The National Institute for Occupational Safety and Health (NIOSH) published research findings on "worst case" aerosol testing parameters for particulate respirator filters. Those previous studies determined the initial instantaneous count penetration of commercial respirator filters. However, filter loading and/or degradation due to the aerosol challenge were not investigated in those prior studies. Since liquid aerosols are reportedly more degrading than solid aerosols, the present study was undertaken to evaluate the effect of dioctyl phthalate (DOP) loading on the efficiency of respirator filter media. Data was collected employing the DOP certification test which uses "a homogeneous liquid aerosol having a particle diameter of 0.3 micrometers, which is generated by vaporization and condensation of dioctyl phthalate." This DOP aerosol is in the "worst case" size region of .1 to .3 micrometers count median diameter. The certification procedure was modified to permit filter penetration monitoring as a function of aerosol loading. A similar experimental protocol was employed using a "worst case" DOP aerosol generated by a cold nebulization technique. High efficiency (HE) respirator filter penetration against these DOP aerosol challenges confirmed that all commercially available HE filters tested gave initial filter efficiencies > 99.97%, which is the limit established in 30 CFR Part 11. Further, the filter efficiency of all HE filters tested remained ≥ 99.97% even after DOP mass loadings of greater than 500 milligrams per filter element. Also, filter penetration data employing a non-toxic potential DOP replacement material, Hitec® 164, gave efficiencies of > 99.97% for all HE filters tested.

Respirator Filter Efficiency Comparison of Dioctyl Phthalate (DOP) and Hitec® 164

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Introduction

Dioctyl phthalate (DOP) is a diester of phthalic acid and is listed in the Merck Index[1] as bis(2-ethylhexyl) phthalate. Other commonly used names include: di(2-ethylhexyl) phthalate (DEHP); di-sec-octyl phthalate; phthalic acid, bis(2-ethylhexyl) ester (IUPAC name); di(2-ethylhexyl) orthophthalate; 1,2 benzenedicarboxylic acid, bis(2-ethylhexyl ester) (CAS name); and Octoil. DOP is used for respirator testing, as a lubricant, and in vacuum pumps. It has long been used in industry as a plasticizer (softening agent to impart viscosity or flexibility) for resins and elastomers used in floor tiles, food packaging systems, industrial tubing and conduits, medical tubing and supplies, dental materials, coatings for drugs, and numerous other products. However, the eleventh edition of the Merck Index[1] notes that "this substance may reasonably be anticipated to be a carcinogen: Fourth Annual Report on Carcinogens (National Toxicology Program [NTP] 85-002, 1985) p 83."

DOP has been used for many years as the standard material for respirator testing. It has been used both as a quantitative fit testing agent and as an aerosol challenge agent for efficiency testing of high efficiency (HE) particulate respirator filters. DOP's use as a quantitative fit testing agent dates back to the late 1960's and early 1970's at the Los Alamos Scientific Laboratory[2]. DOP's use in quantitative fit testing has been discontinued due to DOP's classification as a suspected carcinogen (studies done by the U.S. National Toxicology Program (NTP)[3], the International Agency for Research on Cancer (IARC) Monographs[4], and NIOH (National Institute of Occupational Health, Sweden) and NIOSH (National Institute for Occupational Safety and Health, U.S.) basis for an occupational health standard: Di(2-ethylhexyl) phthalate (DEHP)[5]). Also, the U.S. Army Surgeon General[6] has placed tight controls on DOP's use in any testing of respirators. Thus, agencies presently using DOP for testing, as NIOSH's respirator certification regulations require (30 CFR Part 11 § 11.140-11), are conducting research to find suitable replacement test materials.

To date, NIOSH has published research findings on "worst case" aerosol testing parameters for particulate respirator filters[7-9]. Those studies determined the initial instantaneous count penetration of commercial respirator filters. Filter loading and/or degradation due to the aerosol challenge were not investigated in those prior studies. Since liquid aerosols are reportedly more degrading than solid aerosols[10-13], the present study was undertaken for two reasons: 1) to establish baseline DOP penetration data for respirator filter media as a function of aerosol mass loading, and 2) to evaluate a possible replacement aerosol challenge material, Hitec® 164.

Background

Occupational exposure to DOP occurs during its DOP production, during its addition to plastics, and in aerosol research. Exposure has been characterized in the plastics industry. In a Scandinavian phthalate production plant, Liss et al.[14] measured a workplace DOP concentration of 0.02 - 4.1 milligrams per cubic meter (mg/m^3) (8-hour, time-weighted average [TWA]) among six heavily exposed workers. Forty-four other workers within the plant had exposures below the limit of detection. In an Italian production plant, Glioli et al.[15] measured a total phthalate concentration in the range of 1 to 60 mg/m^3 with an average air concentration of approximately 5 mg/m^3. In a Swedish polyvinyl chloride (PVC) processing plant, total phthalic acid esters were measured between 0.01 to 2.0 mg/m^3[16] for 96 samples from 54 workers (2-hour personal samples). In a Russian PVC processing plant, Milkow et al.[17] measured total phthalate concentrations between 1.7 and 66 mg/m^3. In a German phthalate production plant, Theiss et al.[18] showed DOP concentrations between 0.09 and 0.16 mg/m^3. This is the extent of the occupational exposure data which exists. It is quite limited, and any conclusion as to whether DOP is carcinogenic based on existing data is premature[5]. In fact, no conclusions on dose effects or dose-response relationships are possible due to the scarcity of human data, in general.

The absorption, distribution, metabolism, excretion, retention, and turnover of DOP within biological organisms has been widely studied[5]. Those data show that marked differences exist in the way various species (rodents: rat, mouse, hamster, and guinea pig; mammals: green monkey, cynomolgus monkey, and marmoset) metabolize DOP. In general, the following observations have been made:

- Few inhalation experiments have been performed on animals
- Oral and intraperitoneal dosings indicate that DOP has low acute toxicity
- Prolonged DOP dosing produces hepatomegaly and proliferation of peroxisomes
- In vitro experiments show DOP can affect the cellular genome
- DOP acts as an in vivo tumor promoter in mouse liver but not rat liver
- High doses of DOP in rat and mice feeding studies increased the incidence of hepatocellular carcinoma

Thus, based on the animal data, DOP is concluded to be carcinogenic and teratogenic. However, due to the limited human data, it is impossible to determine the degree of risk to humans. Therefore, DOP must be considered to be potentially carcinogenic and teratogenic to humans.

The American Conference of Government Industrial Hygienists (ACGIH) has established a threshold limit value (TLV) of 5 mg/m^3 - TWA, and 10 mg/m^3 short-term exposure level (STEL)[19]. Likewise, the U.S. Occupational Safety and Health Administration (OSHA) has established a permissible exposure limit (PEL) of 5 mg/m^3 TWA with a 10 mg/m^3 STEL[20]. Further, OSHA has classified DOP as a category I potential carcinogen. This requires that if there are substitutes which are less hazardous to humans than DOP, they must be used in lieu of DOP.

In regard to respirator testing, quantitative fit testing employing DOP has virtually stopped. DOP continues to be used in filter penetrometer machines and similar aerosol generating systems employed in respirator filter evaluation and research. In fact, the NIOSH certification test for evaluating HE respirator filters requires a DOP filter penetrometer measurement. Title 30, Code of Federal Regulations, Part II, Subpart K, Paragraph 11.140-11[21] defines the DOP filter test criteria. The current protocol requires that air-purifying respirator filter units be tested in an atmosphere with a DOP concentration of 100 micrograms per liter (μg/l) and at a continuous flow rate of 32 and 85 liters per minute (Lpm) (16 and 42.5 Lpm for filters used in pairs). An instantaneous challenge time of about 5 to 10 seconds is employed. Total leakage for the filter and connector cannot exceed 0.03 percent penetration (efficiency ≥ 99.97 percent).

Numerous deficiencies exist in the testing methodology for particulate air-purifying respirators contained in 30 CFR Part 11 Subpart K - Dust, Fume, and Mist Respirators[21]. One such shortcoming is integrated versus instantaneous monitoring. The present tests (except for DOP testing of HE filters) gravimetrically measure the penetration averaged over 90 minutes or more, rather than by instantaneous monitoring. These tests are aerosol loading tests in that the filters are exposed to significant mass quantities of the aerosol challenge. Unfortunately, the aerosol's particle size is larger than the "worst case" aerosol. Also, instantaneous monitoring of aerosol penetration is not employed. In the case of HE filters, an instantaneous measurement is determined, but the test duration is only 5 to 10 seconds, and aerosol loading is not considered. The preferred method would be to test all filters with an aerosol loading test which measures the filter media's efficiency over time (with aerosol mass loading) against an aerosol challenge which is in the "worst case" size region (most penetrating aerosol size).

The reason for doing this is that filter media work by two major filtration mechanisms, either mechanical or electrostatic. Mechanical filters have lower initial filter efficiency which increases as a function of filter loading. Respirators containing an electrostatic filter media have a high initial filter efficiency which decreases with filter loading due to charge reduction and/or filter degradation. As a result of these facts, aerosol loading tests for all particulate filter types were incorporated into the proposed revision to 30 CFR Part 11, which was published as 42 CFR Part 84 in the August 27, 1987, Federal Register[22].

The proposed NIOSH requirements for particulate air-purifying respirators are published in Subpart V of 42 CFR Part 84. The classifications for non-powered particulate air-purifying respirators are based on the efficiency of the filter element and are stated in Paragraph 84.270(c):

> "Low efficiency filters have a minimum efficiency of 95 percent; medium efficiency filters have a minimum efficiency of 99 percent; high efficiency filters have a minimum efficiency of 99.97 percent; as tested according to the requirements of this part."

The filter tests are described in Paragraph 84.273 - Particulate instantaneous penetration filter test. This new testing protocol will require that each respirator filter for use against liquid aerosol particles be challenged with an appropriate liquid oil aerosol at a concentration of no more than 200 mg/m^3 until at least 100 milligrams (mg) of the aerosol has been loaded. The filters shall be tested at a continuous flow rate of 32 and 85 Lpm for air-purifying respirators with a single filter and a flow rate of 16 and 42.5 Lpm where filters are used in pairs. The particle size distribution of the test oil aerosol must have an aerodynamic mean diameter of 0.2-0.3 micrometers and a geometric standard deviation below 1.6. The instantaneous penetration is to be measured and recorded throughout the test period.

The filter test requirements in this section are based on the theoretical consideration of single fiber efficiency. This theory analyzes the complex process of fibrous filtration by considering the collection of a particle by an individual fiber that is in the middle of a filter with its axis perpendicular to the air flow. It is assumed a particle striking the filter sticks and is permanently removed.

There are several mechanisms by which particles can collect on this fiber. These mechanisms include interception, inertial impaction, diffusion, gravitational settling, and electrostatic attraction. The depositional mechanism will depend on the aerosol type, the filter composition, and the aerosol flow rate.

Interception can occur when the radius of a particle that is traveling in a gas stream line is greater than the distance from the stream line to the filter's surface. When the ratio of the particle size to the void size of a filter is large, direct interception will predominate.

Inertial impaction occurs from a change in gas flow direction. Particles strike the filter since they tend to remain on their original course due to their relatively greater inertia. Particle deposition by inertial impaction is favored by high gas velocities and dense fiber packing. The operation of this deposition mechanism in a variety of commercially available fibrous filters was demonstrated experimentally in 1951 by Ramskill and Anderson[23].

Particle deposition by diffusion depends on the existence of a concentration gradient. Particles will diffuse from the gas stream where particle concentrations are high, to the surfaces of the fibers where the concentration is low. Diffusion is most effective with small particles and will predominate at low flow rates with large concentration gradients; thus, collection efficiencies increase with decreasing particle size[24].

Gravitational settling is usually neglected when considering filter efficiency. Gravitational attraction does not have any significant effect on particle collection since the settling velocity of airborne particles of hygienic significance are so low and the horizontal components of the filter's surface area are too small. However, gravitational settling can become significant when the face velocity through a filter is very low (< 5 centimeters per second [cm/sec]) or with large particle sizes.

Electrostatic attractions can contribute to particle collection efficiency if either the filter or the aerosol have a static charge. The air flow through a filter can also induce charges on the filter. The forces between a charged particle and its electrical "image" in a neutral fiber have been shown by Lundgren and Whitby[25] to greatly influence particle collection. Zebel[26] has described the factors controlling particle deposition on filters suspended in a uniform electric field with both charged and uncharged particles. This area needs further research.

This study evaluates the filter efficiency of several commercially available respirator filters as a function of aerosol loading in the "worst case" particle size region. DOP, the present test agent, is a good wetting agent and degrades electrostatic filter media. A replacement material for DOP should be at least as effective for screening filter degradation. Hitec® 164 has been suggested by the Chemical Research Development and Engineering Center of the U.S. Army[6] as a possible low toxicity DOP challenge aerosol replacement material. These two aerosol challenges were evaluated in this study. Various generation methods were employed for comparison. The penetration data was analyzed, then compared to determine whether Hitec® 164 would be a suitable replacement candidate to consider for future evaluations.

Materials

The DOP used in the Q-127 penetrometer was supplied by the instrument's manufacturer, Air Techniques Incorporated (ATI).

The DOP used in both the Model 8110 and 8120 Automated Filter Tester (TSI Corporation) was obtained from Minnesota Solvents and Chemical Corporation. The accompanying material and safety data sheet (MSDS) identified Eastman Chemical Products Incorporated as the manufacturer (Appendix 1).

The Hitec® 164 (Lot 200-104) was obtained from Ethyl Corporation. Hitec® 164 was previously manufactured and distributed by the Henkel Corporation under the trade name Emery 3004. It has been proposed by the U.S. Army Chemical Research Development and Engineering Center as a possible replacement material for DOP in hot smoke aerosol instruments. Hitec® 164 is a colorless, odorless liquid of the chemical family of paraffin hydrocarbons (CAS #68037-01-4). This 1-decene hydrogenated homopolymer is produced by direct oligomerization of 1-decene and is used as a synthetic lubricant. Exposure levels for Hitec® 164 have not been established by ACGIH or OSHA, but it has been identified as having low inherent toxicity. The MSDS is enclosed as Appendix 2.

Filter Samples

Three commercial respirator filter manufacturers' products were tested. Three HE filters and one dust, fume, and mist (DFM) filter were included in the study. All filters were tested "as received" from the manufacturer. The filters are described in Table I.

Instrumentation

Three commercially available respirator filter testing instruments were used in this study. They are the ATI Model Q-127 Aerosol Penetrometer, the TSI Model 8110 Automated Filter Tester, and the TSI Model 8120 Automated Filter Tester.

The ATI Model Q-127 DOP penetrometer generates a DOP aerosol which conforms to the definition of DOP contained in 30 CFR Part 11 § 11.3 Definitions (j). This evaporation/condensation aerosol generation process is referred to as a hot aerosol smoke system. It is presently used for certification testing of HE filters (30 CFR Part 11 § 11.183-6). The instrument was designed to (1) make a 0.3 micrometer monodispersed aerosol, (2) measure and control the aerosol particle size and concentration, and (3) measure the percentage penetration of the aerosol through a component like a respirator filter. Basically, DOP is heated and evaporated, then recondensed under controlled conditions to produce a uniform liquid DOP aerosol. By controlling the reservoir temperature, the quenching air temperature and the ratio of vapor containing air to quenching air, the aerosol's characteristics including geometric mean diameter (GMD), geometric standard deviation (σg) and mass concentration can be controlled. Differential Mobility Particle Sizer (DMPS) measurements gave count median diameters (CMD) between .231-.233 micrometers with a σg of 1.18-1.185. The aerosol and dilutor air streams after being combined are fed to an aging chamber where it is stabilized. Aerosol from the aging chamber is used for testing, with the excess being exhausted. The concentration of the DOP aerosol is approximately 100 micrograms per liter. A forward light scattering chamber is used for measuring the filter penetration downstream from the sample chuck. A readout displays the percent penetration on a solid state meter. This instrument is usually employed for initial instantaneous penetration testing. Thus, during a filter loading test, the percent penetration meter was constantly monitored and data recorded manually.

