Particle Instruments

Model 3772/3771 Condensation Particle Counter

Operation and Service Manual

P/N 1980529, Revision C
April 2007

Model 3772

Model 3771

TSI®

Model 3772/3771 Condensation Particle Counter

Operation and Service Manual

Manual History

The following is a history of the Model 3772/3771 Condensation Particle Counter Operation and Service Manual (Part Number 1980529).

Revision	Date
A	February 2006
B	April 2006
C	April 2007

Warranty

Part Number 1980529 / Revision C / April 2007

Address TSI Incorporated / 500 Cardigan Road / Shoreview, MN 55126 / USA

Fax No. 651-490-3824

E-mail Address particle@tsi.com

Limitation of Warranty and Liability
(effective July 2000)

Seller warrants the goods sold hereunder, under normal use and service as described in the operator's manual, shall be free from defects in workmanship and material for (12) months, or the length of time specified in the operator's manual, from the date of shipment to the customer. This warranty period is inclusive of any statutory warranty. This limited warranty is subject to the following exclusions:

a. Hot-wire or hot-film sensors used with research anemometers, and certain other components when indicated in specifications, are warranted for 90 days from the date of shipment.

b. Parts repaired or replaced as a result of repair services are warranted to be free from defects in workmanship and material, under normal use, for 90 days from the date of shipment.

c. Seller does not provide any warranty on finished goods manufactured by others or on any fuses, batteries or other consumable materials. Only the original manufacturer's warranty applies.

d. Unless specifically authorized in a separate writing by Seller, Seller makes no warranty with respect to, and shall have no liability in connection with, goods which are incorporated into other products or equipment, or which are modified by any person other than Seller.

The foregoing is IN LIEU OF all other warranties and is subject to the LIMITATIONS stated herein. **NO OTHER EXPRESS OR IMPLIED WARRANTY OF FITNESS FOR PARTICULAR PURPOSE OR MERCHANTABILITY IS MADE**.

TO THE EXTENT PERMITTED BY LAW, THE EXCLUSIVE REMEDY OF THE USER OR BUYER, AND THE LIMIT OF SELLER'S LIABILITY FOR ANY AND ALL LOSSES, INJURIES, OR DAMAGES CONCERNING THE GOODS (INCLUDING CLAIMS BASED ON CONTRACT, NEGLIGENCE, TORT, STRICT LIABILITY OR OTHERWISE) SHALL BE THE RETURN OF GOODS TO SELLER AND THE REFUND OF THE PURCHASE PRICE, OR, AT THE OPTION OF SELLER, THE REPAIR OR REPLACEMENT OF THE GOODS. IN NO EVENT SHALL SELLER BE LIABLE FOR ANY SPECIAL, CONSEQUENTIAL OR INCIDENTAL DAMAGES. SELLER SHALL NOT BE RESPONSIBLE FOR INSTALLATION, DISMANTLING OR REINSTALLATION COSTS OR CHARGES. No Action, regardless of form, may be brought against Seller more than 12 months after a cause of action has accrued. The goods returned under warranty to Seller's factory shall be at Buyer's risk of loss, and will be returned, if at all, at Seller's risk of loss.

Buyer and all users are deemed to have accepted this LIMITATION OF WARRANTY AND LIABILITY, which contains the complete and exclusive limited warranty of Seller. This LIMITATION OF WARRANTY AND LIABILITY may not be amended, modified or its terms waived, except by writing signed by an Officer of Seller.

Service Policy

Knowing that inoperative or defective instruments are as detrimental to TSI as they are to our customers, our service policy is designed to give prompt attention to any problems. If any malfunction is discovered, please contact your nearest sales office or representative, or call TSI's Customer Service department at 1-800-874-2811 (USA) or (651) 490-2811.

Safety

This section provides instructions to ensure safe and proper operation and handling of the Model 3772/3771 Condensation Particle Counter (CPC).

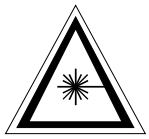
There are no user-serviceable parts inside the instrument. Refer all repair and maintenance to a qualified technician. All maintenance and repair information in this manual is included for use by a qualified technician.

Laser Safety

The Model 3772/3771 CPC is a Class I laser-based instrument. During normal operation, you will not be exposed to laser radiation. However, you must take certain precautions or you may expose yourself to hazardous radiation in the form of intense, focused visible light. Exposure to this light can cause blindness.

Take these precautions:

- Do *not* remove any parts from the CPC unless you are specifically told to do so in this manual.
- Do *not* remove the CPC housings or covers while power is supplied to the instrument.



WARNING
The use of controls, adjustments, or procedures other than those specified in this manual may result in exposure to hazardous optical radiation.

Chemical Safety

The Model 3772/3771 CPC uses n-butyl alcohol (butanol) as a working fluid. Butanol is flammable. Butanol is also toxic if inhaled. Refer to a Material Safety Data Sheet for butanol and take these precautions:

- Use butanol only in a well-ventilated area. Under normal operating conditions butanol is exhausted into the air at approximately 0.015 g per minute.

- Butanol vapor is identified by its characteristically strong odor and can easily be detected. If you smell butanol and develop a headache, or feel faint or nauseous, leave the area at once. Ventilate the area before returning.

C a u t i o n
Butanol is flammable. Butanol is also potentially toxic if inhaled. Use butanol only in a well-ventilated area. If you smell butanol and develop a headache, or feel faint or nauseous, leave the area at once. Ventilate the area before returning.

W A R N I N G
Although the CPC is appropriate for monitoring inert process gases such as nitrogen or argon, it should not be used with hazardous gases such as hydrogen or oxygen. Using the CPC with hazardous gases may cause injury to personnel and damage to equipment.

Description of Safety Labels

This section acquaints you with the advisory and identification labels on the instrument and used in this manual to reinforce the safety features built into the design of the instrument.

Caution

C a u t i o n
Caution means ***be careful***. It means if you do not follow the procedures prescribed in this manual you may do something that might result in equipment damage, or you might have to take something apart and start over again. It also indicates that important information about the operation and maintenance of this instrument is included.

Warning

W A R N I N G
Warning means that unsafe use of the instrument could result in serious injury to you or cause irrevocable damage to the instrument. Follow the procedures prescribed in this manual to use the instrument safely.

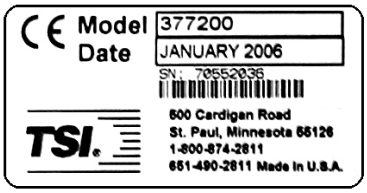
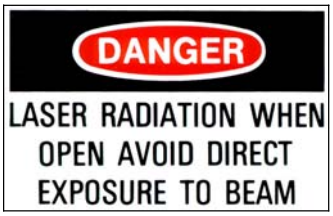
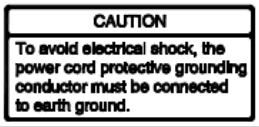
Caution or Warning Symbols

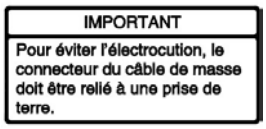
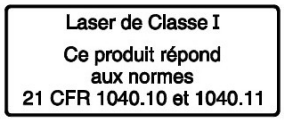
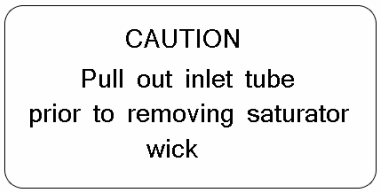
The following symbols may accompany cautions and warnings to indicate the nature and consequences of hazards:

	Warns you that uninsulated voltage within the instrument may have sufficient magnitude to cause electric shock. Therefore, it is dangerous to make any contact with any part inside the instrument.
	Warns you that the instrument contains a laser and that important information about its safe operation and maintenance is included. Therefore, you should read the manual carefully to avoid any exposure to hazardous laser radiation.
	Warns you that the instrument is susceptible to electro-static dissipation (ESD) and ESD protection procedures should be followed to avoid damage.
	Indicates the connector is connected to earth ground and cabinet ground.

Labels

Advisory labels and identification labels are attached to the outside of the CPC housing and to the optics on the inside of the instrument. Labels for the Model 3772/3771 CPC are described below:

1. Serial Number label (back panel)	
2. Laser Radiation label (located internally on the optics housing)	
3.Electrical shock caution label	
4. Laser device compliance label	

5. Caution label	
6. WEEE Directive label (Waste Electrical and Electronic Equipment). (*Item must be recycled properly.*)	
7. French language electrical safety and laser compliance labels	 
8. ETL label for safety certification	
9. TSI Service label	
10. Saturator Wick Removal caution label	

Contents

Figures

Tables

About This Manual

Purpose

This is an operation and service manual for the Model 3772/3771 Condensation Particle Counter (CPC).

