Armstrong Ultrasonic Portable (AUP) Flowmeter Installation & Operations Manual

Please read and save these instructions

Armstrong®

484-EN-V1.3

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1.0 Introduction

The AUP Handheld Ultrasonic Flow & BTU meter is a revolutionary portable meter with multiple functions. **It is the most compact portable meter on the market.** It is designed to accommodate the challenges of onsite flow and energy measurements. The applications include **flow surveys, meter validation, pump performance verification, HVAC and energy balancing, facility management, and other demanding flow and energy monitoring applications.**

The AUP compact design offers a single-handed operation, and extreme ease of use. Using the latest signal processing technology, which has demonstrated its robustness and data measurement repeatability, the portable meter offers highly accurate and reliable measurements. The meter is self-explanatory and simple to follow. The AUP is also a handheld energy meter when it is equipped with a BTU measurement module.

The unique clamp-on fixture design for both of the flow transducers and temperature sensors makes the installation hassle free. No special skills or tools are required. The Li-Ion battery allows the user to measure flow and energy for an extended period of time -up to 8 hours. A built-in data logging function can store nine logs at freely selectable recording intervals, giving the user flexibility in data-logging and data-analysis. The AUP is the **best choice when instant flow and energy measurements are required.**

Features

- Accurately measures energy and flow using non-intrusive technology.
- Capability of measuring bi-directional flow/energy
- Ease of installation and operation
- Ability to measure a wide pipe size range, from 0.75” up to 120”
- Ergonomic design, allowing the main unit to be held and operated with one hand
- Signal quality tracking and self-adaptation for robust performance
- Suitable for pure liquids and liquids with some particles. No dependence on conductivity
- Suitable for all commonly used pipe materials
- Rechargeable battery for 8 hours of operation
- Self-explanatory user interface. Step-by-step Quick Start guidance
- Built-in large data logger
- PC software for data download and real-time data acquisition
- ±0.5% of linearity
- Accuracy: ±1% of reading in velocity plus ±0.03ft/s (10mm/s)

Typical Applications

The AUP handheld flow and BTU meter is a perfect fit for the following applications:

- Energy consumption supervision and water conservation management.
- Cooling system and air conditioning/glycol solutions.
- Water, including hot water, chilled water, city water, sea water, process
- Sewage and drainage water with small particle quantity.
- Oil, including crude oil, lubricating oil, diesel oil, fuel oil, and more
- Various chemicals, including alcohol, acids, and more
- Solvents.
- Beverage and food processors.
- Water and waste treatment.
- Power plants (nuclear, thermal & hydropower) heat energy, boiler feed water.
- Metallurgy and mining applications (e.g., acid recovery)
- Marine operation and maintenance.
- Pulp and paper.
- Pipeline leak detection, inspection, tracking and collection.
- Water distribution network monitoring.

1.1 Principle of Measurement

The AUP ultrasonic flowmeter is designed to measure the velocity of liquid within a closed conduit. It uses the well-known transit-time technology. The transducers are a non-contacting, clamp-on type. They do not block the flow, thus there is no pressure drop. They are easy to install and remove.

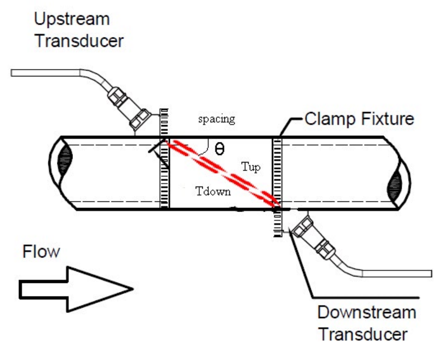
The AUP utilizes a pair of transducers that function as both ultrasonic transmitters and receivers. The transducers are clamped on the outside of a closed pipe at a specific distance from each other. The transducers can be mounted in the Reflect-Method, where the sound transverses the pipe twice, or W-Method, where the sound transverses the pipe four times, or in the Direct-Method, where the transducers are mounted on opposite sides of the pipe and the sound crosses the pipe once. The selection of the mounting methods depends on pipe and liquid characteristics.

The AUP operates by alternately transmitting and receiving a frequency-modulated burst of sound energy between the two transducers and measuring the transit time that it takes for sound to travel between the two transducers. The difference in the transit time measured is directly and exactly related to the velocity of the liquid in the pipe, as shown in the equation and figure on the following page.

Transit Time Operation

Equation 1

$$V = \frac{MD}{\sin 2\theta} \times \frac{\Delta T}{T_{up} \bullet T_{down}}$$



Where:

θ is the angle between the sound path and the flow direction

M is the number of times the sound traverses the flow

D is the pipe diameter

T_{up} is the time for the beam traveling from upstream the transducer to the downstream transducer

T_{down} is the time for the beam traveling from the downstream transducer to the upstream transducer

$\Delta T = T_u p - T_{down}$

1.2. Temperature Measurement

1.2.1 Measurement Channels

The AUP flowmeter is be equipped with two temperature measurement channels in a single port. The two temperature channels can accommodate two PT100 RTD sensors directly. They are used for thermal energy measurement. By combining the flow rate and temperature differential information, AUP can provide valuable information for resource management and process control. The energy measurement may be transmitted to the BAS or SCADA system through the analog or OCT of the meter, allowing AUP to be integrated as an RTU in a flow and energy monitoring network. The capability helps to reduce the cost and complexity while providing immediately needed data. Please not that if the working environment is subjected to strong interference, it is recommended to add external isolation to protect the flowmeter device.

1.2.2 Connecting Temperature Sensor Inputs

The two temperature channels designed for thermal measurement function are connected to the center port (between the two flow transducer ports) on top of the hand held unit. The function can work with a 3-wire or 4-wire PT100 sensor without any extra parts. Thermal energy calculation:

(1) Qt = Q x (T2 – T1) x Ct, (2) Qt = Q x (TC2 – TC1)

Where Qt is the thermal energy (or caloric) consumed, Q is the flow rate, T1 and T2 are the temperature at supply and return points, respectively. Ct is the specific heat (or the thermal capacity coefficient) of the fluid. For water, it is normally about 0.0041868GJ/m3C. TC1 and TC2 are the thermal capacities corresponding to temperature T1 and T2, which are calculated by the flowmeter according to international standards.

The following menu windows may be used when performing thermal energy measurement: M3114

M Menu) 3 (Input/Output) 1 Display 1 Main Window 4 ENERGY-RATE

M → Input/Output → Display → Main Window → Energy-Rate

Press ENT after 3, 1, 1 and 4 to select the option highlighted.

1.3 Product Identification

Each set of the AUP series flow meter has a unique product identification number, or ESN. This number is written into the software and can only be modified by the manufacturer with a special tool. In the case of any hardware failure, please provide this number when contacting the manufacturer. It is displayed in Menu Window M55. The window can be accessed by pressing the following series of keys:

M Menu) 5 (System) 5 (Version/SN#)

See Section 2.4 for more information on display windows.

1.4 Data Integrity and Built-in Time-Keeper

All user-entered configuration values are stored in the built-in, non-volatile flash memory that

can retain the data for over one hundred years. The memory integrity is retained even when the power is disconnected or turned off. Password protection is provided to avoid inadvertent configuration changes or totalizer resets.

A time-keeper is integrated in the flow meter. It works as the time base for flow totalizing. The time-keeper remains operational as long as the battery's terminal voltage is over 1.5V. In the case of battery failure, the time keeper will not keep running, and the time data will be lost. The user must re-enter proper time values after the battery is restored. Improper time values will affect the totalizer as well as many other functions. **Re-entering the time value is a crucial step after battery failure** because the totalizer is a factor in accurate flow rate measurement.

1.5 Technical Specifications

Design	Portable	
Energy Measurement	Measure energy rate and energy total. Optional dual RTD is required	
Flow Velocity Range	± 32 ft/s, bi-directional	
Flow Accuracy	For pipe ≥6”: ±1% of reading ±0.03 ft/s in velocity*	
	For pipe <6”: ±2% of reading ±0.03 ft/s in velocity*	
Temperature Accuracy	Temp: ±1.8˚F	
	Delta Temp: ±0.18˚F with matched RTD sensors	
Repeatability	0.5%	
Response Time	0.5s. Configurable between 0.5s and 99s	
Display/Keypad	LCD with backlight. 4 x 16 letters. 5 x 4 tactile-feedback membrane keypad plus utility 4 keys. Displays instantaneous energy rate/total, flow rate/total (positive, negative and net), velocity.	
Units	English (U.S.) or Metric	
Physical Quantity	Volumetric flow rate, total flow, velocity, temperature, BTU	
Totalizers	Positive totalizer, negative totalizer, net totalizer, manual totalizer	
Output	4-20mA	
	Optically isolated Open Collector Transistor (OCT) output for frequency and pulse.	
Recording	Automatically records the daily total of the last 128 days, the monthly total of the last 64 months and the yearly total of the last 5 years.	
	Built-in data logger (4GB space) for recording energy, velocity, flow, status, and more	
Data Logger	314,572 Lines for 4 items 97,090 Lines for 8 items 61923 Lines for 16 items	
Communication Interface	RS232. Supports the MODBUS protocol	
Software	PC software for data logger download and real-time data acquisition	
Pipe Size Range	3/4” - 120”, depending on transducer	
Pipe Material	All metals, most plastics, some lined pipes	
Liquid Type	Most liquids with fewer than 1% suspended particles < 75um in a full pipe	
Battery	Ion-Li up type to 8 hours	
Liquid Temperature	32˚F - 176˚F or 32˚F - 312˚F , depending on transducer type	
Enclosure	Handset: Plastic with anti-shock protection	Carrying case: Aluminum alloy protective case. Suitable for normal and harsh environment
	1.2 lbs. with batteries	
Protection	IP54	
Dimensions	For handset: 8”x4”x1.5”	
	For carrying case: 21”x17”x6.5”	
Weight	Weight Handset: 1.2 lbs. with batteries	Carrying case: 15 lbs. approximate
Power Source	3 AAA Ni-H built-in batteries. When fully recharged, it will last over 8 hours of operation.	

1.5 Parts Identification

12VDC charger with adapter

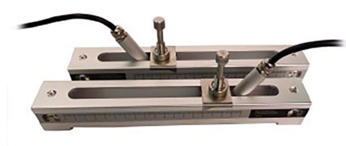
Communication terminal block

RS2* 2MHz

Transducers for pipes ¾" to 2 ½", ≥3" for copper, 0oc/32oF to 150oC/302oF

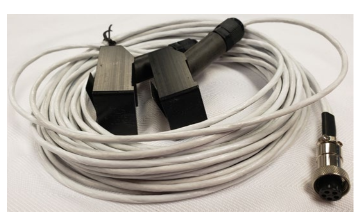
RM* 1MHz

Transducers for pipes 3" to 28", ≥4" for copper, 0oc/32oF to 150oC/302oF



Transducer cables, 15' standard length

Temperature elements with conjoined transmitter connection



*NOTE: AUP may be purchased with one or both sets of transducers shown.

2.0 Flow Rate Measurement

2.1 Built-in Battery

The AUP flow meter can operate either from the built-in Ni-H rechargeable battery or from an external AC power supply. The battery will last over 8 hours of continuous operation when fully charged. In addition, the AC power supply allows the device to run while charging. The red LED will be on when the battery is charging.

The battery-charging circuit employs both constant-current and constant-voltage charging methods. The battery charges quickly at the beginning, and the current tapers off as the battery approaches full power. In other words, the current becomes smaller and smaller throughout the charging process. As, a result, there should be no problems with over-charging. This also means that the process of bringing the device to full power can take up a significant amount of time. We recommend charging the device overnight to get close to 100% power. The charger can be connected to the handset at all times when constant measurement is required. If extended use of the handset is required, it is best to leave the device plugged in.

When fully charged, the terminal voltage peaks at around 4.25V. The terminal voltage is displayed on window menu M56 (press buttons M, 5, and 6, in succession). When the battery is nearly consumed, the battery voltage drops to below 3V. The approximate remaining working time for the battery is indicated Red LED.

in this window as well. The remaining working time is estimated based on the battery voltage at the time. Some errors may occur, especially when the terminal voltage is in the range between 3.70 to -3.90 volts.

For battery maintenance and replacement, please refer to Section 6.3.

2.2 Power On

Press the ON key to turn on the power, and OFF to turn off the power. Once the flow meter is turned on, it will run a self-diagnostic program—checking the hardware first, and then, the software integrity. If there are any abnormalities, corresponding error messages will be displayed. (See Section 6.2 for more information on error messages.)

Under normal conditions, there should be no display of error messages, and the flow meter will proceed to the main window. This menu can also be accessed at any time by pressing the Ex key up to three times, depending on the menu window in use at the time. The main menu will display the signal strength, signal quality, and transit-time ratio. These readings are based on the most recent pipe parameters configured, or by the initial program.

The flow measurement will keep running in the background without change, regardless of any user window browsing or viewing activities. Only when the user enters new pipe parameters will the flow meter change measurement to reflect these alterations.

When new pipe parameters are entered or when the power is turned on, the flow meter will enter into a self-adjusting mode. The device will account for the increase in receiving circuits so that the signal strength will be within a proper range. Using this step, the flow meter finds the best receiving signals. Refer to Sections 2.6 and 2.8 for more information on configuring the pipe parameters.

When the user adjusts the position of the installed transducers, the flow meter will re-adjust the signal gain automatically. Any user-entered configuration value will be stored in the NVRAM (non-volatile memory), until it is modified by the user.

2.3 Keypad

Main Display

Flow Rate

Signal Quality

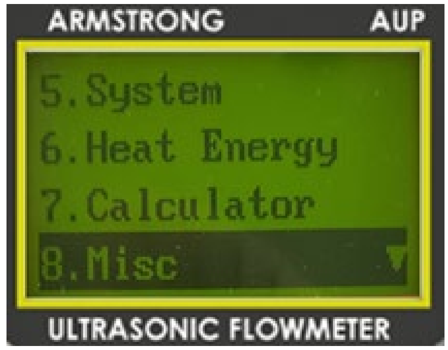
- The SET key is used to configure the pipe parameters.
- The LOG key is used to set up and view the built-in data-logger.
- The CAL key is used to set up calibrations.
- The M key is used to access all the other menu functions.
- The ENT key is the enter key to confirm or acknowledge any input or selections.
- The Ex key is the exit or backspace key.
- The Vi key is used to view measurements.
- The + key is used to navigate up, or to add numbers together.
- The - key is used to navigate down, or to subtract numbers.
- The 0 through 9 and decimal keys are used to enter numeric values or select submenus.

2.4 Initial Programming

It is useful to program certain parameters common to all measurements before you deply your AUP. Press “M” to access the main menus.

M: This key allows access to all eight (8) programming and diagnostic menus, and the place to start when first commissioning the unit.

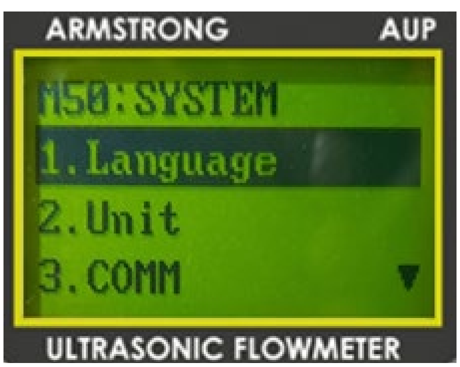
Menus for Information and Programming



Scroll to option 5, “System”, using the down arrow key on the keypad. Press “ENT” to enter this submenu. This menu allows you to select the language of your display, the engineering units for measuring flow and energy, and set the date and time of the instrument.

NOTE: THE FORMAT FOR DATE IS: YY MM DD

AND THE FORMAT FOR TIME IS: HH MM SS IN MILITARY (24 HOUR) TIME



With the language, measuring units and date/time set, you are ready to deploy your AUP.

2.5 Set Menu

The transmitter has four menu access keys

SET: Allows measurement parameters to be set up

LOG: Allows logs to be created, viewed, downloaded and erased

CAL: Allows us to calibrate a pair of transducers with this transmitter

M: This key allows access to all eight (8) programming and diagnostic menus, and the place to start when first commissioning the unit.

SET MENU
S1. Quick Start
S10. Set Mounting Site
S20. Set Pipe Parameters
S30. Fluid Parameters
S40. Transducer Parameters
§2.5 Display Window List
§2.5 Display Window List
§2.5 Display Window List

Set Menu

Display Window List
S2. Set Pipe
S21. Enter OD
S22. Set Wall TH
S23. Set ID
S24. Pipe Material
S25. Set Liner
Exit
3. Set Fluid S31. Fluid Type
S32. Sound Speed
S33. Viscosity
Exit
4. Transducer
S41. Transducer Type
S42. Mount Method
S43. Mount Space
S44. Scale Factor
Exit
S5. Set Filter
S51. Average Filter
S52. Noise Filter
S53. Poor Sig filter
S54. Empty pipe
Exit
6. Exit

2.6 SET, LOG and CAL Menus Set

- Quick Start Windows are solely to help the user get the flow meter up and running as quickly as possible. They include instructions on preparing mounting site, setting pipe parameters, setting fluid parameters, and setting transducer parameters, followed by instructions on transducer installation, verification, and diagnosis.
- SET “Set Pipe” Windows to set pipe parameters. This includes outer diameter, wall thickness, inner diameter, pipe material, and pipe liner.
- SET “Set Fluid” Windows to set fluid parameters. This includes fluid type, sound speed, and viscosity.
- SET “Set Transducer” Windows to set transducer parameters. This includes transducer type, mount method, mount space, and scale factor.
- SET “Set Filter” Windows to set up filter parameters. This includes average filter, noise filter, poor signal filter, and empty pipe.

LOG

- LOG “Log Items” Windows to set up data logging. This includes logging a basic set of 4 items, 8 items, or all 16 items.
- LOG “Log Schedule” Windows to set up schedule for data logging. This includes logging interval, start time, and stop time.
- LOG “Save To” Window to save logged data to a customary file name.
- LOG “View Log” Window to view any previously saved logged data.
- LOG “Clear Log” Window to delete a previously saved logged data.

CAL

- CAL “CAL Zero” Window to set up zero calibration.
- CAL “CAL Linear” Window to set up linear calibration. This includes manual totalizer and a linear table.
- CAL “CAL 0/4 – 20mA” Window to verify that the output of the 0/4 – 20mA is accurate.
- CAL “CAL Temp” Window to set up temperature calibration.

2.7 Additional Diagnostic and Operational Menus

- M11 – M13 Site Windows to store, recall, and delete site parameters, respectively.
- M21 – M24 Diagnosis Windows to display triplet, sound speed, transit time, and Reynolds time, respectively.
- M31 – M38 Input/Output Windows to change display settings, 0/4-20mA CL, OCT output, Relay output, Frequency output, buzzer, alarm, and batch control, respectively.
- M41 – M49 Totalizer Windows to set up totalizer. Includes totalizer unit, multiplier, NET on/off, POS on/off, NEG on/off, totalizer reset, daily, monthly, and yearly totalizer, respectively.
- M51 – M58 System Windows to change and/or view the system settings. Includes language, system units, COMM, date/time, ESN, battery life, set up system lock, and working timer, respectively.
- M61 – M65 Heat Energy Windows to set up the heat energy. Includes location, energy unit, multiplier, total reset, and temperature, respectively.
- M70 Calculator Window that features a scientific calculator.
- M81 – M83 Misc Windows for additional functions such as maximum flow rate, last power off, time powered.