The Model 8110 and 8120 Automated Filter Testers (AFT) use identical aerosol generator systems. In fact, aerosol generation and operation of these two instruments are identical with one exception--the Model 8120 has a built-in aerosol charge neutralizer which was not available when the Model 8110 was purchased. This was confirmed with DMPS aerosol size measurements which gave CMDs of .173-.179 micrometers with a σg between 1.40 and 1.45 for both instruments. This aerosol is somewhat smaller than that generated with the Q-127.

The TSI Model 8110 and 8120 DOP generators consist of a liquid reservoir which contains five compressed air nebulizers. When operating in the high concentration model, as throughout this study, four nebulizers are actuated. The low concentration mode employs only one nebulizer. The manufacturer's specifications and instrument settings were followed to insure proper aerosol generation and instrument function. The generated aerosol, which is maintained at a constant flow through the generator by means of an orifice, then passes through an in-line felt filter pad. This felt pad captures and removes large DOP droplets from the aerosol stream. The excess liquid is deposited in a plastic overflow bottle beneath the pad. Dilutor air is then added, and in a mixing chamber a uniform aerosol concentration forms. This aerosol is then regulated by a flow controller to the desired flow rate and passes to the sample filter chuck where the test specimen is located. Aerosol from the chuck and excess aerosol from the mixing chamber are exhausted.

Both instruments (8110 and 8120) measure the total light scattering intensity with a solid state photometer and process this information with a microprocessor. The intensity of light is a function of particle size and aerosol concentration. Three portals are connected to the photometer: (1) tubing to sample the aerosol concentration before the filter chuck which gives the 100% penetration reading, (2) tubing to which an HE filter is attached to simulate 0% penetration and is used as the zero reference, and (3) tubing to the sample filter chuck assembly for penetration measurements. The filter efficiency can then be calculated as follows:

$$\%\ Filter\ Efficiency = 100 - \%\ Penetration = \left(1 - \frac{Penetration\ Concentration}{Challenge\ Concentration}\right) x100$$

The filter efficiency, time, flow rate, and pressure drop (pressure transducer) are recorded and printed at 1-minute intervals. The challenge concentration is determined at 5-minute intervals during loading tests to reduce the amount of high concentration aerosol passing through the detector.

Aerosol Size Measurements

The aerosol size (count median diameter) and size distribution (geometric standard deviation) were monitored with a TSI Model 3932 Differential Mobility Particle Sizer (DMPS/C) TSI, Inc., St. Paul, Minn. The aerosol was sampled at the point of entrance into the testing chamber. The DMPS measures the aerosol size distribution by the principle of mobility analysis. The DMPS uses an electrostatic classifier and a condensation nucleus counter to measure discrete particle sizes of the aerosol, allowing the instrument to measure accurately the aerosol's distribution.

Experimental Design

The respirator filters were sealed with caulking on a fabricated plastic respirator cartridge holder. The respirator facepiece holders and gaskets were not utilized in order to eliminate any cartridge holder or gasket leakage. An exception was necessary with the Willson T-20 filters where the filter holders had to be used since they use a plastic retainer to mount them on cartridges. In all cases, filters from the same manufacturer's lot were used in order to eliminate any lot-to-lot variability.

The filter's penetration was monitored as a function of time (aerosol loading). Samples tested on the ATI Model Q-127 were manually monitored and percentage penetration data recorded at 15-minute intervals or less. The TSI Model 8110 and 8120 automatically printed out flow rate, pressure drop, and percent filter penetration data every minute. All filters, regardless of instrumentation, were tested at a continuous challenge flow rate. Single air-purifying respirator filter units were tested at 85 Lpm, which is the maximum flow rate required in the present DOP certification test for HE filters (30 CFR Part 11 § 11.140-

11[a]). Where filters are used in pairs on a unit, the continuous flow rate through a single filter element was 42.5 Lpm (30 CFR Part 11 § 11.140-11[b]).

All filters were tested at room temperature "as received" from the manufacturer without any kind of preconditioning. Three samples of each filter were tested since it was previously determined that for HE filters, when three filters were tested, the measured value should be approximately 0.001% of the true value when an alpha level of 0.05 was used.

The filters were challenged against DOP and Hitec® 164 liquid aerosols. DOP was generated by both an evaporization/ condensation process (Q-127) and cold nebulization (8110 AFT and 8120 AFT). The Hitec® 164 was generated only by cold nebulization in the 8110 AFT. These aerosols were not neutralized but used as generated. As part of this study, the filters were tested on the 8120 with and without being neutralized since the 8120 contains a pulse flow controller/ionizing air nozzle system. The pulse controller which is set by the manufacturer has three controls--pulse rate, positive potential, and negative potential. The ionizing air nozzle has two electrodes and produces a balanced quantity of positive and negative ions. These ions are mixed with the aerosol. Thus, charged particles are neutralized by interacting with ions of the opposite polarity.

Aerosol concentrations in all instruments were determined by a gravimetric procedure. Gravimetric analyses were run twice a day, before and after filter loading tests. High efficiency Gelman type A/E glass filters were used for the gravimetric determinations. To assure maximum collection efficiency, a double filter layer was employed. The 102 mm filters fit into the special gravimetric holder supplied with the 8110 and 8120. These gravimetric tests were run at a known flow rate (usually 30 Lpm) for a specified time (usually 40 min.) against the challenge aerosol. The pre- and post-filter pad weights were used to determine the aerosol challenge rate. The average challenge rate for a given day was used to calculate the test filter's aerosol loading. A testing aerosol loading of at least 500 mg was used in practically all cases. The calculated aerosol loading data was used to construct plots of filter efficiency versus the amount of aerosol loading. This data was entered and plots prepared using a Hewlett-Packard Series 200 computer.

The Model 8110 AFT was the only instrument used in Hitec® 164 testing due to availability. After the DOP testing with the Model 8110 was completed, the instrument was thoroughly cleaned and Hitec® 164 added to the generator. The testing was then repeated using the Hitec® 164 aerosol to determine its filter penetration characteristics. If any aerosol is to be a suitable replacement for DOP, its aerosol penetration characteristics must be at least equivalent to those of DOP.

Results and Discussion

DOP and Hitec® 164 were employed as challenge agents for determining respirator filter performance. Respirator filter penetration as a function of aerosol loading (milligrams) was monitored for four commercially available respirator filters. These filters are described in Table I and consist of three HE filters and one new type electret DFM filter.

DOP baseline data was collected on all the filters. All four filters were tested using the present DOP certification filter test (30 CFR Part § 11.130-11, using a homogeneous 0.3 micrometer liquid aerosol generated by vaporization and condensation of DOP). As noted earlier, DMPS aerosol size measurements gave CMDs between .231-.233 micrometers with a σg of 1.18-1.185. The highest continuous flow rate criteria was used (85 Lpm for a single filter and 42.5 Lpm for a single filter of a pair). The only modification made was to extend the testing time (normally 5 to 10 seconds) and monitor the filter's efficiency as a function of loading. The instrument's calibration was checked halfway through each run and adjustments made if necessary. In general, the adjustments were minor, indicating that the Q127 penetrometer was quite stable. This is reflected in the gravimetric data which is given in Table II. However, Figure IV is an example of where a significant adjustment was made. The filter efficiency results for the four filters (each run in triplicate) are shown in Figures 1-12 and summarized in Table III.

The HE filters all gave filter efficiency values (Table III, Figures 1-9) which were greater than 99.97 percent, which is the lowest allowed level established in the present respirator regulations for HE filters. In fact, no filter efficiency value lower than 99.98 percent was observed for the three different HE filters tested. Loading levels for the R57A and R12 filters were approximately 500 milligrams per single filter of the pair. The Pulmosan HE filter is a larger single filter and was exposed at a loading level of approximately 1,000 mg. In all cases, these filters performed extremely well. The August 27, 1987, proposed respirator rule indicated an oil liquid particulate aerosol loading of 100 ± 5 mg was to be employed. This indicated that the commercially available HE filters would meet the criteria in the August 27, 1987, proposed rule even when tested at high aerosol loading levels. All HE filters tested were very efficient (≥ 99.97%).

The results obtained for the electret DFM filter (Table III, Figures 10-12) are not nearly as encouraging. Although the initial percent filter efficiency values were 94.3, 96.8, and 96.3 for runs 1, 2, and 3, respectively, the filters' efficiency dropped off very rapidly with only light aerosol loading. These filters would not have met the efficiency criteria for even the lowest efficiency filter class proposed in the August 27, 1987, document (minimum efficiency of 95 percent). These filters' main particle collection mechanism is electrostatic in nature. However, the data indicates that the filter media is degraded rapidly, probably due to liquid coating, the individual fibers thus dissipating the fiber's charge.

The filter efficiency data for the four filters against a DOP challenge using the TSI Model 8110 AFT are summarized in Table IV, and the individual runs are shown in Figures 13-20. This DOP aerosol is generated by a cold nebulization process employing four atomizers which produced challenge concentration in the range of 82-90 mg/m^3 (Table IV). The filter efficiency results are in agreement with the earlier results reported for the hot smoke DOP Q-127 instrument. All the HE filters gave filter efficiency values greater than 99.97 percent (Table IV, Figures 13-18). The electret DFM filter gave high initial filter efficiency values (96.34% and 95.78%) but degraded rapidly, showing minimum efficiency values of 84.30% and 78.50% after being loaded with 545 mg of DOP challenge aerosol (Table IV, Figures 19-20). The HE filters would meet the August 27, 1987, proposal, but the DFM filter would not meet filter efficiency criteria for any of the classes proposed.

The TSI Model 8120 AFT which was recently purchased by the Certification and Quality Assurance Branch was also employed for

DOP testing. The 8120 AFT is basically identical to the 8110 AFT when used for individual filter efficiency determinations. The results for the four filters are summarized in Table V and depicted in Figures 21-32. Again, as anticipated, all HE filters showed filter efficiencies greater than 99.97 percent (Table V, Figures 21-29). The DFM filter gave results consistent with previous findings. High initial filter efficiency values were seen which rapidly degraded to values which were below any values acceptable according to the August 27, 1987, proposal.

The final set of DOP results were obtained using the 8120 AFT with the exception that the plasma charge neutralizer was activated. The penetration results for the neutralized DOP aerosol are summarized in Table VI and illustrated if Figures 33-44. The gravimetric data was consistent with the results obtained without the plasma neutralizer activated. Again, the HE filters all gave minimum filter efficiencies > 99.97 percent for all loading tests. Also, the DFM filter gave a high initial filter efficiency which degraded rapidly to unacceptable levels.

In order to facilitate a comparison of the filter efficiency results by instrument and aerosol generator type (hot versus cold), Tables VII, VIII, IX, and X were constructed. The tables present the results for a single filter against the different instrumental and aerosol generation processes (Q-127 CMDs between .231-.233 micrometers, σg 1.18-1.185; model 8110 and 8120 CMDs

.173-.179, σg 1.40-1.45). Table VII presents the results for the American Optical R57A HE filter, along with average initial penetration values. This data suggests that little or no difference was seen for the initial filter efficiency results. The average initial efficiencies ranged from 99.993 - 99.997 percent. These results suggest two possibilities: 1) that the methods are basically similar, or 2) that the filters are so highly efficient that differences are not being distinguished. The data for the other two high efficiency filters (Table VIII and IX) present similar results. The average initial filter efficiencies for the Pulmosan HE C263 ranged from 99.993 - 99.994 percent, and the Willson HE R12 values ranged from 99.995 - 99.998 percent. Likewise, the loading results do not suggest any obvious differences. The only conclusion that can be made is that HE filters have extremely high efficiency values and that the filters tested did not degrade with DOP loading. These filters would meet the requirement for the highest efficiency filters proposed in the August 27, 1987, proposal.

Table X presents the summary data for the Willson T-20 DFM filter. The initial filter efficiency results were consistent for the different instruments and aerosol generation methods. Although slight efficiency difference might be present, it would be difficult to isolate their origin with these filters due to filter variability and the rapid filter efficiency degradation seen with the liquid DOP aerosol loading.

The above DOP data was collected to serve as baseline data to which other filter efficiency results could be compared. The ultimate goal is to identify a suitable non-toxic replacement for DOP which has filter penetration characteristics similar to DOP. Some candidates have been suggested by the U.S. Army[6] who is looking for a hot smoke replacement for DOP. They did limited work on cold aerosol generation methodology. One proposed candidate identified was Hitec® 164 due to its physical characteristics being similar to DOP.

The four filters were thus tested against a Hitec® 164 challenge aerosol using the 8110 AFT to determine filter efficiency as a function of aerosol loading. The data is summarized in Table XI, and the individual runs are illustrated in Figures 45-56, whereas Figures 45-47 are for the R57A HE filters, Figures 48-50 are for the C263 HE filters, Figures 51-53 are for the R12 HE filters, and Figures 54-56 are for the T20 DFM filters.

Table XI shows that the gravimetric results ranged from 140-160 mg/m^3 which is higher than determined for DOP at the same instrument parameters. Thus, the Hitec® 164 loaded the filters at a slightly faster rate than DOP. Also, in the 8110, the Hitec® 164 produced a slightly large aerosol (CMDs .186-.192 micrometers, σg 1.41-1.44) than the DOP (CMDs .173-.179 micrometers, σg 1.40-1.45). The 8110 AFT average initial filter efficiency values for the four filters with DOP versus Hitec® 164 are as follows: 1) R57A HE filter 99.997% versus 99.998%; 2) C263 HE filter 99.994% versus 99.997%; 3) R12 HE filter 99.998% versus 99.999%; and 4) T20 DFM filter 96.06% versus 93.36%. The data (Table XII) indicates that in regard to the HE filters, no conclusions can be made due to the high efficiency values determined. In the case of the T20 DFM filters (Table XII), it appears that the initial filter efficiency values might be lower for the Hitec® 164 challenge aerosol. However, if one compares the loading results, the major difference rests in the fact that Hitec® 164 does not degrade the T-20 filters nearly as rapidly or to the same level as DOP. This can be seen in the minimum efficiency values for the T20 filters as follows: 84.30% and 78.50% for DOP at 545 mg loading versus 91.77%, 89.30%, and 89.60% for Hitec® 164 at 573 mg loading. Thus, it would appear that Hitec® 164 is not as critical an aerosol challenge agent as DOP.

Conclusions

This study was conducted to obtain DOP baseline data to be used as a comparison in future studies which evaluate the filter efficiency characteristics of potential non-toxic DOP replacement aerosol challenge agents. In this study, one such substitute agent (Hitec® 164) was investigated following the collection of the background DOP data. Throughout this study, significant findings were obtained and can be generalized as follows:

(1) The HE filters tested showed filter efficiency greater than the minimum criteria set forth in 30 CFR Part 11.

(2) The HE filters did not signficantly degrade with liquid aerosol loading and appear to conform to the criteria proposed in the 42 CFR 84, August 27, 1987, proposal.

(3) No differences could be distinguished between the instrumental and aerosol generation methodology (hot/cold) probably due to (1) the high efficiency of the HE filters, and/or (2) the variability and/or rapid degradation of the DFM filter tested.

(4) The Hitec® 164 does not appear to be a suitable substitute for DOP since it showed a significantly reduced degradation effect on the DFM filter tested and, thus, gave higher efficiencies than DOP.

(5) To test the comparability between liquid aerosol penetration characteristics, filters with efficiencies between 92-98% which do not rapidly degrade would be ideal.

