Particle Instruments

Model 3475 Condensation Monodisperse Aerosol Generator

Instruction Manual

P/N 1933475, Revision E
October 2004

TSI®

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Model 3475 Condensation Monodisperse Aerosol Generator

Instruction Manual

Manual History

The following is a manual history of the Model 3475 Condensation Monodisperse Aerosol Generator Instruction Manual (Part Number 1933475).

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First version	January 1996
A	May 1996
B	October 1998
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(effective July 2000)

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Safety

This section provides instructions for safe and proper handling of the Model 3475 Condensation Monodisperse Aerosol Generator (CMAG).

TSI accepts no liability for damages caused by improper operation, application, cleaning, or use of unsuitable materials for either the aerosol or the nuclei.

Follow the guidelines below to aid you in proper operation of the instrument:

- Read this instruction manual before starting operation.
- *Always* use an inert carrier gas (i.e., nitrogen) when operating this aerosol generator.
- Make sure the maximum pressure at the pressure regulator *never* exceeds 10 bar (145 psi).
- Make sure the maximum pressure at the gas inlet is *always* less than 8 bar (116 psi) and the total flowrate through the aerosol generator *never* exceeds 300 l/h.
- Do *not* restrict the aerosol outlet. The aerosol generator can only work against atmospheric pressure.
- Only use replacement parts supplied by TSI.
- Allow the instrument to cool off before replacing the aerosol material or refilling the aerosol material.
- Make sure the boiling temperature of the aerosol material is higher than the adjusted saturator temperature.
- Remove the main connection before refilling the atomizer with sodium chloride (NaCl) solution.

W A R N I N G
Avoid diffusing aerosol into ambient air.

Labels

The Model 3475 has two labels located on the back panel.

DANGER

HIGH VOLTAGE COMPONENTS WITHIN THIS INSTRUMENT, ALWAYS UNPLUG THE POWER CORD BEFORE REMOVING ANY INSTRUMENT COVERS.

WARNING

SATURATOR AND REHEATER OPERATE AT HIGH TEMPERATURE, ALLOW TO COOL BEFORE REMOVING COVERS.

TO AVOID ELECTRIC SHOCK, THE POWER CORD PROECTIVE GROUNDING CONDUCTOR MUST BE CONNECTED TO EARTH GROUND.

BOTH LINE AND NEUTRAL MAY FUSED.
FOR CONTINUED FIRE PROTECTION, REPLACE ONLY WITH SPECIFIED TYPE AND RATED FUSE.
DISCONNECT INPUT POWER BEFORE REPLACING FUSE.

Figure 1
Model 3475 Back Panel Label

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About This Manual

Purpose

This is an instruction manual for the operation and handling of the Model 3475 Condensation Monodisperse Aerosol Generator.

Reusing and Recycling

As part of TSI Incorporated's effort to have a minimal negative impact on the communities in which its products are manufactured and used:

- This manual uses recyclable paper.
- This manual has been shipped, along with the instrument, in a reusable carton.

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, mail your comments on another sheet of paper to:

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CHAPTER 1
Product Overview

The Model 3475 Condensation Monodisperse Aerosol Generator is used to generate high-concentration monodisperse aerosols.

The aerosol generation principle is based on controlled heterogeneous condensation. Vaporized aerosol material is condensed in a controlled manner onto small sodium chloride (NaCl) particles that are serving as condensation nuclei. This forced condensation allows you to obtain a high grade of monodispersity even at high number concentrations.

The most important features of the Model 3475 aerosol generator are stable operation and ease of use. As a result of both the direct heating of the aerosol material in the saturator and the double bypass arrangement, both particle size and number concentration can be changed very rapidly. Using di-2-ethyl hexyl sebacate (DEHS) as the aerosol material, a particle size range from 0.1 µm to approximately 8 µm (aerodynamic diameter) can be covered with geometric standard deviations less than 1.15.

The compact design and clear layout of the aerosol generator guarantee ease of operation, simple checking of the control parameters, and straightforward maintenance and replacement of the materials used in aerosol generation.

The following table includes the technical specifications for the generator.

Table 1-1
Model 3475 Technical Specifications

Adjustable Particle Size Range:	
Aerodynamic particle diameter	0.1–8 µm (DEHS)
Geometric Standard Deviation	<1.10 from 0.5 to 8 µm <1.25 from 0.1 to 0.5 µm
Number Concentration	>10^6 particles/cc (variable)
Total Flowrate	3.5 to 4.0 L/min (210 to 240 l/h)
Power Supply	110/220V, 60 Hz/50 Hz
Nitrogen Supply	4 L/min at 116 psi
Dimensions (LWH)	250 × 300 × 550 mm (10 × 12 × 22 in.)
Weight	17 kg (37 lb)

Figure 1-1
Model 3475 Condensation Monodisperse Aerosol Generator

CHAPTER 2
Operating Principles

The Model 3475 aerosol generator uses a controlled condensation technique to produce monodisperse aerosols. Figure 2-1 is a block diagram of the generator.

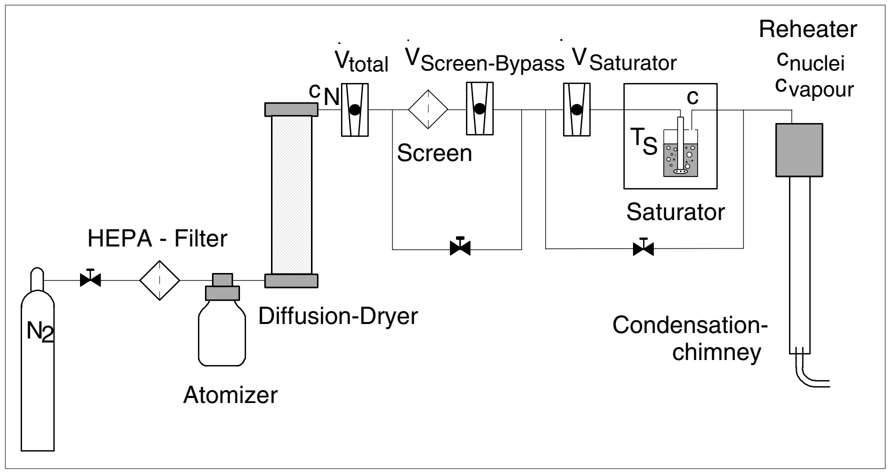

Figure 2-1
Block Diagram of the Model 3475 Aerosol Generator

HEPA Filter

The HEPA-filter ensures that the carrier gas (nitrogen) is clean and does not contaminate the aerosol.

Atomizer, Diffusion Dryer, and Screen Bypass

In the atomizer, a very dilute NaCl solution is sprayed from a nozzle to produce droplets in the size range of 1 to 3 µm. Downstream of the atomizer, a diffusion dryer removes the water from the droplets to produce small crystals with sizes of 10 to 100 nm, depending on the original concentration of the solution. The screen bypass arrangement permits lowering of the concentration of the salt crystals from the original value of 10^6 to 10^7 per cm^3, before the crystals are used as condensation nuclei in a heterogeneous condensation process.

Since the concentration of the final aerosol is approximately the same as the concentration of the nuclei aerosol, the screen-bypass arrangement can be used to control the aerosol concentration within the boundaries imposed by the heterogeneous condensation process.

The size of the aerosol particles is determined by the quantity of available vapor per nucleus.

The number concentration of the nuclei is set by the flows in the screen-bypass.

The vapor concentration in the Model 3475 can be adjusted by two parameters:

- Saturation of the carrier gas at a definite *temperature*.
- Dilution of saturated carrier gas with a *bypass*.

Saturator

The saturation of the gas, with vapor from the aerosol material, takes place in the saturator. The nuclei aerosol bubbles through the aerosol material at a constant temperature. Depending on temperature and vapor pressure, a certain saturation concentration of the vapor is achieved in the bubbles.

The bypass around the saturator allows dilution of the saturated gas. This permits rapid adjustment of particle size by changing the ratio of bypass to total flowrate, rather than by waiting to heat or cool the saturator.

Reheater

The nuclei-vapor mixture is re-heated to ensure that no condensation takes place upstream of the condensation chimney.

Condensation Chimney

In the condensation chimney, the vapor-nuclei mixture is cooled down in a laminar flow and the resulting supersaturation causes the vapor to condense onto the nuclei.

CHAPTER 3
Operating Theory

This chapter describes the theory behind the operation of the Model 3475 Condensation Monodisperse Aerosol Generator.

Characterization of Monodisperse Aerosols

The properties of the log normal distribution are used to characterize monodisperse aerosols. These properties can be calculated by measuring the numbers of particles in different size classes and applying the following formulas:

Median Particle Diameter: $d_m = \prod d_i^{\left(\frac{N_i}{N_{tot}}\right)}$

Geometric Standard Deviation: $\sigma_g = \exp\sqrt{\sum \frac{N_i \cdot \ln^2\left(\frac{d_i}{d_m}\right)}{N_{tot}}}$

where:

d_i Median particle diameter of the i-th class
N_{tot} Total number of the particles counted
N_i Number of particles in the i-th class

For an ideal monodisperse aerosol, the geometric standard deviation must be 1.0 (σ_g=1). According to VDI-guideline 3491, page 1, real aerosols are divided as follows:

- $\sigma_g < 1.15$ monodisperse
- $1.15 \le \sigma_g < 1.5$ quasimonodisperse
- $\sigma_g > 1.5$ polydisperse

Generation of Monodisperse Condensation Aerosols

Condensation techniques are widely used for the generation of monodisperse aerosols. Figure 3-1 illustrates a typical technique.

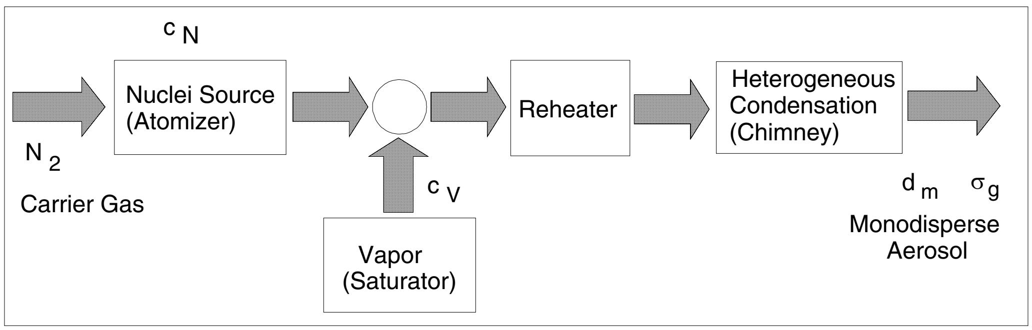

Figure 3-1
Principle of Condensation Techniques

The differences between techniques are found in the manner of the generation of the condensation nuclei, the evaporation of the aerosol material, and the mixing of nuclei and vapor. Figure 3-1 shows that the particle size depends on the amount of vapor per nucleus.

An aerosol generator, according to the principle of Sinclair-LaMer, generates the vapor to saturate the carrier gas at a definite temperature. The particle size can be calculated by the following formula (1), neglecting the losses of aerosol material at the wall of the condensation chimney:

$$d_m^3 = \frac{6}{\pi \kappa \rho} \frac{P_s(T_s)}{T_s} \frac{m_v}{c_N} \frac{1}{e^{4{,}5(\ln \sigma_g)^2}} \sim \frac{c_D}{c_N} \sim \frac{1}{c_N} \frac{P_s(T_s)}{T_s} \qquad (1)$$

where:

d_m	Median particle size
κ	Boltzmann constant
ρ	Density of the aerosol substance
p_s	Saturation vapor pressure of the aerosol material
T_s	Saturator temperature
m_v	Mass of a molecule of the aerosol material
c_N	Number concentration of the condensation nuclei
σ_g	Geometric standard deviation of the aerosol
c_V	Concentration of the vaporized aerosol material
$\dot{V}_{\text{Saturator}}$	Saturator flow
$\dot{V}_{\text{Screen}}$	Screen flow

The formula shows that for a conventional Sinclair-La Mer generator, only one particle size adjustment parameter, the temperature, exists to set the particle size.

The Model 3475 aerosol generator allows both the quick adjustment of the vapor concentration by dilution with a bypass and a variable adjustment of the nuclei concentration by a screen.

