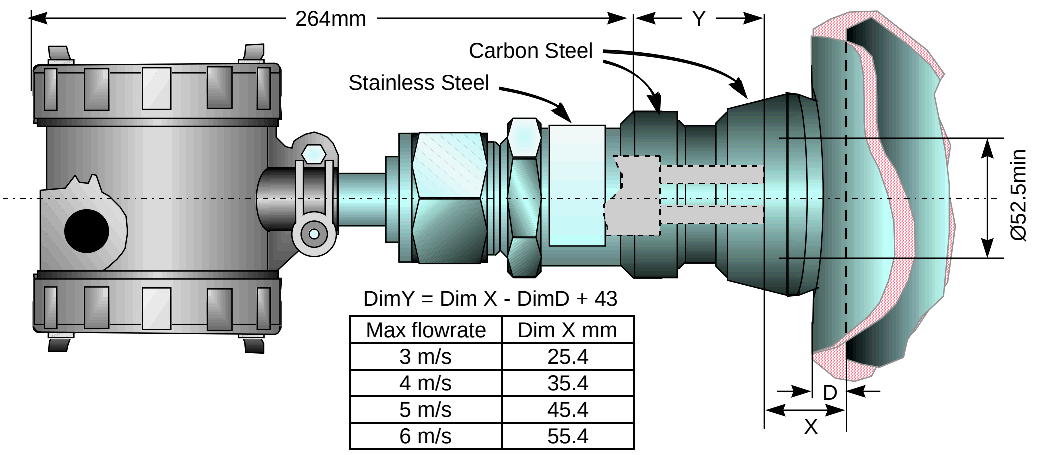
Conditions:

Flow:	0.5 to 3.0m/s at the main pipe wall Operation is possible with higher flow rates, if dimension X is increased *(*see diagram below*)*.
Viscosity limit:	Up to 100cP, or 250cP under some conditions (See section 2.2.2)
Temperature:	-50°C to 200°C

The weldolet has a 1.5" taper lock fitting, and is supplied to be welded on 4", 6", 8" or 10" pipelines. Use of the weldolet ensures that the tines of the 7828 are orientated correctly and are fully inserted into the fluid stream. The length of the weldolet is determined by the flow rate in the main pipeline (refer to the table in the diagram below), and is chosen to ensure that the tines of the 7828 are sufficiently retracted from the main pipe wall. Dimension X should be the smallest possible, consistent with the maximum expected flow rate.

Before fitting the weldolet, the pipeline must be bored through at 52.5mm diameter to accept the viscometer. The weldolet must be welded to the pipeline concentrically with the pre-bored hole. The view shown below is schematic to show the relevant dimensions.

Flow velocity at the pipe wall and fluid viscosity must be within the limits shown to ensure that the fluid within the pocket is constantly refreshed. This installation will not respond as rapidly as the free-stream installation to step changes in viscosity.



DimY = Dim X - DimD + 43

Max flowrate	Dim X mm
3 m/s	25.4
4 m/s	35.4
5 m/s	45.4
6 m/s	55.4

The installation must conform to Schedule 40 pressure ratings. Alternatively, schedule 80 tube may be used, but this will affect the calibration, and must be specified when ordered the sensor.

The weldolet fabrication is rated to 100 Bar at ambient temperature.

Note: Correct installation and pressure testing of the fitting is the responsibility of the user.

2.3.6 FLOW-THROUGH CHAMBER INSTALLATION

This chamber is fabricated by Solartron, and is available with either weld prepared ends or with flange or compression fittings for connection into the process pipe lines. It is available with 1” or 2” inlet and outlet pipes.

Note: The length of the inlet and outlet pipes must not be altered, otherwise the temperature response and stability of the fitting may be adversely affected.

Conditions:

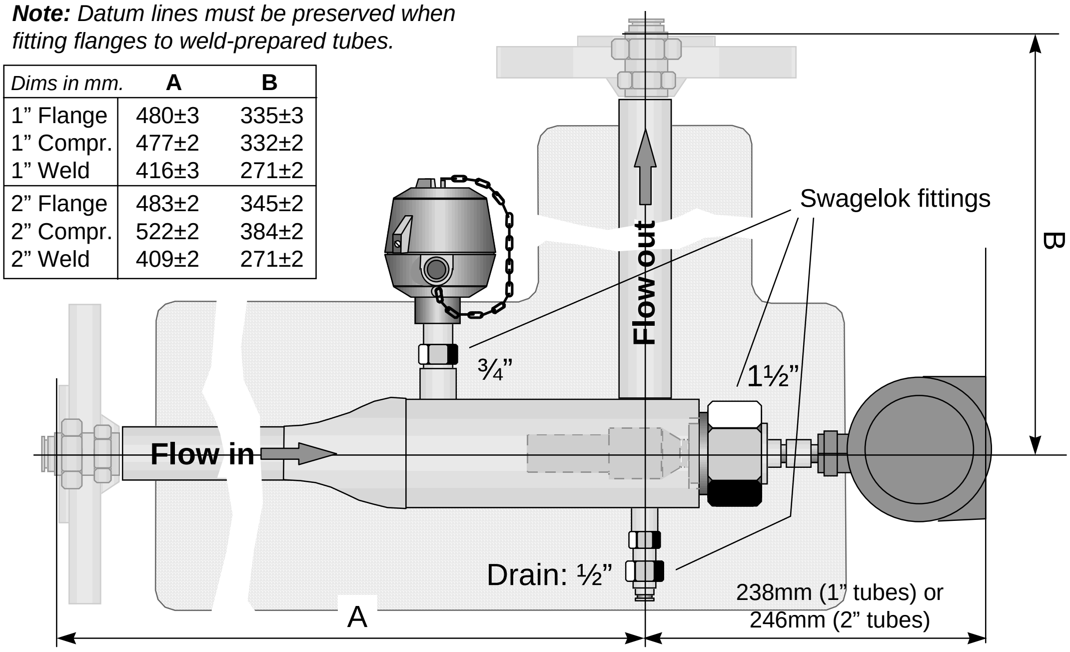
Flow:	constant, between 10 and 30 l/min
Viscosity limit:	Up to 20 000cP
Temperature:	-50 to +200°C
Pressure:	70 bar at 204°C, subject to process connections.

The PT100 is a direct insertion type, without a thermowell, and uses a ¾" Swagelok connection.

The diagram below shows the dimensions of this type of standard installation.

Note: *Datum lines must be preserved when fitting flanges to weld-prepared tubes.*

Dims in mm.	**A**	**B**
1” Flange	480±3	335±3
1” Compr.	477±2	332±2
1” Weld	416±3	271±2
2” Flange	483±2	345±2
2” Compr.	522±2	384±2
2” Weld	409±2	271±2



1" Flow-through chamber

For optimum results the fluid flowing through the chamber should be homogeneous (plug flow). This can be achieved by installing a static mixer immediately before the chamber.

Contact Solartron for advice about using flow-through chambers in hygienic applications.

2.4 INSTALLATION IN THE PIPELINE OR SYSTEM

Density is a sensitive indicator of change in a fluid - a key reason why density measurement is increasingly being chosen as a process measurement.

This means that measurements can be sensitive to extraneous effects and therefore great care must be taken to consider all the factors which may affect measurement when assessing the installation requirements.

Like many other transducers, the optimum performance of the density transmitter depends upon certain conditions of the fluid and configuration of the process pipe-work. By introducing appropriate flow conditioning, the optimum performance of the 7828 can be achieved at any chosen location in the process system.

You must first select a location which serves the application objective; e.g. installed close to the point of control. Then consideration can be given to fluid conditioning at that point. Where the application requirements allow a degree of tolerance in the point chosen for installation, the installation may be able take advantage of natural flow conditioning.

The choice of mechanical installation (free stream, "T" piece or flow-through chamber) will be dictated partly by application needs and partly by the fluid conditions, such as:

- Condition of fluid at the sensor
- Thermal effects
- Flow rate
- Entrained gas
- Solids contamination

2.4.1 FLUID AT THE SENSOR

The fluid in the effective zone of the 7828 must be of uniform composition and at uniform temperature. It must be representative of the fluid flow as a whole.

This is achieved either by mixing of the fluid either using a static inline mixer or taking advantage of any natural pipe condition that tends to cause mixing, such as pump discharge, partially open valves etc. The density transmitter should be installed downstream.

2.4.2 THERMAL EFFECTS

For high viscosity fluids, temperature gradients in the fluid and in the pipe work and fittings immediately upstream and downstream of the transmitter should be minimised in order to reduce the effect of viscosity changes.

Always insulate the transmitter and surrounding pipework thoroughly. Insulation must be at least 1"(25mm) of rockwool, preferably 2" (50mm) and enclosed in a sealed protective casing to prevent moisture ingress, air circulation, and crushing of the insulation. Special insulation jackets are available from Solartron for the flow-through chambers, which, because of the low volumetric flow rates and hence low heat flow, are more vulnerable to temperature effects.

Avoid direct heating or cooling of the transmitter and associated pipework upstream and downstream that is likely to create temperature gradients. If it is necessary to provide protection against cooling due to loss of flow, electrical trace heating may be applied, provided it is thermostatically controlled and the thermostat is set to operate below the minimum operating temperature of the system.

In cases where it is necessary to heat or cool the fluid - to bring it within the temperature range of the transmitter, for example - heat exchangers can be installed in the fluid flow. Solartron can provide more details on this, or provide a complete system if required.

2.4.3 FLOW RATE

Flow rates and velocities should be maintained relatively constant within the limits given. The fluid flow provides a steady heat flow into the transmitter, and the flow rate influences the self-cleaning of the sensor and the dissipation of bubbles and solid contaminants.

Where it is necessary to install the transmitter in a by-pass (either using the free stream installation in a 4” diameter horizontal by-pass, or a flow-through chamber), flow may be maintained using pressure drop, pitot scoop, or by a sample pump. Where a pump is used, the pump should be upstream of the transmitter.

2.4.4 ENTRAINED GAS

Gas pockets can disrupt the measurement. A brief disruption in the signal caused by transient gas pockets can be negated in the internal signal conditioning software, but more frequent disruptions or serious gas entrainment must be avoided. This can be achieved by observing the following conditions:

- Keep pipe lines fully flooded at all times;
- Vent any gas prior to the density transmitter;
- Avoid sudden pressure drops or temperature changes which may cause dissolved gases to break out of the fluid;
- Maintain a back pressure on the system sufficient to prevent gas break out; (e.g. back pressure equivalent to twice the headloss plus twice vapour pressure);
- Maintain flow velocity at the sensor within the specified limits.

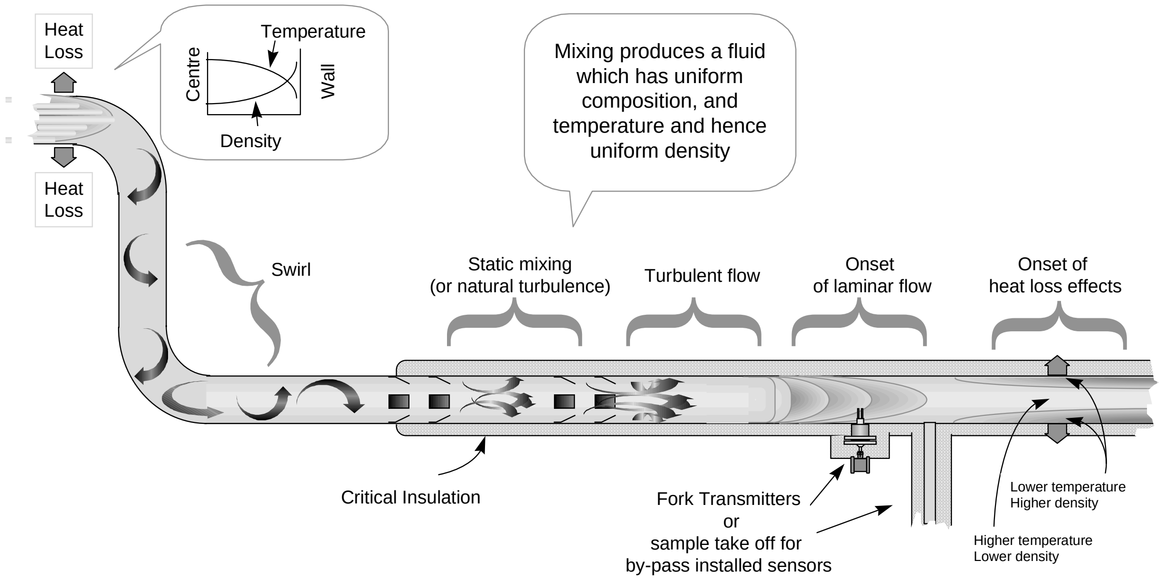
2.4.5 SOLIDS CONTAMINATION

- Avoid sudden changes of velocity that may cause sedimentation.
- Install the transmitter far enough downstream from any pipework configuration which may cause centrifuging of solids (e.g. bends).
- Maintain flow velocity at the sensor within the specified limits.
- Use filtration if necessary.
- Specify the 7828 transmitter with a non-stick PTFE protective layer.

2.4.6 EXAMPLE INSTALLATION

The diagram below illustrates some of the principles outlined in this section. It shows a free-stream density transmitter installation with an additional sample take off. The position of both is such that the static mixing (which could be caused by pump discharge or partially closed valve), has negated the adverse effects of bends and established laminar flow, and has ensured that the fluid is thoroughly mixed and thus of uniform composition and temperature. The ideal place for a free stream or “T” piece installation, or for the by-pass take off point is where the flow has just begun to be laminar.

Note that the insulation extends upstream and downstream far enough to prevent conduction losses in the pipe walls from degrading the temperature conditioning of the fluid at the sensor.



2.5 COMMISSIONING

1. Once the pipework installation has been prepared, and before installing the 7828, fit a blanking flange or compression nut to the 7828 mounting, and pressurise and flush the system.
2. Isolate the system, depressurise and remove the blanking flange or compression nut.
3. Install the 7828.
4. Slowly pressurise the system and check for leaks, particularly if the normal operating temperature is high, or the sensor has been fitted cold; tighten as necessary.
5. Once the system has stabilised and is leak free, fit the insulation material, remembering also to insulate any flanges.

3

Electrical Installation

3.1 INTRODUCTION

The 7828 density transmitter has two outputs:

- A direct 4-20mA output, configurable to give an output proportional to a user-specified range of either
  - density
  - base or referred density
  - temperature
  - a selected special function parameter;
- A Modbus (RS485) interface, giving access to other measurement results, system information and configuration parameters. The Modbus interface is also used to configure the 7828, using a PC running ADView software (see Section 4).

It is recommended that both outputs are installed, requiring a total of six wires (two for each output, and two for power). Although you may not immediately require the Modbus connection, it may be required for in-situ calibration adjustment and future system enhancements, and the cost of the additional wires is trivial compared to the expense of installing them retrospectively.

A number of factors must be taken into account when planning the electrical installation. These include:

- **Power supply** (Section 3.2.1)
- **EMC** (Section 3.2.2)
- **Ground connections** (Section 3.2.3)
- **Cables** (Section 3.2.4)
- **Surge protection** (Section 3.2.5)
- **Use in hazardous areas** (Section 3.5)
- **Modbus connections** (Section 3.4.2)
- **Analog connections** (Section 3.4.5)

Note: If 7828 is to be used in **hazardous** areas, the electrical installation must strictly adhere to the relevant safety drawings, given in Appendix C of the paper manual.

Additional information relevant to **hazardous** area installation is given in section 3.5.

3.2 INSTALLATION CONSIDERATIONS

3.2.1 POWER SUPPLY

The power supply to 7828 must have the following specification:

Voltage: Nominally 24V dc, but in the range 20 to 28V dc

Current: >50mA.

If several 7828 transmitters are to be used within a local area, one power supply can be used to power them all; where the transmitters are distributed over a wide area and cabling costs are high, it may be more cost effective to use several smaller, local power supplies.

The 4-20mA output is NOT self-powered, and requires a 15-28V dc power supply (see section 3.4.6). The main transmitter power supply can be used, if necessary.

If an RS232 to RS485 converter is to be used (for example to connect to a serial port on a PC), this may also require a power supply. The transducer power supply can be used to power the converter, or it may be more convenient to use a separate power supply.

Care should be taken where there is the possibility of significant common-mode voltages between different parts of the system. For example, if the 7828 is local powered from a power supply which is at a different potential to the RS485 ground connection (if used).

3.2.2 EMC

To meet the EC Directive for EMC (Electromagnetic Compatibility) it is recommended that the transmitter be connected using a suitable instrumentation cable containing an overall screen. This should be earthed at both ends of the cable. At the transmitter, the screen can be earthed to the transmitter body (and therefore to the pipework), using a conductive cable gland.

3.2.3 GROUND CONNECTIONS

It is not necessary to earth the transmitter through a separate connection; this is usually achieved directly through the metalwork of the installation.

The electronics and communications connections (RS485/Modbus and Analog 4-20mA) of the 7828 are not connected to the body of the transmitter. This means that the negative terminal of the power supply can be at a different potential to the earthed bodywork.

In the majority of applications, it is not necessary to utilise the RS485 ground connection. In areas where there is a significant amount of electrical noise, higher communications integrity may be obtained by connecting the negative power terminal (pin 2)of the 7828 to the communications ground. If this is done, it is important to ensure that the possibility of ground loops, caused by differences in earth potential, are eliminated.

3.2.4 CABLING

Although it is possible to connect separate cables to the 7828 for power, RS485 and the Analog output, it is recommended that all connections are made through one instrumentation-grade cable. Connections for the Analog and Modbus signals should be individually screened twisted-pairs with an overall screen, foil or braid for the cable.