2.8 Detail of Configuration: SET Menu

Step 1: Enter Pipe Information

All pipe parameters can be entered by pressing keys S1 (e.g., press S1 (e.g. SET, 1, ENT consecutively) and then, scroll down to Step 2 using the ▼/- key. Press ENT. If you are unsure of your pipe's dimensions, you may find them in Section 8.1. Select the type of pipe you are using, and click the corresponding link. Once you have this information, proceed with the following steps.

Outer Diameter 2.375 in

Pipe OD: Enter the pipe outer diameter, and press the ENT key to confirm.

Additional pipe infomration may be found at:
http://www.engineeringtoolbox.com/pipes-tubes-dimensions-t_16.html

Wall Thickness: Press the ▼/- key to scroll down to the next parameter. Press ENT and enter the pipe wall-thickness value. Press ENT again to confirm.

Select Pipe Carbon Steel Stainless Steel Ductile Iron Copper ETC

Pipe Material: If your pipe material is on the list in the previous step, the flow meter will automatically skip this step and go to the next step. You do not have to enter in the Sound Speed unless you have selected Other as your pipe material.

If you selected Other as your pipe material, you will have to enter the sound speed manually. Press ENT which will prompt you to enter the correct sound speed for the pipe wall material you are using. You can find this data in the Appendix 8.1 of the User's Manual. When you are done, press ENT to confirm.

Pipe Lining: Press ▼/- to scroll down, and then press ENT. If your pipe has lining inside, enter the lining information. Press ENT to confirm. Press◄ ("Ex") to go back to the Quick Start menu.

Step 2: Enter Fluid Information

From the Quick Start menu, scroll down to Step 3.

Fluid Water Glycol ETC

Fluid Type: Press ENT and select the item that matches your fluid type. If you do not find a match (non-standard fluid), select item 9 (Other). Press the ENT key to confirm.

Sound Speed in Fluid: If you found your fluid type in the previous step, the flow meter already has the sound speed data. Therefore, skip this step and go on to the next.

Otherwise, exit to the main screen and press keys SET, 3, 2. Press ENT and key in the sound speed of your fluid. You can find this information in Appendix §9.3 of the User's Manual. When you are done, press ENT to confirm.

Step 3: Enter Transducer Installation Information

From the Quick Start menu, scroll down to Step 4.

Transducer Type: Press ENT and select the item that matches your transducer. Use the ▼/- key to scroll down and press ENT and select the proper transducer type from the list. *Note: The type of transducer you are using will be printed on the side of the transducers.* Press ENT to confirm.

XDUCER TYPE RM RS2 other

Mounting Method: Use the ▼/- key to scroll down to the mounting method selection screen. Then, press ENT and select the proper method. Press ENT to confirm. For pipes smaller than 1", use the W method. For pipes from 1" - 12", use the Reflect-Method. For pipes larger than 12", use the Direct-Method. See Section 3.3 for more details on how to select the proper method.

Mounting Spacing: Use the ▼/- key to scroll down to Step 5. The displayed value is the mounting spacing between the two transducers (see the image on the right). Write down this number, as you will need it later when installing the transducers.

INSTALL XDUCER NOW Dist.= 1.8415", V

STOP ***It is extremely important to enter the parameters properly before installing the transducers. Incorrect parameters result in operation errors and inaccurate measurements. Common parameter errors are incorrect wall thickness, usually due to corrosion on the pipe. See Section 3.4 for more details on issues caused by wall thickness problems.***

Enter Transducer Information - Continued

S44
Scale Factor
>=   1.01

1
=>0.951_

Change the Scale Factor: The scale factor can be found printed on the transducer pair. Press keys S44 (e.g., press SET, 4 and 4 keys, consecutively). Then, press the ENT key. Key in the new scale factor of the transducer pair you are planning to use. Press ENT to confirm.

Example:

For common pipe materials and standard liquids, the parameter configuration steps are as following:

- Press the SET key. Make sure that the option “1. Quick Start” is highlighted. Press ENT.
- You should see a “Select Mounting Site” window for information on ideal mounting conditions. Press the down arrow to move on to the next step.
- You should see the “Set Pipe Parameters” window. Press the ENT key to program the pipe parameters. Press ENT to edit the outer diameter. Press ENT again to save. Press the down arrow.
- You should see the “Enter Pipe Wall-Thickness” window. Press ENT to edit the wall-thickness. Press ENT again to save. Press the down arrow.
- You should see the “Select Pipe” window. Press ENT to select the pipe material. Using the up and down arrows, select the appropriate pipe material. Press ENT to save. Press the down arrow.
- You should see the “Has Liner?” window. Press ENT if the pipe has no liner. Press ENT again, use the up and down arrows to select the appropriate liner. Press ENT to save. Use the arrow to exit.
- You should see a “Set Fluid” window. Press the down arrow to access this menu. Press the ENT key. Use the up and down arrows to select the appropriate fluid. Press ENT again to save information. Use the arrow to exit.
- You should see a “Set Transducer” window. Press the ENT key. You should now see the “Transducer Type” window. Press the ENT key once again and use the up and down arrows to select the appropriate transducer type. Press ENT to save.
- Press the down button to access the transducer mounting method. You should see the “Transducer Mount” window. Press ENT to edit the mount method. Use the up and down arrows to select your appropriate method. Press ENT again to save.
- Use the down arrow button to edit the scale factor. You should see the “Enter Transducer Scale Factor” window. Press the ENT key to edit. Enter in the scale factor of the transducer pair you are planning to use. Press ENT key again to save. Use the arrow to exit.
- Press the down arrow to access this menu. You should see an “Install Transducers Now” window. The number displayed on the screen represents the distance between the two transducers (transducer spacing). For more information on installation press the ENT key.

Refer to Quick Start for more information and diagrams.

3.0 Installation

3.1 Mounting Allocation for Transducers

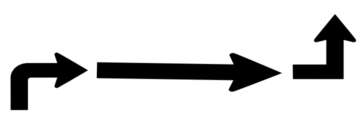
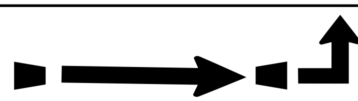
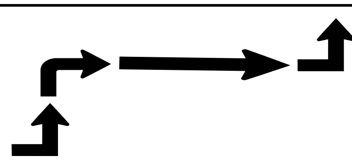
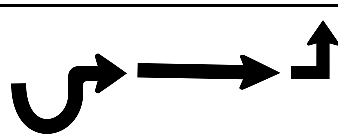
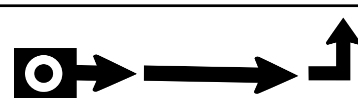
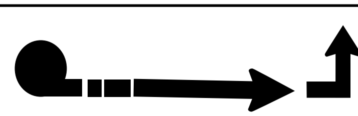
The first step in the installation process is to select an optimal location for installing the transducers in order to make the measurements reliable and accurate.

An optimal location is defined as a long, straight pipeline filled with the liquid to be measured. This pipe can either be in a vertical or horizontal position. However, on a vertical pipe, an upwards flow direction is required. The following instructions will guide the user in finding an optimal location:

Principles to Select an Optimal Location:

1. The straight pipe should be long enough to eliminate any errors measurement errors that may be introduced by non-laminar flow. A straight run of pipe 15 times the pipe outer diameter (represented as 15D) upstream of the intended measurement point is more likely to yield a laminar, or undisturbed, flow. This is an ideal condition for accurate measurement. As a general rule, the longer the straight run, the higher the accuracy. The transducers should be installed at a pipe section where the **length of the straight pipe at the upstream side is at least 10D and the downstream is at least 5D. The transducer installation site should be at least 30D away from the pump**. Refer to Figure 1 below for more details.
2. **Make sure that the pipe is completely filled with liquid.** It is impossible to take an accurate measurement if there are any air bubbles. The equation used to calculate the flow rate assumes the pipe is filled completely with the liquid being measured. For the best results, make sure the pipe is under pressure. This way, it has to be full.
3. Make sure that the temperature on the mounting location does not exceed the range for the transducers. Temperature ratings for AS and AM transducers are found on page 8.
4. If possible, select a relatively new. straight pipe section. Older pipes tend to have corrosions and deposits, which could affect the results. If an old pipe is used, it is **recommended that the corrosion and deposits are treated as if they were a part of the pipe wall or as part of the pipe liner (i.e. adjust the value of the pipe wall thickness or liner thickness parameters to take into account the corrosion or deposit)**. Armstrong Metering offers a wall thickness gauge that may also be used to confirm unknown wall thickness.
5. Some pipes have a type of **plastic liner,** the presence of which can create gaps between liner and inner pipe wall. Air gaps will interfere with the ultrasonic wave transmission within the pipe.

Figure 1.

Piping Configurations and Transducer Orientation Effluent must ALWAYS be vertical flowing UPWARD		Upstream Straight Run	Downstream Straight Run
One 90° Elbow Upstream		10 pipe Ø	5 pipe Ø
Concentric Reducers Up/Down		10 pipe Ø	5 pipe Ø
One Plane Compound Elbow Upstream		12 pipe Ø	5 pipe Ø
Two Plane Compound Elbow Upstream		20 pipe Ø	5 pipe Ø
Valve Upstream		20 pipe Ø	5 pipe Ø
Pump Upstream		30 pipe Ø	5 pipe Ø

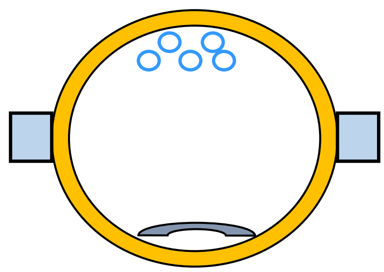
3.2 Transducer Installation

The transducers used by the AUP series ultrasonic flow meter are made of piezoelectric crystals for both transmitting and receiving ultrasonic signals through the wall of liquid piping system. These excellent quality materials deliver high accuracy. The measurement is obtained by calculating the travel-time difference of the ultrasonic signals. Since the difference is very small, the spacing and the alignment of the transducers are critical factors to the accuracy of the measurement and to the performance of the system. **Meticulous care should be taken when installing the transducers.**

Steps to Install the Transducers:

1. Determine an optimal location. The straight pipe at both sides of the transducers needs to be of **sufficient length** (See Page 16 Figure 1). Horizontal pipes typically have gas bubbles inside, especially on the pipe ceiling. There also may be sediment on the pipe base. As a result, it is recommended that the transducers are installed on the side of, rather than the top or bottom of, a horizontal pipe. Tuberculated iron pipe walls will interfere with the accurate reflection of ultrasonic signals.

Figure 2.



Z-Method Transducer Mounting - transducers on opposite sides of pipe

Gas bubbles collect along the top of horizontal pipe runs, while sediments collect in the bottom. Installing the transducers at 90 and 270 degrees, as in the example, eliminates these interferences.

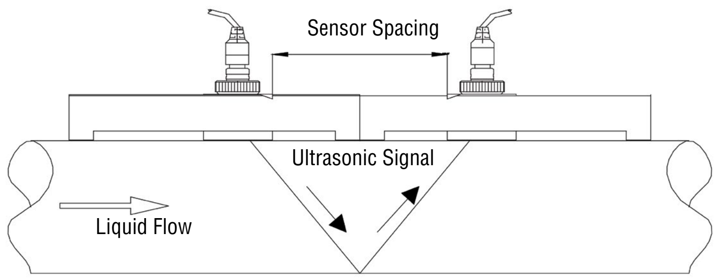
2. Make sure the chosen location is safe for and compatible with the operation of the flow meter. **The AUP is not designed for contact with hazardous materials.**
3. Clean any dust and/or rust off the spot where the transducers are to be installed. For better results, **polishing the pipe's outer surface with a sandpaper is strongly recommended.**
4. Extra care should be taken to avoid any sand or dust particles left between the pipe surface and the transducer surface. Clean the surface thoroughly with a damp towel or sponge. Once the surface is completely clean, dry it with a towel for best results.
5. Apply adequate ultrasonic couplant. **Couplant should be spread over the entire transmitting surface on the transducer and the entire installation surface on the pipe.** The purpose of the couplant is to fill any space between the flat surface of the transducer and the curved surface of the pipe wall. Couplant is provided. Additional couplant materials may include dielectric grease and non-setting silicon.
6. Consider the appropriate method for mounting the transducers on the pipe. There are **two methods of mounting:**
   - **Magnetic mounting rail(s):** If the pipe material is steel or iron, the magnetic force will keep the transducers on the pipe.
   - **Clamp-on fixture:** We provide two of types of clamp-on fixtures. The transducers may be pressed tightly against the pipe with the **nylon straps** provided. Radiator hose clamps are also available as an alternative for a more permanent installation. Turn the screws on the clamps clockwise to tighten, using a screwdriver or a 5/16 socket wrench.

3.3 Transducer Spacing

Reflect-Mode Installation

The Reflect-Method installation is the most widely used method for measurements in pipes ranging from ¾" to 12". These diameters provide a very short sound path. This method doubles the sound path, thus, ensuring an accurate measurement.

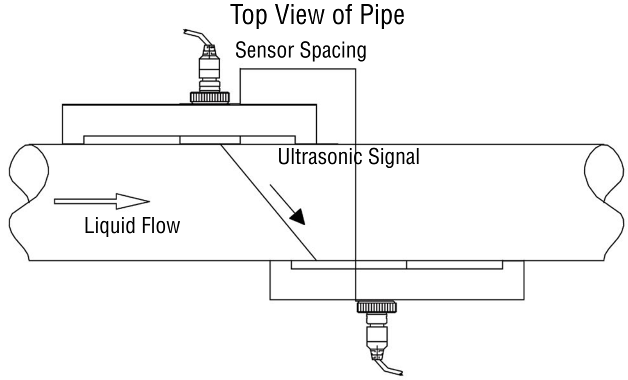
Top View of Pipe



Direct-Mode Installation

The Direct-Method is commonly used for pipe diameters between **12" and 120"**. Signal strength is increased with this method.

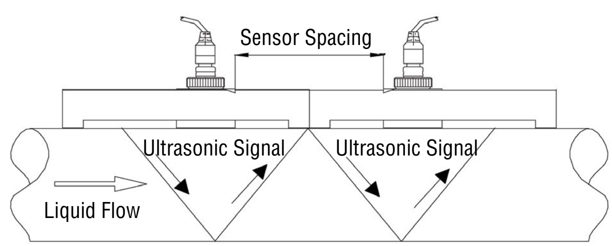
Top View of Pipe



W-Method Installation

The W-method may be used on **plastic pipes** with diameters between ¾" and 4", as an alternative to the R-Method.

Top View of Pipe



3.4 Installation Checkup

After the completion of the transducer installation, the user should check the following items:

- The receiving signal strength
- The signal quality (Q value)
- The delta time (traveling time difference between the upstream and the downstream signals)
- The estimated liquid sound speed
- The transit time ratio

This process will ensure that the flow transducers are installed to produce the most accurate measurement.

3.4.1 Signal Strength

Signal strength, represented as S, is a 3-digit number that represents the amplitude of the receiving ultrasonic signals, as a percent. This value can be seen on the main menu. 00.0 means that there are no signals detected, and 100 is the maximum signal strength that can be received.

The flow meter will operate well when the **signal strength ranges from 30 to 100**. Regardless of the functioning **range, higher signal strength is always desirable**—the higher the number, the more reliable and accurate the results will be. The following methods are recommended to obtain strong signals:

1. Make sure the pipe is in good condition. Polish the outer surface of the pipe and apply more couplant between the pipe and transducers.

2. Carefully adjust the position of the two transducers, both vertically and horizontally. Check the signal strength after each movement. Stop at the position where the signal strength reaches a maximum. Be sure to check the transducer spacing to make sure it is still the same or very close to the figure displayed in S1, Step 5 (see Section 2.6).

3. Each transducer has a signal strength value, and the difference between the two should not be more than 0.1 to ensure the most accurate measurement.

4. If the current location of the transducers provides a signal strength that is lower than 70, try moving into a more favorable location.

3.4.2 Signal Quality

Signal quality is indicated as the Q value for this instrument. This value can be seen on the main menu. A higher Q value means a higher Signal to Noise Ratio (SNR). Higher signal quality yields a higher degree of accuracy. Under normal pipe conditions, the Q value should be in the **range of 60 to 90**. A higher quality is always more desirable.

Causes for a low Q value may be:

- Interference from other instruments and devices nearby such as an electrical frequency converter, which could cause strong interference. If possible, relocate the flow meter to a location where interference is minimal.

- Bad sonic coupling between the transducers and the pipe. If the Q value is not in the desired range, we recommend polishing the pipe surface again. It is important to clean the surface after polishing. We also recommend adding more couplant. Finally, the pipe needs to be in the best condition possible.

- The selected pipe section is not conducive to accurate measurement. In some cases, the pipe material causes this problem with signal quality. For example, carbon steel pipes frequently feature corroded pipe sections, which would change pipe wall thickness values. In this case, we recommend using the Direct-Method for transducer installation. Increase or decrease the spacing between the transducers until the ratio is 100±3. See Section 3.4. D for more details. The user may also move the transducers to a pipe section that is in more favorable condition.

3.4.3 Total Transit Time and Delta Time

The total transit time (or traveling time) and the delta time are both displayed on menu window M23. This window can be accessed by pressing the following series of keys:

M ⟶ **2** (Diagnosis) ⟶ **M23** (Transit Time)

See section 3.4.4 for more details. These values are the primary data used by the instrument to calculate the flow rate. They are the **most important values calculated by the flow meter.** The measured flow rate will vary as the total transit time and delta time vary. Therefore, the total transit time should remain stable or fluctuate only very slightly. **The device will adjust for any variance on its own until it is stable.**

The **delta time** normally varies less than 20%. **If the variation exceeds 20% in either positive or negative direction, there may have been errors in the installation of the transducers.** The user should examine the installation site for any apparent problems. The following list shows some common examples of installation errors that cause inaccuracies with measurement:

- There may be **insufficient couplant** between the transducers and the pipe surface.
- The transducers may not be spaced correctly or may have been placed in a non-favorable location. Either of these issues will cause **weak signal strength and quality.**
- The pipe may be only partially full or there may be air bubbles. If this is the case, the logarithm used to calculate the flow rate will not yield accurate readings. **Make sure that the pipe is completely full and that there are no air bubbles in the liner.**
- The **wall thickness values may be incorrect.** The error may have resulted from corrosion on the pipe. Use the Z-method of installation or move to a more favorable location.

