

Model 3022A Condensation Particle Counter

Instruction Manual

*P/N 1933763, Revision I
August 2002*





Model 3022A Condensation Particle Counter

Instruction Manual

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Manual History

The following is a manual history of the Model 3022A Condensation Particle Counter Instruction Manual (Part Number 1933763).

Revision	Date	Revision	Date
Preliminary	October 1992	E	November 1996
Final	November 1992	F	March 1998
A	January 1993		September 1998
B	December 1993	G	July 2000
C	June 1994	H	July 18, 2000
D	May 1996	I	July 2002

- The Model 3022A Condensation Particle Counter instruction manual (P/N 1933763) was originally published as a Model 3022 Condensation Particle Counter (P/N 1933022) in September 1988. Changes have been made throughout the manual to reflect the model number and engineering changes.
- Revision A reflects changes to the table in Chapter 4, a new safety label, inclusion of ampere ratings (Figure 3-2 and “Specifications”), and some minor corrections throughout the manual.
- Revision B includes a revision to Table 2-1, changes amount of particles from 0.01 to .007 on page 1-1, revises the Customer Service telephone number, and updates drawing 9060266 in Appendix D to Revision F.
- Revision C adds Figure 7-1 showing the setup for photometric calibration mode, revises Figure 9-6, and revises schematic 9060265.
- Revision D updates TSI’s “Limitation of Warranty and Liability” on page iii.
- Revision E adds European Community “CE Mark” standards, revisions to Chapter 2, “Changing the Line Voltage Configuration” and “Changing Fuses,” updates drawing 9060266 in Appendix D to Revision I, and minor changes were made to rest of manual.
- Revision F revises minimum particle size from .008 μm to .007 μm in Table B-1.
- In September 1998, TSI’s area code was changed from 612 to 651.
- In Revision G, the fuse rating in Table B-1 was corrected to read 100/120V ~ 2.0A/250V.
- In Revision H, TSI’s Limitation of Warranty and Liability was updated.
- In Revision I, TSI’s phone numbers and address were updated and reference to *CPCCount Software* was changed to refer to *Aerosol Instrument Manager Software for CPC and EAD*. Appendix D was removed.

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(effective July 2000)

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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 gives instructions to promote safe and proper operation of the Model 3022A Condensation Particle Counter (CPC), samples of warnings found in this manual, and labels attached to the instrument.

Laser Safety

The Model 3022A Condensation Particle Counter 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 invisible 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 housing while power is supplied to the instrument.



W A R N I N G
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 3022A 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.
- 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

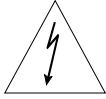





W A R N I N G

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.

Figure 1 shows the internal and external labels for the Model 3022A CPC.

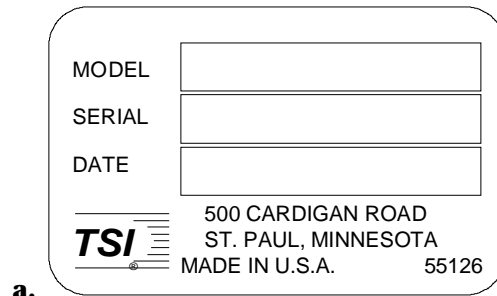


Figure 1

Advisory Labels: (a) identification label (on the back panel); (b) warning label (on the optics housing)

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About This Manual

Purpose

The Model 3022A Condensation Particle Counter (CPC) instruction manual is written for both the installer and the operator, whether a technician or the head of a research laboratory.

Organization

The ten chapters of this manual describe the CPC and explain how to set up, operate, and maintain it.

- ❑ **Chapter 1: Introduction**
This chapter serves as an introduction to the Model 3022A Condensation Particle Counter.
- ❑ **Chapter 2: Unpacking and Setting Up**
This chapter describes the step-by-step procedure for getting the CPC ready to operate.
- ❑ **Chapter 3: Operation and Display**
This chapter describes all of the features and controls that run the CPC, including the front-panel functions and controls, the back-panel components, and some operating specifications and precautions.
- ❑ **Chapter 4: Configuring the CPC**
This chapter describes a feature that allows you to set up and select certain functions and outputs controlled by the internal microprocessor. Read this chapter to learn how to enter into the configuration mode.
- ❑ **Chapter 5: Technical Description**
This chapter details the principle of operation and theory of the condensation nucleus counter.
- ❑ **Chapter 6: Particle Counting**
This chapter describes how the CPC counts and averages data, and displays the particle concentration.

- ❑ **Chapter 7: Calibrating the CPC**
This chapter describes the method used at TSI for calibrating the CPC's photometric particle concentration mode.
- ❑ **Chapter 8: Computer Interface and Commands**
This chapter describes the computer interface hardware and associated software commands. Included is a simple program written in BASIC that demonstrates how to communicate with the CPC.
- ❑ **Chapter 9: Maintenance and Service**
This chapter describes the recommended practices and schedule for routine cleaning, checking and calibration.
- ❑ **Chapter 10: Applications**
This chapter describes some typical applications of the CPC including the Differential Mobility Particle Sizer (DMPS), Diffusion Battery, and filter testing.
- ❑ **Appendix A: References**
This appendix 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 or particle counters is included.
- ❑ **Appendix B: Specifications**
This appendix lists the specifications of the Model 3022A Condensation Particle Counter.
- ❑ **Appendix C: Technical Papers**
This appendix includes two technical papers.
- ❑ **Appendix D: Calibration and Data Sheets**
This appendix contains calibration and data sheets used for the Model 3022A CPC.
- ❑ **Appendix E: Software Disks**
This appendix contains the software disks for the BASIC program provided with the Model 3022A CPC.

Related Product Literature

- ❑ **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 3022A CPC. 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 data collected by a CPC.

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 send your comments to:

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Particle Instruments
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St. Paul, MN 55126
Fax: (651) 490-3824
E-mail Address: particle@tsi.com

CHAPTER 1

Introduction

The Model 3022A Condensation Particle Counter, shown in Figure 1-1, measures the number concentration of submicrometer airborne particles larger than 0.01 micrometer in diameter.

Product Description

The particles are detected and counted by a simple optical detector after a supersaturated vapor condenses onto the particles, causing them to grow into larger droplets. The range of detection is wide, from less than $.007$ particles/cm³ to 9.99×10^6 particles/cm³.



Figure 1-1
TSI Model 3022A Condensation Particle Counter

The Model 3022A offers a laser-diode light source, an internal microprocessor control, the capability of full computer interfacing, a long-life pump, volumetric flow control, and a front panel display of both the concentration and instrument status.

Features

The Condensation Particle Counter (CPC) is an improved version of TSI's earlier Model 3020 and 3022 CPCs with these features:

- New color and graphics
- New membrane switches on the front panel
- New mounting for the display PC board to make it easy to replace an EPROM
- New transformer and internal electrical changes to meet IEC 1010 specifications
- New standard RS-232 connector for IBM-style compatibility.

Applications

The Model 3022A CPC is a general-purpose instrument that can be used in a wide variety of applications.

Typical applications include:

- Basic aerosol research
- Outdoor and indoor air-quality research
- Filter, material, and component testing
- Particle formation and growth studies
- Atmospheric studies
- Particle counter calibration (when used as the reference).

The CPC can also be used as a particle detector in the scanning mobility particle sizer (SMPS) system or the differential mobility particle sizer (DMPS) system, and with a diffusion battery.

CHAPTER 2

Unpacking and Setting Up

This chapter gives unpacking and setup information for the Model 3022A Condensation Particle Counter (CPC).

Packing List

Table 2-1 shows the packing list for the Model 3022A CPC.

Table 2-1
Model 3022A CPC Packing List

Qty.	Description	Part No.
1	CPC sensor	302201
1	Power cable, 110–120V	1303053
	220–240V	1303075
1	12 foot 9-pin (M/F) interface cable	962002
1	Cable adapter 25-pin (F) to 9-pin (M)	962003
1	Nylon plug	1601834
1	Inlet tube, side, 2.8 inches	1503450
1	Inlet tube, back, 5.2 inches	1503452
1	Bottle bracket	1503475
2	Screw, 8-32 × ³ / ₈ , Phillips pan-head	5094090
2	Washer, no. 8 internal tooth	5329031
1	Fill bottle assembly (tested)	1035590
1	Drain bottle assembly (tested)	1035591
1	Filter media for fan	1602071
2	Tube filter	1602061
1	Pump exhaust filter	1602080
1	Instruction manual	1933763
1	Software disk, 3.5-inch format	1905118

Unpacking Instructions

The Condensation Particle Counter comes fully assembled with protective coverings on the Inlet and Liquid Drain ports and electrical connections.

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 9, “Maintenance and Service,” gives instructions for returning the CPC to TSI Incorporated.

Initial Setup

This section contains instructions for initial setup of the Model 3022A CPC. Follow the instructions in the order given.

Protective Caps

Remove all protective caps from the inlet and exit flow ports, as well as from the BNC connectors.

Checking the Line Voltage Configuration

The Model 3022A requires 100/120 volts AC at 1.2 amps or 230/240 volts AC at 0.6 amp with 50 to 60 hertz at any of the voltages. Use the information in this section to verify the line voltage configuration and fusing arrangement matches your local line voltages.

Check the back panel of the instrument for the voltage and fusing requirements. The label is located just above the power entry module.

To change the voltage setting, follow these steps:

- 1.** Disconnect the power from the Model 3022A and remove the line cord. Locate the power-entry module on the back panel of the Model 3022A (Figure 2-1).*
- 2.** Lift off the cover of the fuse and voltage module cover on the back panel of the Model 3022A using a small-blade screwdriver or similar tool (Figure 2-1). Set aside the cover/fuse block assembly.

*Drawings reprinted by permission of Corcom Incorporated, Libertyville, Illinois.

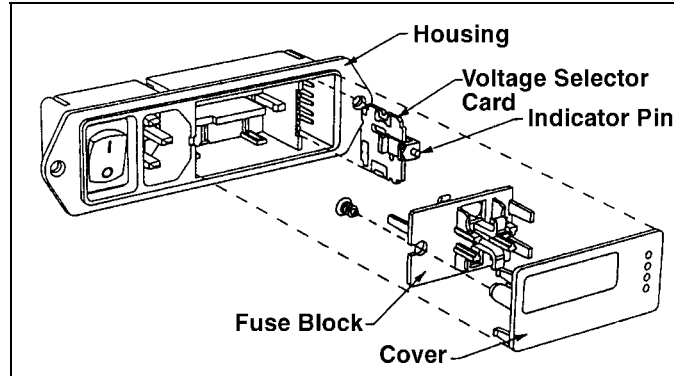


Figure 2-1
Power Entry, Fuse, and Voltage Module

3. Grasp the indicator pin and pull the voltage-selector card straight out of the housing (Figure 2-1).
4. Orient the selector card so that the desired voltage is readable at the bottom.
5. Orient the indicator pin so that it points up when the desired voltage is readable at the bottom. When the pin is fixed and in place, rotate the card 90° clockwise (Figure 2-2).

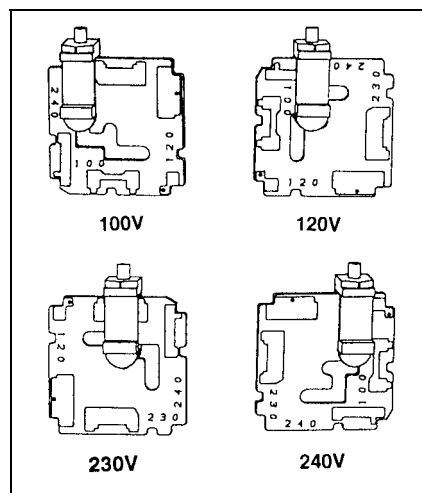


Figure 2-2
Orientation of the Voltage Selector Card

6. Insert the voltage-selector card into the housing, making sure the edge containing the desired voltage is inserted first and the printed side of the card faces the IEC (power cord) connector.
7. Replace the cover, making sure that the indicator pin shows the desired voltage.

Changing the Fuse

1. Disconnect the power from the Model 3022A and remove the line cord.
2. Lift off the power-entry module on the back panel of the Model 3022A using a small-blade screwdriver or similar tool (Figure 2-1).
3. Replace the fuses. Make sure the Fuse(s) are the proper size and rating for the line voltage you are using. The Fusing label is located just above the power entry module on the back panel of the Model 3022A.

Note: *Two European-style 5 × 20 mm fuses are required in the European-Fusing arrangement (Figure 2-4).*

4. Replace the power-entry module cover.

Changing Between European and American-Style Fuses

Before installing the Model 3022A, make sure the fuse is compatible with your site. The Model 3022A works with both North American and European-style fuses. The 100/120-volt model comes with the North American-style fuse and the 230/240-volt model is equipped with the European-style fuse. If you need to change the fuse from North American (Figure 2-3) to the European style (Figure 2-4), or vice versa, follow these steps:

1. Disconnect the power from the Model 3022A and remove the line cord.
2. Lift off the power-entry module on the back panel of the Model 3022A cover using a small-blade screwdriver or similar tool.

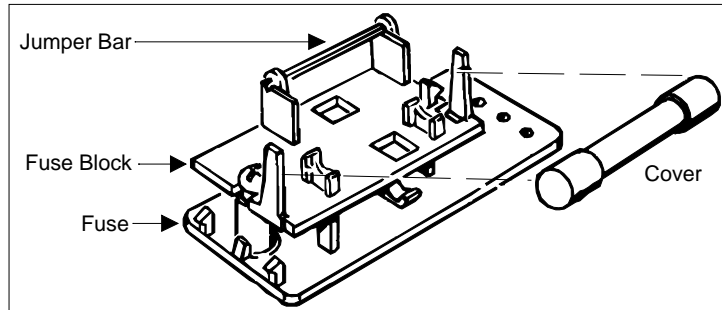


Figure 2-3
North American–Fusing Arrangement

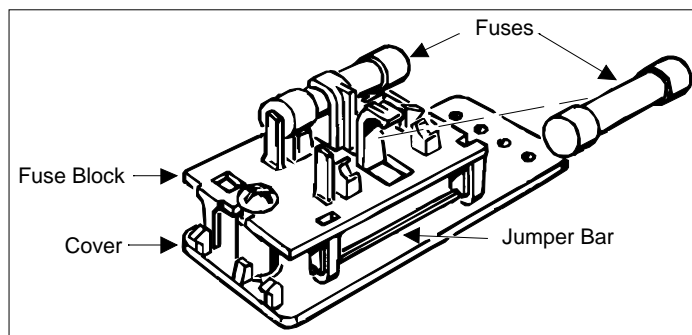


Figure 2-4
European–Fusing Arrangement

3. Loosen the screw on the fuse block two turns.
4. Remove the fuse block (Figure 2-5) by sliding it up and away from the screw. Lift the block from the pedestal.

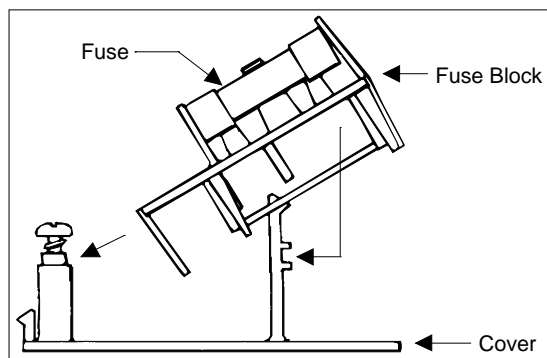


Figure 2-5
Fuse Block/Cover Assembly

5. Change the fuses:

Note: Two European 5 × 20 mm fuses are required in the European-Fusing Arrangement.

Invert the fuse block and slide it back onto the screw and the pedestal.

6. Tighten the screw and replace the power-entry module cover. The fuse(s) that enters the housing first is the active one.

Mounting the Bottle Bracket

Mount the black anodized aluminum bracket (found in the accessory kit) to the back panel using two 8-32 × 3/8-inch screws and two no. 8 lockwashers as shown in Figure 2-6.

Place the fill bottle in the bracket (also found in the accessory kit with tubing and a quick-disconnect fitting). Connect the fitting to the Liquid Supply connector on the back panel. Both mated fittings are leak-tight when disconnected.



Figure 2-6

Mounting the Bottle Bracket: (a) Bottle Bracket; (b) Screw, 8-32 × 3/8 Phillips Pan-head Lockwasher, #8 Internal Tooth; (c) CPC Back Panel

Filling the Bottle with Fluid

Pour the fluid into the fill bottle to at least one-third full. Because of the shut-off fittings, the liquid will not flow into the CPC until the connections are made and the instrument is warmed up.

The standard CPC uses butanol as a working fluid. Use reagent-grade n-butyl alcohol (commonly referred to as “butanol”) to refill the instrument.

Note: *Butanol is not supplied with the CPC. Butanol may be purchased from scientific chemical-supply houses.*



C a u t i o n

Butanol is flammable. It 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.

Changing the Inlet

The inlet of the CPC can be moved to allow sampling from the back panel, the front panel, or the side of the cabinet. When shipped, the CPC is configured to sample from the front panel.

The shortest, most direct aerosol path is from the side of the cabinet. This configuration minimizes particle loss due to impaction or diffusion. If you are using the low-flow mode and sampling from the cabinet’s side, you may eliminate the T fitting and replace it with a connecting fitting to eliminate the dead air trapped in the bypass flow tube. The connecting fitting is not included in the accessory kit and must be purchased separately.

To change the location of the inlet, follow these four steps.

- 1.** Remove the top and bottom covers of the cabinet: first, remove the twelve black screws (six on each side). Then lift the top cover off of the sensor. Next, lift up the sensor by the side handles and move it away from the bottom cover. Remove the handle on the inlet side of the instrument by loosening the four securing screws.

2. Loosen the Swagelok® nuts connected to the CPC's inlet tube as well as the saturator inlet tube (see Figure 2-7). Remove the CPC's inlet tube by sliding it through the front panel.

Note: *It is not necessary to remove the nuts, as shown in Figure 2-7. Just loosen the nuts to avoid losing them.*



Figure 2-7
Removing the Front Inlet Tube; (a) Pull Inlet Tube Out; (b) Loosen Swagelok Nuts, 2 Places

3. Reconfigure the tubes, found in the accessory kit, according to Figures 2-8a through 2-8d. Tighten the fittings finger-tight, then ¼-turn with a wrench.

For Figures 2-8c and 2-8d: To use the side inlet, install the bottom cover, insert the 2.8-in. insert tube, and then tighten the Swagelok nut.

4. Replace the top and bottom of the cabinet and secure with 12 screws.

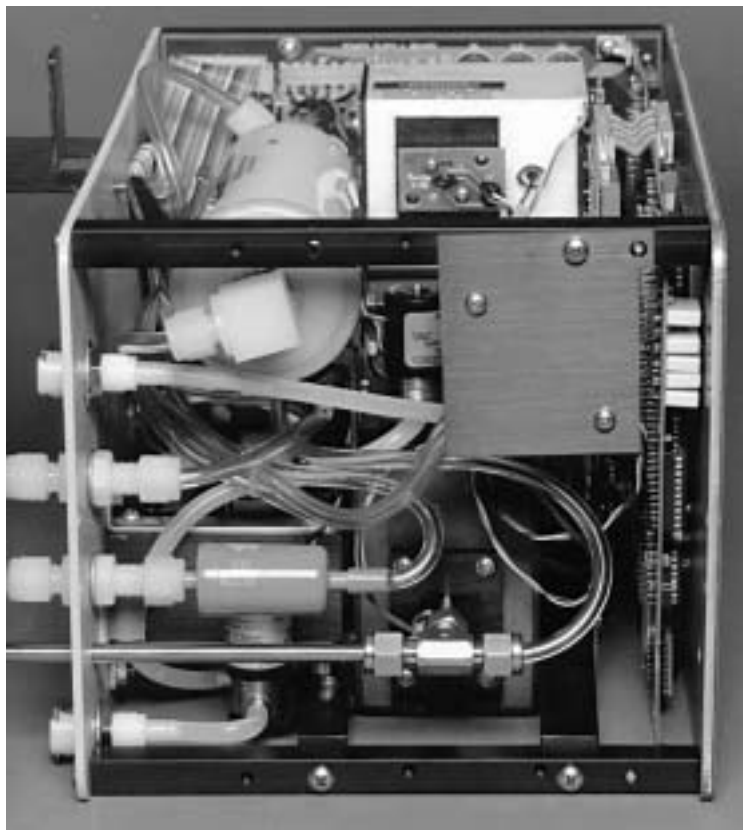


Figure 2-8a
Back Inlet Option for Positioning the Inlet Tube



Figure 2-8b
Front Inlet Option for Positioning the Inlet Tube



Figure 2-8c
Side Inlet Option for Positioning the Inlet Tube



Figure 2-8d
Side Inlet Option with the 2.8-in. Inlet Tube

Applying Power to the CPC

Plug the power cord into the connector on the back panel and then plug it into the AC power source.

Note: *Make certain the power cord is plugged into a grounded power outlet. Position the UCPC so the appliance coupler is easily accessible.*

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

The front panel now displays the phrase “TSI” and begins a warmup sequence. After warm-up, the fluid begins to fill the internal reservoir in the saturator. The CPC is nearly ready to start making measurements.

CHAPTER 3

Operation and Display

This section describes the basic functions of the Model 3022A Condensation Particle Counter (CPC) controls, indicators, and connectors on the front and back panels as well as giving operating specifications and precautions.

Note: *Specific applications for the CPC are covered in Chapter 10.*

Front Panel Functions

The front panel, shown in Figure 3-1, provides information on particle concentration, particle counts, and the status of various operations. It provides access to three types of functions through pushbuttons: primary functions, secondary functions, and configuration functions. (The configuration functions are a special case, described in Chapter 4).

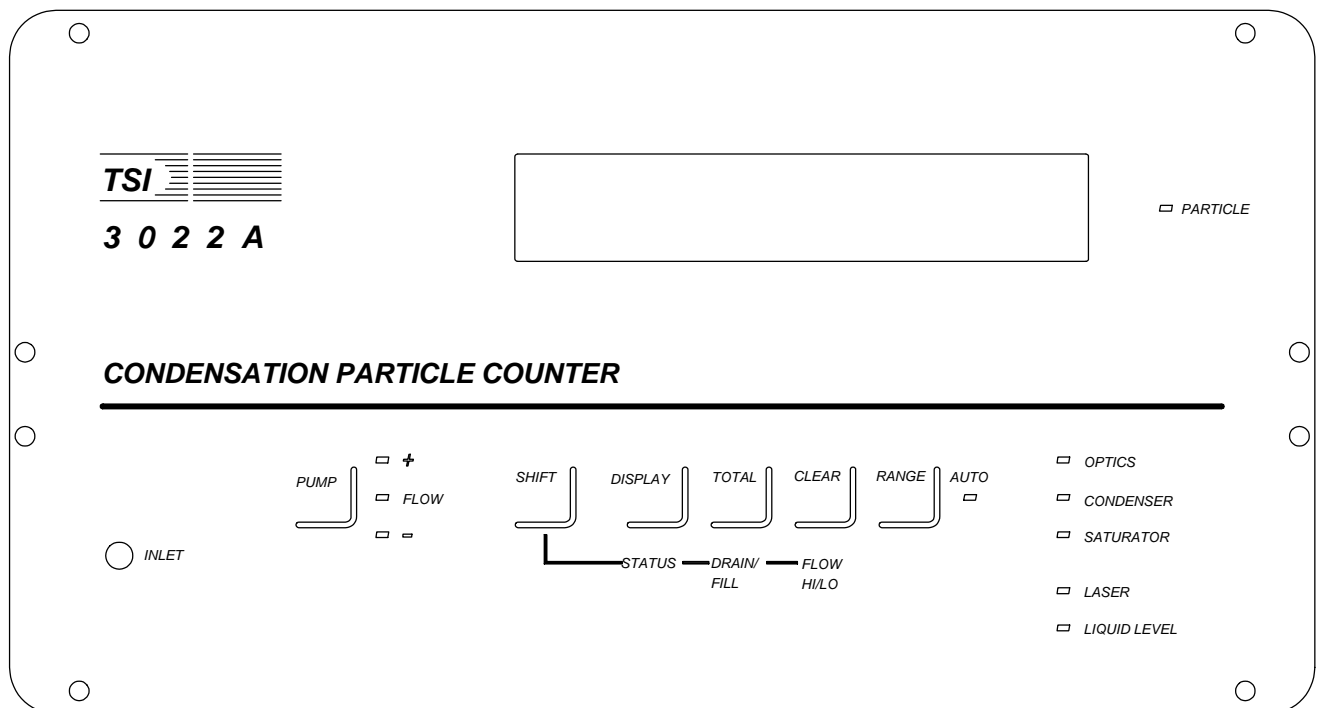


Figure 3-1
CPC Front Panel

Warmup Mode

On power-up, after the initialization sequence, the CPC displays WARM-UP XXX (where XXX is the warm-up period in seconds) and counts down to zero. During warm-up, the CPC does not display concentration values or total counts, but all other functions are accessible.

Since the warm-up period ends when all temperatures and the laser power have reached normal operating levels, the period may end before the 600 seconds have elapsed. If normal operating conditions are not reached within the 600-second countdown, the CPC simply remains in the warm-up mode without further countdown.

After warm-up, the CPC displays a value for concentration or total counts; the pump is either off or on, just as it was when the instrument was last switched off.

Primary Functions

Primary functions are accessed from the front panel's five pushbuttons. They are identified by the labels above the buttons: Pump, Display, Total, Clear, and Range.

Pump

Use this button to switch the pump on or off. The flow level is indicated by three symbols and their indicator lights: the plus sign (+), the word FLOW, and the minus sign (-). The yellow (+) and (-) lights indicate that the flow is too high or too low respectively. The green Flow light means that the sensor flow is $5 \pm 0.5 \text{ cm}^3/\text{s}$, if the flowmeter has been calibrated accurately.

To display the flow value, use the Status button (described below under "Secondary Functions"). Both the flow and a measure of the pump voltage can be monitored with the analog output on the back panel (see Chapter 4).

Display

The button labeled Display allows you to display two types of information: concentration (CONC) and total count (COUNT). Pushing the button toggles between the two types.

The concentration value is averaged over a specific period of time according to the magnitude of the concentration. The data is displayed in units of particles/cm³. Detailed information about concentration averaging is given in Chapter 6.

The total counts represent a cumulative number of particles up to 99,999,999. For the count to be valid, the concentration must be below 10³ particles/cm³ (single-particle counting mode). If the maximum count is exceeded, the display is overranged—indicated by flashing display.

Total

Press the button labeled Total to start and stop the count totalizer. The sample automatically stops when the time is equal to the pre-programmed time setting that you enter during setup (see Chapter 4). The maximum particle count is 99,999,999. If the count is exceeded, the totalizer stops counting and displays 99,999,999.

When counting is in progress, a star flashes on the left side of the display. If the star does not appear, then counting has stopped. The totalizer is operational even if the display shows averaged concentration and not the count total.

Clear

Press the button labeled Clear to clear the buffers for storing total values and concentration averaging values.

Range

Press the button labeled Range to select a fixed exponential range or an auto-range for the concentration display. The green light is *on* when you are in the auto-range mode; it goes off when you are in any of the fixed ranges. The fixed ranges are e1, e2, e3, e4, e5, e6, or no exponent at all. If you are using a fixed range and the concentration exceeds it, the display flashes the highest number possible for that range. Most applications can use auto-range.

Secondary Functions

Secondary functions are accessed by first pressing the Shift button and then pressing one of the buttons that were used for the primary functions. They are identified by the labels below the buttons: Status, Drain/Fill, and Flow Hi/Lo.

Shift

Pressing the button labeled Shift serves two functions: it accesses the secondary functions, or, if already in the secondary functions mode, it returns the primary display (concentration values). In the first function, the display reads Shift until you press a second button. If you press Shift again, the display returns the concentration values.

You can access the secondary functions only when the display reads Shift.

Status

Status displays a set of sensor operating parameters that you can use to check the functioning of the CPC (see Chapter 10). Press the Status button repeatedly to step through the following parameters:

Flow	The volumetric flow is measured in units of cm ³ /s. A hat (^) in front of the number indicates that the CPC is in the high-flow mode; an underline () in front of the number indicates the low-flow mode (see Chapter 5).
T _o	The optics temperature should be 1° higher than the saturator temperature or 36°C.
T _c	The condenser temperature should be at 10°C.
T _s	The saturator temperature should be at 35°C.
DET	The [DET]ector voltage is a measure of the light scattered from particles as detected by the photodetector. The DET should be 0±0.050 volts when no particles are passing through the sensor. (Either the air is clean or the pump is off.) The DET for any given particle concentration is found from the calibration data , on or off the calibration plot, in Appendix D.