The physical dependencies are illustrated by the following formula (2):

$$d_m^3 \sim \frac{P_s(T_s)}{T_s} \frac{1}{c_N} \frac{\dot{V}_{\text{Saturator}}}{\dot{V}_{\text{Screen}}} \tag{2}$$

Adjustment of the Particle Size by the Saturator Flow

According to the following formula (3), the saturator flow is proportional to the third power of the generated particle size.

$$d_m^3 \sim \dot{V}_{\text{Saturator}} \tag{3}$$

Experimental results with the Model 3475 aerosol generator are very close to this theoretical relationship.

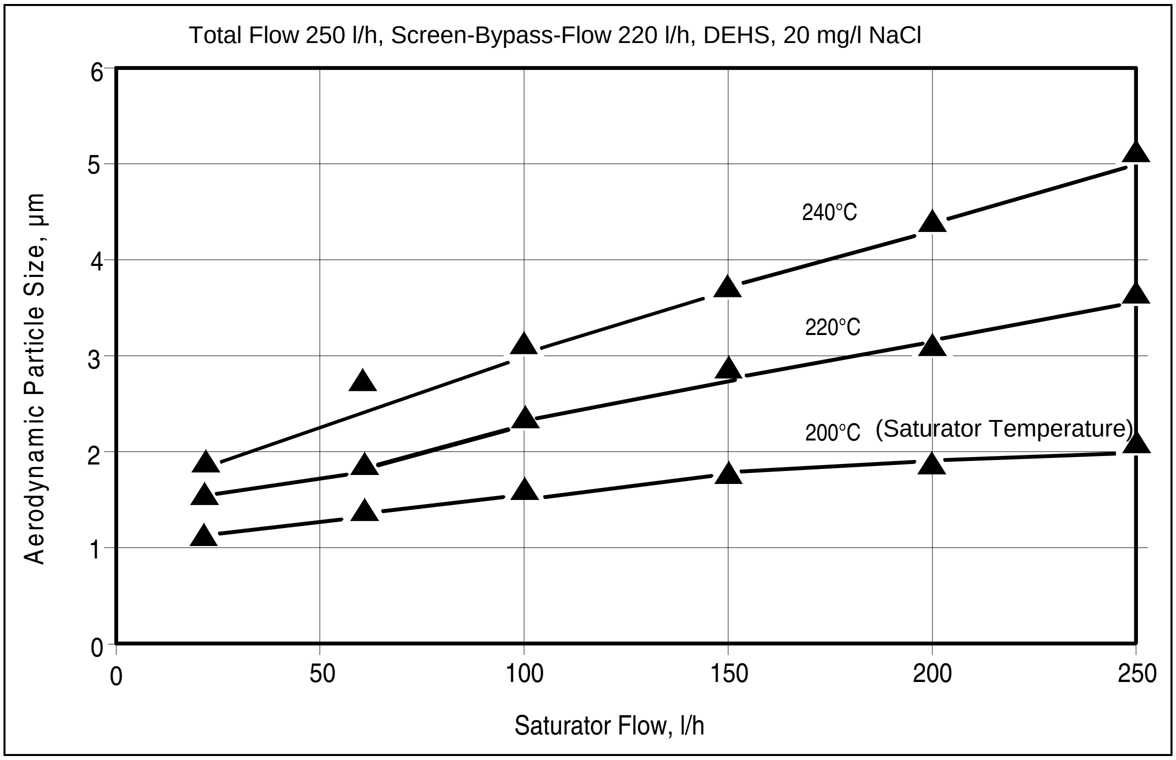

Figure 3-2
Dependency of Particle Size on Saturator Flow

Adjusting the saturator flow allows for very rapid changing of the particle size. Figure 3-2 shows that this type of particle size adjustment yields high resolution at the larger particle sizes due to the shallow slope of the size versus the saturator flow curve.

This advantage is limited for small particles, since the accuracy of adjustment is low for low flowrates, and the particle size reacts very strongly to changes of the saturator flow.

Adjustment of the Particle Size by the Saturator Temperature

The particle size can also be set by the saturator temperature. Formula (2) can be reduced to the following formula (4):

$$d_m^3 \sim \frac{P_s(T_s)}{T_s} \sim \frac{Ae^{BT_s}}{T_s} \tag{4}$$

The saturation vapor pressure of the aerosol material is indicated by $P_s = A * e^{BT}$ (see Appendix A). The particle size dependency on the saturator temperature is illustrated in Figure 3-3.

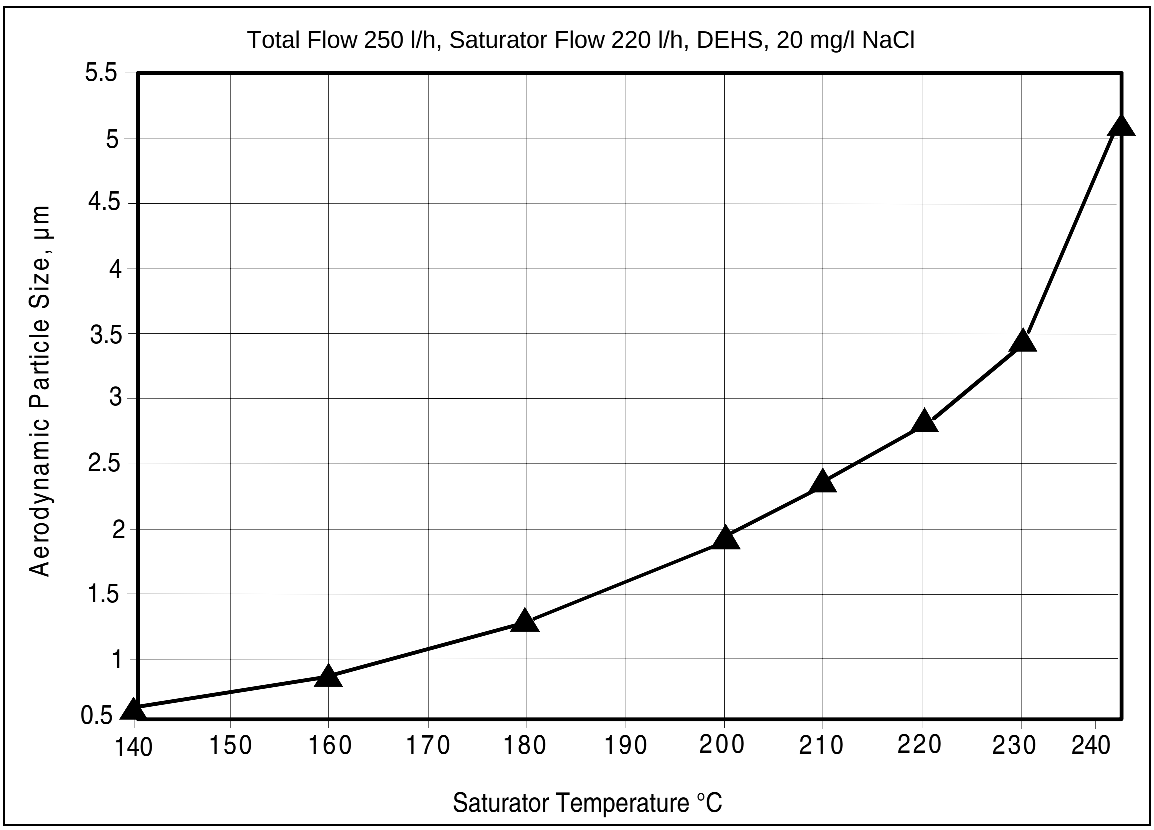

Figure 3-3
Effect of Saturator Temperature on Particle Size

The advantage of adjusting this parameter is the precision over the whole particle size range. The disadvantage is the long waiting time period required to reach stability at the new particle size.

Adjustment of the Number Concentration

The screen bypass permits the varying of the aerosol number concentration. According to formula (2) the change of concentration affects the particle size based on formula (5):

$$d_m^3 \sim \frac{1}{c_N} \tag{5}$$

By increasing the nuclei concentration, a constant amount of vapor condenses onto more nuclei, resulting in smaller generated particles. Conversely, the particles are larger at lower nuclei concentrations.

The maximum particle size is limited by transition to homogeneous condensation. The lower boundary concentration is approximately 0.4×10^6 per cm^3 in the Model 3475.

Figure 3-4 illustrates the increase in particle size as the concentration decreases. At a saturator temperature of only 220°C, it is already possible to generate 8 µm particles:

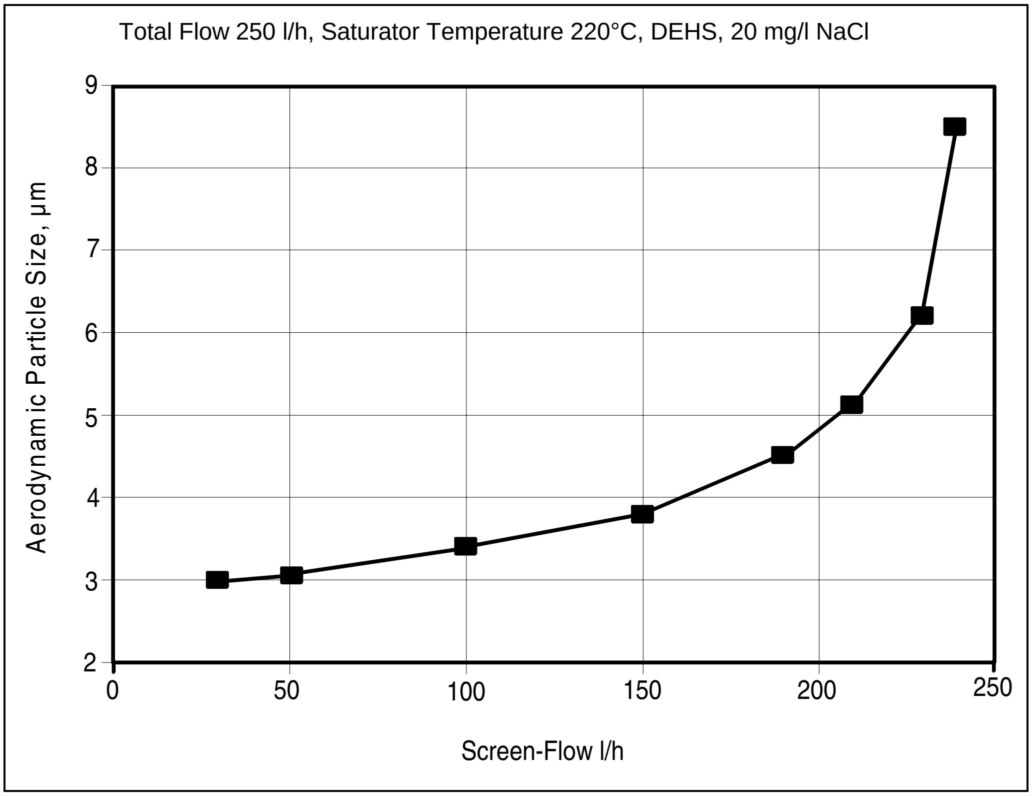

Figure 3-4
Influence of Concentration (Screen Flow) on Particle Size

Generation of Homogeneous Condensation Aerosols

The generator also allows the generation of homogeneously condensed aerosols.

For this purpose, the generator must operate without the nuclei source. This requires removing the sodium chloride solution or ensuring that all the total flow runs through the screen. The generated aerosol is *not monodisperse* but has a very high number concentration of approximately $10^7 - 10^9$ per cm^3. The median particle size is in the range of 100 to 200 nm (Figure 3-5).

Because of the high number concentration, it is possible to produce highly concentrated monodisperse aerosols smaller than 0.1 µm by means of a downstream electrostatic classifier. A concentration of approximately 10^6 per cm^3 is easily obtainable.