Where permissible, the screen should be connected to earth at both ends. (At the 7828, this is best done using a conductive cable gland.)

Cables should conform to BS2538. In the USA, use Belden 9402 (two-pair) or Beldon 85220 (single-pair). Other cables that are suitable are those that meet BS5308 Multipair Instrumentation Types 1 and 2, Belden Types 9500, 9873, 9874, 9773, 9774 etc.

Maximum recommended cable length is 1000m (3200ft.), but care must be taken to ensure that the power supply at the transmitter is at least 20V. Thus, for 24V power supply, the overall resistance for the power supply connections (both wires in series) must be less than 100 ohms.

In addition to the cable, to complete the wiring you will need:

- ½" NPT to M20 gland adaptor
- M20 x 1 cable gland
- ½" NPT blanking plug

These are supplied with the 7828, but you may need alternatives to meet local electrical installation regulations.

In **hazardous areas** these items must be explosion-proof.

3.2.5 SURGE PROTECTION

Careful consideration should be given to the likelihood of power supply surges or lightning strikes. The power supply connections within the 7828 have a surge arrestor fitted to offer protection against power supply transients and, to some extent, indirect lightning strikes.

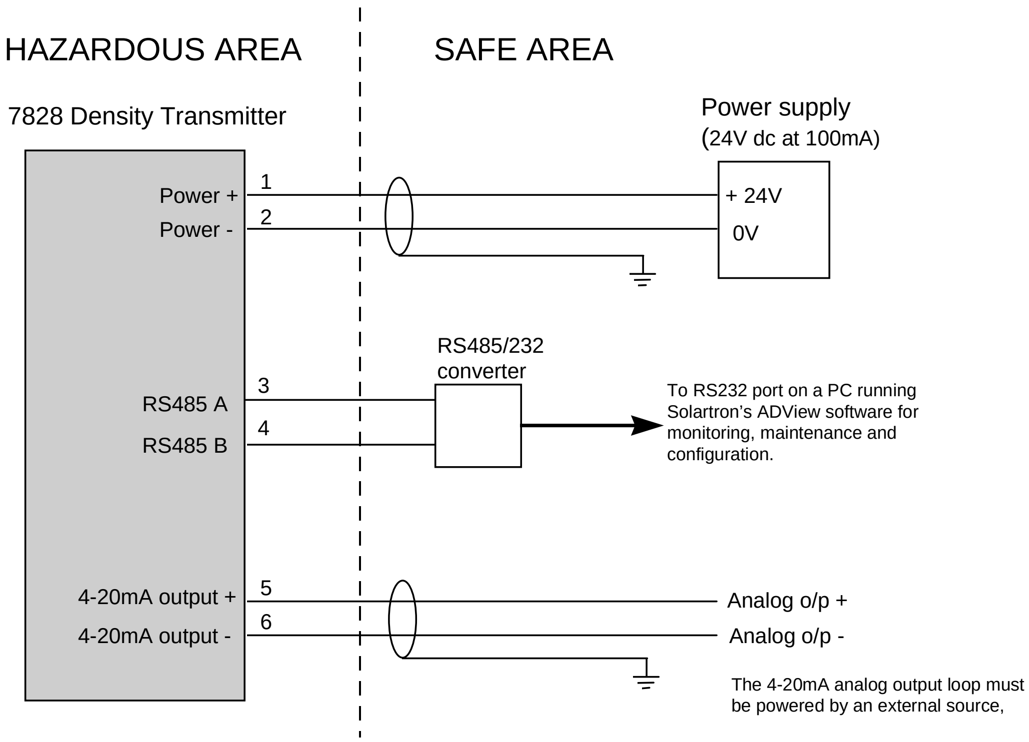
If there is a possibility of lightning strikes, external surge protection devices - one for each pair of signals and the power supply - should be installed as close to the 7828 as possible.

Another method is to connect an MOV (Metal Oxide Varistor) (breakdown voltage >30V) with an NE-2 neon bulb in parallel across each wire and ground. These can be mounted in a junction box close to the 7828.

Further protection may be offered by the use of an independently powered, fully isolated RS485 to RS232 converter, which is essential whenever the Modbus output is permanently connected to a PC. See section 3.4.3.

3.3 WIRING THE 7828

The wiring schedule for the 7828 is shown below.



Notes:

Always conform to local codes of practice and regulations.

The main 24V power supply must supply between 20 and 28V dc at 70mA.

The RS485/232 converter and PC are not normally installed permanently. However it is strongly recommended that the wiring to the 7828 is made at installation.

The 4-20mA analog output is not self-powered: an external supply is required. The main power supply can be used for this purpose if appropriate.

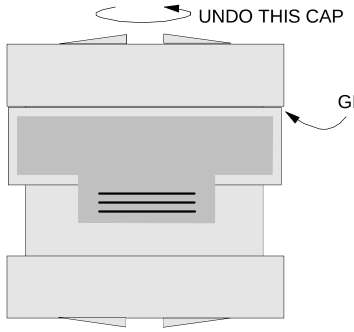
Typically, three pairs of shielded 19/0.30mm^2 (#16 AWG) to 19/0.15mm^2 (#22 AWG) wire are used for wiring.

The naming conventions for RS485 signals differ between manufacturers. If RS485 communications do not function correctly, try swapping the signals over at one end of the link.

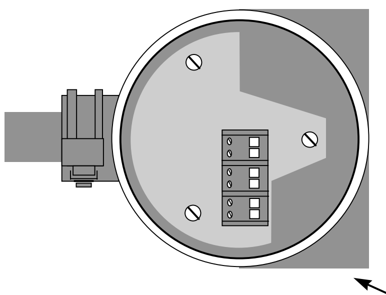
3.3.1 WIRING PROCEDURE

1 Open the Terminal Board side of the 7828 electronics housing by undoing the 2.5mm AF grub screw and unscrewing the lid anticlockwise.

VIEW FROM TOP OF 7828:

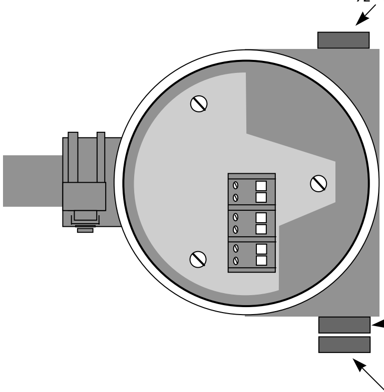


2 With the 7828 mounted horizontally to ensure that the slot in the tines is vertical, the ½" NPT holes will be in a vertical plane. The cable entry should be at the lowest point, to help minimise water ingress.

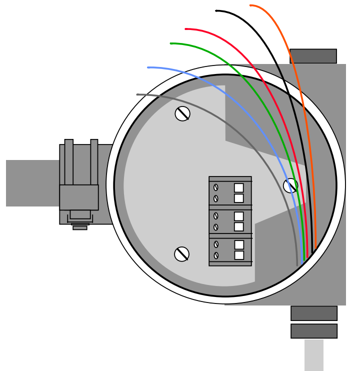


3 Fit the M20 gland adaptor into the lowest hole, then fit the M20 x 1 cable gland to the adapter.

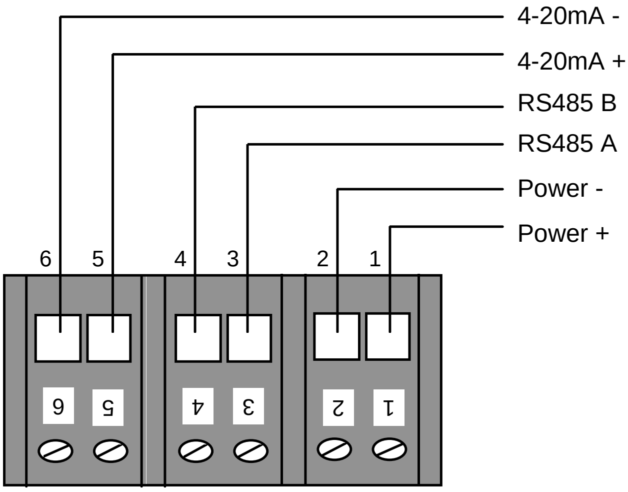
Fit the ½" NPT blanking plug to the unused hole in the 7828.



4 Insert the cable through the cable gland and adaptor so that the multi-core cable is gripped leaving 200mm of free, unscreened wire to connect to the terminal blocks.



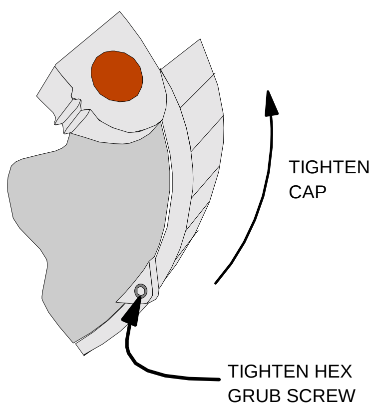
5 Wire up the cable cores as shown:



6 When you have screwed the wires into the correct terminals, carefully tuck the wires around the electronics, and tighten the cable gland

7 Finally, screw the housing cap on fully and tighten the locking grub screw using the 2.5mm AF hex drive.

VIEW FROM UNDERNEATH THE ELECTRONICS HOUSING



3.4 CONNECTIONS

The connections to the 7828 Density Transmitter are quite straightforward:

- Power
- RS485 (Modbus) Communications A/B
- Analog (4 - 20mA).

It is recommended that you install all three connections (six cores) at installation, to avoid the possibility of expensive alterations to the cabling at a later date.

3.4.1 POWER

Connect a suitable 24V power supply to pins 1 and 2 of the transmitter. Ensure that the loop resistance of the cables is such that the voltage at the transmitter terminals is greater than 20 volts. (The maximum voltage at the 7828 terminals is 28V.)

3.4.2 RS485

The Modbus standard uses the RS485 electrical standard. This uses the *difference* between the two signal cores to transmit and detect logic levels, and is therefore able to tolerate significantly higher levels of common mode noise than the more familiar RS232 standard, which utilises the voltage between the signal core and a common earth. A brief summary of some typical characteristics of the two standards is given below.

	RS485	***RS232***
Signal detection	Differential	Single-ended
Receiver threshold	200mV	+1.5V
Transmitter output swing	0 to +5V (no load)	± 8V
	+2 to +3V (120 ohm load)	

A converter is required for communication between the two standards. Further details are given in the next section.

Only two signal connections are required for RS485, usually called A and B, sometimes ‘+’ and ‘-‘.

Note: Unfortunately, different manufacturers have interpreted the standard in different ways. Some have a ‘logic 1’ represented by signal A being more positive than signal B, others have made the opposite interpretation. If you encounter communication difficulties with RS485, the first remedy is to swap over the A and B connections at one end of the network.

For areas which may experience high common mode signals, a third conductor can be used as a ground reference for the communications signals. If used, this should be connected to Pin 2 (Power supply negative) on the 7828.

3.4.3 RS485 TO RS232

Converters are available from a number of sources, and can range from simple, in-line devices which simply plug into a PC's RS232 port, to programmable devices with full isolation between the two networks.

Note: 7828 uses a half-duplex implementation of RS485, such that the A and B signals are used for data transmission in both directions. This requires that the RTS line is toggled to indicate the transmission direction. This can be done by the host computer, or automatically by an RS485/232 converter which has the facility to do so. If you are using Windows NT on your PC, you should use a converter which automatically changes RTS, (as detailed below), otherwise the link may not work correctly.

For **simple installations,** where the following conditions are valid, a simple in-line converter will be satisfactory:-

- the Modbus network is less than about 50m (150ft)
- the number of devices on the bus is low
- no common mode problems

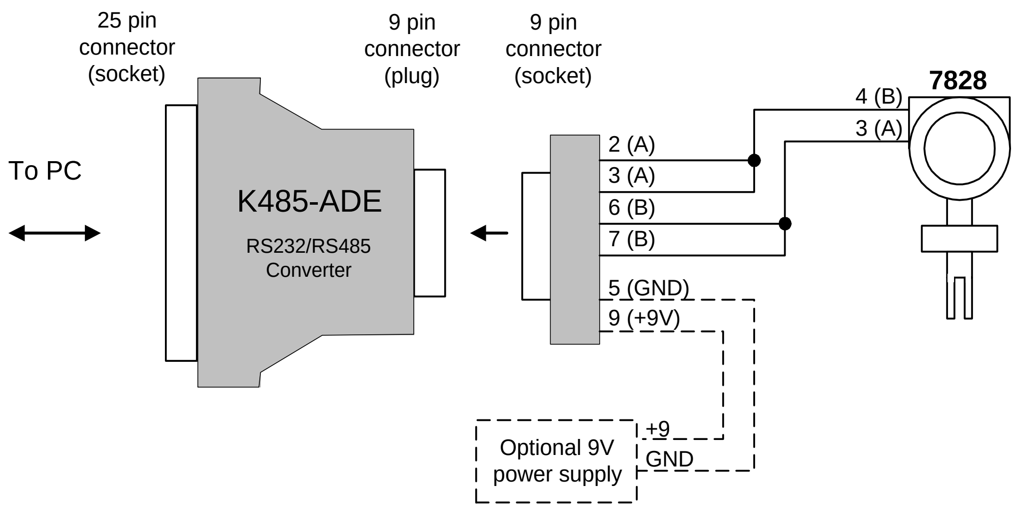
Solartron recommends the K485-ADE converter, manufactured by KK Systems Ltd and obtainable from Solartron (part number 550003520); this will work with Windows 3.1, 95, 98, and NT. The converter's RS485 connection is a 9-way plug, and the RS232 connector is a 25-way socket, which may require an adaptor to plug into the PC's RS232 port (commonly a 9-way plug).

Solartron's ADView software (part number 7828 1A) includes:

- ADView software
- K485-ADE RS485/RS232 converter
- 9-way socket for connections to the 7828
- PC adapter (25-way plug / 9-way socket)

The K485-ADE converter derives its power from the PC's RS232 port RTS or DTR line, which must be held permanently in the high state. This is normally adequate for short distances where there are only a few devices on the network. However, the ability of the port to supply sufficient power is not guaranteed, especially for laptop PCs, and it may be necessary to connect an external power supply. This may also be necessary if you are using Windows NT. In this case a 9V supply can be connected between Pin 9 (+) and Pin 5 (GND) of the RS485 connector. See the manufacturer's technical information for full details.

Connections are shown below. Note that the RS485 signals are reversed between the 7828 and the converter: A goes to B and vice-versa.



For **permanent installations**, and where the network length is more than 100m or so, Solartron recommend and can supply the following DIN-rail mounted device from KK Systems Ltd.

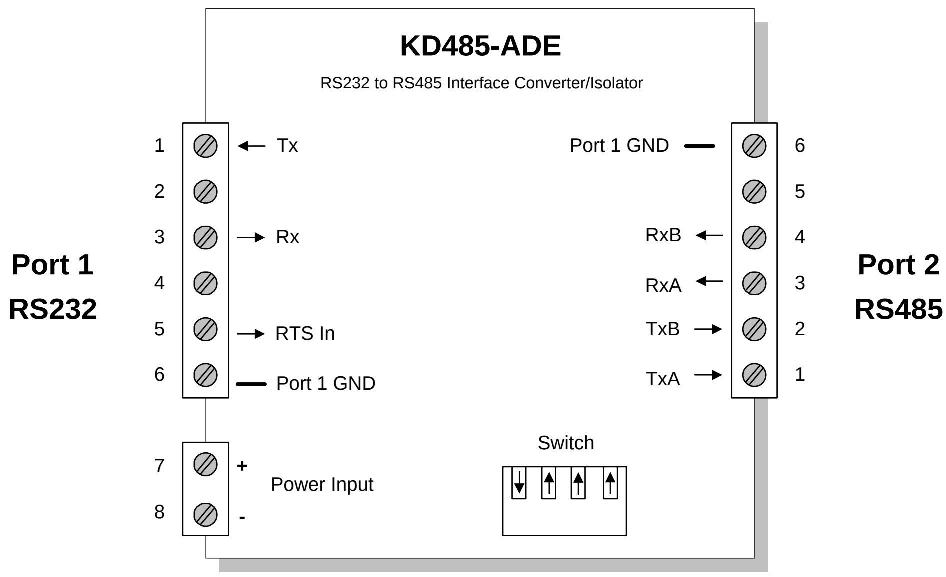
KD485-ADE Solartron part number 550003500

The KD485-ADE is three-way isolated, providing isolation between the two ports and the power supply. It requires a +7 to +35V power supply and typically takes 1 to 2W; (power consumption is largely independent of supply voltage). It is capable of working with Windows 3.1, 95, 98, and NT.

The default configuration of the KD485-ADE has Port 2 configured for 9600 baud.

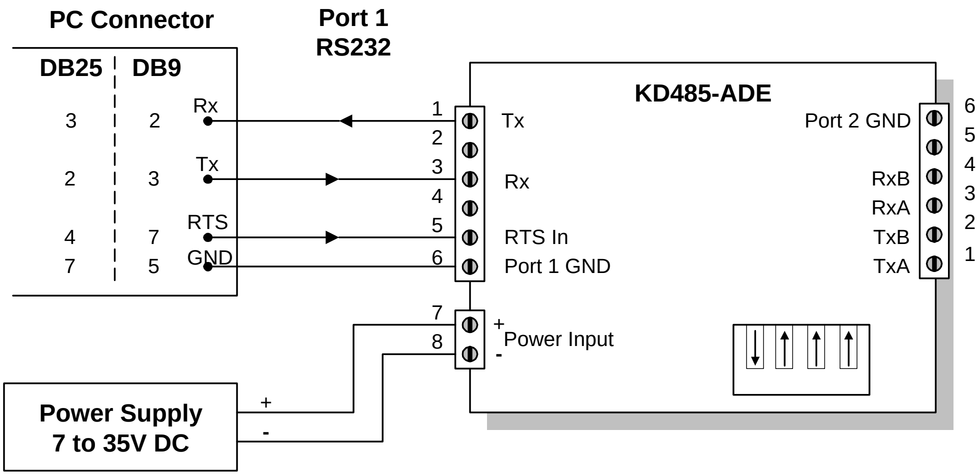
Further details of this device, including configuration, are available in the User Manual which is supplied with the product.