Drain/Fill

Press the Drain/Fill button to toggle between the drain and fill valves.

To drain the CPC, turn off the pump, connect the fitting from the drain bottle to the Liquid Drain connector on the back panel and place the bottle below the CPC's base. Press the Drain/Fill button. The display reads Draining and the drain valve opens. The CPC remains in the draining mode until you manually press the Shift button and Drain/Fill again.

To help start the liquid flow, remove all air from the drain tube and place the drain bottle far below the CPC. If the CPC is at table-height, place the drain bottle on the floor.



C a u t i o n

If the drain bottle contains liquid and if it is placed above the base level of the CPC, the internal reservoir may fill and possibly overflow. The drain valve is not controlled by the liquid level sensor.

To fill the CPC, connect a liquid-filled bottle to the Liquid Supply connector on the back panel and place the bottle in the mounting bracket. Unless the CPC is in the draining mode, the CPC automatically opens and closes the fill valve to keep the internal reservoir full.

You can configure the CPC so that the liquid reservoir must be full to get a readout of the concentration (see “Enabling the Configuration Function” in Chapter 4). This ensures the CPC is fully operational before any data can be taken. In this mode the display reads Filling whenever the fill valve is open.

If the CPC is not configured this way, a concentration value is displayed even if the reservoir is not full. Obviously, if there is no liquid or too little liquid, the concentration value will be wrong. In this mode the display does not read Filling when the fill valve is open.

Flow Hi/Lo

Flow Hi/Lo switches the inlet flow between the low sampling flowrate (5 cm³/s) and the high sampling flowrate (25 cm³/s). According to the current flow mode, the display reads High Flow or Low Flow and then redisplay the concentration value.

Note: *The sensor flow is always 5 cm³/s regardless of the sampling flow. In the high-flow mode, the extra volume of 20 cm³/s becomes, internally, a bypass flow. If you attach additional transport tubing to the inlet of the CPC, the high-flow mode allows the sample to be brought to the CPC faster with lower losses due to particle diffusion.*

In the low-flow mode, extra air is brought through the makeup-air port from the back panel. This keeps the pump running at a high speed to stabilize and smooth the flow through the sensor.

Indicator Lights

The front panel of the CPC uses these indicator lights—Particle, Flow, Auto, Optics, Condenser, Saturator, Laser, Liquid Level, described below.

Particle

The amber light next to Particle flashes briefly each time a particle is detected.

Flow

A green light comes on across from Flow when the flowrate is $5 \pm 0.5 \text{ cm}^3/\text{s}$. A yellow light comes on above Flow when the flowrate is too high; a yellow light comes on below Flow when the flowrate is too low.

Auto

A green light comes on below Auto (next to Range) when you set the display range to the auto-range mode.

Optics, Condenser, Saturator

A green light comes on across from Optics when the optics temperature is $\pm 2^\circ\text{C}$ of the correct temperature. A green light comes on across from Condenser and Saturator when the temperature of each is within 0.5°C of their correct values. The microprocessor normally controls the temperatures to within $\pm 0.3^\circ\text{C}$ of the correct temperature for the condenser and saturator.

Laser

A green light comes on across from Laser when the laser is *on* and operating at the correct power level.

Liquid Level

A green light comes on across from Liquid Level when the liquid level sensor indicates that the reservoir is full.

Back Panel Functions

Refer to Figure 3-2 as you read the following descriptions of the back panel functions.

COM PORT

The 9-pin, D-type, subminiature connector labeled COM PORT, is the communications port compatible with RS-232 devices. A detailed description of the computer interface and its commands is given in Chapter 8.

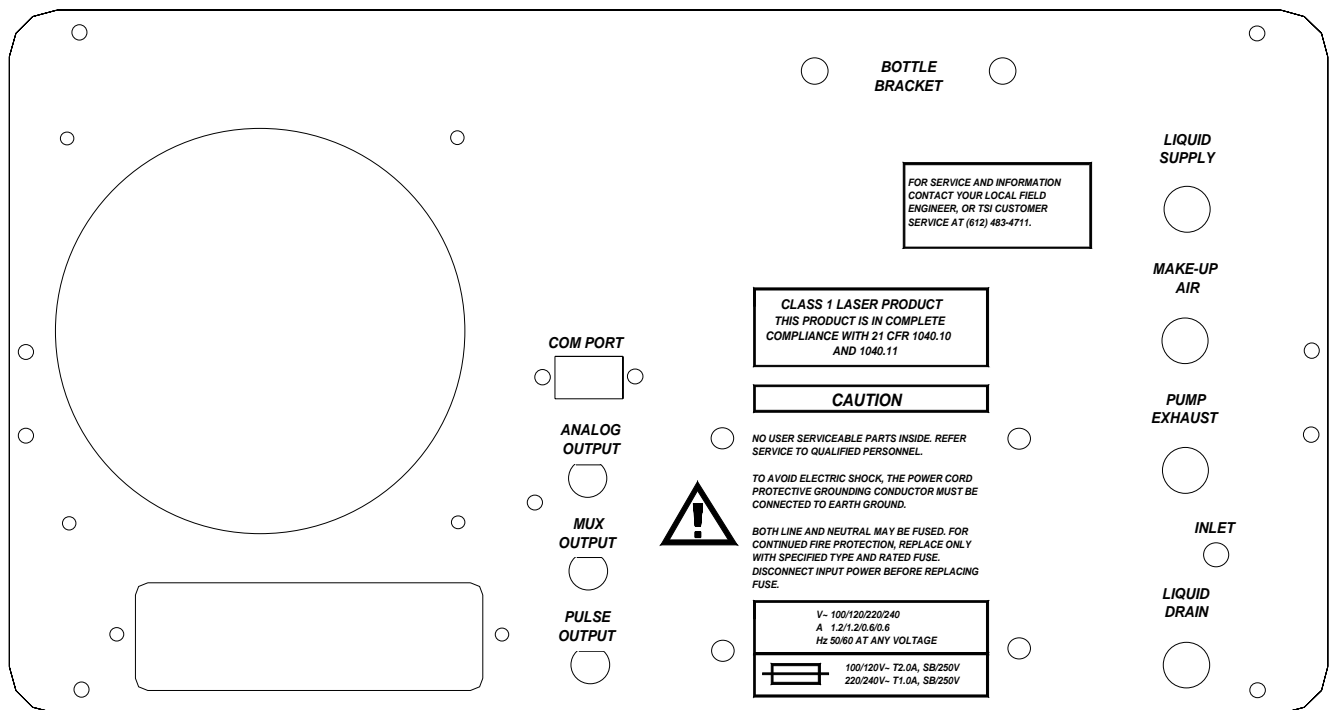


Figure 3-2
CPC Back Panel

Analog Output

Analog Output is a BNC connector that normally transmits a 14-bit signal of 0 to 10 volts (11 volts in Host mode). Use the configuration function to select the voltage you want to output (see Chapter 4).

Mux Output

Mux Output is a BNC connector compatible with TSI's remote and multiplexer processors. The signal transmitted through the output—one for each detected particle—is a 13-volt, 6.4-microsecond square pulse. The output is valid only for concentrations less than 350 particles per cm³ [10 million/ft³].

Pulse Output

Pulse Output is a BNC connector that transmits a 12-volt square pulse, one for each detected particle. The width of the pulse depends on the shape of the photodetector pulse and on the trigger-level of the pulse threshold. A typical width is 3.3 microseconds.

Liquid Supply

Liquid Supply is a quick-disconnect, shut-off connection. Use it with the liquid fill bottle in the mounting bracket just above the connector.

Makeup Air

The Makeup Air inlet uses a ¼-inch nylon Swagelok connector. Makeup air is used in the low-flow mode to increase the pump speed and stabilize the flow through the sensor. The air is filtered in the CPC before it enters the pump. If the inlet is sampling from a slight vacuum, the makeup air may need to be restricted to force more air to enter through the inlet (see "Inlet Pressure" below).

Pump Exhaust

Pump Exhaust uses a ¼-inch nylon Swagelok connector to vent the pump exhaust. If you are sampling from a slightly pressurized system or from a vacuum system, equalize the pressure across the CPC by connecting the pump exhaust to the system downstream of the sampling port (see "Inlet Pressure" below).

Liquid Drain

Liquid Drain is a quick-disconnect, shut-off connection. Use it with the liquid drain bottle placed below the base of the CPC to allow gravity to drain the instrument.

Operating Specifications and Precautions

This section contains operating specifications and precautions. Also refer to the Safety section at the front of this manual and Appendix B, "Specifications."

Ambient Temperature

Do not operate the CPC in ambient temperatures outside the control range of 10°C to 34°C. If you run the CPC outside of this range, its data may be invalid.

Inlet Pressure

The built-in pump and flow sensor cannot control the flow when the pressure at the aerosol inlet, the makeup air inlet, or the pump exhaust is too high or too low. The remedy depends on the sampling mode: high flow or low flow.

First, view the flow display by activating the secondary function "Status;" then follow the directions given for either the high-flow or low-flow mode. As a further aid, monitor the pump-control voltage of the microprocessor using the Analog Output jack on the back panel (see Chapter 4).

High Flow Mode

In the high-flow mode, connect the Pump Exhaust outlet to the same pressure conditions that apply to the inlet so that the pressure drop across the CPC is close to normal conditions.

If you are sampling from a closed system, add a pressure-equalizing line from the pump exhaust to the system downstream of the

sample port. Be careful that your sample port does not sample air from the pump exhaust.

If you cannot vent the pump exhaust back into the system, you must add a flow restrictor (excess pressure at the inlet) or add an additional vacuum pump (insufficient pressure at the inlet) to the pump exhaust port. For example, do this if the system cannot tolerate the vapors of the working fluid or the potential particle contamination from the pump exhaust.

Low Flow Mode

The Low Flow mode is slightly more complicated than the high-flow mode because it also involves the makeup air inlet. Try to equalize the pressure at all the ports so that the microprocessor pump-control voltage is at mid-range. The exact flowrate through the makeup air is unimportant. If the aerosol inlet pressure is too low, try adding a flow restrictor to the makeup air port. (Use an orifice, filter, valve, or other device.) If the inlet pressure is low enough, you may need to completely close off the makeup air and/or equalize the pressure from the pump exhaust port as described above under “High Flow.” If the inlet pressure is too high, add a restrictor to the pump exhaust.

Moving the Counter

When the liquid reservoir is full, avoid tipping or moving the CPC so that liquid does not spill, get sucked up into the optics or bypass air line, or out the inlet.



C a u t i o n

While the pump is on, do *not* tip the counter more than 12° to either side or 45° from front or back. In general, it is better to dry the CPC (see below) before you move it. If the CPC is tilted for more than a few seconds, disconnect the bottle of working fluid to prevent flooding the sensor.

Drying the Counter

The counter must be completely dry of all fluid before shipping (air freight, truck, ship, etc.)

There are two methods of drying the counter:

First Method

- 1.** Disconnect the working fluid supply bottle.
- 2.** Drain the CPC. Use the drain bottle (provided) and put the instrument in drain mode.
- 3.** Switch on the pump and run dry air through the counter for 24 to 48 hours.

Second Method

A disadvantage of this method is the CPC may develop leaks due to the disassembly process.

- 1.** Disconnect the working fluid supply bottle.
- 2.** Drain the CPC. Use the drain bottle (provided) and put the instrument in drain mode.
- 3.** Remove the wick from the reservoir. To do so, refer to Figures 3-3 and 3-4 and follow these steps:
 - a.** Remove the top and bottom covers.
 - b.** Disconnect the Swagelok tee-fitting and inlet tubes.
 - c.** Remove the four screws from the saturator's end-plate. When removing the end plate, be careful not to damage the fragile glass-coated level sensor screwed into the end-plate.
 - d.** Pull the wick from within the saturator.
 - e.** Either ship the instrument without the wick, dry the wick and reinstall it, or else install a new wick.
 - f.** Replace the wick with the cut-away facing downward to clear the liquid level sensor.
 - g.** Reassemble the end-plate and inlet tubes.

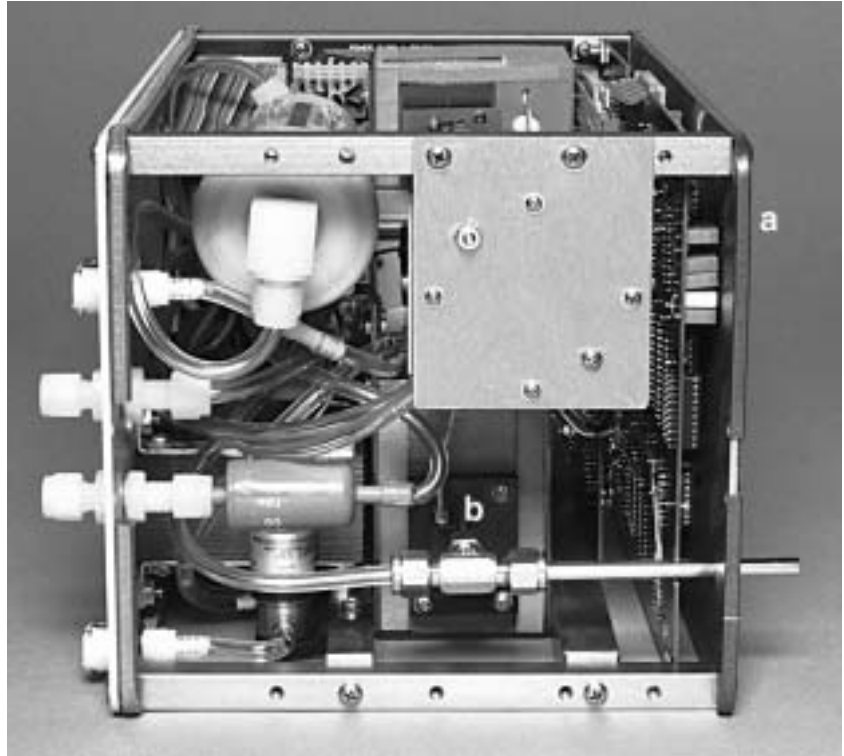


Figure 3-3
Saturator: (a) Front of Counter; (b) End Plate With Four Screws

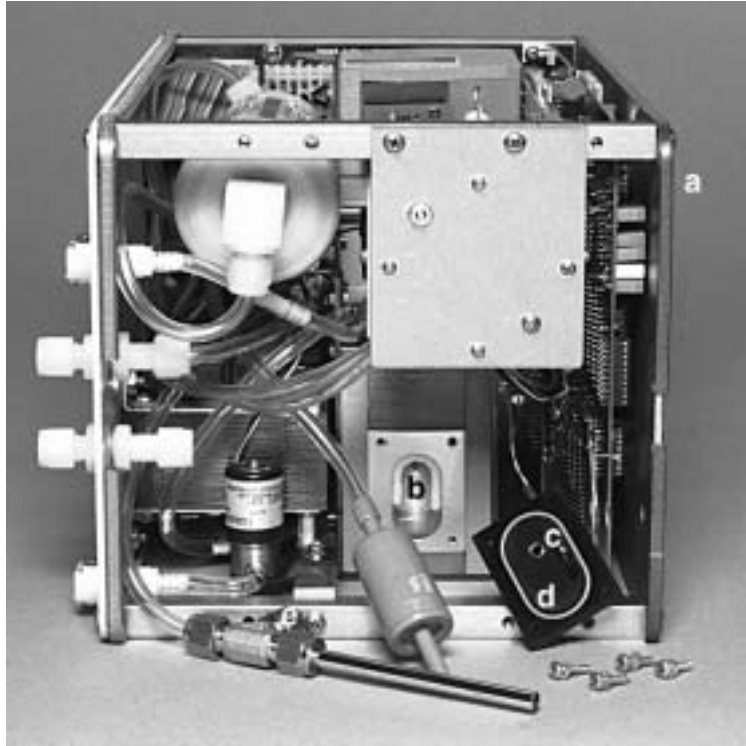


Figure 3-4
Saturator: (a) Front of Counter; (b) Wick; (c) Fill Sensor; (d) End-Plate (Removed);
(e) Inlet Flow; (f) Fluid Line

Configuring the CPC

This chapter describes how to enter the Configuration mode and select the various microprocessor outputs and controls. It also explains how to calibrate the D/A and A/D converters and the flow meter.

Enabling the Configuration Mode

To enable the Configuration mode, first set the red paddle switch on the Display printed circuit (PC) board to “enable.” The board is shipped in the “disable” position so that you cannot unknowingly alter the calibration and setup configuration.

1. Remove power from the CPC and from any instruments connected to the CPC.
2. Remove the top cover from the CPC. The Display board is next to the front panel, as shown in Figure 4-1.

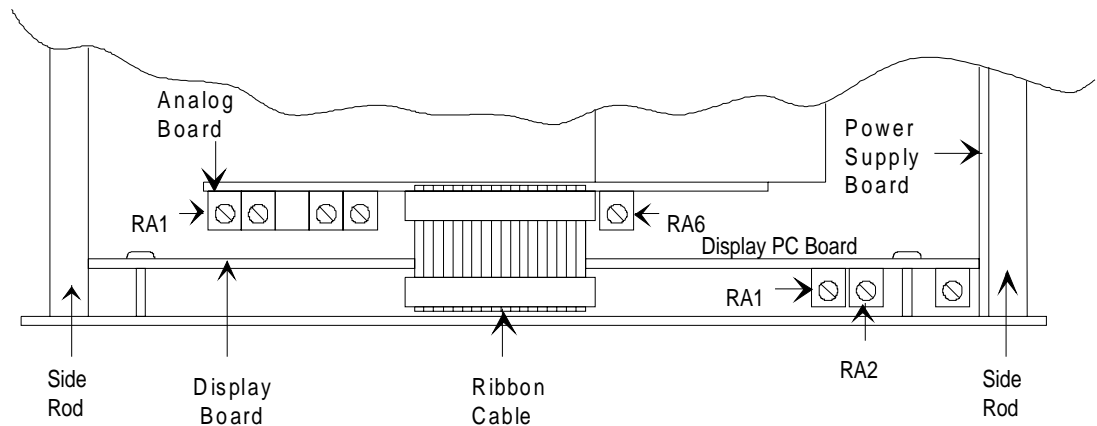


Figure 4-1
Location of PC Boards and Potentiometers

3. Move the red paddle switch to the far right position (Figure 4-2).

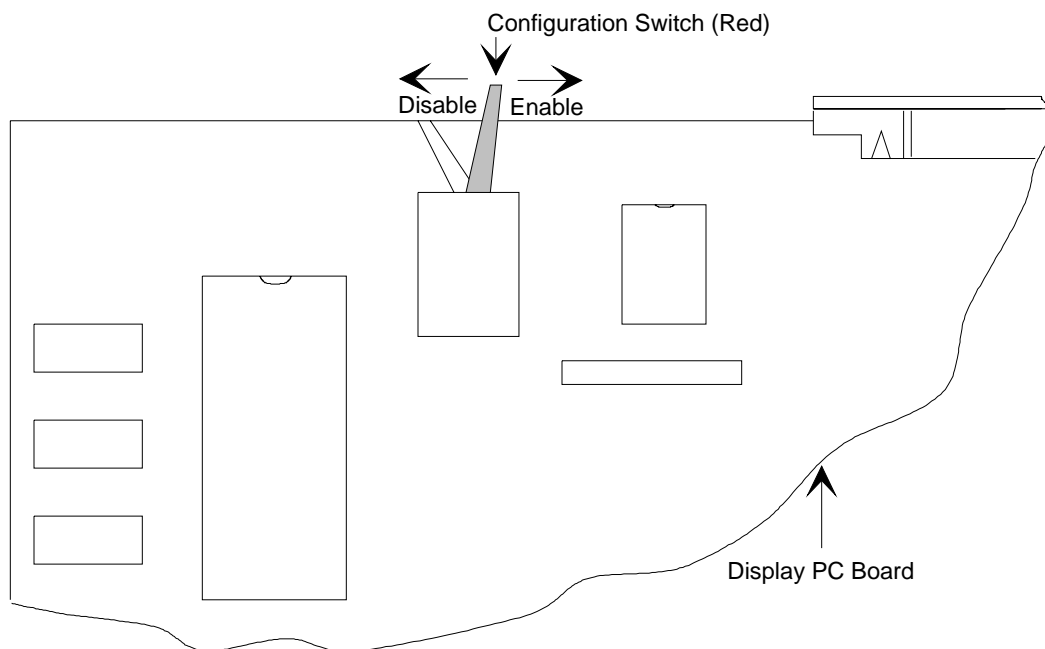


Figure 4-2
Setting the Configuration Switch to Enable the Configuration Mode

- 4. Run the configuration sequence (see “Running the Configuration Function” in this chapter). Be sure the CPC is fully warmed-up before resetting any calibration points.**
- 5. After configuring the CPC, it is a good idea to set the switch back to the disable position to prevent tampering.**
- 6. Replace the top cover.**

Running the Configuration Function

The configuration process is programmed in the CPC and altered by pressing function buttons in response to questions posed on the display.

1. To enter the configuration mode, press Shift, then press Pump. “Set Up Mode” appears momentarily on the front panel display. A series of questions follows.
2. To view the possible responses, press the Total button until the desired response appears. Select it and move on to the next question by pressing the Display button.

Note: *If you answer yes to the question “Calibrate?,” you may have to make some adjustments to the electronics inside the CPC cabinet. The directions for making these adjustments are given in the right-hand column of the table that follows.*



C a u t i o n

Do **not** answer yes to the calibration question until you have completely read this section.

3. When you have completed the steps in the configuration process, press Clear.

Question	Answer	Explanation
Must fill?	Y	Yes: A yes requires that the liquid reservoir be full for concentration display.
	N	No (default)
Total?	20s	Second for total; when the time has elapsed, the counting stops.
	60s	
	200s	
	600s	
	2000s	
	6000s	
	9999s	
	No Lmt	No limit (default)
Output?	E1	0 to 10 particles/cm ³
	E2	0 to 100 particles/cm ³
	E3	0 to 1000 particles/cm ³
	E4	0 to 10,000 particles/cm ³
	E5	0 to 100,000 particles/cm ³
	E6	0 to 1,000,000 particles/cm ³
	E7	0 to 10,000,000 particles/cm ³
	LOG	Logarithmic concentration output; 0 to 10,000,000 particles/cm ³ (0 to 10 volts log: 10 volts = 10,000,000 particles/cm ³ 9 = 1,000,000 8 = 100,000 7 = 10,000 6 = 1,000 5 = 100 4 = 10 3 = 1 2 = 0.1 1 = 0.01 0 = ≤0.001)
	FLOW	Flow in units of cm ³ /s as measured by the volumetric flowmeter; 1 volt = 1 cm ³ /s
	PUMP	0 to 10 volts, microprocessor control range (0 to 255 percent) to the pump. 0 volts represents 1.55 volts to the pump; 10 volts represents 12 volts to the pump. Pump voltage = P (12) + (1-P) (1.55) where P = pump.
HOST	0-11 volt signal that can be set by a [HOST] computer via the RS-232 port. This mode is useful when controlling an instrument such as the Electrostatic Classifier with the 3022A CPC as part of a DMPS or SMPS system.	

continued

Question	Answer	Explanation
	DET	The [DET]ector voltage is a measure of the light scattered from particles as detected by the photodetector. The DET should be 0 ± 0.050 volts when no particles are passing through the sensor (either the air is clean or the pump is off). The DET for any given particle concentration is found from the calibration data, on or off the calibration plot, in Appendix D.
Baud?	110 300 600 1200 2400 4800 9600 19200	Baud rate for RS-232 communication Default
Parity?	Even None	Default
Calibrate?	N Y	No Yes. To enter calibration of D/A, A/D and flow.
D/A Zero		To calibrate the D/A zero, measure the voltage from the Analog Output jack on the back panel with a digital voltmeter. <i>Note: This step is independent of your selection for the analog output above.</i> Remove the top cover of the CPC. Adjust potentiometer RA2 on the Display board (Figure 4-1) to 0 ± 1 mV. Press the Display button.
D/A 10v		Measure the voltage from the Analog Output jack. Adjust potentiometer RA1 on the Display board (Figure 4-1) to $10 \text{ V} \pm 1$ mV. Press the Display button.
Cal A/D?	N Y	No Yes: Answering yes uses the D/A 10-volt output that you just set as a reference in order to set the A/D 10-volt output.
Det	0.000v	This is the photodetector zero. Adjust potentiometer RA6 (Figure 4-1) so the display reads 0.000 ± 0.001 . Press the Display button.

continued

Question	Answer	Explanation
Ref	2.000- 5.000v	This is the reference photodetector. Potentiometer RA1 has been set to maximum so the display reads 2 to 5 volts. Press the Display button.
Flow Cal?	N Y	No Yes: Answering yes requires an external means of measuring the flow to calibrate the internal volumetric flowmeter; see "Flow Calibration" below.
5.00 cm ³ /s 128		Follow instructions under "Condenser Flow Calibration" below.
Zero flow		The pump switches off. Wait 30 seconds until the flow is absolutely zero. Press Display. After a brief delay, the front panel momentarily displays "Set Up Done." Exit the configuration mode.

Flow Calibration

Since the flow calibration is more complicated than described above, a few extra words of guidance are in order.

The calibrated flow is measured by the pressure drop across a capillary tube. The pressure drop at 5.00 cm³/s is approximately 0.48 inch of water. It is measured with a sensitive transducer that has a voltage output of 0 to 5V; this corresponds to 0 to 1 inch of water. When you calibrate the flowrate of the CPC, you are programming the microprocessor to maintain a specific pressure-transducer voltage. The pump voltage is adjusted to maintain a steady pressure drop, which in turn maintains a constant volumetric flow through the CPC.

The calibration is done at two points only: zero flow and 5.00 cm³/s. Other flowrates that may be displayed on the front panel are calculated on the basis of physical principles and normalized to the calibrated points. These other flows may not be accurate but are used simply to show that the flow is either too high or too low and by an approximate amount.

When calibrating the flow, chose an external flowmeter that will have a low pressure drop and measure the actual volumetric flow. If you use a mass flowmeter (one calibrated to standard conditions), convert the standard flow to actual flow with the following equation:

$$\text{Actual flow (cm}^3 \text{ / s)} = \text{std flow (cm}^3 \text{ / s)} \times \left(\frac{T}{293} \times \frac{101.35}{P} \right)$$

where: $T = ^\circ \text{ Kelvin}$
 $P = \text{kPa.}$

Condenser Flow Calibration

To calibrate the condenser flow follow these four steps:

1. When the display on the counter reads “Cond Cal? N,” press the Total button until the “N” changes to “Y.” Press the Display button to continue the calibration. If you answered yes to the calibration, the display changes to “5.00 cm³/s 128.” This indicates the target flow into the counter inlet (5.00 cm³/s) and the power to the pump (0–255), initially set at 128.
2. Connect a flowmeter to the inlet of the CPC and measure the flow. If the flow is *higher* than 5.00 cm³/s, press the Total button repeatedly (the 128 number will decrease) until the external flowmeter reads 5.00 cm³/s. If the flow is *lower* than 5.00 cm³/s, press the Range button repeatedly (the 128 number will increase) until the external flowmeter reads 5.00 cm³/s.

Note: *The condenser flowmeter voltage is available at the Analog Output for reference.*

3. When the flow is correct (as measured by the external flowmeter), press the Display button to record the operating voltage of the internal flowmeter.
4. The display now reads “Zero Flow.” Allow the pump to come to a complete stop (30 seconds) and then press the Display button to record the zero-flow voltage of the internal flowmeter. The display now asks whether the aerosol flow should be calibrated. Answering yes requires that the aerosol flow be calibrated as outlined below. Answering no allows you to exit the calibration procedure and return at a later time.

Note: *Both flows should be calibrated before using the counter.*

Technical Description

The Model 3022A is a continuous-flow, condensation particle counter (CPC) capable of detecting particles as small as 0.01 micrometer in diameter. This section describes the function of the CPC, its subsystems, and components. A discussion of its theory and history is given first.

Theory

The CPC acts very much like an optical particle counter, except that the particles are first enlarged by a condensing vapor to form easily detected droplets. The science behind the CPC, 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 becomes high enough, condensation can take place even if no particles are present. This is called *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.

The degree of supersaturation is measured as a saturation ratio, 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:

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

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 CPC is determined by the operating saturation ratio. For the CPC this ratio is several hundred percent, whereas in the atmosphere, this ratio is only a few percent for water.

Historical Notes

Historically, the CPC 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.

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, 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 airstream 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. 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 flowrate of 0.3 liter per minute. Other versions include cleanroom CNCs (TSI Model 7610 and Model 7620, formerly Model 3760 and Model 3761), U.S. patent no. 4,790,650) and a respirator-fit test CNC (TSI Model 8010). The Model 3022A CPC is patterned after these.