Organization

The following is a guide to the organization of this manual:

- **Chapter 1: Product Overview**
  This chapter gives an introduction to the Model 3772/3771 Condensation Particle Counter, a list of features, and a brief description of how the instrument works.
- **Chapter 2: Unpacking and Setting Up the CPC**
  This chapter gives a packing list and the step-by-step procedure for getting the CPC ready to operate.
- **Chapter 3: Instrument Description**
  This chapter describes features and controls that run the CPC, including the components on the front-panel, back-panel, bottom-panel, cover and inside the instrument. It also covers the basic functions of the instrument.
- **Chapter 4: Instrument Operation**
  This chapter describes the operation of the instruments.
- **Chapter 5: Technical Description**
  This chapter details the principle of operation, theory, and performance of the condensation nucleus counter.
- **Chapter 6: Particle Counting**
  This chapter describes the particle counting modes.
- **Chapter 7: Computer Interface and Commands**
  This chapter describes the computer interface hardware, associated firmware commands, and flash memory card.
- **Chapter 8: Maintenance and Service**
  This chapter describes the recommended practices and schedule for routine cleaning, checking and calibration.

- **Appendix A: Specifications**
  This appendix lists the specifications of the Model 3772/3771 Condensation Particle Counter.
- **Appendix B: Firmware Commands**
  This appendix lists all the serial commands for communications between the CPC and the computer.
- **Appendix C: References**
  This chapter lists all of the references that have been used within the text of the manual. In addition, a general list of references pertaining to condensation nucleus counters is included.

Related Product Literature

- ***Model 3007 Condensation Particle Counter Operation and Service Manual*** (part number 1930035) TSI Incorporated
- ***Model 3010D Condensation Particle Counter Instruction Manual*** (part number 1900064) TSI Incorporated
- ***Model 3775 Condensation Particle Counter Operation and Service Manual*** (part number 1980527) TSI Incorporated
- ***Model 3776 Ultrafine Condensation Particle Counter Operation and Service Manual*** (part number 1980522) TSI Incorporated
- ***Model 3781 Water-based Condensation Particle Counter Operation and Service Manual*** (part number 1930111) TSI Incorporated
- ***Model 3782 Water-based Condensation Particle Counter Operation and Service Manual*** (part number 1930073) TSI Incorporated
- ***Model 3785 Water-based Condensation Particle Counter Operation and Service Manual*** (part number 1933001) TSI Incorporated
- ***Model 3786 Ultrafine Water-based Condensation Particle Counter Operation and Service Manual*** (part number 1930072) TSI Incorporated
- ***Model 376060 Particle Size Selector Instruction Manual*** (part number 1930013) TSI Incorporated
  This manual contains operating instructions for the Model 376060 Particle Size Selector, an accessory for the Model 3772, 3771, 3781 and 3782 CPCs. The Model 376060 is a separating device that removes small particles from an aerosol while passing larger particles.

- ***Aerosol Instrument Manager® Software for CPC and EAD Instruction Manual*** (part number 1930062) TSI Incorporated
  This manual contains operating instructions for Aerosol Instrument Manager Software for CPC and EAD, a software program that monitors, calculates, and displays particle concentration data collected by a CPC or an EAD.

Getting Help

To obtain assistance with the Model 3772/3771 Condensation Particle Counter contact Customer Service:

TSI Incorporated
500 Cardigan Road
Shoreview, MN 55126 USA
Fax: (651) 490-3824
Telephone: 1-800-874-2811 (USA) or (651) 490-2811
E-mail Address: technical.service@tsi.com

Submitting Comments

TSI values your comments and suggestions on this manual. Please use the comment sheet on the last page of this manual to send us your opinion on the manual's usability, to suggest specific improvements, or to report any technical errors.

If the comment sheet has already been used, please mail your comments on another sheet of paper to:

TSI Incorporated
Particle Instruments
500 Cardigan Road
Shoreview, MN 55126
Fax: (651) 490-3824
E-mail Address: particle@tsi.com

CHAPTER 1

Product Overview

This chapter contains an introduction to the Model 3772/3771 Condensation Particle Counter (CPC) and provides a brief explanation of how the instrument operates.

Product Description

The Model 3772/3771 Condensation Particle Counter is a compact, rugged, and full-featured instrument that detects airborne particles down to 10 nanometers in diameter at an aerosol flow rate of 1.0 liter per minute, over a concentration range from 0 to 10^4 particles per cubic centimeter. These CPCs are ideally suited for applications that do not require measurement of high concentrations, such as basic aerosol research, filter and air-cleaner testing, particle counter calibration, environmental monitoring, mobile aerosol studies, particle shedding and component testing, and atmospheric and climate studies. The Model 3772 CPC is also compatible with TSI Scanning Mobility Particle Sizer™ (SMPS™) spectrometers for particle size distribution measurements.

The successor to the Model 3010, 3760A, and 3762 CPCs, the Model 3772 and 3771 CPCs offer many new features and improvements:

- Fast response to rapid changes in aerosol concentration ($T_{95} \cong 3$ seconds)
- Butanol-friendly features, including anti-spill design, water-removal system, and improved resistance to optics flooding
- Removable saturator wick for easy transport and maintenance
- USB and Ethernet available
- Auto recovery from power failure

The Model 3772 CPC offers the following additional features:

- Built-in SMPS compatibility
- Particle concentration, total counts, instrument status or user settings shown on enhanced front panel LCD display
- Built-in data logging and storage capability with removable memory card

Figure 1-1
Model 3772 Condensation Particle Counter

Figure 1-2
Model 3771 Condensation Particle Counter

How it Works

In the Model 3772/3771 Condensation Particle Counter (CPC), an aerosol sample is drawn continuously through a heated saturator in which butanol is vaporized and diffuses into the sample stream. Together, the aerosol sample and butanol vapor pass into a cooled condenser where the butanol vapor becomes supersaturated and ready to condense. Particles present in the sample stream serve as condensation nuclei. Once condensation begins, particles that are larger than a threshold diameter quickly grow into larger droplets and pass through an optical detector where they are counted easily.

The Model 3772/3771 CPC detects particles as small as 10 nanometer in diameter and employs single-particle-count-mode operation to measure concentrations up to 10^4 particles per cubic centimeter. The detector counts individual pulses produced as each particle (droplet) passes through the sensing zone. A high signal-to-noise ratio and continuous, live-time coincidence correction provide great measurement accuracy, even at very low concentrations. An

external vacuum pump is required to draw the aerosol sample into the CPC. The 1.0 L/min aerosol flow rate is controlled accurately and reliably using an internal critical orifice.

The CPCs use a laser-diode light source and diode photodetector to collect scattered light from particles. An internal microprocessor is used for instrument control and data processing.

Model 3772 CPC has a two-line LCD display which presents real-time number concentration, totalizer function, and enables easy-to-use menus for control operation functions and presents instrument status information and user settings. A variety of communication options for computer data acquisition are available. The 3772 CPC also includes on-board data logging and storage using a removable flash memory card. Model 3771 has no display and no memory card.

CHAPTER 2

Unpacking and Setting up the CPC

Use the information in this chapter to unpack the Model 3772/3771 Condensation Particle Counter (CPC) and set it up.

Packing List

Tables 2-1 and 2-2 show the components shipped with the Model 3772 and 3771 CPCs.

Table 2-1
Model 3772 CPC Packing List

Qty.	Description
1	Model 3772 CPC and Operation Manual
1	Power cable
1	Aerosol Instrument Manager® Software
1	Fill Bottle
1	Drain Bottle
1	Bottle Bracket
1	Vacuum Drain Bottle Cap
1	RS-232 Cable (9-pin M/F, 12 ft)
1	USB I/O Cable A/B 6 ft
1	SanDisk ImageMate 5-in-1 Card Reader
1	Data Memory Card
1	Saturator Wick CPC 3772
2	Water Removal Filter Inline, 25 micron 1/16" barb
3	Butanol Fill/Drain Filter Inline, 73 micron 1/8" barb
2	Saturator Base O-Ring FVMQ 1-010
1	Saturator Base O-Ring FVMQ 1-030
1	Saturator Base O-Ring EPDM 1-027
1	Ziploc® Bag 6” × 6” (for saturator wick)
1	Krytox® O-ring Grease
1	Checkout Data Sheet
1	Certificate of Conformance

®Ziploc is a registered trademark of SC Johnson & Son, Inc.
®Krytox® is a registered trademark of DuPont.

Table 2-2
Model 3771 CPC Packing List

Qty.	Description
1	Model 3771 CPC and Operation Manual
1	Power cable
1	Aerosol Instrument Manager® Software
1	Fill Bottle
1	Drain Bottle
1	Bottle Bracket
1	Vacuum Drain Bottle Cap
1	RS-232 Cable (9-pin M/F, 12 ft)
1	USB I/O Cable A/B 6 ft
1	Saturator Wick CPC 3771
2	Water Removal Filter Inline, 25 micron 1/16" barb
3	Butanol Fill/Drain Filter Inline, 73 micron 1/8" barb
2	Saturator Base O-Ring FVMQ 1-010
1	Saturator Base O-Ring FVMQ 1-030
1	Saturator Base O-Ring EPDM 1-027
1	Ziploc® Bag 6" × 6" (for saturator wick)
1	Krytox® O-ring Grease
1	Checkout Data Sheet
1	Certificate of Conformance

Note: *Some items above and those for future maintenance are available for purchase as kits from TSI. A complete list of replacement part kits is included in the maintenance section in Chapter 8.*

Unpacking

The Model 3772/3771 CPC comes fully assembled with protective coverings on the inlet sample port, exit ports, and analog connectors. The CPC comes packaged with the accessory kit. Use the packing list (Table 2-1 or Table 2-2) to make certain that there are no missing components.