The connections are shown below.



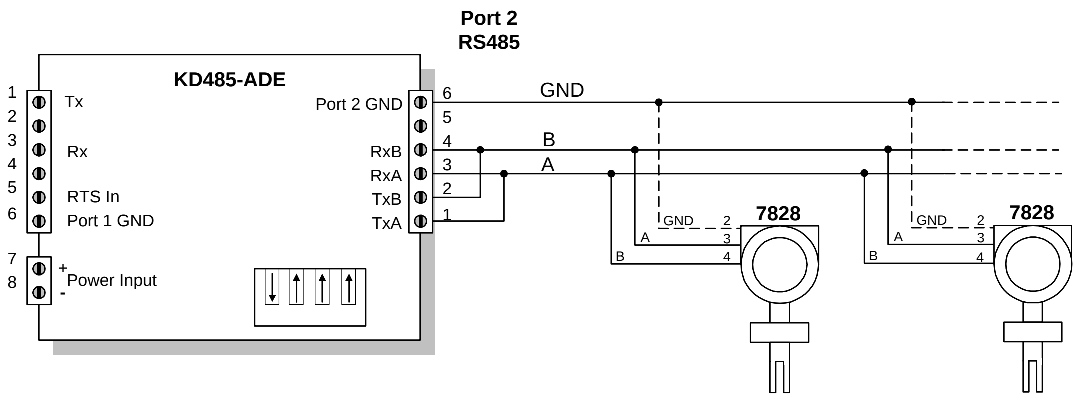
The switch on the KD485-ADE should be set with SW1 On (to enable half-duplex operation on Port 2), with the other three switches (SW2, 3, 4) set to Off.

Connections to the RS232 port (Port 1) are shown below:



Note: For a PC running Windows NT, the RTS connection can be omitted.

Connections to the RS485 port (Port 2) are:



Note: The 'A' signals on the 7828 must be connected to the 'B' signal on the converter, and vice-versa.

In most systems, the ground connection will be unnecessary.

When two or more devices are connected on the same RS485 network, this is known as a **multidrop** configuration (see next section). Each device must be configured with its unique slave address before being installed on the network.

3.4.4 RS485 MULTIDROP

When several devices are connected in parallel on an RS485 network, this is known as multi-drop. Although it is theoretically possible to have up to 256 devices, in practice this is limited to around 32 or less, depending largely on the driving power of the Master. Each device has a unique slave address. For 7828 this address must be individually programmed, using the ADView software running on a PC, before being connected to the multi-drop network (see section 4.4.3 for details).

Wiring is quite straightforward: simply connect A terminal to A terminal, B to B. On some devices, the RS485 signals may be marked + and -. The + signal generally corresponds to the A signal, and the - signal to B.

3.4.5 TRANSMISSION MODE

The 7828 RS485 interface uses the following parameter settings, which are not selectable:

Baud rate:	9600
Bits:	8
Parity:	None
Stop bits:	2.

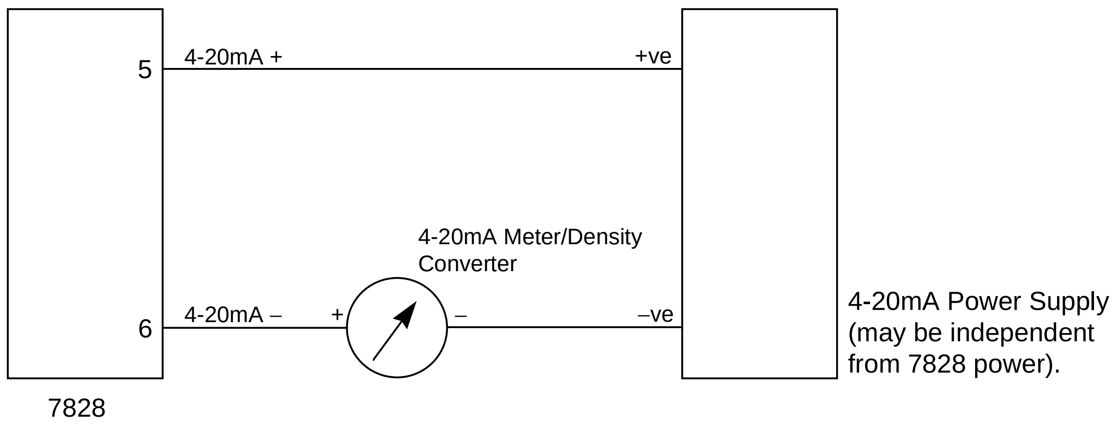
3.4.6 ANALOG 4-20MA OUTPUT

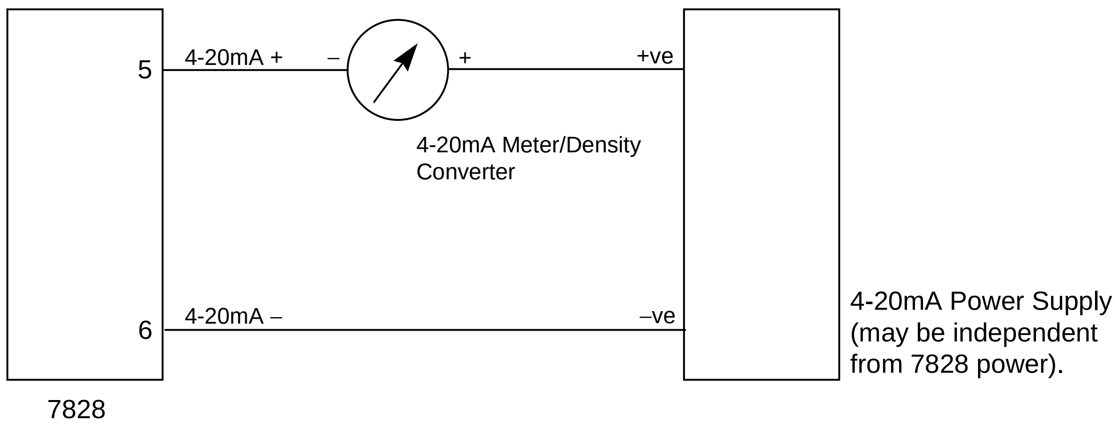
The 4-20mA output of the 7828 can be configured to be proportional to a user-defined range of either density, base or referred density, temperature, or one of the special functions. Fault conditions within the 7828 are indicated by a 2mA output. If this is detected, the Modbus link can be used to interrogate the transmitter to establish the likely cause of the problem.

The 4-20mA output is isolated (floating) from the power supply of the 7828, and can therefore be connected to any power supply/current measuring device, within the limits stated in the specification, i.e., 15 to 28V dc at the 4-20mA terminals of the 7828.

A power supply is also required for the 7828 itself, but this can also power the 4-20mA loop, if appropriate.

Two typical configurations to the analog output are shown below.





3.5 INSTALLATION IN EXPLOSIVE AREAS

The 7828 density transmitter is an explosion/flame-proof device, and therefore the connections shown in the wiring schedule are applicable. However, it is essential to observe the rules of compliance with Current Standards concerning flameproof equipment:

1. The electronic housing covers should be tightened securely and locked in position by their locking screws.
2. The electrical cable or conduit should have an appropriate explosion proof cable gland fitted.
3. If any electrical conduit entry port is not used it should be blanked off using the appropriate Explosion Proof plug, with the plug entered to a depth of at least five threads.
4. The spigot must be locked in place.

4

Using ADView

4.1 WHAT IS ADVIEW?

ADView is a software package provided by Solartron to enable you to configure our density and viscosity transmitters and view and save data from them, to check that they are functioning correctly. ADView is installed on a PC, and interacts with the transmitter via one of the PC's serial (RS232) ports.

ADView requires Microsoft's Windows operating system: Windows 3.1, 95, 98 or NT.

Note: To connect to an RS485/Modbus device, such as the 7828, you will need an adapter between the PC and the transmitter (see Section 3).

ADView provides many useful facilities, such as:

- Setting up serial link to communicate with 7828
- Configuring the transmitter
- Displaying data in real time, or as a graph
- Logging data to a file
- Verifying correct operation of the system, and diagnosing faults
- Loading or storing Modbus register values
- Read/write to individual Modbus registers.

4.2 INSTALLING ADVIEW

Identify the three floppy disks containing the installation files for ADView.

Insert Disk #1 into an appropriate drive on your PC.

Run 'setup.exe'. (Open File Manager or Windows Explorer, choose "File... Run..." and then "Browse..." to find the 'setup.exe'.)

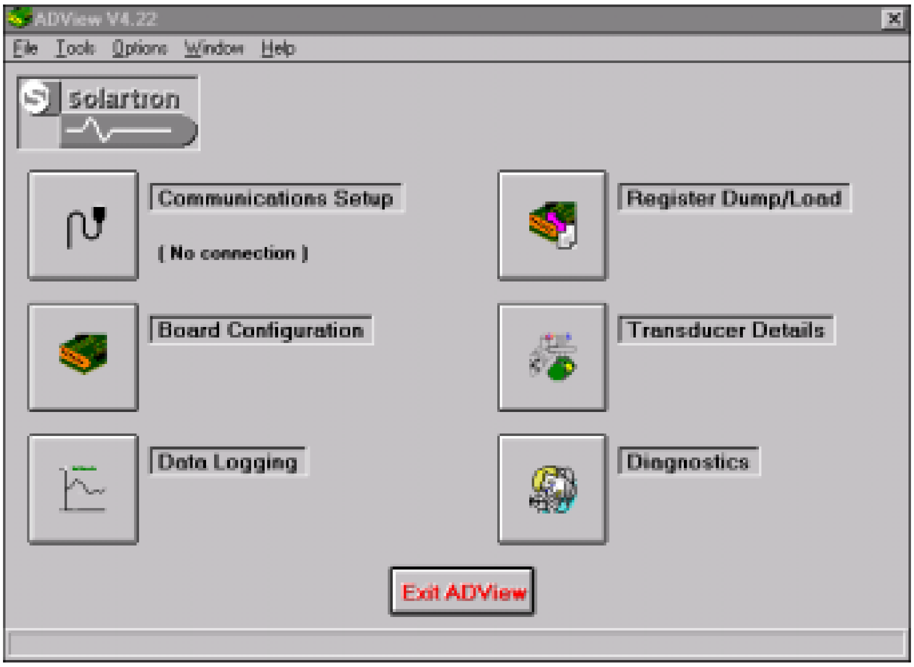
This will start the installation program. You will be asked to supply your name and organisation name for registration purposes, and supply a directory path into which ADView's files can be loaded (a default directory path will be suggested).

Follow the installation instructions until installation is complete. It will normally only take a few minutes. You can abandon the installation if you need to do so.

4.3 STARTING ADVIEW

The installation process sets up a program group on your desktop. Double-click on the ADView icon to start the program. The window shown below will appear.

Note: *Developments in ADView may mean that the screen shots which illustrate this section differ slightly from the ones you will see on your PC screen.*



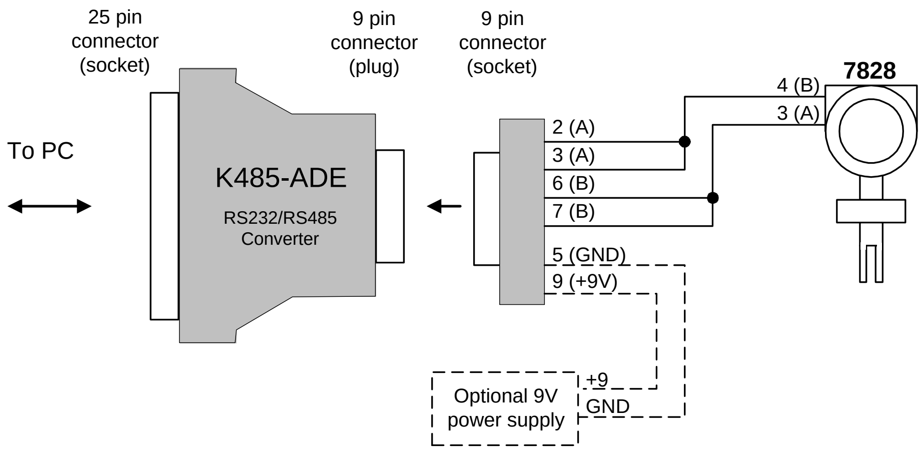
Each of the six icons gives you access to the various facilities of ADView. You can choose to connect a Modbus device to one of the PC's serial ports, or you can use ADView's built in simulation of a tube or fork density transmitter, such as the 7835 or 7828, to gain some experience with the software.

To run the simulation, choose "Options - Simulate board response" from the menu bar, and choose the 'Fork densitometer' option. When this is chosen, ADView ignores the serial port, and supplies simulated data.

4.3.1 SETTING UP SERIAL COMMUNICATIONS

To operate with a real Modbus device, you will need to connect it to a suitable power supply (see the technical manual for the device), and to a serial port on the PC (usually via an RS485 (Modbus) to RS232 converter). The diagram below shows the connections for a simple converter, although for permanent installations you may prefer to use a more sophisticated converter which offers isolation between ports.

Full details for connecting to the RS485/Modbus link on 7828 are given in Section 3.



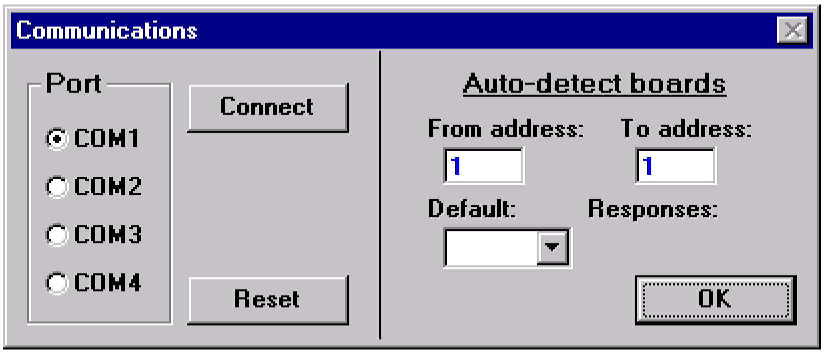
ADView automatically configures the selected port with the correct settings for the device. For 7828 this is 9k6 baud, 8 data bits, no parity, 1 stop bit, Xon/Xoff (software) flow control.

Note for Windows NT users

An interesting feature of Windows NT is that it does not allow the RTS line to be toggled directly; any attempt to do so will result in a crash or other problem. Unfortunately, some RS485/232 converters require RTS to be toggled. To overcome this difficulty, ADView reads the OS environment variable to determine whether the operating system is Windows NT. If it is, ADView does not toggle RTS, and you will need to use an RS232/485 adapter which automatically switches the data direction without using RTS.

To set the OS variable, click on the Start button, then choose Settings - Control Panel. Click on the System icon, and select the Environment tab. A list of environment variables and their values is shown. If OS does not appear in the list, type 'OS' (no speechmarks) in the Variable text box, and 'Windows_NT' (no speechmarks or spaces) in the Value box.

To check whether the link is working, you can use ADView's auto-detect facility. Select the correct port, then click on the Connect button in the Communications dialog box. ADView will set the port communications parameters, and then attempt to establish contact with any Modbus devices connected to the serial link, within the address limits set in the dialogue box.



When it finds a device, the message box below appears:

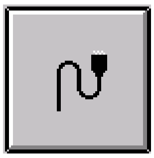
If no active device is found, a warning message is given:

In this case, check that the device is powered up correctly, that the cables and adapter are pushed fully home, and that the communications settings on the device and selected serial port are the same.

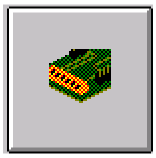
4.4 USING ADVIEW

4.4.1 ADVIEW FACILITIES

The main ADView window gives access to the various facilities available. A brief description of each is listed below. Using the facilities is largely intuitive, and hands-on experience is probably the best way to learn about the system.

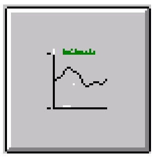


Communications
Sets up and checks RS232/485 communications (see section 4.3.1)



Board Configuration
(See section 4.4.4.) Enables you to select the measured parameter and range for the analog output, and to configure density referral by entering matrix values or K factors, as well as special calculations, line pressure and averaging time.

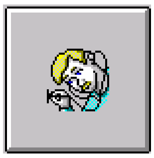
Displays instantaneous values of a selectable output parameter and the analog output.



Data logging
(See section **Error! Reference source not found.**.) Provides tabular data from transmitters of line and base density, temperature and special function. One parameter can be displayed as a graph.

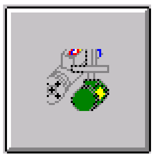
Data can also be logged to a file in either Excel (tab delimited) or Notepad (space delimited) formats.

The frequency at which results are logged can be set, and logging can be started and stopped.



Diagnostics
Enables you to view:
- live sensor readings
- the status of the meter
- values of working coefficients

You can also verify calculations.



Transducer details
Shows a list of details such as type, serial number, calibration dates, software version, etc.

Register dump/load
With this facility you can dump the contents of all (or selected) Modbus registers from the device, or alternatively transmit values to them. File format is selectable (Excel/tab delimited, or Notepad/Space delimited).

Use this to quit from ADView.