3.4.4 Transit Time Ratio

This ratio is used to check the quality of the transducer installation. It also verifies whether the entered pipe parameters are consistent to their actual values. If the pipe parameters are correct and the transducers are installed properly, the transit time ratio should be in the **range of 100±3**. If this range is not met, the user should verify the following:

- The entered pipe parameters are correct
- The actual spacing of the transducers the same as or close to what shown on window S1, Step 5 (See Section 2.6)
- The transducers are installed properly and are facing the right direction
- The mounting location is stable
- The pipe-run upstream and downstream of the transducers is straight
- The pipe is in adequate condition; the most common pipe quality issues are too much corrosion or too much deposition inside the pipe
- There are no interference sources inside the pipe
- All aspects of the device meet the measurement requirements as listed above

4.0 How To: A Quick Function Reference

Please Perform Initial Setup 2.4 Before Proceeding

4.1 How To Check If The Instrument Is Working Properly

The lower right-hand corner of the LCD display features the symbol corresponding to the device's current level of functionality. The following list explains the most commonly-seen symbols:

1. Generally speaking, when "R" is displayed, the device is working properly.
2. If an "H" flashes, then the received signal may be poor. See Section 6.0 for more on troubleshooting.
3. If an "I" is displayed, then no signal was detected.
4. If a "J" is displayed, then the hardware of this instrument may be out of order. See Section 6.0 for more details.

4.2 How To Check The Liquid Flowing Direction

1. Make sure that the instrument is working properly. There should be an "R" displayed in the lower right hand-corner of the screen.
2. Check the flow rate display. If the value is **positive**, the direction of the flow will be **from the upstream transducer, which is connected to the upstream connector of the meter, to the downstream transducer**; if the value is **negative**, the direction will be f**rom the downstream transducer to the upstream transducer**.

4.3 How To Change The Unit's Measurement System

The device can operate in either the English or the Metric system. This option can be accessed using the following series of keys:

M → System → Unit (M52) → Metric/English

4.4 How To Select A Flow Rate Unit

Press keys M52, followed by the second sub-menu option "Flow Rate Unit" to select the flow rate unit as well as the corresponding time unit. This can be accessed as follows:

M → System → Unit (M52) → Flow Rate Unit

Be sure to set all the values 1 through 4 in this submenu to the units required- selecting "Metric/English" in submenu 1 alone will not change the unit values for flow, interval, totalization or energy.

4.5 How To Use The Totalizer Multiplier

The user must enter the proper multiplying factor for the totalizer multiplier. In addition, the user should make sure that the rate of the totalizer pulse is not too fast or too slow. We recommend a speed of 2-3 pulses per minute. This setting can be accessed by pressing the following series of keys:

M → Totalizer → Multiplier (M42)

If the totalizer multiplying factor is too small, the output pulse will be very fast and there could be a loss of pulses. The designed minimum pulse is 500 milliseconds.

If the totalizer multiplying factor is too large, the output pulse will be very slow, which might be a problem if the master device requires fast response.

4.6 How To Turn On And Off Totalizers

Use menu window M43, M44, and M45 to turn on or turn off the NET, POS, and NEG totalizers, respectively. These menus can be accessed as follows:

M → Totalizer → NET on/off (M42), POS on/off (M43), or NEG on/off (M44)

4.7 How To Reset The Totalizer

Use menu window M46 to reset the flow rate totalizers. This can be accessed as follows: M → Totalizer → 6.TOT Reset (M46)

4.8 How To Use The Damping Filter To Stabilize The Reading

The damper acts as a filter for a stable reading. This setting can be adjusted in the “Avg Filter” menu, which can be accessed through the following series of keys:

SET → Set Filter → ENT.

If a “0” is entered, there is no damping. A bigger number generally brings a more stable effect. However, a balance is required; bigger damping numbers will slow down the instruments response time.

4.9 How To Use The Zero-Cutoff Function (Noise Filter)

This function can be accessed by pressing the following series of keys:

SET → 5 → 2

4.10 How To Perform Zero Calibration

The AUP has been calibrated at the factory with the transducer pair(s) provided to you. Changing the factory calibration settings will invalidate the device’s measurement. It is possible to reset the “Zero Calibration” in the field, using a section of completely charged piping or known dimensions, which section can be fully isolated by upstream and downstream valves and confirmed so. With the transducers properly installed, pipe completely full and flow stopped downstream, then upstream, perform the zero calibration by pressing the following series of keys:

CAL → Zero Cal. Press the ENT key to start the zero calibration. The device will count down 30 seconds. When this is complete, press “1” to accept the new zero calibration.

4.11 How To Change The Flow Rate Scale Factor

The scale factor (SF) is the ratio between the “actual flow rate” and the flow rate measured by the flow meter. It can be determined with standard flow calibration equipment. This value can be adjusted by pressing the following series of keys:

SET → Quick Start → Set Transducer Parameters → Scale Factor. Press the ENT key to edit the scale factor.

4.12 How To Use The Password Lock

The password lock provides a means of preventing inadvertent configuration changes or totalizer resets. When the system is locked, the user can still browse menu windows, but cannot make any modifications to the windows.

The password locking/unlocking can be done in menu window M57, which can be accessed with the following series of keys:

M → System → M57.

The system can be locked with or without a password. A password-free lock can be enabled by pressing the ENT key while in menu window M57. A personalized password can also be set up. It must consist of 1 to 4 digits.

4.13 How To Use The Built-In Data Logger

1. The built-in logger has a space of 4 GB of memory/4000 individual logs. Choosing 4 items will allow 314,572 lines, 8 items will allow 97,090 lines, and 16 items will allow 61,923 lines of data.
2. Use window L10 to save the data to be collected in a specific numeric file name; otherwise the device will save the data to a file named “current”. This can be accessed using the following series of keys: LOG → Log Items 1) Save To.
   Use LOG → Log Items 2) Log items to select 4 items (flowrate, flow total, date, time), 8 items (flowrate, flow total, BTU rate, BTU total, Ts, Tr, date, time), or 16 items (all of the above + signal strength and other diagnostics). Use LOG → Schedule and L31, L32, L33 to set up the starting time, time interval, and logging duration, respectively.
3. Use window L40 to view saved data in the logger buffer. This window can be accessed using the following series of keys: LOG → View Log.
4. Use window L50 to clear any unwanted logging data remaining in the RS-232C interface and in the logger buffer. This window can be accessed using the following series of keys: LOG → Clear Log.
5. The data stored in the data logger can be downloaded to any PC as a *csv file using the terminal block interface and RW software provided. See the RW instructions Section 9.5.

4.14 How To Use The Frequency Output

All AUP series flow meters have a Frequency Output functionality. The signal for each device represents its flow rate for the purpose of communicating with other devices. The emitted frequency output signal is designed to connect with other instruments.

The Frequency Output is completely user-configurable. Usually, three parameters are configured:

1. Enter the frequency range in the "Freq Range" window as follows: M → Input/Output → Frequency Output → Freq Range
2. Enter the lower limit of flow rate in the "Freq Min" window as follows: M → Input/Output → Frequency Output → Freq Min
3. Enter the higher limit of flow rate in the "Freq Max" window as follows: M → Input/Output → Frequency Output → Freq Max

Example: Assume that the flow rate varies in a range from 0m3/h to 3000m3/h and the required output signal frequency should be in the range 200Hz to 1000Hz. The user should enter 0 for the "Freq Min" window, 3000 for the "Freq Max" window, and 200 followed by 1000 for the "Freq Range" windows.

***Please note that the user needs to select the frequency output option ***

4.15 How To Use The Totalizer Pulse Output

The flow meter will produce a pulse output with every unit of liquid flow. This pulse could be used by an external pulse counter to measure the accumulation of the flow rate. Refer to Sections 4.4 and 4.5 for the set up totalizer units and multiplier. The totalizer pulse output can only be connected to OCT devices or BUZZER hardware devices.

Example: Assume that the POS totalizer pulse output is needed and every pulse represents 0.1 cubic meter of liquid flow. Assume also that the pulse output is connected to an internal buzzer. With every 0.1 cubic meter of flow, we need the BUZZER to beep for a while. In order to achieve this, the following steps must be performed.

1. Select the Cubic Meter (m3) unit in window M52 → Flow Rate unit. This can be accessed as follows:

   M → System → Unit (M 52) → Flow Rate Unit → Change Volume
2. Select the Multiplier factor as '2. X 0.1' in menu window M41.

4.16 How To Set Up The Alarm Signal

There are two types of hardware alarm signals that are available with this instrument. One is the buzzer and the other is the OCT output. The triggering sources of the alarming events for both the Buzzer and the OCT output could be:

1. There is no receiving signal.
2. The signal received is too weak.
3. The flowmeter is not in normal measurement mode.
4. The flow direction is changed.
5. Overflow occurs at the Frequency Output.
6. The flow is out of the specified range.

4.17 How To Use The Built-In Buzzer

The built-in buzzer is user-configurable. It can be used as an alarm. Use menu window M36, which may be accessed as follows: M → Input/Output → Buzzer (M36)

4.18 How To Use The Oct Output

The OCT output is on/off type. It is user-configurable. The user can access this menu by pressing the following series of keys M33.

4.19 How To Modify The Built-In Calendar

No modification on the built-in calendar will be needed in most cases. The calendar consumes insignificant amount of power. Modifications will only be needed when the battery has been totally exhausted or when the replacement battery takes too long that the original time data is lost. Use window menu M54 to change the time and date. This menu can be accessed as follows:
M → System → Date/Time (M54)

4.20 How To Adjust The LCD Contrast

Use M312 to adjust the LCD contrast. The adjusted results will be stored in the EEPROM so that the MASTER ERASE (factory default restoration) will make no effect on the contrast. M312 may be accessed as follows:
M → Input/Output → M31: Display → M312: LCD Bklt

4.21 How To Use The RS232 Serial Interface

This menu can be accessed by pressing buttons M, 5, and 3, in succession (M53).

4.22 How To View The Totalizers

Use menu windows M47, M48, and M49 to view the daily, monthly, and yearly totalizer, respectively. These menu windows may be accessed as follows: M → Totalizer → M47: Daily TOT (or M48: Monthly TOT or M49: Yearly TOT).

4.23 How To Use The Working Timer

Use the working timer to check the time elapsed during a particular operation, or over the total time the device is powered (default). For example, use it as a timer to show how long a fully-charged battery will last. In menu window M58 press ENT key and select YES to reset the working time. M58 may be accessed as follows: M → System → M58: Work Timer.

4.24 How To Use The Manual Totalizer

Use menu window C21, which can be accessed as follows: CAL → Linear Cal → C21: Man Totalizer. Press any key to start and press the key again to stop the totalizer.

4.25 How To Check The ESN

Every set of the AUP series flowmeter utilizes a unique ESN to identify the meter—the ESN in an eight-digit number that provides the product version and manufacturing date.

The user can also employ the ESN for instrumentation management.

The ESN is displayed in menu window M55, which can be accessed as follows: M → System → Version/SN# (M55).

4.26 How To Check The Battery Life

The battery life is displayed on window M56, which can be accessed by pressing buttons M, 5, and 6, consecutively.

4.27 How To Calibrate The Flow Meter

There are 4 calibration functions for the AUP: Zero Calibration, Linear Calibration, 0/4-20 mA loop calibration, and temperature calibration. For information on zero calibration in the field, please see Section 4.28. These are factory operations. To maintain the validity of the device function, please refer your AUP to a qualified third party instrument calibration service.

5.0 Menu Window Details

Key	Sub-Key	Window Number		Function
SET	Quick Start	Step 1: Mounting Site	S1	Window which provides instructions on selecting a mounting site: - Pipe is full - Straight pipe: 10D upstream, 5D downstream - Vertical pipe: flow must go up. - Horizontal pipe: transducer must be on the side of pipe.
		Step 2: Set Pipe Parameters	S2a	Window for entering the outer diameter of the pipe Valid range: 0 to 120”.
			S2b	Window for entering pipe wall thickness
			S2c	Window for selecting pipe material Standard pipe materials (no need to enter the material sound speed) include: (1) Carbon steel (2) Stainless steel (3) Cast iron (4) Ductile iron (5) Copper (6) PVC (7) Aluminum (8) Asbestos (9) Fiberglass (10) Other
			S2d	Window for selecting the liner material. Select none (1) for pipes without any liner. Standard liner materials (no need to enter liner sound speed) include: (2) Tar Epoxy (3) Rubber (4) Mortar (5) Polypropylene (6) Polystyrol (7) Polystyrene (8) Polyester (9) Polyethylene (10) Ebonite (11) Teflon (12) Other
		S3: Set Fluid Parameters	S3a	Window for selecting fluid type For standard liquids (no need to enter liquid sound speed) include: (1) Water (2) Sea Water (3) Kerosene (4) Gasoline (5) Fuel oil (6) Crude Oil (7) Propane at -45C (8) Butane at 0C (9) Other liquids (10) Diesel Oil (11) Caster Oil (12) Peanut Oil (13) #90 Gasoline (14) #93 Gasoline (15) Alcohol (16) Hot water at 125C

Key	Sub-Key	Window Number		Function
		S4: Set Transducer Parameters	S4a	Window for selecting transducer type There are 3 different types of transducers for selection (AS, AM, and AL).
			S4b	Window for selecting the transducer mounting methods Four methods can be selected: (0) Reflect-Method (1) Direct-Method (2) W-Method
			S4c	Window to set the flow rate scale factor. The factory default is ‘1’. Keep this value as ‘1’ when no calibration has been made.
		S5: Install Transducer Now	S5a	Window for transducer mount distance and installation: a) Mark 2 spots of the same side on pipe surface, with the distance equal to the number shown. b) Sand & clean the spots, make surface smooth. c) Put compound on transducer surface. d) Clamp transducer onto pipe. Cable towards outside. e) Finish wiring then power up.
		S6: Verify	Window to verify the signal strength, signal quality and transit time ratio shown	
		S7: Diagnose	Window to Diagnose Triplet	
	Set Pipe	S21: Set OD	Window for entering the outer diameter of the pipe. Valid range: 0 to 120”.	
		S22: Set Wall TH	Window for entering the pipe wall thickness.	
		S23: Set ID	Window for entering the inner diameter of the pipe. If pipe outer diameter and wall thickness are entered correctly, the inner diameter will be calculated automatically, thus no need to change anything in this window.	
		S24: Pipe Material	Window for selecting pipe material Standard pipe materials (no need to enter the material sound speed) include: (1) Carbon steel (2) Stainless steel (3) Cast iron (4) Ductile iron (5) Copper (6) PVC (7) Aluminum (8) Asbestos (9) Fiberglass (10) Other	
		S25: Set Liner	Window for selecting the liner material. Select none (1) for pipes without any liner. Standard liner materials (no need to enter liner sound speed) include: (2) Tar Epoxy (3) Rubber (4) Mortar (5) Polypropylene (6) Polystyrol (7) Polystyrene (8) Polyester (9) Polyethylene (10) Ebonite (11) Teflon (12) Other	

Key	Sub-Key	Window Number	Function
	Set Fluid	S31: Fluid Type	Window for selecting fluid type For standard liquids (no need to enter liquid sound speed) include: (0) Water (1) Sea Water (2) Kerosene (3) Gasoline (4) Fuel oil (5) Crude Oil (6) Propane at -45C (7) Butane at 0C (8) Other liquids (9) Diesel Oil (10) Caster Oil (11) Peanut Oil (12) #90 Gasoline (13) #93 Gasoline (14) Alcohol (15) Hot water at 125C
		S32: Sound Speed	Window for entering the sound speed of non-standard liner materials
		S33: Viscosity	Window for entering the viscosity of non-standard liquids
	Set Transducer	S41: Transducer Type	Window for selecting transducer type There are 3 different types of transducers for selection: AL, AM, and AS.
		S42: Mount Method	Window for selecting the transducer mounting methods Four methods can be selected: (0) Reflect-Method (1) Direct-Method (2) W-Method
		S43: Mount Space	Window to display the transducer mounting space or distance.
		S44: Scale Factor	Window to set the flow rate scale factor. The factory default is ‘1’. Keep this value as ‘1’ when no calibration has been made.
	Set Filter	S51: Damping Filter	Window to set the damping constant.
		S52: Noise Filter	Window to set the velocity cutoff for noise flow.
		S53: Poor Signal Filter	Window to set the poor signal filter. If last reading was acceptable, select (1) Yes. If last reading was not acceptable, select (2) No.
		S54: Empty Pipe	Window to establish setting for an empty pipe. During normal operation, pipe should be full.
LOG	Log Items	L10: Basic 4 Items	Window to instruct device to log only basic information.
		L10: All 8 Items	Window to instruct device to log 8 items available on AUP.
		L10: All 16 Items	Window to instruct device to log all 16 items available on AUP.
	Schedule	L11: Log interval	Window for entering the interval at which the flowmeter will log data.
		L12: Start Time	Window for entering the start time of the logger. (Year-Month-Day and Hour-Minute-Second)
		L13: Stop Time	Window for entering the end time of the logger. (Year-Month-Day and Hour-Minute-Second)
	Save To	L20	Window to save recorded log to a customizable file name.
	View Log	L30	Window to view a previously recorded log.
	Clear Log	L40	Window to view a previously recorded log.

Key	Sub-Key	Window Number		Function
CAL	Zero Cal	C10		Window to set up the Zero point. Make sure the liquid in the pipe is not running during setup.
	Linear Cal	C21: Man Totalizer		Window for manual totalizer used for calibration. Press any key to start and press the key again to stop the totalizer.
		C22: Linear Table		Window to view linear table (1) Add data point. (2) View table.
	0/4 – 20 mA Cal	C31: Verify		Verify 0/4-20 mA loop.
		C32: Calibrate		Currently unavailable for the AUP
	Temp Cal	C41: T1/T2		Window to display temperature for supply line and return line.
		C42: Calibrate		Window to calibrate temperature sensors. User must enter password. Use resistors to recalibrate sensors.
M	Site	M11: Save Site		Window to store the pipe parameters into the internal NVRAM (non-volatile memory).
		M12: Recall Site		Window to recall the previously saved pipe parameters
		M13: Delete Site		Window to delete previously saved pipe parameters
	Diagnosis	M21: Triplet		Window to display the signal strength, signal quality and transit time ratio.
		M22: Sound Speed		Window to display the estimated sound speed of the fluid in the pipe. If this value has an obvious difference with the actual fluid sound speed, the user is recommended to check if the pipe parameters are correct and if the transducer installation is good.
		M23: Transit-time		Window to display the total transit time and delta time (transit time difference between upstream and downstream traveling).
		M24: Reynolds		Window to display the Reynolds number and the pipe factor used by the flow rate measurement program. Note, the pipe factor is rarely used.
	Input/ Output	M31: Display	M311: Main Window	Window to control main window display. Choose between flow rate, velocity, TOT-POS, and ENERGY-RATE.
			M312: LCD Backlight	Window to control the LCD display backlight. The entered value indicates how many seconds the backlight will be on with every key pressing.
			M313: Buzzer	Window to turn buzzer on or off.
		M32: 0/4-20 mA CL	CL Mode	Select the current loop (CL) mode.
			Output Parameter	Enter flow rate.
			Parameter Minimum	Enter minimum for 0/4 mA signal.
			Parameter Maximum	Enter maximum for 20 mA signal.
			CL Reading	Display present output of the current loop circuit.
		M33: OCT Output	Pulse Width	OCT (Open Collector Output) setup. By selecting a proper triggering source, the OCT circuit will close when the trigger event occurs
			Trigger Source	Select the pulse type for the trigger source.
		M34: Relay Output		Window to select event for relay trigger source.
		M35: Frequency Output	Frequency Range	Window to set up the frequency range (lower limit and upper limit) for the frequency output. Valid values: 0Hz-9999Hz. Factory default is 1-1001 Hz
			Frequency Minimum	Window to set up the minimum flow rate which corresponds to the lower frequency limit of the frequency output.
			Frequency Maximum	Window to set up the maximum flow rate which corresponds to the upper frequency limit of the frequency output.
		M36: Buzzer		Window to set up the buzzer. If a proper input source is selected, the buzzer will beep when the trigger event occurs.
		M37: Alarm	#1 Low Limit	Alarm #1 lower threshold setup. Below this threshold the #1 Alarm will be triggered. There are two alarming methods. User must select the alarming output items from window M33 or M36.
			#1 High Limit	Alarm #1 upper threshold setup.
			#2 High Limit	Alarm #2 upper threshold setup.
			#2 Low Limit	Alarm #2 lower threshold setup.
		M38: Batch Control		Window to access the built-in batch controller.