The CPC box contains special foam cutouts designed to protect the instrument during shipment. Save the original packaging materials for future use should you need to ship the instrument or return the instrument to TSI for service. Also keep the protective coverings for ports for shipping.

To avoid contaminating the instrument or the environment the CPC is monitoring, do *not* remove the protective covers until you are ready to install the instrument.

If anything is missing or appears to be damaged, contact your TSI representative or contact TSI Customer Service at 1-800-874-2811 (USA) or (651) 490-2811. Chapter 8, "Maintenance and Service," gives instructions for returning the CPC to TSI Incorporated.

Setting Up

This section contains instructions for setting up the Model 3772/3771 CPC. Follow the instructions in the order given.

Remove Protective Caps

Remove all protective caps from the inlet sample port and exit flow ports at the back of the instrument, also remove covers from the BNC connectors.

Mounting the Bracket and Fill Bottle

Mount the black anodized aluminum Bottle Bracket to the back panel using two 8-32 × ⅜-inch screws and two no. 8 lock-washers found in the mounting hole locations. Refer to the location of the bottle bracket shown in Figure 2-1.

Find the Fill Bottle in the accessory kit. Connect the bottle tube fitting to the Butanol Fill port at the back panel of the instrument. Position the bottle with the fitting oriented for minimal stress on the tubing connector on the back panel and place the bottle in the bracket. Both mated fittings are leak-tight when disconnected.

Figure 2-1
View of Fill Bottle Bracket Mounting

Filling the Fill Bottle with Butanol

The Model 3772/3771 CPC uses reagent-grade n-butyl alcohol (butanol) as the working fluid for particle growth. Pour the butanol into the Fill Bottle to at least one-third full. Because of the leak-tight fittings and internal solenoid valve, liquid will not flow into the CPC until the connections are made, the instrument is switched on, and warm-up cycle is complete.

Note: *Due to shipping regulations on flammable materials, n-butyl alcohol (butanol) is not supplied with the CPC. Butanol may be purchased from scientific chemical supply houses. Reagent grade of butanol is required.*

Connecting the Butanol Drain Bottle

A drain bottle should be connected to the Liquid Drain port at the back panel of the CPC. The drain bottle collects butanol drained from the CPC prior to transport and holds condensed water and butanol removed from the condenser when the water removal system is turned on (see note below). Draining butanol is described in Chapter 8 "Maintenance and Service".

Note: *The water removal system will not work without a drain bottle connected to the drain port. Refer to Chapter 4 for more details on water removal system.*

C a u t i o n
Butanol is flammable. Butanol is also potentially toxic if inhaled. Use butanol only in a well-ventilated area. If you smell butanol and develop a headache, or feel faint or nauseous, leave the area at once. Ventilate the area before returning.

Apply Power to the CPC

Plug the power cord into the receptacle on the back panel of the CPC and then plug it into the AC power source. The instrument uses a universal power supply that accepts a variety of input voltages identified below.

Power 100 – 240 VAC, 50/60 Hz, 210 W maximum

Note: *Make certain the power cord is plugged into a grounded power outlet. Position the CPC so the power connector is easily accessible.*

Apply power to the CPC by turning on the switch next to the power cord on the back panel.

The instrument begins a warm-up sequence which typically lasts ten minutes at room temperature. On the 3772, a ten-minute countdown is displayed on the front panel. Particle concentration will not be accurately measured during warm-up. After warm-up completes, the fluid begins to fill the internal butanol reservoir in the saturator.

Supply External Vacuum to the CPC

An external vacuum port is located in the lower right-hand corner of the CPC back panel. An external vacuum must be connected to this port before the CPC can count particles. Vacuum source, either a central building vacuum or a stand-alone vacuum source (e.g., TSI Model 3032 Vacuum Pump), should provide at least 60 kPa (18 in. Hg) vacuum and 1.0 L/min critical flow at the inlet of each CPC. Details of vacuum specifications are given in Chapter 5.

Positioning the CPC

Place the CPC on a level surface. Ensure the cooling fan on the back panel of the CPC is exposed to ambient air.

Note: *If the CPC has n-butyl alcohol (butanol) in the reservoir, be very careful when moving the CPC. See "Moving and Shipping the CPC" section for details.*

CHAPTER 3

Instrument Description

Use the information in this chapter to become familiar with the location and function of controls, indicators, and connectors on the Model 3772 and 3771 Condensation Particle Counters (CPC).

Model 3772 Front Panel

The main components of the 3772 front panel include the two-line LCD display, six-key push button keypad, flash memory card slot, aerosol inlet, two LED indicator lights (particle and status). These are identified in Figure 3-1 and described below.

LCD Display and Keypad

The two-line backlit LCD provides continuous real-time display of sample data and is used in conjunction with the keypad to display option menus, instrument status information, and user settings. Refer to Chapter 4 for details on how to make selections and change options on the menus.

Figure 3-1
View of the Model 3772 Front Panel

Aerosol Inlet

The aerosol inlet is located on the front panel. The inlet consists of a ¼" OD tube suitable for use with common tube fittings. Permanent fittings with metal locking ferrules should be avoided since this can deform the tube when overtightened, leading to leaks.

Status Light

The status light indicates the working status of the CPC. It will light only when the key performance parameters of the CPC fall within an acceptable range. More information on the status light is provided in Chapter 4.

Particle Light

The particle light flashes each time a particle is detected. At high particle counting levels (>10 counts per second) the light appears continuously on.

Flash Memory Card Slot

The Model 3772 CPC provides storage of particle concentration data using a standard flash memory card. A flash memory card is included. Refer to Using the Flash Memory Card in Chapter 4 for more on how to use the Flash Memory Card. Technical information is also found in Chapter 7.

Model 3771 Front Panel

The main components of the 3771 front panel include the aerosol inlet and two LED indicator lights (particle and status). These are identified in Figure 3-2 and operate the same as described above for the 3772.

Figure 3-2
View of the Model 3771 Front Panel

Model 3772/3771 Back Panel

As shown in Figure 3-3, the back panel of the 3772/3771 CPC has power and data connections, analog input/output connections, external vacuum port, butanol fill and drain ports, and cooling fan. The function of the ports and connectors are clearly labeled.

AC Connector and Switch

Plug the supplied AC power cable into this receptacle. The instrument power switch is integrated into this AC receptacle at the top.

USB Communication Port

The Model 3772/3771 CPC provides a USB port for use with the TSI Aerosol Instrument Manager® software included with the instrument. When USB communications are used with the software, the computer automatically recognizes the CPC as a TSI instrument. Additional information on USB communications is found in Chapter 7 and also in the Aerosol Instrument Manager software manual.

Note: *Up to three CPCs can be simultaneously connected to one computer running Aerosol Instrument Manager software with USB connections.*

Figure 3-3
Back Panel of the Model 3772/3771 CPC

RS-232 Serial Connections

The Model 3772/3771 CPC provides two standard 9-pin RS-232 serial ports that allow communication between a computer and the CPC. Serial commands are sent to and from the computer to monitor instrument status information, to retrieve and monitor data, and to provide a variety of control functions such as turning the water removal system on and off (Serial 1 only). Aerosol Instrument Manager software may be used with Serial 1 as well as USB. Information on RS-232 communications can be found in Chapter 7, "Computer Interfaces and Commands".

Analog Inputs

The CPC can monitor the analog voltages from two external sources via the analog input BNC connectors on the back panel, labeled Analog Input 1 and Analog Input 2. The input voltage range for these ports is 0 to 10 volts. On the 3772 the analog voltages can be displayed on the LCD display and saved to the removable Flash Memory Card or a computer. Voltages from external pressure, flow, or temperature transducers can be correlated to particle concentration in real time.

Amplification must be supplied by the user to bring low voltage signals to the appropriate 0 to 10 volt range for best resolution.

DMA/Analog Output and Pulse Output

The DMA/Analog Output port provides an analog 0–10 V signal linearly proportional to particle concentration. This particle concentration is corrected for coincidence and equals the concentration displayed on the front panel of the CPC and the concentration saved to the Flash Memory Card or computer. Refer to Chapter 4 for details. In addition, on the 3772 this port can be configured by the Aerosol Instrument Manager software to provide the ramped voltage signal needed when the 3772 CPC is used as part of the Scanning Mobility Particle Sizer™ (SMPS™) spectrometer. Although this port on the 3771 is also labeled DMA/Analog Output, the DMA function is not available for the 3771.