Baseline DOP has been collected, and the evaluation of potential DOP non-toxic replacement aerosols can continue.

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Table I

Commercial Respirator Filters Tested

Manufacturer	Filter Type	Filter Description	Model	Lot Number	Single Filter Test Flow Rate Lpm
American Optical	Dusts, fumes, and mists; asbestos-containing dusts and mists; radionuclides and radon daughters	High efficiency filter paper	R57A	092986	42.5
Pulmosan	Dusts, fumes, mists, and radionuclides	High efficiency filter paper	C263	6H261	85
Willson	Dusts, fumes, mists, and radionuclides	High efficiency filter paper	R12	14180035 Feb. 14, 1984	42.5
Willson	Dust, fume, and mist and radon daughters	Electret spun polymer fibers	T-20	71301	42.5

Table II

DOP Gravimetric Determination for ATI Q-127 Penetrometer

Test Day	AM Concentration mg/m^3	PM Concentration mg/m^3	AVG Concentration mg/m^3
1	97.5	105.6	101.6
2	86.8	98.8	92.8
3	103.8	103.5	103.7
4	111.4	123.5	117.5
5	92.8	97.0	94.9
6	107.6	92.9	100.3

Overall Mean 101.8
S Dev 9.4

Table III
Summary of the Q-127 DOP Filter Efficiency Loading Results

Figure #	Filter	Type	Run#	Initial	Min.	Max.	Aerosol Loaded (mg)
1	AO R57A	HE	1	99.998	99.998	100	473
2	AO R57A	HE	2	99.996	99.996	100	473
3	AO R57A	HE	3	99.996	99.996	99.997	473
4	Pulmosan C263	HE	1	99.994	99.993	99.999	1057
5	Pulmosan C263	HE	2	99.994	99.993	99.994	1057
6	Pulmosan C263	HE	3	99.994	99.990	99.994	1057
7	Willson R12	HE	1	99.997	99.994	99.997	518
8	Willson R12	HE	2	99.996	99.994	99.996	518
9	Willson R12	HE	3	99.991	99.985	99.991	518
10	Willson T20	DFM	1	94.31	79.30	94.31	511
11	Willson T20	DFM	2	96.81	84.40	96.81	511
12	Willson T20	DFM	3	96.30	86.30	96.30	511

Table IV

Summary of the TSI 8110 Automated Filter Tester DOP Filter Efficiency Loading Results

Figure #	Filter	Type	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)	Gravimetrics (mg/m^3) AM	PM
13	AO R57A	HE	1	99.996	99.996	99.998	553	84.6	88.8
14	AO R57A	HE	2	99.998	99.998	99.998	553	84.6	88.8
15	Pulmosan C263	HE	1	99.995	99.990	99.995	1114	84.9	89.9
16	Pulmosan C263	HE	2	99.993	99.986	99.993	1090	82.1	88.8
17	Willson R12	HE	1	99.998	99.995	99.998	530	83.5	82.8
18	Willson R12	HE	2	99.997	99.995	99.997	530	83.5	82.8
19	Willson T20	DFM	1	96.34	84.30	96.34	545	88.4	82.7
20	Willson T20	DFM	2	95.78	78.50	95.78	545	88.4	82.7

Table V

Summary of the TSI 8120 Automated Filter Tester DOP Filter Efficiency Loading Results

Figure #	Filter	Type	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)	Gravimetrics (mg/m^3) AM	PM
21	AO R57A	HE	1	99.992	99.992	99.996	1167	111.5	117.2
22	AO R57A	HE	2	99.995	99.994	99.997	1142	109.1	114.9
23	AO R57A	HE	3	99.993	99.993	99.997	736	74.0	73.3
24	Pulmosan C263	HE	1	99.992	99.990	99.993	627	106.4	120.5
25	Pulmosan C263	HE	2	99.995	99.993	99.995	627	106.4	120.5
26	Pulmosan C263	HE	3	99.995	99.993	99.996	627	106.4	120.5
27	Willson R12	HE	1	99.998	99.996	99.998	466	72.1	73.9
28	Willson R12	HE	2	99.998	99.992	99.998	716	111.3	113.4
29	Willson R12	HE	3	99.997	99.992	99.997	716	111.3	113.4
30	Willson T20	DFM	1	93.64	77.70	93.64	591	98.1	108.1
31	Willson T20	DFM	2	94.41	75.60	94.41	591	98.1	108.1
32	Willson T20	DFM	3	95.44	80.50	95.44	591	98.1	108.1

Table VI

Summary of TSI 8120 Automated Filter Tester Neutralized DOP Filter Efficiency Loading Results

Figure #	Filter	Type	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)	Gravimetrics (mg/m^3) AM	PM
33	AO R57A	HE	1	99.993	99.993	99.996	726	113.6	114.2
34	AO R57A	HE	2	99.997	99.995	99.997	726	113.6	114.2
35	AO R57A	HE	3	99.995	99.995	99.996	581	113.6	114.2
36	Pulmosan C263	HE	1	99.993	99.991	99.994	735	133.3	132.9
37	Pulmosan C263	HE	2	99.993	99.989	99.993	735	133.3	132.9
38	Pulmosan C263	HE	3	99.994	99.990	99.994	735	133.3	132.9
39	Willson R12	HE	1	99.997	99.993	99.997	680	104.4	108.9
40	Willson R12	HE	2	99.997	99.993	99.997	680	104.4	108.9
41	Willson R12	HE	3	99.998	99.994	99.998	680	104.4	108.9
42	Willson T20	DFM	1	94.26	75.20	94.26	576	98.4	102.6
43	Willson T20	DFM	2	94.22	77.50	94.22	576	98.4	102.6
44	Willson T20	DFM	3	94.38	77.80	94.38	640	98.4	102.6

Table VII

Summary of DOP Loading Results for American Optical HE R57A Filters

	Figure #	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)
Q-127 Hot Smoke Instrument	1	1	99.998	99.998	100	473
	2	2	99.996	99.996	100	473
	3	3	99.996	99.996	99.997	473
			AVG 99.997			
TSI Model 8110 Cold AFT Instrument	13	1	99.996	99.996	99.998	553
	14	2	99.998	99.998	99.998	553
			AVG 99.997			
TSI Model 8120 Cold AFT Instrument	21	1	99.992	99.992	99.996	1167
	22	2	99.995	99.994	99.997	1142
	23	3	99.993	99.993	99.997	736
			AVG 99.993			
TSI Model 8120 Cold AFT with Neutralizer	33	1	99.993	99.993	99.996	726
	34	2	99.997	99.995	99.997	726
	35	3	99.995	99.995	99.996	581
			AVG 99.995			

Table VIII

Summary of DOP Loading Results for Pulmosan HE C263 Filters

	Figure #	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)
Q-127 Hot Smoke Instrument	4	1	99.994	99.993	99.999	1057
	5	2	99.994	99.993	99.994	1057
	6	3	99.994	99.990	99.994	1057
			AVG 99.994			
TSI Model 8110 Cold AFT Instrument	15	1	99.995	99.990	99.995	1114
	16	2	99.993	99.986	99.993	1090
			AVG 99.994			
TSI Model 8120 Cold AFT Instrument	24	1	99.992	99.990	99.993	627
	25	2	99.995	99.993	99.995	627
	26	3	99.995	99.993	99.996	627
			AVG 99.994			
TSI Model 8120 Cold AFT with Neutralizer	36	1	99.993	99.991	99.994	735
	37	2	99.993	99.989	99.993	735
	38	3	99.994	99.990	99.994	735
			AVG 99.993			

Table IX

Summary of DOP Loading Results for Willson HE R12 Filters

	Figure #	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)
Q-127 Hot Smoke Instrument	7	1	99.997	99.994	99.997	518
	8	2	99.996	99.994	99.996	518
	9	3	99.991	99.985	99.991	518
			AVG 99.995			
TSI Model 8110 Cold AFT Instrument	17	1	99.998	99.995	99.998	530
	18	2	99.997	99.995	99.997	530
			AVG 99.998			
TSI Model 8120 Cold AFT Instrument	27	1	99.998	99.996	99.998	466
	28	2	99.998	99.992	99.998	716
	29	3	99.997	99.992	99.997	716
			AVG 99.998			
TSI Model 8120 Cold AFT with Neutralizer	39	1	99.997	99.993	99.997	680
	40	2	99.997	99.993	99.997	680
	41	3	99.998	99.994	99.998	680
			AVG 99.997			

Table X

Summary of DOP Loading Results for Willson Dust, Fume, and Mist T-20 Filters

	Figure #	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)
Q-127 Hot Smoke Instrument	10	1	94.31	79.30	94.31	511
	11	2	96.81	84.40	96.81	511
	12	3	96.30	86.30	96.30	511
			AVG 95.81			
TSI Model 8110 Cold AFT Instrument	19	1	96.34	84.30	96.34	545
	20	2	95.78	78.50	95.78	545
			AVG 96.06			
TSI Model 8120 Cold AFT Instrument	30	1	93.64	77.70	93.64	591
	31	2	94.41	75.60	94.41	591
	32	3	95.44	80.50	95.44	591
			AVG 94.50			
TSI Model 8120 Cold AFT with Neutralizer	42	1	94.26	75.20	94.26	576
	43	2	94.22	77.50	94.22	576
	44	3	94.38	77.80	94.38	640
			AVG 94.29			

Table XI

Summary of the TSI 8110 Automated Filter Tester Hitec ® 164 Filter Efficiency Loading Results

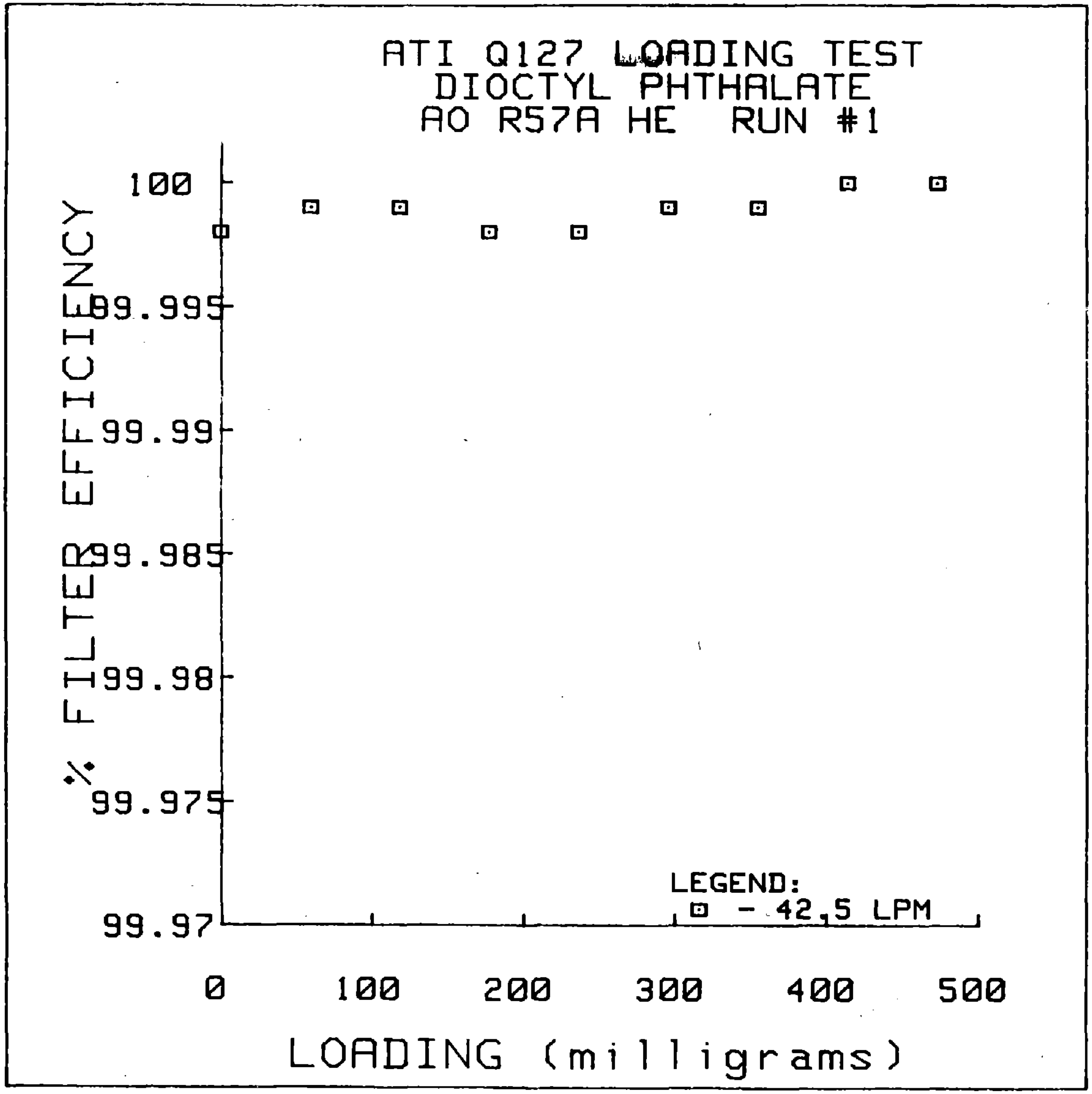
Figure #	Filter	Type	Run#	Filter Efficiency (%) Initial	Min.	Max.	Maximum Aerosol Loaded (mg)	Gravimetrics (mg/m^3) AM	PM
45	AO R57A	HE	1	99.999	99.994	99.999	559	143.5	148.3
46	AO R57A	HE	2	99.997	99.995	99.998	559	143.5	148.3
47	AO R57A	HE	3	99.998	99.996	99.998	559	143.5	148.3
48	Pulmosan C263	HE	1	99.998	99.994	99.998	589	150.8	157.5
49	Pulmosan C263	HE	2	99.995	99.994	99.996	589	150.8	157.5
50	Pulmosan C263	HE	3	99.997	99.996	99.997	589	150.8	157.5
51	Willson R12	HE	1	99.999	99.991	99.999	555	140.9	149.6
52	Willson R12	HE	2	99.998	99.996	99.999	555	140.9	149.6
53	Willson R12	HE	3	99.999	99.997	99.999	555	140.9	149.6
54	Willson T20	DFM	1	94.42	91.77	94.42	573	149.8	150.0
55	Willson T20	DFM	2	92.55	89.30	92.55	573	149.8	150.0
56	Willson T20	DFM	3	93.12	89.60	93.12	573	149.8	150.0

Table XII

Summary of TSI 8110 Automated Filter Tester DOP and Hitec 164 Average Initial Filter Efficiency Loading Results

Filter	Average Initial Filter Efficiency (%) DOP	Hitec 164
AO R57A	99.997	99.998
Pulmosan C263	99.994	99.997
Willson R12	99.998	99.999
Willson T20	96.06	93.36