Key	Sub-Key	Window Number	Function		
	Totalizer	M4(1): Flow Multiplier	Window to set the totalizer multiplying factor for the flow rate. The multiplying factor ranges from 0.001 to 10000.		
		M4(2): Flow NET ON/OFF	Window for turning on or off the NET totalizer.		
		M4(3): Flow POS ON/OFF	Window for turning on or off the POS totalizer.		
		M4(4): Flow NEG ON/OFF	Window for turning on or off the NEG totalizer.		
		M4(5): Flow TOT Reset	Window for: (2) Totalizer reset (3) Restore the factory default settings. Press the dot key followed by the backspace key. Attention, it is recommended to make notes on the parameters before doing the restoration.		
		M4(6):Engineering Multiplier	Window to set the multiplying factor for the Engineering Units for totalizer.		
		M4(7): Engineering TOT Reset	Window to reset the Engineering Units for totalizer.		
		M4(8): Daily TOT	Window to set up for daily totalizer.		
		M4(9): Monthly TOT	Window to set up for monthly totalizer.		
		M4(10): Yearly TOT	Window to set up for yearly totalizer.		
	System	M51: Language	Window to set up the language Selection – English or Chinese.		
		M52: Unit	Metric/ English	Window for selecting unit system. 'Metric' is the factory default. The conversion from English to Metric or vice versa will not affect the unit for totalizers.	
			Flow rate unit	Change Volume	Window for selecting flow rate unit system. Flow rate can be in: 1. Cubic meter (m3) 2. Liter (l) 3. USA gallon (gal) 4. Imperial Gallon (igl) 5. Million USA gallon (mgl) 6. Cubic feet (cf) 7. USA oil barrel (bal) 8. Imperial oil barrel (ib)
				Change Time	The flow unit in terms of time can be per day, per hour, per minute or per second. So there are 36 different flow rate units in total for selection.
			Flow rate TOT Unit	Window for selecting flow rate totalizer unit system. This can be in: 1. Cubic meter (m3) 2. Liter (l) 3. USA gallon (gal) 4. Imperial Gallon (igl) 5. Million USA gallon (mgl) 6. Cubic feet (cf) 7. USA oil barrel (bal) 8. Imperial oil barrel (ib)	
		M53: COMM	Port Configuration	Window for RS-232 serial communication setup.	
			Protocol	Window for communication protocol selection.	
			Monitor	Window to verify the data being logged.	
		M54: Date/Time	M54	Window for setting the date and time.	
		M55: Version/ SN#	Window to display version information and Electronic Serial Number (ESN) that are unique for each AUP series flowmeter.		
		M56: Battery	Window that displays the current battery voltage.		
		M57: System Lock	Window to set up systems lock to avoid modification of the system parameters.		
		M58: Work Timer	Working timer. It can be reset by pressing ENT key, and then select YES.		

Key	Sub-Key	Window Number	Function
	Heat Energy	M61: Location	Window to configure the location of the transducers. They can be placed on the supply or the return line.
		M62: Temp	Window to view the temperature of both transducers.
	Calculator		Window which includes scientific calculator for the convenience of field applications. All the mathematic operators are selected from a list.
	Misc.	M81: Max Flowrate	Window to view maximum flow rate for the day and for the month.
		M82: Last Power Off	Window to display the last recorded time the device was powered off.
		M83: Power On Time	Window to display the last recorded time the device was powered on.

6.0 Troubleshooting

6.1 Power-on Errors

When powered on, the AUP series ultrasonic flow meter will automatically start the self-diagnostic process to determine if there are any hardware and/or software problems. If a problem is identified, an error message will be displayed. The following table shows the possible error messages, the corresponding causes, and their solutions.

Error Message	Causes	Solutions
ROM Parity Error	ROM operation illegal/error	1. Reboot the system 2. Contact Armstrong's VERIS Flow Measurement Group
Stored Data Error	User entered parameters were lost	Press ENT key to restore the default configuration
SCPU Fatal Error	SCPU hardware fatal error	1. Reboot the system 2. Contact Armstrong's VERIS Flow Measurement Group
System Clock Slow or Fast Error	Problem with the system clock or the crystal oscillator	
CPU or IRQ Error	Problem with RAM chip	
System RAM error	Problem with RAM chip	
Time Date Error	Problem with date/time chip	1. Initialize the calendar in menu window M54 2. Contact Armstrong's VERIS Flow Measurement Group
No Display, Erratic or Abnormal Operation	Problem with wiring	Double-check wiring connections
No response to key pressing	Keypad is locked; bad plug connection	Press keys M, 5, and 7, consecutively (M57). From there, unlock the keypad.
Reboot Repetitively	Hardware problems	Contact Armstrong's VERIS Flow Measurement Group

6.2 Working Status Errors

The AUP series ultrasonic flow meter will show an Error Code (i.e. a single letter, e.g. I, R, etc.) in the lower right corner of the main menu window. When any abnormal error code shoes, counter-measures should be taken.

Error Code	Message Displayed On Main Menu Window	Causes	Solutions
R	System Normal	No Error	
I	No Signal	• Unable to receive signal • Transducers installed improperly • Loose contact, or not enough couplant between transducer and pipe surface • Pipe liners are too thick, or the deposition inside the pipe is too thick.Transducer cables are not properly connected.	1. Polish the pipe surface and clean the spot. Remove paint. 2. Make sure there is adequate couplant. 3. Make sure the transducer is in tight contact with pipe surface 4. Check transducer cables 5. Check installation parameter settings 6. Find a better measurement site (newer pipe, no corrosion, no deposition)
J	Hardware Error	Hardware problem	Contact the manufacturer
H	Poor Sig. Detected	Poor signal detected. Similar to error code I.	Refer to error code I.
E	Current Loop Over 20mA	4-20mA loop output over 120%. Improper settings for current loop output	1. Ignore it if current loop output is not used 2. Check current loop settings in menu window M32 3. Confirm if the actual flow rate is too high
Q	Frequency Output Over	• The frequency output is 120% over • Improper settings for frequency output. • The actual flow rate is too high.	1. Ignore if frequency output is not used. 2. Check the values entered in menu window M35 3. Use a larger value in M35 if needed 4. Confirm if the actual flow rate is too high
F	System RAM Error Date Time Error CPU or IRQ Error ROM Parity Error	• Temporary problems with RAM, RTC • Permanent problems with hardware	1. Reboot the system 2. Refer to the table om Sectiion 6.1, and contact the manufacturer

Error Code	Message Displayed On Main Menu Window	Causes	Solutions
G	Adjusting Gain > s1 Adjusting Gain > s2 Adjusting Gain > s3 Adjusting Gain > s4 (Shown in status)	Instrument is in progress of adjusting the gain for the signal, and the number indicates the progressive steps.	No need for action
K	Empty Pipe	• No liquid inside the pipe • Low flow cut off (LFC) is set too high- default is 0.09 ft/s.	1. If the pipe is not full, relocate the flow meter to where the pipe is full of liquid. 2. Reset S-5-2

6.3 Battery Maintenance and Replacement

The AUP features a Ni-H rechargeable battery. Therefore, it is recommended to discharge the battery by leaving the instrument **on** (it will automatically turn **off** after a few minutes) every 3 months.

In between these times, the battery can be fully charged with the supplied AC adapter. To get close to 100% battery power, charge the device overnight.

When not connected to the AC adapter, the battery should last **up to 8 hours after being fully charged**. When the device's battery is no longer sustaining that life, this normally indicates that the battery has exceeded its product life. The typical product life of a battery is 2-3 years.

6.4 Other Problems and Solutions

Q: Why does the instrument display 0.0000 flow rate while the liquid in the pipe is actually flowing? The signal strength, R, is in good range and the signal quality, Q, is a satisfactory value.

A: The problem is likely to be caused by an incorrect zero calibration. The user may have conducted the zero point set up while the flow was not at a complete standstill. To solve this problem, press keys C1 and follow the directions given.

Q: Why is the displayed flow rate much lower or much higher than the actual flow rate in the pipe despite being under normal working conditions?

A: There are three possible explanations for this error:

1. The entered offset value may be incorrect. Enter "0" offset in window M**FIND**
2. Incorrect transducer installation. Re-install the transducers carefully.
3. The zero calibration was set wrong. Press keys C1 and redo the zero calibration setup. The flow inside the pipe needs to be at a standstill. This menu can be accessed as follows: CAL → Zero Cal

Q: Why is there no signal even when the installation requirements are met, pipe is new, and pipe material is in good quality?

A: Check the following:

- Is the installation method suitable for the pipe size?
- Are the entered installation parameters correct?
- Are the wirings correct?
- Is there adequate couplant? Are the transducers in good contact with pipe?
- Is the pipe full?
- Is the distance between the transducers true to the value shown in window S43? Accessed as follows: SET → Set Transducer → Mount Space (S43). This should be the same figure from the set-up process, which was accessed on Step 5 under the Quick Start menu window (S1, Step 5).
- Are the transducers facing the right direction?

Q: If the pipe in use features a heavily scaled inside, and/or poor or no signal detected, is it possible to conduct a measurement? Are there options for conducting a measurement on an old pipe?

A: Follow the instructions below:

- Check if the pipe is filled with liquid.
- Try the Direct-Method. If the pipe is close to a wall and it is hard to do the Direct-Method installation, the user may use an inclined pipe or even vertical pipe with an upward flow direction.
- Carefully select a good pipe section and fully polish/clean the installation area of the pipe surface. Apply a wide band of couplant on each transducer face. Install the transducers properly. See Section 3.0 for more details on proper transducer installation.
- Slowly and carefully move each transducer with respect to each other around the installation point until the maximum signal is found. Be sure that the new installation location is free of scales inside the pipe and that the pipe is properly rounded (not distorted). This way the sound waves will not bounce outside of the intended area.
- For pipe with a thick scale inside or outside, try to clean the scale off – if accessible from the inside. **Note: This method is not always successful. Therefore, in that case, adequate sound wave transmission is not possible due to the layer of scale between the transducers and inside pipe wall.
- For any performance concerns, or to review the instructions provided, please contact the Armstrong VERIS Flow Measurement Group at 303-652-8550.

7.0 Communication

7.1 General

The AUP series ultrasonic flow meter uses a simple USB communication interface for access to a variety of communication devices. The AUP includes an extension with a DB-9 connector. This meter uses ModBus for communication. The user can configure the flow meter to acquire measurements from a PC by completing the following steps:

- Install the USB driver on the PC. This will generate a virtual COM port for the flow meter
- Connect the flow meter to the PC through the USB cable provided with the flow meter unit
- Check the flow meter COM port settings (Baud rate, parity, etc.)
- Install the RW software on the PC

7.2 Connect the Flowmeter to a PC

A standard USB cable is provided with your AUP unit. Simply plug the cable to the flow meter USB port on one end and to the computer on the other end. Then, turn on the flow meter. Your computer should automatically detect the USB connection and sign a virtual COM port (VCOM).

Note: you need to install the USB driver before connecting the USB cable.

7.3 Check the Flowmeter COM Port Settings

Go to menu window M53 to check the COM port settings on your flow meter. baude rate is displayed under 1. Port Config. Write down the baud rate. It is needed later in order to set up the computer's COM port. If you want to change the baud rate, press ENT key while in the Port Config window and select the proper baud rate. Press ENT key again to confirm the change.

```
M53: COMM
1. Port Config
2. Protocol
3. Monitor
```

7.4 Set Up PC Software

Please see Appendix A Section 8.5 for directions on using the RW software to download recorded data from the AUP.

7.5 Communication Protocol

The protocol is comprised of a set of basic commands that are strings in ASCII format, ending with a carriage (CR) and line feed (LF). Commonly used commands are listed in the following table:

Command	Function	Data Format
DQD(CR)	Return flow rate per day	±d.ddddddE±dd (CR) (LF)*
DQH(CR)	Return flow rate per hour	±d.ddddddE±dd (CR) (LF)
DQM(CR)	Return flow rate per minute	±d.ddddddE±dd (CR) (LF)
DQS(CR)	Return flow rate per second	±d.ddddddE±dd (CR) (LF)
DV(CR)	Return instantaneous flow velocity	±d.ddddddE±dd (CR) (LF)
DI+(CR)	Return POS totalizer	±dddddddE±d (CR) (LF)**
DI-(CR)	Return NEG totalizer	±dddddddE±d (CR) (LF)
DIN(CR)	Return NET totalizer	±dddddddE±d (CR) (LF)
DID(CR)	Return Identification Number (IDN)	ddddd (CR) (LF)
DL(CR)	Return signal strength and signal quality	S=ddd,ddd Q=dd (CR)(LF)
DT(CR)	Return the current date and time	yy-mm-ddhh:mm:ss (CR)(LF)
M@(CR)***	Send a key value as if a key is pressed	
LCD(CR)	Return the current display contents	
FOdddd(CR)	Force the FO output to output a frequency of dddd Hz	
ESN(CR)	Return the ESN of the flowmeter	Ddddddd (CR)(LF)
RING(CR)	Handshaking Request from a MODEM	
OK(CR)	Acknowledgment from a MODEM	No action
GA	Command for GSM messaging	Please contact the manufacturer for detail
GB	Command for GSM messaging	
GC	Command for GSM messaging	
DUMP(CR)	Return the print buffer content	In ASCII string format
DUMP0(CR)	Clear the whole print buffer	In ASCII string format
DUMP1(CR)	Return the whole print buffer content	In ASCII string Format, 24KB in length
W	Prefix of an IDN-addressing- based networking command. The IDN address is a word, ranging 0-65534.	
N	Prefix of an IDN-addressing- based networking command. The IDN address here is a single byte value, ranging 00- 255.	Not recommend for use.
P	Prefix of any command with checksum	
&	Command binder to make a longer command by combining up to 6 commands	

Notes * CR stands for Carriage Return and LF for Line Feed.

** "d" stands for a digit number of 0~9.

*** @ stands for the key value, e.g., 30H for the value of ASCII key "0".

7.6 Protocol Prefix Usage

1. Prefix P

   The prefix P can be added before any command in the above table to have the returning data followed with two bytes of CRC check sum, which is the adding sum of the original character string.

   Take the Return POS Totalizer Value command, DI+(CR), as an example. Assume that DI+(CR) would return +1234567E+0m3(CR)(LF)(the string in hexadecimal is 2BH, 31H, 32H, 33H, 34H, 35H, 36H, 37H, 45H, 2BH, 30H, 6DH, 33H, 20H, 0DH, 0AH) , then PDI(CR) would return +1234567E+0m3!F7(CR)(LF). The'!' acts as the starter of the check sum (F7) which is obtained by adding up the string 2BH, 31H, 32H, 33H, 34H, 35H, 36H, 37H, 45H, 2BH, 30H, 6DH, 33H, 20H.

   Please note that it is allowed to not have data entry or to have SPACES (20H) character before the '!' character.

2. Prefix W

   The prefix W is used for networking commands. The format of a networking command is: W + IDN address string + basic command.

   The IDN address should have a value between 0 and 65534, except 13(0DH), 10 (0AH), 42(2AH,*), 38(26H, &).

   For example, if we want to visit the instantaneous flow velocity of device IDN=12345, the following command should be sent to this device: W12345DV(CR). The corresponding binary code is 57H, 31H, 32H, 33H, 34H, 35H, 44H, 56H, 0DH.

3. Prefix N

   The prefix N is a single byte IDN network address, not recommended in a new design.

4. Command Binder &

   The & command binder or connector can connect up to 6 basic commands to form a longer command so that it will make the programming much easier. For example, assume we want device IDN=4321 to return the flow rate, velocity and POS totalizer value simultaneously. The combined command would be W4321DQD&DV&DI+(CR), and the result would be: +1234567E+0m3(CR)

Appendix A

8.1 Pipe Dimensional Tables

Table A1: Standard Copper Tubes According ASTM B88.

Nominal Size (in)	Actual Outside Diameter (in)		Tolerance on Outside Diameter (in)		Wall Thickness (in)	
			Annealed	Drawn	Nominal	Tolerance
Type K						
¾	⅞	0.875	0.003	0.001	0.065	0.006
1	1 ⅛	1.125	0.004	0.002	0.065	0.006
1 ¼	1 ⅜	1.375	0.004	0.002	0.065	0.006
1 ½	1 ⅝	1.625	0.005	0.002	0.072	0.007
2	2 ⅛	2.125	0.005	0.002	0.083	0.008
2 ½	2 ⅝	2.625	0.005	0.002	0.095	0.01
3	3 ⅛	3.125	0.005	0.002	0.109	0.011
3 ½	3 ⅝	3.625	0.005	0.002	0.12	0.012
4	4 ⅛	4.125	0.005	0.002	0.134	0.013
Type L						
¾	⅞	0.875	0.003	0.001	0.045	0.004
1	1 ⅛	1.125	0.004	0.002	0.05	0.005
1 ¼	1 ⅜	1.375	0.004	0.002	0.055	0.006
1 ¼	1 ⅝	1.625	0.005	0.002	0.06	0.006
2	2 ⅛	2.215	0.005	0.002	0.07	0.007
2 ½	2 ⅝	2.625	0.005	0.002	0.08	0.008
3	3 ⅛	3.125	0.005	0.002	0.09	0.009
3 ½	3 ⅝	3.625	0.005	0.002	0.1	0.01
4	4 ⅛	4.125	0.005	0.002	0.114	0.011

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
1/8	0.405	0.049	-	-	10S
		0.068	STD	40	40S
		0.095	XS	80	80S
1/4	0.540	0.065	-	-	10S
		0.088	STD	40	40S
		0.119	XS	80	80S
3/8	0.675	0.065	-	-	10S
		0.091	STD	40	40S
		0.126	XS	80	80S
1/2	0.840	0.065	-	-	5S
		0.083	-	-	10S
		0.109	STD	40	40S
		0.147	XS	80	80S
		0.187	-	160	-
		0.294	XXS	-	-
3/4	1.050	0.065	-	-	5S
		0.083	-	-	10S
		0.113	STD	40	40S
		0.154	XS	80	80S
		0.219	-	160	-
		0.308	XXS	-	-
1	1.315	0.065	-	-	5S
		0.109	-	-	10S
		0.133	STD	40	40S
		0.179	XS	80	80S
		0.25	-	160	-
		0.358	XXS	-	-
1 1/4	1.660	0.065	-	-	5S
		0.109	-	-	10S
		0.140	STD	40	40S
		0.191	XS	80	80S
		0.250	-	160	-
		0.382	XXS	-	-
1 1/2	1.900	0.065	-	-	5S
		0.109	-	-	10S
		0.145	STD	40	40S
		0.200	XS	80	80S
		0.281	-	160	-
		0.4	XXS	-	-

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes - Continued

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
2	2.375	0.065	.	.	5S
		0.109	.	.	10S
		0.154	STD	40	40S
		0.218	XS	80	80S
		0.344	.	160	.
		0.436	XXS	.	.
2 1/2	2.875	0.083	.	.	5S
		0.120	.	.	10S
		0.203	STD	40	40S
		0.276	XS	80	80S
		0.375	.	160	.
		0.552	XXS	.	.
3	3.500	0.083	.	.	5S
		0.120	.	.	10S
		0.216	STD	40	40S
		0.300	XS	80	80S
		0.438	.	160	.
		0.600	XXS	.	.
3 1/2	4.000	0.083	.	.	5S
		0.120	.	.	10S
		0.226	STD	40	40S
		0.318	XS	80	80S
4	4.500	0.083	.	.	5S
		0.120	.	.	10S
		0.237	STD	40	40S
		0.337	XS	80	80S
		0.438	.	120	.
		0.531	.	160	.
		0.674	XXS	.	.
5	5.563	0.109	.	.	5S
		0.134	.	.	10S
		0.258	STD	40	40S
		0.375	XS	80	80S
		0.500	.	120	.
		0.625	.	160	.
		0.750	XXS	.	.
6	6.625	0.109	.	.	5S
		0.134	.	.	10S
		0.280	STD	40	40S
		0.432	XS	80	80S
		0.562	.	120	.
		0.718	.	160	.
		0.864	XXS	.	.