Pulse Output port provides a 5-volt (50-ohm termination) digital pulse for each particle detected. This enables you to use your own counting electronics hardware or provides a particle trigger for special applications. The width of the pulse depends on both the shape of the photodetector pulse and the trigger-level of the pulse threshold. Typical (nominal) pulse widths are 350 nanoseconds (see Figure 3-4) for the 3772/3771 CPC. To provide accurate pulse counts, *use a counter that is capable of counting pulses with a width of 50 nanoseconds or less.*

Particle concentrations calculated based on the particle counts from the counting electronics hardware are *not corrected* for particle coincidence. Thus, the concentration obtained this way might be slightly lower than the displayed concentration when particle concentration is high. Refer to Chapter 6 “Particle Counting” for coincidence correction for pulse output.

The Pulse Output is a way to get raw particle count information. This information is also available through serial command. Using the SSTART,2 command, described in Appendix B, you can read raw, uncorrected, particle counts. TSI recommends using the

SSTART,2 command for raw counts as then all the information is shipped which is used to calculate the corrected concentration, and there are no issues with the counters ability to accurately count the pulses.

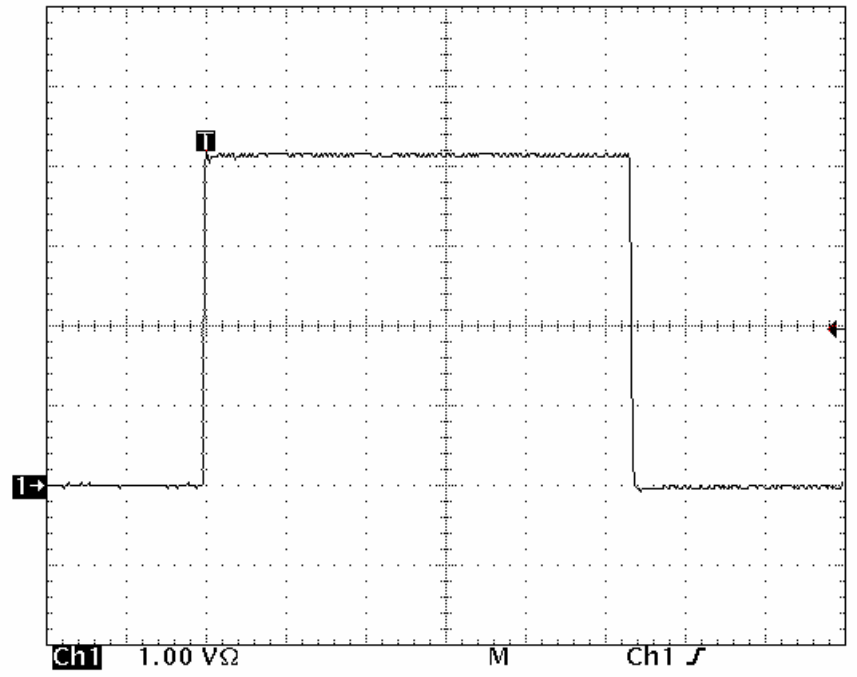


Figure 3-4
Sample Digital Pulse from Pulse Output Port at the Back Panel of the CPC

Ethernet Communication Port

Instrument status including particle concentration of the Model 3772/3771 CPC can be monitored remotely from a local area network or over the internet using the Ethernet communication port. Ethernet communications are described further in Chapter 7, "Computer Interfaces and Commands".

Butanol Fill Port

Butanol is supplied from the butanol fill bottle to the instrument at the Butanol Fill port quick connect fitting.

External Vacuum Port

By attaching an external vacuum to this port, critical flow is established through the critical orifice described in Chapter 5. The flow through this port contains butanol vapor so the external vacuum must be properly vented away from work areas or use

charcoal filter to absorb the butanol vapor. Charcoal filters can be ordered through TSI (P/N 1031492 and P/N 1031493). See Chapter 8 “Maintenance and Service.”

Drain Port

This port is used to drain the working fluid (butanol) from the 5 cm^3 liquid reservoir and is used when collecting water extracted using the Water Removal system. See Chapters 3 and 4 for more on the water removal feature.

Instrument Cooling Fan

This fan cools internal electronics and dissipates heat generated during cooling of the condenser. The fan is provided with a guard and a removable filter that should be cleaned of dust periodically.

Cover

The cover refers to the removable section of the chassis covering the top and sides of the CPC. It is secured to the chassis with four screws on the bottom and two on the top and it can be removed for access to the interior of the Model 3772/3771 CPC. Refer to Chapter 8 for details.

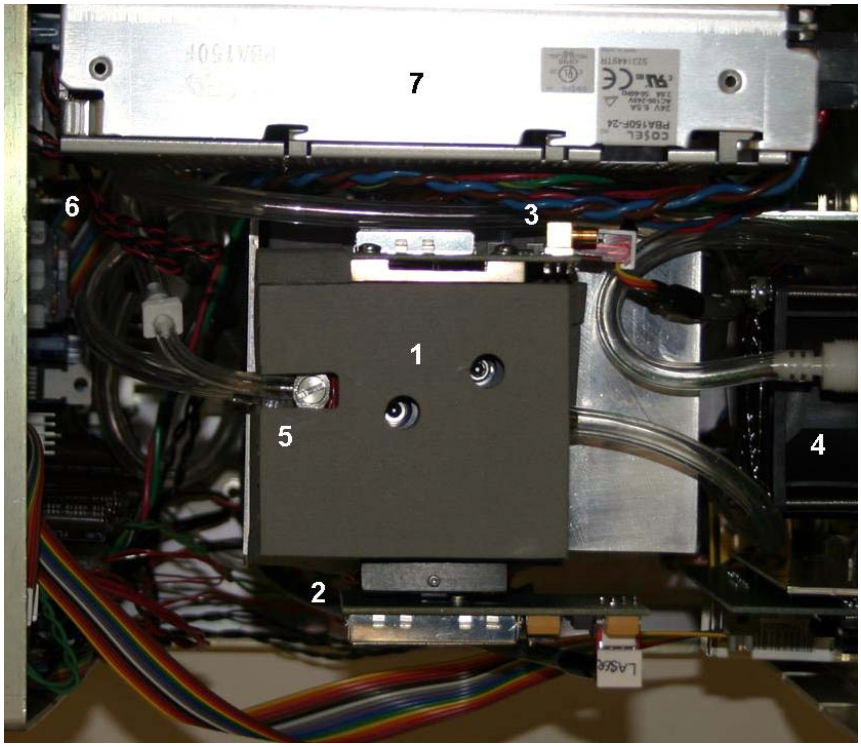
Bottom Panel

The bottom portion of the chassis provides access to the saturator wick. As shown in Figure 3-5, the saturator base, which is attached to the wick, is visible above the centrally located 2.5-inch diameter hole on the bottom panel. The base and wick can be removed for maintenance and transport, as described in Chapter 8.

Figure 3-5
Bottom Panel Showing Removable Saturator Base

Internal Instrument Components

Internal components are described in this section and identified in Figure 3-6 and Figure 3-7.



1. Sensor assembly
2. Water removal pump
3. Butanol fill filter
4. Fan
5. Critical orifice
6. Pressure transducers
7. Power supply

Figure 3-6
Internal Components of the Model 3772/3771 CPC

Water Removal Pump

The Model 3772/3771 CPC uses a micro-flow Water Removal Pump to remove condensate from the condenser. The Water Removal Pump draws condensed butanol and water from the condensate collection reservoir. Water removal prevents contamination of the butanol during operation in a high humidity environment. When activated, the pump runs continuously. A drain bottle must be connected for water removal to occur. For information on operating the water removal pump refer to Chapter 4, "User Settings."

Filters

The CPCs use three liquid filters. One liquid filter is used to filter butanol supplied from the fill bottle while a second filters the butanol drain line. The third is used to filter the condensed water and butanol mixture before it passes through the Water Removal Pump.

Valves

Solenoid fill and drain valves enable butanol to be added or removed from the liquid reservoir. The fill valve is actuated when the Auto-Fill is turned ON and the level sensor indicates a low butanol level in the liquid reservoir. When the butanol fill bottle is connected, butanol flows into the reservoir until the level sensor indicates a full state. On the 3772, the drain valve is activated through the front panel or through serial command. On the 3771, the drain valve is activated through serial command. Butanol is drained prior to shipment or removal of the saturator wick. See "User Settings" in Chapter 4 and "Maintenance and Service" in Chapter 8.

Pressure Transducers

The Model 3772/3771 CPC uses three pressure transducers for monitoring instrument flows. The differential pressure across the Critical Orifice is measured to verify that a critical pressure is maintained across the orifice. Differential pressure across the nozzle is measured and verifies the nozzle in the optics block is free from obstruction. The ambient pressure is also measured. These pressure transducers are mounted to the main PC board. On the 3772, pressure information is viewable via the front panel display. On both 3772 and 3771 CPCs, pressure information is available through serial commands.