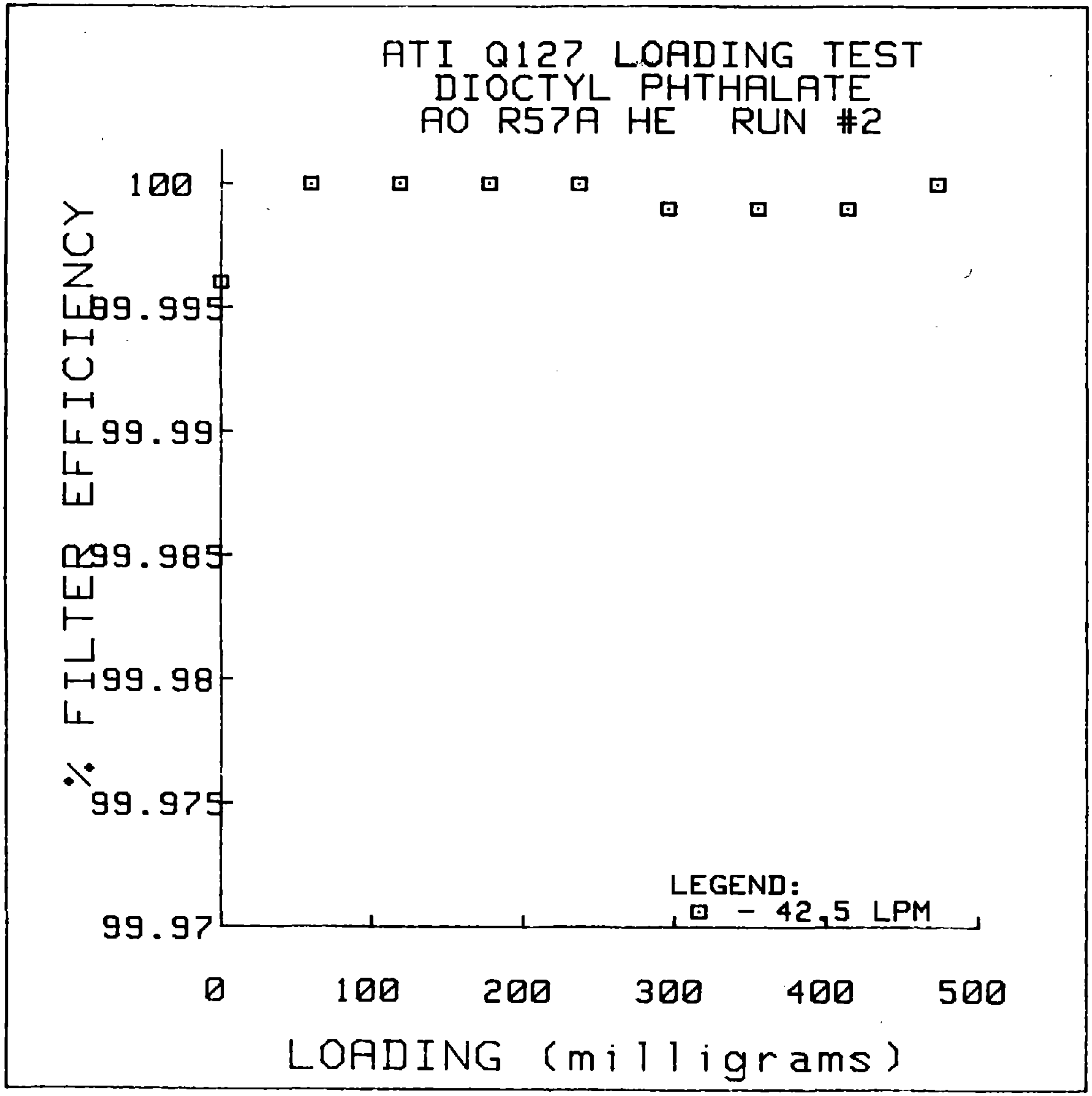
Figure 1



Q127 DOP LOADING TEST AO R57A #1
DATA FOR 42.5 LPM

0	99.998
59.125	99.999
118.25	99.999
177.375	99.998
236.5	99.998
295.625	99.999
354.75	99.999
413.875	100
473	100

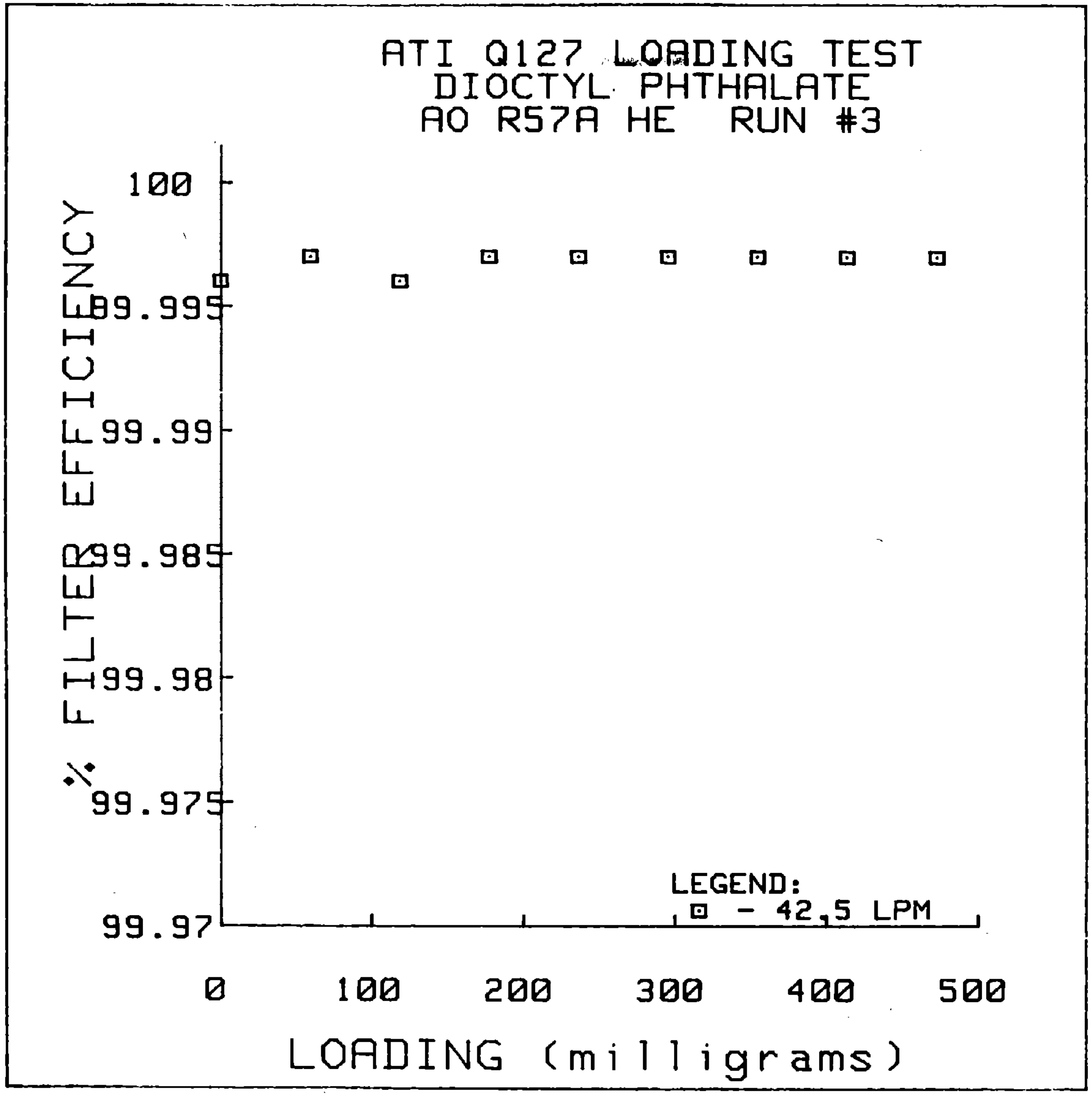
Figure 2



Q127 DOP LOADING TEST AO R57A #2
DATA FOR 42.5 LPM

0	99.996
59.125	100
118.25	100
177.375	100
236.5	100
295.625	99.999
354.75	99.999
413.875	99.999
473	100

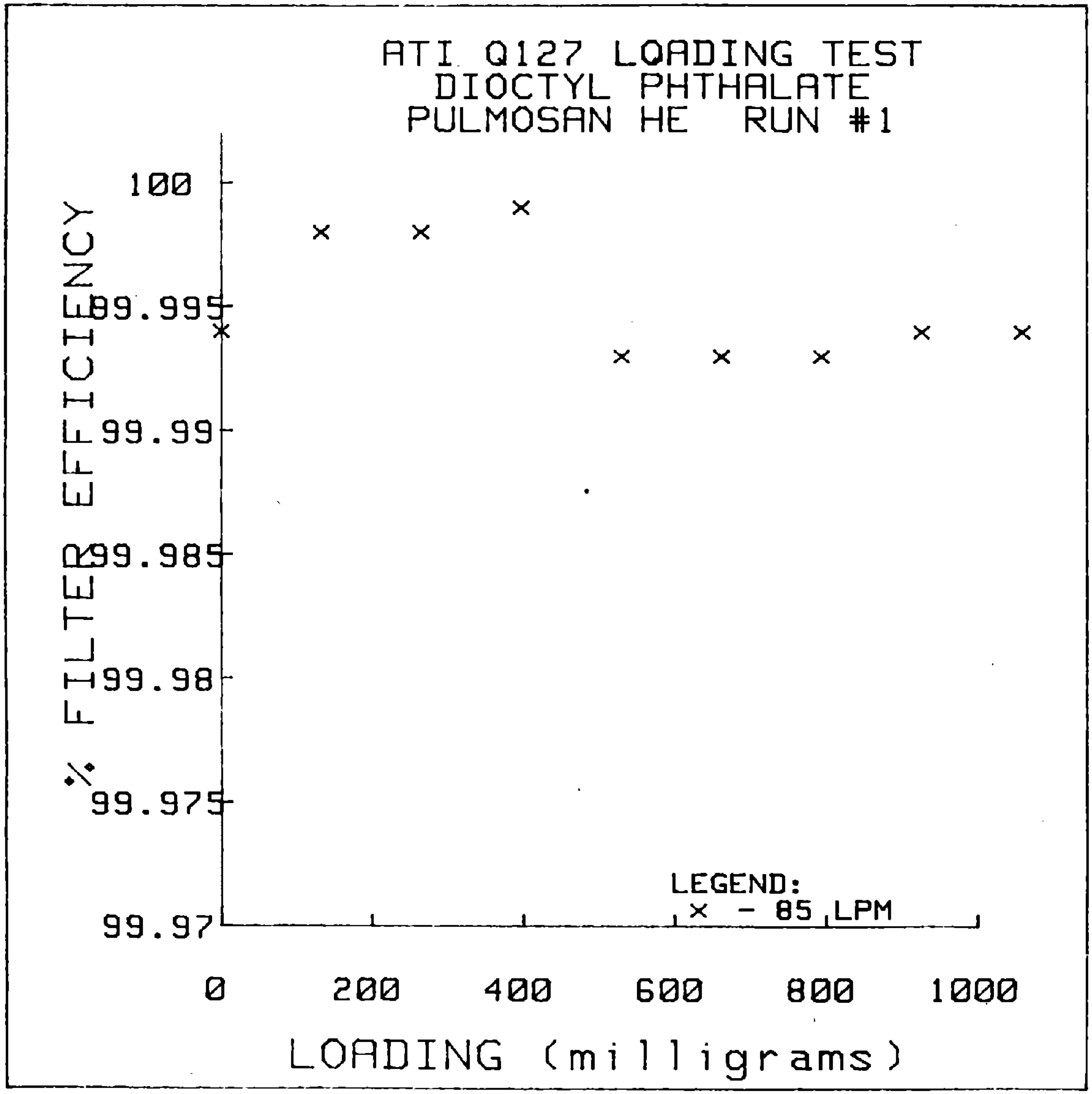
Figure 3



Q127 DOP LOADING TEST AO R57A #3
DATA FOR 42.5 LPM

0	99.996
59.125	99.997
118.25	99.996
177.375	99.997
236.5	99.997
295.625	99.997
354.75	99.997
413.875	99.997
473	99.997

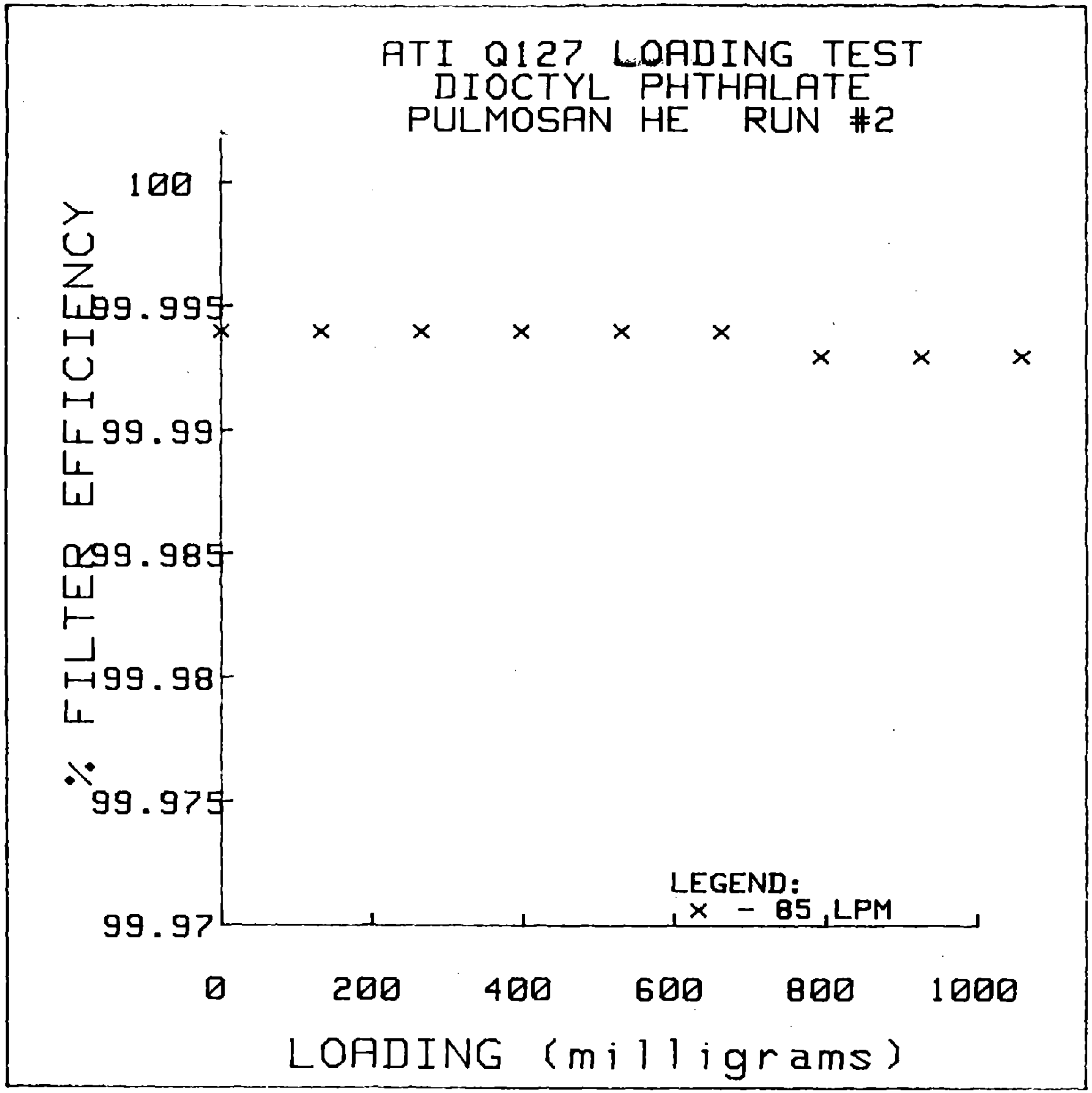
Figure 4



Q127 DOP LOADING PULMOSAN HE #1
DATA FOR 85 LPM

0	99.994
132.175	99.998
264.35	99.998
396.525	99.999
528.7	99.993
660.875	99.993
793.05	99.993
925.225	99.994
1057.4	99.994