Looking at the flow path in the CPC, 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. Nearly 100 percent of particles greater than 0.02 micrometer are detected with a gradual drop-off in detection efficiency below that size. Another version of the CPC confines the aerosol to the centerline of the condenser tube where supersaturation is the highest. The result is higher detection efficiency for small particles down to 3 nanometers and faster response time, but with an increase in the complexity of the instrument and a reduction in sample flowrate. This enhanced version for ultrafine particle detection is TSI's Model 3025A Ultrafine CPC.

The wide dynamic range of both the Model 3020 CNC and Model 3022A CPC has made them useful in four areas: measuring filter efficiency, atmospheric studies, cleanroom monitoring, and basic aerosol research. These are the detectors most commonly used with submicron size-distribution measurement systems such as the diffusion battery (Sem et al. [1980]) and differential electrical mobility classifier (Keady et al. [1983]).

Design of the CPC

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

Sensor

The sensor itself is made up of a saturator, condenser, and optical detector, as shown in Figure 5-1. The aerosol enters the saturator section and passes through a heated, liquid-soaked wick. The wick dips into the liquid reservoir and continually draws liquid up through the inclined tube. The liquid evaporates and saturates the aerosol stream with vapor.

The vapor-saturated aerosol then passes into a vertical condenser tube, which is cooled using a thermoelectric device. The vapor cools, becomes supersaturated, and begins to condense on the particle 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 tube runs back down into the saturator and is absorbed into the wick for reuse.

The sensor's focusing optics consist of a laser diode, collimating lens, and cylindrical lens. This combination forms a horizontal ribbon of laser light above the aerosol exit nozzle measuring 10 micrometers by 2 millimeters. The collecting optics incorporate a pair of aspheric lenses that collect the light scattered by the droplets at 90° side-scatter and focus this light onto a low-noise photodiode. The main beam is blocked by a light-stop in the rear of the sensing chamber. A reference photodiode is mounted at the back of the light-stop; it monitors the intensity of the incident beam. The surface temperature of the optics housing is maintained at a higher level than the saturator to avoid condensation on the lens surfaces.

The CPC uses three modes of particle counting: single-particle realtime counting; single-particle "live-time" counting; and photometric calibration.

At concentrations below 1000 particles/cm³, the individual electrical pulses generated by light scattered from individual droplets are *all* counted over the actual time, that is, in "real" time. At concentrations between 1000 and 10,000 particles/cm³, the individual electrical pulses are counted, but only when the signal-processing electronics is available for counting, that is, in "live-time." The length of time during which a particle is actually being detected is called the "dead-time" and is not included in the live-time. This arrangement automatically corrects for particle coincidence. At concentrations above 10,000 particles/cm³, the

instrument measures the total light scattered from all droplets present in the viewing volume at any time. The DC voltage from the photodetector is calibrated against a known concentration using an electrical mobility technique. For more information, see Chapter 6 and Chapter 7.

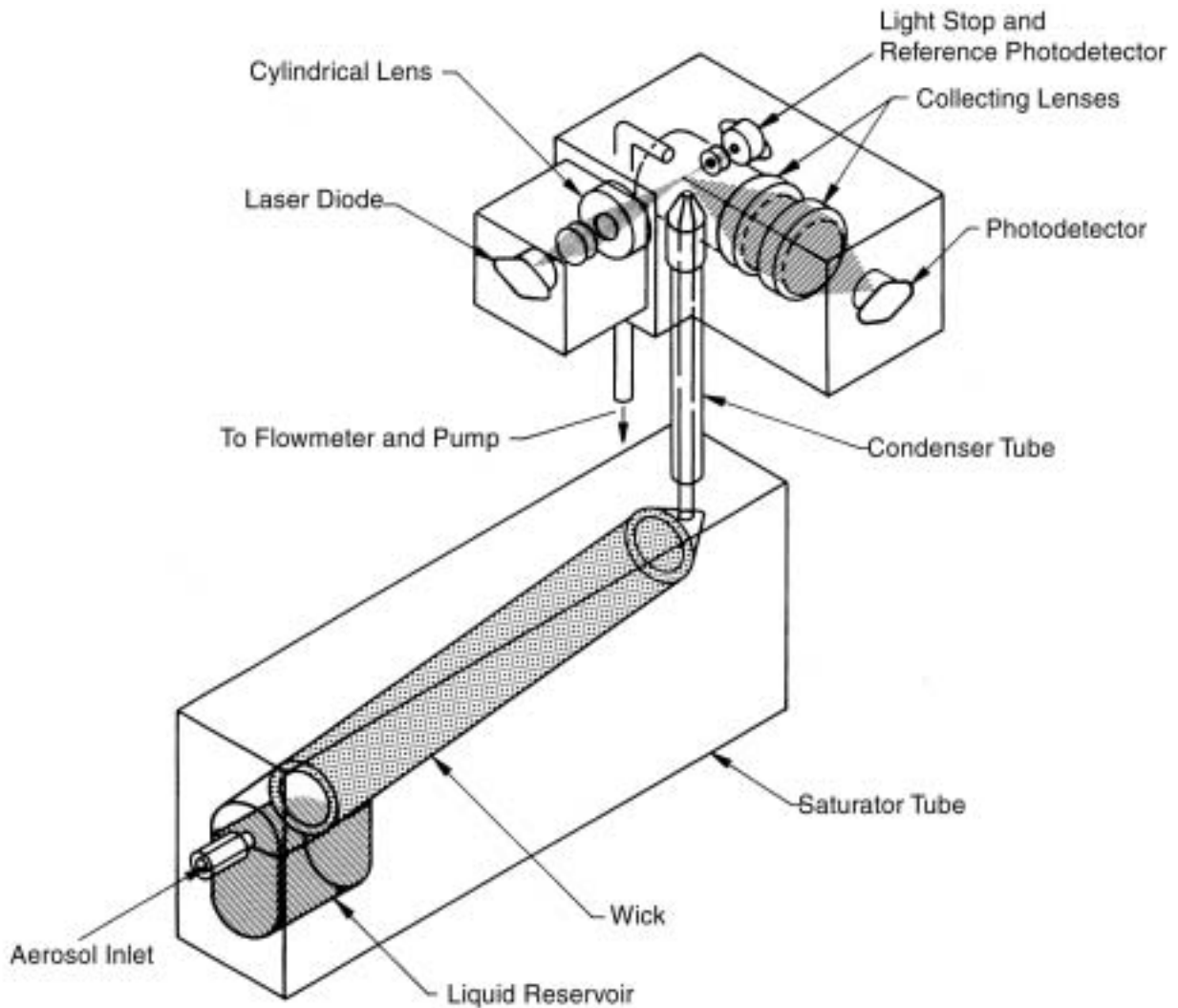


Figure 5-1
Drawing of the CPC Sensor

Microprocessor

The CPC incorporates an Intel 80188 microprocessor to control all its functions. The microprocessor uses a 32KB EPROM* chip for program memory and an 8KB RAM** chip for making calculations and running count buffers. An additional 8KB of EPROM stores nonvolatile information such as the photometric calibration.

An analog-to-digital (A/D) converter is connected to the microprocessor and measures photodetector voltages, temperatures, and flowrates. (The temperatures and flowrate controls are based on the raw data received by the A/D converter). Counters within the microprocessor keep track of the particle pulses detected by the photodetector. The display, pushbuttons, and RS-232 communications are also controlled by the microprocessor.

Flow System

Figure 5-2 is a flow schematic of the CPC. The CPC has two inlet flow options: high flow (1.5 L/min), low flow (0.3 L/min). The flowrate through the sensor is always 0.3 L/min, independent of the inlet flow. For information on how to enter these modes, see "The Front Panel" in Chapter 3.

* Electronically Programmable Read Only Memory

** Random Access Memory

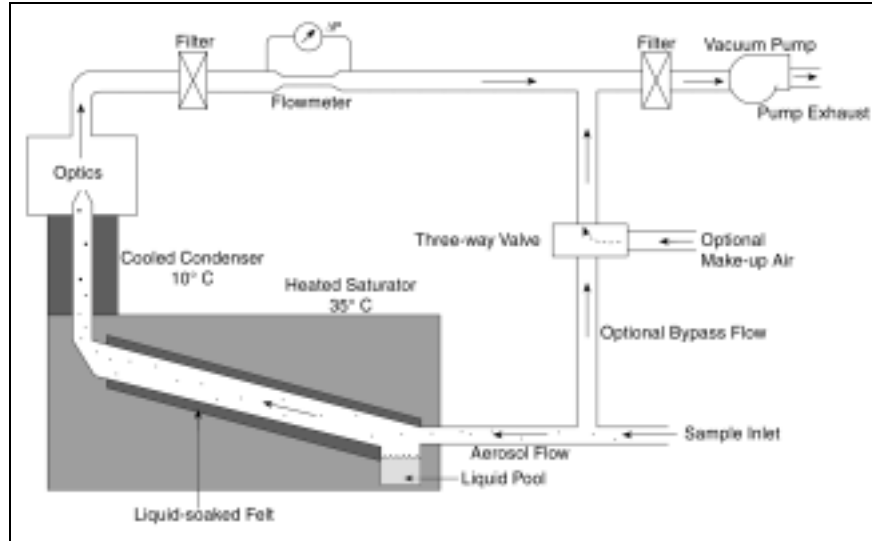


Figure 5-2
Flow Schematic of the CPC

High Flow

The high-flow option allows the sample to be brought to the CPC faster; this minimizes response time and diffusional particle losses. In the high-flow mode, the three-way valve is opened to the bypass flow, the flow of makeup air is shut off. A total of 1.5 liters per minute ($\pm 10\%$) is drawn into the CPC's inlet. The flow splits so that 0.3 liter per minute flows through the sensor and 1.2 liters per minute flows through the bypass. Together, the flowmeter and microprocessor control the vacuum pump to maintain the flowrate through the condenser (Flow on front panel). The accuracy of the sensor flow is based on a two-point calibration at 0 and at 0.3 liter per minute.

Low Flow

The low-flow option allows the minimum flowrate when a high flow is undesirable, for example, when using the CPC with the Differential Mobility Particle Sizer (DMPS) system or the Scanning Mobility Particle Sizer (SMPS) system. In the low-flow mode, the three-way valve is open to the flow of makeup air, the bypass flow is shut off. Only 0.3 liter per minute is drawn into the inlet and carried directly into the sensor.

The flowmeter and microprocessor control the vacuum pump to maintain the flowrate through the sensor, just as is done in the high-flow mode. The makeup flow is uncontrolled and the magnitude of the flowrate is unimportant. It is important, however, that the pump operate below its maximum 12 volts so that there is some range in the feedback control. If the inlet pressure is lower than the pressure of the makeup air, you may need to add a restrictor to the makeup air to force more air to come through the inlet and produce a lower pump voltage. For more details, see “Inlet Pressure” in Chapter 3.

Filters and Restrictors

There are three particle filters in the flow system. A low-pressure-drop, HEPA filter is placed just upstream of the pump and a tube filter is placed upstream of the capillary flowmeter. A low-efficiency filter downstream of the pump acts as a noise muffler. An orifice restrictor is placed between the flowmeter and the tee-fitting that joins the sensor flow and bypass flow (not shown in Figure 5-1). The restrictor balances the pressure drop between the two flow paths so that 1.2 liters per minute flows through the bypass when operating in the high-flow mode. An orifice restrictor is also placed in the make-up air line to balance the flows between the inlet and makeup.

Flowmeter

The volumetric flowmeter uses a sensitive pressure transmitter to measure the pressure drop across a capillary tube. The capillary tube has an inside diameter of 1.092 millimeters and length of 3.777 centimeters. The pressure drop is linearly related to volumetric flowrate plus an additional contribution equal to $0.58 \rho u^2$ (Schlichting [1955]). The pressure drop can be calculated from the following relationship:

$$\Delta P = aQ^2 + bQ$$

where ΔP = pressure drop in dynes/cm²
 $a = 8(1.16)\rho / (\pi^2 d^4)$, where ρ = gas density in g/cm³
 $b = 128\mu l / (\pi d^4)$, where μ = gas absolute viscosity in
g/cm/s and l = capillary length in cm
 d = capillary diameter in cm
 Q = flowrate in cm³/s

The pressure drop of the CPC capillary is approximately 1.2 centimeters of water at 5.0 cm³/s. The pressure drop for each instrument varies according to the actual diameter of the capillary tube, its length, and surface roughness. The temperature of the tube is held constant because it is next to the heat-controlled saturator block. This keeps the dimensions of the tube stable.

Pump

The compact pump is an oil-free rotary pump with eight carbon vanes. It uses a DC motor and is nearly pulsation-free. The components that come in contact with the air are corrosion-resistant materials.

CHAPTER 6

Particle Counting

The Model 3022A Condensation Particle Counter (CPC) uses three methods of particle counting for concentration calculations: single-particle, realtime counting; single-particle live-time counting; and photometric calibration. This chapter focuses on counting the individual particles up to a concentration of 10,000/cm³.

Note: *Photometric calibration is described in greater detail in Chapter 7.*

Optical Detection

Submicrometer particles are drawn into the CPC and enlarged by condensation of a supersaturated vapor into droplets that measure several micrometers in diameter. The droplets pass through a lighted viewing volume where they scatter light. The scattered-light pulses are collected by a photodetector and converted into electrical pulses. The electrical pulses are then counted and their rate (calculated) is a measure of particle concentration. The optical detector used in this process is described in Chapter 5.

Single-Particle, Realtime Counting

At particle concentrations below 1000/cm³, the concentration is calculated by counting the individual pulses from the photodetector and by counting the real time. The particle pulses are typically 1.4-volts high, 5-microseconds wide at the base, and 3.3-microseconds wide at the trigger-threshold point* (see Figure 6-1). The counting trigger-threshold voltage is about 750 millivolts. The threshold has a hysteresis of about 100 millivolts so that another particle cannot be detected until the voltage first drops below 650 millivolts. This prevents false counting of noise pulses riding on top of the particle pulse.

While the pulse exists, the counter is disabled, that is, it cannot count another pulse until the present pulse is completed. A second particle entering the viewing volume while the first remains can

* Actual pulse heights for your CPC are listed on the data sheets in Appendix E.

extend the pulse width and thus, the time the counter is disabled. In this situation the counter can be described as “paralyzable,” because at sufficiently high particle rates the pulse width extends indefinitely, thus paralyzing the counter.

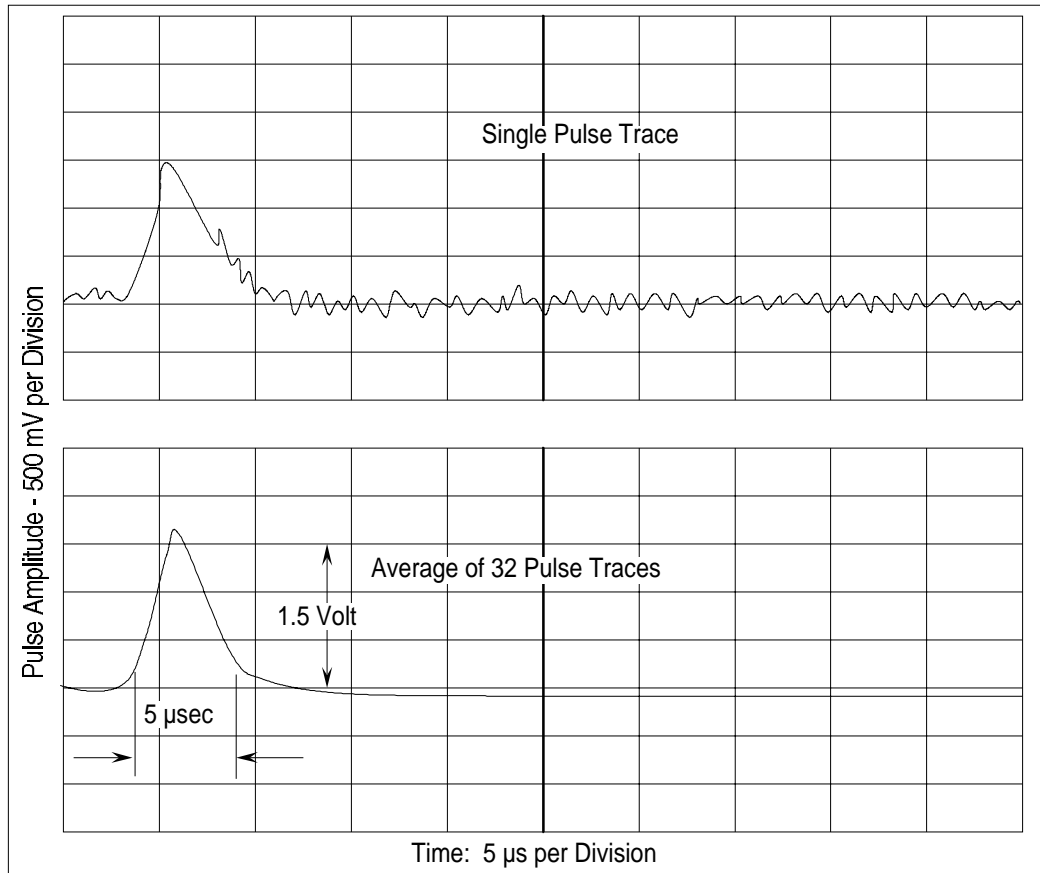


Figure 6-1
Typical Digital Pulse Trace From the Photodetector

The statistics for a paralyzable counter give the relationship of the measured particle concentration to the true concentration as:

$$C_a = C_i \exp(-QtC_a)$$

where C_a = actual or true concentration in particles/cm³
 C_i = indicated or measured concentration in particles/cm³
 Q = flowrate at 5.0 cm³/s
 t = time the counter is disabled for a single particle (approximately 4 μs in the CPC)
 QtC_a = the average number of particles that occur during the disabled period t .

Since C_a cannot be solved directly and is a double-valued function of C_i , the equation can be closely approximated by using C_i in place of C_a in the exponent.

For low concentrations—where the average time between the arrival of particles is much larger than the disable time ($QtC_a < 0.01$)—coincidence is low and no correction of the measured concentration is necessary. At higher concentrations, correction of coincidence is required and the internal microprocessor does *not* automatically correct for coincidence.

The effect of coincidence in the CPC up to 1000 particles/cm³ is small, as can be seen in Table 6-1.

Table 6-1
 Coincidence Correction for Concentrations up to 1000 Particles/cm³

Indicated Concentration (particles/cm ³)	Correction Factor $\exp(QtC_i)$	Correct Concentration (particles/cm ³)
9.99e2	1.020	1.02e3
9.00e2	1.018	9.16e2
5.00e2	1.010	5.05e2
1.00e2	1.002	1.00e2

Total Count Accuracy

At very low concentrations, the accuracy of the measurement in the single-particle-counting mode is limited by statistical error. If the total number of particles counted (total mode) in each interval is very small, the uncertainty in the count is large. The statistical error of the count σ_r is related to the total count n by

$$\sigma_r = \sqrt{n}.$$

The accuracy of the concentration is increased by sampling for a longer period. The concentration is calculated by:

$$\text{concentration} = \text{total counts/volume of air sampled}$$

$$\begin{aligned} \text{where volume} &= Q \times \text{time} \\ &= 5 \text{ (cm}^3\text{/s)} \times \text{time (s)}. \end{aligned}$$

Single-Particle, Live-Time Counting

In the concentration range of 1000 to 10,000 particles/cm³, the CPC uses a different method of counting single particles that is independent of t . The coincidence correction is applied directly by measuring particle counts over the live-time of the counter.

Since the time t during which the particle passes through the viewing volume effectively disables the counter, the value should not be included in the sample time. The actual particle rate equals the number of counted particles divided by the time no pulses were present during the measurement time. A high-speed clock and accumulator measure the live-time or the time in the spaces between particle pulses. At the start of the measurement, the accumulator is cleared and the clock started. The accumulator adds up the live-time and the counter adds up pulse counts until the accumulator reaches a value that triggers the counter and clock to stop. The particle concentration is then calculated by

$$C_a = \frac{\text{number of counted particles}}{\text{accumulated live-time}} \times \frac{1}{\text{flowrate}}$$

Photometric Calibration

For concentrations greater than 10,000 particles/cm³, the overall amount of light scattered from the droplets is measured as a DC voltage from the photodetector and then calibrated to a known concentration. The method of calibration is explained in Chapter 7.

Autoranging

Three running-average buffers and one live-time buffer are used to average particle counts. The buffers are updated every second, discarding the oldest 1-second value.

There is one buffer for each of four averages: 1, 2, 20, and 200 seconds. The photometric mode is used for displays with exponents of e4, e5, and e6. The 1-second live-time counter is used with exponent display, e3; the 2-second buffer with exponent display, e2; the 20-second buffer with exponent display, e1, and no exponent; and the 200-second buffer is used when the display shows three digits after the decimal.

The autoranging algorithm chooses among these buffers or selects the photometric calibration. A downward hysteresis of 10 percent is used when going from one exponent range to another in order to avoid rapid and unreadable display changes. If the display is on a fixed exponent range, then the correct buffer or photometric calibration is used for the concentration magnitude, but the display has a fixed exponent range.

All buffers are cleared when you press the Clear button.

CHAPTER 7

Calibrating the CPC

This chapter gives a description of the calibration methods used by TSI to calibrate the Model 3022A Condensation Particle Counter (CPC).

In the realtime and live-time, single-particle-counting modes (below 10,000 particles/cm³), no calibration is required except for flowrate. The particle concentration is simply calculated from the flowrate, time, and number of particles that pass through the sensing chamber.

Figure 7-1 shows the setup for calibrating in the photometric calibration mode, the Model 3022A Condensation Particle Counter (CPC) is calibrated according to two different methods. From 10,000 to about 500,000 particles/cm³, the standard method used is an electrostatic mobility classifier and an aerosol electrometer. For details of this calibration procedure, see Appendix C.

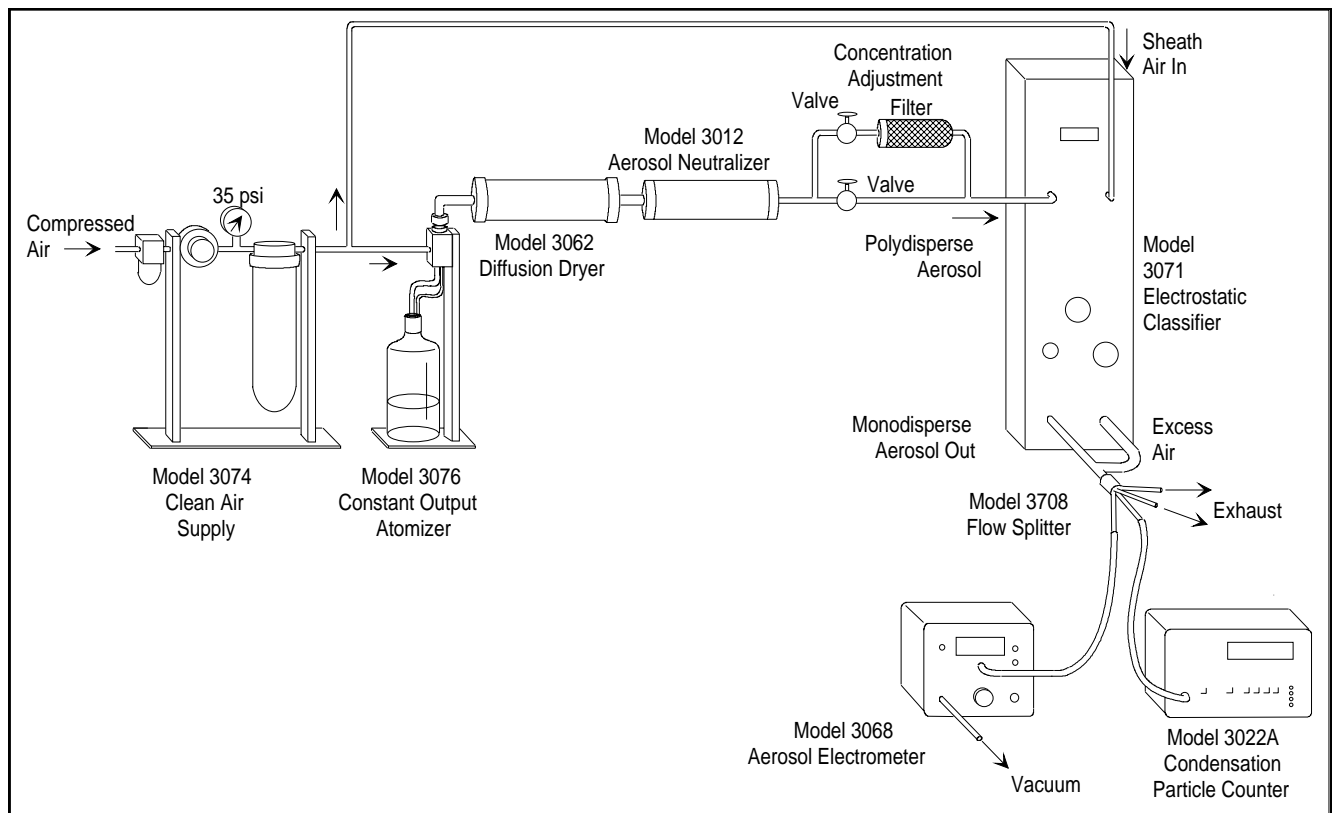


Figure 7-1
Calibration of the Condensation Particle Counter

The second method is the dilution-bridge technique, which allows the CPC to be calibrated from 500,000 to 8,000,000 particles/cm³ (Figure 7-2). It uses three parallel capillary tubes, one with a high-efficiency filter. The flowrate through the tubes is selected to give an appreciable pressure drop (on the order of 2.5 cm of water). The pressure drop is identical across all three legs (A, B, and C) with identical flowrates in each leg.

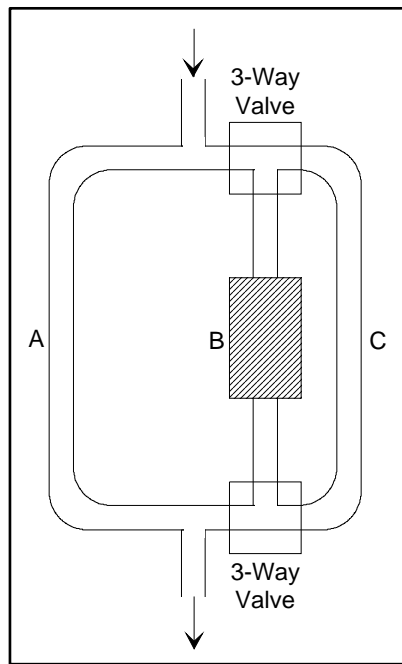


Figure 7-2
Dilution Bridge Used for High-Concentration Particles

To begin with, the three-way valves are adjusted so that the flow is through A and B—the tube with a low-pressure-drop HEPA filter. An aerosol of unknown concentration enters the tubes at one end and exits at the other end. The concentration of the aerosol entering the dilution bridge is adjusted so that the output concentration measured by the CPC is in the range that has been previously calibrated by the electrical method. The three-way valves are then switched so that the flow is through tubes A and C. This doubles the concentration of the aerosol entering the CPC. Using this procedure, in sequence, the calibration can be carried to any range. The technique has been used successfully by Pollak [1959].

CHAPTER 8

Computer Interface and Commands

This chapter gives computer interface and communication information for the Model 3022A Condensation Particle Counter (CPC) as well as a transcript of the BASIC program provided with the CPC.

Computer Interface

This section gives the hardware connection information for the Model 3022A CPC and an IBM-compatible computer.

Pin Connectors

The Model 3022A Condensation Particle Counter (CPC) has one 9-pin, D-type subminiature connector on the back panel labeled COM PORT. An external computer, if used, should be connected to COM PORT (shown in Figure 8-1). If more than one CPC is used, each CPC must be connected to a separate COM port on the computer.

The communications port is configured at the factory to work with RS-232-type devices. RS-232 is a popular communications standard supported by many mainframe computers and most personal computers. Figure 8-1 shows the connector pins on the COM PORT; Table 8-1 lists the signal connections.