Electronics Boards

Four electronics boards identified in Figure 3-7, are used in Model 3772/3771 CPC. The boards include main PC board, laser board, detector board, and communication connector board. The 3772 also includes a fifth board—flash memory board.

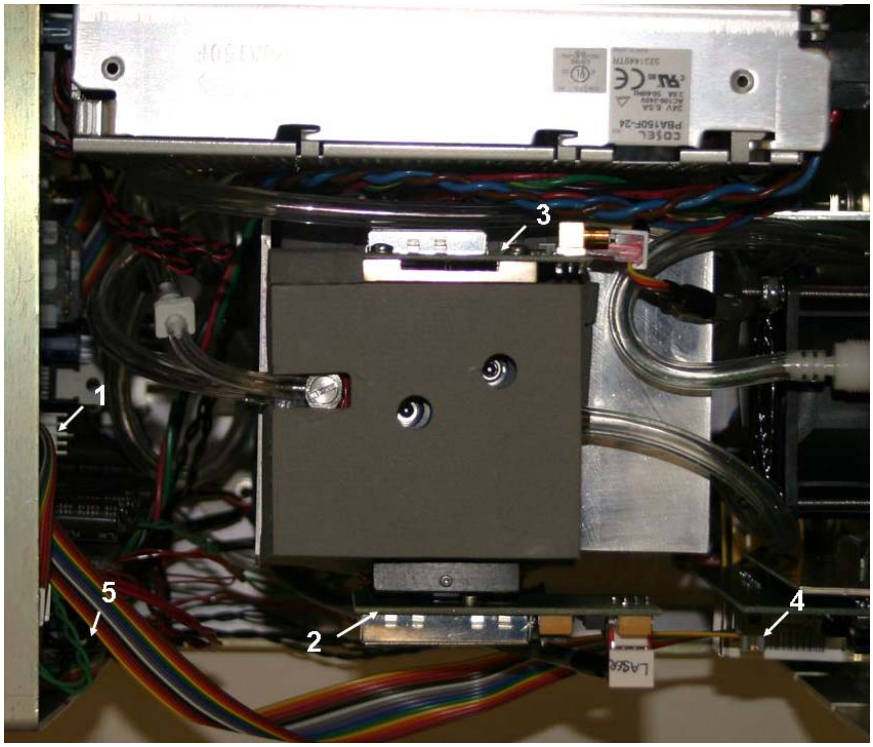


Figure 3-7
Electronics Boards inside the Model 3772/3771 CPC

1. Main PC board
2. Laser board
3. Detector board
4. Communication connector board
5. Flash memory board (3772 only)

Basic Instrument Functions

This section describes basic instrument functions.

Concentration Measurement

Particle concentration is presented as particles per cubic centimeter (p/cc). For the 3772, the particle concentration is displayed on the front panel LCD in numeric form. For both CPCs, data is collected using the Aerosol Instrument Manager software or other terminal program (such as HyperTerminal). Particle concentration is determined from the count rate (particles counted per tenth of a second) and the aerosol flow rate, nominally 1000 cubic centimeters per minute (cm^3/min). The concentration is also live-time corrected for coincidence. Refer to Chapter 6 "Live-Time Counting" for more information.

Total Count Mode (3772 only)

Total Count Mode (also called totalizer mode) counts number of particles in a given time period. This mode is used to improve counting resolution at very low particle concentrations. Time and number of counts are shown on the front panel display of the 3772.

Water Removal

When the aerosol sample has a dew point above the condenser temperature of 22°C, water vapor may condense on the walls of the condenser and run back into the saturator, contaminating the butanol over time. Unlike its predecessor, the Model 3010, 3760A, or 3762 CPC, the Model 3772/3771 CPC is able to capture condensed water vapor and remove it, significantly reducing butanol contamination in high humidity environment. The water removal process increases the butanol consumption. For additional information refer to Chapter 4.

Internal Data Logging (3772 only)

A removable Flash Memory Card can be inserted in the slot on the 3772 front panel to store data including particle concentration and analog input data. Data can then be transferred to a computer for further data processing. Refer to Chapter 4 for more details. It is not recommended you use a Flash Memory Card and Aerosol Instrument Manager software or terminal program to collect data simultaneously to avoid data transfer interference.

Remote Access of Instrument

The Model 3772/3771 CPC provides an Ethernet port to connect the instrument to a network for monitoring status information. Status information includes saturator, condenser, optics temperatures, laser power, and particle concentration, etc. The data is updated once every five seconds. Refer to Chapter 7 for more details.

External Vacuum Pump or Source

The external vacuum pump or source must provide sufficient vacuum to maintain a critical pressure across the critical orifice, while providing an aerosol flow of 1.0 L/min. At an atmospheric pressure of 100 kPa (1 atm), an external pump or other vacuum source must provide at least 60 kPa (18 in. Hg) of vacuum and 1.0 L/min inlet volumetric flow for each CPC supported. TSI offers Model 3032 Vacuum Pump for one CPC and Model 3033 Vacuum Pump for multiple CPCs. Contact TSI technical support for more information on use of an external vacuum pump.

Flow Rate Control

The Model 3772/3771 CPC uses a critical orifice to accurately control the air flow in the instrument. The critical orifice operates at or below a critical pressure to control the 1.0 L/min volumetric aerosol flow. More is found in Chapter 5 "Technical Description."

Problems with the aerosol flow can be detected by monitoring the pressure drop across the nozzle, and verifying that the critical orifice pressure is maintained.

Temperature Control

The temperatures of the condenser, saturator, and optics are maintained at 22 °C, 39 °C, and 40 °C, respectively, with specified ambient temperatures in the operating range of 10 to 35 °C. The temperatures are controlled through feedback circuits on the main electronics board and are viewable via firmware commands. For the 3772, the temperatures are also viewable with the Status display screen. If the temperatures are out of range on either CPC, the status indicator LED on the front panel will be off. For ambient temperatures outside the instrument operating range, the instrument temperature performance may not be maintained. Moderate increases in saturator temperature and optics are tolerated in some instances, depending on measurement requirements.

Inlet Pressure Measurement

With adequate external vacuum, the instrument is capable of operating at inlet pressures in the range of 75 to 105 kPa. The inlet pressure is measured by an absolute pressure sensor, and is essentially the barometric pressure if no inlet restriction is present. Inlet Pressure is accessible through firmware commands on both 3772 and 3771 CPCs and it is also viewable via the Status display screen for the 3772. Refer to Chapter 4 for more details.

CHAPTER 4

Instrument Operation

This chapter describes the basic operation of the Model 3772/3771 Condensation Particle Counter (CPC) and provides information on the use of controls, indicators, and connectors found on the front and back panels.

Operating Precautions

Read the following before applying power to the 3772/3771 CPC:

- ❑ Review the operating specifications for the CPC in Appendix A.
- ❑ Do **not** operate the CPC outside the range of 10 to 35 °C. If the CPC is operated outside this range, the displayed concentration may be inaccurate.
- ❑ If the CPC reservoir contains butanol, be very careful when moving the CPC. Refer to "Moving and Shipping the CPC" for more details.

WARNING
Although the CPC is appropriate for monitoring inert process gases such as nitrogen or argon, it should not be used with hazardous gases such as hydrogen or oxygen. Using the CPC with hazardous gases may cause injury to personnel and damage to equipment.

Power Switch

The power switch is found on the back panel of the CPC. The switch is combined with the power cord receptacle.

Warm-up

When the CPC is turned on, the saturator, condenser, and optics have to reach set operating temperatures. This "warm-up interval" takes about 10 minutes at room temperature. The Status LED indicator on the front panel will remain unlit during this time. Under extremes in ambient temperature, it may take considerably longer for the instrument to warm-up.

On the 3772 front panel display, a countdown is also displayed during the warm-up time, as shown in Figure 4-1.

Figure 4-1
Model 3772 Display During Warm-Up

When warm-up is complete, the concentration is automatically displayed for the 3772 as shown in Figure 4-2. The concentration can also be displayed before the warm-up is complete by pressing the **ESC** key ESC at any time.

Figure 4-2
Model 3772 Display After Warm-Up is Completed

Status Indicator

A status LED indicator on the front panel of the Model 3772/3771 CPC indicates the overall status of the CPC. It will remain unlit if a key parameter falls outside of the acceptable operating range. Parameters monitored include instrument temperatures, pressures, and liquid level. Generally it will light after warm-up time is complete, an external vacuum is applied, and butanol has filled the reservoir. See Chapter 8 for troubleshooting instructions if the Status indicator LED does not turn on.

Particle Indicator

A particle LED indicator light on the front panel of the CPCs indicates particle counts.

Communication

CPC measurement data, instrument status, and user settings are available through firmware communication for both Models 3771 and 3772 and also viewable through the front panel for Model 3772. For more information on firmware communication, see Chapter 7 and Appendix B.

Model 3772 LCD Display and Keypad

In addition to firmware communication, Model 3772 presents measurement data, instrument status, and user settings on a 2-line, 16-character, alphanumeric LCD display. You can navigate the menu options using the six-button keypad. The display and keypad are shown in Figure 4-3.