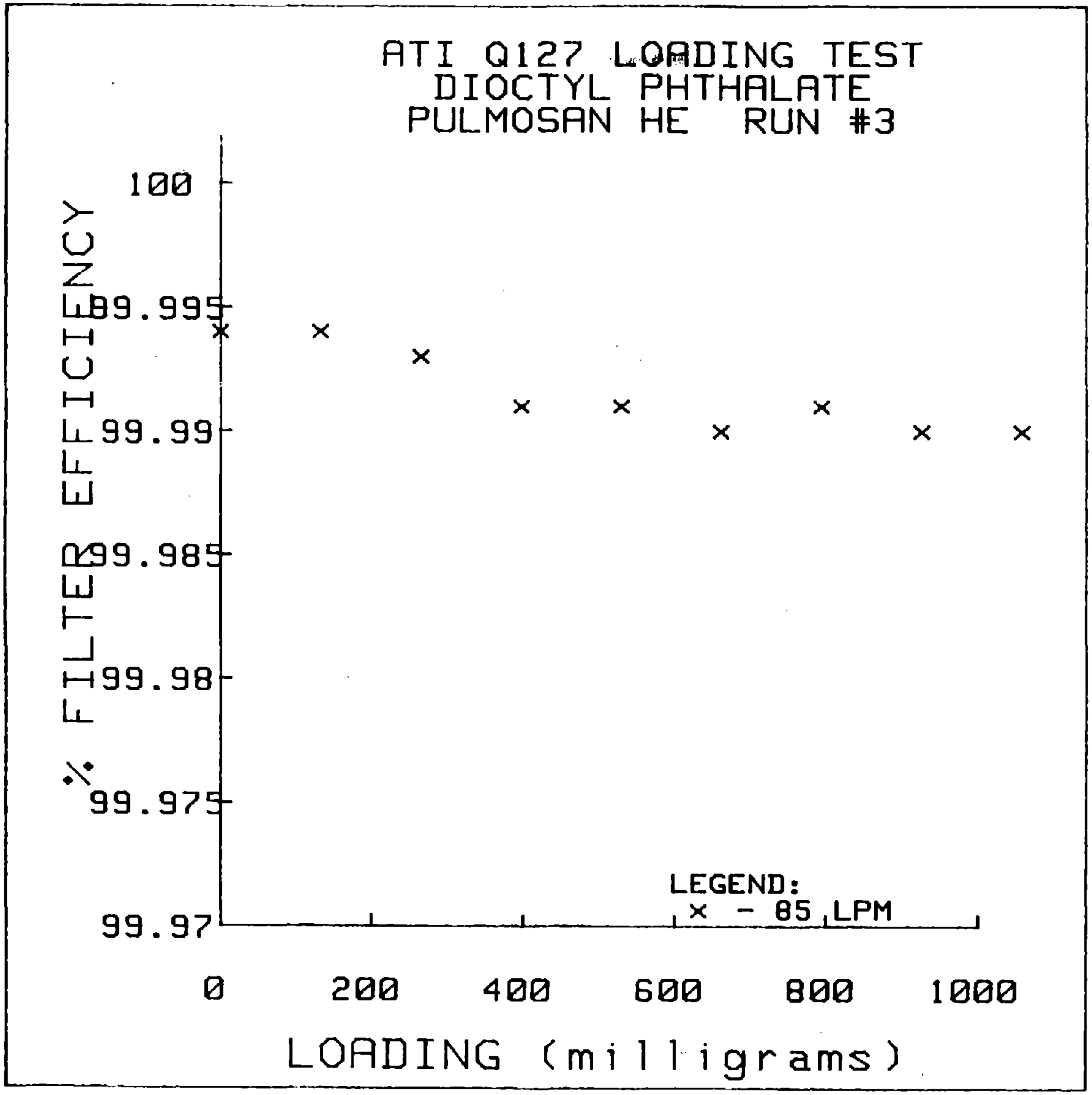
Figure 5



Q127 DOP LOADING PULMOSAN HE #2
DATA FOR 85 LPM

0	99.994
132.175	99.994
264.35	99.994
396.525	99.994
528.7	99.994
660.875	99.994
793.05	99.993
925.225	99.993
1057.4	99.993

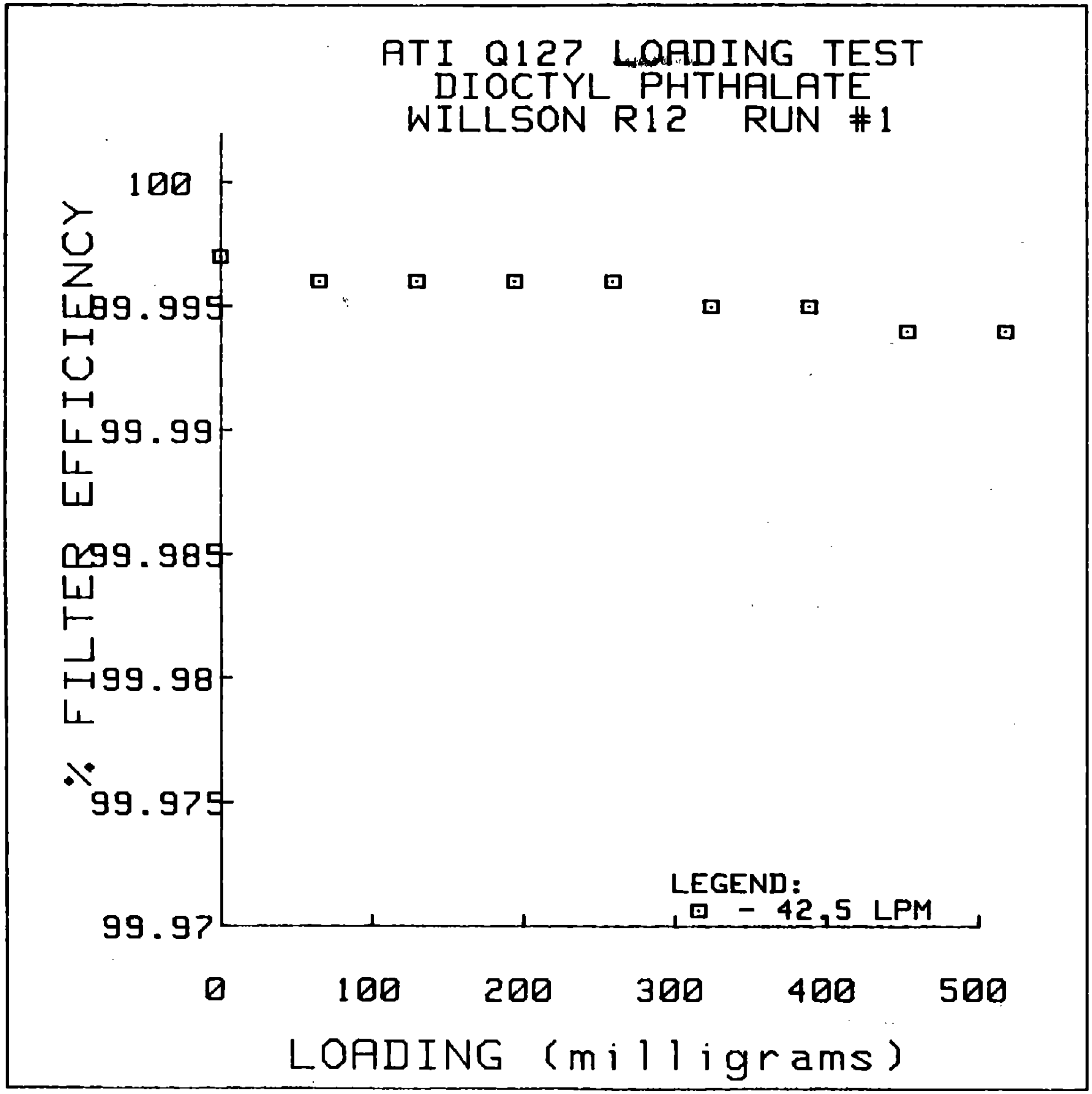
Figure 6



Q127 DOP LOADING PULMOSAN HE #3
DATA FOR 85 LPM

0	99.994
132.175	99.994
264.35	99.993
396.525	99.991
528.7	99.991
660.875	99.99
793.05	99.991
925.225	99.99
1057.4	99.99

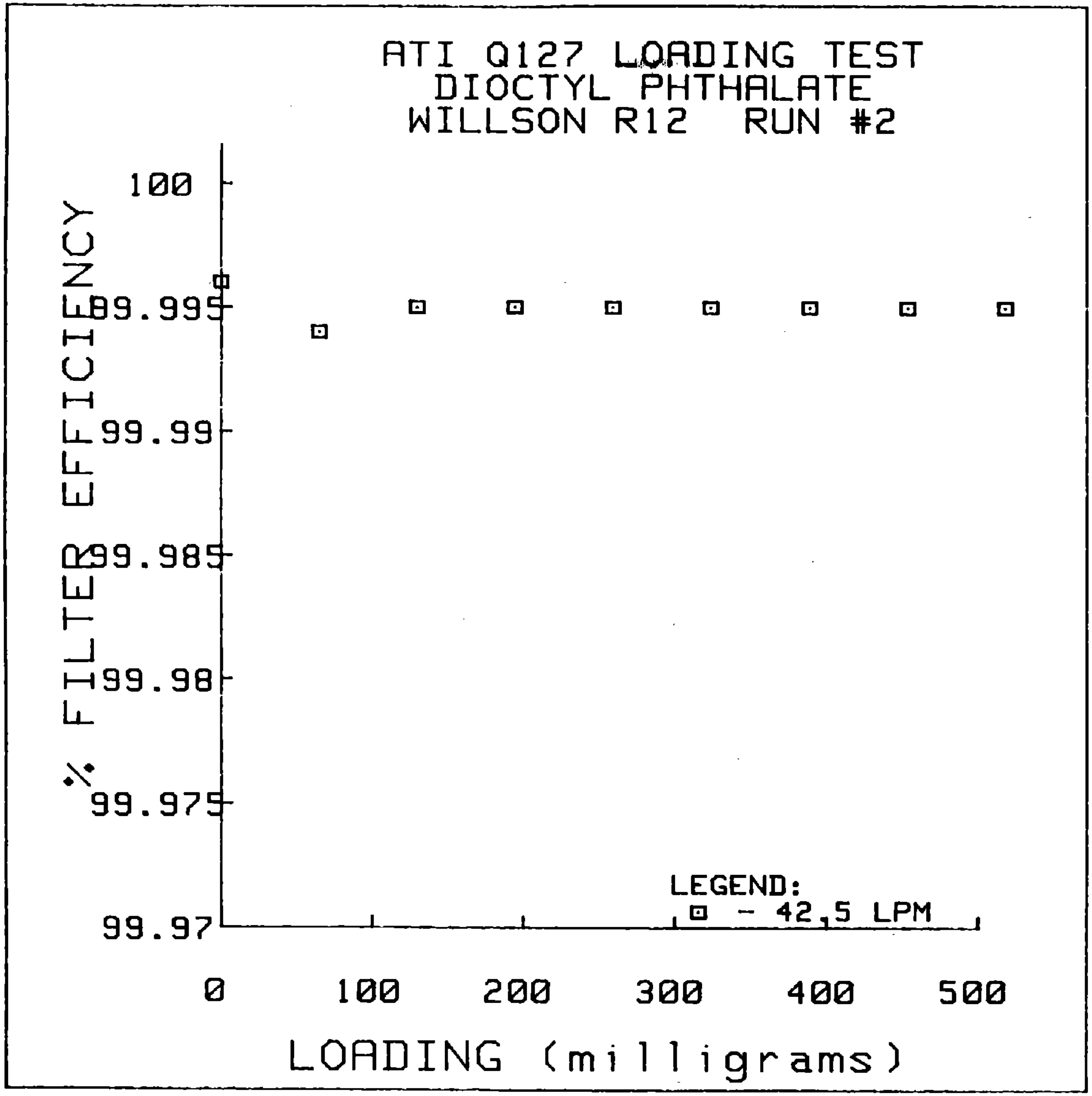
Figure 7



Q127 DOP LOADING TEST WILL R12 #1
DATA FOR 42.5 LPM

0	99.997
64.725	99.996
129.45	99.996
194.175	99.996
258.9	99.996
323.625	99.995
388.35	99.995
453.075	99.994
517.8	99.994

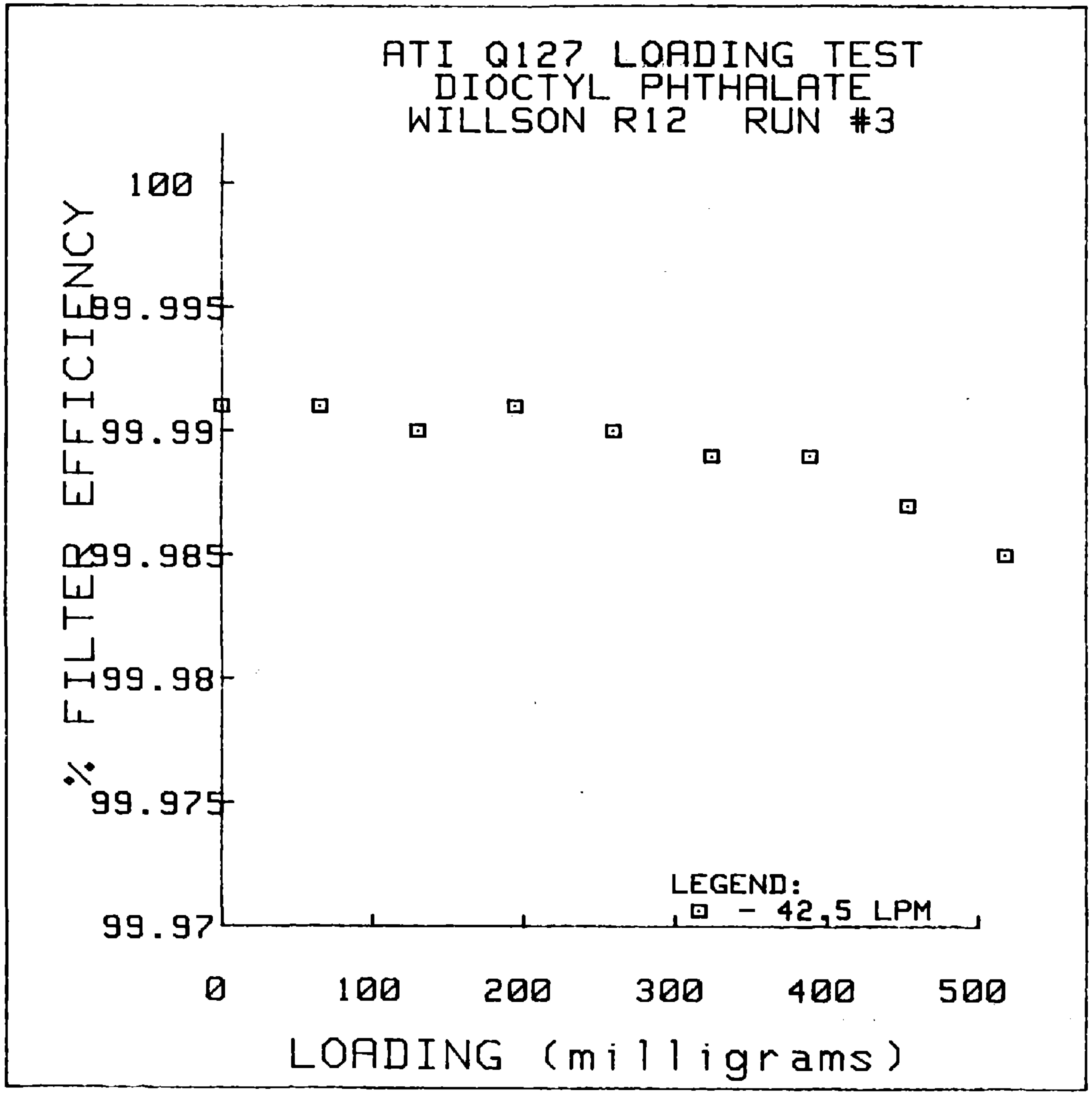
Figure 8



Q127 DOP LOADING TEST WILL R12 #2
DATA FOR 42.5 LPM

0	99.996
64.725	99.994
129.45	99.995
194.175	99.995
258.9	99.995
323.625	99.995
388.35	99.995
453.075	99.995
517.8	99.995