4.4.2 MENU BAR

File	Exit	Another way of quitting ADView
Tools	Health Check	Determines whether the system is functioning correctly
	Register Read/Write	A facility for reading or writing to any of the Modbus registers (see section 4.4.7)
	Direct Comms	Enables you to specify exactly what will be transmitted on the Serial link (see Appendix D).
	Engineer Status	Only used by Solartron service engineers
Options	Simulate board response/ Actual Board	Allows you to select between these two options
	Enable / disable screensaver	Allows you to select between these two options. When enabled, the screensaver operates as configured by the Windows system settings.
Window		Provides a means of opening or selecting ADView's facilities.
Help	Help on ADView	Limited help text, best read when first using ADView.
	About ADView	Displays software version number.

4.4.3 CONFIGURING A SLAVE ADDRESS

The 7828 factory configuration sets the slave address to 1. However, in many applications it will be necessary to allocate another address. In a multi-drop application, where several Modbus devices are connected on the same network, it is essential to configure unique slave addresses for each device.

To do this, you will need to run ADView and use the Register Read/Write facility, detailed in section 4.4.7. Check the value in Register 30 (Modbus Slave Address). If it is not the required value, enter the desired value and click on the write button. The 7828 will now be configured with the new slave address.

4.4.4 BOARD CONFIGURATION

The 7828 configuration controls the way in which the transmitter will process and present data, user settings, calibration constants and other factors. This data is stored in non-volatile memory known as registers; a full list of the registers used in 7828 is given in Appendix D.

To configure the 7828 it is necessary to write data into the configuration registers using the RS485/Modbus link. ADView provides a convenient and graphical way of doing this without you needing to know about register addresses and data formats.

Certain parameters are not available for configuration by ADView, including the Density Offset value which may be required to fine tune the calibration of the transmitter (see Section 5). However, ADView does have tools for reading and writing to individual Modbus registers (using the Tools -> Register Read/Write facility), and for direct communication on the Modbus (using Tools -> Direct Comms). More details and examples are given in Appendix D, but for the significant majority of applications these tools will not be required.

The factory-installed default configuration is listed in Appendix A (Specification).

WARNING: *There is no facility within ADView or the 7828 to 'reset' the transmitter to a default configuration.*

Therefore, before attempting any alterations to the configuration, you are strongly advised to use the Register Dump/Load facility in ADView to store the existing configuration (see section 4.4.5). Then, if any mishap occurs, you will be able to restore the configuration from the saved file.

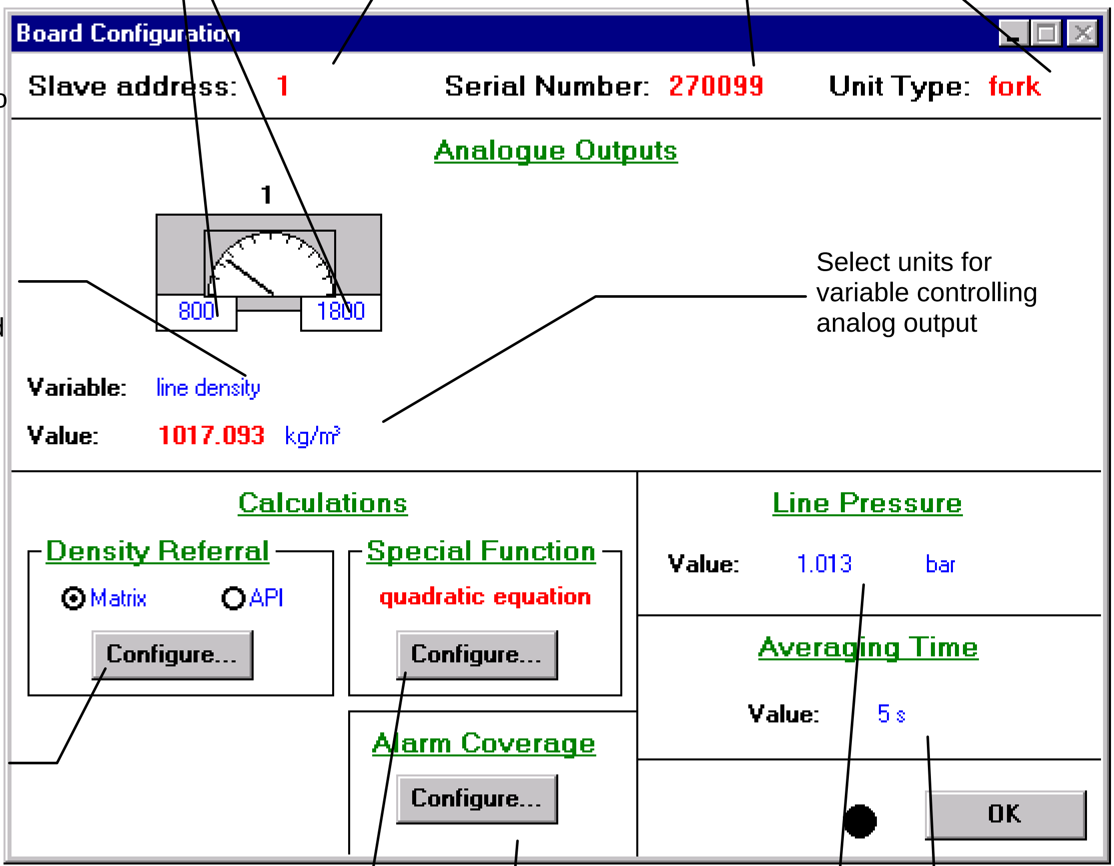
ADView's Board Configuration window is shown below:

Shows which unit is being configured.

Enter values of variable to give 4mA and 20mA analog outputs

Select variable to control 4-20mA output.

The calculated parameters (special functions) available depend on whether Matrix or API referral is selected.



Select units for variable controlling analog output

Select referral type - see text for more details.

Click on 'Configure..' to select and configure Special function (calculated parameter). See text for more details.

Enter line pressure value here.

Select from 1s to 100s, or no averaging.

Select any combination of:
- General system fault
- Analog fault
- User selectable range

to invoke an alarm (2mA) condition on the analog output.

To exit from any of the configuration windows without making any changes, press the Escape key on your computer.

Referral Calculation
To configure the referral calculation, you will need to enter the relevant information.

For matrix referral, this is a set of four values of density for each of up to five different temperatures; Appendix B gives more details on this.

For API referral, you can select the product type, which automatically adjusts the coefficients of the General Density Equation (see Section 5XX), or enter your own values.

Special Functions
The range of special functions (calculated parameters) that are available depends on the referral type selected.

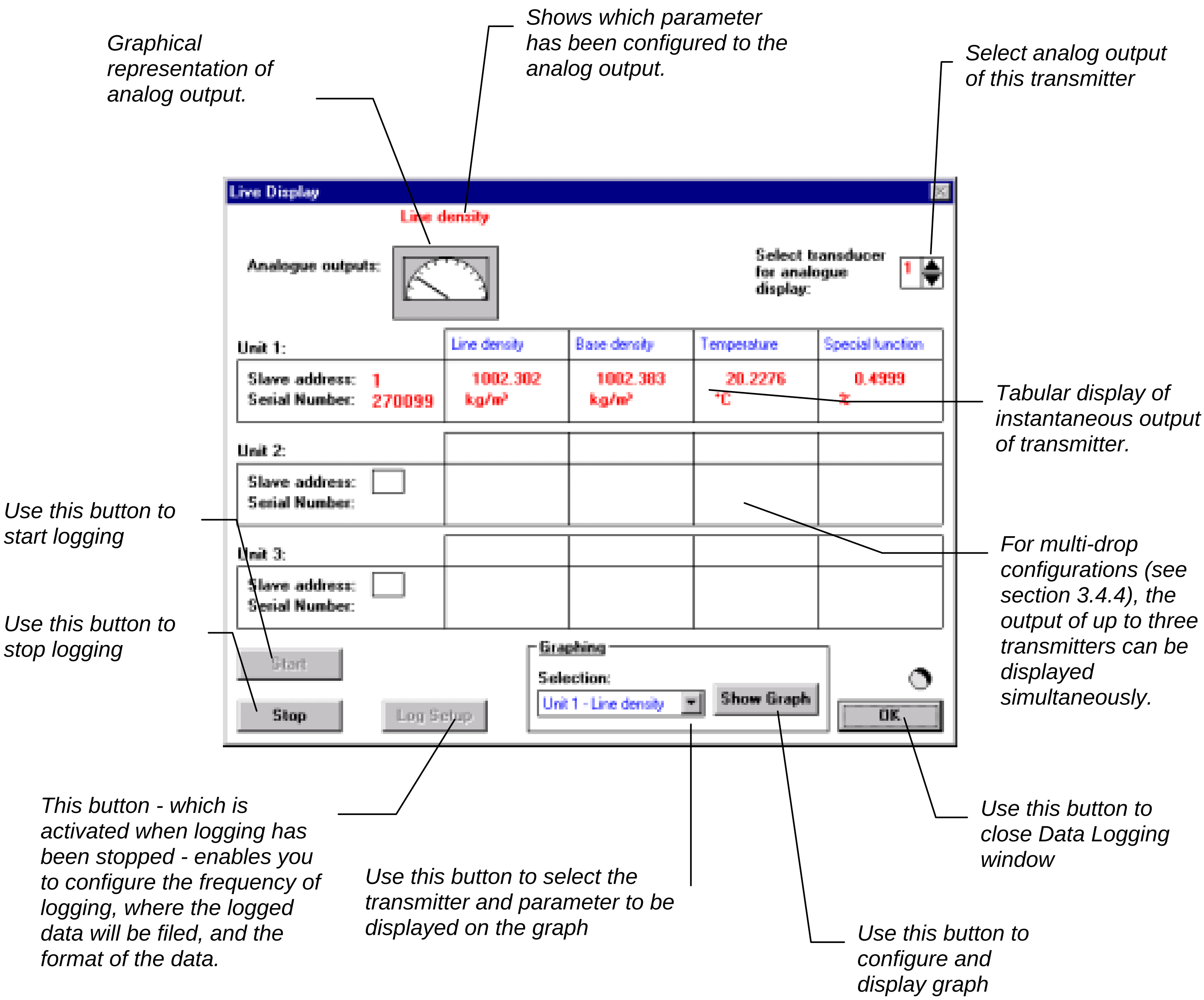
Special Function	***API referral***	***Matrix referral***
Specific Gravity	✔	✔
API°	✔	
% mass		✔
% volume		✔
° Baumé		✔
° Brix		✔
User defined quadratic		✔
None	✔	✔

When you select the Special Function you require, the configuration window will alter to allow you to input the relevant parameters, if applicable. Note that you can only select one Special Function to be available at any one time.

When you are satisfied with the configuration, you should save it to a file, using the Register Dump/Load facility, as a safeguard against subsequent loss or alteration.

4.4.5 DATA LOGGING

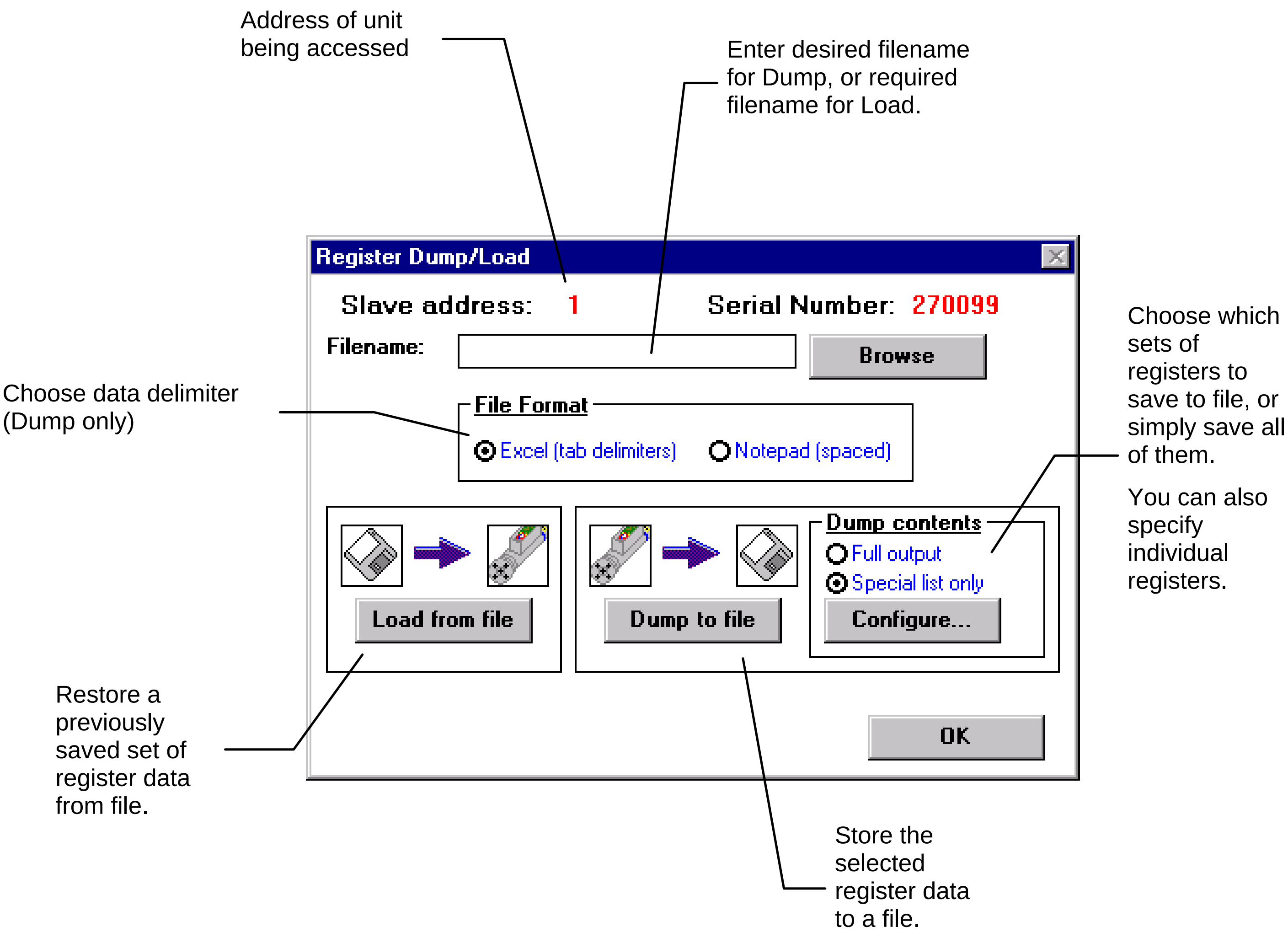
ADView's Data Logging function is a useful tool for checking setups and performing experimental data capture. The diagram below explains some of the features.



4.4.6 REGISTER DUMP/LOAD

This facility is essential for saving the configuration of your 7828. You should use it to save the current configuration before you start to alter it, in order to restore it if things go wrong for any reason. Also, if you send the transmitter away for servicing or re-calibration, you should save the current configuration.

Details are given below.

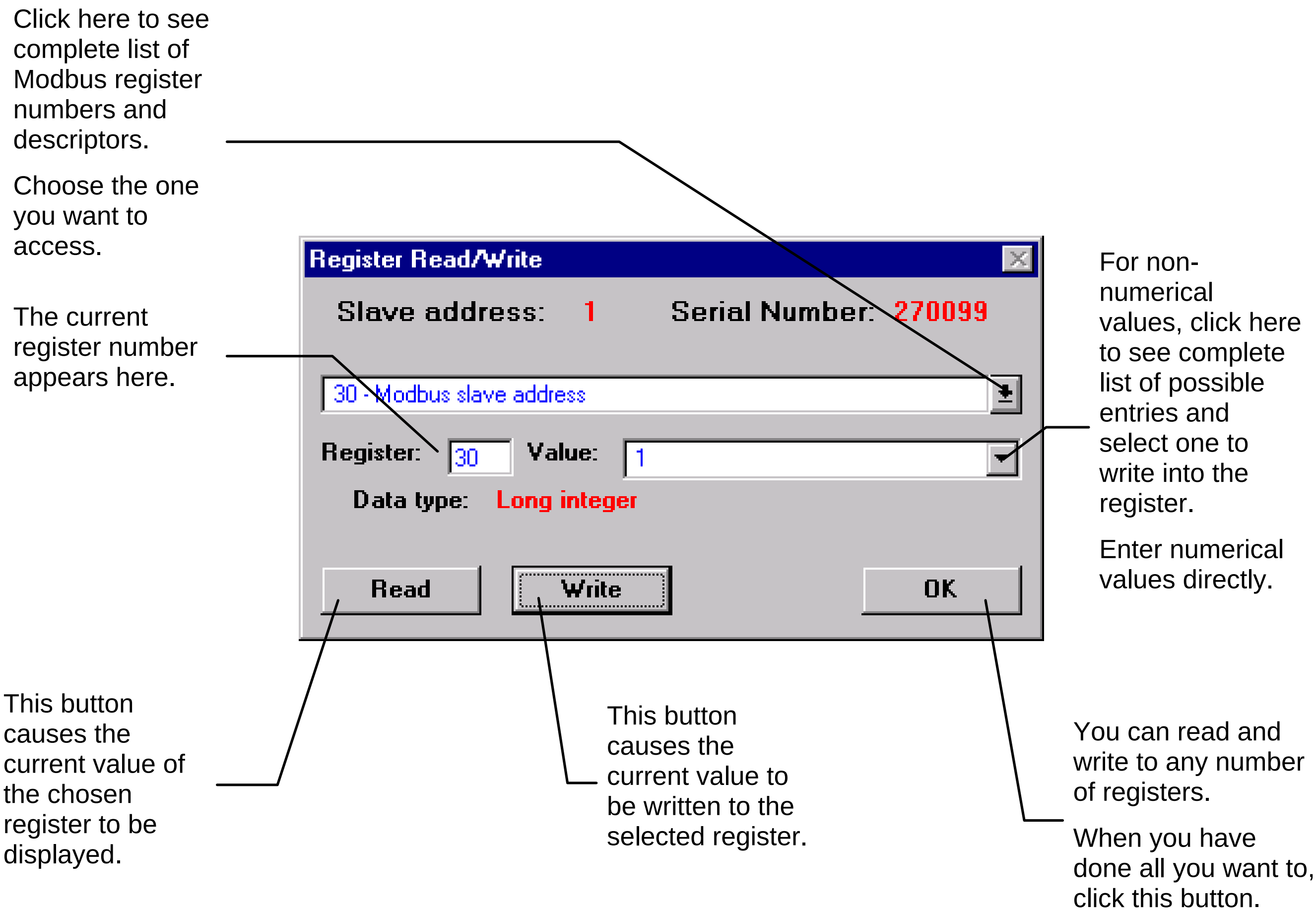


4.4.7 REGISTER READ/WRITE

In a few cases, it may be useful to write directly to a single Modbus register. (See Appendix D for a complete list of 7828's registers.) Two likely occasions are to set the Slave Address of the unit, and to configure a density offset.