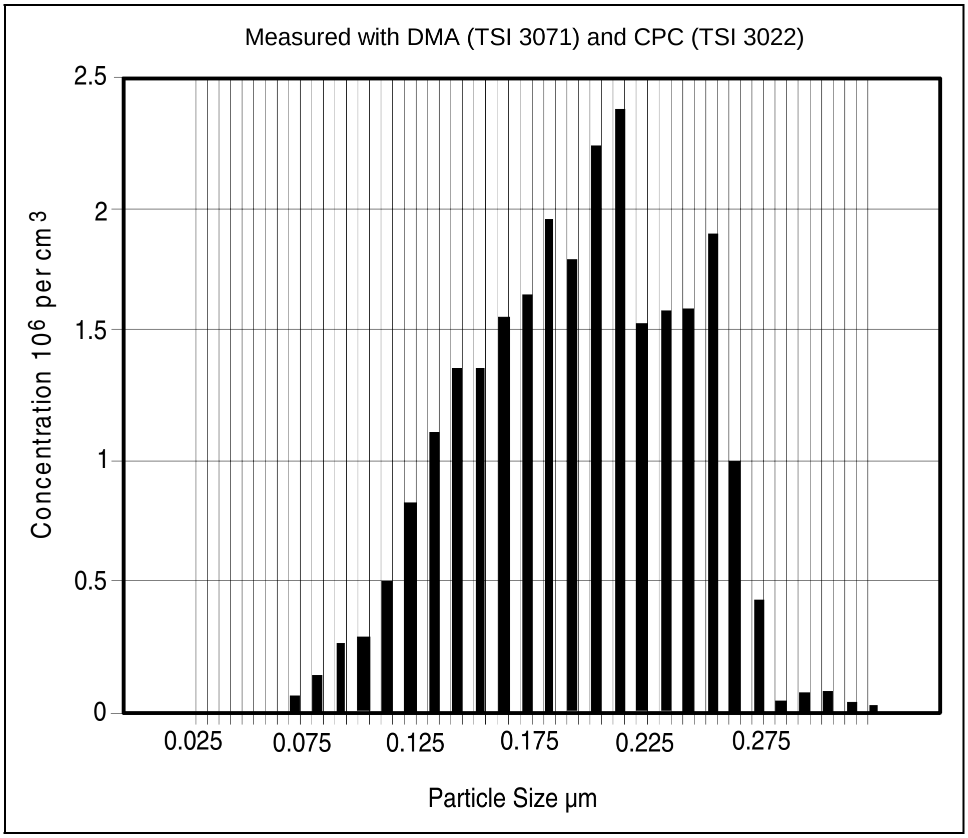

Figure 3-5
Homogeneously Condensed Aerosol

CHAPTER 4

Using the Model 3475 Aerosol Generator

This chapter describes the components of the Model 3475 aerosol generator in detail and includes instructions on properly setting up and using the generator.

Operating Summary

The basic operation of the Model 3475 aerosol generator is summarized in the following steps. Detailed operating instructions appear in the remainder of this chapter.

1. Fill the atomizer with NaCl solution (20 mg/l).
2. Fill the saturator with DEHS or another aerosol material.
3. Ensure adequate ventilation for surplus aerosol.
4. Close the pressure valve (no flow).
5. Connect the nitrogen supply to the generator through the pressure valve.
6. Connect the main plug and switch it on.
7. Set the required saturator temperature at the temperature controller.
8. Check the reheater temperature (300°C for DEHS).
9. Allow time for the temperature to stabilize.
10. Open the pressure valve slowly and adjust the total flow.
11. Set the required aerosol concentration by adjusting the screen flow.
12. Control the particle size by adjusting the saturator flow.

The aerosol is available at the required particle size and concentration within a short time after the temperature stabilizes.

Main Components of the Model 3475

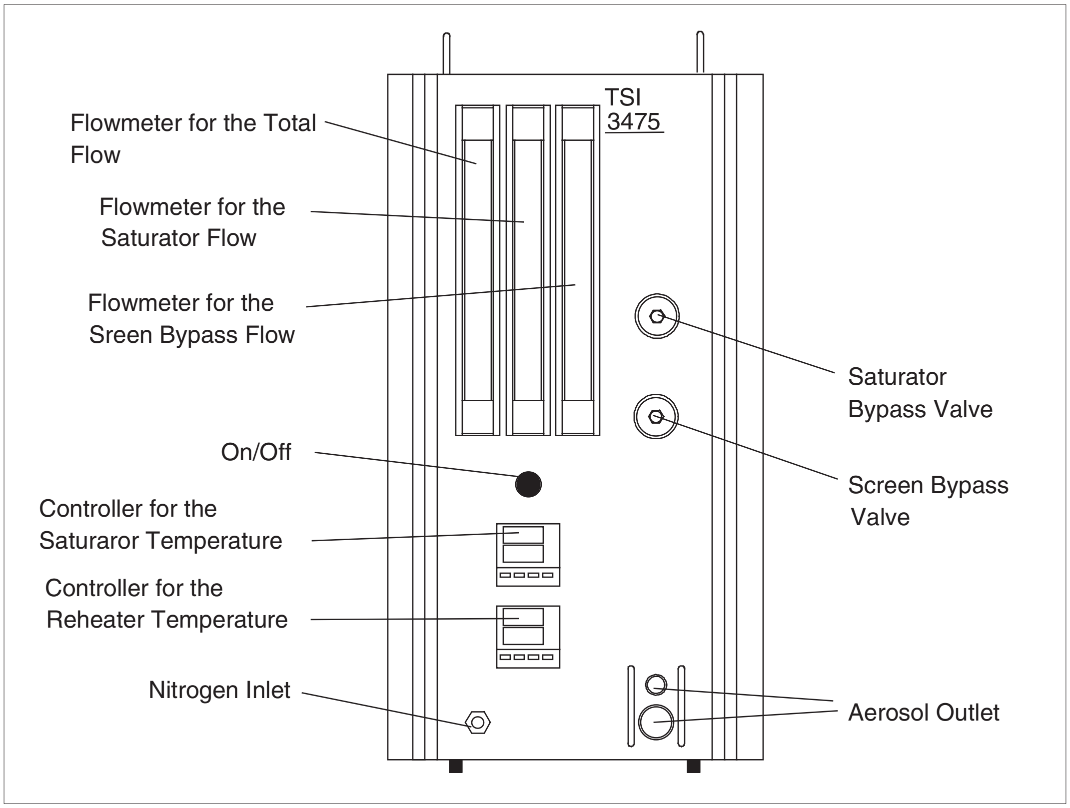

Figure 4-1
Operating Panel of the Model 3475

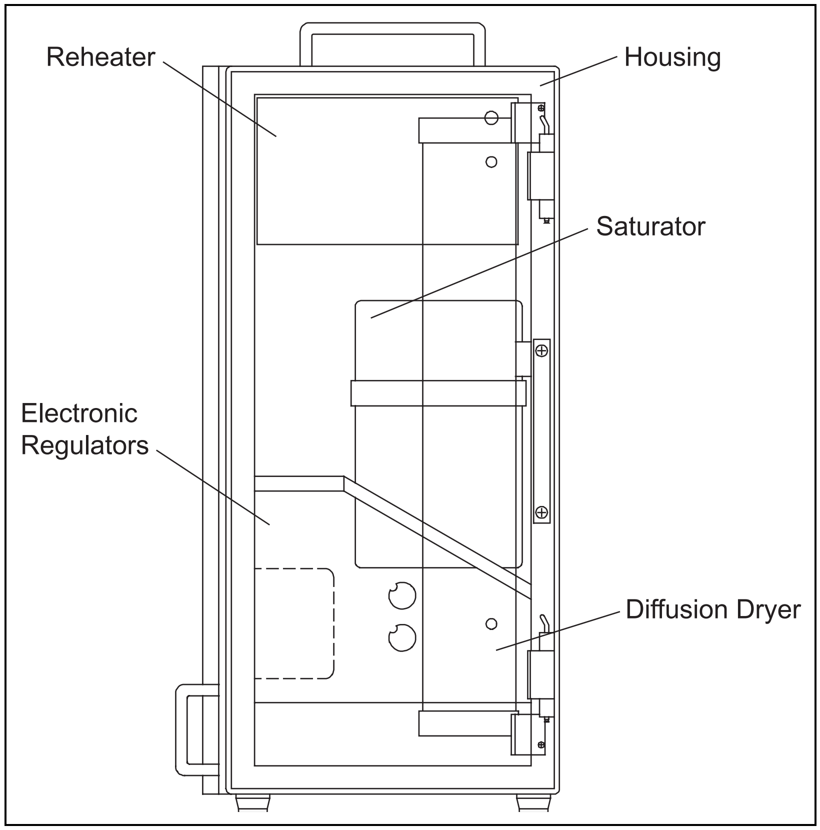

Figure 4-2
Side View of the Model 3475

Flowmeter

For measuring the total, the screen, and the saturator flow, mechanical flowmeters are used. Before using the generator, be sure to follow the guidelines below:

- Open the pressure regulation valve slowly so as not to expose the generator to a sudden surge. The diameter (center) of the red ball in the flowmeter indicates the pressure reading.

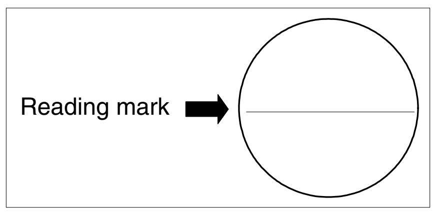

Figure 4-3
Red Ball with Pressure Reading Mark

- To guarantee precise measurements, the ball and the measuring pipe must be clean. If necessary, clean these flowmeter components as described below:
  1. Open the protective cap by pushing on both sides.
  2. Push the measuring pipe into the upper outlet housing (about 6–7 mm). First remove the lower end and then the whole measuring pipe from the flowmeter.
  3. Clean the pipe and the ball with reagent grade alcohol.
  4. Reverse these steps to reassemble the flowmeter.

The flowrate is shown by a mm scale, which makes it possible to use several carrier gases at different absolute pressures.

For nitrogen and atmospheric pressure, the relationship between flowrate and flowmeter reading is shown in Figure 4-4.

For other gases and pressures, the calibration curves can be provided. Contact your TSI representative.

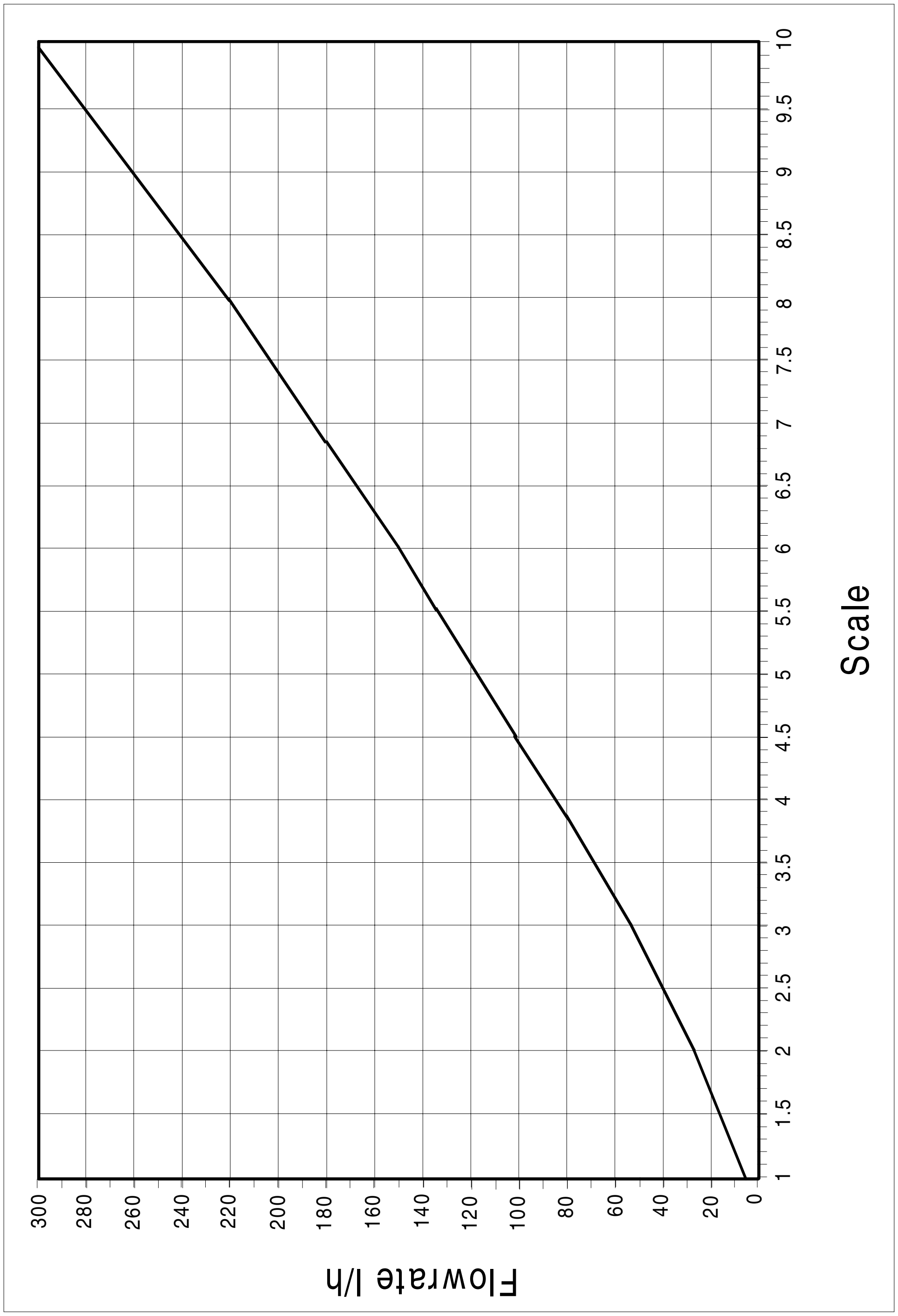

Figure 4-4
Relationship between Reference Dimension of the Flowmeter and Flowrate

Temperature Controller

Microprocessor controllers are used to achieve precise adjustment of the temperatures. Figure 4-5 illustrates the actual and set values as displayed on the controller.