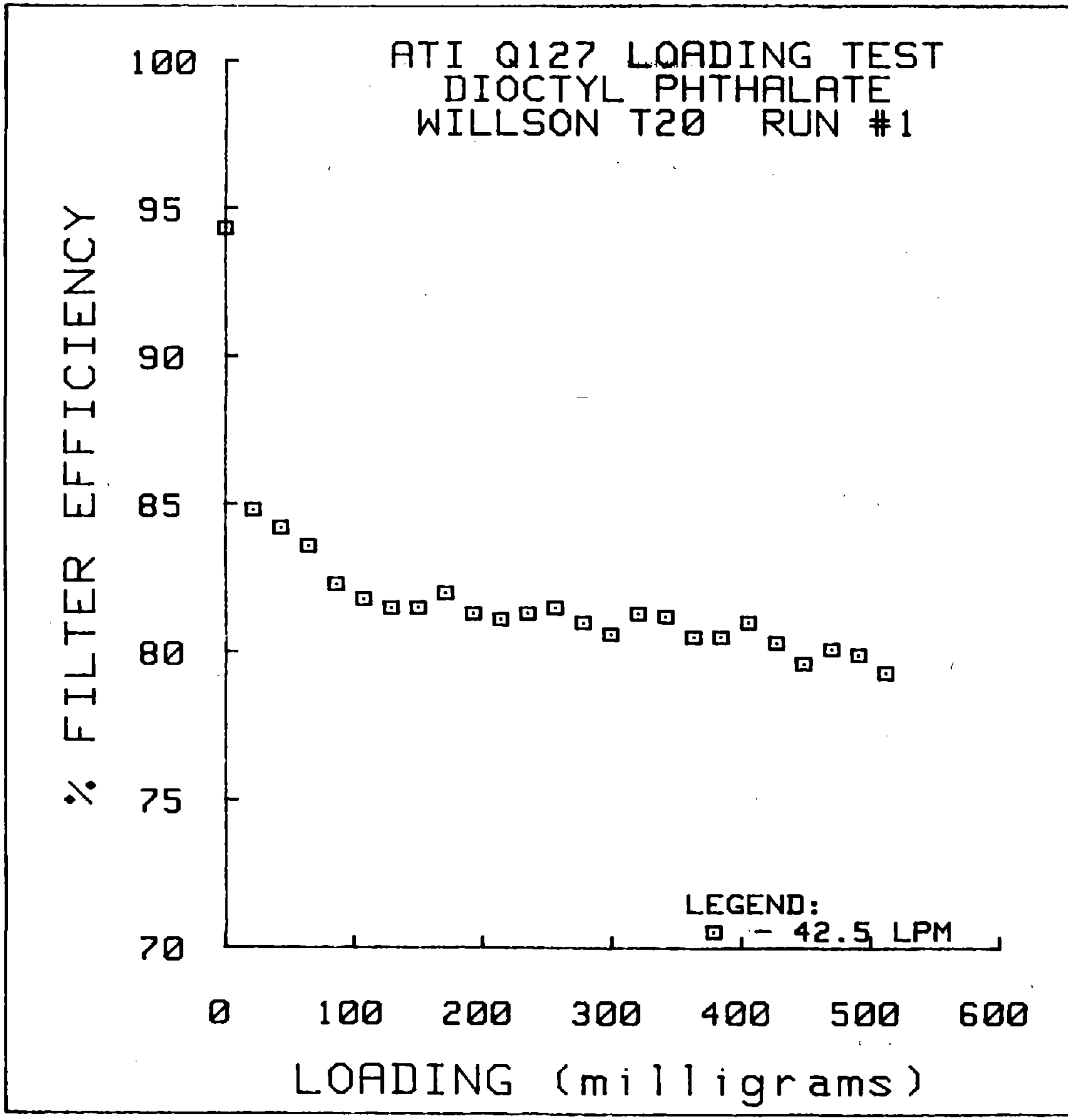
Figure 9



Q127 DOP LOADING TEST WILL R12 #3
DATA FOR 42.5 LPM

0	99.991
64.725	99.991
129.45	99.99
194.175	99.991
258.9	99.99
323.625	99.989
388.35	99.989
453.075	99.987
517.8	99.985

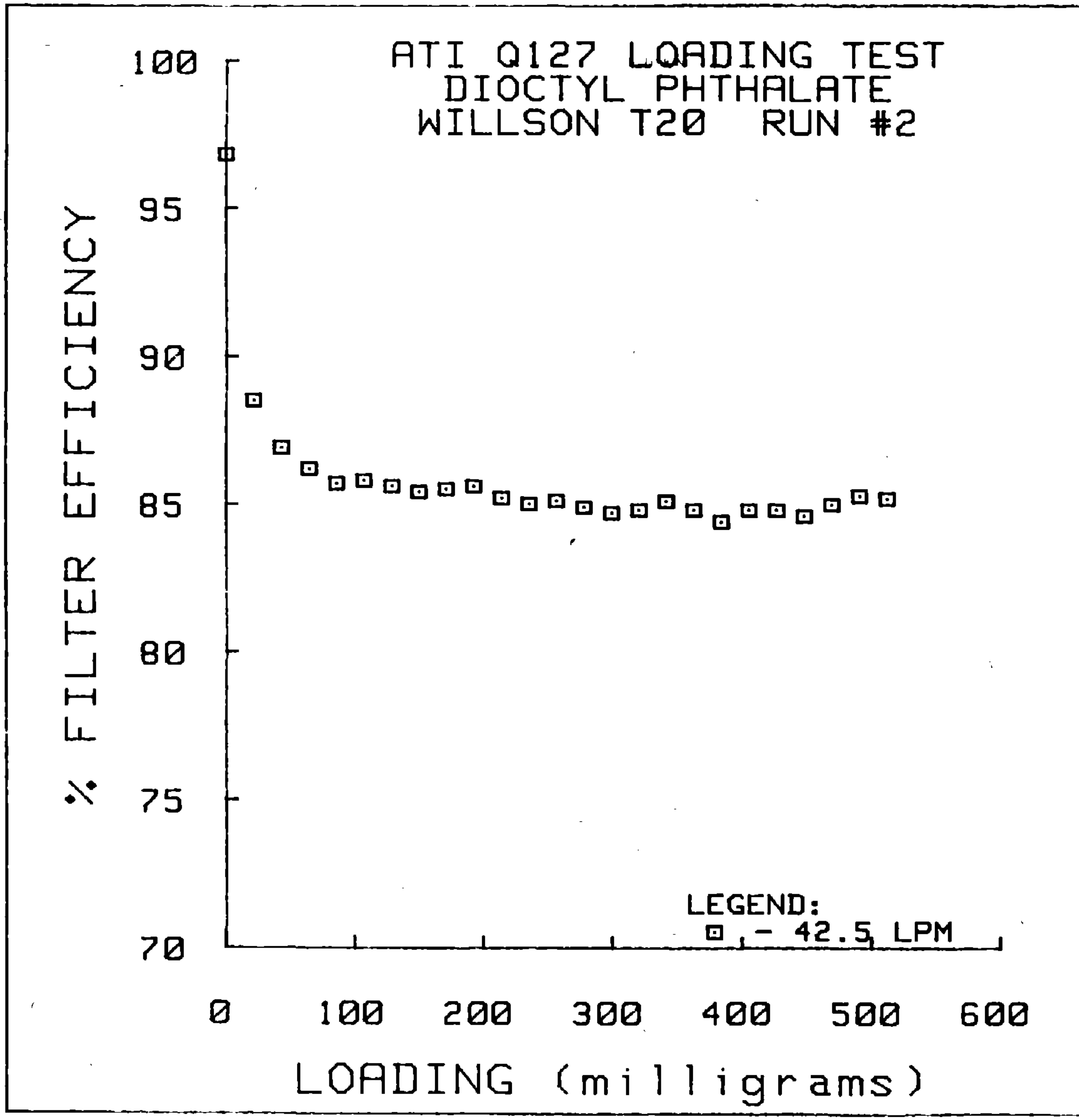
Figure 10



ATI Q127 DOP LOADING TEST WILLSON T20 #1
DATA FOR 42.5 LPM

0	94.31
21.3083	84.8
42.6167	84.2
63.925	83.6
85.2333	82.3
106.5417	81.8
127.85	81.5
149.1583	81.5
170.4667	82
191.775	81.3
213.0833	81.1
234.3917	81.3
255.7	81.5
277.0083	81
298.3167	80.6
319.625	81.3
340.9333	81.2
362.2417	80.5
383.55	80.5
404.8583	81
426.1667	80.3
447.475	79.6
468.7833	80.1
490.0917	79.9
511.4	79.3

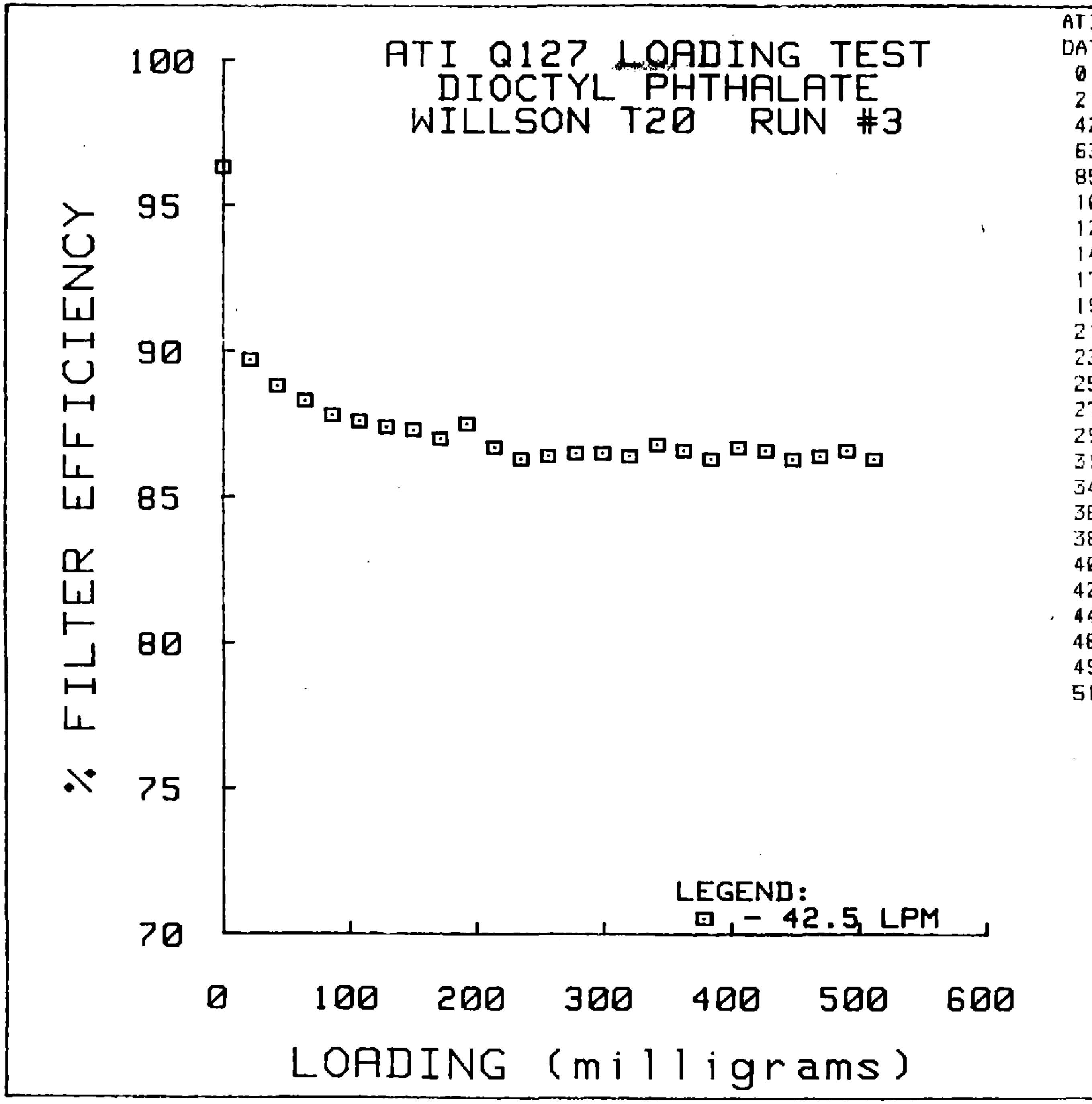
Figure 11



ATI Q127 DOP LOADING TEST WILLSON T20 #2
DATA FOR 42.5 LPM

0	96.81
21.3083	88.5
42.6167	86.9
63.925	86.2
85.2333	85.7
106.5417	85.8
127.85	85.6
149.1583	85.4
170.4667	85.5
191.775	85.6
213.0833	85.2
234.3917	85
255.7	85.1
277.0083	84.9
298.3167	84.7
319.625	84.8
340.9333	85.1
362.2417	84.8
383.55	84.4
404.8583	84.8
426.1667	84.8
447.475	84.6
468.7833	85
490.0917	85.3
511.4	85.2