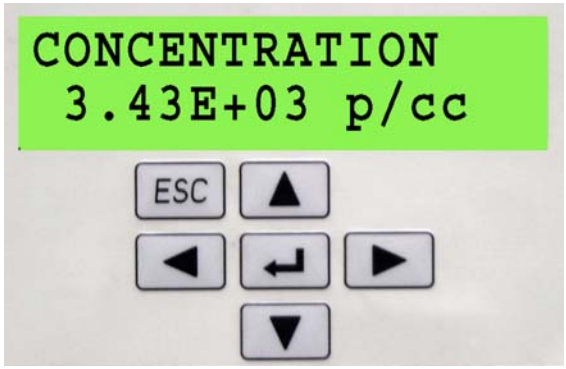


Figure 4-3
Model 3772 Front Panel LCD Display and Keypad

Model 3772 Keypad Navigation

As shown in Figure 4-3, the keypad has six keys: scroll left ◄, scroll right ►, scroll up ▲, scroll down ▼, **Enter** ↵, and **ESC** ESC. Detailed navigation instructions are described below. Generally,

- The up and down arrows are used to scroll through a given menu.
- The left and right arrows are used to configure user settings. The new setting becomes active immediately after the setting is selected.
- The **Enter** ↵ key displays submenus.
- The **ESC** ESC key returns the display out of a submenu.

The control menu has a two-tier hierarchy. There are four primary functions: Concentration, User Settings, Status, and Total Count Mode. By pressing the up ▲ or down ▼ arrow, the display will scroll through these four functions.

Two of the primary functions, User Settings and Status, have submenus. A submenu can be accessed by pressing the **Enter** ↵ key. Once inside a submenu, the up ▲ or down ▼ arrow can be used to scroll through the features. The submenu for User Settings contains all the options for configuring the CPC. The submenu for Status contains all the parameters for monitoring the CPC. The

primary functions are summarized below along with their submenus. These are described in detail in the following sections.

Primary Function	Secondary Submenu
Concentration *Aerosol concentration measured in [p/cc]*	No submenu available.
User Settings *Displays features available for configuration*	Data Logging, Water Removal, Totalizer Time, Auto Fill, Analog Out, Data Averaging, and Drain.
Status *Displays operating parameters and status of CPC*	Saturator Temperature, Condenser Temperature, Optics Temperature, Cabinet Temperature, Ambient Pressure, Orifice Pressure, Nozzle Pressure, Laser Current, Liquid Level, Analog Input 1, Analog Input 2, Flash Status, USB status, Firmware Version
Total Count Mode *Accumulates particle counts and clock time*	No submenu available.

Concentration

The CPC measures aerosol concentration in particles per cubic centimeter. The 3772 displays a Concentration screen as shown in Figure 4-3. This is the default display. Pressing **ESC** ESC twice from any other screen returns the display to Concentration screen. The LCD is updated once per second. For both 3771 and 3772, concentration data can be accessed through firmware communication using "RD" command. Refer to Chapter 7 and Appendix B for more information on firmware commands. The maximum concentration limit for the 3772/3771 is 10,000 particles/cm^3.

When concentration exceeds 10,000 particles/cm^3 for a 3772, two exclamation marks appear on the LCD main display, one in front of the concentration value and one after. For both 3772 and 3771 CPCs, measurements with concentrations that exceed 10,000 are flagged and the status LED will be turned off.

Total Count Mode (3772 only)

Total Count Mode allows particle counts to be accumulated and displayed as shown in Figure 4-4. Total Count Mode is generally useful for tests at very low particle concentrations (e.g., below 10.0 particles/cm^3), such as evaluation of high efficiency filters.

To access Total Count Mode from the default Concentration screen, press the down ▼ arrow once. When first accessed, the display appears as shown in Figure 4-5. By pressing **Enter** ↵, the screen changes to Figure 4-5. Pressing **Enter** ↵ again at this screen will cycle between Start, Stop, and Reset. The CPC will count time and total particles once Start is set. The sample automatically stops when the time is equal to the Totalizer Time. Totalizer Time can be set in the User Setting submenu.

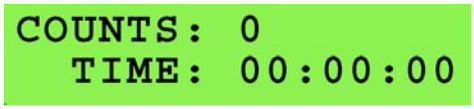


Figure 4-4
Total Count Mode Data Screen

Figure 4-5
Initial Total Count Mode Data Screen

User Settings

User settings can be configured through firmware commands on both 3772 and 3771. Refer to Chapter 7 and Appendix B for information on firmware commands. On the 3772, User Settings is also accessible from the front panel display. It is a primary function accessible from the default Concentration screen by pressing the up arrow ▲ once. The screen appears as in Figure 4-6. Pressing **Enter** ↵ once brings up the submenu. Once inside the submenu, the up ▲ or down ▼ arrow can be used to scroll through a list of configurable settings. To change a setting, use the left ◄ or right ► arrow. The setting takes effect immediately after it is selected. Pressing **ESC** ESC once returns the display to User Settings as shown in Figure 4-6. User settings in the menu are described under individual headings below, beginning with the Data Logging.

Figure 4-6
User Settings Display

Data Logging (3772 only)

Data can be saved on a Flash memory card on the 3772. By default Data Logging is “OFF.” To initiate data logging, switch the Data Logging user setting to “ON” by pressing the left ◄ or right ► arrow once. Logging will begin immediately. Press the arrow again to toggle Data Logging to “OFF” to stop. More information on data logging is provided under “Using the Flash Memory Card.” Use the Data Averaging option in User Settings to set the data averaging interval for data collection.

Water Removal

The Water Removal option provides ON/OFF control for the water removal feature of the CPC. The default setting is “OFF.” On the 3772 it can be set from the Water Removal option in the submenu of User Settings. Pressing the left ◄ or right ► arrow toggles Water Removal system on or off. On either 3772 or 3771 CPC, it can be turned on using the “SAWR” firmware command. See Chapter 7 and Appendix B for information on firmware commands.

Water Removal system is used in hot/humid environments to eliminate contamination of the butanol working fluid by condensed water vapor. Water removal keeps the CPC operating at peak performance.

Water removal is achieved by collecting all condensate from the cooled condenser before it has a chance to return and remix with the butanol in the heated saturator. The collected condensate is pumped to the Drain port and flows into the supplied Drain Bottle.

Important Note: The Drain Bottle must be connected for the water removal system to work properly.

Butanol Consumption	The water removal feature removes condensed butanol as well as water, increasing butanol consumption. The operator may elect not to use water removal in cool/dry environments to preserve butanol. When water removal is not used, butanol is recycled. A full bottle of butanol (1 liter) lasts approximately 7 days with the water removal system ON and last 15 days with the water removal system OFF.

Totalizer Time (3772 only)

The Totalizer Time feature is available from the User Settings submenu. Use this feature with the Total Count Mode function to select the time period for accumulating counts. Three options are available: 1 minute, 60 minutes, and Continuous. The default

setting is “Continuous.” Pressing the left ◄ or right ► arrow will cycle through these three options. Time and count accumulation stops once the time is complete. The accumulation can also be ended manually prior to the end of a sampling period from the Total Count Mode display.

Auto Fill

When the Auto-Fill option is ON, the instrument fills with butanol automatically when the liquid level indicator in the butanol reservoir detects a low butanol level condition. Selecting Auto-Fill OFF prevents the fill valve from opening despite a low butanol level. **Note that a Drain command will turn Auto-Fill to OFF.** Auto-Fill can be turned back on by using the Auto-Fill setting or by restarting the CPC.

On the 3772, an Auto Fill option is available in the User Setting submenu. Pressing the left ◄ or right ► arrow will toggle Auto-Fill ON or OFF. On both 3771 and 3772, Auto-Fill can be set ON or OFF with the “SFILL” firmware command. See Chapter 7 and Appendix B for more information on firmware commands.

Analog Out

The Analog Out setting configures the signal from the “DMA/Analog Output” port on the back panel. This analog signal is from 0 to 10 V. There are five options available to select: OFF, 1E+1, 1E+2, 1E+3, 1E+4. The analog signal is linearly proportional to particle concentration when it is turned on. The relationship between voltage output and particle concentration is listed below.

Option	Concentration Range for Analog Output 0–10 V	Relation
OFF	0 V independent of concentration	-
1E+1	0 to 10 particles/cm^3	linear
1E+2	0 to 100 particles/cm^3	linear
1E+3	0 to 1,000 particles/cm^3	linear
1E+4	0 to 10,000 particles/cm^3	linear
OFF	0 V independent of concentration	-

On the 3772, the Analog Out option is available in the User Settings submenu. Pressing the left ◄ or right ► arrow will cycle through the options. The scaling and OFF options are available to the 3771 and 3772 through the “SAO” firmware command. See Chapter 7 and Appendix B for more information on firmware commands.