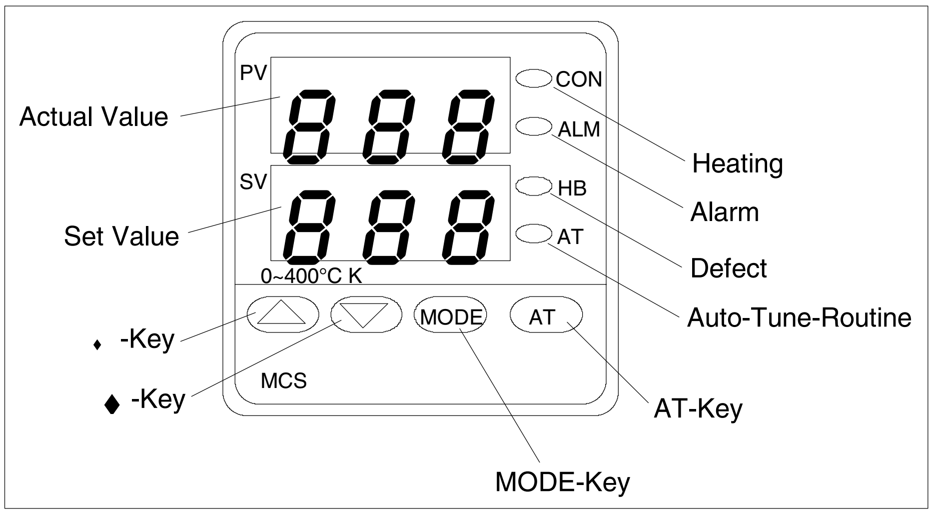

Figure 4-5
Actual and Set Controller Values

Controller Operations:

- **Setting the required temperature:**
  The temperature can be set with three or four keystrokes. First, press the **MODE**-key. "ϟ" is observed on the upper display. Then, use the ↑ and ↓ keys to set the required temperature. Last, press the **MODE** key again and the controller begins to operate with the new temperature setting. Both thermostats operate in the range of 0 to 400°C.

- **Auto-tune-routine:**
  The controller works as a PID-regulator optimized for start-up. The auto-tune-routine determines quickly the constants of the regulator. The controller automatically examines the whole temperature range and analyses its regulation behavior. There are two different optimization routines:

1. Start-up behavior at large temperature differences:
   - The controller determines the parameters at start-up of the regulator.
   - At a temperature of approximately 5 percent less than the set temperature, the regulator stops this auto-tune routine.

2. Regulation behavior in the 10% range:
   - If the actual temperature varies less than 10% from the set value and you start the auto-tune routine, the controller optimizes the regulation parameters for this temperature range until it reaches the required temperature.
   - The auto-tune routine is started by pressing the AT key. During the routine, the yellow AT LED blinks.
   - Depending on the actual temperature, the first or the second optimization routine is selected automatically. After reaching the optimized state, the routine ends automatically.

Regulation Valve

Connect the supply pressure regulator to the Model 3475 aerosol generator with a quick-coupling adapter. The supply pressure to the regulator must not exceed 10 bar (145 psi) and the pressure applied to the generator must not exceed 8 bar (116 psi).

Set the pressure by rotating the control knob. Rotating the knob clockwise increases the pressure. Rotating the knob fully counterclockwise completely closes the valve.

Lock the valve at a specific setting by turning the control knob to the desired setting and then pushing the knob.

Filling the Saturator

The saturator must be sufficiently full during operation. Two marks on the saturator-vessel show the minimum and the maximum levels of the aerosol material. If the level is too high, the aerosol material will bubble directly into the reheater and the bypass. If the level is too low, the heating element is not completely covered by the aerosol material. This results in local overheating of the aerosol material, which can discolor it.

Notes: *1. Check the liquid level in the saturator before turning on the generator and during long term operation.*

2. Allow the saturator to cool down before refilling it.

To refill the saturator, loosen the long holding spring on the lower end of the saturator housing and remove the vessel-housing. The vessel is held by two small springs. After removing these springs, twist the vessel to remove it. Reverse these steps to reassemble the saturator.

Note: *The long spring is held in place by two small indents on the bottom edge of the vessel housing. Make sure the spring is firmly in place to secure the housing.*

Filling the Atomizer

The atomizer sprays a low-concentration sodium chloride solution. To guarantee reproducible results, always use a fresh solution of the same concentration. For long term research programs, the preparation of a larger amount of solution is recommended. Be sure to store the solution in a refrigerator.

Depending on your requirements, use a concentration of 20 to 200 mg sodium chloride per liter clean water for standard operation of the Model 3475. The number of nuclei produced increases when the concentration of the solution is increased. However, a higher concentration adversely affects the monodispersity of the generator at small particle sizes.

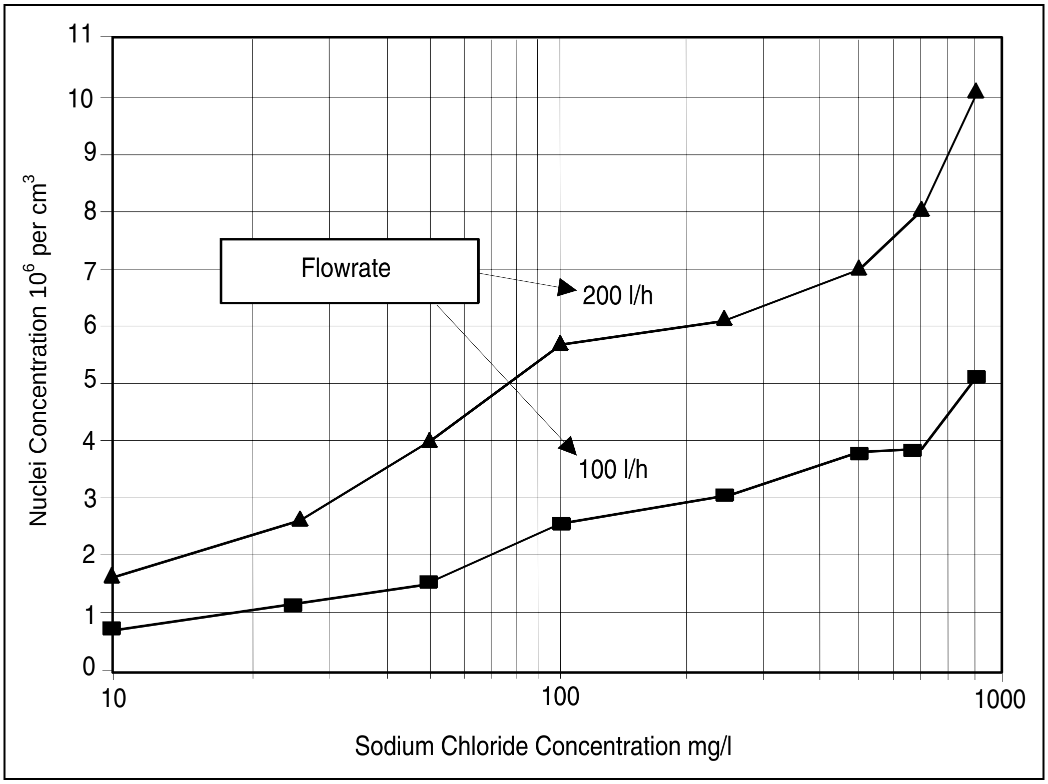

Figure 4-6
Relationship between NaCl Solution Concentration and Number Concentration of Nuclei

After a certain time, increasing contamination of the solution can occur in the form of microorganisms. This causes an appreciable increase in the nuclei concentration.

Note: *The aerosol concentration is not the same as the nuclei concentration.*

The real aerosol concentration is lower than the nuclei concentration, because of losses in the pipes, valves, and saturator.

Before using the Model 3475, clean the atomizer and fill it with fresh NaCl solution. Unscrew the bottle from its red cover to clean and refill it. Perform the following steps to remove and clean the atomizer nozzle, which is located under the red bottle cover.

1. Unscrew the red cover and remove the bottle.
2. Unscrew the nozzle assembly by turning the large screw at the top of the assembly.
3. Remove the atomizer supply tube by turning the small screw under the nozzle.
4. Clean the nozzle in an ultrasonic bath, or probe it with a metal brooch to remove any accumulated material. Blow air through the nozzle after cleaning to make sure it is clear.
5. Reverse these steps to reassemble the nozzle and reattach the atomizer bottle.

Note: *When replacing the atomizer bottle, make sure the gasket under the red cap is seated properly to prevent leaks.*

Regenerating and Changing the Silica Gel

Water is removed from the sprayed Sodium Chloride droplets in the diffusion dryer. It is absorbed into the crystal structure of the silica gel. The color of the silica gel indicates its saturation state:

- *orange*: Silica gel is dry and can be used.
- *white/colorless*: Silica gel is saturated and should be regenerated.

To regenerate the silica gel, pour it out of the dryer and slowly heat it (maximum temperature: 150°C—see Appendix B). You can recognize the dried silica gel by the orange color. To avoid absorbing water from the ambient air, the silica gel should be cooled in a desiccator.

Perform the following steps to remove the silica gel from the dryer:

1. Disconnect the nitrogen supply from the Model 3475.
2. Unscrew the tube connectors at the bottom of the dryer and at the atomizer. Pull off the tubes.
3. Remove the bottle containing the sodium chloride solution from the atomizer.

4. Unscrew the two fixing screws of the dryer and remove the dryer from the housing.
5. Open the cap of the dryer with a coin and pour out the silica gel.

After regenerating the silica gel, reassemble the dryer by performing the above steps in reverse order.

Since the atomizer operates with overpressure, make sure all connections are tight. The generator operates for more than 12 hours with freshly-regenerated silica gel.

Using Solid Aerosol Materials

Materials which are solid at room temperature (Carnauba waxes, paraffins, stearic acid) can be used for aerosol generation. These materials can be handled as described below.

1. The chosen solid material has to be powdered and can be filled in a 200 ml flask. In order to change the material state from solid to liquid it can be melted in a heating mantle. (Set the saturator temperature (no higher than 85°C for Carnauba waxes) to the melting point of the used material.)
2. The liquid material can be poured into the saturator vessel. Be careful when handling the hot flask and liquid.
3. Operation of the aerosol generator is now the same as using a liquid substance like DEHS. Take care that the simple aerosol outlet is mounted.
4. After operation, the generator can normally be switched off and cooled down.

   Tensions which are caused by the process of cooling (solidification) and heating (melting) the aerosol material can lead to destructions of the glass-made heating spiral.

   In order to avoid those destructions, the aerosol material must be poured out of the saturator vessel while it is liquid. The aerosol material should be cooled down to lower than the melting temperature in the flask (for Carnauba waxes 85°C). Be careful when handling the hot flask and liquid.

The instrument can be restarted as described in Step 1 and 2.

5. Cleaning of the condensation chimney can be easily performed using a hot air blower (see accessories).

Caution: If the aerosol material is not fully melted, do **not** flow carrier gas through the saturator vessel.