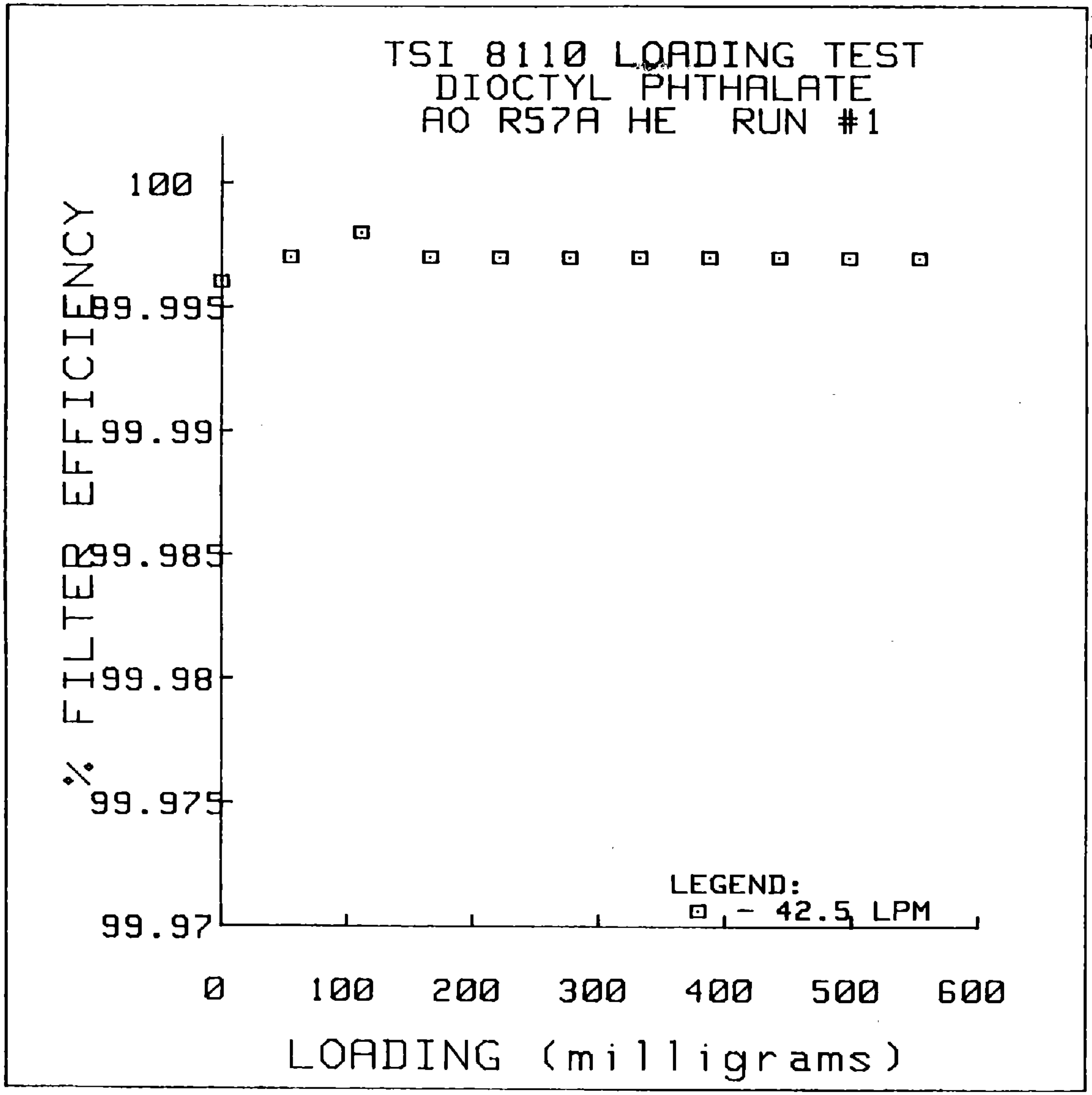
Figure 12



ATI Q127 DOP LOADING TEST WILLSON T20 #3
DATA FOR 42.5 LPM

0	96.3
21.3083	89.7
42.6167	88.8
63.925	88.3
85.2333	87.8
106.5417	87.6
127.85	87.4
149.1583	87.3
170.4667	87
191.775	87.5
213.0833	86.7
234.3917	86.3
255.7	86.4
277.0083	86.5
298.3167	86.5
319.625	86.4
340.9333	86.8
362.2417	86.6
383.55	86.3
404.8583	86.7
426.1667	86.6
447.475	86.3
468.7833	86.4
490.0917	86.6
511.4	86.3

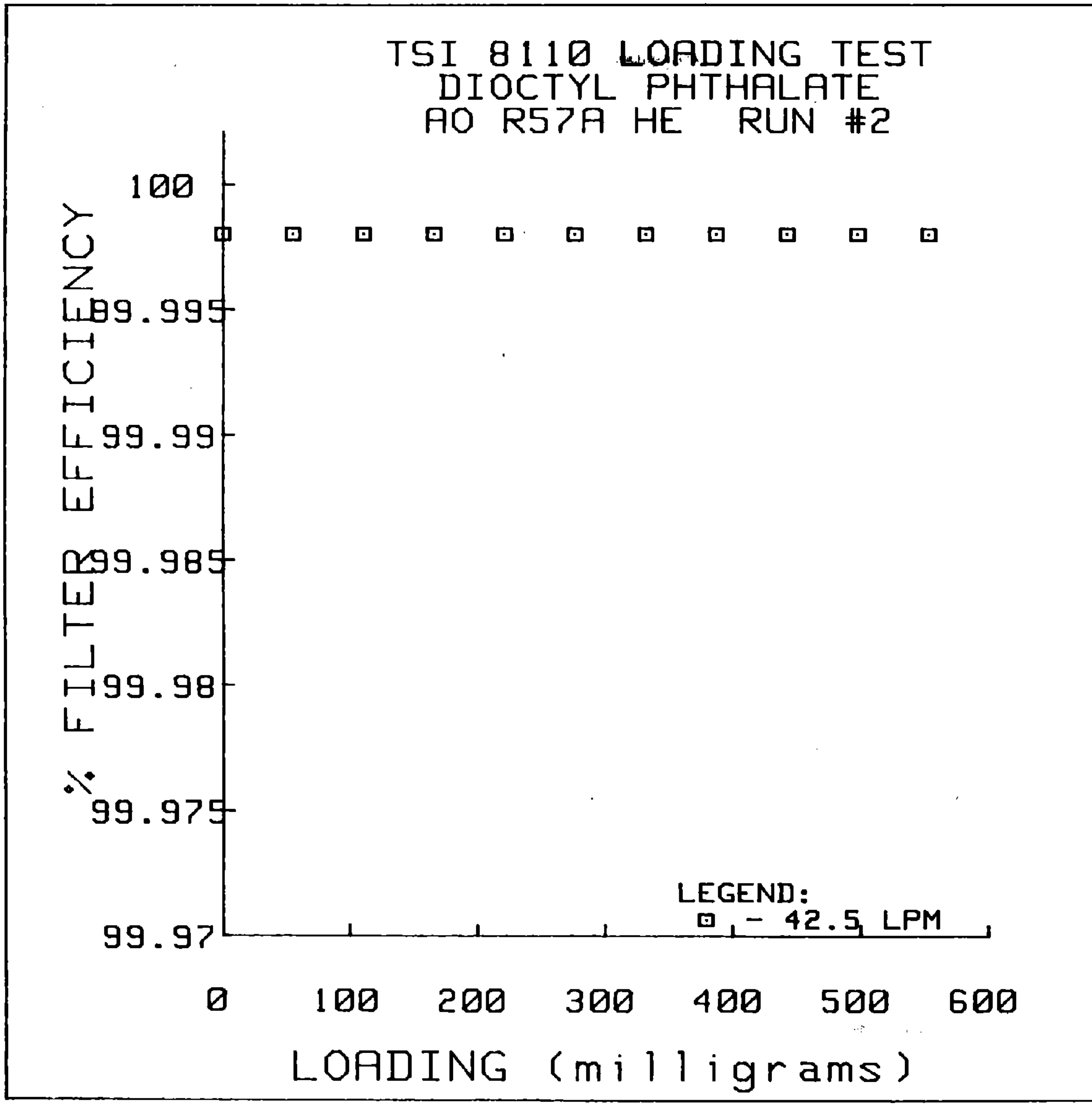
Figure 13



TSI 8110 DOP LOADING TEST AO R57A HE #
DATA FOR 42.5 LPM

0	99.996
55.3037	99.997
110.6075	99.998
165.9112	99.997
221.2149	99.997
276.5187	99.997
331.8224	99.997
387.1261	99.997
442.4299	99.997
497.7336	99.997
553.0373	99.997

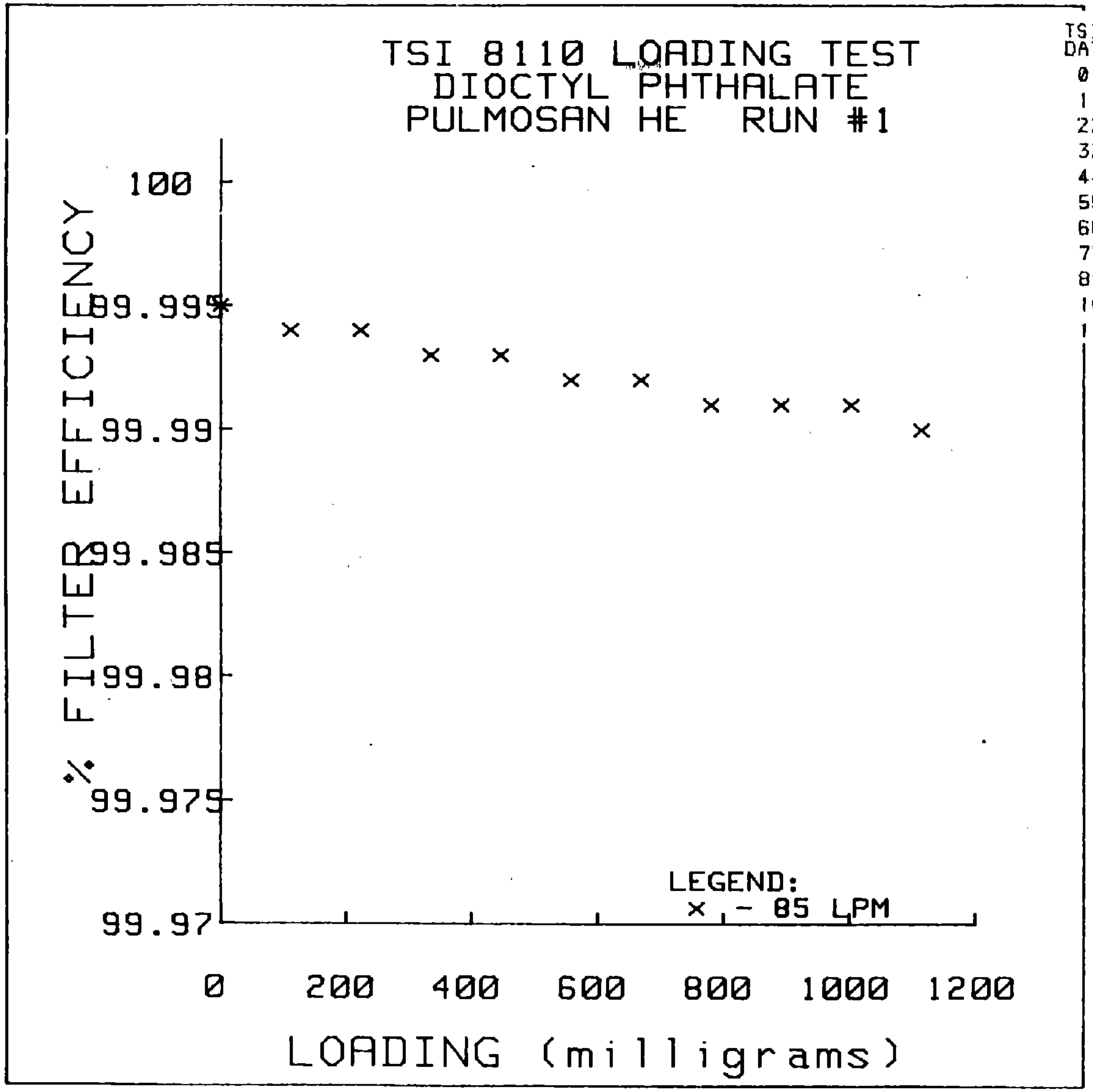
Figure 14



TSI 8110 DOP LOADING TEST AO R57A HE #2
DATA FOR 42.5 LPM

0	99.998
55.3037	99.998
110.6075	99.998
165.9112	99.998
221.2149	99.998
276.5187	99.998
331.8224	99.998
387.1261	99.998
442.4299	99.998
497.7336	99.998
553.0373	99.998

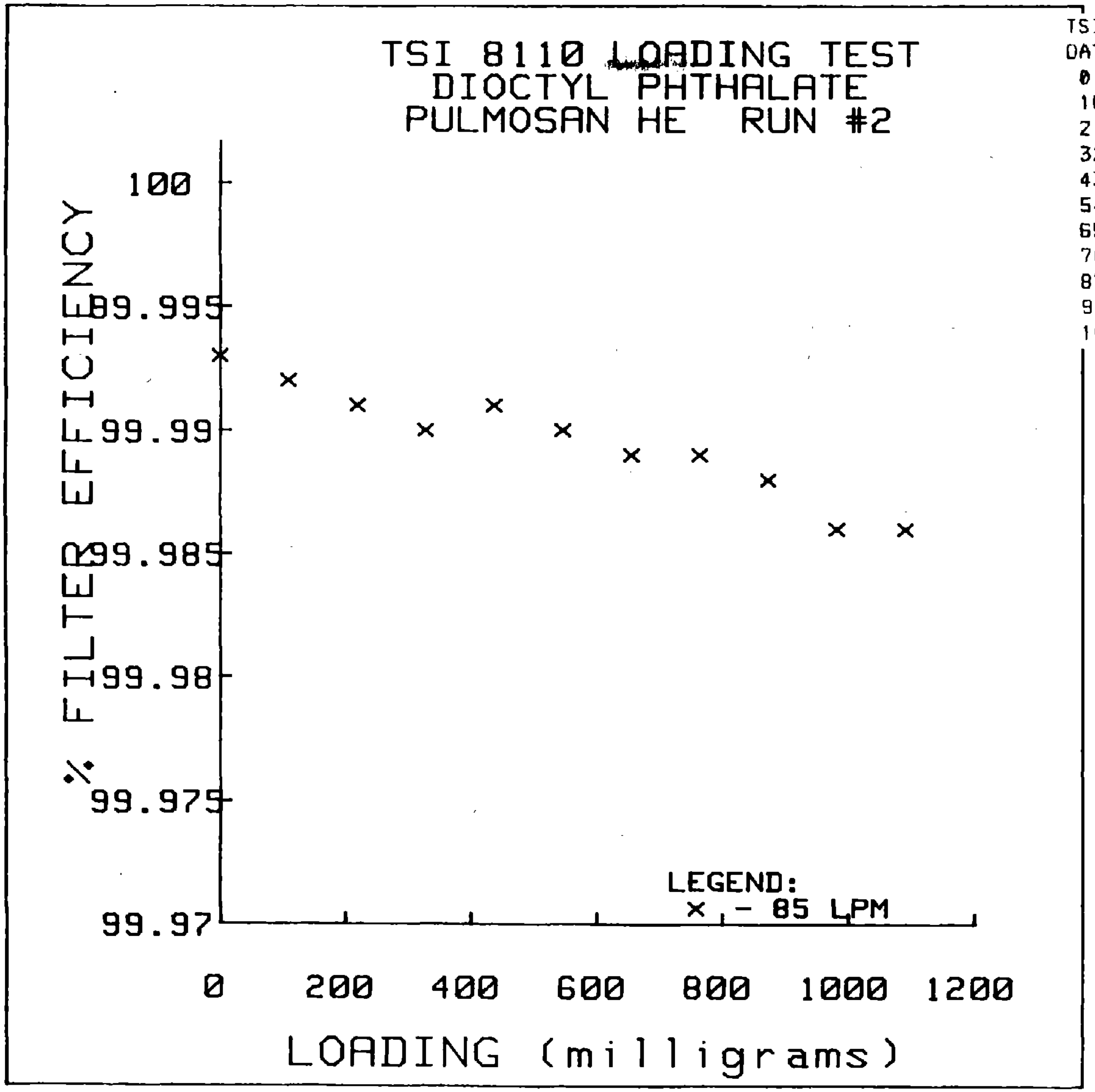
Figure 15



TSI 8110 DOP LOADING TEST PULMOSAN HE #1
DATA FOR 85 LPM

0	99.995
111.4055	99.994
222.811	99.994
334.2165	99.993
445.622	99.993
557.0274	99.992
668.4329	99.992
779.8384	99.991
891.2439	99.991
1002.6494	99.991
1114.0549	99.99