Warning: *Before making any changes to individual registers, you should save the current configuration to a file (section 4.4.5), to safeguard your configuration if anything goes wrong.*

From ADView's menu bar, select Tools -> Register Read/Write.



5
Calibration Check

5.1 CALIBRATION

5.1.1 FACTORY CALIBRATION

The 7828 Insertion Liquid Density Transmitter is calibrated within a standard physical boundary (typically 52.5mm diameter) against Transfer Standard instruments traceable to National Standards, prior to leaving the factory. Three fluids ranging in density from 1 to 1000 kg/m^3 are used to establish the general density equation constants. The temperature coefficients are derived from the air point and material properties.

The calibration procedure relies on units being immersed in fluids whose density is defined by Transfer Standards. Great attention is paid to producing temperature equilibrium between the fluid, the unit under test and the Transfer Standard. In this way, accurate calibration coefficients covering the required density range can be produced.

All instruments are over-checked on water to verify the calibration. This check is monitored by the Solartron Quality Assurance Department.

5.1.2 CALIBRATION OF TRANSFER STANDARDS

The Transfer Standard instruments used in the calibration are selected instruments which are calibrated by the British Calibration Service Calibration Laboratory and are certified.

Transfer Standard calibration uses a number of density-certified liquids, one of which is water. The densities of these reference liquids are obtained using the Primary Measurement System whereby glass sinkers of defined volume are weighed in samples of the liquids.

Calibration of the Transfer Standard instruments is performed under closely controlled laboratory conditions and a calibration certificate is issued. Calibrations are repeated, typically every six months, producing a well documented density standard.

5.1.3 INSTRUMENT CALIBRATION

Each 7828 Transmitter is issued with its own calibration which is programmed in to the instrument electronics before it leaves the factory. The calibration data is shown on a calibration certificate supplied with the instrument, an example of which is shown overleaf. The calibration contains four important pieces of data:

a. The instrument serial number.

b. The output signal/density relationship; this is based on three calibration points across the sensor's operating density range.

c. Temperature coefficient data; this defines the correction which should be applied to achieve the best accuracy if the instrument is operating at product temperatures other than 20°C.

d. One instrument air data point for check calibration purposes.

5.1.4 GENERAL DENSITY EQUATION

The General Density Equation, used to calibrate the 7828 and shown in the Calibration certificate is:

$$\rho = K0 + K1\tau + K2\tau^2$$

where ρ is the calculated density, τ is the time period (in μs) of the tuning fork, and K0, K1 and K2 are density coefficients.

When the 7828 is calibrated in a known environment, K0, K1 and K2 are selected to optimise the density measurement across the calibrated density range.

As you can also see in the sample calibration certificate, temperature effects are also compensated for using a second equation:

$$\rho' = \rho(1 + K18(t - 20)) + K19(t - 20)$$

where ρ' is the new (temperature compensated) density value, t is the measurement temperature, and K18 and K19 are temperature correction coefficients.

The values for all the K coefficients - shown on the calibration certificate - are programmed into the 7828's registers, and should not be altered.

If the 7828 is used in an application dissimilar to the one for which it was originally calibrated, it may be necessary to re-calculate the K coefficients. Contact Solartron for further details.

5.2 SAMPLE CALIBRATION CERTIFICATE

solartron

CALIBRATION CERTIFICATE

7828ACAAAALABA

Serial No : 289999
Cal. Date : 11JUL99
Pressure Test : 30 BAR

LIQUID INSERTION DENSITOMETER

DENSITY CALIBRATION AT 20 DEG. C mounted in the recommended shroud

DENSITY [KG/M3]	PERIODIC TIME [uS]
0	1162.445
300	1237.936
500	1285.826
700	1332.011
800	1354.519
900	1376.662
1000	1398.457
1100	1419.920
1600	1522.742

DENSITY = K0 + K1.T + K2.T**2

K0 = -2.260962E+03
K1 = 3.975850E-02
K2 = 1.639000E-03

INSTRUMENT CHECK DATA

Air Point (20 C) Periodic Time = 1162.472 uS

TEMPERATURE COEFFICIENT DATA

Dt=D(1+K18(t-20))+K19(t-20)

K18 = -4.893078E-04
K19 = -9.667962E-01

where D = Density (Uncorrected)
Dt = Density (Temperature Corrected)
T = Periodic Time (uS)
t = Temperature (DEG.C)

FINAL TEST & INSPECTION

Ref No:- LD7828/V1.0

DATE : 13JUL99

Note: This is an **example** only - it is **NOT** the calibration certificate for your 7828.

5.3 USER CALIBRATION CHECKS

5.3.1 AMBIENT AIR CALIBRATION CHECK

An air check is a simple and convenient method to see if any long term drift or corrosion and deposition on the tines has occurred.

Ambient air check procedure:

1. Isolate and, if necessary, disconnect the transducer from the pipeline.
2. Clean and dry the wetted parts of the transducer and leave them open to the ambient air.
3. Apply power to the instrument and check that the time period of the instrument agrees with the figure shown on the calibration certificate to within ±100ns. If the 7828 is not at 20°C, compensate for this by adding an offset of +110ns for every °C above 20°C, or by subtracting an offset of +110ns/°C below 20°C.
4. Refit the transducer to the pipeline if serviceable or remove for further servicing.

5.3.2 ON-LINE CALIBRATION ADJUSTMENT

An on-line calibration adjustment may be required if:-

a) The physical boundary surrounding the tines is different from the physical boundary used for the factory calibration.

b) The viscosity of the fluid is greater than 500cP.

c) If the velocity of sound of the fluid is significantly different from the fluid used for the factory calibration. In practice this affects the density measurement by less than ±1 kg/m^3.

d) If the unit has suffered long term drift or corrosion of the tines.

The 7828 is a very accurate and stable instrument, and will normally provide good measurements. If it is suspected of giving incorrect results, you should confirm this by carefully checking the integrity of the fluid temperature measurement, and compare this with the temperature measurement given by 7828. You should also verify the integrity of the density check measurement. It is only after you have eliminated all other possible causes of error that you should attempt to make adjustments to the calibration of 7828.

Normally the calibration adjustment is made by configuring a simple density offset into the instrument. If a more detailed calibration adjustment is required, such as a 2 or 3 fluid calibration adjustment for offset and scale, then refer to Solartron.

Calibration adjustment - stable liquids:

1. Using ADView (see chapter 4), reset the line density offset (register 173) to 0, and the line density scaling factor (register 174) to 1.
2. Ensure that the system has reached its stable operating temperature.
3. With the 7828 operating at typical process conditions, draw off a sample of the liquid into a suitable container, and note the 7828 density reading and the operating temperature.

4. Measure the density of the sample under defined laboratory conditions using a hydrometer or other suitable equipment. Refer this to the operating conditions at the transducer.
5. Calculate the density offset required to make the 7828 measurement the same as the measured density of the sample.
6. Using ADView's Register Read/Write tool (see section 4.4.7), configure the 7828 with the calculated line density offset (Register 173).

Calibration adjustment - unstable or high vapour pressure liquids:

A pressure pyknometer and its associated pipework can be coupled to the pipeline so that a sample of the product flows through it.

1. Using ADView (see chapter 4), reset the line density offset (register 173) to 0, and the line density scaling factor (register 174) to 1.
2. Ensure that the system has reached its stable operating temperature.
3. When equilibrium conditions of product flow are reached, note the 7828 density reading and temperature and simultaneously isolate the pyknometer from the sample flow.
4. Remove the pyknometer for weighing to establish the product density.
5. Compare the pyknometer reading with the 7828 reading and compute the density offset required.
6. Using ADView's Register Read/Write tool (see section 4.4.7), configure the 7828 with the calculated line density offset (Register 173).

For further details on these procedures, reference should be made to:

Institute of Petroleum:	Petroleum Measurement Manual Part VII Section 1 - Method IP 160
Institute of Petroleum:	Petroleum Measurement Manual Part VII Section 2 - Continuous Density Measurement
American Petroleum Institute:	Manual of Petroleum Measurement Standards Chapter 14 - Natural Gas Fluids - Section 6: Installing and proving density meters used to measure hydrocarbon liquid with densities between 0.3 and 0.7gm/cc at 15.56°C (60°F) and saturation vapour pressure, Sept 1979.

6
Maintenance

WARNING: ***If the transmitter being serviced is to be used in a hazardous area, the rules of compliance with current standards concerning flameproof equipment must be strictly adhered to.***

6.1 GENERAL

The 7828 Density Transmitter has no moving parts and maintenance is limited to simple visual checks for leaks and physical damage.

ADView's Data Logging facility can be used whenever necessary to verify that the transmitter is functioning correctly.

Check calibrations should be carried out at specified intervals in order to identify a malfunction or a deterioration in transmitter performance. If a fault or a drop in performance is detected, further tests are required to identify the cause of the fault. Remedial action is limited to cleaning the transducer tines, making good any poor connections, and replacing the internal electronics. In the extreme cases the complete transducer may need to be replaced.

Note: The electronics within the 7828 contain calibration information relevant to that particular transmitter only. The circuit boards operate as a pair, and therefore both boards must be changed together. Contact Solartron for more details if you need to change the boards.

CAUTION: **Care is essential in handling of the transducer during its removal from and fitment to the pipeline/tank and during transportation. Wherever possible, retain and use the original packaging.**

6.2 GENERAL MAINTENANCE

This procedure is recommended for periodic maintenance and can also be used when fault finding.

6.2.1 PHYSICAL CHECKS

a. Examine the transmitter, its electronics housing and cables for any signs of damage and corrosion.

b. Make sure that the spigot connection is tight.

c. Check the transmitter for sign of leakage.

d. Check that there is no ingress of water/fluid into the electronics housing.

e. Ensure that the threads on the covers are well greased (graphite grease) and that the ‘O’ rings are in good condition.

Note: The covers MUST be completely screwed down and, in the case of an explosion-proof enclosure application, DO NOT FAIL to tighten the locking screws.

6.2.2 ELECTRICAL CHECK

Check the power supply and current consumption at the transmitter terminals, pins 1 and 2. These should give:

35mA to 42mA at 22.8V to 25.2V

If the current consumption outside this range, contact Solartron.

6.2.3 CALIBRATION CHECK

a. Carry out a check calibration as detailed in Section 5.

b. Compare the results obtained with the previous calibration figures to identify any substantial deterioration in transducer performance or any malfunction.

Notes:

1. A drop in transducer performance is likely due to a build up of deposition on the tines which can be removed by the application of a suitable solvent. See section 6.3.1 below.

2. Malfunctions generally could be the result of electrical/electronic faults in either the transducer or the readout equipment. Always check the readout equipment first before attention is directed to the transducer.

6.3 FAULT ANALYSIS AND REMEDIAL ACTION

A fault may be categorised as either an erratic reading or a reading which is outside limits.

Electrical faults can also cause symptoms which appear to affect the readings and it is recommended that the electrical system is checked first, before removing the transmitter for servicing.

Fault	*Possible cause*	*Remedy*
Readings fluctuate slightly, i.e., are noisy	Analog output averaging time not long enough	Increase the averaging time using ADView's Board Configuration facility (see section 4).
Erratic readings	Gas bubbles around tines Cavitation Severe vibration Severe electrical interference Large amount of contaminants	Remove primary cause; e.g.: - install air release units to release gas; - apply back pressure to discourage formation of bubbles; - remove cause of vibration Alternatively, it may be necessary to adjust the Time Period Trap (see section 6.3.2)
Readings outside limits	Deposition and/or corrosion on the tines.	Clean tines (see section 6.3.1)
Analog output = 0mA	No power to analog output	If voltage across pins 5 and 6 is not 15 to 28V, replace power supply.
	Analog output circuit failure	Use ADView's facility to set the analog output to 4, 12 or 20mA (in Board Configuration) to check whether the output is functioning. If not, replace circuit boards.
Analog output is 2mA	Alarm condition caused by lack of power to 7828	If voltage across pins 1 and 2 is not 20 to 28V, check and replace main power supply.
	Alarm condition caused by other internal failure	Use ADView Diagnostics to check that phase locked loop is in lock.
Temperature readings incorrect	If other readings from 7828 are correct (i.e. analog output and Modbus appear to be functioning correctly), the temperature sensor has probably failed.	Return the transmitter to Solartron for servicing.

Fault	***Possible cause***	***Remedy***
7828 does not communicate with ADView	Power failure to 7828	Check power supply to 7828 and converter; replace if necessary
	Power supply to RS485/232 converter failed.	
	A and B Modbus connections reversed	Check wiring
	RS485/232 converter failed, wired incorrectly, or connected the wrong way round	Try another converter
	ADView incorrectly installed on PC	Re-install ADView
	Incorrect Slave address chosen for 7828	Check slave address
	RS232 port on PC failed.	Connect to another free RS232 port on the PC, if available. Alternatively connect a known working RS232 device to the PC to check that the port is working.

6.3.1 MECHANICAL SERVICING

This mainly comprises the cleaning of any deposition or corrosion from the tines. Deposition is removed by the use of a suitable solvent. For corrosion, solvent and the careful use of a fine abrasive will usually be sufficient. However where extensive corrosion has been treated, it is highly recommended that a full calibration is carried out to check the transmitter characteristics.

CAUTION: Care is essential in handling the transducer during transit, installation, and removal from the pipeline/tank.

6.3.2 TIME PERIOD TRAP

Disturbances in the fluid caused by bubbles, cavitation or contaminants can cause sudden changes in the measured output, which may, under some circumstances, give rise to instability (i.e. hunting) in a control system relying on the measurement. The 7828 can maintain the analog output during such perturbations by ignoring the aberrant measurement, and maintaining the output at the last good measured value. This facility is known as the Time Period Trap (TPT).

Under all normal circumstances, the factory settings for the TPT should be used. However, in extreme cases it may be necessary to alter the settings to meet the demands of a particular system. This should only be done after monitoring the behaviour of the system for some time, to establish the normal running conditions.

Great care must be taken not to reduce the sensitivity of the transmitter so that normal response to fluctuations in the fluid is impaired.

The time period trap facility works as follows:

After each measurement of the time period (of the 7828's vibrating tines) the new value is compared with the previous value. If the difference between them is **smaller** than the allowable tolerance, the output is updated to correspond to the new measured value, and the TPT remains inoperative; i.e., operation is normal. If the difference **exceeds** the allowable tolerance, the output remains at the its previous level, and does not follow the apparent sudden change in value.

This process is repeated until either:

(a) the latest measured value falls back to the level of the original value, indicating that the transient has passed; or

(b) the TPT count is reached. At this point it is assumed that the change in value is not due to a random disturbance, and the output adopts the value of the latest reading.

Two Modbus Registers control the operation of the Time Period Trap facility. These can be changed, if necessary, using ADView's Register Read/Write facility (see section 4).

Modbus Register 138: contains the maximum allowable change in the time period between readings, specified in µs. The preset value is 10.

Modbus Register 137: contains the Time period count, which is the maximum number of measurements to be rejected before resuming normal operation; the preset value is 2. If the value is set to 0, TPT is disabled, and the output will always follow the time period measurement. If you want to program another value, it should be determined experimentally, and be equal to the length of the longest undesirable transients which are likely to arise. If the value is set too high, the 7828 will be slow to respond to genuine changes in the fluid properties.

A

Specification

A.1 GENERAL

The 7828 Insertion Density Transmitter comprises a vibrating fork density sensor, with processing electronics within the housing which provide full on node configuration; all signal processing, calculations, and calibration adjustments are made without the need for external electronics.

A 4-20mA analog output is available, proportional to a user-defined range of either line density, base density, temperature, or one of the available special functions (calculated parameters).

An RS485 serial communications link is also available, which utilises the Modbus protocol to provide a means of configuring the device, retrieving data measurements, and performing diagnostics.

ADView, a PC software application running under Windows 3.1, 95, 98 or NT, is available for data logging, configuration and diagnostics purposes.