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes - Continued

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
8	8.625	0.109	-	-	5S
		0.148	-	-	10S
		0.250	-	20	-
		0.277	-	30	-
		0.322	STD	40	40S
		0.406	-	60	-
		0.500	XS	80	80S
		0.594	-	100	-
		0.719	-	120	-
		0.812	-	140	-
		0.875	XXS	-	-
		0.906	-	160	-
10	10.750	0.134	-	-	5S
		0.165	-	-	10S
		0.25	-	20	-
		0.307	-	30	-
		0.365	STD	40	40S
		0.500	XS	60	80S
		0.594	-	80	-
		0.719	-	100	-
		0.844	-	120	-
		1.000	-	140	-
		1.125	-	160	-
12	12.750	0.156	-	-	5S
		0.180	-	-	10S
		0.250	-	20	-
		0.330	-	30	-
		0.375	STD	-	40S
		0.406	-	40	-
		0.500	XS	-	80S
		0.562	-	60	-
		0.688	-	80	-
		0.844	-	100	-
		1.00	-	120	-
		1.125	-	140	-
		1.312	-	160	-

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes - Continued

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
14	14.000	0.156	-	-	5S
		0.188	-	-	10S
		0.250	-	10	-
		0.312	-	20	-
		0.375	STD	30	-
		0.438	-	40	-
		0.500	XS	-	-
		0.594	-	60	-
		0.750	-	80	-
		0.938	-	100	-
		1.094	-	120	-
		1.250	-	140	-
		1.406	--	160	-
16	16.000	0.165	-	-	5S
		0.188	-	-	10S
		0.25	-	10	-
		0.312	-	20	-
		0.375	STD	30	-
		0.500	XS	40	-
		0.656	-	60	-
		0.844	-	80	-
		1.031	-	100	-
		1.219	-	120	-
		1.438	-	140	-
		1.594	-	160	-
18	18.000	0.165	-	-	5S
		0.188	-	-	10S
		0.250	-	10	-
		0.312	-	20	-
		0.375	STD	-	-
		0.438	-	30	-
		0.500	XS	-	-
		0.562	-	40	-
		0.750	-	60	-
		0.938	-	80	-
		1.156	-	100	-
		1.375	-	120	-
		1.562	-	140	-
		1.781	-	160	-

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes - Continued

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
20	20.000	0.188	-	-	5S
		0.218	-	-	10S
		0.250	-	10	-
		0.375	STD	20	-
		0.500	XS	30	-
		0.594	-	40	-
		0.812	-	60	-
		1.031	-	80	-
		1.281	-	100	-
		1.500	-	120	-
		1.750	-	140	-
		1.969	-	160	-
22	22.000	0.188	-	-	5S
		0.218	-	-	10S
		0.250	-	10	-
		0.375	STD	20	-
		0.500	XS	30	-
		0.875	-	60	-
		1.125	-	80	-
		1.375	-	100	-
		1.625	-	120	-
		1.875	-	140	-
		2.125	-	160	-
24	24.000	0.218	-	-	5S
		0.250	-	10	10S
		0.375	STD	20	-
		0.500	XS	-	-
		0.562	-	30	-
		0.688	-	40	-
		0.969	-	60	-
		1.219	-	80	-
		1.531	-	100	-
		1.812	-	120	-
		2.062	-	140	-
		2.344	-	160	-
26	26.000	0.312	-	10	-
		0.375	STD	-	-
		0.500	XS	20	-
28	28.000	0.312	-	10	-
		0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-

Table A2: Standard ANSI Pipe Size Data for Carbon Steel and Stainless Steel Pipes - Continued

Nominal Pipe Size (in)	Outside Diameter (in)	Wall Thickness (in)	ANSI B 36.10 Carbon Steel Wall Thickness	ANSI B 36.10 Carbon Steel Schedule Number	ANSI B 36.19 Stainless Steel Schedule Number
30	30.000	0.250	-	-	5S
		0.312	-	10	10S
		0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-
		0.750	-	40	-
32	32.000	0.312	-	10	-
		0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-
		0.688	-	40	-
34	34.000	0.344	-	10	-
		0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-
		0.688	-	40	-
36	36.000	0.312	-	10	-
		0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-
		0.750	-	40	-
42	42.000	0.375	STD	-	-
		0.500	XS	20	-
		0.625	-	30	-
		0.750	-	40	-
48	48.000	0.375	STD	-	-
		0.500	XS	-	-

Table A3: Standard Classes of Cast Iron Pipe

Nominal Pipe Size (in)	CLASS A		CLASS B		CLASS C		CLASS D	
	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)
3	3.80	0.39	3.96	0.42	3.96	0.45	3.96	0.48
4	4.80	0.42	5.00	0.45	5.00	0.48	5.00	0.52
6	6.90	0.44	7.10	0.48	7.10	0.51	7.10	0.55
8	9.05	0.46	9.05	0.51	9.30	0.56	9.30	0.60
10	11.10	0.50	11.10	0.57	11.40	0.62	11.40	0.68
12	13.20	0.54	13.20	0.62	13.50	0.68	13.50	0.75
14	15.30	0.57	15.30	0.66	15.65	0.74	15.65	0.82
16	17.40	0.60	17.40	0.70	17.80	0.80	17.80	0.89
18	19.50	0.64	19.50	0.75	19.92	0.87	19.92	0.96
20	21.60	0.67	21.60	0.80	22.06	0.92	22.06	1.03
24	25.80	0.76	25.80	0.89	26.32	1.04	26.32	1.16
30	31.74	0.88	32.00	1.03	32.40	1.20	32.74	1.37
36	37.96	0.99	38.30	1.15	38.70	1.36	39.16	1.58
42	44.20	1.10	44.50	1.28	45.10	1.54	45.58	1.78
48	50.50	1.26	50.80	1.42	51.40	1.71	51.98	1.96
54	56.66	1.35	57.10	1.55	57.80	1.90	58.40	2.23
60	62.80	1.39	63.40	1.67	64.20	2.00	64.82	2.38
72	75.34	1.62	76.00	1.95	76.88	2.39	-	-
84	87.54	1.72	88.54	2.22	-	-	-	-

Nominal Pipe Size (in)	Class E		Class F		Class G		Class H	
	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)	Outer Diameter (in)	Wall Thickness (in)
3	7.22	0.58	7.22	0.61	7.38	0.65	7.38	0.69
4	9.42	0.66	9.42	0.66	9.60	0.75	9.60	0.80
6	11.60	0.74	11.60	0.80	11.84	0.86	11.84	0.92
8	13.78	0.82	13.78	0.89	14.08	0.97	14.08	1.04
10	15.98	0.90	15.98	0.99	16.32	1.07	16.32	1.16
12	18.16	0.90	18.16	1.08	18.54	1.18	18.54	1.27
14	20.34	1.07	20.34	1.17	20.78	1.28	20.78	1.39
16	22.54	1.15	22.54	1.27	23.02	1.39	23.02	1.51
18	26.90	1.31	26.90	1.45	27.76	1.75	27.76	1.88
20	33.10	1.55	33.46	1.73	-	-	-	-
24	39.60	1.80	40.04	2.02	-	-	-	-
30	33.10	1.55	33.46	1.73	-	-	-	-
32	39.60	1.80	40.04	2.02	-	-	-	-
42	-	-	-	-	-	-	-	-
48	-	-	-	-	-	-	-	-
54	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-
72	-	-	-	-	-	-	-	-
84	-	-	-	-	-	-	-	-

Table A4: Standard Classes of Cast Ductile Iron Pipe

Nominal Pipe Size (in)	Outer Diameter (in)	Pipe Wall Thickness (in)						
		Class 50	Class 51	Class 52	Class 53	Class 54	Class 55	Class 56
3	3.96	-	0.25	0.28	0.31	0.34	0.37	0.40
4	4.80	-	0.26	0.29	0.32	0.35	0.38	0.41
6	6.90	0.25	0.28	0.31	0.34	0.37	0.40	0.43
8	9.05	0.27	0.30	0.33	0.36	0.39	0.42	0.45
10	11.10	0.29	0.32	0.35	0.38	0.41	0.44	0.47
12	13.20	0.31	0.34	0.37	0.40	0.43	0.46	0.49
14	15.30	0.33	0.36	0.39	0.42	0.45	0.48	0.51
16	17.40	0.34	0.37	0.40	0.43	0.46	0.49	0.52
18	19.50	0.35	0.38	0.41	0.44	0.47	0.50	0.53
20	21.60	0.36	0.39	0.42	0.45	0.48	0.051	0.54
24	25.80	0.38	0.41	0.44	0.47	0.50	0.53	0.56
30	32.00	0.39	0.43	0.48	0.51	0.55	0.59	0.63
36	38.30	0.43	0.47	0.53	0.58	0.63	0.68	0.73
42	44.50	0.47	0.53	0.59	0.65	0.71	0.77	0.83
48	50.80	0.51	0.58	0.65	0.72	0.79	0.86	0.93
54	57.56	0.57	0.65	0.73	0.81	0.89	0.97	1.05

8.2 Speed of Sound in Solids

Table A5: Speed of Sounds in Solids

Material	Sound Speed Shear Wave (25°C)		Sound Speed Long. Wave (25°C)	
	m/s	ft/s	mm/μs	in./μs
Steel, 1% Carbon, hardened	3,150	10,335	5.88	0.232
Carbon Steel	3,230	10,598	5.89	0.232
Mild Steel	3,235	10,614	5.89	0.232
Steel, 1% Carbon	3,220	10,565	-	-
302 Stainless Steel	3,120	10,236	5.690	0.224
303 Stainless Steel	3,120	10,236	5.640	0.222
304 Stainless Steel	3,141	10,306	5.920	0.233
304L Stainless Steel	3,070	10,073	5.790	0.228
316 Stainless Steel	3,272	10,735	5.720	0.225
347 Stainless Steel	3,095	10,512	5.720	0.225
Aluminum	3,100	10,171	6.32	0.249
Aluminum (rolled)	3,040	9,974	-	-
Copper	2,260	7,415	4.66	0.184
Copper (annealed)	2,325	7,628	-	-
Copper (rolled)	2,270	7,448	-	-
CuNi (70%Cu 30%Ni)	2,540	8,334	5.03	0.198
CuNi (90%Cu 10%Ni)	2,060	6,759	4.01	0.158
Brass (Naval)	2,120	6,923	4.43	0.174
Gold (hard-drawn)	1,200	3,937	3.24	0.128
Inconel	3,020	9,909	5.82	0.229
Iron (electrolytic)	3,240	10,630	5.90	0.232
Iron (Armco)	3,240	10,630	5.90	0.232
Ductile Iron	3,000	9,843	-	-
Cast Iron	2,500	8,203	4.55	0.179
Monel	2,720	8,924	5.35	0.211
Nickel	2,960	9,712	5.63	0.222
Tin, rolled	1,670	5,479	3.32	0.131
Titanium	3,125	10,253	6.10	0.240
Tungsten, annealed	2,890	9,482	5.18	0.204
Tungsten, drawn	2,640	8,661	-	-
Tungsten, carbide	3,980	13,058	-	-
Zinc, rolled	2,440	8,005	4.17	0.164
Glass, Pyrex	3,280	10,761	5.61	0.221
Glass, heavy silicate flint	2,380	7,808	-	-
Glass, light borate crown	2,840	9,318	5.26	0.207
Nylon	1,150	3,772	2.40	0.095
Nylon, 6-6	1,070	3,510	-	-
Polyethylene (HD)	-	-	2.31	0.091
Polyethylene (LD)	540	1,772	1.94	0.076
PVC, CPVC	1,060	3,477	2.40	0.095
Acrylic	1,430	4,690	2.73	0.108
Asbestos Cement	-	-	2.20	0.087
Tar Epoxy	-	-	2.00	0.079
Mortar	-	-	2.50	0.098
Rubber	-	-	1.90	0.075

8.3 Sound Speed in Water at Temperature

Table A6: Sound Speed in Water at at Atmospheric Pressure

Temperature		Sound Speed in Water
°C	°F	m/s
0	32.0	1,402
1	33.8	1,407
2	35.6	1,412
3	37.4	1,417
4	39.2	1,421
5	41.0	1,426
6	42.8	1,430
7	44.6	1,434
8	46.4	1,439
9	48.2	1,443
10	50.0	1,447
11	51.8	1,451
12	53.6	1,455
13	55.4	1,458
14	57.2	1,462
15	59.0	1,465
16	60.8	1,469
17	62.6	1,472
18	64.4	1,476
19	66.2	1,479
20	68.0	1,482
21	69.8	1,485
22	71.6	1,488
23	73.4	1,491
24	75.2	1,493
25	77.0	1,496
26	78.8	1,499
27	80.6	1,501
28	82.4	1,504
29	84.2	1,506
30	86.0	1,509
31	87.8	1,511
32	89.6	1,513
33	91.4	1,515
34	93.2	1,517
35	95.0	1,519
36	96.8	1,521
37	98.6	1,523
38	100.4	1,525
39	102.2	1,527
40	104.0	1,528
41	105.8	1,530
42	107.6	1,532
43	109.4	1,534
44	111.2	1,535
45	113.0	1,536
46	114.8	1,538
47	116.6	1,539
48	118.4	1,540
49	120.2	1,541
50	122.0	1,543
51	123.8	1,543
52	125.6	1,544
53	127.4	1,545
54	129.2	1,546
55	131.0	1,547
56	132.8	1,548
57	134.6	1,548
58	136.4	1,549
59	138.2	1,550
60	140.0	1,550
61	141.8	1,551
62	143.6	1,552
63	145.4	1,552
64	147.2	1,553
65	149.0	1,553
66	150.8	1,553
67	152.6	1,554
68	154.4	1,554
69	156.2	1,554
70	158.0	1,554
71	159.8	1,554
72	161.6	1,555
73	163.4	1,555
74	165.2	1,555
75	167.0	1,555
76	168.8	1,555
77	170.6	1,554
78	172.4	1,554
79	174.2	1,554
80	176.0	1,554
81	177.8	1,554
82	179.6	1,553
83	181.4	1,553
84	183.2	1,553
85	185.0	1,552
86	186.8	1,552
87	188.6	1,552
88	190.4	1,551
89	192.2	1,551
90	194.0	1,550
91	195.8	1,549
92	197.6	1,549
93	199.4	1,548
94	201.2	1,547
95	203.0	1,547
96	204.8	1,546
97	206.6	1,545
98	208.4	1,544
99	210.2	1,543

8.4 Sound Speed in Liquids

Table A7: Sound Speed in Liquids

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m²/s	ft²/s
Acetic anhydride (22)	$(CH_3CO)_2O$	1.082 (20°C)	1,180	3,871.4	2.5	0.769	8.274
Acetic acid, anhydride (22)	$(CH_3CO)^2O$	1.082 (20°C)	1,180	3,871.4	2.5	0.769	8.274
Acetic acid, nitrile	C_2H_3N	0.783	1,290	4,232.3	4.1	0.441	4.745
Acetic acid, ethyl ester (33)	$C_4H_8O_2$	0.901	1,085	3,559.7	4.4	0.467	5.025
Acetic acid, methyl ester	$C_3H_6O_2$	0.934	1,211	3,973.1	-	0.407	4.379
Acetone	C_3H_6O	0.791	1,174	3,851.7	4.5	0.399	4.293
Acetonitrile	C_2H_3N	0.783	1,290	4,232.3	4.1	0.441	4.745
Acetonylacetone	$C_6H_{10}O_2$	0.729	1,399	4,589.9	3.6	-	-
Acetylen dichloride	$C_2H_2Cl_2$	1.26	1,015	3,330.1	3.8	0.400	4.304
Acetylene tetrabromide (47)	$C_2H_2Br_4$	2.966	1,027	3,369.4	-	-	-
Acetylene tetrachloride (47)	$C_2H_2Cl_4$	1.595	1,147	3,763.1	-	1.156 (15°C)	12.438 (59°F)
Alcohol	C_2H_6O	0.789	1,207	3,960	4.0	1.396	15.02
Alkazene-13	$C_{15}H_{24}$	0.86	1,317	4,320.9	3.9	-	-
Alkazene-25	$C_{10}H_{12}Cl_2$	1.20	1,307	4,288.1	3.4	-	-
2-Amino-ethanol	C_2H_7NO	1.018	1,724	5,656.2	3.4	-	-
2-Aminotolidine (46)	C_7H_9N	0.999 (20°C)	1,618	5,308.4	-	4.394 (20°C)	47.279 (68°F)
4-Aminotolidine (46)	C_7H_9N	0.966 (45°C)	1,480	4,855.6	-	1.863 (50°C)	20.045 (122°F)
Ammonia (35)	NH_3	0.771	1,729 (-33°C)	5,672.6 (-27°F)	6.68	0.292 (-33°C)	3.141 (-27°F)
Amorphous Polyolefin	-	0.98	962.6 (190°C)	3158.2 (374°F)	-	26,600	286,000
t-Amyl alcohol	$C_5H_{12}O$	0.81	1,204	3,950.1		4.374	47.064
Aminobenzene (41)	$C_6H_5NO_2$	1.022	1,639	5,377.3	4.0	3.63	39.058
Aniline (41)	$C_6H_5NO_2$	1.022	1,639	5,377.3	4.0	3.63	39.058
Argon (45)	Ar	1.400 (-188°C)	853 (-188°C)	2798.6 (-306°F)	-	-	-
Azine	C_6H_5N	0.982	1,415	4,642.4	4.1	0.992 (20°C)	10.673 (68°F)
Benzene (29, 40, 41)	C_6H_6	0.879	1,306	4,284.8	4.65	0.711	7.65
Benzol (29, 40, 41)	C_6H_6	0.879	1,306	4,284.8	4.65	0.711	7.65
Bromine (21)	Br_2	2.928	889	2,916.7	3.0	0.323	3.475
Bromo-benzene (46)	C_6H_5Br	1.522	1,170 (20°C)	3,838.6 (68°F)	-	0.693	7.456
1-Bromo-butane (46)	C_4H_9Br	1.276 (20°C)	1,019 (20°C)	3,343.2 (68°F)	-	0.49 (15°C)	5.272 (59°F)
Bromo-ethane (46)	C_2H_5Br	1.460 (20°C)	900 (20°C)	2,952.8 (68°F)	-	0.275	2.959
Bromoform (46, 47)	$CHBr_3$	2.89 (20°C)	918	3,011.8	3.1	0.654	7.037
n-Butane (2)	C_4H_{10}	0.601 (0°C)	1,085 (-5°C)	3,559.7 (23°F)	5.8	-	-