Note: *This pin configuration is not compatible with earlier TSI serial cables. The connections have been changed in this instrument to allow compatibility with the standard IBM AT-style serial cables.*

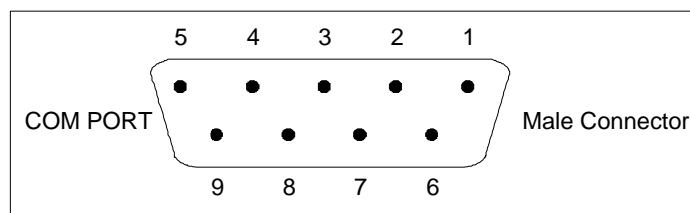


Figure 8-1
Connector Pin Designations

Table 8-1
Signal Connections for RS-232 Configurations

Pin Number	RS-232 Signal
1	GND
2	Transmit Output
3	Receive Input
4	(Reserved)
5	GND
6	—
7	—
8	—
9	—

Baud Rate

The baud-rate setting is the CPC's rate of communication in terms of bits per second (baud). The standard setting is 9600 baud, or about 960 characters per second. At higher baud rates, the distance between the computer and the CPC may need to be shortened to reduce transmission errors. The recommended maximum distance is 100 meters.

The baud rate, which must match that of the host device connected to the COM PORT. The possible baud rates are 110, 300, 600, 1200, 2400, 4800, 9600, and 19200. Select the baud rate in the configuration function (see Chapter 4).

Parity

Parity is the additional bit that accompanies data to confirm that it is transmitted correctly. It is set in the Configuration mode (Chapter 4) so that the number of "1" bits (HIGH) in a transmitted character is always an even number—hence, *even* parity. In the configuration mode you can select either even parity or no parity. The CPC uses even parity as the default setting.

Computer Commands

The commands that are transmitted to the CPC are ASCII strings; they are followed by a carriage return and a line feed. In response to any incorrect or undecipherable transmissions, the CPC transmits the word ERROR followed by a carriage return and line feed. Table 8-2 lists the commands and the CPC responses. A simple computer program written in BASIC is listed in the next section to demonstrate the possible interfacing that you can do with the CPC.

Table 8-2
Computer Commands

Command	Typical CPC Response	Description
Cx,y	OK	The Calibration command saves a concentration value for a given voltage. To enter the calibration data, the configuration paddle switch must first be in the enable position (see Figure 3-2). There are 121 calibration points in the CPC: "x" is any voltage in units of one-tenth of a volt. For example, 1 = 0.1 volt and 120 = 12.0 volts. "y" is particle concentration in particles/cm ³ , where 9,990,000 is the largest number allowed. Example: C0,0 C107,78900 C120,9990000
C	0,0	The C command by itself lists the calibration data.

continued

Table 8-2
Computer Commands *(continued)*

Command	Typical CPC Response	Description
D	Time Counts,0 0,0 . . (16) . . 0,0	The Dump command initiates a dump of the time and count data in the same manner as a Model 3701 or 7110 Multiplexer. The currently saved accumulator data is transferred to the serial port. "Time" is the number of seconds since the last D command (99,999,999 maximum). The Channel A (total) and Channel B counts are sent (99,999,999 counts maximum) for each of the 16 channels. Since the CPC has only one channel of data, Channel B and the last 15 pairs of data are all zero.
ESC	No Response	The Escape command (ASCII 27) causes the CPC to reset its address command to the power-on condition (null address) and then pass an ESC to Port B. This command does not require a carriage return or line feed.
I	Label	Identify calibration label.
L	OK	The L command inputs the calibration label (80 characters maximum). To enter the label, the configuration paddle switch must first be in the enable position (see Figure 3-2). A typical label might include the date of calibration and the working fluid.
R0	FULL NOTFULL	Read liquid level status
R1	10.0	Read condenser temperature, °C
R2	35.0	Read saturator temperature, °C
R3	36.0	Read optics temperature, °C
R4	5.01	Read flow, cm ³ /s

continued

Table 8-2
Computer Commands (*continued*)

Command	Typical CPC Response	Description
R5	READY NOTREADY	Read environment. READY implies that the temperatures, flow and alcohol level are all within the operating range.
R6	2.000	Read reference detector, volts (set for maximum of 2-4 volts)
R7	2.345	Read detector voltage, volts
R8	4410583	Read 200-second buffer (counts in the last 200 seconds)
R9	36773	Read 20-second buffer (counts in the last 20 seconds)
RA	3724	Read 2-second buffer (counts in the last 2 seconds)
RB	1771	Read 1-second buffer (counts in the last second)
RC	9441	Read photometric concentration, no matter what the concentration exponent range. Can also be 0 or 9990000 (overrange)
RD	2.34E2	Read the concentration as displayed on the front panel. The concentration may have been derived from the photometric calibration, single-particle counting or live-time counting.
RE	128	Read microprocessor pump-control value (a number from 0 to 255, corresponding to a pump voltage of approximately 1.55 to 12 volts).
S	3 0 . . . 0	The Sensor command sends data on the current saved sensor types (identical to the Model 3701 or 7110). Sensor type 3 is for the Model 3022A CPC or Model 3020 CNC. There are 16 lines total, the last 15 of which are zeros.

continued

Table 8-2
Computer Commands (*continued*)

Command	Typical CPC Response	Description
Vx	x	The Voltage Set command sets the analog output to "Host", where the response "x" is a number from 0 to 11000 that equals the desired voltage in millivolts. See Chapter 4, "Configuring the CPC."
Wdisplay	OK	Write a message to be displayed on the front panel display. For example: "WHello" displays "Hello" on the front panel. "W" returns the display to normal. The front panel has a maximum of 12 characters.
X0	OK	Execute laser <i>off</i>
X1	OK	Execute laser <i>on</i>
X2	OK	Execute pump motor <i>off</i>
X3	OK	Execute pump motor <i>on</i>
X4	OK	Execute draining (open drain valve)
X5	OK	Execute filling (close drain valve and open fill valve until full). The fill valve does not open if the liquid level sensor indicates that the reservoir is full.
X6	OK	Execute reset of concentration buffers
X7	OK	Execute low-flow mode
X8	OK	Execute high-flow mode

BASIC Program: TSICPC

The following BASIC program, which runs only on IBM personal computers or IBM-compatibles, demonstrates how the computer interfaces with the CPC using the commands described above. The program can be used to read concentration and total counts over regular preset time intervals. The data can be stored on disk or printed on a printer. A computer is not necessary for normal operation of the CPC.

The program is loaded on one 3.5-inch disk. To run the program, first boot the computer and load BASICA or a compatible BASIC interpreter. To load the program, type <LOAD "TSICPC.BAS"> and then type <RUN>.

The program has self-explanatory, easy-to-use menus. The various tasks performed by the program are explained in earlier sections of this manual.

This program is intended as a reference guide to those who wish to write their own software. It may be modified as desired. However, TSI cannot support any user-written software except as illustrated in this manual.

Note: *The display nested under (3) Read Menu, (D) Read time, counts and concentration, and (1) Start the measurement gives two concentration measurements. The first is the concentration that can be read from the front panel of the CPC. The second is the averaged concentration over the time interval. It is calculated by dividing the counts by the time and the flowrate:*

$$\text{Concentration} \left(\frac{\text{Particles}}{\text{cm}^3} \right) = \frac{\text{Counts}}{\text{Time} \times \text{Flowrate}}$$

```

11 REM
12 REM *****
14 REM
15 REM PROGRAM: TSICPC.BAS VERSION 1.2 8-FEB-1989
16 REM THIS PROGRAM IS A TEST PROGRAM FOR THE CPC 3022A. IT
18 REM PROVIDES THE COMMANDS FOR THE UNIT TO INTERFACE WITH THE
20 REM COMPUTER.
22 REM
24 REM *****
26 REM
28 CLEAR : KEY OFF : WIDTH 80
30 REM
34 OPTION BASE 1 : J =1 : PSIG$ = "OFF" : PFLAG = 2
36 REM
38 CLS : LOCATE 4,25 : PRINT " TSI INCORPORATED"
40 LOCATE 9, 18 : PRINT "*****"
41 LOCATE 10,18 : PRINT "*" *
42 LOCATE 11,18 : PRINT "*" TEST PROGRAM FOR CPC 3022A *
43 LOCATE 12,18 : PRINT "*" *
44 LOCATE 13,18 : PRINT "*****"
48 LOCATE 15,18 : PRINT "PRESS ENTER TO CONTINUE"
50 LOCATE 16,18 : PRINT "PRESS 'ESC' TO END"
52 REM
54 I$ = INKEY$ : IF I$ = CHR$(27) THEN CLS : END
56 IF I$ = "" THEN 54 ELSE 58
58 IF I% = CHR$(13) THEN 130 ELSE 54

```

```

126 REM
127 REM -----
128 REM
130 A = INP (1021) : OPEN "COM1:1200,E,7,1,RS,CS,DS,CD" AS #3
132 PRINT # 3, "A00" : GOSUB 9000
140 CLS : LOCATE 4,25 : PRINT "MAIN MENU"
142     LOCATE 7,15 : PRINT "( 1 ) REINITIALIZE THE ADDRESS OF THE UNIT"
144     LOCATE 8,15 : PRINT "( 2 ) PURGE THE UNIT"
146     LOCATE 9,15 : PRINT "( 3 ) READ MENU"
148     LOCATE 10,15 : PRINT "( 4 ) SET ANALOG OUTPUT VOLTAGE"
150     LOCATE 11,15 : PRINT "( 5 ) WRITE MESSAGE TO DISPLAY"
151     LOCATE 12,15 : PRINT "( 6 ) DELETE MESSAGE ON DISPLAY"
152     LOCATE 13,15 : PRINT "( 7 ) TASK MENU"
154     LOCATE 14,15 : PRINT "(ESC) TERMINATE THE PROGRAM"
156 I$ = INKEY$ : IF I$ = "1" THEN GOSUB 180 : GOTO 140
158             IF I$ = "2" THEN GOSUB 190 : GOTO 140
160             IF I$ = "3" THEN GOSUB 200 : GOTO 140
162             IF I$ = "4" THEN GOSUB 210 : GOTO 140
164             IF I$ = "5" THEN GOSUB 220 : GOTO 140
165             IF I$ = "6" THEN GOSUB 230 : GOTO 140
166             IF I$ = "7" THEN GOSUB 240 : GOTO 140
168             IF I$ = CHR$(27) THEN CLOSE # 3 : CLS : END
170             GOTO 156
171 END
172 REM
175 REM -----
176 REM
178 REM   REINITIALIZE THE UNIT TO A POWER ON CONDITION
179 REM
180 CLS : PRINT # 3, CHR$(27);
181 LOCATE 8,15 : PRINT "ENTER A NEW ADDRESS TO THE UNIT "
182 LOCATE 9,15 : PRINT "(the address can be 00 thru 99)"
183 LOCATE 12,18 : INPUT ADRES : AD$ = STR$(ADRES) : ADD$ = A$ + AD$
184 PRINT # 3, ADD$ : GOSUB 9000
185 RETURN
187 REM
188 REM   PURGE THE UNIT FOR THE GIVEN NUMBER OF SECONDS
189 REM
190 CLS : LOCATE 8,15 : PRINT "ENTER THE NUMBER OF SECONDS FOR PURGING"
191     LOCATE 9,15 : PRINT "(maximum is 999 seconds)"
192     LOCATE 10,15 : INPUT PTIME : PP$ = STR$(PTIME) : PL = LEN(PP$)
193     P% = "P" + RIGHT$(PP$,PL-1) : GOSUB 2000
194 RETURN
197 REM
198 REM   GO TO THE READ MENU FOR VARIOUS READINGS
199 REM
200 CLS : GOSUB 270 : RETURN
207 REM
208 REM   SET THE ANALOG OUTPUT VOLTAGE
209 REM
210 CLS : LOCATE 8,15 : PRINT "ENTER THE ANALOG OUTPUT VOLTAGE IN millivolt"
211     LOCATE 9,15 : PRINT "(maximum is 11000 millivolts)"
212     LOCATE 10,15 : INPUT AVOLT : AV$ = STR$(AVOLT) : AL = LEN(AV$)
213     AV$ = "V" + RIGHT$(AV$,AL-1)
214     PRINT # 3, AV$ : GOSUB 9000
215 RETURN
217 REM

```

```

218 REM WRITE MESSAGE TO DISPLAY ON THE FRONT PANEL
219 REM
220 CLS : LOCATE 8,15 : PRINT "ENTER THE MESSAGE TO BE DISPLAY ON THE PANEL"
221 LOCATE 9,15 : PRINT "(maximum # of characters is 12)"
222 LOCATE 10,15 : INPUT D$ : D$ = D$ + " " : WW$ = "W" + D$
223 PRINT # 3, WW$ : GOSUB 9000
225 RETURN
227 REM
228 REM CLEAR THE MESSAGE ON THE FRONT PANEL DISPLAY
229 REM
230 CLS : PRINT # 3, "W " : GOSUB 9000 : PRINT # 3, "W@" : GOSUB 9000
231 RETURN
237 REM
238 REM PERFORM VARIOUS TASKS -- TASK MENU
239 REM
240 CLS : LOCATE 4,25 : PRINT "TASK MENU"
241 LOCATE 7,15 : PRINT "( 1 ) EXECUTE LASER OFF"
242 LOCATE 8,15 : PRINT "( 2 ) EXECUTE LASER ON"
243 LOCATE 9,15 : PRINT "( 3 ) EXECUTE PUMP MOTOR OFF"
244 LOCATE 10,15 : PRINT "( 4 ) EXECUTE PUMP MOTOR ON"
245 LOCATE 11,15 : PRINT "( 5 ) EXECUTE DRAINING"
246 LOCATE 12,15 : PRINT "( 6 ) EXECUTE FILLING"
247 LOCATE 13,15 : PRINT "( 7 ) EXECUTE RESET OF CONCENTRATION BUFFER"
248 LOCATE 14,15 : PRINT "( 8 ) LOW FLOW SETTING"
249 LOCATE 15,15 : PRINT "( 9 ) HIGH FLOW SETTING"
250 LOCATE 16,15 : PRINT "(ESC) RETURN TO THE MAIN MENU"
251 I$ = INKEY$ : IF I$ = "1" THEN GOSUB 500 : GOTO 240
252 IF I$ = "2" THEN GOSUB 510 : GOTO 240
253 IF I$ = "3" THEN GOSUB 520 : GOTO 240
254 IF I$ = "4" THEN GOSUB 530 : GOTO 240
255 IF I$ = "5" THEN GOSUB 540 : GOTO 240
256 IF I$ = "6" THEN GOSUB 550 : GOTO 240
257 IF I$ = "7" THEN GOSUB 560 : GOTO 240
258 IF I$ = "8" THEN GOSUB 570 : GOTO 240
259 IF I$ = "9" THEN GOSUB 580 : GOTO 240
260 IF I$ = CHR$(27) THEN RETURN
261 GOTO 251
262 RETURN
267 REM
268 REM -----
269 REM
270 CLS : LOCATE 4,25 : PRINT "READ MENU" : FILE$ = ""
275 LOCATE 8,15 : PRINT "( 1 ) READ LIQUID LEVEL"
280 LOCATE 9,15 : PRINT "( 2 ) READ CONDENSOR TEMPERATURE"
290 LOCATE 10,15 : PRINT "( 3 ) READ SATURATOR TEMPERATURE"
300 LOCATE 11,15 : PRINT "( 4 ) READ OPTICS TEMPERATURE"
310 LOCATE 12,15 : PRINT "( 5 ) READ FLOW"
320 LOCATE 13,15 : PRINT "( 6 ) READ ENVIRONMENT"
330 LOCATE 14,15 : PRINT "( 7 ) READ REFERENCE DETECTOR"
340 LOCATE 15,15 : PRINT "( 8 ) READ DETECTOR VOLTAGE"
350 LOCATE 16,15 : PRINT "( 9 ) READ 200 SECOND BUFFER"
360 LOCATE 17,15 : PRINT "( A ) READ 20 SECOND BUFFER"
370 LOCATE 18,15 : PRINT "( B ) READ 2 SECOND BUFFER"
380 LOCATE 19,15 : PRINT "( C ) READ 1 SECOND BUFFER"
390 LOCATE 20,15 : PRINT "( D ) READ TIME, COUNTS AND CONCENTRATION"
391 LOCATE 21,15 : PRINT "( E ) READ THE MICROPROCESSOR PUMP CONTROL OUTPUT"
392 LOCATE 22M15 : PRINT "(ESC) RETURN TO THE MAIN MENU"

```

```

393 J$ = INKEY$ : IF J$ = "1" THEN GOSUB 2050 : GOTO 270
394         IF J$ = "2" THEN GOSUB 3000 : GOTO 270
395         IF J$ = "3" THEN GOSUB 3050 : GOTO 270
396         IF J$ = "4" THEN GOSUB 4000 : GOTO 270
397         IF J$ = "5" THEN GOSUB 4050 : GOTO 270
398         IF J$ = "6" THEN GOSUB 5000 : GOTO 270
399         IF J$ = "7" THEN GOSUB 5050 : GOTO 270
400         IF J$ = "8" THEN GOSUB 6000 : GOTO 270
401         IF J$ = "9" THEN GOSUB 6050 : GOTO 270
402         IF J$ = "A" THEN GOSUB 7000 : GOTO 270
403         IF J$ = "B" THEN GOSUB 7050 : GOTO 270
404         IF J$ = "C" THEN GOSUB 8000 : GOTO 270
405         IF J$ = "D" THEN GOSUB 8050 : GOTO 270
406         IF J$ = "E" THEN GOSUB 8950 : GOTO 270
407         IF J$ = CHR$(27) THEN RETURN
408         GOTO 393
409 RETURN
495 REM
496 REM -----
497 REM
498 REM   COMMANDS CORRESPOND TO THE TASK MENU
499 REM
500 PRINT # 3, "X0" : RETURN
510 PRINT # 3, "X1" : RETURN
520 PRINT # 3, "X2" : RETURN
530 PRINT # 3, "X3" : RETURN
540 PRINT # 3, "X4" : RETURN
550 PRINT # 3, "X5" : RETURN
560 PRINT # 3, "X6" : RETURN
570 PRINT # 3, "X7" : RETURN
580 PRINT # 3, "X8" : RETURN
590 REM
1996 REM -----
1997 REM
1998 REM   SUBROUTINE FOR PURGING
1999 REM
2000 PRINT # 3, P$
2001 CLS : LOCATE 5,15 : PRINT "PURGING IS IN PROGRESS"
2002 TT = TIMER + PTIME
2003 LOCATE 10,15 : PRINT "PURGING TIME IS IN " : LOCATE 10,42 : PRINT "SEC
ONDS:
2004 WHILE TIMER < (TT - .5)
2006     LOCATE 10,35 : PRINT INT(TT - TIMER)
2008 WEND
2009 GOSUB 9000
2010 RETURN
2012 REM
2046 REM -----
2047 REM
2048 REM   SUBROUTINE FOR READING THE LIQUID LEVEL
2049 REM
2050 PRINT # 3, "R0"
2052 GOSUB 9000 : IF ZZ$ = "" THEN 2052 ELSE 2054
2054 LIQLEVEL$ = ZZ$
2056 CLS : LOCATE 5,15 : PRINT "THE LIQUID LEVEL IS "; LIQLEVEL$
2058 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
2060 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 2060

```

```

2062 REM
2996 REM-----
2997 REM
2998 REM SUBROUTINE FOR READING THE CONDENSOR TEMPERATURE
2999 REM
3000 PRINT # 3, "R1"
3002 GOSUB 9000 : IF ZZ$ = "" THEN 3002 ELSE 3004
3004 CONDTEMP = VAL(ZZ$)
3006 CLS : LOCATE 5,15 : PRINT "THE CONDENSOR TEMPERATURE IS "; CONDTEMP ;
"oC"
3008 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
3010 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 3010
3012 REM
3046 REM-----
3047 REM
3048 REM SUBROUTINE FOR READING THE SATURATOR TEMPERATURE
3049 REM
3050 PRINT # 3, "R2"
3052 GOSUB 9000 : IF ZZ$ = "" THEN 3052 ELSE 3054
3054 SATTEMP = VAL(ZZ$)
3056 CLS : LOCATE 5,15 : PRINT "THE SATURATOR TEMPERATURE IS ";SATTEMP ; "o
C"
3058 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
3060 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 3060
3062 REM
3996 REM-----
3997 REM
3998 REM SUBROUTINE FOR READING THE OPTICS TEMPERATURE
3999 REM
4000 PRINT # 3, "R3"
4002 GOSUB 9000 : IF ZZ$ = "" THEN 4002 ELSE 4004
4004 OPTTEMP = VAL(ZZ$)
4006 CLS : LOCATE 5,15 : PRINT "THE OPTICS TEMPERATURE IS "; OPTTEMP ; "oC"

4008 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
4010 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 4010
4012 REM
4046 REM-----
4047 REM
4048 REM SUBROUTINE FOR REDING THE FLOW
4049 REM
4050 PRINT # 3, "R4"
4052 GOSUB 9000 : IF ZZ$ = "" THEN 4052 ELSE 4054
4054 FFLOW = VAL(ZZ$)
4056 CLS : LOCATE 5,15 : PRINT "THE FLOW IS "' FFLOW ; "cc/second"
4058 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
4060 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 4060
4062 REM
4996 REM-----
4997 REM
4998 REM SUBROUTINE FOR READING THE ENVIRONMENT
4999 REM
5000 PRINT # 3, "R5"
5002 GOSUB 9000 : IF ZZ$ = "" THEN 5002 ELSE 5004
5004 ENV$ = ZZ$
5006 CLS : LOCATE 5,15 : PRINT " THE ENVIRONMENT IS "; ENV$
5008 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"

```

```

5010      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 5010
5012 REM
5046 REM-----
5047 REM
5048 REM  SUBROUTINE FOR READING THE REFERENCE DETECTOR
5049 REM
5050      PRINT # 3, "R6"
5052      GOSUB 9000 : IF ZZ$ = "" THEN 5052 ELSE 5054
5054      REFDET = VAL(ZZ%)
5056      CLS : LOCATE 5,15 : PRINT "THE REFERENCE DETECTOR IS "; REFDET; "volt"

5058      LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
5060      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 5060
5062 REM
5996 REM-----
5997 REM
5998 REM  SUBROUTINE FOR READING THE DETECTOR VOLTAGE
5999 REM
6000      PRINT # 3, "R7"
6002      GOSUB 9000 : IF ZZ$ = "" THEN 6002 ELSE 6004
6004      DETVOLT = VAL(ZZ%)
6006      CLS : LOCATE 5,15 : PRINT "THE DETECTOR VOLTAGE IS "; DETVOLT; "volt"
6008      LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
6010      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 6010
6012 REM
6046 REM-----
6047 REM
6048 REM  SUBROUTINE FOR READING THE 200 SECOND BUFFER
6049 REM
6050      PRINT # 3, "R8"
6052      GOSUB 9000 : IF ZZ$ = "" THEN 6052 ELSE 6054
6054      BUF200 = VAL(ZZ%)
6056      CLS : LOCATE 5,15 : PRINT "THE 200 SECOND BUFFER IS "; BUF200
6057      LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
6058      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 6058
6060 REM
6996 REM-----
6997 REM
6998 REM  SUBROUTINE FOR READING THE 20 SECOND BUFFER
6999 REM
7000      PRINT # 3, "R9"
7002      GOSUB 9000 : IF ZZ$ = "" THEN 7002 ELSE 7004
7004      BUF20 = VAL(ZZ%)
7006      CLS : LOCATE 5,15 : PRINT "THE 20 SECOND BUFFER IS "; BUF20
7008      LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
7010      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 7010
7012 REM
7046 REM-----
7047 REM
7048 REM  SUBROUTINE FOR READING THE 2 SECOND BUFFER
7049 REM
7050      PRINT # 3, "RA"
7052      GOSUB 9000 : IF ZZ$ = "" THEN 7052 ELSE 7054
7054      BUF2 = VAL(ZZ%)
7056      CLS : LOCATE 5,15 : PRINT "THE 2 SECOND BUFFER IS "; BUF2
7058      LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
7060      I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 7060

```

```

7062 REM-----
7996 REM-----
7997 REM
7998 REM SUBROUTINE FOR READING THE 1 SECOND BUFFER
7999 REM
8000 PRINT # 3, "RB"
8002 GOSUB 9000 : IF ZZ$ = "" THEN 8002 ELSE 8004
8004 BUF1 = VAL(ZZ$)
8006 CLS : LOCATE 5,15 : PRINT "THE 1 SECOND BUFFER IS "; BUF1
8008 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
8010 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 8010
8012 REM
8046 REM-----
8047 REM
8048 REM MENU FOR THE CONCENTRATION, COUNTS AND TIME MEASUREMENTS
8049 REM
8050 CLS : LOCATE 4,25 : PRINT "CONCENTRATION MENU"
8052 LOCATE 7,15 : PRINT "( 1 ) START THE MEASUREMENT"
8054 LOCATE 8,15 : PRINT "( 2 ) SET THE TIME INTERVAL"
8056 LOCATE 9,15 : PRINT "( 3 ) STORE DATA IN DATA FILE"
8058 LOCATE 10,15 : PRINT "( 4 ) HAVE PRINTOUT DURING MEASUREMENT"
8059 LOCATE 11,15 : PRINT "( 5 ) NO PRINTOUT DURING MEASUREMENT"
8060 LOCATE 12,15 : PRINT "(ESC) RETURN TO THE READ MENU"
8061 LOCATE 22,5 : PRINT "PRINTER IS ' ' ; PSIG$ ; ' ' : "
8062 LOCATE 22,30 : PRINT "FILENAME IS ' ' ; FILE$ ; ' ' "
8063 LOCATE 23,5 : PRINT "TIME INTERVAL IS " ; DT ; "seconds"
8064 I$ = INKEY$ : IF I$ = "1" THEN GOSUB 8500 : GOTO 8050
8065 IF I$ = "2" THEN GOSUB 8800 : GOTO 8050
8066 IF I$ = "3" THEN GOSUB 8900 : GOTO 8050
8068 IF I$ = "4" THEN PFLAG = 1 : PSIG$ = "ON" : GOTO 8050
8070 IF I$ = "5" THEN PFLAG = 2 : PSIG$ = "OFF" : GOTO 8050
8072 IF I$ = CHR$(27) THEN CLOSE # 1 : RETURN
8074 GOTO 8064
8076 RETURN
8078 REM
8496 REM-----
8497 REM
8498 REM SUBROUTINE FOR THE CONCENTRATION, COUNTS AND TIME MEASUREMENTS
8499 REM
8500 CLS : LOCATE 4,10 : PRINT "THE TIME INTERVAL IN seconds"
8503 LOCATE 16,10 : PRINT "THE AVERAGE CONCENTRATION OVER THE TIME INTERVAL IN p
articles/cc"
8504 LOCATE 8,10 : PRINT "THE CPC CONCENTRATION IN particles/cc"
8506 LOCATE 12,10 : PRINT "THE COUNTS SINCE THE LAST MEASUREMENT "
8508 LOCATE 22,10 : PRINT "HIT 'S' TO STOP:"
8509 IF PFLAG = 1 THEN LPRINT " TIME CONCENTRATION COUNTS"
8510 REM
8512 GOSUB 8568 : IF I$ = "S" OR I$ = "s" THEN RETURN ELSE GOSUB 8532 : GOSUB 860
0
8514 REM
8516 IF PFLAG = 1 THEN PRINT # 1, REALT$, CON, TCOUNT, AVECON
8517 IF PFLAG = 1 THEN LPRINT REALT$, CON, TCOUNT, AVECON
8518 REM
8520 I$ = INKEY$ : IF I$ = "S" OR I$ = "s" THEN RETURN ELSE 8522
8522 IF I$ = "" THEN 8512 ELSE 8520
8526 REM
8528 REM READ CONCENTRATION

```

```

8530 REM
8532 PRINT # 3, "RD"
8533 GOSUB 9000 : IF ZZ$ = "" THEN 8533 ELSE 8534
8534 CONL = VAL(ZZ$) : IF CONL > 10000 THEN 8542 ELSE 8550
8536 REM
8538 REM READ PHOTOMETRIC CONCENTRATION
8540 REM
8542 PRINT # 3, "RC"
8544 GOSUB 9000 : IF ZZ$ = "" THEN 8544 ELSE 8546
8546 CONH = VAL(ZZ$)
8548 CON = CONH : GOTO 8558
8550 CON = CONL
8552 REM
8554 REM PRINTOUT THE CONCENTRATION
8556 REM
8558 LOCATE 10,18 : PRINT "          " : LOCATE 10,18 : PRINT CON
8559 RETURN
8560 REM
8561 REM-----
8562 REM
8564 REM SUBROUTINE FOR COUNTING THE TIME INTERVAL IN SECONDS
8566 REM
8568 T = TIMER + DT
8570 WHILE TIMER < (T - .5)
8571     IF T > 86399! AND TIMER < .5 THEN T = T - 86400!
8575     LOCATE 6,20 : PRINT INT(T - TIMER)
8576     I$ = INKEY$:IF I% = "s" OR I$ = "S" THEN RETURN
8578 WEND
8579 REM RETRIEVE THE REAL TIME FROM THE COMPUTER
8580 REM
8582 REALT$ = TIME$ ' the real time has the form "hh:mm:ss"
8584 RETURN
8586 REM
8596 REM-----
8597 REM
8598 REM SUBROUTINE FOR TAKING THE TOTAL COUNTS
8599 REM
8600 PRINT # 3, "D"
8602 GOSUB 9000 : TOTIME = VAL(ZZ$)
8604 GOSUB 9000 : N = LEN (ZZ$) : N1 = N - 2 : ZZZ$ = LEFT$(ZZ$,N1) : TCOUNT = VA
8605 AVECON = TCOUNT/(TOTIME*5)
L(ZZZ$)
8606 FOR I = 1 TO 15
8608     GOSUB 9000
8610 NEXT I
8612 LOCATE 14,18 : PRINT "          " : LOCATE 14,18 : PRINT TCOUNT

8613 LOCATE 18,18 : PRINT "          " : LOCATE 18,18 :
PRINT AVECON
8614 RETURN
8616 REM
8796 REM-----
8797 REM
8798 REM GET THE TIME INTERVAL
8799 REM
8800 CLS : LOCATE 10,5 : PRINT "ENTER THE TIME INTERVAL IN SECONDS"
8802 LOCATE 12,8 : INPUT DT

```



```

8804 RETURN
8806 REM
8896 REM-----
8897 REM
8898 REM INPUT THE DATA FILE NAME
8899 REM
8900 CLS : LOCATE 10,5 : PRINT "INPUT THE FILENAME OF THE DATA FILE"
8902 LOCATE 12,8 : INPUT FILE$
8904 OPEN FILE$ FOR OUTPUT AS # 1
8906 FFLAG = 1 'set FFLAG = 1 for storing the data
8908 RETURN
8910 REM
8912 REM-----
8940 REM
8942 REM SUBROUTINE FOR READING THE MICROPROCESSOR PUMP CONTROL OUTPUT
8944 REM
8950 PRINT # 3, "RE"
8952 GOSUB 9000 : IF ZZ$ = "" THEN 8952 ELSE 8954
8954 DUTYC = VAL(ZZ$) : DUTYV = 10.45/255! * DUTYC+1.55
8956 CLS : LOCATE 5,15 : PRINT "OUTPUT OF THE MICROPROCESSOR CONTROL :"
8958 LOCATE 6,20 : PRINT "(output of 0 is equivalent to 1.55 volt;"
8960 LOCATE 7,20 : PRINT " output of 255 is equivalent to 12 volt. )"
8962 LOCATE 8,22 : PRINT "OUTPUT = "; DUTYC; " ("; DUTYV; "volt)"
8964 LOCATE 22,15 : PRINT "HIT 'M' TO RETURN TO THE MAIN MENU"
8966 I$ = INKEY$ : IF I$ = "M" OR I$ = "m" THEN RETURN ELSE 8966
8968 REM
8970 REM-----
8996 REM-----
8997 REM
8998 REM SUBROUTINE TO TAKE DATA FROM CPC
8999 REM
9000 Z$ = "" : ZZ$ = "" : K = 0
9002 WHILE K < 1000
9004 IF LOC(3) > 0 THEN Z$ = INPUT$(1,#3) : K = 0
9006 IF Z$ = CHR$(13) THEN RETURN
9008 IF Z$ <> CHR$(10) AND Z$ <> "" THEN ZZ$ = ZZ$ + Z$ : Z$ = ""
9010 K = K + 1
9012 WEND
9014 RETURN
9016 REM
9020 REM*****

```


CHAPTER 9

Maintenance and Service

Regular maintenance of your CPC will help ensure years of useful operation. The frequency of service depends on the frequency of use and the cleanliness of the air measured. This section describes how to check and service some components of the CPC.