A.2 SPECIFICATION

A.2.1 SENSOR PERFORMANCE

Density measurement

Measurement technology	Tuning Fork driven/sensed by piezoelectric crystals
Operating range	0 to 3 g/cc (0 to 3000kg/m^3)
Calibrated range	0.6-1.25g/cc (600 to 1250kg/m^3)
Accuracy	±1 kg/m^3
Repeatability	±0.1 kg/m^3
Temperature coefficient	
uncorrected at 1000 kg/m^3	-1.5 kg/m^3/°C
corrected	0.1 kg/m^3/°C
Fluid viscosity range	0 to 20 000cP (for viscosities above 500cP, in-situ calibration is recommended)
Pressure effect	Negligible

Temperature

Temperature Technology	PT100 platinum resistance thermometer in tuning fork
Integral PRT Temperature Range	-50° to +200°C
Integral PRT Temperature Accuracy	BS1904 Class B , DIN 43760 Class B

A.2.2 ENVIRONMENTAL

Operating temperature range	-50° to +200°C (-58° to 392°F)
Max. operating pressure	207 bar (3000psi)
Enclosure Type	Die cast low copper alloy Polyurethane paint finish
Protection	IP66
Max. weight	6.7 kg
Max. vibration	0.5g continuous

A.2.3 TRANSMITTER POWER SUPPLY

Minimum Input Voltage	20V
Maximum Input Voltage	28V
Current Consumption	35 to 45mA

A.2.4 ANALOG OUTPUT

Number of channels	1
Range	3.9mA to 20.8mA
Alarm Condition	2mA
Nominal Power Supply	24V
Maximum Terminal voltage	28V
Minimum Terminal voltage	15V
Isolation to Main Power Supply	75Vdc rated
Accuracy @20°C	±0.1% reading ±0.05% FS
Repeatability (-40°C to +85°C)	±0.05% FS

A.2.5 RS485 INTERFACE

Connections	A and B signals (screw terminals)
Communications protocal	Modbus RTU
Isolation	None - RS485 in same circuit as main power supply
Baud rate	9600 (fixed)
Termination	not required

A.2.6 APPROVALS

EMC	EN50081-2:1994
	EN50082-2:1995
Approvals	EEx d IIC T4 (BASEEFA)
	CSA Class 1, Division 1, Group C (pending)

A.3 FACTORY DEFAULT CONFIGURATION

The 7828 can be supplied in one of three standard configurations (see Section 1.2, 7828 Options).

For Factory Configuration Option A, the 7828 is set to provide line density as the 4-20mA output, and the units are kg/m^3 for density and °C for temperature.

For Option B, API base density is configured for output to the 4-20mA port, and the units are g/cc and °F.

For Option C, Matrix referral is used to calculate the base density output, and the matrix will have been configured to the customer's specification. All other default settings are as for Option A.

The default values for these three configurations are shown below.

		Options A and C	***Option B***
Analog output	Variable	Line density	Base density (API)
	Units	kg/m^3	g/cc
	4mA setting	500	0.5
	20mA setting	1500	1.5
Alarms	Coverage	General system Analog output User range	General system Analog output User range
	Hysteresis	2%	2%
Alarm user range	Variable	Line density	Line density
	Units	kg/m^3	g/cc
	Low setting	0	0
	High setting	1000	1
Density calculations	Temperature units	° C	° F
	Temperature offset	0	0
	Pressure units	bar	psi
	Pressure set value	1.1013	14.5
	Line density units	kg/m^3	g/cc
	Line density scale factor	1	1
	Line density offset	0	0
Matrix referral	Reference temperatures	All 20 *	All 68
	Reference densities	All 0 *	All 0
	Base temperature	20 *	68

API referral	Product type	General crude	General crude
	User K0	+0000E+00	+0000E+00
	User K1	+0000E+00	+0000E+00
	Base temperature	15	60
	Base pressure	1.1013	14.5
Special Functions	Type	None	None
	Name	*0 (None)*	*0 (None)*
	Units	None	None
	Density of water (d)	998	0.998
	Density of Product A	0	0
	Density of Product B	0	0
	Quadratic coefficients (A,B,C)	0	0
Output averaging time		1s	1s
Modbus	Slave address	1	1
	Byte order	Big Endian	Big Endian
	Register size	16 bit	16 bit
Hardware type		Advanced fork	Advanced fork

*** -** For Option C, the Matrix referral constants will have been configured to the customer’s specification.

B
Calculated Parameters

B.1 INTRODUCTION

The 7828 Density Transmitter is capable of calculating a number of parameters based on the measured line density and temperature. These calculated parameters are often referred to as ‘special functions’. Only one calculated parameter is available at any one time; it can be used to control the analog (4-20mA) output, and can also be accessed as a digital value (Modbus Register 260).

This section describes the algorithms used in these calculations.

The availability of the calculated parameters is dependent on whether Matrix or API is chosen as the density referral method.

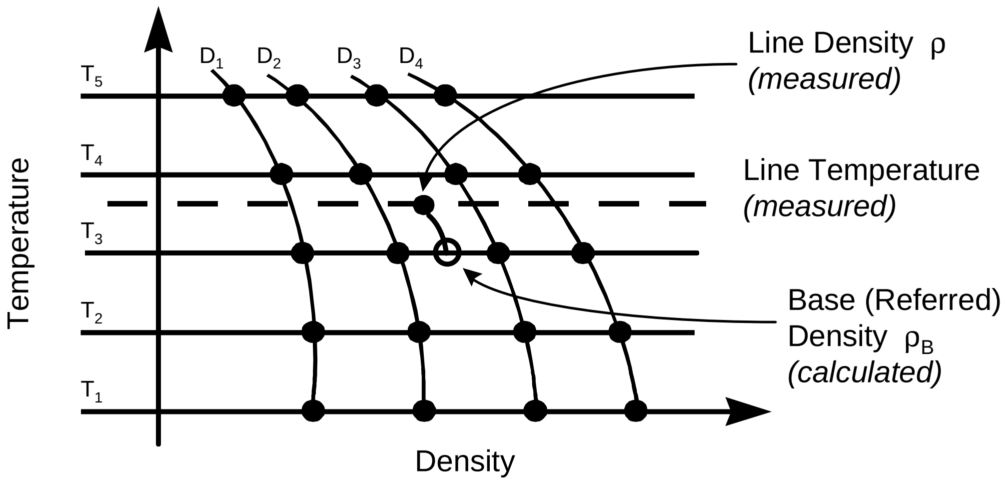
Special Function	***API referral***	***Matrix referral***
Specific Gravity	✔	✔
API°	✔	
% mass		✔
% volume		✔
° Baumé		✔
° Brix		✔
User defined quadratic		✔
None	✔	✔

B.2 BASE DENSITY REFERRAL

Base density is the density of the fluid at a specified base (or referral) temperature which is different to the line (i.e., the actual) temperature of the fluid. Base density can be calculated by either a Matrix referral method or by the API Referral method.

B.2.1 MATRIX DENSITY REFERRAL.

The Matrix Density Referral method uses a process of interpolation and extrapolation between a matrix of known density and temperature reference points to determine the liquid density at a specified base temperature different to the line temperature. A typical referral matrix is shown below.



The lines D_1 to D_4 plot the density of four product types for which the density is known at five different reference temperatures, T_1 to T_5. Using this information, and the measured line density and temperature, the 7828 calculates the base density at the base temperature.

The information required for the referral is:

- Five reference temperatures
- The density for each of four product types at the five reference temperatures(20 reference points in all)
- The base temperature, which must be one of the five reference temperatures.

All 20 reference points must be specified, otherwise 7828 cannot calculate the base density. If you do not have all the relevant data, enter a sensible estimate for the missing reference points.

The easiest way of entering these values is by using the Board Configuration facility of ADView. Section 4 tells you how to do this.

B.2.2 API DENSITY REFERRAL

This calculation uses an iterative process to determine the density at the base temperature by applying temperature and pressure corrections using the API-ASTM-IP petroleum measurement tables.

The information required for the API density is:-

- Reference pressure and reference temperature
- Line pressure - this is not measured by 7828, and must be entered as part of the configuration.
- Product type: Refined product, crude product or user defined.

Density/Temperature Relationship

Correction factors in the revised API-ASTM-IP petroleum measurement tables are based on the following correlation equations:

$$\rho t / \rho_{15} = \exp (-\alpha_{15} \Delta t (1 + 0.8 \alpha_{15} \Delta t))$$

where:

ρt	=	Density at line temperature t°C
ρ_{15}	=	Density at base temperature 15°C.
Δt	=	(t - 15) °C
α_{15}	=	Tangent thermal expansion coefficient per deg C at base temperature of 15°C.

The tangent coefficient differs for each of the major groups of hydrocarbons. It is obtained from the following relationship:

$$\alpha_{15} = \frac{K_0 + K_1 \rho_{15}}{\rho_{15}^{\;2}}$$

where K_0 and K_1 are known as the API factors.

Hydrocarbon Group Selection

The hydrocarbon group can be selected as:

- General refined products
- General crude products
- User defined.

K_0 and K_1 are programmed into the 7828 for the first two groups.

For refined products the values of K_0 and K_1 are automatically selected according to the corrected density:

Hydrocarbon Group	***Density Range (kg/m³)***	K_0	K_1
Gasolines	654 to 779	346.42278	0.43884
Jet Fuels	779 to 839	594.54180	0.0000
Fuel Oils	839 to 1075	186.9696	0.48618

For Crude Oil the API factors are:

Product	K_0	K_1
Crude oil	613.972226	0.0000

User defined factors can be entered as any sensible value.

Density / Pressure Relationship

Isothermal secant compressibility can be defined by the simplified equation:-

$$\beta = \frac{1}{V_0}\left[\frac{\delta V_1}{P_1}\right]_t$$

where liquid volume changes from V_0 to V_1 as the gauge pressure changes from zero (atmospheric) to P_1

where β = Isothermal secant compressibility at temperature t

δV_1 = Change of volume from V_0 to V_1

P_1 = Gauge pressure reading (P - 1.013) bars

hence

$$\frac{\rho_0}{\rho_1} = 1 - \beta P_1$$

where

ρ_0 = Corrected density at zero (atmospheric) gauge.

ρ_1 = Uncorrected density

P_1 = (P - 1.013) where P is pressure in bars (P - base)

A correlation equation has been established for β from the available compressibility data; i.e.,

$\log_e C = -1.62080 + 0.00021592t + 0.87096 \times 10^6(\rho_{15})^{-2} + 4.2092t \times 10^3(\rho_{15})^{-2}$ per bar

where

β	=	$C \times 10^4$ Bar
t	=	Temperature in deg C
ρ	=	ρ_{15} / 1000 = oil density at 15 °C (kg/litre)

B.3 CALCULATED PARAMETERS

These are also known as Special Functions

B.3.1 SPECIFIC GRAVITY

$$\text{Specific Gravity (SG)} = \frac{\text{Base density (@ Tref)}}{\text{Density of water (@Tref)}}$$

B.3.2 DEGREES BAUMÉ

(Only available when Matrix referral is selected.)

$$\text{Degrees Baumé} = 145 - \left(\frac{145}{\text{Base density}}\right)$$

where Base density is measured in g/cc.

B.3.3 DEGREES BRIX

(Only available when Matrix referral is selected.)

$$\text{Degrees Brix} = 318.906 - \left(\frac{384.341}{\text{SG}}\right) + \left(\frac{66.1086}{\text{SG}^2}\right)$$

where SG is Specific gravity.

B.3.4 QUADRATIC EQUATION

(Only available when Matrix referral is selected.)

The following quadratic equation is implemented:-

$$y = A + B\left(\frac{\rho_B}{d}\right) + C\left(\frac{\rho_B}{d}\right)^2$$

where:-

A, B ,C are User programmable constants.

d = density of water (also a programmable constant).

ρ_B = base density.

B.3.5 % MASS

(Only available when Matrix referral is selected.)

$$\text{\% mass of product A} = \frac{\left(K_1\left(\rho_B - K_2\right)\right)}{\left(\rho_B\left(K_1 - K_2\right)\right)} * 100$$

where:-

K_1 = base density of product A

K_2 = base density of product B

ρ_B = base density.of mixture

B.3.6 % VOLUME

(Only available when Matrix referral is selected.)

$$\text{\% volume of product A} = \frac{\rho_B - K_2}{K_1 - K_2} * 100$$

where:-

K_1 = base density of product A

K_2 = base density of product B

ρ_B = base density.of mixture

B.3.7 API DEGREES

(Only available when API referral is selected.)

$$API = \frac{141.5}{SG} - 131.5$$

(The base density used for specific gravity value is determined from API density referral.)

C
Safety Certification

C.1 INTRODUCTION

The paper (hard copy) of this Appendix contains copies of the Safety and EMC Conformity certificates for the 7828.

The electronic (Acrobat) version does not include the certificates. Please contact Solartron if you need to have copies of them.

Certificate Type	*Number*	*Date*	*Issuing Authority*	*No. of pages*	*Comments*
Company Licence	0131	16-Mar-00	EECS	7	List of equipment which may be manufactured with BASEEFA mark. + Change of certificate holder + Change of marking registration
Certificate of Conformity	Ex 91C1359	30-Oct-91	BASEEFA	4	Prime certificate and schedules for 7826ACA transducer, with variations for fork tube material and flange type Class: EEx d IIC T4
C of C Variation	Ex 91C1359/1	26-Feb-93	BASEEFA	2	Addition of 7827 Viscometer
C of C Variation	Ex 91C1359/2	22-Oct-93	BASEEFA	2	Addition of PTFE coating variants, other minor amendments
C of C Variation	Ex 91C1359/3	31-Aug-94	BASEEFA	2	Alternative potting materials
C of C Variation	Ex 91C1359/4	28-Nov-94	BASEEFA	2	Minor amendments
C of C Variation	Ex 91C1359/5	22-Dec-95	BASEEFA	2	Minor amendments to terminal board
C of C Supplement	Ex 91C1359/6	11-Sep-97	BASEEFA	2	Alternative form for transducer housing
C of C Supplement	Ex 91C1359/7	1-Jul-99	BASEEFA	4	Var 1: Minor amendments Var 2: Introduction of 7828
C of C Supplement	Ex 91C1359/8	2-Nov-99	BASEEFA	2	Minor modifications to certification label.
C of C Supplement	Ex 91C1359/9	08-Nov-00	BASEEFA	2	Minor modifications to certification label. Alternative materials for vibrating element, flange and spigot
Flameproof Cert.	EECS 0941/01/001	27-Jun-97	BASEEFA	1	Release from pressure testing
Declaration of Conformance	(None)	Jul-99	Solartron	1	European EMC conformity declaration BS EN 50081-1:1992 BS EN 50082-2:1995

D

Modbus Communications

D.1 INTRODUCTION

The Modbus/RS485 communications facility on the 7828 can be useful in a number of ways. It is the only means of configuring the transmitter, and also gives access to diagnostic information not available on the analog output. Digital representations of the measured and calculated parameters are also available which lead to higher accuracy, and greater integration in digital networks and systems.

The RS485 serial interface of the 7828 Density Transmitter communicates using the RTU Modbus protocol, which is a well established system used in many industrial applications. The protocol defines the way in which messages will be transmitted between Modbus devices, and details how the data will be formatted and ordered.

It is beyond the scope of this manual to give a full description of the protocol, but a useful reference on Modbus is the "Modbus Protocol Reference Guide" (PI-MBUS-200 Rev.D). (1992) published by Modicon Industrial Automation Systems Inc., Massachusetts.

A Modbus network can have only one **Master** at any one time, with up to 32 **Slaves**. The 7828 acts as a slave device, and only communicates on the network when it receives a request for information from a Master device such as a computer or a PLC.

The implementation used on the 7828 is fully compliant with the Modicon Specification. All information is stored in memory locations in the 7828 referred to as **Modbus Registers.** These store all the data required to control the operation, calculations and data output of the 7828. Modbus communication with the transmitter consists of reading or writing to these registers.

The 7828 implements only two Modbus commands:-

- **Command 3** **Read Modbus Register**, and
- **Command 16 (10_{16})** **Write Modbus Register**.

Any number of registers can be read with Command 3, but only one register can be written to for each Command 16. This restriction does not limit the performance of the system, since all functions are mapped into the register structure in one way or another.

In most cases, it is unnecessary to understand the detail of the protocol, as this is taken care of by the application program. For example, Solartron's ADView software enables you to configure the transmitter, and even read or write to individual Modbus registers, without you needing to know about Modbus.

However, if you are using a proprietary software package, or developing your own application software, the information given in this section will be invaluable.

D.2 ACCESSING MODBUS REGISTERS

Any device which can drive the RS485 interface on the 7828 can, in theory, access the Modbus registers. In practice, some sort of user interface is required to simplify the process.

ADView, which is distributed with the 7828, offers several ways of accessing the registers.

Board Configuration:	A graphical interface for viewing and setting the main configuration parameters of the 7828. Direct access to registers is not offered.
Register Read/Write	This tool provides a simple window from which to read and write to named and numbered registers. When you write to a register, you are presented with a set of allowable values from which to choose. Thus the tool is only useful for communicating with Solartron transmitters. This is the simplest and most foolproof way of directly accessing the registers. Section 4 gives full details.
Direct Communications	This is another tool which allows you to compose a sequence of data to be transmitted to/from the Modbus. This can be used to communicate with any Modbus device, providing that you know the register addresses, data format, indices, etc. The composition of the data is entirely up to the user, although the tool does compute and insert a checksum. Only those well versed in the use of Modbus protocol should attempt to use this facility. It is mainly designed for testing Modbus transmissions which are subsequently to be used in an application specific environment. A worked example of using this tool is given in section D.7.

D.2.1 ESTABLISHING MODBUS COMMUNICATIONS

If the transducer Slave address or the values of Registers 47 and 48 are not known, Modbus communications cannot be carried out successfully, and it will be necessary to establish the current values in these items. If you are using ADView, you can search for the addresses of all connected slaves, and then interrogate the appropriate registers for each one.

If you are not using ADView, section D.6 gives a procedure which will enable you to ascertain this information.