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.						
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
2-Butanol	$C_4H_{10}O$	0.81	1,240	4,068.2	3.3	3.239	34.851
sec-Butylalcohol	$C_4H_{10}O$	0.81	1,240	4,068.2	3.3	3.239	34.851
n-Butyl bromide (46)	C_4H_9Br	1.276 (20°C)	1,019 (20°C)	3,343.2 (68°F)	-	0.49 (15°C)	5.272 (59°F)
n-Butyl chloride (22, 46)	C_4H_9Cl	0.887	1,140	3,740.2	4.57	0.529 (15°C)	5.692 (59°F)
tert Butyl chloride	C_4H_9Cl	0.84	984	3,228.3	4.2	0.646	6.95
Butyl oleate	$C_{22}H_{42}O_2$	-	1,404	4,606.3	3.0	-	-
2, 3 Butylene glycol	$C_4H_{10}O_2$	1.019	1,484	4,868.8	1.51	-	-
Cadmium (7)	Cd	-	2,237.7 (400°C)	7,341.5 (752°F)	-	1.355cp (440°C)	14.579 (824°F)
Carbinol (40, 41)	CH_4O	0.791 (20°C)	1,076	3,530.2	2.92	0.695	7.478
Carbitol	$C_6H_{14}O_3$	0.988	1,458	4,783.5	-	-	-
Carbon dioxide (26)	CO_2	1.101 (-37°C)	839 (-37°C)	2,752.6 (-35°F)	7.71	0.137 (-37°C)	1.474 (-35°F)
Carbon disulphide	CS_2	1.261 (22°C)	1,149	3,769.7	-	0.278	2.991
Carbon tetrachloride (33, 35, 47)	CCl_4	1.595 (20°C)	926	3038.1	2.48	0.607	6.531
Carbon tetrafluoride (14) (Freon 14)	CF_4	1.75 (-150°C)	875.2 (-150°C)	2,871.5 (-238°F)	6.61	-	
Cetane (23)	$C_{16}H_{34}$	0.773 (20°C)	1,338	4,389.8	3.71	4.32	46.483
Chloro-benezene	C_6H_5Cl	1.106	1,273	4,176.5	3.6	0.722	7.768
1-Chloro-butane (22, 46)	C_4H_9Cl	0.887	1,140	3,740.2	4.57	0.529 (15°C)	5.692 (59°F)
Chloro-diFluoromethane (3) (Freon 22)	$CHClF_2$	1.491 (-69°C)	893.9 (-50°C)	2,932.7 (-58°F)	4.79	-	-
Chloroform (47)	$CHCl_3$	1.489	979	3,211.9	3.4	0.55	5.918
1-Chloro-propane (47)	C_3H7Cl	0.892	1,058	3,471.1	-	0.378	4.067
Chlorotrifluoromethane (5)	$CClF_3$	-	724 (-82°C)	2,375.3 (-116°F)	5.26	-	-
Cinnamaldehyde	C_9H_8O	1.112	1,554	5,098.4	3.2	-	-
Cinnamic aldehyde	C_9H_8O	1.112	1,554	5,098.4	3.2	-	-
Colamine	C_2H_7NO	1.018	1,724	5,656.2	3.4	-	-
o-Cresol (46)	C_7H_8O	1.047 (20°C)	1,541 (20°C)	5,055.8 (68°F)	-	4.29 (40°C)	46.16 (104°F)
m-Cresol (46)	C_7H_8O	1.034 (20°C)	1,500 (20°C)	4,921.3 (68°F)	-	5.979 (40°C)	64.334 (104°F)
Cyanomethane	C_2H_3N	0.783	1,290	4,232.3	4.1	0.441	4.745
Cyclohexane (15)	C_6H_{12}	0.779 (20°C)	1,248	4,094.5	5.41	1.31 (17°C)	14.095 (63°F)
Cyclohexanol	$C_6H_{12}O$	0.962	1,454	4,770.3	3.6	0.071 (17°C)	0.764 (63°F)
Cyclohexanone	$C_6H_{10}O$	0.948	1,423	4,668.6	4.0	-	-
Decane (46)	$C_{10}H_{22}$	0.730	1,252	4,107.6	-	1.26 (20°C)	13.55 (68°F)

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		∆v/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
1-Decene (27)	$C_{10}H_{2}0$	0.746	1,235	4,051.8	4.0	-	-
n-Decylene (27)	$C_{10}H_{2}0$	0.746	1,235	4,051.8	4.0	-	-
Diacetyl	$C_4H_6O_2$	0.99	1,236	4,055.1	4.6	-	-
Diamylamine	$C_{10}H_{23}N$	-	1,256	4,120.7	3.9	-	-
1,2 Dibromo-ethane (47)	$C_2H_4Br_2$	2.18	995	3,264.4	-	0.79 (20°C)	8.5 (68°F)
trans-1,2-Dibromoethene (47)	$C_2H_2Br_2$	2.231	935	3,067.6	-	-	-
Dibutyl phthalate	$C_8H_{22}O_4$		1,408	4,619.4	-	-	-
Dichloro-t-butyl alcohol	$C_4H_8Cl_2O$		1,304	4,278.2	3.8	-	-
2,3 Dichlorodioxane	$C_2H_6Cl_2O_2$		1,391	4,563.6	3.7	-	-
Dichlorodifluoromethane (3) (Freon 12)	CCl_2F_2	1.516 (40°C)	774.1	2,539.7	4.24	-	-
1,2 Dichloro ethane (47)	$C_2H_4Cl_2$	1.253	1,193	3,914	-	0.61	6.563
cis1,2-Dichloro-ethene (3, 47)	$C_2H_2Cl_2$	1.284	1,061	3,481	-	-	-
trans1,2-Dichloro-ethene (3, 47)	$C_2H_2Cl_2$	1.257	1,010	3,313.6	-	-	-
Dichloro-fluoromethane (3) (Freon 21)	$CHCl_2F$	1.426 (0°C)	891 (0°C)	2,923.2 (32°F)	3.97	-	-
1-2-Dichlorohexafluoro-cyclobutane (47)	$C_4Cl_2F_6$	1.654	669	2,194.9	-	-	-
1-3-Dichloro-isobutane	$C_4H_8Cl_2$	1.14	1,220	4,002.6	3.4	-	-
Dichloro methane (3)	CH_2Cl_2	1.327	1,070	3,510.5	3.94	0.31	3.335
1,1-Dichloro-1,2,2,2 tetra fluoroethane	$CClF_2$-$CClF_2$	1.455	665.3 (-10°C)	2,182.7 (14°F)	3.73	-	-
Diethyl ether	$C_4H_{10}O$	0.713	985	3,231.6	4.87	0.311	3.346
Diethylene glycol	$C_4H_{10}O_3$	1.116	1,586	5,203.4	2.4	-	-
Diethylene glycol, monoethyl ether	$C_6H_{14}O_3$	0.988	1,458	4,783.5	-	-	-
Diethylenimide oxide	C_4H_9NO	1.00	1,442	4,731	3.8	-	-
1,2-bis(DiFluoramino) butane (43)	$C_4H_8(NF_2)_2$	1.216	1,000	3,280.8	-	-	-
1,2-bis(DiFluoramino)-2-methylpropane (43)	$C_4H_9(NF_2)_2$	1.213	900	2,952.8	-	-	-
1,2-bis(DiFluoramino) propane (43)	$C_3H_6(NF_2)_2$	1.265	960	3,149.6	-	-	-
2,2-bis(DiFluoramino propane (43)	$C_3H_6(NF_2)_2$	1.254	890	2920	-	-	-
2,2-Dihydroxydiethyl ether	$C_4H_{10}O_3$	1.116	1,586	5,203.4	2.4	-	-
Dihydroxyethane	$C_2H_6O_2$	1.113	1,658	5,439.6	2.1	-	-
1,3-Dimethyl-benzene (46)	C_8H_{10}	0.868 (15°C)	1,343 (20°C)	4,406.2 (68°F)	-	0.749 (15°C)	8.059 (59°F)
1,2-Dimethyl-benzene (29, 46)	C_8H_{10}	0.897 (20°C)	1,331.5	4,368.4	4.1	0.903 (20°C)	9.716 (68°F)
1,4-Dimethyl-benzene (46)	C_8H_{10}	-	1,334 (20°C)	4,376.6 (68°F)	-	0.662	7.123

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted. Specific Gravity	Sound Speed		$\Delta v/°C$	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
2,2-Dimethyl-butane (29, 33)	C_6H_{14}	0.649 (20°C)	1,079	3,540	-	-	-
Dimethyl ketone	C_3H_6O	0.791	1,174	3,851.7	4.5	0.399	4.293
Dimethyl pentane (47)	C_7H_{16}	0.674	1,063	3,487.5	-	-	-
Dimethyl phthalate	$C_8H_{10}O_4$	1.2	1,463	4,799.9	-	-	-
Diiodo-methane	CH_2I_2	3.235	980	3,215.2	-	-	-
Dioxane	$C_4H_8O_2$	1.033	1,376	4,514.4	-	-	-
Dodecane (23)	$C_{12}H_{26}$	0.749	1,279	4,196.2	3.85	1.80	19.368
1,2-Ethanediol	$C_2H_6O_2$	1.113	1,658	5,439.6	2.1	-	-
Ethanenitrile	C_2H_3N	0.783	1,290	4,232.3	-	0.441	4.745
Ethanoic anhydride (22)	$(CH_3CO)_2O$	1.082	1,180	3,871.4	-	0.769	8.274
Ethanol	C_2H_6O	0.789	1,207	3,960	4.0	1.39	14.956
Ethanol amide	C_2H_7NO	1.018	1,724	5,656.2	3.4	-	-
Ethoxyethane	$C_4H_{10}O$	0.713	985	3,231.6	4.87	0.311	3.346
Ethyl acetate (33)	$C_4H_8O_2$	0.901	1,085	3,559.7	4.4	0.489	5.263
Ethyl alcohol	C_2H_6O	0.789	1,207	3,960	4.0	1.396	15.020
Ethyl benzene (46)	C_8H_{10}	0.867 (20°C)	1,338 (20°C)	4,389.8 (68°F)	-	0.797 (17°C)	8.575 (63°F)
Ethyl Bromide (46)	C_2H_5Br	1.461 (20°C)	900 (20°C)	2,952.8 (68°F)	-	0.275 (20°C)	2.959 (68°F)
Ethyliodide (46)	C_2H_5I	1.950 (20°C)	876 (20°C)	2874 (68°F)	-	0.29	3.12
Ether	$C_4H_{10}O$	0.713	985	3231.6	4.87	0.311	3.346
Ethyl ether	$C_4H_{10}O$	0.713	985	3231.6	4.87	0.311	3.346
Ethylene bromide (47)	$C_2H_4Br_2$	2.18	995	3264.4	-	0.79	8.5
Ethylene chloride (47)	$C_2H_4Cl_2$	1.253	1,193	3914	-	0.61	6.563
Ethylene glycol	$C_2H_6O_2$	1.113	1,658	5439.6	2.1	17.208 (20°C)	185.158 (68°F)
d-Fenochone	$C_{10}H_{16}O$	0.947	1,320	4330.7	-	0.22	2.367
d-2-Fenechanone	$C_{10}H_{16}O$	0.947	1,320	4330.7	-	0.22	2.367
Fluorine	F	0.545 (-143°C)	403 (-143°C)	1322.2 (-225°F)	11.31	-	-
Fluoro-benzene (46)	C_6H_5F	1.024 (20°C)	1,189	3900.9	-	0.584 (20°C)	6.283 (68°F)
Formaldehyde, methyl ester	$C_2H_4O_2$	0.974	1,127	3697.5	4.02	-	-
Formamide	CH_3NO	1.134 (20°C)	1,622	5321.5	2.2	2.91	31.311
Formic acid, amide	CH_3NO	1.134 (20°C)	1,622	5321.5	-	2.91	31.311
Freon R12	-	-	774.2	2540	-	-	-
Furfural	$C_5H_4O_2$	1.157	1,444	4737.5	3.7	-	-
Furfuryl alcohol	$C_5H_6O^2$	1.135	1,450	4757.2	3.4	-	-
Fural	$C_5H_4O_2$	1.157	1,444	4737.5	3.7	-	-
2-Furaldehyde	$C_5H_4O_2$	1.157	1,444	4737.5	3.7	-	-
2-Furancarboxaldehyde	$C_5H_4O_2$	1.157	1,444	4737.5	3.7	-	-

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
2-Furyl-Methanol	$C_5H_6O_2$	1.135	1,450	4757.2	3.4	-	-
Gallium	Ga	6.095	2,870 (30°C)	9416 (86°F)	-	-	-
Glycerin	$C_3H_8O_3$	1.26	1,904	6246.7	2.2	757.1	8,081.836
Glycerol	$C_3H_8O_3$	1.26	1,904	6246.7	2.2	757.1	8,081.836
Glycol	$C_2H_6O_2$	1.113	1658	5439.6	2.1	-	-
50% Glycol / 50% H2O	-	-	1,578	5,177	-	-	-
Helium (45)	He_4	0.125 (-269°C)	183 (-269°C)	600.4 (-452°F)	-	0.025	0.269
Heptane (22, 23)	C_7H_{16}	0.684 (20°C)	1,131	3,710.6	4.25	0.598 (20°C)	6.434 (68°F)
n-Heptane (29, 33)	C_7H_{16}	0.684 (20°C)	1,180	3,871.3	4.0	-	-
Hexachloro- Cyclopentadiene (47)	C_5Cl_6	1.718	1,150	3,773	-	-	-
Hexadecane (23)	$C_{16}H_{34}$	0.773 (20°C)	1,338	4,389.8	3.71	4.32 (20°C)	46.483 (68°F)
Hexalin	$C_6H_{12}O$	0.962	1,454	4,770.3	3.6	70.69 (17°C)	760.882 (63°F)
Hexane (16, 22, 23)	C_6H_{14}	0.659	1,112	3,648.3	2.71	0.446	4.798
n-Hexane (29, 33)	C_6H_{14}	0.649 (20°C)	1,079	3,540	4.53	-	-
2,5-Hexanedione	$C_6H_{10}O_2$	0.729	1,399	4,589.9	3.6	-	-
n-Hexanol	$C_6H_{14}O$	0.819	1,300	4,265.1	3.8	-	-
Hexahydrobenzene (15)	C_6H_{12}	0.779	1,248	4,094.5	5.41	1.31 (17°C)	14.095 (63°F)
Hexahydrophenol	$C_6H_{12}O$	0.962	1,454	4,770.3	3.6	-	-
Hexamethylene (15)	C_6H_{12}	0.779	1,248	4,094.5	5.41	1.31 (17°C)	14.095 (63°F)
Hydrogen (45)	H_2	0.071 (-256°C)	1,187 (-256°C)	3,894.4 (-429°F)	-	0.003 (-256°C)	0.032 (-429°F)
2-Hydroxy-toluene (46)	C_7H_8O	1.047 (20°C)	1,541 (20°C)	5,055.8 (68°F)	-	4.29 (40°C)	46.16 (104°F)
3-Hydroxy-toluene (46)	C_7H_8O	1.034 (20°C)	1,500 (20°C)	4,921.3 (68°F)	-	5.979 (40°C)	64.334 (104°F)
Iodo-benzene (46)	C_6H_5I	1.823	1,114 (20°C)	3,654.9 (68°F)	-	0.954	-
Iodo-ethane (46)	C_2H_5I	1.950 (20°C)	876 (20°C)	2,874 (68°F)	-	0.29	3.12
Iodo-methane	CH_3I	2.28 (20°C)	978	3,208.7	-	0.211	2.27
Isobutyl acetate (22)	$C_6H_{12}O$	-	1,180 (27°C)	3,871.4 (81°F)	4.85	-	-
Isobutanol	$C_4H_{10}O$	0.81 (20°C)	1,212	3,976.4	-	-	-
Iso-Butane	-	-	1,219.8	4002	-	-	-
Isopentane (36)	C_5H_{12}	0.62 (20°C)	980	3,215.2	4.8	0.34	3.658