Data Averaging (3772 only)

When Data Logging is set to “ON”, data is averaged over selected Data Averaging Period for saving to the flash memory card. The Data Average Periods available are 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, or 60 seconds. By default the Data Average Period is 1 second.

To change the Data Average Period, the Data Logging option first must be set to “OFF.” Then in the Data Average Period display, press the right ▶ or left ◀ arrow to cycle through the available Data Average Periods. When the desired period is displayed, press **ESC** ESC to return to the User Settings screen.

The Aerosol Instrument Manager software provides more choices for data average period. See the software manual for details. It is not recommended you use a Flash Memory Card and Aerosol Instrument Manager software or terminal program to collect data simultaneously to avoid data transfer interference.

Drain

The Drain feature is used as part of the process to drain butanol from the reservoir. It opens the drain valve and turns Auto-Fill mode OFF. When the drain is complete, Auto-Fill must be turned back on by using Auto-Fill setting or by restarting the CPC. For specific instructions on draining butanol, refer to the section “Draining Butanol from the Butanol Reservoir” in Chapter 8.

On the 3772 the Drain feature is available from the User Settings submenu. Pressing the left ◀ or right ▶ arrow toggles Drain ON or OFF. On the 3771 the Drain feature is controlled through the “SDRAIN” firmware command. Refer to Chapter 7 and Appendix B for further information on firmware commands.

Status

Status information provides data from instrument sensors useful to confirm basic performance and for troubleshooting. The Status parameters are described below, beginning with Saturator Temperature.

Status parameters are accessible through firmware commands for both CPCs. Refer to Chapter 7 and Appendix B for further information on firmware commands.

On the 3772, the parameters are also available from the Status menu. To access the Status menu on 3772, start at the default

Concentration screen and press the up ▲ arrow twice. The Status screen appears as shown in Figure 4-7. Press the **Enter** ↵ key to view the submenus for Status. Toggle through submenus (status parameters) with the up ▲ or down ▼ arrow. Pressing **ESC** ESC once returns the display to the Status screen as shown in Figure 4-7. If any of the status parameters deviates from the normal condition, the status light is off and there are two exclamation marks around the parameter: one before and one after, as shown in Figure 4-8.

Figure 4-7
Status Display

Figure 4-8
Status Parameter Display for Diagnostics

Saturator Temp (Temperature)

Saturator temperature is 39.0 °C when the instrument warm up is complete and the instrument has stabilized. The saturator provides saturated butanol vapor that mixes with aerosol particles in the condenser.

Condenser Temp (Temperature)

Particle growth occurs in the condenser as butanol vapor from the saturator is cooled, supersaturated, and condenses on sampled aerosol particles. The condenser temperature is maintained at 22.0 °C.

Optics Temp (Temperature)

The optics temperature is maintained at 40.0 °C. This is above the saturation temperature and prevents butanol from condensing on the lenses and other internal components in the particle detection optics.

Cabinet Temp (Temperature)

The cabinet temperature measures the temperature inside the CPC.

Ambient Pressure

Ambient pressure is the barometric air pressure in kPa. Inlet air pressure is very close to the barometric pressure when sampling directly from the ambient environment. A restriction at the inlet will change the inlet air pressure. The instrument is designed to operate with an inlet pressure between 75 and 105 kPa.

Orifice Pressure

Orifice pressure is the differential pressure across the aerosol flow critical orifice in kPa. Identification of the orifice is found in the flow schematic Figure 5-1.

Nozzle Pressure

Nozzle pressure is the differential pressure across the nozzle between the condenser and the optics chamber in kPa. Identification of the nozzle is found in the flow schematic Figure 5-1.

Laser Current

Laser power is monitored by an internal detector in the diode laser package. If laser light energy drops and the laser current is below 35 mA, an Error is indicated and the Status light is OFF.

Liquid Level

FULL is indicated if adequate butanol is present in the liquid reservoir. Liquid level is detected by a heated RTD (Resistance Temperature Detector) level detector. If the liquid level is low, NOT FULL is indicated.

Analog Inputs

Analog Input 1 and 2 display voltages supplied to the BNC connectors at the back panel of the instrument. These analog data inputs have a range of 0 to 10 volts. Voltages can come from a variety of sources at the operator's discretion. Signals should be gained up or down so the outputs fall into the 0-to-10-volt window with maximum resolution. On both 3772 and 3771 CPCs, analog input data is saved along with concentration data through firmware commands or to a computer running Aerosol Instrument Manager software. On the 3772 analog input data can also be saved to the Flash Memory Card when a card is present and data logging is ON.

Flash Status (3772 only)

When a flash memory card is present, READY is indicated. When a flash memory card is present and data logging is ON, LOGGING is indicated. When there is not a flash memory card, REMOVED is indicated. See more details below.

USB Status

When the USB port on the back panel of the 3772/3771 CPC is connected, the status indicates CONNECTED. The status indicates DISCONNECTED when there is no connection to the USB port.

Firmware Version

This option shows the current firmware version of the instrument.

Using the Flash Memory Card (3772 only)

Particle concentration data and analog input data can be saved to a Flash Memory Card inserted in the slot at the middle right of the front panel. Insert the card with the label facing right.

Data logging is initiated (turned ON) from the front panel under the User Settings Menu. A file having a .DAT extension is created and will sample one hour of CPC data. Additional files will be created automatically each hour, i.e., having one hour of data. A shorter file is created if the test is stopped by turning Data Logging OFF. Data is lost if an open file is improperly closed, by turning the instrument off or removing the flash memory card.

To read saved data to computer, connect the supplied card reader to your computer using the USB cable. Insert the flash card in the reader. Your computer will recognize the card reader and display a window showing several options. Select the option **Open folder to view files** to access the test files on the installed memory card. The file names are based on the date and time when the test was initiated.

The Aerosol Instrument Manager® software described below retrieves files from the flash memory card for data display. Refer to your Aerosol Instrument Manager software instruction manual for information on importing .DAT data files.

Additional technical information on the flash memory card is found in Chapter 7.

Notes: *Data cannot be saved to the flash memory card and to the computer through Aerosol Instrument Manager software simultaneously.*

Keep the amount of data stored in the flash memory card under 64 MB to avoid long overhead time before generating a new data file each hour in the card.

Caution

Remove the flash memory card following the correct procedures:

1. Use *Safely Remove Hardware* option in Windows to disconnect the card reader from the computer—stop USB Mass Storage Device.
2. After the message *Safe To Remove Hardware: The "USB Mass Storage Device" device can now be safely removed from the system* appears, physically remove the flash memory card from the card reader.

Failure to follow these procedures may result in failure to log data with the flash memory card.

Aerosol Instrument Manager® Software

Aerosol Instrument Manager® software is supplied with the 3772/3771 CPCs. This program provides many useful data acquisition, display, processing, and download functions used in particle measurements. Review the supplied Aerosol Instrument Manager software manual for complete information on software functions.

Moving and Shipping the CPC

Make sure the Model 3772/3771 CPC is turned off and remains upright while moving the instrument. There is no need to drain the CPC before moving the CPC. Prior to shipping, however, it is necessary to drain butanol from the instrument and to dry the instrument. Refer to "Draining Butanol from the Butanol Reservoir" in Chapter 8 to drain the CPC. Remove the saturator wick to expedite the drying process. The Model 3772/3771 CPC was designed so that the wick is easily removed. Refer to "Removing and Installing the Saturator Wick" in Chapter 8. To dry the instrument without taking the wick out, run the CPC continuously with vacuum on at least overnight. During drying, place a HEPA filter at the inlet. It may take up to 20 hours to completely dry the instrument so the particle concentration reads zero.

TSI recommends that you keep the original packaging (carton and foam inserts) of the CPC for use whenever the CPC is shipped, including when it is returned to TSI for service. Always seal off the

sampling inlet to prevent debris from entering the instrument and drain and dry the CPC before shipping.

Caution
With the vacuum on and butanol in the reservoir, do **not** tip the counter more than 10° in any direction. It is recommended to turn off the CPC and disconnect the butanol fill bottle before the CPC is being moved or tilted for longer than a few seconds to prevent flooding the sensor.

CHAPTER 5

Technical Description

The Model 3772/3771 CPC is a continuous-flow condensation particle counter that detects particles as small as 10 nanometers (50% detection efficiency) in diameter. This section describes the function of the CPC, its subsystems and its components. A discussion of operation theory and history is given first.

Theory

The CPC acts very much like an optical particle counter. However, the particles are first enlarged by a condensing vapor to form easily detectable droplets. The science behind the counter, therefore, is focused on how to condense the vapor onto the particles. Portions of the following discussion are taken from a paper by Keady et al. [1986].

When the vapor surrounding particles reaches a certain degree of supersaturation, the vapor begins to condense onto the particles. This is called *heterogeneous* condensation. If supersaturation is too high, condensation can take place even if no particles are present. This is referred to as *homogeneous nucleation* or *self-nucleation,* whereby molecules of the vapor form clusters due to the natural motion of the gas and attractive van der Waals forces to form nucleation sites. This condition is avoided by accurately controlling operating temperatures. The CPC operates below the supersaturation ratio to avoid homogenous nucleation.