Changing the Filters

There are three filters inside the CPC. Change them at regular intervals (depending on use) or whenever they become dirty, clogged, or wet.

HEPA Filter

The large HEPA filter collects particles from the combination of sample flow and either bypass airflow or makeup airflow before the flow enters the pump. The filter has a very large surface area for collecting the particles and need not be changed very often.

To change the filter, remove the top cabinet cover and pull the filter out of its holding clips. Remove the two end fittings and replace them on a new filter. Make sure that the connections are leak-tight.

To order replacement HEPA filters, use TSI part number 1602051; or, you can order HEPA capsule filters (no. 12144) directly from the manufacturer:

Gelman Sciences, Inc.
600 S. Wagner Road
Ann Arbor, MI 48106 / USA
Telephone: (313) 665-0651
Telex: 810-223-6037

Tube Filter

The tube filter is in the sensor housing, surrounded by foam insulation. It filters out particles from the sample air after passing by the optical detector and before reaching the capillary flowmeter.

Replace it at least once a year (two are supplied in the accessory kit). Follow these six steps.

1. To replace the tube filter, first disconnect the fill bottle and drain the liquid from the CPC so you can tip it on end.
2. Remove the covers at the top and bottom of the cabinet.
3. Find the filter plug on the bottom of the CPC (Figure 9-1): the filter plug is on the lower right-hand side of the sensor housing.
4. Unscrew and remove the plug.
5. Pull out the filter tube and replace it with a new filter (Figure 9-2). Make sure the tube is centered and fits snugly inside the mounting hole.



Figure 9-1
Locating the Filter Plug on the Bottom of the CPC: (a) Power Supply PC Board; (b) Filter Plug; (c) Front Panel



Figure 9-2
Replacing the Filter Tube: (a) Filter

- 6. Replace the filter plug and tighten it so that the end of the plug is flush with the sensor housing.**

To order the tube filters, order part number 1602061; or, order a Microfibre filter tube (no. 050-11-BX) directly from the manufacturer:

Balston, Inc
703 Massachusetts Ave
P.O. Box C
Lexington MA 02173 / USA

Pump Exhaust Filter (DQ)

The pump exhaust filter is located between the exit port of the pump and the pump exhaust fitting on the back panel. The filter is not necessary to run the CPC but reduces noise from the pump and filters any particles generated from the pump that pass to the exhaust port. In time, the filter becomes clogged and causes the pump to work too hard.

To replace the filter using the replacement in the accessory kit, remove the cabinet covers and remove the filter from the pump exhaust fitting. Remove the tubing from both ends of the muffler and replace them with new.

To order the pump exhaust filter, order part number 1602080 from TSI; or order filter no. DFU-9933-05-DQ directly from the manufacturer:

Balston, Inc
703 Massachusetts Ave
P.O. Box C
Lexington MA 02173 / USA
Telephone: (800) 343-3048
TWX: 92-3481

Checking the CPC for Leaks

A leak anywhere in the CPC sensor upstream of the flowmeter changes the flowrate of the sample air. Symptoms of a leak include incorrect flows, incorrect particle concentrations, as well as larger and/or wider photodetector pulse heights than are indicated by the calibration data sheet.

To check the CPC for leaks, perform the following eight steps.

- 1.** Drain the liquid and switch off the power.
- 2.** Remove the top cabinet cover.
- 3.** Disconnect the pump from the leak-check by disconnecting the Swagelok fitting on the exit side of the HEPA filter.

4. Disconnect the pressure transducer air tubes and plug the ends. The pressure transducer must *not* be subjected to high vacuum or high pressure.
5. Plug the inlet of the CPC. Connect a vacuum source to the exit side of the HEPA filter. Connect a pressure gauge or manometer to the vacuum as shown in Figure 9-3. Place a shut-off valve between the vacuum pump and the pressure gauge.

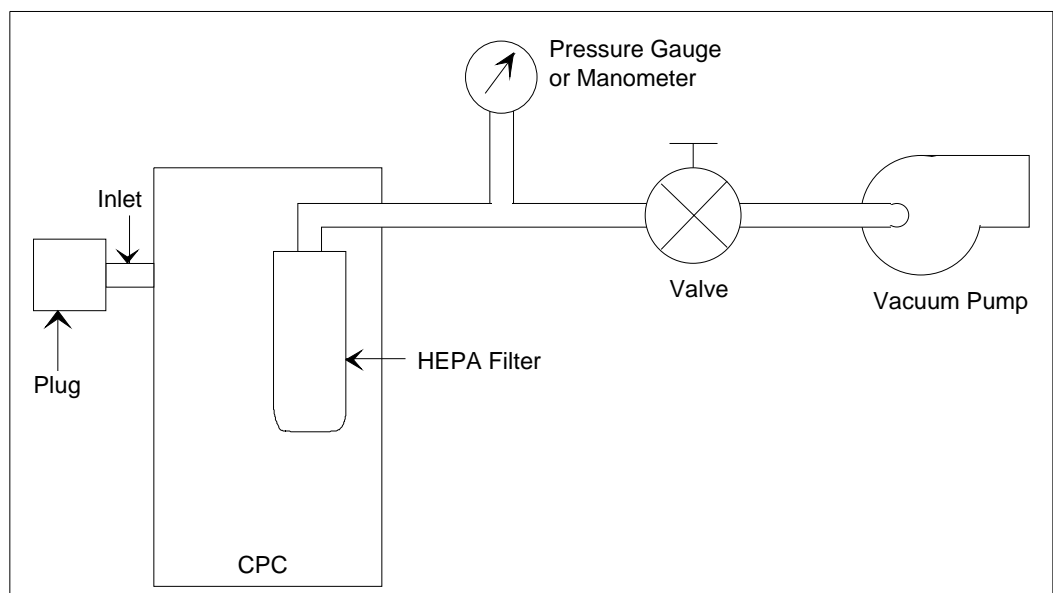


Figure 9-3
Checking for Leaks With a Vacuum

6. Draw at least 560 mm Hg [300 inches of water] vacuum through the instrument and close the valve. Switch off the vacuum pump.
7. Check that the CPC loses no more than 5.6 mm Hg [3 inches of water] vacuum in a 10-minute period.
8. If you find that the CPC leaks, first tighten all fittings and screws and repeat the vacuum test. To locate a small leak, replace the vacuum source with a compressed air source as shown in Figure 9-4. Introduce approximately 69 kPa [10 psig] into the CPC. Search for leaks by squirting a soap-and-water solution around fittings, O-ring seals and any other possible leak locations. A leak shows up as numerous small bubbles in the

soapy water. Repair the leak and retest with the vacuum leak test.

If you cannot locate and/or repair a leak yourself, contact TSI for assistance.

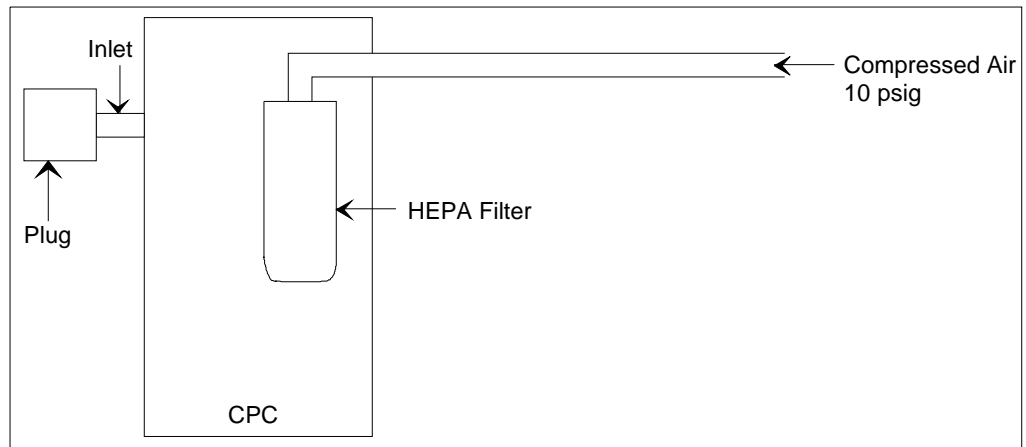


Figure 9-4
Checking for Leaks With Compressed Air

Installing an EPROM

Upgrading the EPROM is a special maintenance procedure. This procedure is not considered routine and should only be attempted by someone who is familiar with the operation of the CPC and who is technically qualified.

You are encouraged to call TSI for assistance in performing special maintenance. It may also be helpful to have the technician, tools, and the CPC close to the telephone when discussing the problem with a TSI technician. Refer to Chapter 9 for directions on contacting a technical resource at TSI.



C a u t i o n

To avoid damage to the CPC circuitry, use electrostatic discharge (ESD) precautions when removing the cover of the CPC:

- Use only a table top with a grounded conducting surface.
- Wear a grounded, static-discharging wrist strap

Refer to Figures 9-5 and 9-6 and the following instructions to install an EPROM in a Model 3022A CPC.

Tools Needed

You need a small, flat screwdriver or 28-pin chip extractor, a Phillips-head screwdriver, a grounded, static-discharging wriststrap, and an antistatic mat.

- 1.** Remove power from the CPC and from any other instruments connected to the CPC.
- 2.** Place the CPC on an antistatic mat. If the liquid reservoir is full, avoid tipping or moving the CPC so that liquid does not spill.
- 3.** Using Figure 9-5 as a reference, remove the following screws on the CPC. Separate the screws as you remove them so you can reassemble the CPC correctly.
 - a.** Remove three screws from each side of the CPC top cover and remove the top cover.
 - b.** Remove the four corner screws from the CPC front panel.
 - c.** Remove the four screws and washers from the CPC front panel connecting the panel to the side bars.
- 4.** Remove the front panel.

Note: *Optional*

The CPC front panel is connected to the display board with a ribbon cable. (The display board is the large circuit board parallel to the front panel.) As you remove the front panel, you can disconnect the ribbon cable on the display board, or you can leave it attached.

- 5.** Find the EPROM on the display board, the large circuit board parallel to the CPC front panel (Figure 9-6). To remove the old EPROM from the display board, use a 28-pin chip extractor or

insert the tip of a medium-size flat screwdriver under the short sides of the chip and *gently* twist.

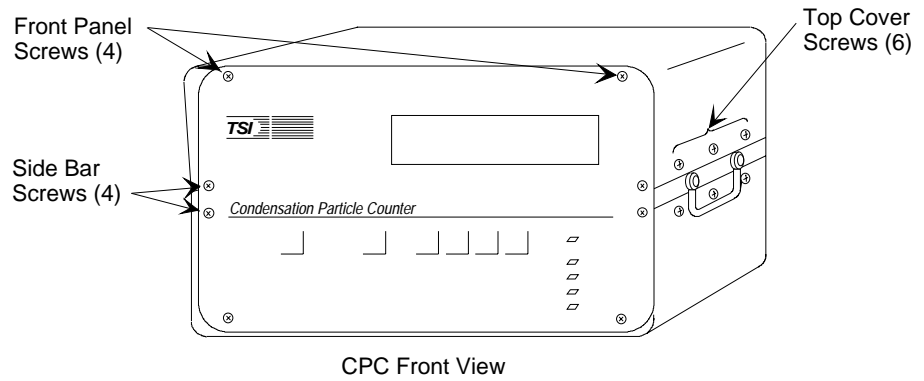


Figure 9-5
Model 3022A CPC Screw Locations

6. Remove the updated version of the EPROM from its static protective wrapper.

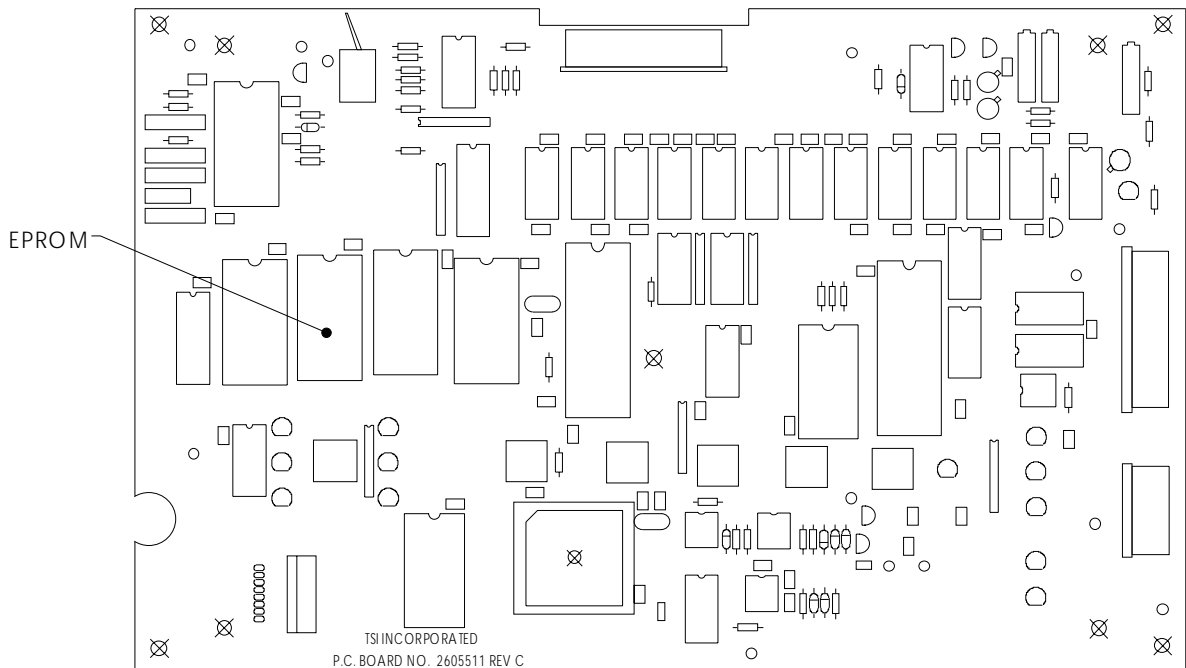


Figure 9-6
EPROM Location on the Model 3022A CPC Display Board

- 7.** Align the new EPROM in the socket, making sure the EPROM's notch matches the notch on the circuit board (Figure 9-6). Apply pressure to the center of the chip until it snaps down into the socket. Press *firmly* to make sure it is seated properly and ensure there are no bent or unseated pins.
- 8.** Using Figure 9-5 as a reference, reassemble the CPC:
 - a.** If disconnected, reconnect the ribbon cable connector to the display board.
 - b.** Replace the front panel, threading the inlet nozzle through the hole on the panel and positioning the top of the panel so it is level with the CPC chassis.
 - c.** Replace four screws with washers on the CPC front panel, attaching the panel to the side bars.
 - d.** Replace four corner screws on the CPC front panel, attaching the panel to the chassis.
 - e.** Replace the top cover on the CPC. Make sure the vented side of the cover is opposite the CPC fan. Attach the cover with six screws.
- 9.** Apply power to the CPC and make sure the LEDs function.
- 10.** If the CPC is not functioning properly, remove power and make sure the EPROM is positioned correctly and seated, and there are no bent pins. If the CPC still does not function properly, contact a TSI representative for assistance.

Failures

The microprocessor in the CPC checks many of the internal parameters for functional failures. If your CPC should encounter any of these failures, the front panel will read "FAILURE #X" where "X" is the code number of the failure. The following table lists the failures and possible ways to correct them. If you cannot fix the problem yourself, call TSI for assistance.

Table 9-1
Troubleshooting CPC Problems

No.	Problem	Suggested Solution
1	Optics temperature is out of normal operating range.	Change optics thermistor.*
2	Condenser temperature is out of normal operating range.	Change condenser thermistor.*
3	Saturator temperature is out of normal operating range.	Change saturator thermistor.*
4	Calibration data is nonmonotonic because the calibration data is missing or incorrect.	Reload the calibration.*
5	A/D measuring the 10-volt reference is out of range (8000–15,000 equivalent counts per 10 volts).	Recalibrate the A/D in the configuration (Chapter 4). Check that the D/A is producing 10 volts.
6	Total maximum number is invalid.	Rerun the configuration (Chapter 4)
7	Analog output voltage is invalid.	Rerun the configuration (Chapter 4)
8	Baud rate is invalid.	Rerun the configuration (Chapter 4)
9	Divide by 0 error (internal processing error)	Remove, then re-apply power.

*Contact TSI Incorporated.

Technical Contacts

- ❑ If you have any difficulty installing the CPC, or if you have technical or application questions about this instrument, contact an applications engineer at TSI Incorporated, (651) 490-2833.
- ❑ If the CPC fails, or if you are returning it for service, contact TSI Customer Service at 1-800-874-2811 (USA) or (651) 490-2811.

Returning the CPC for Service

Call TSI Customer Service at 1-800-874-2811 (USA) or (651) 490-2811 for specific return instructions. Customer Service will need this information when you call:

- The instrument model number
- The instrument serial number
- A purchase order number (unless under warranty)
- A billing address
- A shipping address.

Read the instructions in Chapter 3 under “Operating Specifications and Precautions” before moving the CPC. Use the original packing material to return the instrument to TSI. If you no longer have the original packing material, seal off the inlets and outlets to prevent debris from entering the instrument and ensure that the indicator lights and the connectors on the instrument front and back panels are protected.

Applications

The following discussion covers just a few of the many applications for the CPC.

Clean Air

The 3022A CPC is ideal for measuring low particle concentrations. Since the particle-pulse amplitude is relatively high, there is little likelihood of falsely triggering on electrical noise when no particles are present. The accuracy of the single-particle-counting mode is limited only by the accuracy of the flowrate.

However, the 3022A CPC may not be suitable for placement in very clean areas since its pump, fan and hot electrical components may produce some contaminating particles. If you wish to use the CPC in a cleanroom or clean zone, place the instrument downstream and out of the way of any critical clean areas.

The Model 3010 CPC, the Model 7610 (formerly Model 3760) or Model 7620 (formerly Model 3761) Cleanroom CPC is more suitable for monitoring clean areas because these instruments are designed not to produce particles. Please contact TSI for more information about these CPCs.

Using the CPC With a Multiplexer/Processor

The TSI line of Multiplexer/Processors (M/P) are central, data collection and data processing instruments for up to 16 cleanroom-monitoring particle sensors or environmental sensors. They require a digital, 13-volt input pulse, 6.4-microseconds wide. The maximum concentration that can be collected is 350 particles/cm³ [10 million/ft³]. The Mux Output on the back panel of the CPC provides the correct digital pulse output for the M/P.

Testing Filter Efficiency

The CPC is ideal for testing the efficiency of filters because of its high concentration limit of 9.99×10^6 particles/cm³ and its extreme accuracy at low concentrations. At high concentrations there is no need for a diluter. Since the CPC detects nearly 100 percent of particles above 0.02 micrometer, the CPC can detect all particles in the size range of interest.

The filter testing paper in Appendix C describes the use of a CPC for testing filters. The CPC discussed here is very similar to the Model 3022A CPC.

Using the CPC With a Diffusion Battery

The CPC measures the number concentration of an aerosol, but gives no information about its size distribution; the droplet size is independent of the size of the initial particle. A diffusion battery separates particles according to their size for particle diameters below about 0.2 micrometer. For a more complete measurement of the concentration and size distribution of an aerosol, operate the CPC in series with a diffusion battery.

TSI's Model 3040/3042 Diffusion Battery and Switching Valve consists of a diffusion battery with a pump, flowmeter, and automatic switcher for sampling successive ports in the battery. The system in Figure 10-1 automatically steps through the ports to make repeated measurements of the concentration and size distribution of any test aerosol smaller than 0.2 micrometer. Use the CPC's low-flow mode and plug the makeup air when sampling from the diffusion battery or switching valve.

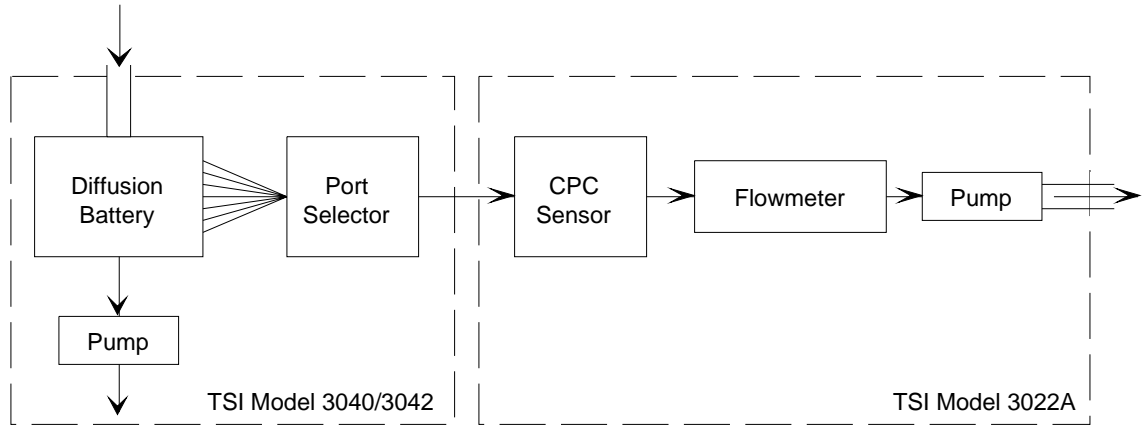


Figure 10-1
CPC, Diffusion, Battery and Switching Valve System for Measuring the Size Distribution of Aerosols Below 0.2 Micrometer in Diameter

Differential Mobility Particle Sizer

A higher resolution system that measures size distribution consists of a CPC with an electrostatic classifier (EC) along with interconnecting hardware and software. Figure 10-2 shows the DMPS system in the underpressure mode.

The 3022A CPC has an advantage over the earlier Model 3020 CPC because it can control the EC's center-rod voltage directly from the CPC. There is no need for an additional interface box.

To electrically connect the CPC to the EC, connect a cable from the analog BNC port on the back panel of the CPC to the BNC connector on the back of an EC. Connect the computer's interface cable between the serial port of the computer and the COM PORT on the back panel of the CPC. Set the analog output to HOST (see "Configuration" in Chapter 4). To run the DMPS system, follow the instructions given in the menus of the DMPS computer program.

The tubing connections depend on the flowrate you select for the electrostatic classifier. For monodisperse aerosol flows greater than 1.5 liters per minute, run the CPC in the high-flow mode. For monodisperse aerosol flows less than 1.5 liters per minute, you must run the CPC in the low-flow mode. In the low-flow mode, you

need to plug the makeup air flow to force more air to be drawn from the reduced-pressure inlet (see "Inlet Pressure" in Chapter 4).

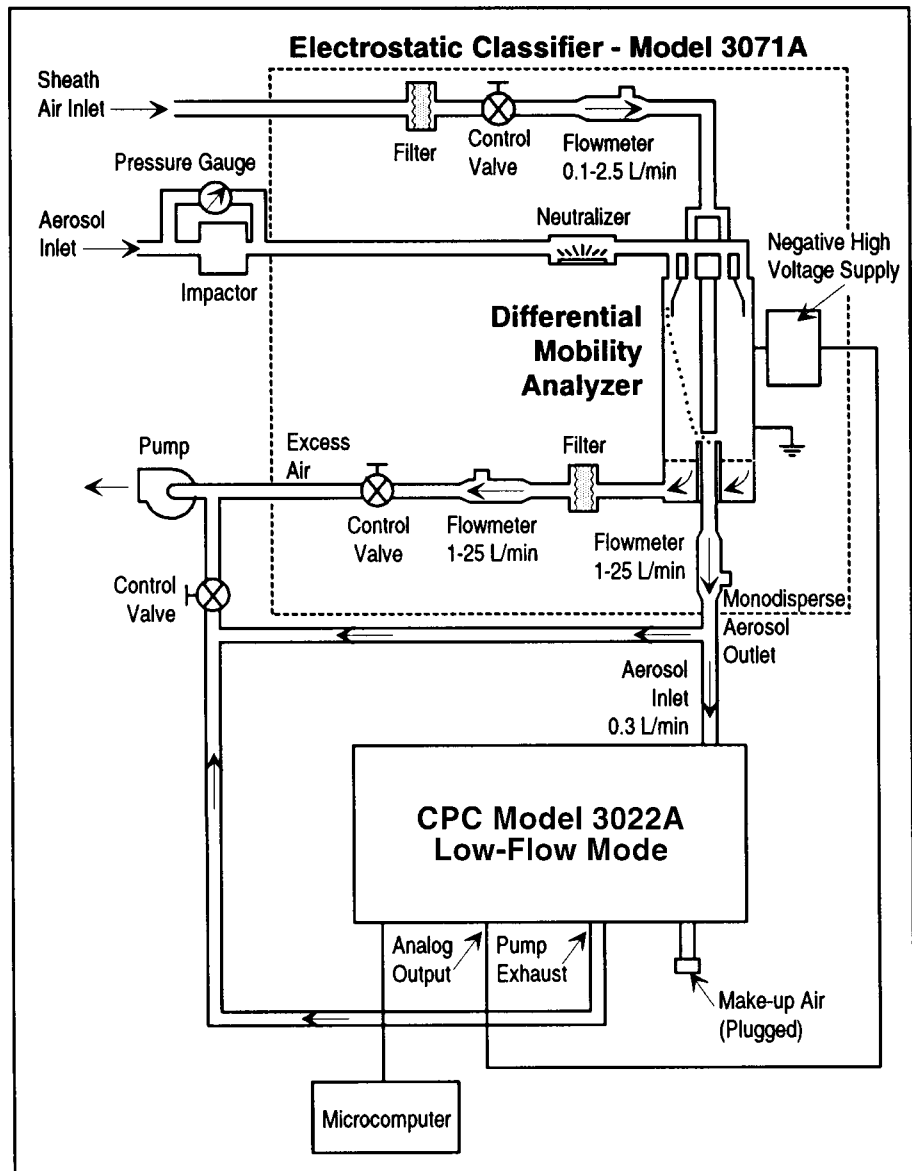


Figure 10-2
Schematic of the DMPS/CPC in the Underpressure Mode

APPENDIX A

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The following sources have been used in the text of this manual.