Caution: TSI does not assume liability for damages caused by overheating of instrument parts during cleaning as described. The condensation chimney should only be heated shortly to allow the material to flow down. In all cases the outlet should be cleaned externally. Using a second saturator is recommended if it is necessary to change often between solid and liquid aerosol materials.

The reheater temperature depends on the material to be used and should be set to a value at which the condensation starts when the aerosol enters the condensation chimney (can be seen by condensation on the surrounding wall).

For Carnauba wax a reheater temperature of 350°C is recommended.

Changing the Saturator

Changing the saturator can be easily performed using the following steps:

1. Unscrew and unplug the electrical saturator connector (lower connection).
2. Disconnect the saturator from the protective ground board.
3. Unplug the tubing between the saturator outlet and the reheater inlet.
4. Unscrew two saturator mounting screws on the right-hand side of the instrument housing. Removing the saturator should be done with mounted isolation cap.

5. The replacement saturator can be assembled in reverse order.

Caution: Before restarting operation, ensure that the saturator is connected to the protective ground board in the right order.

Additional Operating Guidelines

Before turning on the Model 3475 aerosol generator, check the following:

- ❑ Is the saturator sufficiently filled?
- ❑ Is the pressure valve closed at the inlet?
- ❑ Is there adequate ventilation of surplus aerosol?

To generate a specific particle size, you must set the saturator temperature, the saturator flow, and the screen flow correctly. Refer to Appendix A for help in selecting the correct flow settings. Set the saturator temperature at the upper temperature controller. The optimal temperature for DEHS (or other aerosol material such as DOP) is 220°C.

Note*: The saturator temperature must be lower than the boiling point of the aerosol material.*

1. Check the reheater temperature. It should be approximately 50°C higher than the boiling point of the aerosol material. When using DEHS (or DOP), a reheater temperature of 300°C is recommended.
2. Wait until the saturator and reheater temperatures reach the set values.
3. Open the pressure valve slowly and set the required total flow. A flowrate of 250 l/h corresponds to a pressure of about 5 bar (72.5 psi) [see Appendix A].
4. Set the correct bypass flows for screen and saturator.

Initially, as the gas begins to flow, the saturator temperature deviates briefly from the set value. After a short time, the required aerosol stream is generated.

To guarantee high monodispersity of the aerosol, the double outlet for the generator allows an isokinetic exhausting of the center aerosol stream.

CHAPTER 5
Troubleshooting

This chapter presents common error conditions. It explains possible causes for the errors and provides instructions for correcting them.

Monodispersity is Insufficient

- Reheater temperature is too high or too low. Adjust the temperature.
- Silica gel is saturated with water. Refer to Chapter 4 for information on drying the gel.

Aerosol Concentration too High and Particle Size too Small

The atomizer produces too many nuclei.

- Concentration of the sodium chloride solution is too high. Replace the solution. Refer to Chapter 4 for additional information.
- Sodium chloride solution is stale or contaminated. Replace the solution. Refer to Chapter 4 for additional information.

Reheater or Saturator Temperature shows Strong Fluctuation

The parameters of the temperature controller are incorrect.

- Start the auto-tune-routine. Refer to Chapter 4 for instructions.

Total Flow too Low

The total flow is too low, even though the inlet pressure gauge indicates an acceptable pressure. Either the atomizer-nozzle or nitrogen filter is plugged.

Atomizer nozzle is plugged:

- ❑ Unscrew the nozzle assembly and clean the nozzle. Refer to Chapter 4 for instructions.

Nitrogen filter is plugged:

- ❑ Unclamp the nitrogen filter from the blue tubing and replace it with a new filter.

Saturator Flow too Low

The saturator flow can be too low, even though the adjustment is correct. There are possible leaks in the generator.

- ❑ Check tubes for tight connections.
- ❑ Check tubes for kinks or compressions.

Screen Flow too Low

The screen filter is clogged. Remove the screen filter from the clear tubing and replace it with a new screen filter.

DEHS Bubbles out of Saturator into Reheater

There is too much foam from the DEHS (or other aerosol material).

- There is too much DEHS in the saturator. Remove the excess DEHS. Refer to Chapter 4 for instructions on removing the saturator.
- The DEHS is contaminated. Replace the DEHS. Refer to Chapter 4 for instructions on refilling the saturator.

If the recommended action does not solve the problem, contact TSI for further assistance. DEHS and other aerosol materials, spare parts, and silica gel are available from TSI.

APPENDIX A

Guidelines for Parameter Settings

This appendix contains graphs of the types of measurements made with the Model 3475. These examples are intended only as guidelines to help you set parameters for use of the Model 3475 in your own environment. The examples are organized as follows:

1. Selected measurements from the Model 3475.
   - Particle size as a function of the saturator flow
   - Particle size as a function of the saturator temperature
   - Particle size as a function of the screen flow
   - Particle size as a function of the nuclei concentration
   - Geometric standard deviation depending on the saturator temperature and flow
   - Particle size as a function of saturator temperature and flow
   - Nuclei concentration as a function of the screen flow