The degree of supersaturation is measured as a saturation ratio (P/P_s), which is defined as the actual vapor partial-pressure divided by the saturation vapor pressure for a given temperature:

$$\text{supersaturation} = \frac{P}{P_s}$$

For a given saturation ratio, the vapor can condense onto particles only if they are large enough. The minimum particle size capable of acting as a condensation nucleus is called the *Kelvin diameter* and is evaluated from the following relationship:

$$\text{saturation ratio} = \frac{P}{P_s} = \exp\frac{(4\gamma M)}{\rho RTd}$$

where γ = surface tension of the condensing fluid
M = molecular weight of the condensing fluid
ρ = density of the condensing fluid
R = universal gas constant
T = absolute temperature
d = Kelvin diameter

The higher the saturation ratio, the smaller the Kelvin diameter.

The saturation vapor pressure P_s is defined for a flat liquid surface. For a round liquid surface, such as the surface of a droplet, the actual saturation vapor pressure is greater. In other words, the smaller the droplet, the easier it is for the vapor molecules to escape the liquid surface. The Kelvin diameter defines the critical equilibrium diameter at which a pure droplet is stable—there is neither condensation nor evaporation. Smaller liquid particles will evaporate and larger particles grow even larger by condensation. The larger particle will grow until the vapor is depleted, causing the saturation ratio to fall until it is in equilibrium with the particle droplet.

If the saturation ratio is controlled to a level below the critical saturation ratio—the point at which homogeneous nucleation takes place—condensation will not take place in a particle-free environment.

The lower size sensitivity of the counter is determined by the operating saturation ratio. For the counter this ratio is several hundred percent, whereas in the atmosphere, this ratio is only a few percent for water.

History

Historically, the counter has been called a condensation nucleus counter (CNC). CNC technology uses three techniques to cool and supersaturate the condensing vapor: adiabatic expansion, two-flow mixing, and diffusional thermal cooling. The Model 3772/3771 CPC uses the latter.

Adiabatic Expansion CNC

The first CNC was developed over a century ago by John Aitken [1888]. His simple and completely mechanical device cooled water-saturated air by adiabatic expansion using a pump. The droplets were counted as they fell onto a counting grid and a calculation was made to determine the concentration of dust particles in the sample

volume. He made several improvements to his invention and his portable dust counter was used for many years (Aitken [1890–91]).

Other significant developments in adiabatic-expansion CNCs include the use of electrical photodetectors to measure the light attenuation from cloud formation (Bradbury and Meuron [1938], Nolan and Pollak [1946], Rich [1955], Pollak and Metneiks [1959]); the use of under- and overpressure systems; and automation using electrically controlled valves and flow systems. The amount of light attenuated from the droplet cloud is monotonically related to the concentration of particles and is calibrated either by manual counting techniques, calculated from theory of particle light-scattering, or by using an electrical classification and counting method (Liu and Pui [1974]). A historical review of the expansion CNCs is given by Nolan [1972], Hogan [1979], and Miller and Bodhaine [1982].

Two-Flow Mixing CNC

Another cooling method turbulently mixes two vapor-saturated flows, one hot and one cold, to rapidly cool and supersaturate the vapor (Kousaka et al. [1982]). The condensation and droplet growth are fairly rapid and uniform. The flows can be passed continuously (that is, non-pulsating) through the mixing chamber onto a single-particle-counting optical detector.

Diffusional Thermal CNC

A continuous-flow, diffusional, alcohol-based, thermal-cooling CNC (Bricard et al. [1976], Sinclair and Hoopes [1975], Agarwal and Sem [1980]) first saturates the air sample with alcohol vapor as the sample passes over a heated pool of liquid alcohol. The vapor-saturated air stream flows into a cold condenser tube where the air is cooled by thermal diffusion. The alcohol condenses onto the particles and the droplets grow to about 10 to 12 micrometers. The droplets are counted by a single-particle-counting optical detector.

Continuous-flow, diffusional, water-based CPCs (TSI Model 3781, 3782, 3785, and 3786 WCPCs) were developed between 2003 and 2006. Using a patented technique (Technology from Aerosol Dynamic Inc., U.S. Patent No. 6,712,881), an aerosol sample is drawn continuously through a cooled saturator and then into a heated condenser, where water vapor diffuses to the centerline of the condenser faster than heat is transferred from the warm walls, producing supersaturated conditions for water vapor condensing onto the particles.

Model 3760, 3762, and 3010 was introduced in early 90s and was replaced by Model 3772/3771 in 2005. Both the 3772/3771 CPC and the 3782 WCPC work only in the single count mode at relatively high aerosol flow rates of 1.0 and 0.6 L/min respectively. The 3772/3771 CPC uses n-butyl alcohol as the working fluid and an external vacuum pump or source to drive the 1 L/min aerosol flow rate. The 3782 WCPC uses water as the working fluid and uses an internal vacuum pump to drive the 0.6 L/min aerosol flow. Both 3772/3771 and 3782 can detect 10 nm particles at 50% detection efficiency. The 3782 can also be set to have a D_{50} of 20 nm.

For high-concentration measurements, a classical photometric light-scattering technique is used. The first commercial version of this type of CNC (TSI Model 3020) used n-butyl alcohol as the condensing fluid and has a flow rate of 0.3 L/min. TSI's Model 3020 CNC was replaced in 1988 by the Model 3022A, which was replaced again in 2005 by the Model 3775 CPC. Both the Model 3775 CPC and the 3785 WCPC use the photometric mode of operation to monitor high particle concentrations up to 10^7 particles/cm^3. These CPCs are general-purpose instruments suitable for a wide variety of applications.

The Model 3025 Ultrafine Condensation Particle Counter (UCPC) was developed in 1989 and was replaced by the Model 3776 UCPC in 2005. The 3776 has a lower size detection limit and a higher aerosol flow rate compared to the 3025A. Both the 3776 UCPC and 3786 UWCPC utilize sheath-air-flow design to lower the size detection limit. When growing the particles in the condenser chamber, the highest saturation ratio occurs on the centerline of the flow stream at some distance down the condensing tube (Stolzenburg [1988]). Although the saturation ratio is not uniform across the flow profile due to thermal gradients, the lower size-sensitivity can still be predicted and measured. Using sheath air, the UCPC confines the aerosol to the centerline of the condenser tube where level of supersaturation is the highest. The result is very high detection efficiency for small particles. The high sensitivity of the Model 3776 UCPC and the Model 3786 UWCPC makes them the only instruments of their kind that can detect particulates down to 2.5 nm. This makes them useful for atmospheric studies, nucleation, cleanroom monitoring, and basic aerosol research, etc. The sheath-air-flow design of the two CPCs also significantly reduces the response time for particle detection and particle diffusion losses. This occurs because aerosol particles are routed directly from the inlet to the condenser and optics, not through the saturator.

The Model 3781 WCPC is a small size and light weight instrument that detects particles down to 6 nm and operates in single count mode for concentrations up to 5×10^5 particles/cm^3.

The Model 3007 CPC was developed in 2001. It is a hand-held, battery powered instrument with a size detection limit of 10 nm. It uses isopropyl alcohol as the working fluid.

Currently, six CPCs (Models 3772, 3775, 3776, 3782, 3785, and 3786) are also commonly used with submicron size-distribution measurement systems such as the Scanning Mobility Particle Sizer™ (SMPS™) Spectrometers (TSI Model 3936).

Design of the CPC

The basic instrument consists of three major subsystems: the sensor, the microprocessor-based signal-processing electronics, and the flow system. The sensor and the flow system are described below.

Sensor

The sensor is made up of saturator, condenser, and optical detector, shown schematically in Figure 5-1. The sensor grows the sampled aerosol particles into larger droplets and detects them optically. The laminar aerosol flow enters the saturator section where it passes through a heated, liquid-soaked cylindrical wick. The liquid evaporates and saturates the air flow with butanol vapor. Butanol is replenished from a reservoir and a fill bottle.

The flow of combined aerosol and butanol vapor is then cooled using a thermoelectric device (TED) in the condenser. The vapor becomes supersaturated and condenses on the aerosol particles (condensation nuclei) to form larger droplets. The droplets pass from the condenser tube through a nozzle into the optical detector. Liquid that condenses on the walls of the condenser tube runs back down and is removed by the water removal system into the drain bottle when the system is ON. Otherwise, the liquid goes back into the saturator and is absorbed into the wick for reuse.

The sensor's optical detector is comprised of a laser diode, collimating lens, cylindrical lens, collection lenses, and photodiode detector. The laser and collimating lens form a horizontal ribbon of laser light above the aerosol exit nozzle. The collection lenses and detector incorporate a pair of aspheric lenses that collect the light scattered by the droplets and focus the light onto a low-noise photodiode. A reference photodiode is used to maintain constant laser power output. The surface temperature of the optics housing is maintained at a higher level than the saturator to avoid condensation on the lens surfaces.