D.3 MODBUS IMPLEMENTATION

D.3.1 REGISTER SIZE AND CONTENT

All registers are 32 bits (whether they are integer or floating point types), although the Modbus specification states that registers are 16 bits and addresses and 'number of register' fields assume all registers are 16 bits long. All floating point values are in IEEE single precision format.

Registers are contiguous in the Modbus register 'address space'. There is a one-to-one mapping of 32-bit 7828 register numbers to 16-bit Modbus register numbers. Therefore, only the full 32 bits of any register can be accessed. The upper and lower 16-bit segments have the same Modbus register number and consequently cannot be individually read.

Registers 47 and 48 within the 7828 allow the Modbus 'dialect' to be changed to suit the communicating device if it cannot easily be re-programmed. This is most easily done using ADView's Register Read/Write tool (see Section 4).

Their usage is as follows:

Modbus Byte Ordering

Register 47 contents	Modbus Byte Ordering
00000000_{16}	Big Endian (i.e. MSB first)
$FFFFFFFF_{16}$	Little Endian (i.e. LSB first)

Modbus Register Size

Register 48 contents	Modbus Register size
00000000_{16}	16 bits
$FFFFFFFF_{16}$	32 bits

16 bit Register Size (Register 48 = 00000000_{16})

In order to read 32-bit registers when Modbus registers are dealt with in units of 16 bits, you must specify **twice** the number of 32-bit register you want to read in the 'number of registers' field. E.g., to read one 32-bit register, use '2'. If an attempt is made to read an odd number of registers, the command will fail.

32 bit Register Size (Register 48 = $FFFFFFFF_{16}$)

In order to read 32-bit registers when Modbus registers are dealt with in units of 32 bits, you specify the actual number of registers you want in the 'number of registers' field. (E.g. to read two 32-bit register in this mode, use '2'.

D.4 MODBUS REGISTER ASSIGNMENTS

Each register is identified by a unique number, and the list is organised by this number. For each register, the contents are described, along with the data type of the contents.

The data type is always 32 bits unless stated otherwise. Variable names are given for reference purposes only. They have no other use.

Note: All units locations (registers 3, 4, 5 and 26) **MUST** be set before entering other values.

In some cases the data in a register is used to represent a non-numerical quantity, known as an index. For example, the units of density can be kg/m^3, gm/cc, lb/gal or lb/ft^3 and these are represented by the numbers 91 to 94. Thus if Register 3 (line density) contains the value (index) 91, this means that the units of line density are kg/m^3. Index values may, of course, be used for more than one register.

Tables of these indices are given in section D.5.

Register	**Function**	**Data Type**	**Index Table** *(where applicable)*
0	API product type	Long integer	D.5.1
1	API referral reference temperature	4-byte float	
2	API referral reference pressure	4-byte float	
3	Line density units	Long integer	D.5.2
4	Base density units	Long integer	D.5.2
5	Temperature units	Long integer	D.5.2
6	Special function calculation type	Long integer	D.5.3
7	Special function quadratic equation name	Long integer	D.5.4
8	Special function quadratic eqn. Units[1]	Long integer	D.5.5
9	Output averaging time	Long integer	D.5.6
10	Analog output selected variable	Long integer	D.5.7
14	PWM factor for 4mA on analog output	Long integer	
15	PWM factor for 20mA on analog output	Long integer	
20	PRT calibration factor	4-byte float	
21	Crystal oscillator calibration factor	4-byte float	
22	Diagnostics flags	Long integer	
23	Line density value when fixed by diagnostics	4-byte float	
24	Base density value when fixed by diagnostics	4-byte float	
25	Temperature value when fixed by diagnostics	4-byte float	
26	Pressure Units		D.5.2
27	Referral temperature for matrix referral	Long integer	D.5.8
29	Alarm coverage	Long integer	D.5.9

30	Modbus Slave address	Long integer	
31	Hysteresis on alarm output on analog output	Long integer	D.5.10
47	Modbus byte order		D.3.1
48	Modbus register size		D.3.1
49	Software type	Long integer	D.5.11
61	Hardware type	Long integer	D.5.12
64	Write-protected copy of PRT factor	4-byte float	
65	Write-protected copy of crystal factor	4-byte float	
66	Write-protected copy of analog output 4mA PWM factor	Long integer	
67	Write-protected copy of analog output 20mA PWM factor	Long integer	
127	Stored checksum for the FRAM	Long integer	
128	K0	4-byte float	
129	K1	4-byte float	
130	K2	4-byte float	
131	K18	4-byte float	
132	K19	4-byte float	
137	Transducer time period trap count	Long integer	
138	Transducer time period trap (difference in µs)	4-byte float	
139	Time period value when fixed by diagnostics	4-byte float	
140	Value represented by 4mA on analog output	4-byte float	
141	Value represented by 20mA on analog output	4-byte float	
146	Line pressure	4-byte float	
147 - 151	Temperatures for matrix referral	4-byte float	
152 - 171	Densities for matrix referral	4-byte float	
172	Atmospheric pressure	4-byte float	
173	Line density offset	4-byte float	
174	Line density scaling factor	4-byte float	
175	Special function calculation parameter A	4-byte float	
176	Special function calculation parameter B	4-byte float	
177	Special function calculation parameter C	4-byte float	
178	Special function parameter d / density of water	4-byte float	
179	Density of product A for special function calc.	4-byte float	
180	Density of product B for special function calc.	4-byte float	
181	Temperature offset	4-byte float	
182	User K0 value for API referral	4-byte float	

183	User K1 value for API referral	4-byte float	
184	User selected alarm variable	Long integer	D.5.13
185	User range (alarm) high value	4-byte float	
186	User range (alarm) low value	4-byte float	
192	Write-protected copy of K0	4-byte float	
193	Write-protected copy of K1	4-byte float	
194	Write-protected copy of K2	4-byte float	
195	Write-protected copy of K18	4-byte float	
196	Write-protected copy of K19	4-byte float	
201	Unit’s original calibration date	Long integer	
202	Unit’s most recent calibration date	Long integer	
203	Unit’s serial number	Long integer	
204	Unit type	Long integer	D.5.14
256	Status Register	Long integer	D.5.15
257	Corrected line density *	4-byte float	
258	Corrected base density *	4-byte float	
259	Line temperature *	4-byte float	
260	Special function calculation result*	4-byte float	
261	Transducer time period (in µs) *	4-byte float	
262	FRAM calculated checksums	Long integer	
263	PRT resistance * (in ohms)	4-byte float	
264	Transducer coil pickup level * (in volts)	4-byte float	
265	Transducer resonance Q value [2]	4-byte float	
266	Electronics board temperature (in °C)		
267/8	Software version string *	String	

* These are live values. Although they can be written to, it would be pointless.

[1] Special function units are not used in units conversions (they are for indication only), so can be set at any time.

[2] This value is only valid when bit 3 (hex 08) is set in the diagnostics flag register (22), after a 1 second pause.

D.5 INDEX CODES

This section provides an interpretation of the numerical indices used to represent non-numerical values.

D.5.1 API PRODUCT TYPE

Used in Register 0. (The user values for K0 and K1 are stored in Registers 182 and 183.)

Index	Product Type
0	Crude (general crude)
1	Refined (general product)
2	User K0 and K1

D.5.2 PRESSURE, TEMPERATURE, DENSITY AND OTHER UNITS

Used in Registers 3, 4, 5 and 26.

Index	Units
6	psi A
7	bar A
10	kg / cm^2
11	Pa
12	kPa
32	°C
33	°F
57	%
90	SGU
91	g / cm^2
92	kg / m^3
93	lb / gal
94	lb / ft^3
101	° Brix
102	° Baume heavy
104	° API

D.5.3 SPECIAL FUNCTION

Used in Register 6.

Index	Calculation
0	none
1	% mass
2	% volume
3	Specific Gravity
4	° Baume
5	° Brix
6	General Quadratic Equation
7	° API

D.5.4 SPECIAL FUNCTION QUADRATIC EQUATION NAME

Used in Register 7.

Index	Name
0	none
1	Density
2	% Mass
3	% Volume
4	° Baume
5	° Brix
6	Specific Gravity
7	Gravity
8	API
9	Plato
10	Twaddle
11	° Alcohol
12	(reserved)
13	(reserved)
14	(reserved)
15	(reserved)
16	(reserved)
17	(reserved)
18	(reserved)
19	(reserved)

D.5.5 SPECIAL FUNCTION QUADRATIC EQUATION UNITS

Used in Register 8.

Index	**Name**
0	none
57	%

D.5.6 OUTPUT AVERAGING TIME

Used in Register 9.

Index	**Averaging Time**
0	none
1	1 s
2	2 s
3	5 s
4	10 s
5	20 s
6	50 s
7	100 s

D.5.7 ANALOGUE OUTPUT SELECTION

Used in Register 10.

Index	**Output**
0	Density
1	Referred Density
2	Temperature
3	Special Function
4	4 mA
5	12 mA
6	20 mA

D.5.8 REFERRAL TEMPERATURE

Used in Register 27

Index	Referral Temperature
0	Lowest temperature value in matrix
1	
2	↓
3	
4	Highest temperature value in matrix

D.5.9 ALARM COVERAGE

Used in Register 29.

Bit Pattern	Coverage
0x00000001	4 - 20 mA output 1 alarm
0x00000008	System error
0x00000010	User defined alarm

D.5.10 ALARM HYSTERESIS

Used in Register 31.

Index	4 - 20 mA Output Hysteresis
0	0 %
1	0.5 %
2	1 %
3	2 %
4	5 %
5	10 %

D.5.11 SOFTWARE VERSION

Used in Register 49.

Index	Density Referral
0	Matrix
1	API

D.5.12 HARDWARE TYPE

Used in Registers 61.

Index	Meter Type
1	Advanced Fork

D.5.13 USER SELECTED ALARM VARIABLE

User in Register 184.

Index	Variable
0	Line density
1	Base density
2	Temperature
3	Time Period
4	PRT resistance
5	Special Function
6	Pickup level
7	None

D.5.14 UNIT TYPE

Used on Register 204.

Index	Transmitter type
5	Advanced fork

D.5.15 STATUS REGISTER FLAGS

Used in Register 256.

Bit	Hex Value	Flag Name	Definition
0	00000001	ST_IN_LOCK	P.L.L. is IN LOCK
1	00000002	ST_DIAG_ON	DIAGnostics ON
2	00000004	ST_FT1_ALM	4 to 20 mA output 1 in ALarM
3	00000008	ST_FT2_ALM *	4 to 20 mA output 2 in ALarM
4	00000010	ST_FT3_ALM *	4 to 20 mA output 3 in ALarM
5	00000020	ST_HART_BOARD *	whether HART BOARD is fitted
6	00000040	ST_RS232_BOARD *	whether RS232 BOARD is fitted
7	00000080	ST_SWITCH_BOARD *	whether SWITCH BOARD is fitted
8	00000100	ST_EXP0_BOARD	(reserved for future expansion)
9	00000200	ST_EXP1_BOARD	(reserved for future expansion)
10	00000400	ST_EXP2_BOARD	(reserved for future expansion)
11	00000800	ST_EXP3_BOARD	(reserved for future expansion)
12	00001000	ST_FT3_HART *	HART is in control of its 4 to 20 mA output
13	00002000	ST_BAD_STATUS	STATUS register corruption
14	00004000	ST_STAT_CORR	one or more STATus registers have been CORRected
15	00008000	ST_TOTAL_DEATH	status registers not updating - assume the worst
16	00010000	ST_USER_ALM	User defined variable in alarm
17	00020000		
18	00040000		
19	00080000		
20	00100000		
21	00200000	ST_TEMP_HI	TEMPerature reading too HIgh
22	00400000	ST_TEMP_LOW	TEMPerature reading too LOW
23	00800000	ST_ROM_CSF	ROM CheckSum Fail flag
24	01000000	ST_FRAM0_WPF	FRAM0 Write Protect Fail
25	02000000	ST_FRAM1_WPF *	FRAM1 Write Protect Fail
26	04000000	ST_FRAM0_RWE	FRAM0 Read/Write Error
27	08000000	ST_FRAM1_RWE *	FRAM1 Read/Write Error
28	10000000	ST_FRAM0_CSF	FRAM0 CheckSum Fail flag
29	20000000	ST_FRAM1_CSF *	FRAM1 CheckSum Fail flag
30	40000000	ST_FRAM0_ACK	FRAM0 ACK/data error
31	80000000	ST_FRAM1_ACK *	FRAM1 ACK/data error

* - The status flags marked thus refer to hardware features not present in the 7828. They can safely be ignored.

D.6 ESTABLISHING MODBUS COMMUNICATIONS

Using ADView, it is possible to establish which devices are available on the network, and their slave addresses. However, if you are not using ADView, the following procedure can be adopted.

If the transducer Slave address or the values of Registers 47 and 48 are not known, Modbus communications cannot be carried out successfully, and it will be necessary to establish the current values in these items. The following procedure will do this.

The process is:

a) Find the slave address by trying all possible values until a response is received.

b) Establish whether the register size is 16 or 32 bits by reading register 48.

c) Find the byte order by reading register 47.

a) Make sure only the transducer is connected to the Modbus Master, then send the following message (Read Register 47):

Slave Address	**Command**		**Register Address**			**Checksum**
00	03	00	47_{10}	00	02	checksum

Wait for a response. If there is none, repeat the same message, with the Slave address changed to 1, and await a response. Repeat the process until a response is obtained. This will show the slave address of the transducer.

b) Send the following message (Read Register 48):

Slave Address	**Command**		**Register Address**			**Checksum**
nn	03	00	48_{10}	00	02	checksum

where nn is the transducer's slave address.

The transducer will respond with either:

Slave Address	Comman d		Data Bytes	Checksu m
nn	03	04	4 data bytes	checksum

showing that the transducer is set to 16 bits register size, or:

Slave Address	**Command**		**Data Bytes**	**Checksum**
nn	03	08	8 data bytes	checksum

showing that the transducer is set to 32 bits register size. Thus, by reading the third byte of the response, you can deduce the value of Register 48.

c) Send the following message (Read Register 47):

Slave Address	Command		Register Address			Checksum
nn	03	00	47_{10}	00	02	checksum

where nn is the transducer's slave address.

The transducer will respond with either:

Slave Address	Command		Data Bytes	Checksum
nn	03	04	4 data bytes	checksum

or:

Slave Address	Command		Data Bytes	Checksum
nn	03	08	8 data bytes	checksum

Examine the first four bytes of the data. If they are all 00, then the transducer is in Big Endian mode; if they are all FF, then the mode is Little Endian.

D.7 EXAMPLE OF DIRECT MODBUS ACCESS

In many applications, direct access to Modbus will be unnecessary; ADView provides a way of configuring the 7828, and for accessing individual registers. This example describes how to access the 7828 directly, without the help of ADView.

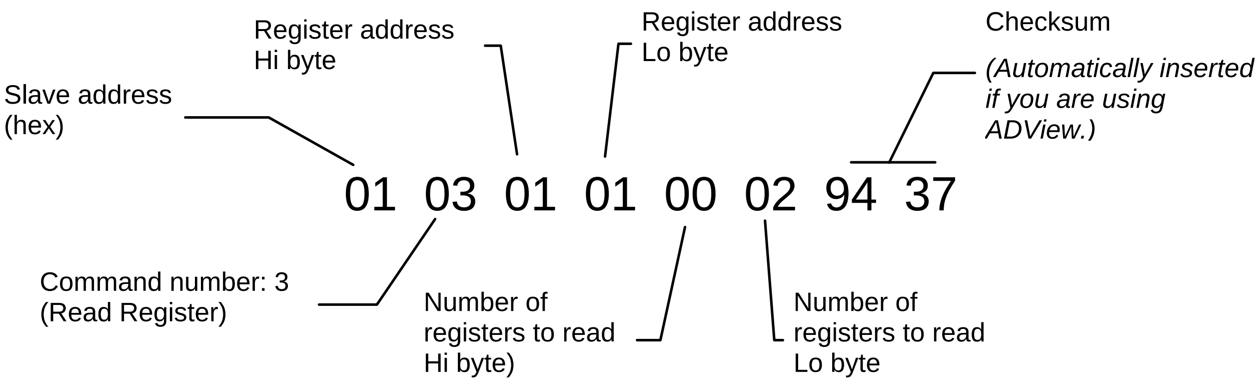
However, before you start, you should configure the transmitter using ADView (described in Section 4), and also set the Modbus Byte Order and Register Size (see section D.3.1).

Note: You can use ADView's Direct Communications tool to test out the following sequences, or any others you want to try. This has the added advantage that ADView calculates and inserts the checksum value for you.