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APPENDIX B

Specifications

The following specifications—which are subject to change—describe the most important data of the major components.

Table B-1
Specifications of the Model 3022A CPC

Minimum particle size	50% detection at .007 μm 90% detection at 0.015 μm
Flowrate	
Sensor	0.3 L/min \pm 0.015 L/min
Inlet, high-flow	1.5 L/min \pm 0.15 L/min
Inlet, low-flow	0.3 L/min \pm 0.015 L/min
Working fluid	
n-butyl alcohol	
saturator temperature	35°C \pm 0.3°C
condenser temperature	10°C \pm 0.3°C
optics temperature	36°C \pm 2.0°C
Concentration	0 to 9.99×10^6 particles/cm ³
Accuracy	\pm 10% up to 5×10^5 /cm ³ \pm 20% from 5×10^5 to 9.99×10^6 /cm ³
Particle-pulse height of the photodetector	\cong 1.4 V typical
Laser power	\cong 3–5 mW
Detector	See calibration data, Appendix D
Environmental conditions	Indoor use Altitude up to 2000 m (6500 ft) Ambient temperature range n-butyl alcohol 10–37°C Ambient humidity 0–90% RH noncondensing Overvoltage category II Pollution degree II
False background counts	0.01 particle/cm ³
Response time.....	<13 seconds for 95% to concentration step changes
Dimensions L \times H \times W (nominal)	24 cm \times 20 cm \times 38 cm (9.5 in. \times 8 in. \times 15 in.)
Weight	11 kg (25 lb)
Power	100/120 V at 50/60 Hz, 200 W, 1.2 amps maximum 230/240 V at 50/60 Hz, 200 W, 0.6 amps maximum
Fuse	100/120V ~ T 2.0A/250V 230/240V ~ T 1.0A/250V

APPENDIX C

Technical Papers

This appendix contains two technical papers:

Agarwal, J.K. and G. J. Sem [1978]

“Generating Submicron Monodisperse Aerosols for Instrument Calibration”

TSI Quarterly, Vol. 4, No. 2, May–June, pp. 3–8

Agarwal, J.K., G.J. Sem and R.J. Remainz [1985]

“Filter Testing With a Continuous-Flow, Single-Particle-Counting Condensation Nucleus Counter”

TSI Quarterly, Vol. 11, No. 1, January–March, pp. 3–12

GENERATING SUBMICRON MONODISPERSE AEROSOLS FOR INSTRUMENT CALIBRATION

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 TSI Incorporated, St. Paul, Minnesota

The electrostatic classification method is the only known technique for generating monodisperse submicron aerosol of known size. Conventionally, an aerosol electrometer measures the particle concentration of such aerosol. A newly developed condensation nucleus counter, capable of counting single particles, provides another primary method for submicron particle concentration measurements. We found the experimental agreement between these two primary methods to be within 5%.

I. Introduction

A monodisperse aerosol of known size and concentration is useful for instrument calibrations, for basic research on the behavior of aerosols, and for studies of other physical phenomena. The electrostatic classification method of Liu and Pui¹ is the only known technique for generating submicron monodisperse aerosols of known size and concentration. The purpose of this paper is to describe the electrostatic classification method and its application in calibrating a newly developed condensation nucleus counter.

II. Description

The basic electrostatic classification method consists of first generating a polydisperse aerosol with an atomizer and then extracting particles within a narrow size range from this aerosol with a differential electrical mobility classifier. An aerosol electrometer measures particle concentration.

Figure 1 schematically shows the complete system needed to generate monodisperse aerosol for instrument calibration. The first element is an air supply system (TSI Model 3074) used to supply clean, dry air to the

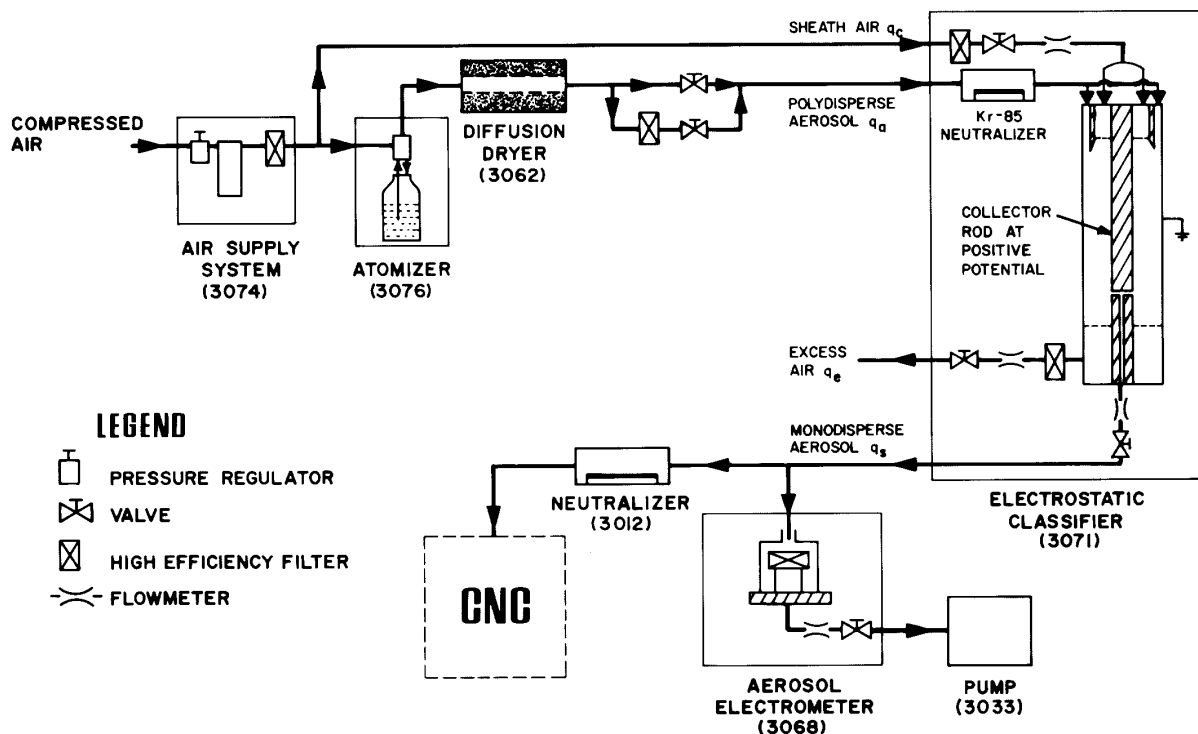


Figure 1. Schematic representation of the electrostatic classification method for generating submicron monodisperse aerosol. TSI model numbers shown in parentheses.

atomizer and to the classifier. The air supply contains a pressure regulator, desiccant air drier, and high efficiency filter. The desiccant air drier removes water and oil vapors from a laboratory compressed air supply. The second element of the system is an atomizer (TSI Model 3076) used to generate polydisperse aerosol. The atomizer, using a recirculating solution, can generate polydisperse aerosol from nearly any water soluble material. The polydisperse aerosol then enters a diffusion drier where the aerosol dries without being diluted. The diffusion drier consists of an inner cylinder made of wire screen and an acrylic outer cylinder. The annular space between the two tubes contains silica gel which absorbs moisture from aerosol passing through the inner tube. The dried polydisperse aerosol then enters the electrostatic classifier (EC, TSI Model 3071).

Classifier

In the EC, a Kr-85 radioactive source brings the polydisperse aerosol to a stable, Boltzmann equilibrium charge level. This process is called aerosol neutralization. At this equilibrium state, the distribution of charges on the particles is given by Boltzmann's Law:

$$\frac{N_{n_p}}{N_0} = \exp\left(\frac{-n_p^2 e^2}{D_p kT}\right) \quad (1)$$

where N_{n_p} and N_0 are the relative number of particles carrying n_p and 0 units of charge, D_p is particle diameter, k is Boltzmann's Constant, T is absolute temperature, and e ($= 1.6 \times 10^{-19}$ coulombs) is the elementary unit of charge. Table I shows the predicted charge distribution according to Boltzmann's Law for particles of various sizes. For $D_p < 0.1 \mu\text{m}$, Table I shows that the majority of particles are either neutral or singly charged.

The neutralized aerosol then enters a differential mobility analyzer (DMA) which classifies the particles according to their electrical mobility. The electrical mobility of a particle is a measure of its ability to move in an electrical field, expressed as the field-induced velocity component per unit electric field intensity. For spheres, the electrical mobility Z_p is related to particle diameter D_p by Equation 2:

$D_p, \mu\text{m}$	Percent of particles carrying n_p elementary charge units								
	$n_p = -4$	-3	-2	-1	0	+1	+2	+3	+4
0.01					0.34	99.32	0.34		
0.02					5.23	89.53	5.23		
0.04					16.22	67.10	16.22	0.23	
0.06				0.23	16.22	67.10	16.22	0.23	
0.08		0.01	1.25	21.30	54.88	21.30	1.25	0.01	
0.10		0.08	2.78	23.37	47.53	23.37	2.78	0.08	
0.20		0.26	4.39	24.09	42.52	24.09	4.39	0.26	
0.40	0.32	2.33	9.66	22.63	30.06	22.63	9.66	2.33	0.32
0.60	2.19	5.92	12.05	18.44	21.26	18.44	12.05	5.92	2.19
0.80	3.82	7.41	11.89	15.79	17.36	15.79	11.89	7.41	3.82
1.00	4.83	7.94	11.32	14.00	15.03	14.00	11.32	7.94	4.83
1.00	5.42	8.06	10.71	12.70	13.45	12.70	10.71	8.06	5.42

Table I. Distribution of charges on aerosol particles according to Boltzmann's Law²

$$Z_p = \frac{neC}{3\pi\mu D_p} \quad (2)$$

where n is the number of elementary charges on the particle, μ is the gas viscosity, and C is the Cunningham slip correction. Figure 2 shows the relationship between electrical mobility and particle diameter for singly-charged particles.

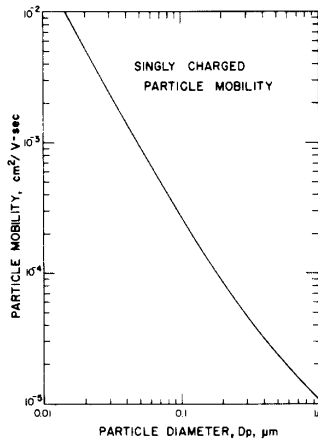


Figure 2. Electrical mobility as a function of particle diameter for singly-charged particles.

Figure 3 schematically shows that the DMA consists of two concentric metal cylinders. Polydisperse aerosol (q_a) and clean sheath air (q_c) enter the analyzer at the top and flow laminarily down the annular space between the cylinders. The aerosol surrounds the central clean air core. A negative volt-

age, applied to the inner metal cylinder (collector rod), causes the particles of positive polarity to be attracted to the collector rod. Particles with higher mobility are precipitated on the upper portion of the rod and those with lower mobility are carried along with the excess air. Only a few particles within a narrow range of electrical mobilities exit through the slit at the bottom of the collector rod.

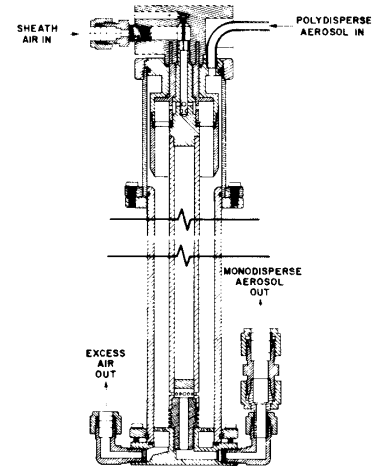


Figure 3. Cross-sectional view of the differential mobility analyzer.

The mean electrical mobility Z_p of the particles extracted through the slit is given by:

$$Z_p = \frac{[q_t - \frac{1}{2}(q_s + q_a)] \ln \frac{r_2}{r_1}}{2\pi VL} \quad (3)$$

where q_t is total air flow, q_a is polydisperse aerosol flow and q_s is monodisperse aerosol flow, r_1 and r_2 are the inner and outer radii of the annular space, V is the applied voltage on the collector rod, and L is the length of the collector rod between the center of the aerosol entrance and the center of the exit slit.

Particles carrying no charge have zero electrical mobility and are not extracted through the slit of the collector rod. Table I shows that, for particles smaller than $0.1 \mu\text{m}$, the singly-charged particles outnumber the particles with more charges. Thus, if we set the collector rod voltage to extract particles smaller than $0.1 \mu\text{m}$, particles exiting from the differential mobility analyzer will be essentially singly-charged. The diameter of particles exiting through the slit for any voltage setting, can then be calculated from Equations 2 and 3. Figure 4 shows the relationship between the diameter of singly-charged particles and the collector rod voltage for normal operating conditions of the commercial DMA.

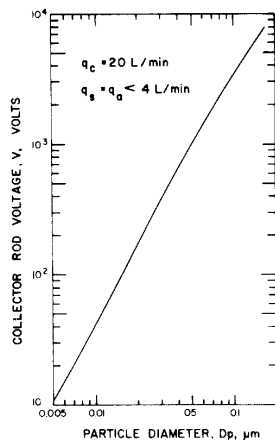


Figure 4. Collector rod voltage as a function of particle diameter for normal operating conditions of the DMA.

Aerosol Electrometer

An aerosol electrometer (AE, TSI Model 3068) measures the particle concentration of aerosol exiting from the classifier. Aerosol is drawn into the AE by an external pump. A built-in flowmeter measures aerosol sample rate. An electrically isolated high efficiency filter collects the charged particles. A highly sensitive electrometer measures the electrical current draining from

the filter. Since the particles exiting from the classifier are primarily singly-charged, the electrometer current is directly proportional to particle concentration. The particle concentration N of the sampled aerosol is:

$$N = I/eQ \quad (4)$$

where I is electrometer current, e is the elementary unit of charge, and Q is volumetric aerosol flow rate.

III. Interference Effect of Multiply-Charged Particles

The output aerosol contains not only the singly-charged particles of the desired size, but also some multiply-charged particles of larger sizes. A first approximation for correcting the effect of doubly-charged particles was described by Pui and Liu². Figure 5 shows the size distribution of polydisperse aerosol generated by an atomizer. Let us suppose that we set the DMA to extract $0.2 \mu\text{m}$ singly-charged particles. According to Table I, 22.6% of $0.2 \mu\text{m}$ particles carry one positive unit of charge. This is represented by the cross-hatched area under the curve at $0.2 \mu\text{m}$. The doubly-charged particles of $0.32 \mu\text{m}$ diameter have the same electrical mobility as the singly-charged particles of $0.2 \mu\text{m}$.

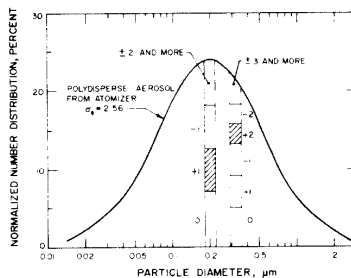


Figure 5. Typical size distribution of the polydisperse aerosol generated by an atomizer. Singly-charged particles and doubly-charged particles of same mobility are extracted by the DMA².

These particles are also extracted through the slit of the DMA. The AE counts each $0.32 \mu\text{m}$ particle as two $0.2 \mu\text{m}$ particles. To account for doubly-charged particles, Equation 4 is rewritten:

$$N = \frac{I}{eQ} K_2 \quad (5)$$

where K_2 is the correction factor accounting for the interference effect of doubly-

charged particles, ignoring any particles with more than 2 charges. Let us suppose that the concentration of singly-charged and doubly-charged particles in the aerosol extracted from the DMA are N_1 and N_2 respectively. Then the electrometer current I is:

$$I = Q(N_1 e + N_2 2e) = QN' e \quad (6)$$

Where N' is the apparent particle concentration. The true particle concentration N is:

$$N = N_1 + N_2 \quad (7)$$

Combining Equations 6 and 7:

$$K_2 = \frac{N}{N'} = \frac{N_1 + N_2}{N_1 + 2N_2} = \frac{1 + N_2/N_1}{1 + 2N_2/N_1} \quad (8)$$

The ratio N_2/N_1 , and hence K_2 , is calculated from the particle size distribution of incoming polydisperse aerosol and Boltzmann's Law.

The median size of a polydisperse aerosol generated by a standard atomizer is controlled by atomizing a solution of specific concentration. Figure 6 shows the relationship between median particle diameter of the polydisperse aerosol and solute concentration in the recirculating atomizer. The concentration of the solute must be selected so that the median diameter of the polydisperse aerosol matches the monodisperse aerosol exiting from the EC. For this condition, the particle concentration of monodisperse aerosol exiting from the EC is maximized. The EC should not be used to extract monodisperse particles smaller than the median size of incoming polydisperse aerosol because the interference effect of multiply-charged particles increases significantly.

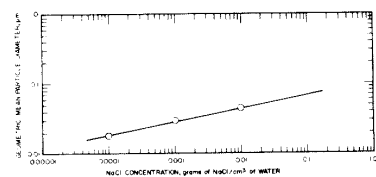


Figure 6. Relationship between NaCl concentration and mean particle diameter for TSI Model 3076 Atomizer.

The electrostatic classification method described above provides a convenient source of monodisperse aerosol for instrument

calibration. The diameter of the aerosol particles is calculated using Equations 2 and 3. The AE measures particle concentration. Equation 5 describes the number concentration of the monodisperse aerosol in terms of AE measurements. The result is a monodisperse submicron aerosol with known particle diameter and concentration. The next section describes the application of this system to the calibration of a condensation nucleus counter (CNC).

IV. Calibration of CNC

A CNC is an instrument which measures the number concentration of submicron aerosol particles. Figure 7 schematically shows a new CNC³ (TSI Model 3020). Aerosol first enters an inclined tube covered with a Dacron felt lining which saturates the aerosol with n-butyl alcohol vapor at 35°C. The saturated aerosol then enters a vertical condensation tube maintained at 10°C. In the condenser, alcohol vapor condenses on the aerosol particles, making the particles grow into larger droplets. The droplets then exit through a 1.0 mm diameter nozzle into a viewing volume illuminated by a narrow beam of light. The light beam is generated by an optical system consisting of a light bulb, a focusing lens, a narrow slit aperture, and an imaging lens. The beam is

stopped before the receiving lens. The receiving lens collects light scattered by the droplets and focuses the scattered light onto a photodetector.

The CNC has two modes of operation: (1) count mode and (2) photometric mode. In the count mode, the CNC counts electrical pulses generated by the light scattered from individual droplets as they pass through the viewing volume. The instrument calculates particle concentration from the number of pulses per second and the aerosol sample rate. The CNC automatically switches to the photometric mode if particle concentration is higher than 10^3 particles/cm³. In the photometric mode, the CNC detects the mean dc level of total light scattered by all particles in the viewing volume. In this mode, the CNC must be calibrated with an aerosol of known concentration.

We generated 0.05 μm diameter NaCl aerosol using the system shown in Figure 1. We used a 0.001 gm/cm³ NaCl-water solution in the atomizer. We adjusted the pressure regulator of the air supply system to 35 psig (240 kPa). We connected the output of the atomizer to the polydisperse aerosol inlet of the EC through a dilution system (see Figure 1). We varied the particle concentration of monodisperse aerosol

exiting from the classifier by changing the concentration of polydisperse aerosol entering the classifier. Sheath air, monodisperse aerosol, and excess air flow rates of the classifier were 20, 3, and 20 L/min, respectively. The collector rod voltage was 1 kV.

The monodisperse aerosol exiting from the classifier was simultaneously sampled by the AE and the CNC. A Kr-85 radioactive source neutralized the aerosol entering the CNC. The AE sample rate was 2 L/min. We obtained a maximum particle concentration of 2×10^5 particles/cm³ using this arrangement. By setting the pressure regulator of the air supply system at 55 psig (380 kPa) we obtained a maximum particle concentration of 7×10^5 particles/cm³. Figure 8 shows the CNC photodetector output as a function of aerosol particle concentration. All data points shown in Figure 8 were obtained in a few hours. The scatter between calibration points is small.

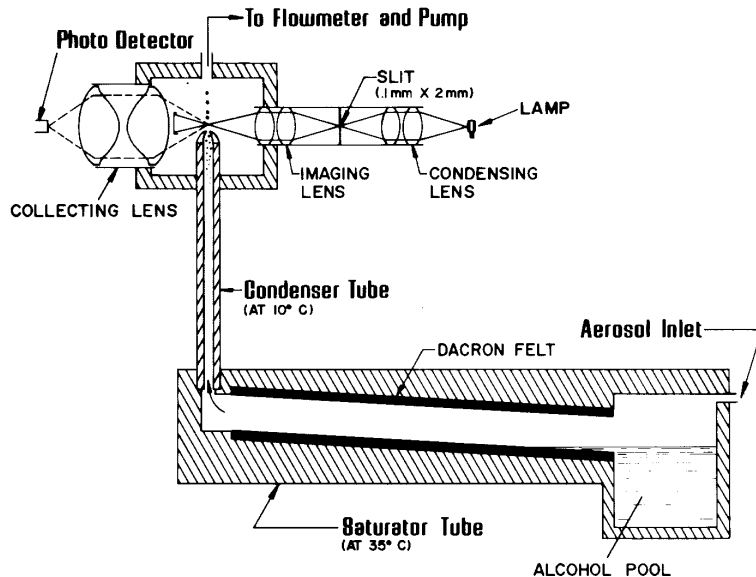


Figure 7. Schematic diagram of the condensation nucleus counter.

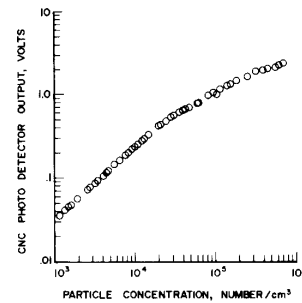


Figure 8. Calibration of CNC in the photometric mode.

The electrostatic classification method described above provides a fast, convenient, primary method for calibrating submicron instruments. Other methods, such as collecting the particle samples on a substrate and then counting them under an electron microscope are expensive and time consuming. We have extensively used this method during the development of the CNC to optimize various operating parameters of the CNC. We could change a parameter and recalibrate the CNC (5 - 10 data points) in less than one hour, saving considerable time over any other known method.

V. Comparison Between the AE and the CNC Count Mode

The CNC operating in the count mode provides another primary method for measuring the particle concentration of submicron

aerosol. In this mode, the particle concentration is computed from the number of pulses counted per second and the aerosol sample rate. However, the occasional presence of multiple particles in the sensing volume at a given time limits this method to particle concentrations below 1000 particles/cm³. We compared the CNC operating in the count mode with AE measurements. For this comparison, we mixed the excess air and the monodisperse aerosol exiting from the EC and fed this diluted aerosol to the AE and the CNC. The AE sampled aerosol at a rate of 10 L/min. Figure 9 shows the comparison between the two techniques. The CNC readings were corrected for coincidence losses³. The two primary methods agree within 5% of each other, well within the limits of experimental accuracy. Such close agreement between two independent, primary methods not only proves the validity of both methods, but also testifies to the precision of both methods.

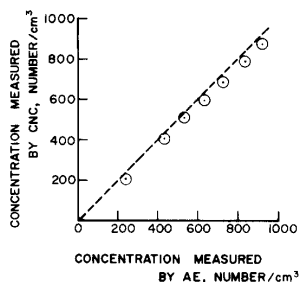


Figure 9. Comparison between the aerosol electrometer and the CNC count mode.

VI. Particle Size Distribution Measurement

To experimentally measure the particle size distribution of the generated monodisperse aerosol, a particle sizer of high resolution is necessary. Knutson and Whitby^{4,5} and Hoppel⁶ have used a DMA similar to the one described in Section II for particle size distribution measurements. We have used a DMA and CNC combination to measure the particle size distribution of the generated monodisperse aerosol.

Figure 10 schematically shows the experimental set up. Section II described the monodisperse aerosol generation system shown on the left. We generated 0.05 μm NaCl particles by selecting the operating parameters described in Section IV. The collector rod voltage of the first EC was

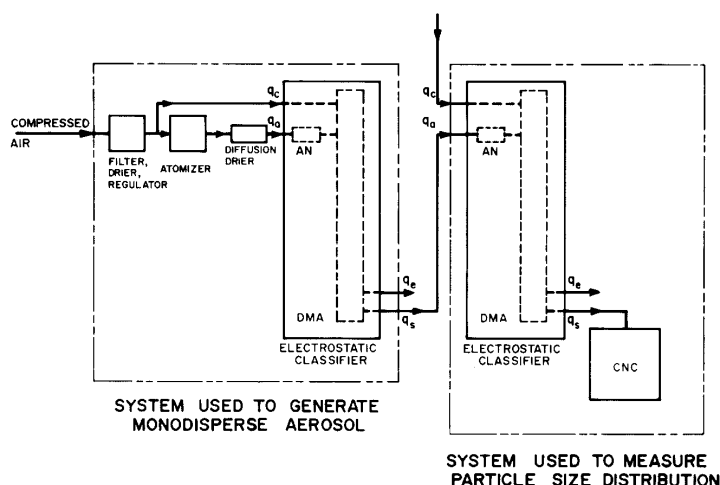


Figure 10. Schematic diagram of the system used to measure the size distribution of the aerosol. AN – aerosol neutralizer, DMA – differential mobility analyzer.

set at 1 kV. At this voltage, the mobility of particles exiting through the slit of the collector rod is $9.26 \times 10^{-4} \text{ cm}^2/\text{V}\cdot\text{sec}$.

Singly-charged 0.05 μm , doubly-charged 0.074 μm and triply-charged 0.091 μm particles, all had the mobility of $9.26 \times 10^{-4} \text{ cm}^2/\text{V}\cdot\text{sec}$ and exited through the slit of the collector rod. The aerosol then passed through a neutralizer which again applied the Boltzmann charge level to the particles. Table II shows the distribution of charges on the 0.05 μm , 0.074 μm , and 0.091 μm particles according to Boltzmann's Law. The 0.05 μm particles were all singly-charged before entering the neutralizer. After passing through the neutralizer, 62.2% of them carry no charge and 18.24% carry one positive unit charge. Similarly, the 0.074 μm particles were all doubly-charged before neutralization, but after neutralization, 49.56% have no charge, 22.9% have one positive unit charge, and 0.62% have two

positive unit charges. We then measured the particle size distribution of this neutralized 'monodisperse' aerosol with a second DMA followed by a CNC as shown on the right side of Figure 10. The aerosol entered into the second DMA through the polydisperse aerosol entrance. The clean sheath air to the second DMA came from an external clean air source. The CNC measured the particle concentration of the aerosol exiting through the slit of the collector rod of the second DMA. For a given collector rod voltage setting, particles of a specific electrical mobility exit through the slit. Equation 3 shows the relationship between the collector rod voltage and the particle mobility. We varied the collector rod voltage over the entire range for which the CNC could detect any particles. Figure 11 shows the relationship between the collector rod voltage and the CNC count. We observe four (4) distinct peaks. Table III shows the particle mobility corresponding to the collector rod voltage at which

$D_p, \mu\text{m}$	Percent of particles carrying n_p elementary charge units						
	-3	-2	-1	0	+1	+2	+3
0.050		0.62	19.24	60.20	19.24	0.62	
0.074	0.05	2.27	22.90	49.56	22.90	2.27	0.05
0.091	0.16	3.64	23.87	44.68	23.87	3.64	0.16

Table II. Theoretical distribution of charges on the aerosol particles used for CNC calibration according to Boltzmann's Law

Analyzer Voltage Corresponding to Peak, V (Volts)	Corresponding Mobility, Z_p ($\text{cm}^2/\text{V}\cdot\text{sec}$)	Particle Size, d_p (μm)	Concentration Measured by CNC (No/cm^3)	Concentration After Correcting for CNC Coincidence (No/cm^3)	Calculated No. Conc. in the Test Aerosol* (No/cm^3)
950	9.26×10^{-4}	0.05	630	692	3597
1950	4.51×10^{-4}	0.074	200	206	900
2800	3.14×10^{-4}	0.091	72	73	301

*Calculated by dividing the coincidence corrected CNC measurement by the fraction carrying a single positive charge from Table II.