2. Physical Data of DEHS
   - General data
   - Vapor pressure

3. Calibration curves for the flowmeter

4. Pressure-Flow Graph

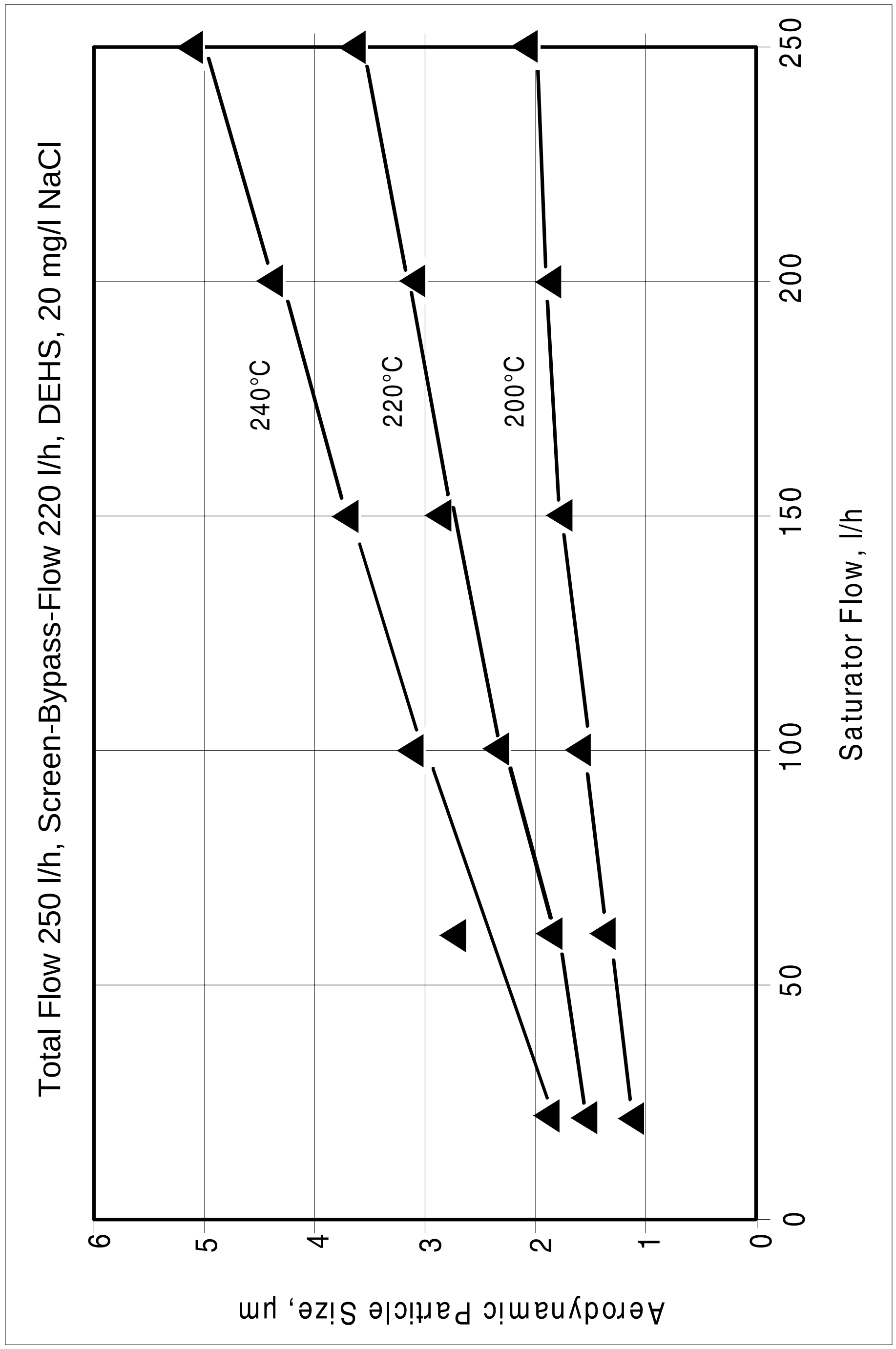

Figure A-1
Particle Size as Function of Saturator Flow

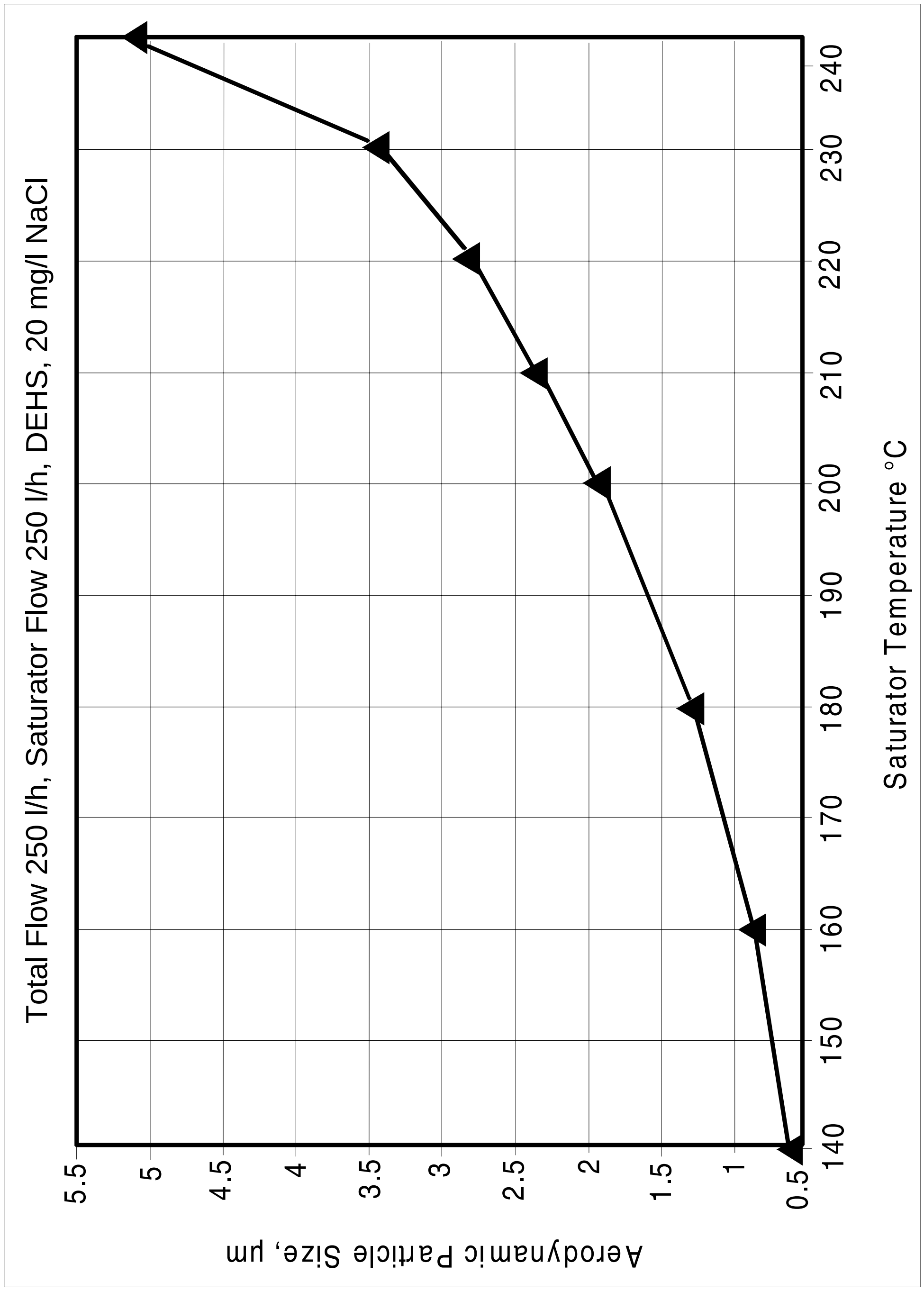

Figure A-2
Particle Size as Function of Saturator Temperature

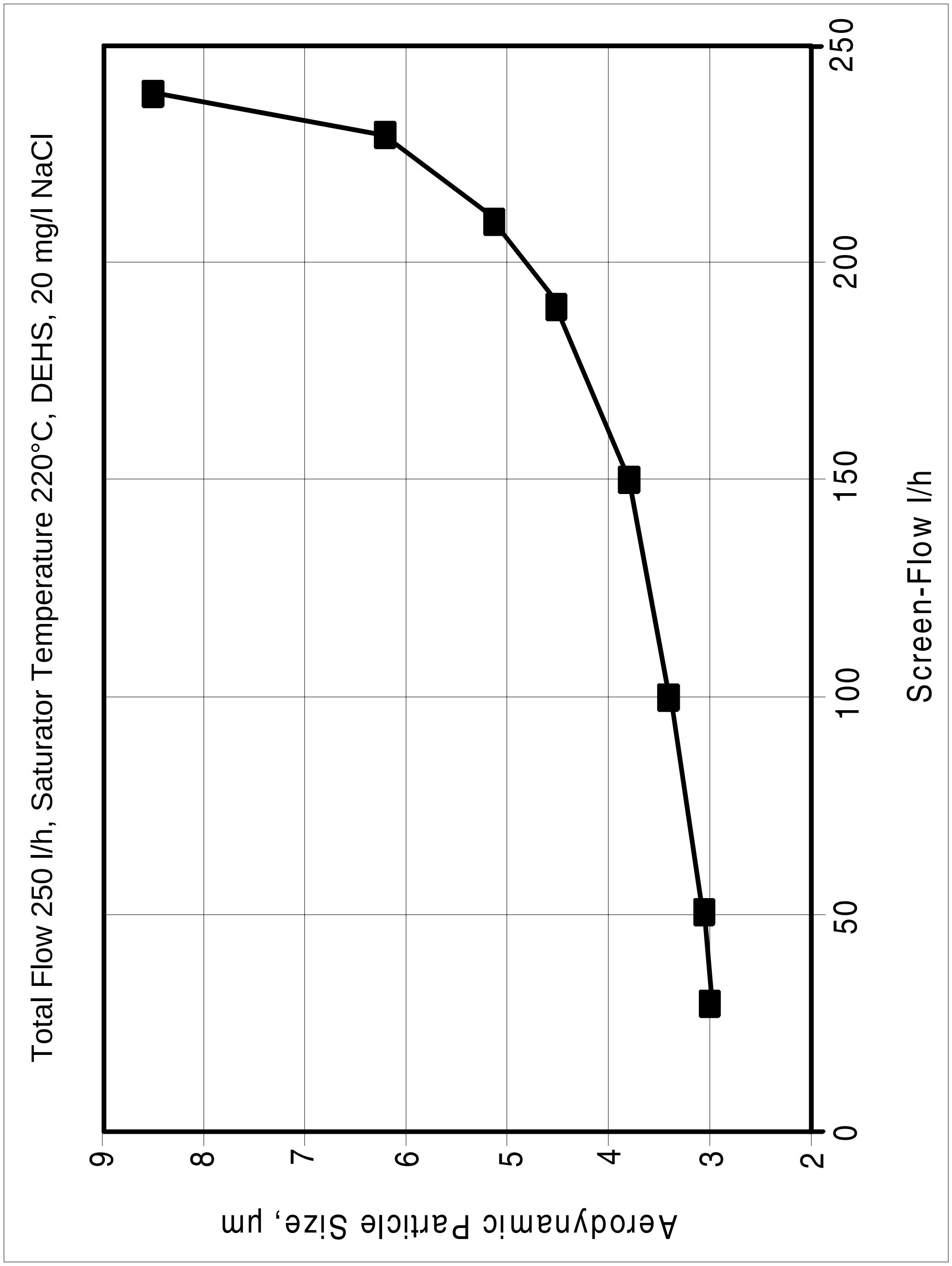

Figure A-3
Particle Size as Function of Screen Flow

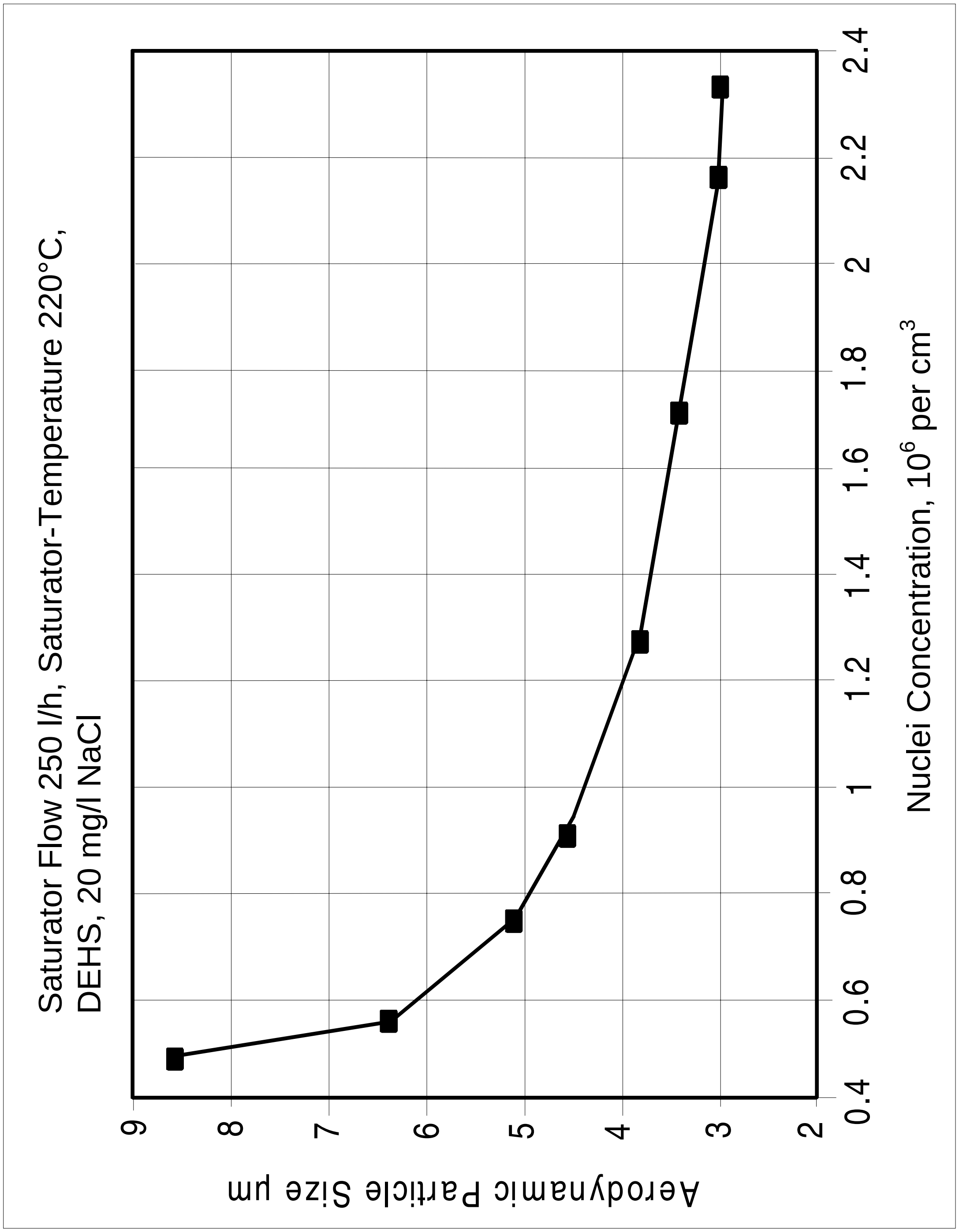

Figure A-4
Particle Size as Function Of Nuclei Concentration

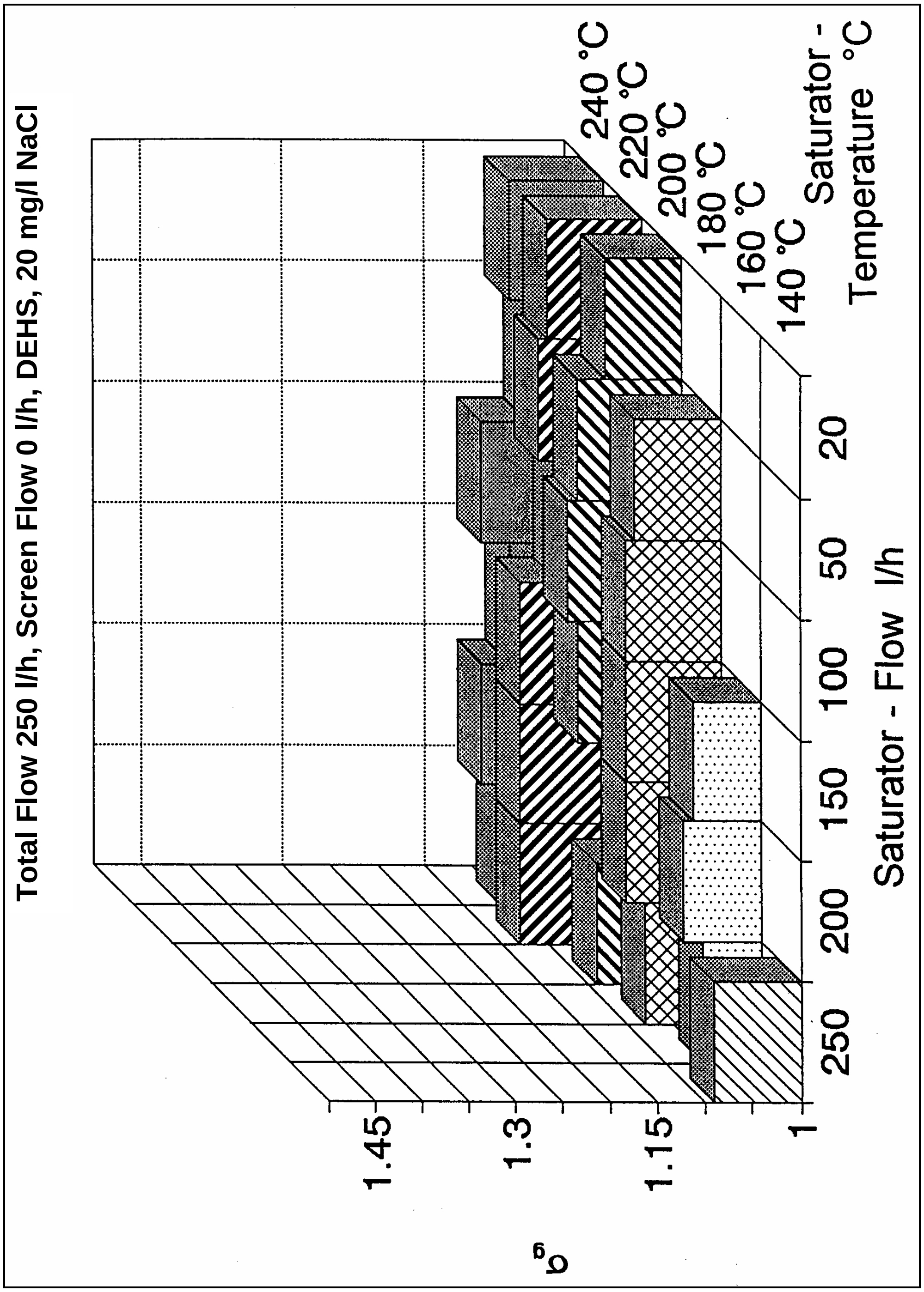

Figure A-5
Geometric Standard Deviation Depending on Saturator Temperature and Flow