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
Isopropanol (46)	C_3H_8O	0.785 (20°C)	1,170 (20°C)	3,838.6 (68°F)	-	2.718	29.245
Isopropyl alcohol (46)	C_3H_8O	0.785 (20°C)	1,170 (20°C)	3,838.6 (68°F)	-	2.718	29.245
Kerosene		0.81	1,324	4,343.8	3.6	-	-
Ketohexamethylene	$C_6H_{10}O$	0.948	1,423	4,668.6	4.0	-	-
Lithium fluoride (42)	LiF		2,485 (900°C)	8,152.9 (1652°F)	1.29	-	-
Mercury (45)	Hg	13.594	1,449 (24°C)	4,753.9 (75°F)	-	0.114	1.226
Mesityloxide	$C_6H_{16}O$	0.85	1,310	4,297.9	-	-	-
Methane (25, 28, 38, 39)	CH_4	0.162 (-89°C)	405 (-89°C)	1,328.7 (-128°F)	17.5	-	-
Methanol (40, 41)	CH_4O	0.791 (20°C)	1,076	3,530.2	2.92	0.695	7.478
Methyl acetate	$C_3H_6O_2$	0.934	1,211	3,973.1	-	0.407	4.379
o-Methylaniline (46)	C_7H_9N	0.999 (20°C)	1,618	5,308.4	-	4.394 (20°C)	47.279 (68°F)
4-Methylaniline (46)	C_7H_9N	0.966 (45°C)	1,480	4,855.6	-	1.863 (50°C)	20.095 (122°F)
Methyl alcohol (40, 44)	CH_4O	0.791 (20°C)	1,076	3,530.2	2.92	0.695	7.478
Methyl benzene (16, 52)	C_7H_8	0.867	1,328 (20°C)	4,357 (68°F)	4.27	0.644	7.144
2-Methyl-butane (36)	C_5H_{12}	0.62 (20°C)	980	3,215.2	-	0.34	3.658
Methyl carbinol	C_2H_6O	0.789	1,207	3,960	4.0	1.396	
Methyl-chloroform (47)	$C_2H_3Cl_3$	1.33	985	3,231.6	-	0.902 (20°C)	9.705 (68°F)
Methyl-cyanide	C_2H_3N	0.783	1,290	4,232.3	-	0.441	4.745
3-Methyl cyclohexanol	$C_7H_{14}O$	0.92	1,400	4,593.2	-	-	-
Methylene chloride (3)	CH_2Cl_2	1.327	1,070	3,510.5	3.94	0.31	3.335
Methylene iodide	CH_2I_2	3.235	980	3,215.2	-	-	-
Methyl formate (22)	$C_2H_4O_2$	0.974 (20°C)	1,127	3,697.5	4.02	-	-
Methyl iodide	CH_3I	2.28 (20°C)	978	3,208.7	-	0.211	2.27
a-Methyl naphthalene	$C_{11}H_{10}$	1.090	1,510	4,954.1	3.7	-	-
2-Methylphenol (46)	C_7H_8O	1.047 (20°C)	1,541 (20°C)	5,055.8 (68°F)	-	4.29 (40°C)	46.16 (104°F)
3-Methylphenol (46)	C_7H_8O	1.034 (20°C)	1,500 (20°C)	4,921.3 (68°F)	-	5.979 (40°C)	64.334 (104°F)
Milk, homogenized	-		1,548	5,080	-	-	-
Morpholine	C_4H_9NO	1.00	1,442	4,731	3.8	-	-
Naphtha	-	0.76	1,225	4,019	-	-	-
Natural Gas (37)	-	0.316 (-103°C)	753 (-103°C)	2,470.5 (-153°F)	-	-	-
Neon (45)	Ne	1.207 (-246°C)	595 (-246°C)	1,952.1 (-411°F)	-	-	-

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m^2/s	ft^2/s
Nitrobenzene (46)	$C_6H_5NO_2$	1.204 (20°C)	1,415 (20°C)	4,642.4 (68°F)	-	1.514	16.29
Nitrogen (45)	N_2	0.808 (-199°C)	962 (-199°C)	3,156.2 (-326°F)	-	0.217 (-199°C)	2.334 (-326°F)
Nitromethane (43)	CH_3NO_2	1.135	1,300	4,265.1	4.0	0.549	5.907
Nonane (23)	C_9H_2O	0.718 (20°C)	1,207	3,960	4.04	0.99 (20°C)	10.652 (68°F)
1-Nonene (27)	C_9H_{18}	0.736 (20°C)	1,207	3,960	4.0	-	-
Octane (23)	C_8H_{18}	0.703	1,172	3,845.1	4.14	0.73	7.857
n-Octane (29)	C_8H_{18}	0.704 (20°C)	1,212.5	3,978	3.50	0.737	.930)
1-Octene (27)	C_8H_{16}	0.723 (20°C)	1,175.5	3,856.6	4.10	-	-
Oil of Camphor Sassafrassy	-	-	1,390	4,560.4	3.8	-	-
Oil, Car (SAE 20a.30)	-	1.74	870	2,854.3	-	190	2,045.093
Oil, Castor	$C_{11}H_{10}O_{10}$	0.969	1,477	4,845.8	3.6	0.670	7.209
Oil, Diesel	-	0.80	1,250	4,101	-	-	-
Oil, Fuel AA gravity	-	0.99	1,485	4,872	3.7	-	-
Oil (Lubricating X200)	-	-	1,530	5,019.9	-	-	-
Oil (Olive)	-	0.912	1,431	4,694.9	2.75	100	1,076.365
Oil (Peanut)	-	0.936	1,458	4,783.5	-	-	-
Oil (Sperm)	-	0.88	1,440	4,724.4	-	-	-
Oil, 6	-	-	1,509 (22°C)	4,951 (72°F)	-	-	-
2,2-Oxydiethanol	$C_4H_{10}O_3$	1.116	1,586	5,203.4	2.4	-	-
Oxygen (45)	O_2	1.155 (-186°C)	952 (-186°C)	3,123.4 (-303°F)	-	0.173	1.861
Pentachloro-ethane (47)	C_2HCl_5	1.687	1,082	3,549.9	-	-	-
Pentalin (47)	C_2HCl_5	1.687	1,082	3,549.9	-	-	-
Pentane (36)	C_5H_{12}	0.626 (20°C)	1,020	3,346.5	-	0.363	3.905
n-Pentane (47)	C_5H_{12}	0.557	1,006	3,300.5	-	0.41	4.413
Perchlorocyclopentadiene (47)	C_5Cl_6	1.718	1,150	3,773	-	-	-
Perchloro-ethylene (47)	C_2Cl_4	1.632	1,036	3,399	-	-	-
Perfluoro-1-Hepten (47)	C_7F_{14}	1.67	583	1,912.7	-	-	-
Perfluoro-n-Hexane (47)	C_6F_{14}	1.672	508	1,666.7	-	-	-
Phene (29, 40, 41)	C_6H_6	0.879	1,306	4,284.8	4.65	0.711	7.65
b-Phenyl acrolein	C_9H_8O	1.112	1,554	5,098.4	3.2		
Phenylamine (41)	$C_6H_5NO_2$	1.022	1,639	5,377.3	4.0	3.63	39.058
Phenyl bromide (46)	C_6H_5Br	1.522	1,170 (20°C)	3,838.6 (68°F)	-	0.693	7.456
Phenyl chloride	C_6H_5Cl	1.106	1,273	4,176.5	3.6	0.722	7.768
Phenyl iodide (46)	C_6H_5I	1.823	1,114 (20°C)	3,654.9 (68°F)	-	0.954 (15°C)	10.265 (59°F)

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m²/s	ft²/s
Phenyl methane (16, 52)	C_7H_8	0.867 (20°C)	1,328 (20°C)	4,357 (68°F)	4.27	0.644	6.929
3-Phenyl propenal	C_9H_8O	1.112	1,554	5,098.4	3.2	-	-
Phthalardione	$C_8H_4O_3$	-	1,125 (152°C)	3,691 (306°F)	-	-	-
Phthalic acid, anhydride	$C_8H_4O_3$	-	1,125 (152°C)	3,691 (306°F)	-	-	-
Pthalic anhydride	$C_8H_4O_3$	-	1,125 (152°C)	3,691 (306°F)	-	-	-
Pimelic ketone	$C_6H_{10}O$	0.948	1,423	4,668.6	4.0	-	-
Plexiglas, Lucite, Acrylic	-	-	2,651	8,698	-	-	-
Polyterpene Resin	-	0.77	1,099.8 (190°C)	3,608.4 (374°F)	-	39,000	419,500
Potassium bromide (42)	KBr	-	1,169 (900°C)	3,835.3 (1652°F)	0.71	.715cp (900°C)	7.693 (1652°F)
Potassium fluoride (42)	KF	-	1,792 (900°C)	5,879.3 (1652°F)	1.03	-	-
Potassium iodide (42)	KI	-	985 (900°C)	3,231.6 (1652°F)	0.64	-	-
Potassium nitrate (48)	KNO_3	1.859 (352°C)	1,740.1 (352°C)	5,709 (666°F)	1.1	1.19 (327°C)	12.804 (621°F)
Propane (2, 13) (-45° to -130°C)	C_3H_8	0.585 (-45°C)	1,003 (-45°C)	3,290.6 (-49°F)	5.7	-	-
1,2,3-Propanetriol	$C_3H_8O_3$	1.26	1,904	6,246.7	2.2	0.001	-
1-Propanol (46)	C_3H_8O	0.78 (20°C)	1,222 (20°C)	4,009.2 (68°F)	-	-	-
2-Propanol (46)	C_3H_8O	0.785 (20°C)	1,170 (20°C)	3,838.6 (68°F)	-	2.718	29.245
2-Propanone	C_3H_6O	0.791	1,174	3,851.7	4.5	0.399	4.293
Propene (17, 18, 35)	C_3H_6	0.563 (-13°C)	963 (-13°C)	3,159.4 (9°F)	6.32	-	-
n-Propyl acetate (22)	$C_5H_{10}O_2$		1,280 (2°C)	4,199 (36°F)	4.63	-	-
n-Propyl-alcohol	C_3H_8O	0.78 (20°C)	1,222 (20°C)	4,009.2 (68°F)	-	2.549	27.427
Propylchloride (47)	C_3H_7Cl	0.892	1,058	3,471.1	-	0.378	4.067
Propylene (17, 18, 35)	C_3H_6	0.563 (-13°C)	963 (-13°C)	(3159.4) (9°F)	6.32	-	-
Pyridine	C_6H_5N	0.982	1,415	4,642.4	4.1	0.992 (20°C)	10.673 (68°F)
Refrigerant 11 (3, 4)	CCl_3F	1.49	828.3 (0°C)	2,717.5 (32°F)	3.56	-	-
Refrigerant 12 (3)	CCl_2F_2	1.516 (-40°C)	774.1 (-40°C)	2,539.7 (-40°F)	4.24	-	-
Refrigerant 14 (14)	CF_4	1.75 (-150°C)	875.24 (-150°C)	2,871.5 (-238°F)	6.61	-	-
Refrigerant 21 (3)	$CHCl_2F$	1.426 (0°C)	891 (0°C)	2,923.2 (32°F)	3.97	-	-

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m²/s	ft²/s
Refrigerant 22 (3)	$CHClF_2$	1.491 (-69°C)	893.9 (50°C)	2,932.7 (122°F)	4.79	-	-
Refrigerant 113 (3)	$CCl_2F\text{-}CClF_2$	1.563	783.7 (0°C)	2,571.2 (32°F)	3.44	-	-
Refrigerant 114 (3)	$CClF_2\text{-}CClF_2$	1.455	665.3 (-10°C)	2,182.7 (14°F)	3.73	-	-
Refrigerant 115 (3)	C_2ClF_5	-	656.4 (-50°C)	2,153.5 (-58°F)	4.42	-	-
Refrigerant C318 (3)	C_4F_8	1.62 (-20°C)	574 (-10°C)	1,883.2 (14°F)	3.88	-	-
Selenium (8)	Se	-	1,072 (250°C)	3,517.1 (482°F)	0.68	-	-
Silicone (30 cp)	-	0.993	990	3,248	-	30	322.8
Sodium fluoride (42)	NaF	0.877	2,082 (1000°C)	6,830.7 (1832°F)	1.32	-	-
Sodium nitrate (48)	$NaNO_3$	1.884 (336°C)	1,763.3 (336°C)	5,785.1 (637°F)	0.74	1.37 (336°C)	14.74 (637°F)
Sodium nitrite (48)	$NaNO_2$	1.805 (292°C)	1,876.8 (292°C)	6,157.5 (558°F)	-	-	-
Solvesso #3	-	0.877	1,370	4,494.8	3.7	-	-
Spirit of wine	C_2H_6O	0.789	1,207	3,960	4.0	1.396	15.02
Sulfur (7, 8, 10)	S	-	1,177 (250°C)	3,861.5 (482°F)	-1.13	-	-
Sulfuric Acid (1)	H_2SO_4	1.841	1,257.6	4,126	1.43	11.16	120.081
Tellurium (7)	Te	-	991 (450°C)	3,251.3 (842°F)	0.73	-	-
1,1,2,2-Tetrabromo-ethane (47)	$C_2H_2Br_4$	2.966	1,027	3,369.4	-	-	-
1,1,2,2-Tetrachloro-ethane (67)	$C_2H_2Cl_4$	1.595	1,147	3,763.1	-	1.156 (15°C)	12.438 (59°F)
Tetrachloroethane (46)	$C_2H_2Cl_4$	1.553 (20°C)	1,170 (20°C)	3,838.6 (68°F)	-	1.19	12.804
Tetrachloro-ethene (47)	C_2Cl_4	1.632	1,036	3,399	-	-	-
Tetrachloro-Methane (33, 47)	CCl_4	1.595 (20°C)	926	3,038.1	-	0.607	6.531
Tetradecane (46)	$C_{14}H_3O$	0.763 (20°C)	1,331 (20°C)	4,366.8 (68°F)	-	2.86 (20°C)	30.773 (68°F)
Tetraethylene glycol	$C_8H_{18}O_5$	1.123	1,586	5,203.4	3.0	-	-
Tetrafluoro-methane (14) (Freon 14)	CF_4	1.75 (-150°C)	875.24 (-150°C)	2,871.5 (-238°F)	6.61	-	-
Tetrahydro-1,4-isoxazine	C_4H_9NO	1.000	1,442	4,731	3.8	-	-
Toluene (16, 52)	C_7H_8	0.867 (20°C)	1,328 (20°C)	4,357 (68°F)	4.27	0.644	6.929
o-Toluidine (46)	C_7H_9N	0.999 (20°C)	1,618	5,308.4	-	4.394 (20°C)	47.279 (68°F)
p-Toluidine (46)	C_7H_9N	0.966 (45°C)	1,480	4,855.6	-	1.863 (50°C)	20.053 (122°F)
Toluol	C_7H_8	0.866	1,308	4,291.3	4.2	0.58	6.24

Table A7: Sound Speed in Liquids - Continued

Substance	Chemical Formula	All data given at 25°C (77°F) unless otherwise noted.					
		Specific Gravity	Sound Speed		Δv/°C	Kinematic Viscosity x10^{-6}	
			m/s	ft/s	m/s/°C	m²/s	ft²/s
Tribromo-methane (46, 47)	$CHBr_3$	2.89 (20°C)	918	3,011.8	-	0.654	7.037
1,1,1-Trichloro-ethane (47)	$C_2H_3Cl_3$	1.33	985	3,231.6	-	0.902 (20°C)	9.705 (68°F)
Trichloro-ethene (47)	C_2HCl_3	1.464	1,028	3,372.7	-	-	-
Trichloro-fluoromethane (3) (Freon 11)	CCl_3F	1.49	828.3 (0°C)	2,717.5 (32°F)	3.56	-	-
Trichloro-methane (47)	$CHCl_3$	1.489	979	3,211.9	3.4	0.55	5.918
1,1,2-Trichloro- 1,2,2-Trifluoro-Etham	$CCl_2F\text{-}CClF_2$	1.563	783.7 (0°C)	2,571.2 (32°F)	-	-	-
Triethyl-amine (33)	$C_6H_{15}N$	0.726	1,123	3,684.4	4.47	-	-
Triethylene glycol	$C_6H_{14}O_4$	1.123	1,608	5,275.6	3.8	-	-
1,1,1-Trifluoro- 2-Chloro-2-Bromo-Ethane	$C_2HClBrF_3$	1.869	693	2,273.6	-	-	-
1,2,2-Trifluorotrichloro- ethane (Freon 113)	$CCl_2F\text{-}CClF_2$	1.563	783.7 (0°C)	2,571.2 (32°F)	3.44	-	-
d-1,3,3-Trimethylnorcamphor	$C_{10}H_{16}O$	0.947	1,320	4,330.7	-	0.22	2.367
Trinitrotoluene (43)	$C_7H_5(NO_2)_3$	1.64	1,610 (81°C)	5,282.2 (178°F)	-	-	-
Turpentine	-	0.88	1,255	4,117.5		1.4	15.064
Unisis 800	-	0.87	1,346	4,416			
Water, distilled (49, 50)	H_2O	0.996	1,498	4,914.7	-2.4	1.00	10.76
Water, heavy	D_2O		1,400	4,593	-	-	-
Water, sea		1.025	1,531	5,023	-2.4	1.00	10.76
Wood Alcohol (40, 41)	CH_4O	0.791 (20°C)	1,076	3,530.2	2.92	0.695	7.478
Xenon (45)	Xe	-	630 (-109°C)	2,067 (-164°F)	-	-	-
m-Xylene (46)	C_8H_{10}	0.868 (15°C)	1,343 (20°C)	4,406.2 (68°F)	-	0.749 (15°C)	8.059 (59°F)
o-Xylene (29, 46)	C_8H_{10}	0.897 (20°C)	1,331.5	4,368.4	4.1	0.903 (20°C)	9.716 (68°F)
p-Xylene (46)	C_8H_{10}	-	1,334 (20°C)	4,376.6 (68°F)	-	0.662	7.123
Xylene hexafluoride	$C_8H_4F_6$	1.37	879	2,883.9	-	0.613	6.595
Zinc (7)	Zn	-	3,298 (450°C)	10,820.2 (842°F)	-	-	-

8.5 Retrieving Data from the AUP

RW DATA LOG RETRIEVAL GUIDE AUP PORTABLE FLOW METER

TOOLS:

AUPA-TB terminal box

12VDC wall charger

USB-A to USB-mini cable (terminal box to computer)

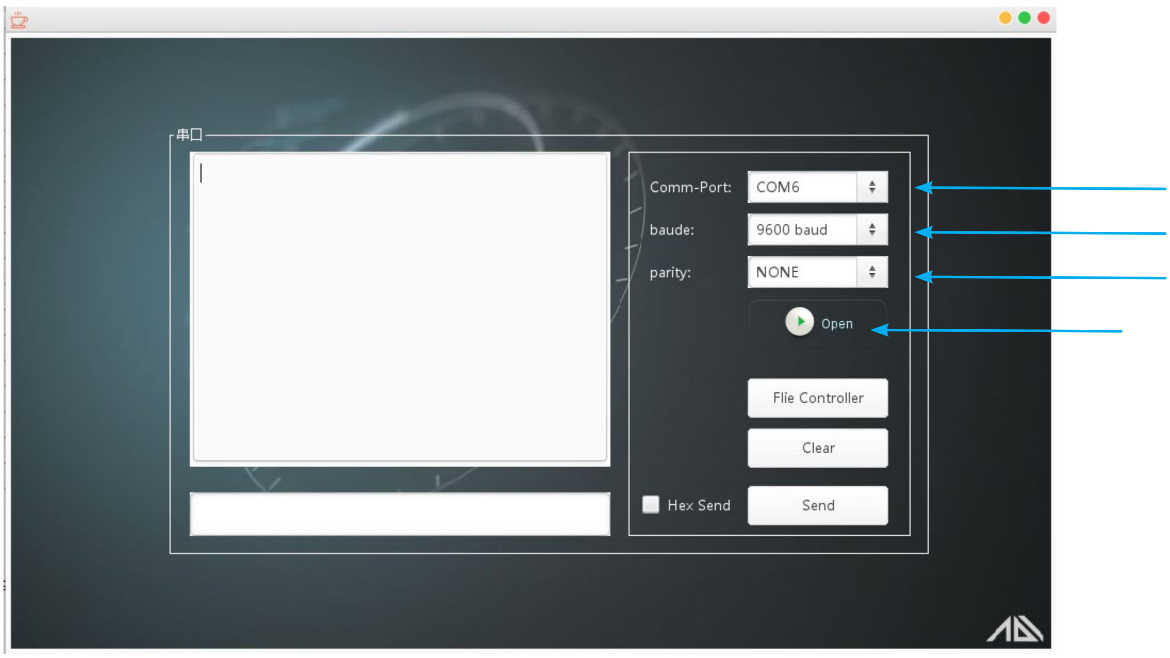
15 pin communication cable (terminal box to AUP)