Table III. Measured relative number concentration of the aerosol particles used for CNC calibration

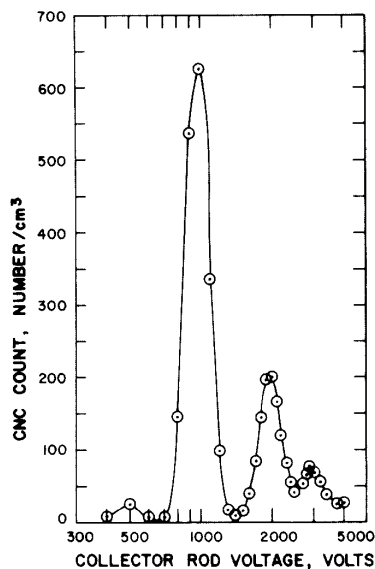


Figure 11. Particle concentration measured by the CNC vs. collector rod voltage of the second DMA.

these peaks occurred. From the relationship of particle size to electrical mobility (see Figure 2), it is evident that the peaks at 950V, 1950V, and 2800V correspond to

the singly-charged particles with diameters of 0.05 μm , 0.074 μm , and 0.091 μm , respectively. The peak at 500V represents the doubly-charged 0.05 μm diameter particles.

Figure 11 shows the relative particle concentration of the singly-charged fraction of 0.05 μm , 0.074 μm , and 0.091 μm particles that exited from the second DMA. Table II shows that 19.24% of the 0.05 μm particles entering the second DMA were singly-charged. The true particle concentration of the 0.05 μm entering the second DMA can be obtained by dividing the measured peak concentration by 0.1924. The calculated true particle concentrations of 0.05 μm , 0.074 μm and 0.091 μm particles are shown in the last column of Table III. Table III shows that the generated aerosol consisted primarily of 0.05 μm particles. The percentage of 0.074 μm and 0.091 μm particles are small. The interference effect of these larger particles can be accounted for by a procedure similar to the one described in Section III.

The DMA/CNC combination used here to measure the size distribution of the monodisperse aerosol is a powerful particle sizing tool. Its high sensitivity and high resolution

is demonstrated by detecting and resolving the four peaks in the aerosol. Hoppe⁶ has recently shown that this technique can be applied to polydisperse submicron aerosols of unknown size distribution.

VII. Conclusion

The electrostatic classification method of generating submicron monodisperse aerosol is a very useful technique for instrument calibration. We have used this technique not only for the final calibration of our new CNC, but also for optimization of various operating parameters during the development of the CNC.

The new CNC operating in the single particle counting mode and the electrostatic classification technique are both primary methods of measuring certain aerosol concentrations. When compared, the two primary methods agree within 5%, well within the limits of experimental accuracy.

The EC combined with a highly sensitive CNC becomes a submicron particle sizing technique with high resolution and sensitivity. This technique will be a very useful tool for future aerosol measurements.

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Filter Testing with the Continuous-Flow, Single-Particle-Counting Condensation Nucleus Counter

By

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ABSTRACT

HIGH EFFICIENCY PARTICULATE AIR (HEPA) FILTERS ARE WIDELY USED FOR A VARIETY OF PURPOSES. IN MOST APPLICATIONS, IT IS IMPORTANT THAT THE FILTERS WORK PROPERLY AT ALL TIMES. FILTERS CAN BE TESTED BY CHALLENGING THEM WITH AN AEROSOL AND MEASURING THE PARTICLE CONCENTRATION UPSTREAM AND DOWNSTREAM OF THE FILTER. MOST TEST METHODS USED IN THE PAST CANNOT ACCURATELY MEASURE FILTER EFFICIENCIES GREATER THAN 99.99% OR ARE LABOR INTENSIVE OR BOTH.

BECAUSE OF ITS UNIQUE ABILITY TO MEASURE CONCENTRATIONS OF PARTICLES $>0.01 \mu\text{m}$ FROM LESS THAN 0.01 TO 10^7 PARTICLES/ CM^3 , THE SINGLE-PARTICLE-COUNTING CONDENSATION NUCLEUS COUNTER (CNC) IS AN IDEAL SENSOR FOR FILTER TESTING. SEVERAL SYSTEMS FOR TESTING FILTERS HAVE BEEN DEVELOPED USING THE CNC AS THE SENSOR. THESE SYSTEMS INCLUDE A RESPIRATOR CARTRIDGE TEST SYSTEM, AUTOMATED FILTER PENETRATION TEST SYSTEM FOR LARGE FILTERS, FILTER TEST STAND FOR RESEARCH AND DEVELOPMENT WORK, AND RESPIRATOR QUANTITATIVE FIT TESTING SYSTEM. THE SYSTEMS ARE DESCRIBED IN DETAIL ALONG WITH SOME TEST DATA.

RESUME

LES FILTRES HEPA (HIGH EFFICIENCY PARTICULATE AIR) SONT LARGEMENT UTILISES POUR DIFFERENTES APPLICATIONS.

POUR PLUSIEURS D'ENTRE ELLES, IL EST IMPORTANT QUE LES FILTRES FONCTIONNENT CORRECTEMENT EN PERMANENCE. ON PEUT LES TESTER EN MESURANT LA CONCENTRATION DE PARTICULES EN AMONT ET EN AVANT DU FILTRE APRES AVOIR INJECTE UN AEROSOL.

LA PLUPART DES METHODES DE TEST UTILISEES PAR LE PASSE NE POUVAIENT PAS MESURER PRECISEMENT L'EFFICACITE DES FILTRES AU-DESSUS DE 99.99% OU BIEN ELLES ETAIENT TRES LABORIEUSES. CERTAINES PRESENTAIENT CES DEUX INCONVENIENTS A LA FOIS. PARCE QU'IL EST CAPABLE DE MESURER LES CONCENTRATIONS DE MOINS DE 0.01 JUSQU'A 10^7 PARTICULES/ CM^3 POUR DES PARTICULES DE DIAMETRE SUPERIEUR A 0.01 MICRON, LE COMPTEUR A NOYAUX DE CONDENSATION EST UN CAPTEUR IDEAL POUR LES TESTS DE FILTRES.

PLUSIEURS SYSTEMES DE TEST DE FILTRES ONT AINSI ETÉ DEVELOPPES AVEC LE CNC COMME CAPTEUR.

CE SONT EN PARTICULIER: UN SYSTEME DE TEST DE CARTOUCHES DE RESPIRATEURS, UN SYSTEME DE TEST AUTOMATIQUE DE PENETRATION POUR LES GRANDS FILTRES, UN BANC DE TEST DE FILTRES DESTINE A LA RECHERCHE ET AU DEVELOPPEMENT ET UN SYSTEME DE CONTROLE DE MASQUES RESPIRATOIRES. CET ARTICLE DECRIT EN DETAIL CES SYSTEMES ET PRESENTE QUELQUES RESULTATS.

ZUSAMMENFASSUNG

SCHWEBSTOFFFILTER DER KLASSEN S, T UND U WERDEN IN SEHR UNTERSCHIEDLICHEN BEREICHEN FUER VERSCHIEDENE ZWECKE EINGESETZT. ES IST WICHTIG, DASS DIESE FILTER IMMER KORREKT ARBEITEN. FILTER KOENNEN GETESTET WERDEN, INDEM MAN DIE PARTIKELKONZENTRATION EINES TESTAEROSOLS VOR UND HINTER DEM FILTER MISST. DIE MEISTEN TESTMETHODEN, DIE MAN IN DER VERGANGENHEIT EINGESETZT HAT, WAREN NICHT IN DER LAGE, ABSCHIEDEGRADE GROESSER 99.99% EXAKT ZU BESTIMMEN, ODER ABER SOLCHE METHODEN WAREN SEHR ARBEITSINTENSIV UND TEUER. AUFGRUND DER EINZIGARTIGEN MOEGLICHKEIT, PARTIKELKONZENTRATIONEN VON PARTIKELGROESSER 0.01 MICROMETER IN EINEM BEREICH VON 0.01 BIS 10^7 PARTIKEL/ CM^3 ZU BESTIMMEN IST DER EINZELPARTIKEL-ZAEHLLENDE CONDENSATION NUCLEOUS COUNTER (CNC) DER IDEALE SENSOR FUER FILTERTESTS. VERSCHIEDENSTE SYSTEME FUER FILTERTESTS SIND MIT DEM CNC ALS SENSOR ENTWICKELT WORDEN. IM FOLGENDEN WERDEN UNTER ANDEREM TESTSTAENDE FUER ATEM-SCHUTZMASKEN, AUTOMATISCHE FILTERDURCHDRINGUNGSTESTSYSTEME FUER GROSSE FILTER, FILTERTESTSTAENDE FUER FORSCHUNG UND ENTWICKLUNG UND ANDERE BESCHRIEBEN. ES WERDEN EINIGE DATEN UND ERGEBNISSE GEZEIGT.

Introduction

High efficiency particulate air (HEPA) filters provide particle-free air for various purposes. Some of the most common examples are the following: (1) respirators provide particle-free breathing air to industrial workers; (2) large banks of filters provide a particle-free environment for manufacturing; (3) in-line filters provide particle-free air

and other gases for critical semiconductor manufacturing processes; (4) large banks of filters provide bacteria- and virus-free environments for surgery; (5) in nuclear power plants, filters capture radioactive particles before they escape to the atmosphere, especially in case of an accident; and (6) filter banks and masks protect military personnel from harmful chemical and biological agents which may be released

by the enemy. In all of the above applications, the filters must work properly at all times. Failure to do so may give rise to life threatening situations or heavy economic loss.

The primary causes for failure of filters are faulty media, faulty manufacturing, faulty installation, and rupture after installation. To discover these problems as early as possible, it is necessary that testing be done (1)

during manufacturing for process control, (2) after manufacturing for quality control, (3) during installation to insure proper installation, (4) after installation for certification, and (5) periodically during operation for continued assurance of proper performance.

The ability of a filter to remove particles can be tested by challenging the filter with an aerosol and measuring the particle concentration upstream and downstream of the filter. The filter penetration (P) is the ratio of downstream particle concentration to upstream particle concentration. Filter efficiency (E) is defined as:

$$E = 1 - P$$

The two key elements of a filter testing technique are the challenge aerosol and the particle detector. Ideally, the challenge aerosol should be the same aerosol the filter is expected to encounter in the intended application. However, the challenge aerosol is often selected solely because it is the only aerosol which the selected particle detector is able to detect.

In the past, photometers have been the most commonly used particle detectors for filter testing work. The primary reason for this is that photometers were the only practical detectors available when most of the existing filter testing techniques were developed about 20-40 years ago. Other particle detection techniques that are occasionally used are (1) flame photometry to detect sodium chloride particles, (2) fluorometry to detect fluorescein or uranine particles, and (3) gravimetric measurements to detect solid particles.

Traditional Filter Testing Techniques

A challenge aerosol and a particle concentration detector are basic requirements of every filter testing technique. The only differences between the various traditional techniques are with the type of challenge aerosol and with the type of particle concentration detector.

The most commonly used filter testing technique is the dioctyl phthalate (DOP)/photometer technique.¹ The challenge aerosol is generated by either nebulizing DOP or by quenching a

DOP vapor. The amount of aerosol generated by either method can vary over a wide range. The particle concentration detector is typically a forward-scattering photometer employing a white light bulb as the light source and a sensitive photomultiplier tube as the photodetector. The basic problem with this technique is that, even though the photometer is able to accurately measure high concentration aerosols, its sensitivity decreases sharply as the particle concentration decreases. Hence, to measure the particle concentration found downstream of a high-efficiency filter, the zero of the photomultiplier tube must be frequently adjusted to compensate for electronic and photometric noise drift. Even then, this technique is not capable of measuring penetrations lower than 0.0001, a rather poor HEPA filter. Second, the photometer is sensitive to the size distribution of the aerosol. Hence, the size distribution of the challenge aerosol must be carefully controlled to match the size distribution of the aerosol with which the photometer was originally calibrated. This requirement makes the challenge aerosol generator complex and bulky. Third, to overcome the zero noise drift problem, upstream concentration must be high, causing significant loading and contaminating of the filter during its test. Finally, the required level of downstream concentration may adversely contaminate the clean room or area downstream of the filter during the test.

The second method is the sodium chloride/flame photometer technique. Sodium chloride (or other sodium salt) challenge aerosol is generated either by feeding a sodium chloride stick to a subliming flame and then quenching the vapor to form NaCl particles or by nebulizing a sodium chloride solution to form saline solution droplets and then drying them. A flame photometer, serving as the particle detector, has a combustion flame supported by an external supply of compressed air and propane fuel. As NaCl particles pass through the flame, the burning sodium emits yellow light of a specific wavelength. The intensity of the yellow light is measured by a sensitive photomultiplier tube preceded by an optical filter which passes only the sodium lines. The intensity of the sodium line, and hence the photomultiplier tube

output, is directly related to the concentration of NaCl aerosol particles.

The main shortcoming of this test method is the detector. The detector must use a flammable propane fuel and must have a flame for its operation. The detector is insensitive at low particle concentrations, so a relatively high concentration of challenge aerosol must be used. The sensitivity of this instrument for smaller particles (smaller than 0.3 μm diameter) decreases rapidly with decreasing size because the amount of sodium in a particle is a cubic function of particle diameter.

Another particle detector which has been used in some applications is a single-particle-counting optical particle counter (OPC). Conventional white light optical particle counters do not sense particles smaller than 0.3 μm , a severe limitation for HEPA filters which have their most penetrating size at or below 0.3 μm . Active scattering OPC's do sense smaller particles. The He-Ne laser-based instruments are specified to measure particles down to 0.1 μm and He-Cd based instruments are specified to go down to 0.06 μm . However, these instruments require frequent adjustments and calibrations. The fact that one must put an inlet and some optics inside the laser cavity limits the stability and reliability of the laser. Active scattering optical particle counters cannot detect concentrations above a few hundred particles per cubic centimeter because if more than one particle occupies the sensing zone simultaneously, they are detected as a single particle. Hence, these instruments are quite suitable to measure particle concentration downstream of a filter. However, the particle concentration upstream of a high efficiency HEPA filter is so high that it must be diluted by several orders of magnitude before entering the detector.² Such dilution systems are usually cumbersome.

Some filter testing standards specify gravimetric techniques. Challenge aerosol is generated by dispersing a powder such as silica dust into the airstream. The aerosol concentration upstream and downstream of the test filter is determined by collecting the particles on two separate sample filters and weighing the filters on a microbalance. This technique requires con-

siderable time to collect the downstream sample making it ineffective for high-efficiency filters. It is a labor-intensive technique and limited to low-efficiency filters.

Some researchers have used fluorescein challenge aerosol and fluorometric analysis of sample filters to measure the particle concentration upstream and downstream of the test filter. This method is considerably more sensitive than the gravimetric technique, but shares the problem of being labor-intensive. Both techniques are dominated by the large particles in the challenge and penetrating aerosols because they contain the most mass and fluorescent material. One particle of 1 μm diameter will influence the measurement just as much as 1000 particles of 0.1 μm diameter because mass is a cubic function of diameter.

The CNC Method

The continuous-flow condensation nucleus counter (CNC, TSI Model 3020) is a major improvement over other methods of particle detection for filter testing. The CNC first grows submicrometer particles to supermicrometer alcohol droplets and then measures the alcohol droplet concentration. This makes the CNC sensitive to particles as small as 0.01 μm diameter, but insensitive to variations in particle size, shape, composition, and refraction index. Thus, a filter test method using the CNC as the particle detector can use virtually any aerosol as the challenge aerosol. The CNC has a single-particle-counting mode in which it counts particles individually as they go through the sensing volume. Because of this feature, the CNC is capable of accurately measuring extremely low particle concentrations found downstream of the most efficient HEPA filters. For higher particle concentrations normally found at the upstream side of the filter, the CNC switches to photometric mode where the particle concentration is measured from the total light scattered by the cloud of alcohol droplets in the sensing volume. Because of this dual mode capability, the CNC can measure particle concentrations from less than 0.01 particles/cm³ to 10⁷ particles/cm³. These features make the CNC a nearly ideal instrument for filter testing.

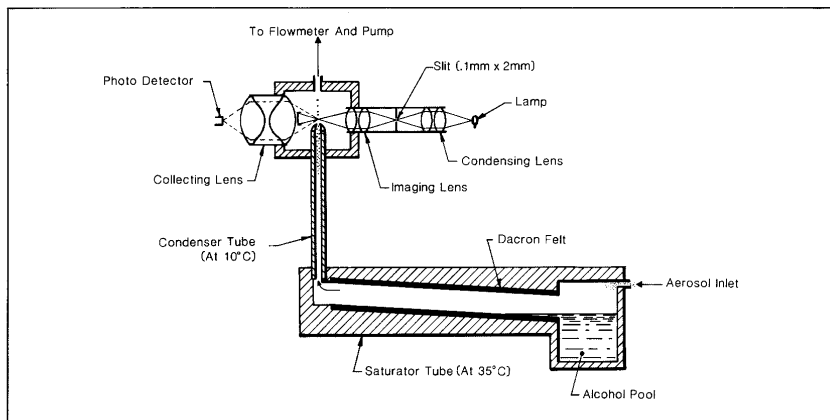


Figure 1. Schematic of condensation nucleus counter sensor.

Condensation nucleus counters were originally developed to count small particles in the atmosphere. These particles, sometimes called condensation nuclei, play an important role in cloud formation. CNCs were used during and after World War II for submarine detection. The presence of large numbers of submicrometer particles in the atmosphere indicated the presence of the plume from a diesel-powered submarine.

Agarwal and Sem³ describe the TSI CNC shown schematically in Figure 1. The CNC consists of a saturator, condenser, and light-scattering particle sensor. Figure 2 is a photograph of the TSI Model 3020 Condensation Nucleus Counter.

Aerosol enters the inlet and passes through the saturator, an inclined tube with the inside covered by a thick Dacron[®] felt lining. The lower end of the felt lining dips into an alcohol reservoir located at the inlet end of the saturator. The felt becomes saturated with alcohol, providing a larger surface area for alcohol evaporation. An

electrical resistance heater maintains the saturator at 35°C.

The aerosol, saturated with alcohol vapor, then enters a 4 mm diameter by 80 mm long vertical condenser tube. A thermoelectric cooling device maintains the condenser tube at 10°C. Alcohol vapor condenses on the aerosol particles causing them to grow to droplets approximately 12 μm in diameter. The droplets pass from the condenser tube into the sensing volume through a 1 mm diameter nozzle.

The sensor consists of a light source, focusing optics, collecting optics, and photodetector. The light source is a halogen light bulb. Condensing lenses first focus the light onto a 0.1 mm x 2 mm horizontal slit-aperture. The imaging lenses then form a 1:1 image of the slit above the aerosol exit nozzle. The main light beam enters a light trap just ahead of the collecting optics. The collecting optics consist of a pair of aspheric lenses which collect the light scattered by the droplets within a 90° solid forward angle around the light stop and focus the collected light onto a low noise photodiode having 5 mm² of sensing area. The surface temperature of the focusing and collecting optics is maintained at 35°C to avoid alcohol condensation on the lens surface.

As mentioned earlier, the CNC has two modes of operation: (1) count mode and (2) photometric mode. At concentrations below 1000 particles/cm³, the CNC counts electrical pulses generated by light scattered from individual droplets. The photodetector output signal passes through a noise filter and a Schmitt triggering circuit,



Figure 2. TSI Model 3020 Condensation Nucleus Counter.

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resulting in a 5 volt pulse for each droplet. The 5 volt pulses are counted for a specific time period and converted to particle concentration, which is digitally displayed on the front panel of the CNC. When connected to an external frequency counter, the 5 volt pulses allow measurement of extremely low particle concentrations, even lower than 0.01 particles/cm³.

At particle concentrations above 1000 particles/cm³, the photodetector measures the total light from all the droplets present in the viewing volume at any time. The photodetector output passes through an eight segment linearizer circuit which provides a voltage signal linearly proportional to the particle concentration.

The traditional filter testing techniques previously described were developed many years ago using what was then state-of-the-art technology. They were adequate for that time, but they do not meet many of today's needs. The most penetrating size of many HEPA filters is now well below 0.3 μm and sometimes below 0.1 μm. Filters with much higher efficiencies are available today. The traditional particle detection techniques do not have the sensitivity to detect the ultra-low particle concentrations found downstream of these filters. Also, the traditional techniques require substantial human interaction and cannot be easily automated.

During the past five years, we have designed several filter test systems for several applications, all using the CNC as the primary particle detector. The following sections summarize these designs.

Respirator Cartridge Test System

A standard method for testing respirator cartridges in the U.S.A. is the gravimetric technique using silica dust. In 1982, we developed an instrumentation system which measures particulate respirator filter efficiencies using the CNC for the National Institute for Occupational Safety and Health (NIOSH). The system was subsequently evaluated and used by NIOSH. This system and its performance are described by Remiarz et al.⁴

In addition to testing efficiencies,

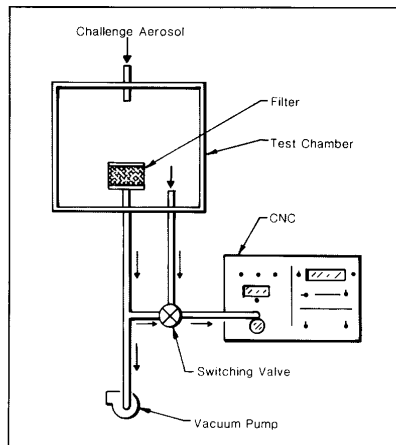


Figure 3. Operating principle of the respirator test system.

the system measures respirator flow rates and pressure drops. The system monitors all three parameters over time to obtain respirator loading data. Up to three respirators can be tested simultaneously and automatically. A dedicated microcomputer system monitors, reads, and controls the instruments and performs extensive data analysis and data presentation, including cross-correlations between the tested parameters.

Figure 3 shows the basic method for testing the respirators. The CNC sequentially measures particle concentrations upstream and downstream of the respirator. Figure 4 shows a schematic diagram of the complete three-channel respirator testing system.

The flow through the system starts from the stainless steel test chamber. There is an inlet at the top of the chamber for the challenge aerosol and an exit at the back of the chamber. Three other outlets direct the aerosol to the respirator to be tested, a fourth

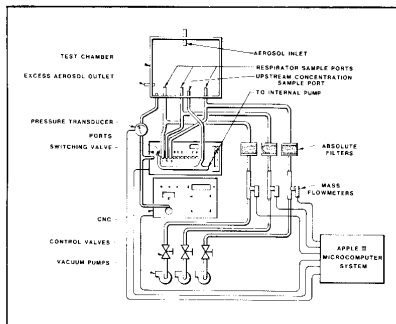


Figure 4. Three-channel respirator cartridge test system.

outlet is for measuring the challenge aerosol concentration, and a fifth outlet is for the upstream port of a differential pressure transducer which measures the pressure drop across the respirators.

After the aerosol has passed through the test filter, the aerosol flow path from each of the three filter sampling ports branches. One branch goes to a high-efficiency filter, thermal mass flow meter (TSI Model 2011B), control valve, and vacuum pump. The other branch goes to a port on the switching valve (TSI Model 3042). The chamber concentration sampling port also branches, with one branch leading to the vacuum pump in the switching valve and the other branch leading to the first port on the switching valve. The output of the switching valve leads to the second port of the pressure transducer and to the inlet of the CNC. Figure 5 is a photograph of the complete respirator testing system.

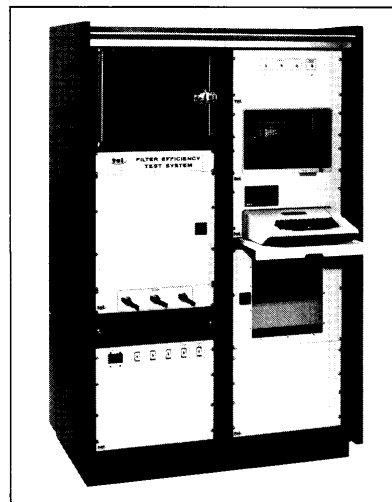


Figure 5. Respirator efficiency test system.

A microcomputer system controls the respirator tester. The CNC, switching valve, flow meters, and pressure transducer all interface to the microcomputer system. The microcomputer system consists of an Apple II microcomputer, Apple Disk II drive and controller card, IDS Prism 80 printer, Grappler printer interface card, Zenith video monitor, California Computer Systems A/D card and real-time clock card, and a 16K memory card for additional memory. Special control electronics were also designed and built for the system. In addition to

keeping track of the time, the micro-computer system controls the switching valve and reads the CNC, flow meter, and pressure transducer outputs. The computer does extensive data analysis, including cross-correlations between the tested parameters. Continuous, automatic sampling over time periods as long as 6½ days is possible using this micro-computer system.

Commercially available high-efficiency filter cartridges were selected to demonstrate the reproducibility of the system. The filters were also used to determine whether the system was sensitive enough to monitor small changes in penetration as a function of flow rate. The filters were cartridges certified for use against dusts, fumes, mists and radionuclides and with rated efficiencies greater than 99.97% by the DOP technique.

The challenge aerosol was sodium chloride generated with a Model AP-6310G NaCl Aerosol Generator manufactured by Sibata Science Technology Ltd. This generator supplies airborne

particles by nebulizing a solution of 10% NaCl in distilled water into a mist, dispersing the mist, and subsequently drying the droplets, leaving solid NaCl particles. Contained within the instrument is a mist-classifying impactor stage (3 mm spacing) which regulates the aerosol's size and distribution. Finally, the aerosol was passed through a Krypton-85 radioactive neutralizer (TSI Model 3054) to reduce the electrostatic charge level on the particles.

A single lot of a commercially available high-efficiency filter cartridge was tested over a period of one month. NaCl aerosol challenged the filters for durations of up to 90 minutes per run. A continuous flow of either 16, 42.5, or 85 l/min passed through a single filter cartridge.

The results from this study showed that all filters had an efficiency of greater than 99.97% when tested against the NaCl challenge aerosol at the three flow rates. Figure 6 shows typical test data from a reproducibility study at 85 l/min. As can be seen from

TSI FILTER EFFICIENCY TEST SYSTEM							
TEST START TIME: 14:37:03		TUESDAY		05/31/83			
FILTER #1:							
FILTER #2:							
FILTER #3:							
TIME (MIN.)	CHAMBER CONC (#/CC)	FLOW (L/MIN)	DELTA P (IN H2O)	FILTER CONC (#/CC)	PENE (%)	EFFIC. (%)	
1	1604500	1 86.35	1.391	59.825	0.003728	99.996272	
		2 83.64	1.659	76.565	0.004771	99.995229	
		3 83.60	1.651	63.0775	0.003931	99.996069	
3	1280500	1 85.65	1.416	44.47	0.003472	99.996528	
		2 83.46	1.682	44.895	0.003506	99.996494	
		3 83.41	1.674	37.185	0.002903	99.997097	
5	1323000	1 85.31	1.440	39.065	0.002952	99.997048	
		2 83.64	1.709	37.175	0.002809	99.997191	
		3 83.41	1.711	37.6525	0.002845	99.997155	
7	2473000	1 84.12	1.475	26.42	0.001068	99.998932	
		2 83.64	1.747	26.8475	0.001085	99.998915	
		3 83.23	1.757	19.0825	0.000771	99.999229	
9	1429000	1 84.12	1.507	18.875	0.001320	99.99868	
		2 83.64	1.784	19.11	0.001337	99.998663	
		3 83.41	1.804	15.03	0.001051	99.998949	
11	1328000	1 84.12	1.545	11.1925	0.000842	99.999158	
		2 83.64	1.829	15.7325	0.001184	99.998816	
		3 83.41	1.854	9.2825	0.000498	99.999302	
13	2033000	1 86.00	1.575	9.112500	0.000448	99.999552	
		2 83.46	1.890	21.3225	0.001048	99.998952	
		3 83.23	1.907	5.207	0.000256	99.999744	

Figure 6. Respirator efficiency test system data

this printout, the microcomputer kept track of the chamber concentration, concentration downstream of each respirator, time of day and date, flow rate, pressure drop, respirator efficiency, and penetration.