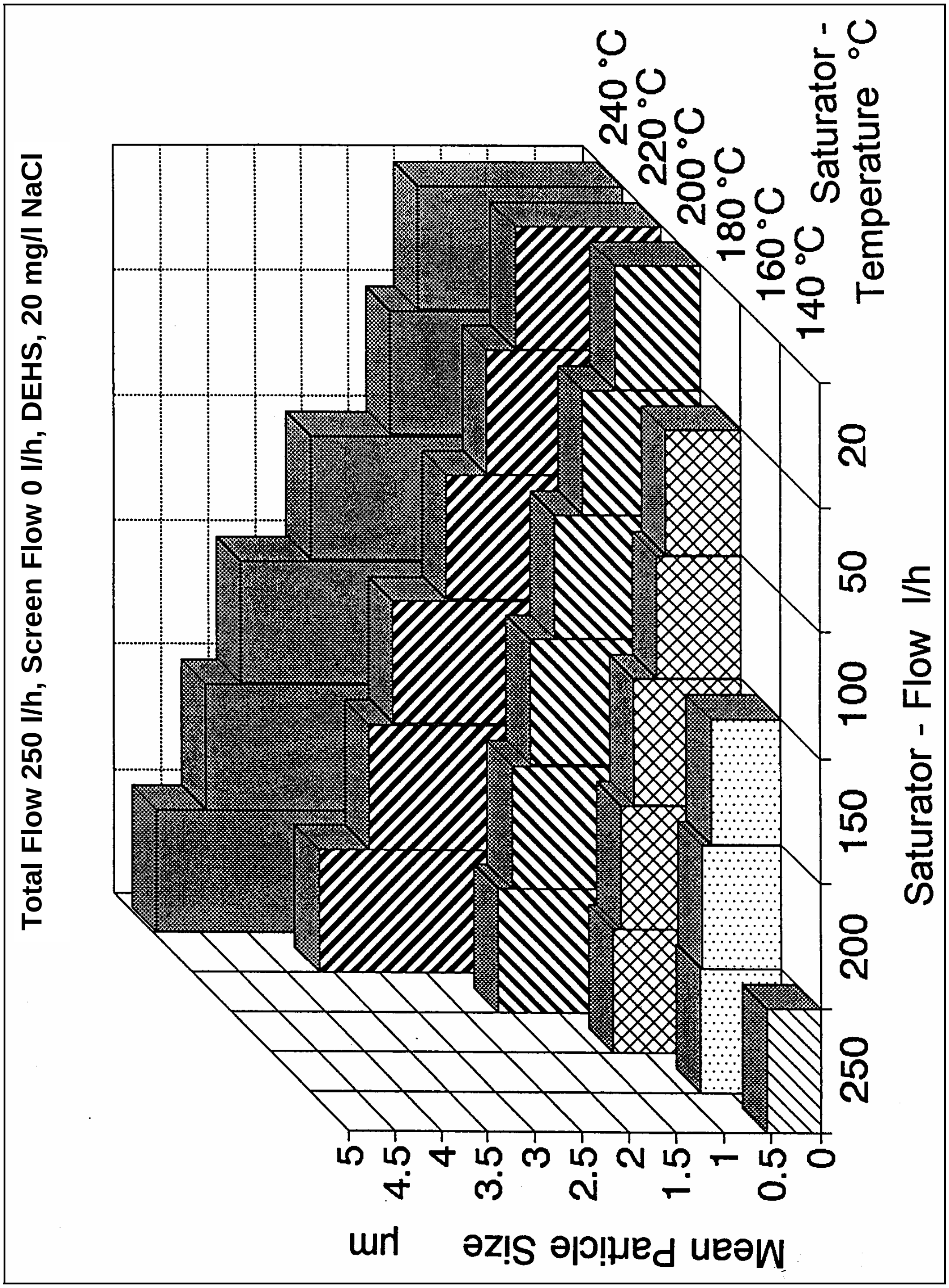

Figure A-6
Particle Size as Function of Saturator Temperature and Flow

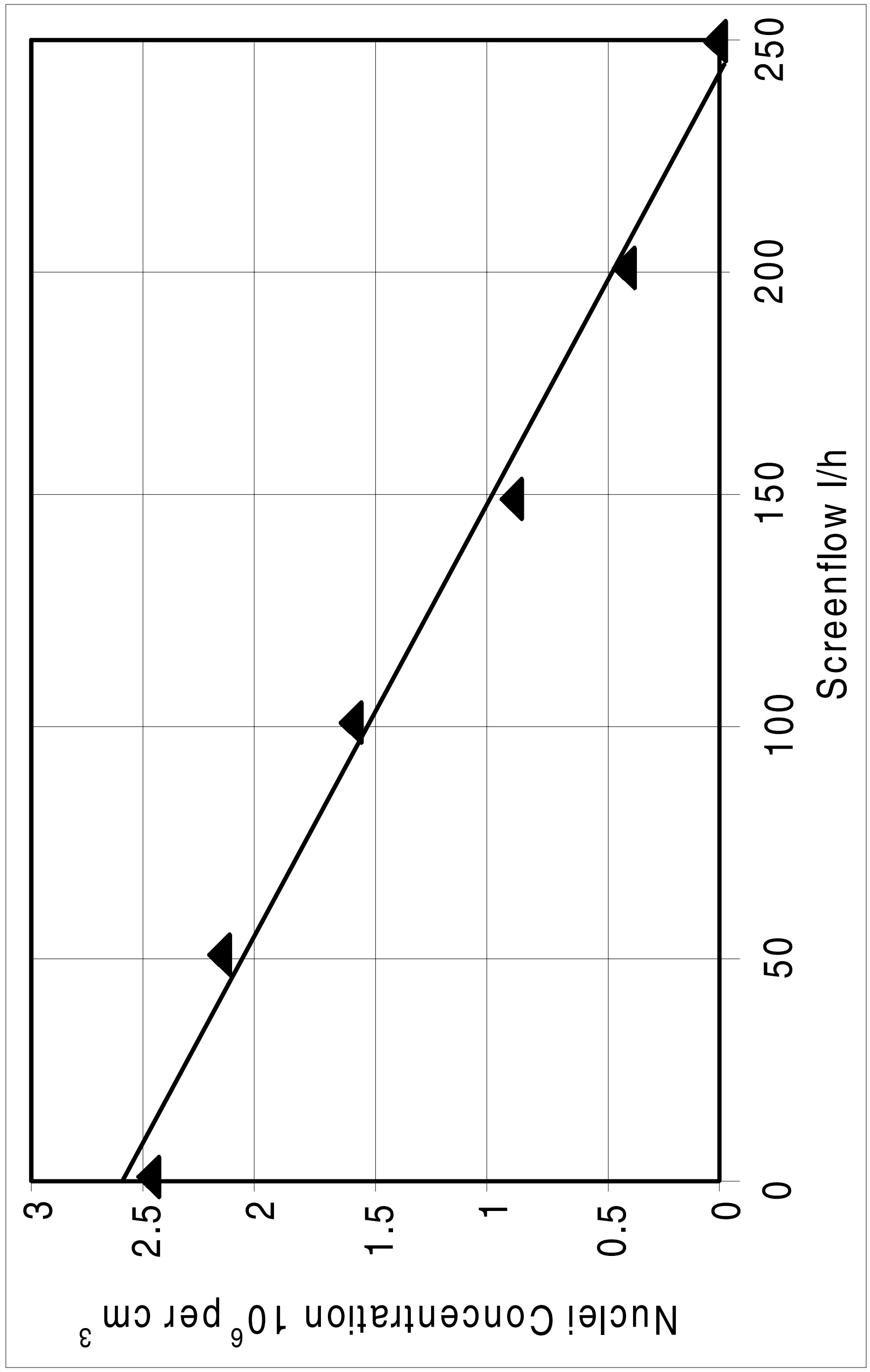

Figure A-7
Nuclei Concentration as Function of Screen Flow

DEHS General Data

Common name:	Di-2-ethyl-hexyl-sebacate
Formula:	$C_{26}H_{50}O_4$
Density:	0.912 kg/cm^3
Melting point:	225 K (–48°C)
Boiling point:	529 K (256°C)

Refractive index	**Wave length (nm)**
1.450	650
1.452	600
1.4535	550
1.4545	500
1.4585	450