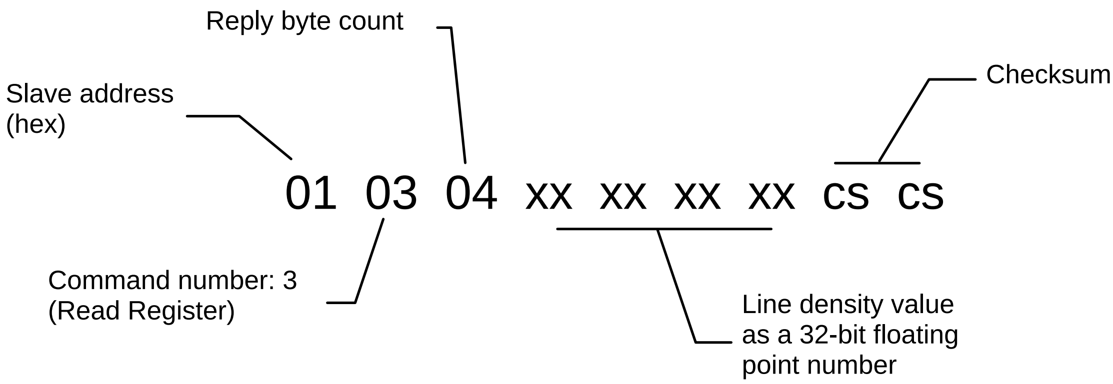
D.7.1 EXAMPLE 1: READING LINE DENSITY (16-BIT REGISTER SIZE)

The 7828 is assumed to have been configured with Register Size = 16-bit (Register 48 = 0), and has slave address = 1

The following string will read the line density, which is held in Register 257 (0101_{16})



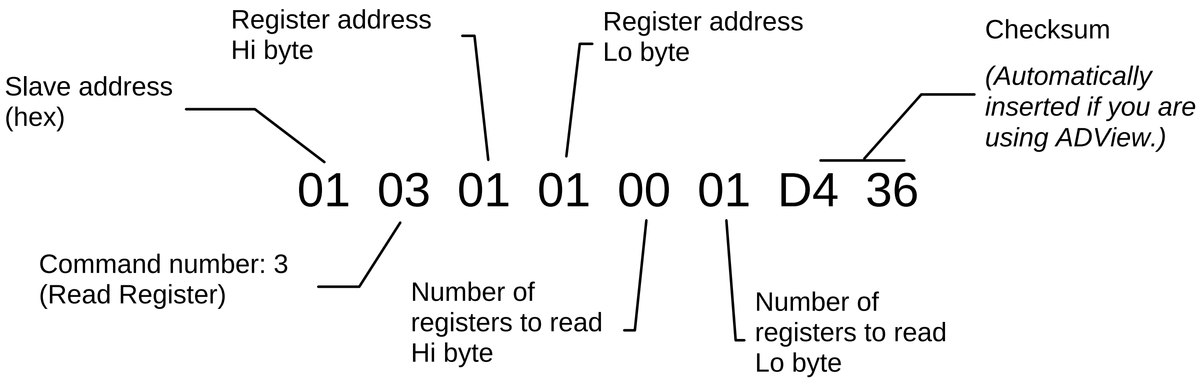
<u>The reply from the 7828 will be:</u>



D.7.2 EXAMPLE 2: READING LINE DENSITY (32-BIT REGISTER SIZE)

The 7828 is assumed to have been configured with Register Size = 32-bit (Register 48 = $FFFF_{16}$), and has slave address = 1

The following string will read the line density, which is held in Register 257 (0101_{16})



The reply from the 7828 will be the same as for Example 1.

E
Reference Data

E.1 CONVERSION TABLES

To convert the left hand column of units into the top row of units, multiply by the factor in the box.

E.1.1 LENGTH UNITS

	inches	yards	metres
inches	1	0.0278	0.0254
yards	36	1	0.9144
metres	39.37	1.0936	1

E.1.2 MASS UNITS

	lb	ton	kg
lb	1	4.464E-4	0.4536
ton	2240	1	1016.05
kg	2.2046	9.832E-1	1

E.1.3 MASS FLOW UNITS

	kg/s	kg/h	Tonne/h	lb/s	lb/m	lb/h	US GPM	US BPH
kg/s	1	3600	3.6	2.2046	132.28	7936.5	15.848/SG	22.624/SG
kg/h	0.000277	1	0.001	0.000612	0.03674	2.2046	0.0044/SG	0.0063/SG
Tonne/h	0.277777	1000	1	0.612384	36.74309	2204.585	4.4033/SG	6.2933/SG
lb/s	0.4536	1632.92	1.63296	1	60	3600	7.1891/SG	10.267/SG
lb/m	0.00756	27.215	0.027216	0.016666	1	60	0.1198/SG	0.1712/SG
lb/h	0.000126	0.4536	0.000453	0.000277	0.016666	1	0.002/SG	0.0029/SG
US GPM	0.0631 x SG	227.12 x SG	0.2271 x SG	0.1391 x SG	8.345 x SG	500.71 x SG	1	1.428571
US BPH	0.0442 x SG	158.98 x G	0.1589 x SG	0.0974 x SG	5.8419 x SG	350.5 x SG	0.7	1

SG = Specific Gravity in g/cc

E.1.4 VOLUME FLOW UNITS

	lt/m	m^3/s	m^3/h	m^3/d	US GPH	US GPM	US BPH	US BPD
lt/m	1	0.000016	0.06	1.44	0.004402	0.264171	0.377388	9.057315
m^3/s	60000	1	3600	86400	264.1717	15850.30	22643.28	543438.9
m^3/h	16.66666	0.000277	1	24	0.073381	4.402861	6.289802	150.9552
m^3/d	0.694444	1.16E-5	0.041666	1	0.003057	0.183452	0.262075	6.289802
US GPH	227.125	0.003785	13.6275	327.06	1	0.016666	0.023809	0.571428
US GPM	3.785416	6.31E-5	0.227125	5.451	60	1	1.428571	34.28571
US BPH	2.649791	4.42E-5	0.158987	3.8157	42	0.7	1	24
US BPD	0.110407	1.84E-6	0.006624	0.158987	1.75	0.029166	0.041666	1

E.1.5 VOLUME/CAPACITY UNITS

	in^3	ft^3	m^3	litres	gal
in^3	1	5.787E-4	1.639E-5	0.01639	4.329E-3
ft^3	1728	1	2.832E-2	28.32	7.4805 (US liq)
m^3	6.1024E+4	0.0353	1	1000	264.2 (US liq)
litres	61.02	0.0353	0.001	1	0.2642 (US liq)
gal	231.0	0.1357	3.785E-3	3.785	1

1 Imperial gallon = 1.20095 U.S. liquid gallons

E.1.6 TEMPERATURE UNITS

	°C	°F	Kelvin
°C	1	(°C/5 x 9)+32	+273.15
°F	5/9 x (°F-32)	1	
Kelvin	-273.15		1

E.1.7 PRESSURE UNITS

	Bar	PSI	kPa	kg/cm^2	mmHg
Bar	1	14.5	100	1.019716	750.2
PSI	0.0689476	1	6.89476	0.070307	51.737
kPa	0.01	0.145	1	0.009807	7.502
kg/cm^2	0.980665	14.22	102.02	1	735.683
mmHg	0.001333	0.0193285	0.1333	0.0013593	1

E.1.8 DENSITY UNITS

	kg/m^3	g/cc	lb/ft^3	lb/US gal
kg/m^3	1	0.001	0.062428	0.008345
g/cc	1000	1	62.428	8.34543
lb/ft^3	16.0185	0.01602	1	0.133681
lb/US gal	119.8264	0.119826	7.4805	1

E.1.9 DYNAMIC VISCOSITY UNITS

	cP	Pa.s	$kgf.s/m^2$	Slug/ftS	$lbf.s/ft^2$
cP	1	0.001	0.000102	0.000021	0.000021
Pa.s	1000	1	0.101972	0.020885	0.020885
$kgf.s/m^2$	9806.65	9.80665	1		
Slug/ftS	47880.3	47.8803		1	1
$lbf.s/ft^2$	47880.3	47.8803		1	1

E.1.10 KINEMATIC VISCOSITY UNITS

	cS	mm^2/s	m^2/s	in^2/s	ft^2/s	cm^2/s
cS	1	1	1.0E-6	0.00155	0.010765	0.01
mm^2/s	1	1	1.0E-6	0.00155	0.010765	0.01
m^2/s	1000000	1000000	1	1550	10.7649	10000
in^2/s	645.16	645.16	0.000645	1	0.006944	6.4516
ft^2/s	92.8944	2.8944	0.092864	144	1	0.928944
cm^2/s	100	100	0.0001	0.155	1.0765	1

Note: The **dynamic viscosity** (η) of a Newtonian fluid is given by:

$$\eta = \tau \times dv / dr$$

where

τ = shearing stress between two planes parallel with the direction of flow

dv / dr = velocity gradient at right angles to the direction of flow.

The dimensions of dynamic viscosity are $M L^{-1} T^{-1}$ and the SI unit is Pascal seconds (Pa s).

The kinematic viscosity (ν) is the ratio of the dynamic viscosity to the density ρ

The dimensions of kinematic viscosity are $L^2 T^{-1}$ and the SI unit is square metres per second (m^2/s).

E.2 PRODUCT DATA

E.2.1 DENSITY/TEMPERATURE RELATIONSHIP OF HYDROCARBON PRODUCTS

Crude Oil

Temp (°C)	Density (kg/m³)								
60	738.91	765.06	791.94	817.15	843.11	869.01	894.86	920.87	946.46
55	742.96	768.98	794.93	820.83	846.68	872.48	898.24	923.95	949.63
50	747.00	772.89	798.72	824.51	850.25	875.94	901.80	927.23	952.82
45	751.03	776.79	802.50	828.17	853.81	879.40	904.96	930.50	956.00
40	755.05	780.68	806.27	831.83	857.36	882.85	908.32	933.76	959.18
35	759.06	784.57	810.04	835.48	860.90	886.30	911.67	937.02	962.36
30	763.06	788.44	813.79	839.12	864.44	889.73	915.01	940.28	965.53
25	767.05	792.30	817.54	842.76	867.97	893.16	918.35	943.52	968.89
20	771.03	796.18	821.27	846.38	871.49	896.59	921.68	946.77	971.85
15.556	774.56	799.57	824.59	849.60	874.61	899.62	924.63	949.64	974.65
15	775.00	800.00	825.00	850.00	875.00	900.00	925.00	950.00	975.00
10	778.95	803.83	828.72	853.61	878.50	903.41	928.32	953.23	978.15
5	782.90	807.65	832.42	857.20	882.00	906.81	931.62	958.45	981.29
0	786.83	811.46	836.12	860.79	885.49	910.21	934.92	959.66	984.42

Refined Products

Temp. (°C)	Density (kg/m^3)								
60	605.51	657.32	708.88	766.17	817.90	868.47	918.99	969.45	1019.87
55	610.59	662.12	713.50	769.97	821.49	872.00	922.46	972.87	1023.24
50	615.51	666.91	718.11	773.75	825.08	875.53	925.92	976.28	1026.60
45	620.49	671.68	722.71	777.53	828.67	879.04	929.38	979.69	1029.96
40	625.45	676.44	727.29	781.30	832.24	882.56	932.84	983.09	1033.32
35	630.40	681.18	731.86	785.86	835.81	886.06	938.28	986.48	1038.67
30	635.33	685.92	736.42	788.81	839.37	889.56	939.72	989.87	1040.01
25	640.24	690.63	740.96	792.55	842.92	893.04	943.16	993.26	1043.35
20	645.13	695.32	745.49	796.28	846.46	896.53	846.58	996.63	1046.68
15.556	649.46	699.48	749.50	799.59	849.61	899.61	949.62	999.63	1049.63
15	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1000.00	1050.00
10	654.85	704.66	754.50	803.71	853.53	903.47	953.41	1003.36	1053.32
5	659.67	709.30	758.97	807.41	857.04	906.92	956.81	1006.72	1056.63
0	664.47	713.92	763.44	811.10	860.55	910.37	960.20	1010.07	1059.93

The above tables are derived from equations which form the basis of the data in the Revised Petroleum Measurement Tables (IP 200, ASTM D1250, API 2540 and ISO R91 Addendum 1).

The density temperature relationship used is:

$$\rho_t = \rho_{15} \exp\left[-\alpha_{15}\Delta_t\left(1+0.8\alpha_{15}\Delta_t\right)\right]$$

where:

ρ_t = Density at line temperature t°C (kg/m^3)

ρ_{15} = Density at base temperature 15°C (kg/m^3)

Δ_t = (t -15)°C (i.e., t - base temperature)

α_{15} = Tangent thermal expansion coefficient per °C at base temperature 15°C

The tangent thermal expansion coefficient differs for each of the major groups of hydrocarbons. It is obtained using the following relationship:

$$\alpha_{15} = \frac{K_0 + K_1\rho_{15}}{\rho_{15}^{\;2}}$$

where K_0 and K_1 are the API factors and are defined below:

Product	Density Range (kg/m^3)	K_0	K_1
Crude Oil	771 - 981	613.97226	0.00000
Gasolines	654 - 779	346.42278	0.43884
Kerosines	779 - 839	594.54180	0.00000
Fuel Oils	839 - 1075	186.96960	0.48618

E.2.2 PLATINUM RESISTANCE LAW (TO DIN 43 760)

°C	Ohms	°C	Ohms	°C	Ohms	°C	Ohms
-50	80.31	5	101.91	60	123.24	115	144.17
-45	82.29	10	103.90	65	125.16	120	146.06
-40	84.27	15	105.85	70	127.07	125	147.94
-35	86.25	20	107.79	75	128.98	130	149.82
-30	88.22	25	109.73	80	130.89	135	151.70
-25	90.19	30	111.67	85	132.80	140	153.58
-20	92.16	35	113.61	90	134.70	145	155.45
-15	94.12	40	115.54	95	136.60	150	157.31
-10	96.09	45	117.47	100	138.50	155	159.18
-5	98.04	50	119.40	105	140.39	160	161.04
0	100.00	55	121.32	110	142.29	165	162.90

°F	Ohms	°F	Ohms
0	93.03	100	114.68
10	95.21	110	116.83
20	97.39	120	118.97
30	99.57	130	121.11
32	100.00	140	123.24
40	101.74	150	125.37
50	103.90	160	127.50
60	106.07	170	129.62
70	108.23	180	131.74
80	110.38	190	133.86
90	112.53	200	135.97

E.2.3 DENSITY OF AMBIENT AIR (IN KG/M^3)

Air Pressure	Air Temperature (°C)						
(mb)	6	10	14	18	22	26	30
900	1.122	1.105	1.089	1.073	1.057	1.041	1.025
930	1.159	1.142	1.125	1.109	1.092	1.076	1.060
960	1.197	1.179	1.162	1.145	1.128	1.111	1.094
990	1.234	1.216	1.198	1.180	1.163	1.146	1.129
1020	1.271	1.253	1.234	1.216	1.199	1.181	1.163

Taken at a relative humidity of 50%

E.2.4 DENSITY OF WATER (IN KG/M^3 TO ITS - 90 TEMPERATURE SCALE)

Temp °C	0	2	4	6	8	10	12	14	16	18
0	999.840	999.940	999.972	999.940	999.848	999.699	999.497	999.244	998.943	998.595
20	998.203	997.769	997.295	996.782	996.231	995.645	995.024	994.369	993.681	992.962
40	992.212	991.432	990.623	989.786	988.922	988.030	987.113	986.169	985.201	984.208
60	983.191	982.150	981.086	980.000	978.890	977.759	976.607	975.432	974.237	973.021
80	971.785	970.528	969.252	967.955	966.640	965.305	963.950	962.577	961.185	959.774
100	958.345									

Use pure, bubble-free water

F
C.O.S.H.H. Document

The form, Number T89004, contained in this Appendix, must be copied and completed whenever a Solartron transducer is to be returned for servicing, calibration or repair to Solartron or one of their agents. This must be done before the product is shipped.

The purpose of the form is to inform Solartron of any potentially hazardous chemicals which may be present in the transducer, or that may have leaked into the casing.

Solartron
Victoria Road, Farnborough, Hampshire, GU14 7PW, England
Telephone: +44 (0)1252 376666 Fax: +44 (0)1252 543854

C.O.S.H.H.
DOCUMENT

HEALTH AND SAFETY CLEARANCE

1.0 This form must be used when returning transducers for service/calibration.

2.0 A completed copy of this form should be faxed to +44 (0)1252 376666 or sent by 1st class post to ensure that we have this information before we receive the equipment. A further copy should be handed to the carrier with the equipment.

3.0 Failure to complete the form or comply with the procedure will lead to delays in servicing the equipment.

4.0 Please complete the following sections.

4.1 Transducer Type: ....

4.2 Serial No.: ....

4.3.0 Details of all substances passed through the transducer.

4.3.1 Chemical names:

(a) ....

(b) ....

(c) ....

(d) ....

4.3.2 Precautions to be taken in handling of these substances.

(a) ....

(b) ....

(c) ....

(d) ....

4.3.3 Action to be taken in the event of human contact or spillage.

4.4 Any further information which you consider relevant.

4.5 Please complete Section 4.5.1 if substances are not toxic, or Section 4.5.2 if they are.

4.5.1 **I hereby confirm that the equipment specified above has not come into contact with any toxic or hazardous substances.**

Signed: ....

Name: ....

Position: ....

For and on behalf of: ....

....

Date: ....

4.5.2 **I hereby confirm that the only toxic or hazardous substances that the equipment specified above has been in contact with are named above, that the information given is correct and that the following actions have been taken:**

1. The equipment has been drained.

2. The inlet/outlet ports have been sealed and the equipment has been securely packed and labelled in accordance with Health and Safety procedures.

3. The carrier has been informed of the hazardous nature of the consignment.

Signed: ....

Name: ....

Position: ....

For and on behalf of: ....

....

Date: ....

Carrier to be used: ....

....

IMPORTANT: Before returning any product for servicing, this form must be completed and sent to Solartron, or the official distributor undertaking the servicing.

Form No.: T89004

Solartron Mobrey Limited
158 Edinburgh Avenue Slough Berks England SL1 4UE
Tel: 01753 756600 Fax: 01753 823589
e-mail: sales@solartron.com www.solartronmobrey.com
a Roxboro Group Company

Bestobell Mobrey GmbH	Deutschland	tel: 0211/99 808-0
Solartron Mobrey Ltd	China	tel: 021 6353 5652
Mobrey sp z o o	Polska	tel: 022 871 7865
Mobrey AB	Sverige	tel: 08-725 01 00
Mobrey SA	France	tel: 01.34.30.28.30
Mobrey SA-NV	Belgium	tel: 02/465 3879
Solartron Mobrey	USA	tel: (281) 398 7890

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