The system includes graphic displays of several types. Plots of the measured parameters versus time and cross-correlations between pressure and flow rate, efficiency and flow rate, efficiency and pressure drop, and penetration and flow rate, and penetration and pressure drop are available. Figures 7 through 11 are plots of test data. Figure 7 shows chamber concentration versus time, Figure 8 shows flow rate versus time for filter #3, Figure 9 shows pressure drop versus time for filter #3, Figure 10 shows percent penetration versus time for

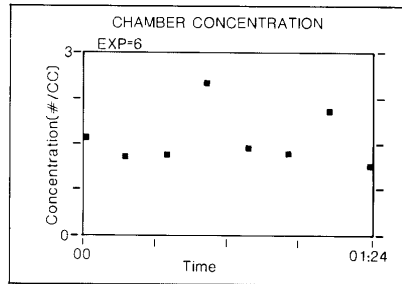


Figure 7. Plot of chamber concentration versus time.

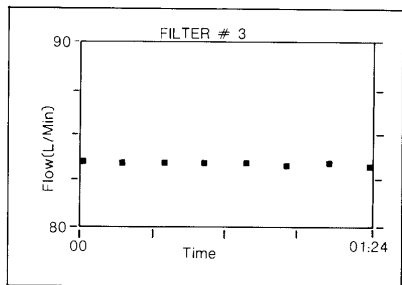


Figure 8. Plot of flow rate versus time for Filter #3.

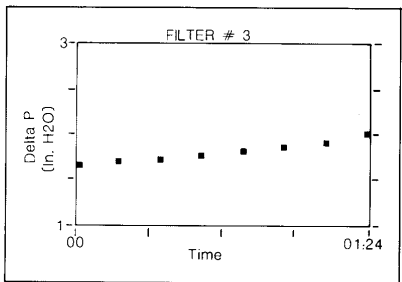


Figure 9. Plot of pressure drop versus time for Filter #3.

filter #1, and Figure 11 shows percent efficiency versus time for filter #1. We see that as the filter loads, its efficiency improves, but the pressure drop across the filter increases.

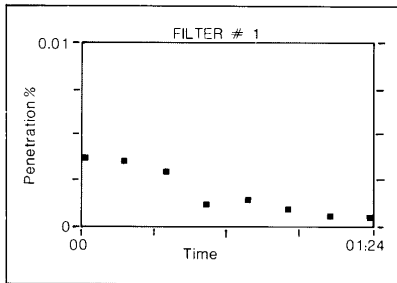


Figure 10. Plot of percent penetration versus time for Filter #1.

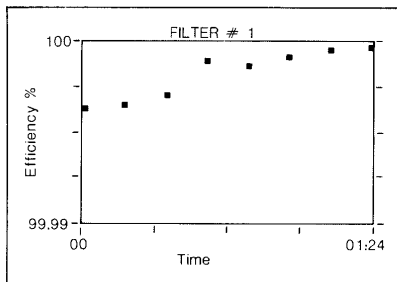


Figure 11. Plot of percent efficiency versus time for Filter #1.

The data from a reproducibility study at 85 l/min flow rate confirmed that this test system is capable of monitoring filter efficiencies with great precision. Table 1 represents the results for 19 filters from the same lot. Table 1 also shows the means and standard deviations for the percent penetration and the percent efficiency. The standard deviation is 10×10^{-4} for the percent penetration and efficiency. Alternatively, one could calculate the relative standard deviation for the penetration to be 25%. It is important to realize that these variabilities come from two sources. The first is that caused by instrumental errors and the second arises from filter-to-filter variability within the batch. Unfortunately, these two are not separable in this test.

Table 2 presents the data obtained at flow rates of 16 l/min and 42.5 l/min through the same single filters. Table 3 summarizes this data. As can be seen, the efficiency increases as the flow rate decreases, with the order of magnitude of the penetration changing. This is

Table 1. Reproducibility study of high-efficiency filters at 85 l/min flow rate.

Sample no.	Chamber conc. (#/cc)	Flow (l/min)	Delta P (in. H ₂ O)	Downstream filter conc. (#/cc)	Penetration (%)	Efficiency (%)
1	2498000	84.79	1.407	132.55	53.06×10^{-4}	99.994694
2	2498000	84.53	1.456	101.05	40.45×10^{-4}	99.995955
3	2498000	84.15	1.326	104.8	41.95×10^{-4}	99.995805
4	3476500	84.45	1.394	79.05	22.92×10^{-4}	99.997708
5	3476500	84.35	1.376	81.225	23.36×10^{-4}	99.997664
6	3476500	84.15	1.446	83.1125	23.90×10^{-4}	99.99761
7	1020500	83.44	1.363	38.1725	37.40×10^{-4}	99.99626
8	1020500	83.82	1.414	63.275	62.00×10^{-4}	99.9938
9	1020500	83.78	1.410	39.1375	38.35×10^{-4}	99.996165
10	1171500	87.04	1.528	56.8175	48.49×10^{-4}	99.995151
11	1171500	84.00	1.495	46.255	39.48×10^{-4}	99.996052
12	1171500	83.97	1.402	49.9075	42.60×10^{-4}	99.99574
13	1604500	86.35	1.391	59.825	37.28×10^{-4}	99.996272
14	1604500	83.64	1.656	76.565	47.71×10^{-4}	99.995229
15	1604500	83.60	1.651	63.0775	39.31×10^{-4}	99.996069
16	1981000	84.29	1.439	83.825	42.31×10^{-4}	99.995769
17	1981000	83.97	1.480	85.3075	43.06×10^{-4}	99.995694
18	2378000	85.07	1.411	116.5	48.99×10^{-4}	99.995101
19	2633000	85.45	1.492	90.37750	34.32×10^{-4}	99.996568
Mean					40×10^{-4}	99.9960
Standard Deviation					10×10^{-4}	10×10^{-4}

Table 2. Filter efficiency as a function of flow rate of high-efficiency filters.

Filter sample no.	Chamber conc. (#/cc)	Flow (l/min)	Delta P (in H ₂ O)	Downstream filter conc. (#/cc)	Penetration (%)	Efficiency (%)
1	3287500	16.29	0.2239	0.355	1.0×10^{-5}	99.99999
2	3287500	16.22	0.2214	0.2905	0.08×10^{-5}	99.999992
3	2633000	16.29	0.2189	0.6495	2.40×10^{-5}	99.999976
4	3903000	41.92	0.6155	31.87	8.167×10^{-4}	99.999184
5	3903000	41.53	0.6338	25.29	6.47×10^{-4}	99.999353
6	2378000	42.35	0.6220	19	7.98×10^{-4}	99.999202
7	2633000	42.25	0.6347	0.5685	0.21×10^{-4}	99.999979

what one would expect for this type of filter. Data of this type is easily obtainable with the system due to its accurate flow measurement capabilities and enhanced sensitivity over other detectors. It should be noted that these filters have an efficiency significantly greater than 99.97% for this NaCl challenge aerosol, even at a flow rate of 85 l/min which is much higher than the flows used for certifying these filters when tested with DOP. However, it is important to remember that the system measures the number concentration efficiency whereas the standard DOP efficiency is a function of the amount of light scattered by the aerosol. For

Table 3. Summary of filter efficiency as a function of flow rate.

Flow (l/min)	Mean penetration	Mean efficiency
16	0.000014	99.999986
42.5	0.000570	99.999429
85	0.004037	99.995963

this reason, the efficiencies are not directly comparable.

Filter Penetration Test System

Large high-efficiency space filters (several square feet in cross-sectional area) must be tested for several reasons, one of the most common being quality control. This application requires an easy-to-use, reliable, automated system. Figure 12 shows a system designed for this application. The system is self-contained with its own blower, air compressor, aerosol generator, and an instrumentation rack.

A multi-jet nebulizer generates the challenge aerosol. The nebulizer uses the Wright jet-baffle principle. Figure 13 schematically illustrates the principle of operation. Incoming pressurized air creates a high-velocity nebuliz-

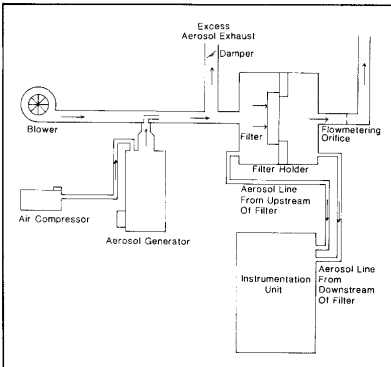


Figure 12. Filter penetration test system.

ing air jet which in turn creates low pressure in the liquid tube. The low pressure draws the solution up through the tube. The high-velocity air jet breaks the liquid into fine droplets. The spherical impactor removes most of the large droplets. Figure 14 shows

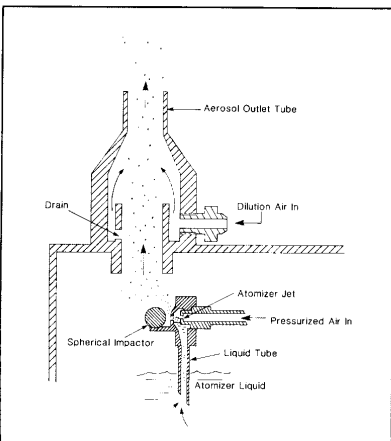


Figure 13. Operating principle of nebulizer jet.

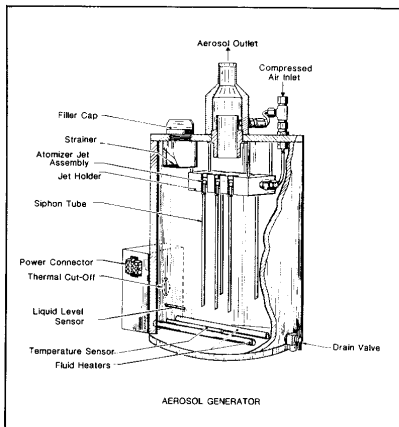


Figure 14. Multiple-jet aerosol generator.

an aerosol generator. The generator shown has five jets, but any number of jets can be selected depending upon the size of the filter to be tested.

The liquid reservoir has a capacity of 6 liters. Corn oil, DOP, or many other liquids or solutions may be nebulized in this generator. The normal consumption for corn oil is 6.7 ml/hour per jet. The generator contains a fiber optics liquid level sensor interfaced to the data handling system. The sensor indicates when only 0.5 l of liquid remains, serving as an early warning of low liquid levels.

Figures 15 and 16 show the size distribution of corn oil aerosol produced by this generator. A differential mobility particle sizer (DMPS) described by Keady et al⁵ was used to measure these size distributions. The corn oil aerosol from the particle generator has a number mean diameter of 0.30 μm and a geometric standard deviation of 1.69. The output of this generator is very stable. Figure 17 is a strip chart recording indicating that output particle concentration measured by the CNC did not vary more than a few percent over 70 minutes. This indicates that both the

aerosol generator and CNC are stable instruments. Because neither the CNC nor the aerosol generator are sensitive to particle composition, aerosols other than corn oil could be used in the system.

A blower supplies dilution air to the filter holder. The design of the filter holder depends on the size and shape of the filters to be tested. Figure 18 shows the instrumentation rack. It consists of a switching valve, CNC, control module, and microprocessor-based data handling system (DHS). The instrumentation unit has a key pad (twelve keys) for entering filter identification information, a video monitor for displaying test parameters and test results, and a printer. The function of the switching valve is to connect the CNC to the upstream or downstream side of the filter at the command of the DHS. The instrumentation unit also contains a pressure transducer connected between the upstream and downstream sides of the filter.

The microprocessor-based DHS runs the system. The program is contained on programmed read-only memory (PROM) in the DHS. Figure

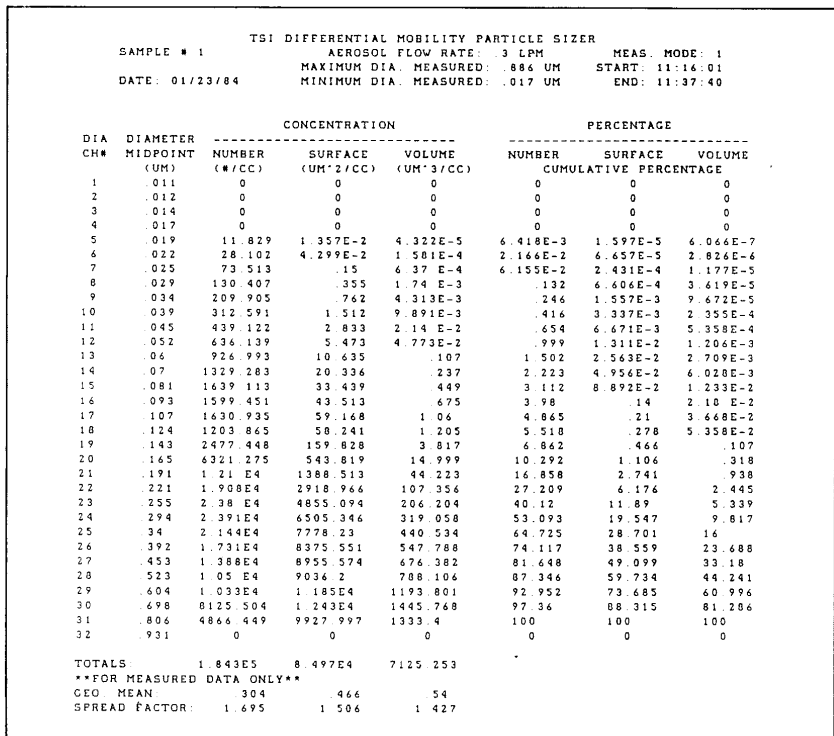
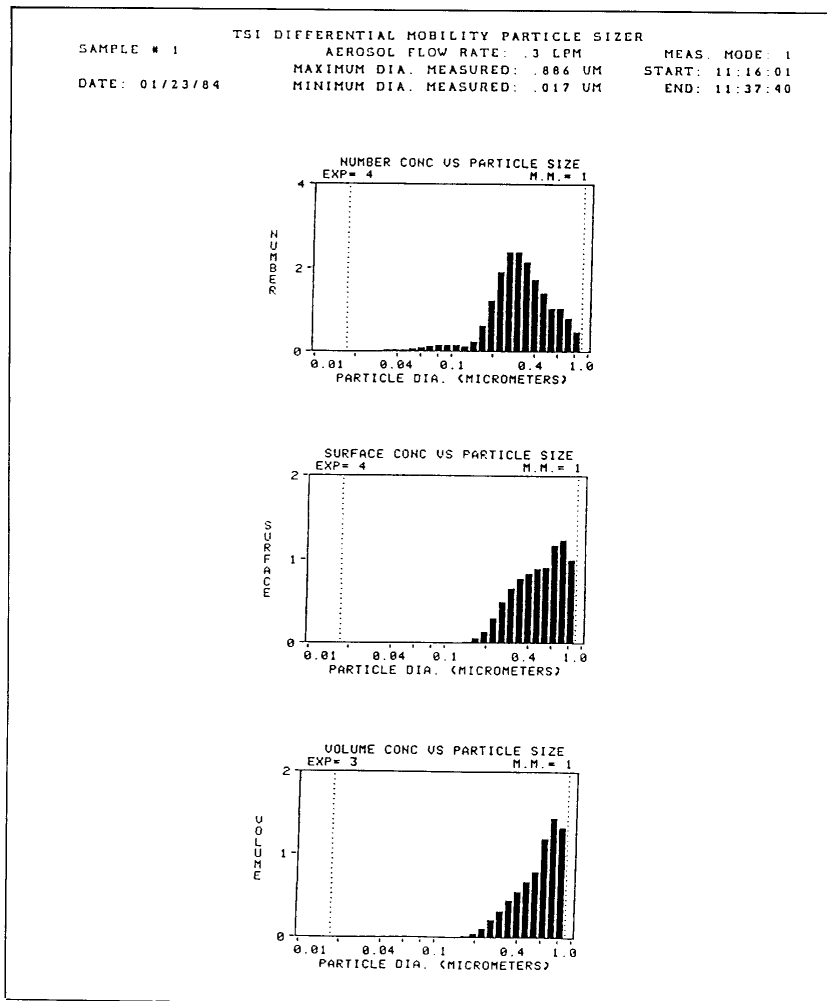
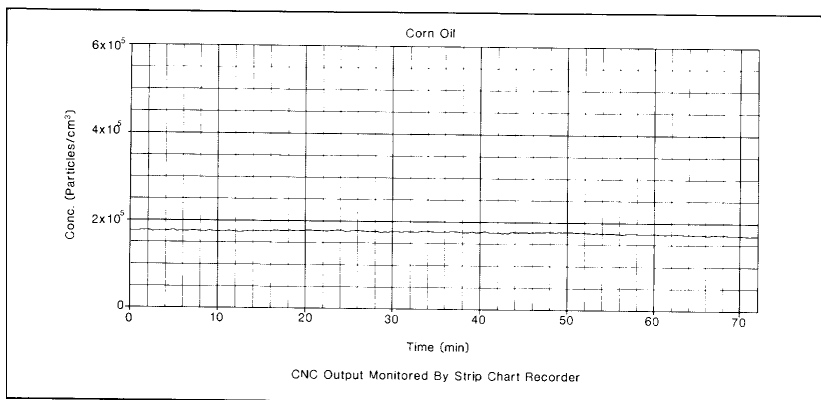


Figure 15. Size distribution of corn oil aerosol generated by multiple-jet atomizer.



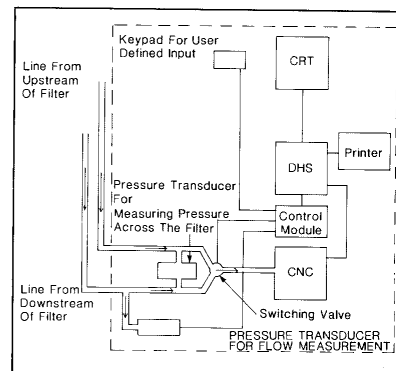
19 is a block diagram of the DHS. The DHS reads the outputs of the CNC, flow meter, and pressure transducer and calculates the particle penetration

through the filter. The results of the test are shown on the video display and also printed. The system also includes an RS-232 interface. This permits the



interfacing of an external computer to the DHS, thereby enhancing data analysis, data storage, and data management capabilities. The control module interfaces the DHS to the other parts of the system. It provides inputs to the DHS and executes commands from the DHS such as controlling the switching valve.

The operation of the system is very simple. The operator mounts the filter in the system using the appropriate filter holder. The operator then uses the keypad to enter some information which identifies the filter and test number. The start button begins the test sequence. The system controls the rest of the test without operator interaction.



From the identifying information regarding the filter, the DHS decides the challenge aerosol flow rate and challenge aerosol particle concentration. The DHS then turns on the required number of jets in the aerosol generator. The DHS checks the pressure drop across the filter, flow rate through the filter, and particle concentration upstream of the filter. It also performs routine system checks to ensure that the system is operating properly. A flashing message on the video monitor notifies the operator of any malfunction or deviation from the preset guidelines. A series of diagnostic routines then can identify the source of the problem.

Once the system has reached a steady state operating condition, the DHS records the challenge aerosol particle concentration, aerosol flow rate, and the pressure drop across the test filter. Next, the DHS connects the CNC to the downstream side of the

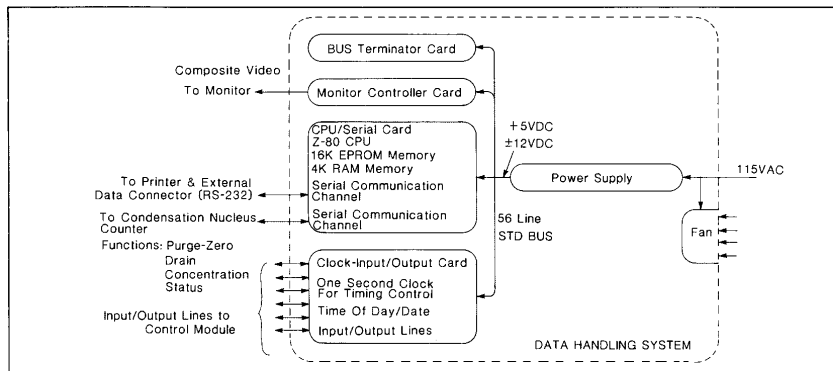


Figure 19. Block diagram of data handling system (DHS).

filter so that the CNC can measure the particle concentration at that point. Finally, the DHS calculates the efficiency of the filter, displays the test results on the video display, and prints the results.

Filter Test Stand For Research and Development

The research and development personnel of filter manufacturing companies often need a flexible system with which they can evaluate a filter. This system should have the capability of evaluating filter efficiency as a function of particle size for the 0.01 to 10 μm diameter range. The system should also have the ability to measure the flow rate through the filter and pressure drop across the filter.

A system designed for this application is shown schematically in Figure 20. The Model 3020 CNC is used to measure particle concentrations of submicrometer aerosols. The TSI Model APS 33[®] is used to measure the concentration of particles larger than 0.5 μm . The APS 33 is described by Remiarz et al.⁶

The challenge aerosol is generated using two different techniques. To measure the filter efficiencies for particles $\leq 0.5 \mu\text{m}$, the challenge aerosol is generated using a submicrometer monodisperse aerosol generation system. This system incorporates the electrostatic classification method, described by Liu and Pui,⁷ which is the only known technique for generating monodisperse submicrometer aerosols of known size.

Referring to Figure 20, the air supply system is used to supply clean,

dry air to the atomizers and to the classifier. The atomizers are used to generate polydisperse aerosol from nearly any water soluble material. Three solenoid valve-controlled atomizers are used, each having a different solution concentration. This is necessary to cover the large range of particle sizes required. The output of the atomizers passes through a diffusion dryer where the aerosol dries without being diluted. The dried polydisperse aerosol then passes through the electrostatic classifier (EC). In the EC, the aerosol passes through a differential mobility analyzer (DMA), which classifies the particles exiting

from the EC. The resulting mono-disperse aerosol goes to the test chamber.

To measure the filter efficiency of particles $>0.5 \mu\text{m}$, three solenoid valve-controlled atomizers are used. The atomizers contain polystyrene latex (PSL) spheres of known sizes. The output from the atomizers passes through a diffusion dryer and then into the test chamber.

The test chamber has six ports. Two of these are for the challenge aerosol. The third port is for dilution air. The fourth is an exit leading to a high efficiency filter for excess challenge aerosol. The final two ports are used to measure the concentrations upstream and downstream of the filter. The filter attaches to the downstream sampling port. A pressure transducer connects across the two sampling lines to measure the pressure drop across the filter. The lines from the two sampling ports go to vacuum pumps so there is a continuous flow of aerosol through the sampling lines. The sampling line connected to the filter also contains a thermal mass flow meter and control valve. The flow rate through the filter is adjustable from 10 to 80 l/min. The APS and CNC draw samples from the sampling lines. A switching valve is

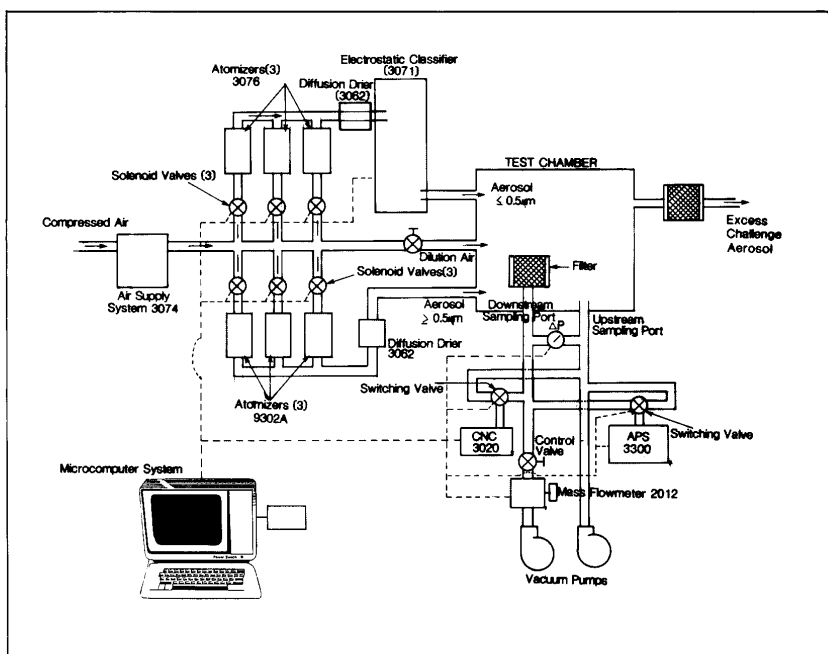


Figure 20. Schematic of filter test stand for research and development.

located near the inlet of each instrument to control which line is being sampled.

The entire test system is controlled by a microcomputer system which consists of an IBM PC, video monitor, and printer. The microcomputer system is interfaced to the solenoid valves, electrostatic classifier, switching valves, thermal mass flow meter, APS and CNC. The system controls the valves and electrostatic classifier; reads the outputs of the flow meter, APS and CNC; and calculates and displays the resulting data.

Because the microcomputer system controls the filter test system, operation is simple and straightforward. The filter to be tested is first placed into the test chamber and connected to the downstream sampling port. The flow rate through the filter is then set using the control valve and thermal mass flow meter. The test is then started by pressing a key on the computer. The computer then turns on one of the Model 3076 atomizers and sets the EC center rod to the proper voltage for the correct particle size. The CNC then measures the concentrations upstream and downstream of the filter. The computer then switches the EC center rod voltage for a second particle size, and the CNC again measures the particle concentrations upstream and downstream of the filter. Next, the computer switches to another atomizer and repeats the procedure. This is repeated until all of the data is taken for particles $\leq 0.5 \mu\text{m}$.

Next, the computer turns on one of the Model 9302 atomizers and the APS measures the PSL concentrations upstream and downstream of the filter. This is repeated with each of the atomizers. At the end of the test, the computer calculates, displays and prints the resulting test data.

Respirator Quantitative Fit Testing System

The most widely used method for respirator quantitative fit testing is the DOP/photometer method. Willeke et al⁸ were the first to demonstrate the advantage of using a TSI CNC for this application. We have designed a completely automated system using the CNC. Figure 21 shows the system.

It has four major components: (1) condensation nucleus counter, (2) aerosol generation system, (3) test chamber, and (4) data handling system.

The aerosol generation system is similar to that described previously under the filter penetration test system. The test chamber is a large fiberglass chamber with downward air flow. The subject, wearing the respirator, walks into the chamber, connects a sampling line to the respirator, and pushes a start button. After that, the test is fully automated. The data handling system is also similar to the filter penetration test system described previously. The data handling system measures the particle concentration in the test chamber and inside the respirator. It then displays the protection factor, which is the inverse of penetration. The data handling system also directs the respirator wearer to perform appropriate exercises at specific times.

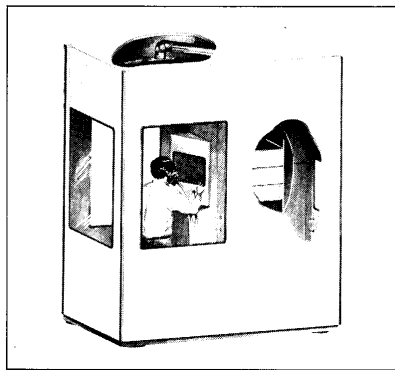


Figure 21. Respirator quantitative fit testing system.

Conclusion

Several filter test systems using the CNC have been designed, built, and tested. All of these systems emphasize automation, leading to simplified operation and elaborate data presentation. In all cases, a high degree of user satisfaction was achieved. In some cases, the users were able to test filters ten or even a hundred times faster than before.

Another observation was that many filters have filtration efficiencies much higher than claimed by their manufacturers. We believe this is because the DOP/photometer technique is not sensitive enough to differentiate between filters having efficiencies of

99.99% and filters having higher efficiencies. Hence, the manufacturers of higher efficiency filters did not have a way to prove that their filters were more efficient.

In conclusion, as HEPA filters improve in efficiency, one expects to find fewer submicrometer particles downstream of these filters during filter testing. To test these filters one should use a particle counter that is capable of counting particles at low concentrations. The TSI Model 3020 single-particle-counting CNC is ideally suited for this.

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APPENDIX D

Calibration and Data Sheets

This appendix includes the following calibration and data sheets:

- 3022 Data Sheet
- Calibration Data Sheet
- Photometric Calibration Curve
- Plotted Calibration Curve (Output versus Concentration)

APPENDIX E

Software Disk

This appendix includes software for the TSICPC.BAS program.

Refer to Chapter 7 for information on using the software.



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