RW Software

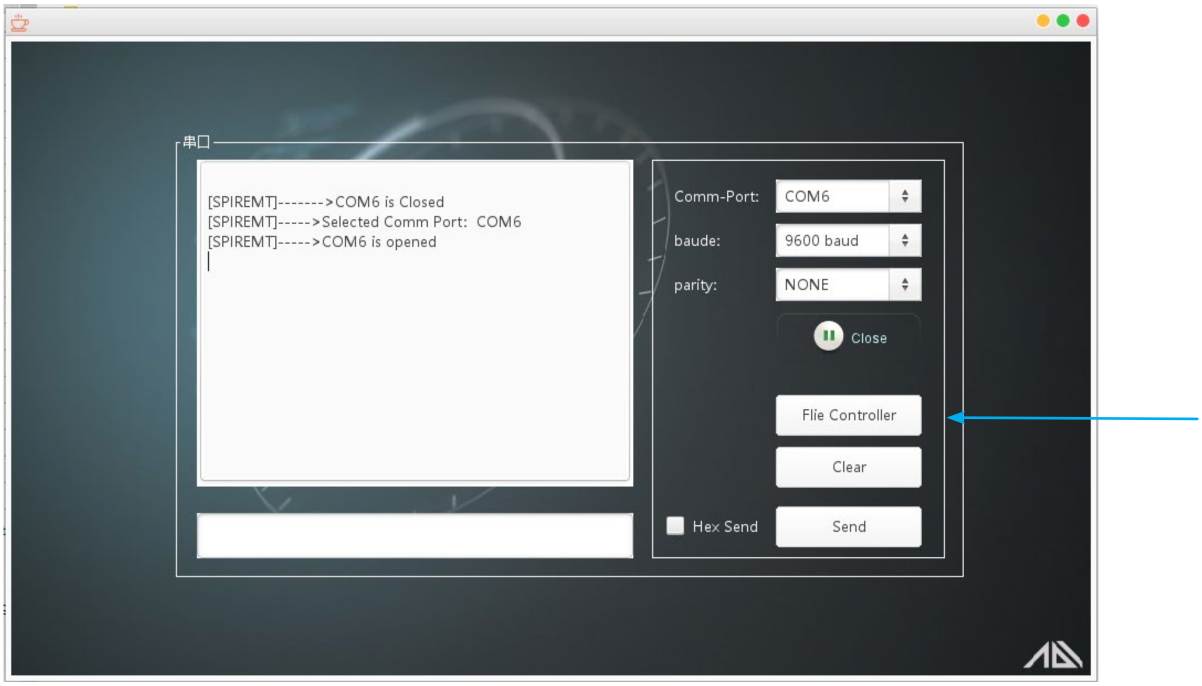
Connect the AUP to computer through the terminal box AUPA-TB using the cables as described above. Power the terminal box with the wall charger. Turn on the AUP.

Certain operations in this program will take longer to execute than others, and may be interrupted with repeated actuation.

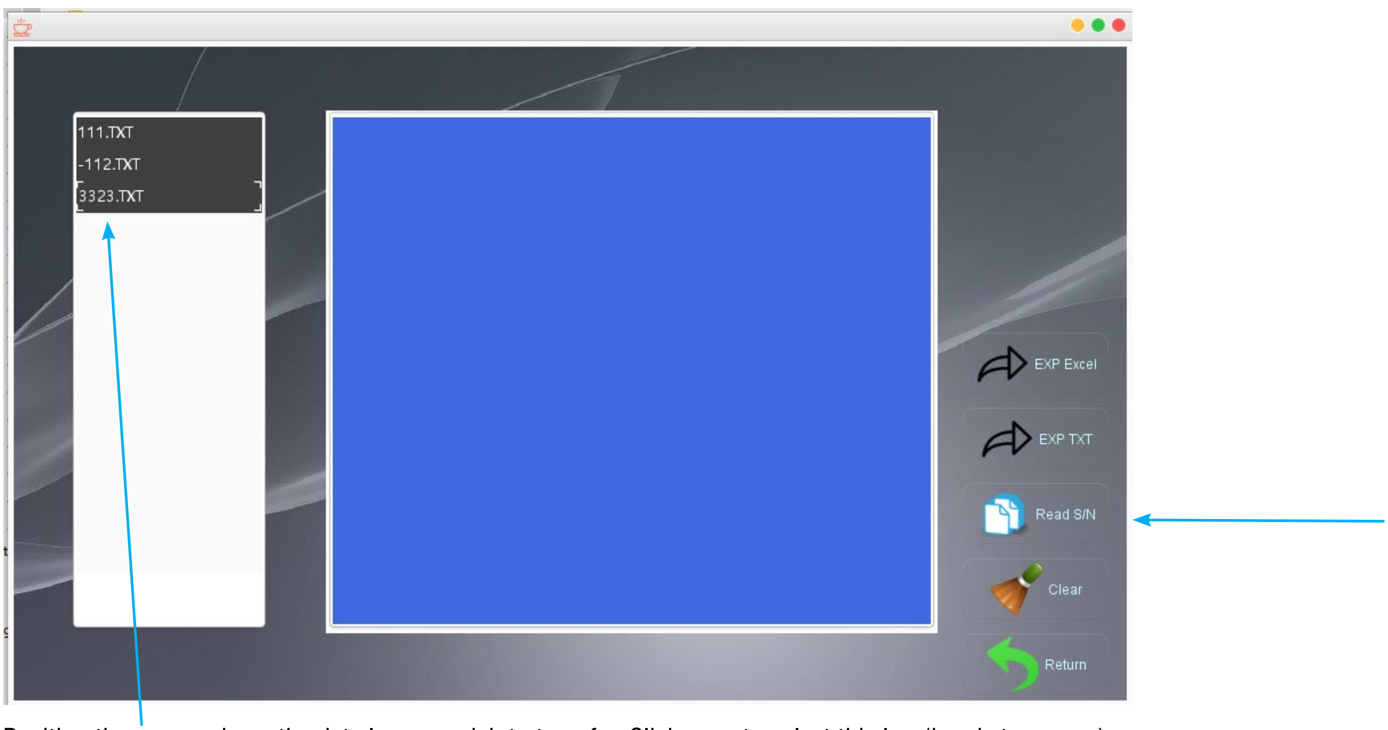
On the computer, open the RW.exe program. Identify the com port that connects the USB cable to the terminal box (Control Panel, Device Manager, COM and LPT, silicon labs CP210x USB to UART bridge, com _). Set the COM port to match, and set the Baud rate to match the Baud rate of the AUP (Menu, 5, 3, ENT, select BAUD from menu. 9600 or higher recommended). Parity should be set to "NONE".



Open tab label will change to Close, and the screen confirms that the com port is open.

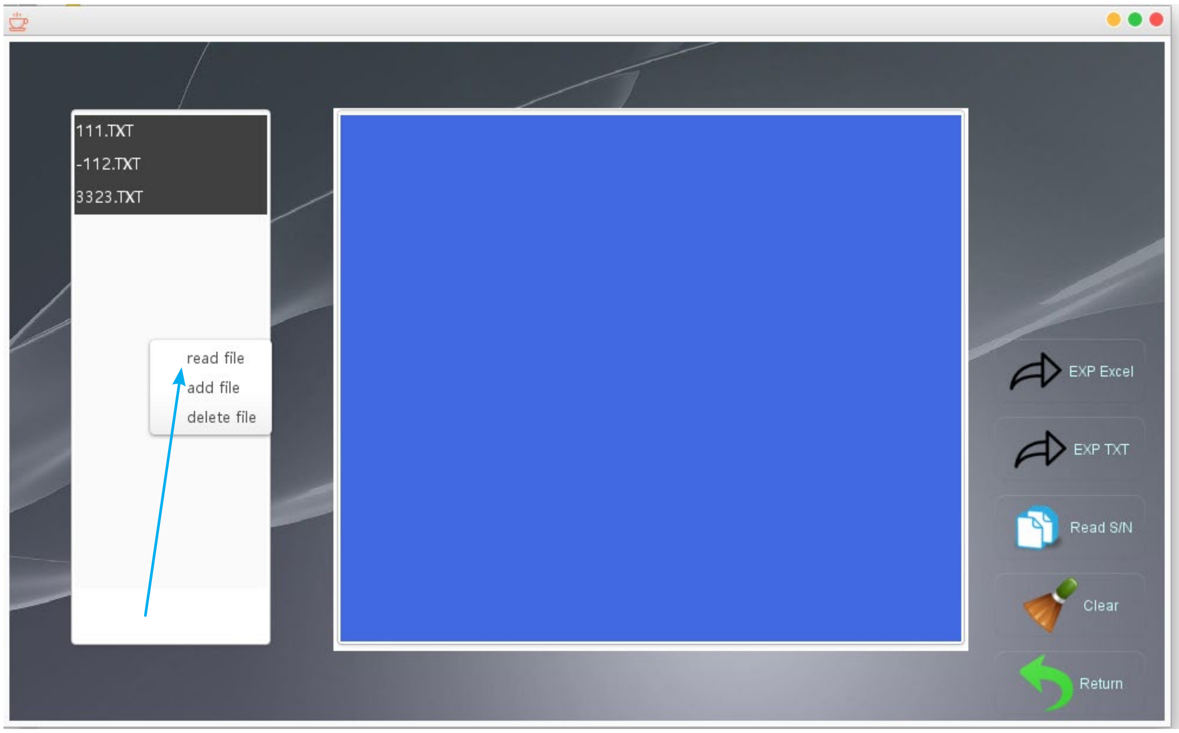


Move the cursor to the File Controller tab and open the data reading interface.
Move the cursor to the Read SN tab and access the data logs stored on the AUP.



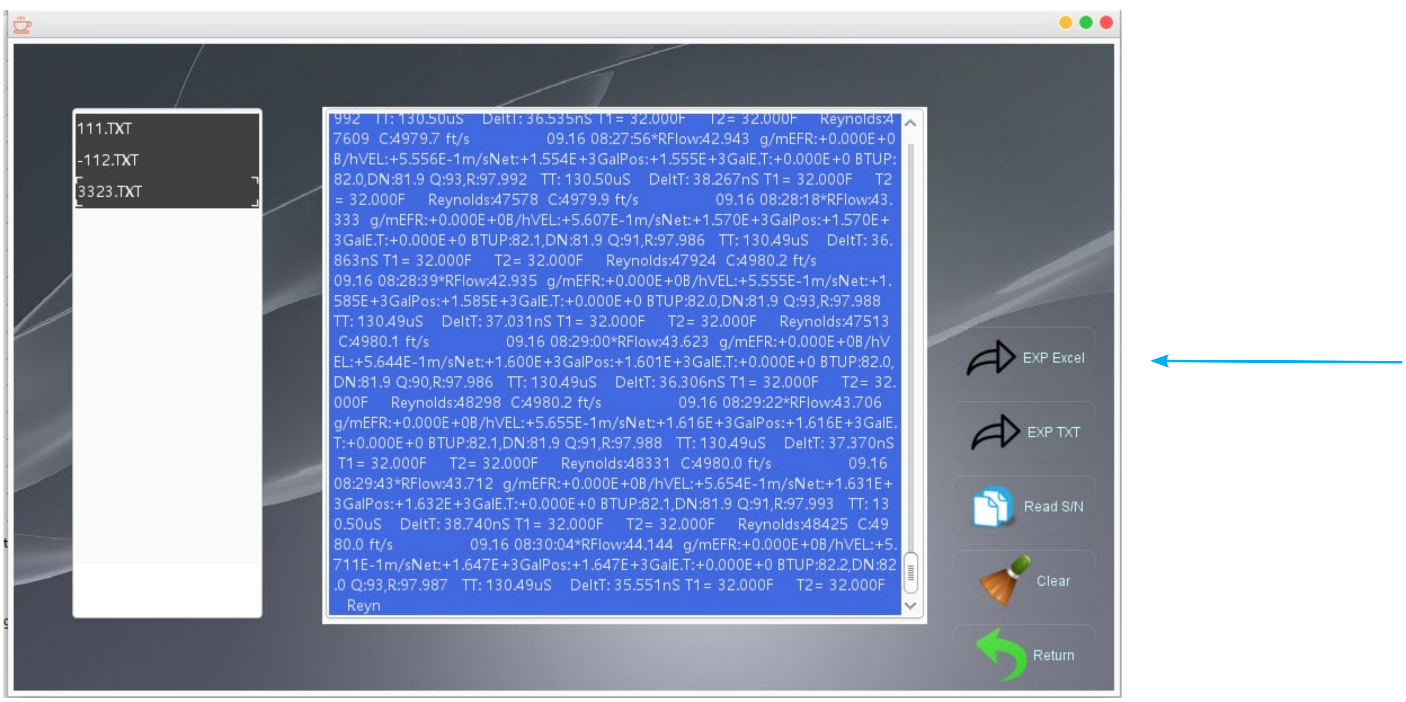
Position the cursor above the data log you wish to transfer. Click once to select this log (brackets appear).

Move the cursor to the white field below and click once. The Option Box appears.

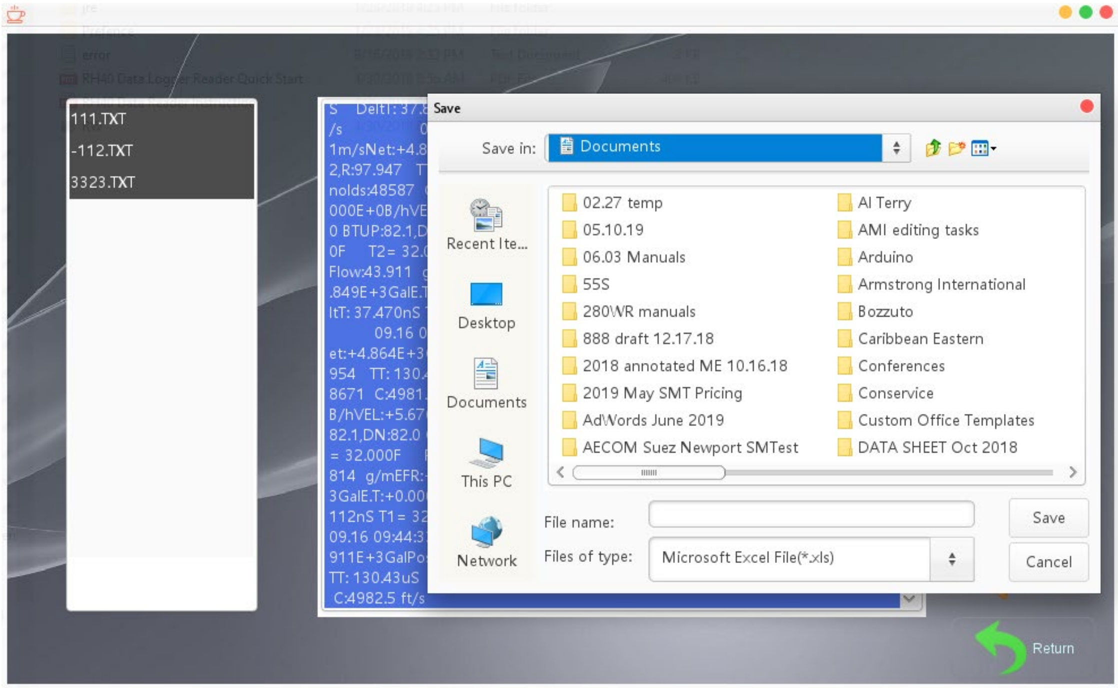


Select "read file".

The selected log data populates the center field on the screen. Depending on log size, this may take several minutes. The data will move continually on the screen as it transfers from the AUP. When the data stops moving, transfer is complete.

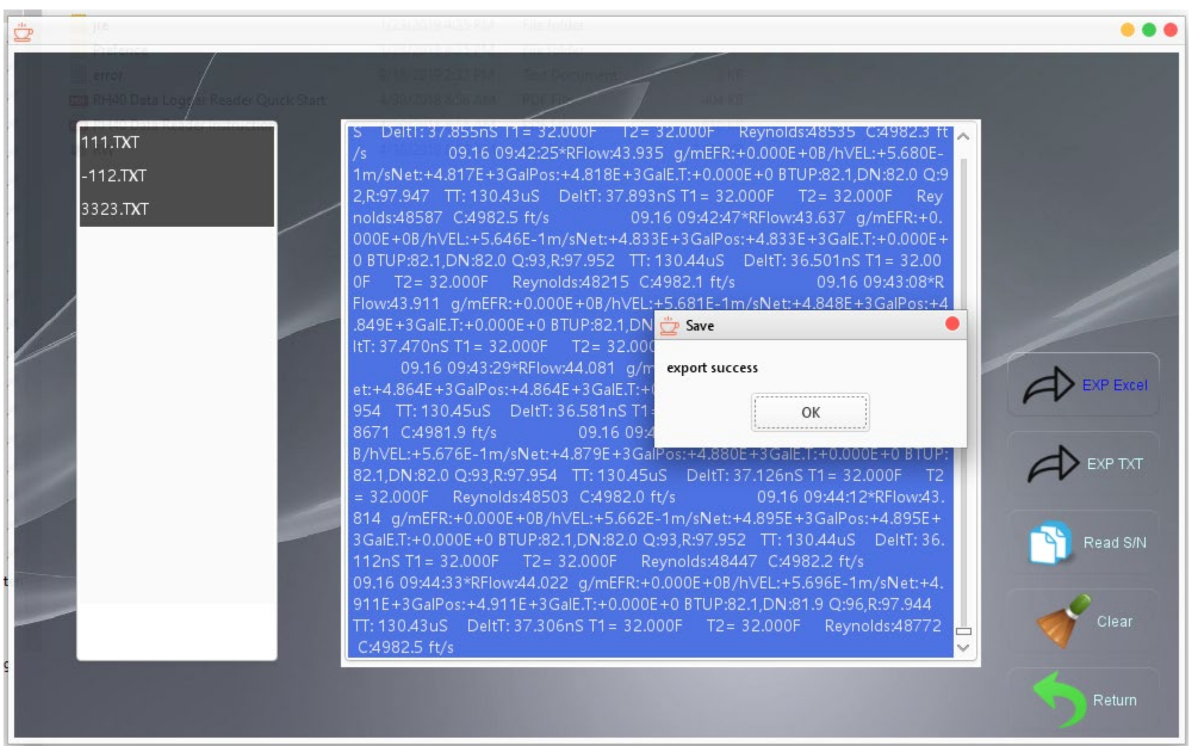


Move the cursor to the “EXP Excel” tab and transfer the data to your computer.



NAME THE FILE WITH THE EXTENSION “csv”. This will ensure properly formatted data.

The program will confirm the successful data transfer.



Select “OK” tab, then “Clear” and “Return” tabs to return to the previous screen, and exit the program.

Notes

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