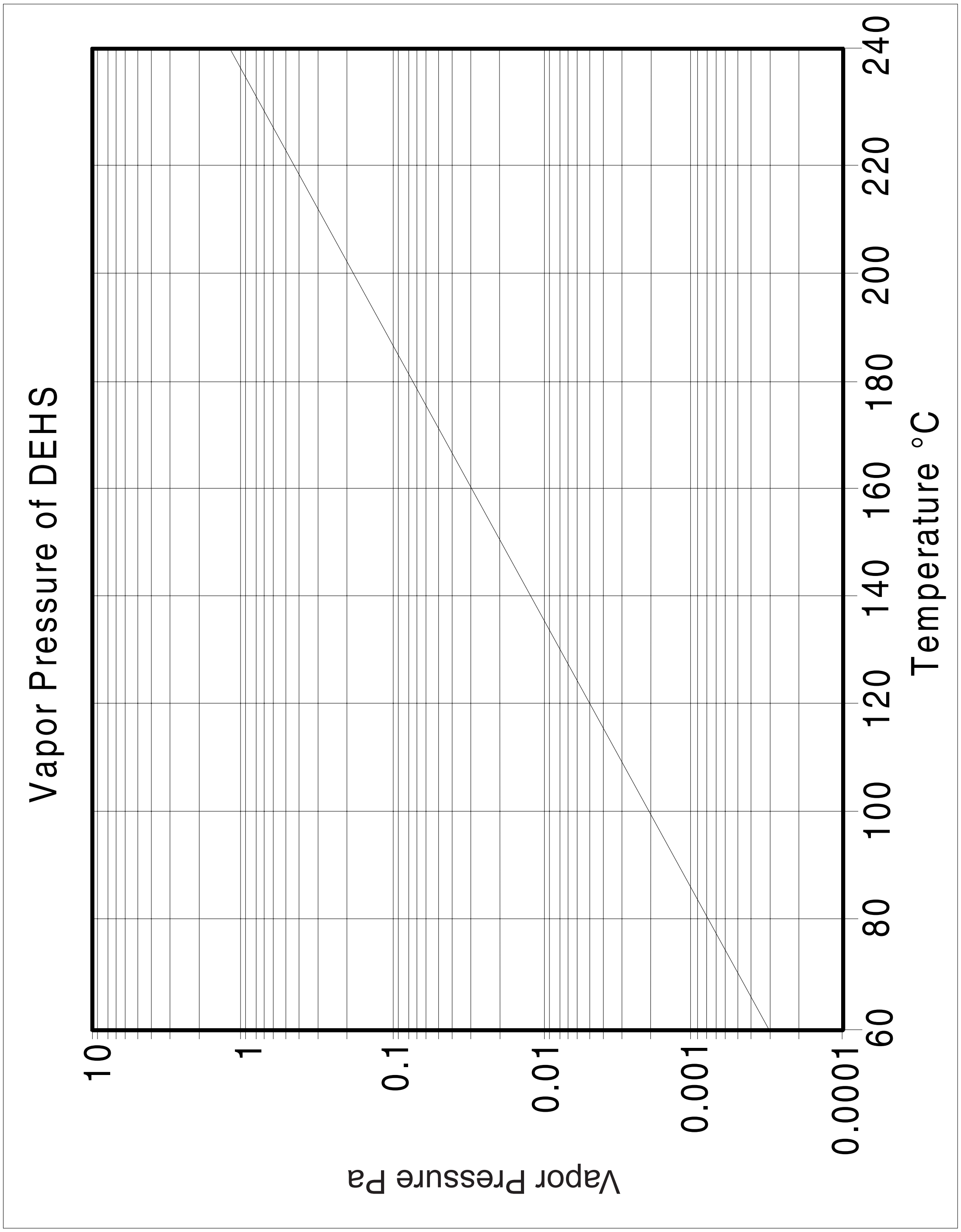

Figure A-8
DEHS Vapor Pressure

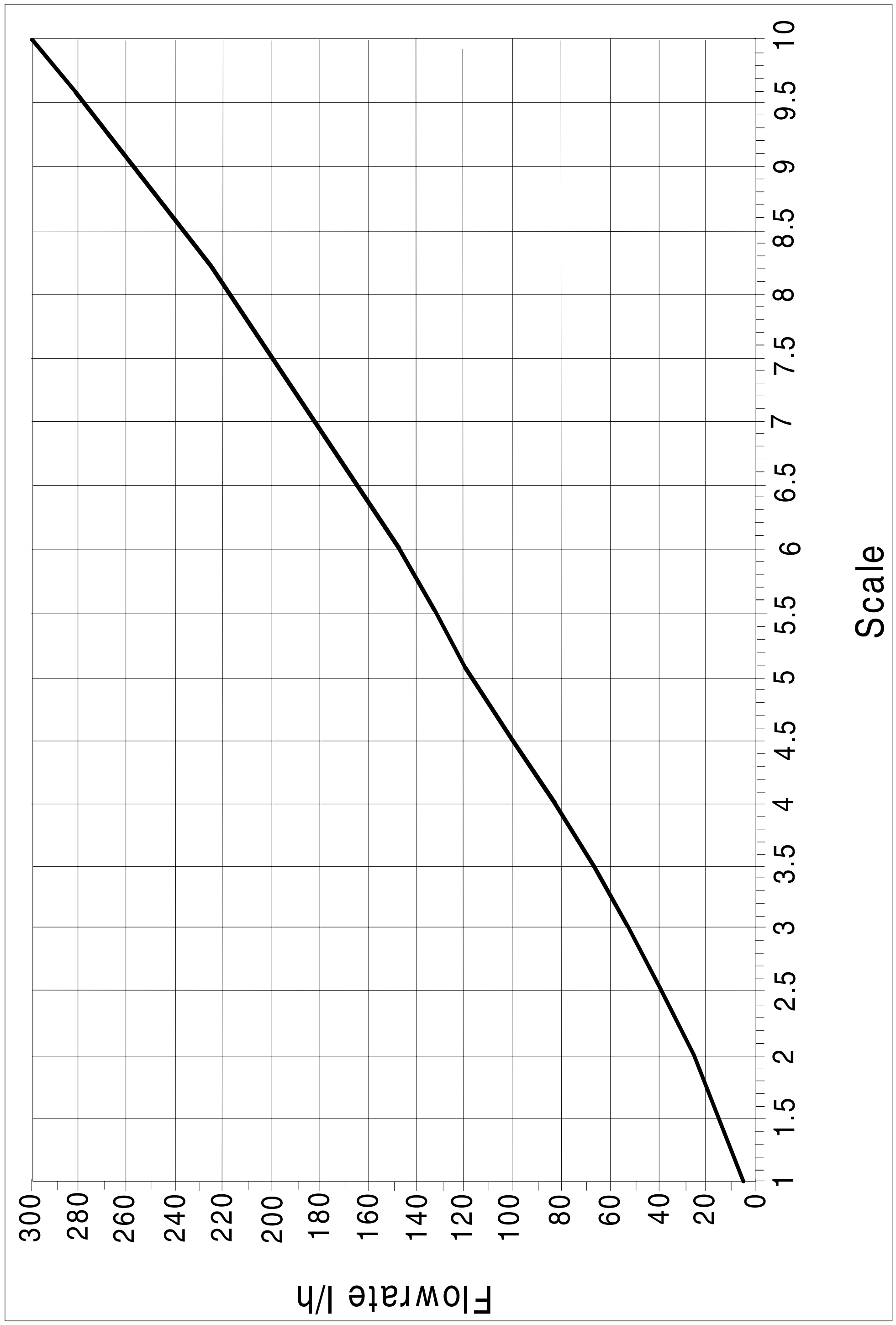

Figure A-9
Calibration Curve for Flowmeter

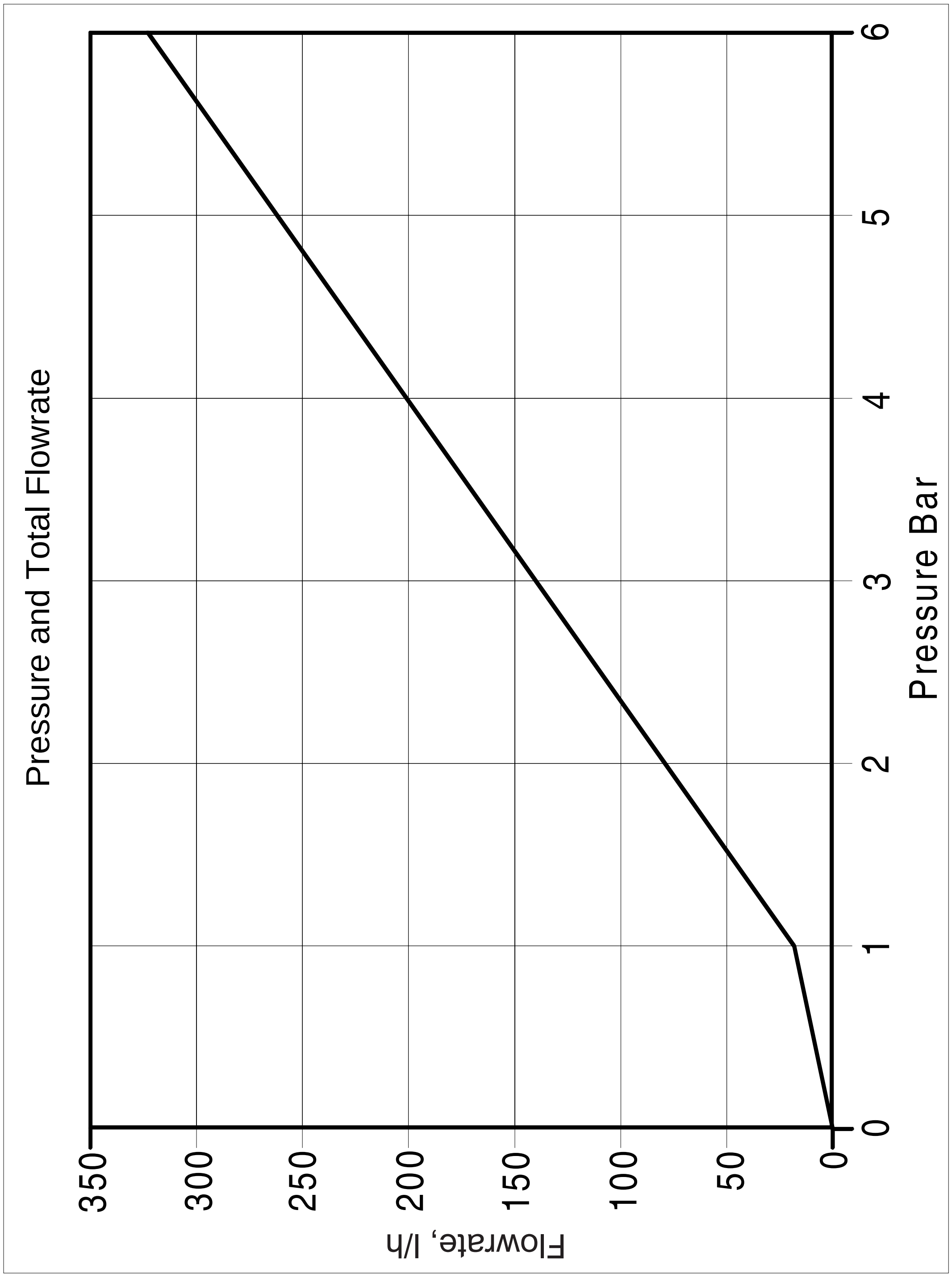

Figure A-10
Pressure and Total Flowrate Graph

APPENDIX B

Indicator Gel Data

Physical Data of Sorbsil® C Chamäleon Indicator Gel

Product Identity	Iron compound impregnated silica gel
Bulk density	0.7 g/cm^3
Physical State	Granules
Granular Size	2.5 – 5.0mm
Color	Orange
Residual moisture	<2%
BET surface area	800 m^2/g
Pore volume	0.40 ml/g
Adsorption capacity (water vapor) at 25°C	Ca. 11 weight percentage at 20% RH Ca. 23 weight percentage at 40% RH Ca. 32 weight percentage at 80% RH
Color change	from orange to white/nearly colorless at approximately 40 - 50% relative humidity
Ph	2.0 (10% aqueous solution)
Melting Point	>1000°C
Flash Point	Not applicable
Conditions to Avoid	Temperatures in excess of 150°C*

*Regeneration of the product by microwave drying must be avoided.

Color change of Sorbsil® C Chamäleon:

APPENDIX C

Frequently Asked Questions

Condensation Monodisperse Aerosol Generator and Process Aerosol Monitor Frequently Asked Questions

In which applications has the generator been used successfully?

- **Particle seeding**
  Measuring particle velocity and flow distributions
- **Aerosol research**
  Calibration of particle sizing instruments and test aerosol
- **Filter testing**
  Measuring filtration efficiency at certain particle sizes with high concentrations using a low cost particle detector
- **Inhalation studies**
  Measuring deposition of particles in human air passages

What would be a brief description of the generator's operating principle?

Vapor condenses on small salt nuclei in a controlled manner. The amount of vapor and the number of nuclei can be adjusted before the nuclei vapor mixture starts to condensate at the entry to a laminar flow condensation tube where the nuclei grow up to uniform particles.

What are the main properties of the output aerosol?

The generated aerosol has a high particle number concentration (10^6#/cm^3) with spherical, electrically neutral particles of uniform diameter. The salt nuclei serve only to promote defined condensation and can be neglected in terms of contributing to the aerosol properties.

How can I change the particle size quickly?

Controlling the flow through the saturator bypass allows the fastest particle size adjustment. Also, by changing the temperature in the saturator an adjustment can be done within a couple of minutes.

Is it possible to adjust the particle concentration?

Using the "screen" bypass reduces the number of nuclei available for condensation and leads to a lower particle concentration. Tests have shown that a minimum nuclei concentration of 10^5#/cm^3 is required to get heterogeneous condensation. Otherwise, the generated aerosol will not be monodisperse because of homogeneous condensation during which vapor is condensating on itself.

Which aerosol materials can be used?

All oily substances that are volatile at low temperatures (low vapor pressure at room conditions) are suitable. DEHS, DOP, Emery 3004, paraffins, stearic acid, Carnauba wax have been widely used.

For precise and stable particle generation, single-component materials are recommended to avoid different vaporization points.

Is it possible to generate solid particles?

If the material to be used for vapor production is solid at room conditions, the generated aerosol will also contain solid particles. You will need to pay attention to the melting procedure of the material. Other operating procedures will be similar to that of using liquids.

The generator is designed for ease-of-use, i.e., the saturator can easily be replaced if a quick change to another aerosol material is required.

Why is nitrogen recommended as the carrier gas?

As the aerosol material inside the saturator is kept at relatively high temperatures (200–300°C) a high rate of oxidization can be expected. This can be avoided by using nitrogen as the carrier gas.

How long will the generator work continuously?

The duration for continuous aerosol generation depends on the particle size to be generated. Assuming 1 µm particles are produced, the generator can work continuously for over 16 hours.

How safe is it to work with materials at 250°C?

The generator is designed for safe operation and easy handling. All hot units like saturator and reheater are completely housed in order to avoid direct contact. Side doors on both sides of the housing can be opened to allow easy access to atomizer, diffusion dryer, and saturator. During aerosol generation these doors should be closed for safety reasons.

What can I use to monitor the generated aerosol?

For monitoring the generator's output the Model 3375 Process Aerosol Monitor can be used. This instrument is based on the light extinction principle and simultaneously detects the actual particle size and their number concentration. It can be connected directly to the generator outlet.

What would be a brief description of the PAM principle?

The light transmission through a particle stream will be reduced based on both the number of particles and the particle size (photometer principle). The noise of light transmission is also affected by these two variables as the number of particles inside the sensing volume will not be constant and can be assumed as statistically distributed. Both light transmission and its noise are measured from a monodisperse aerosol to determine the particle size and concentration.

For which aerosol material is the PAM calibrated?

The PAM has been calibrated for materials with a refractive index of 1.45 by using a TSI® Aerodynamic Particle Sizer® (APS) as a reference instrument. The response of the PAM will not be strongly affected by different indices in the range from 1.4 to 1.5 as applicable for most commonly used substances. For other materials, the PAM can be delivered with a special calibration.

Is it possible to use the PAM for other applications?

The PAM detects the mean particle size and concentration of monodisperse aerosols. For a monomodal aerosol, the PAM gives useful information on these two parameters if the particle size and number concentration are within its measuring range of 0.5 to 10 µm and 10^4 to 10^7#/cm^3, respectively.

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