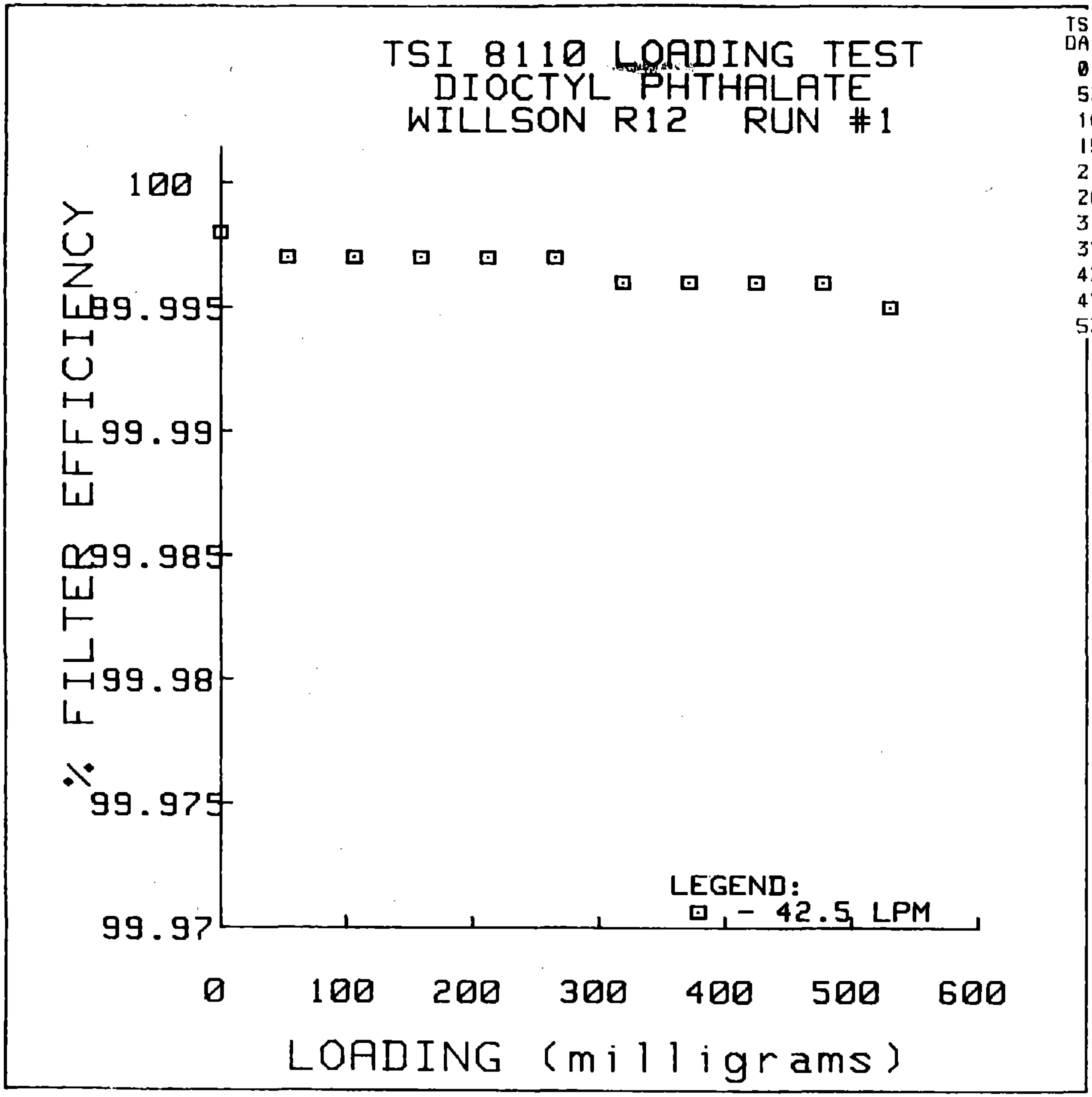
Figure 16



TSI 8110 DOP LOADING TEST PULMOSAN HE #2
DATA FOR 85 LPM

0	99.993
108.9916	99.992
217.9832	99.991
326.9749	99.99
435.9665	99.991
544.9581	99.99
653.9497	99.989
762.9414	99.989
871.933	99.988
980.9246	99.986
1089.9162	99.986

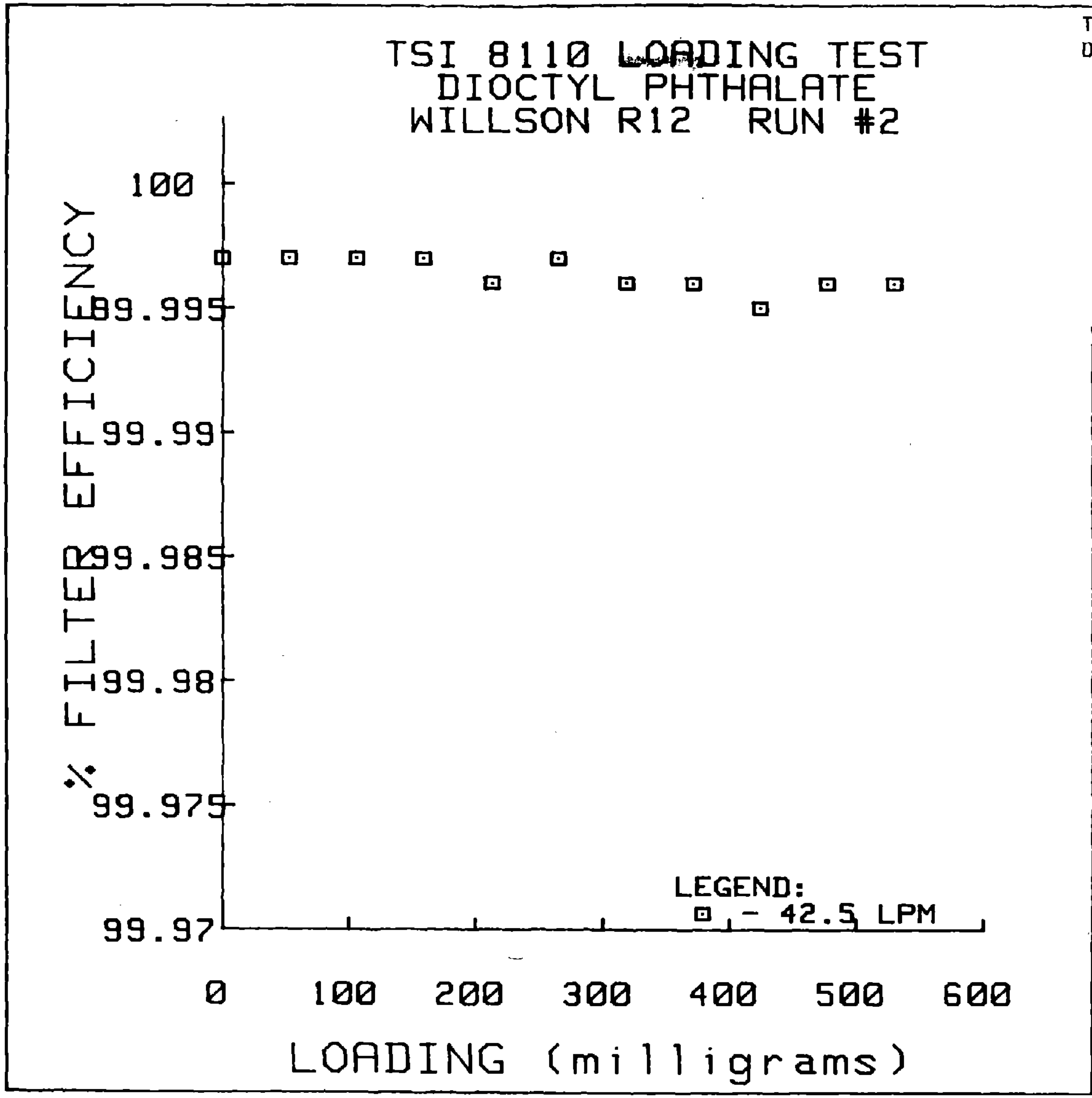
Figure 17



TSI 8110 DOP LOADING TEST WILLSON R12 #1
DATA FOR 42.5 LPM

0	99.998
53.0002	99.997
106.0003	99.997
159.0005	99.997
212.0007	99.997
265.0008	99.997
318.001	99.996
371.0012	99.996
424.0013	99.996
477.0015	99.996
530.0016	99.995

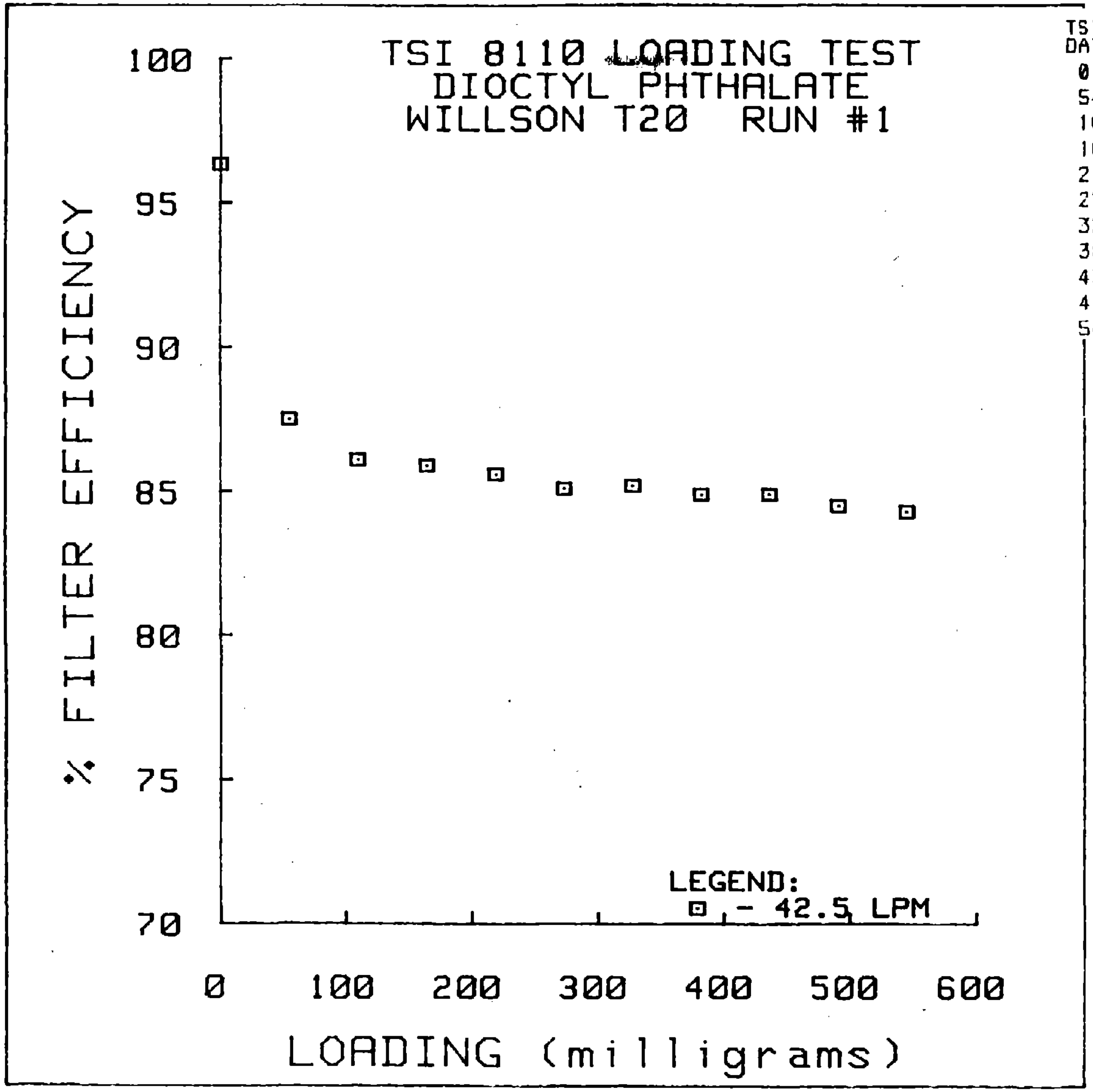
Figure 18



TSI 8110 DOP LOADING TEST WILLSON R12 #2
DATA FOR 42.5 LPM

0	99.997
53.0002	99.997
106.0003	99.997
159.0005	99.997
212.0007	99.996
265.0008	99.997
318.001	99.996
371.0012	99.996
424.0013	99.995
477.0013	99.996
530.0016	99.996

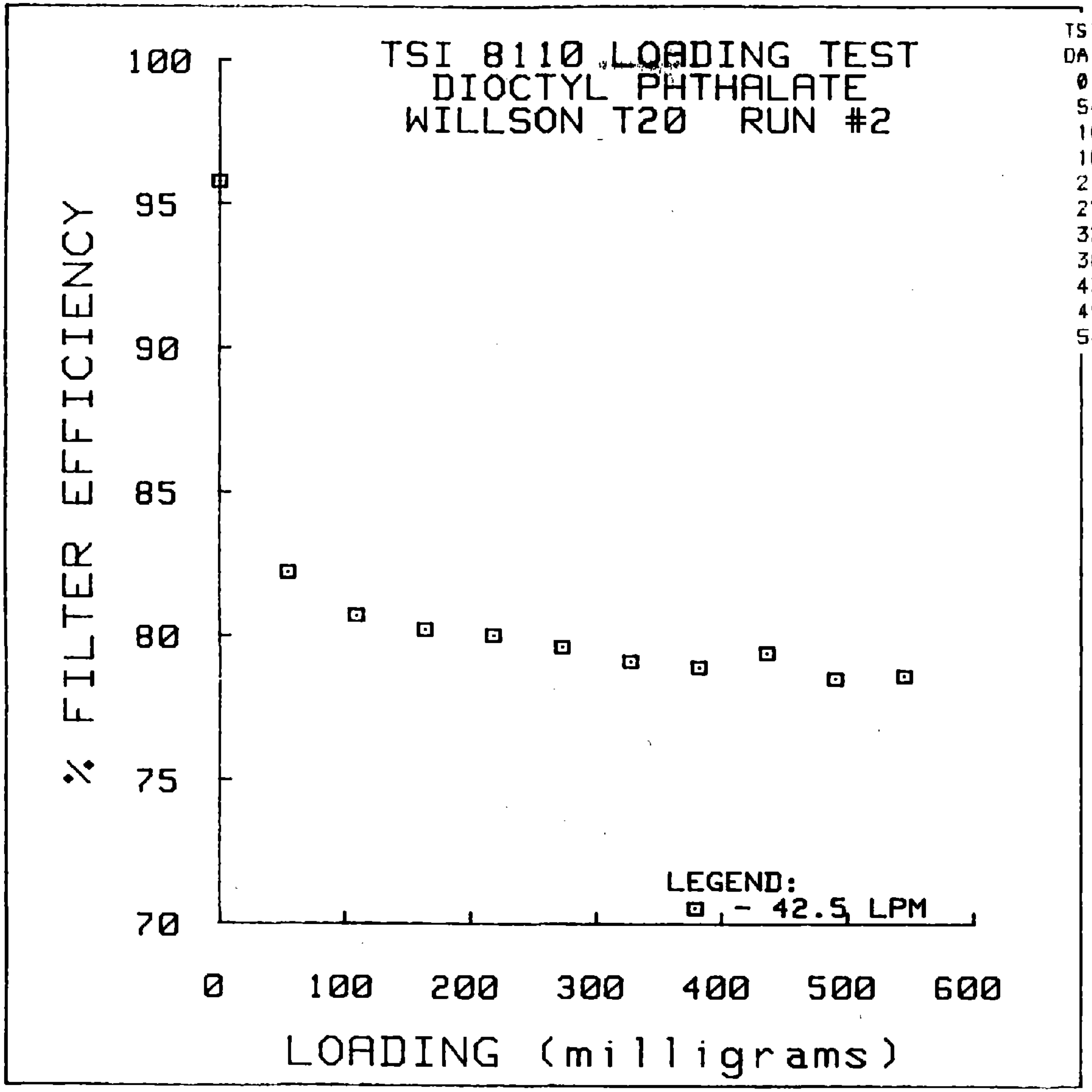
Figure 19



TSI 8110 DOP LOADING TEST WILLSON T20 #
DATA FOR 42.5 LPM

0	96.34
54.4807	87.5
108.9614	86.1
163.4422	85.9
217.9229	85.6
272.4036	85.1
326.8843	85.2
381.365	84.9
435.8458	84.9
490.3265	84.5
544.8072	84.3

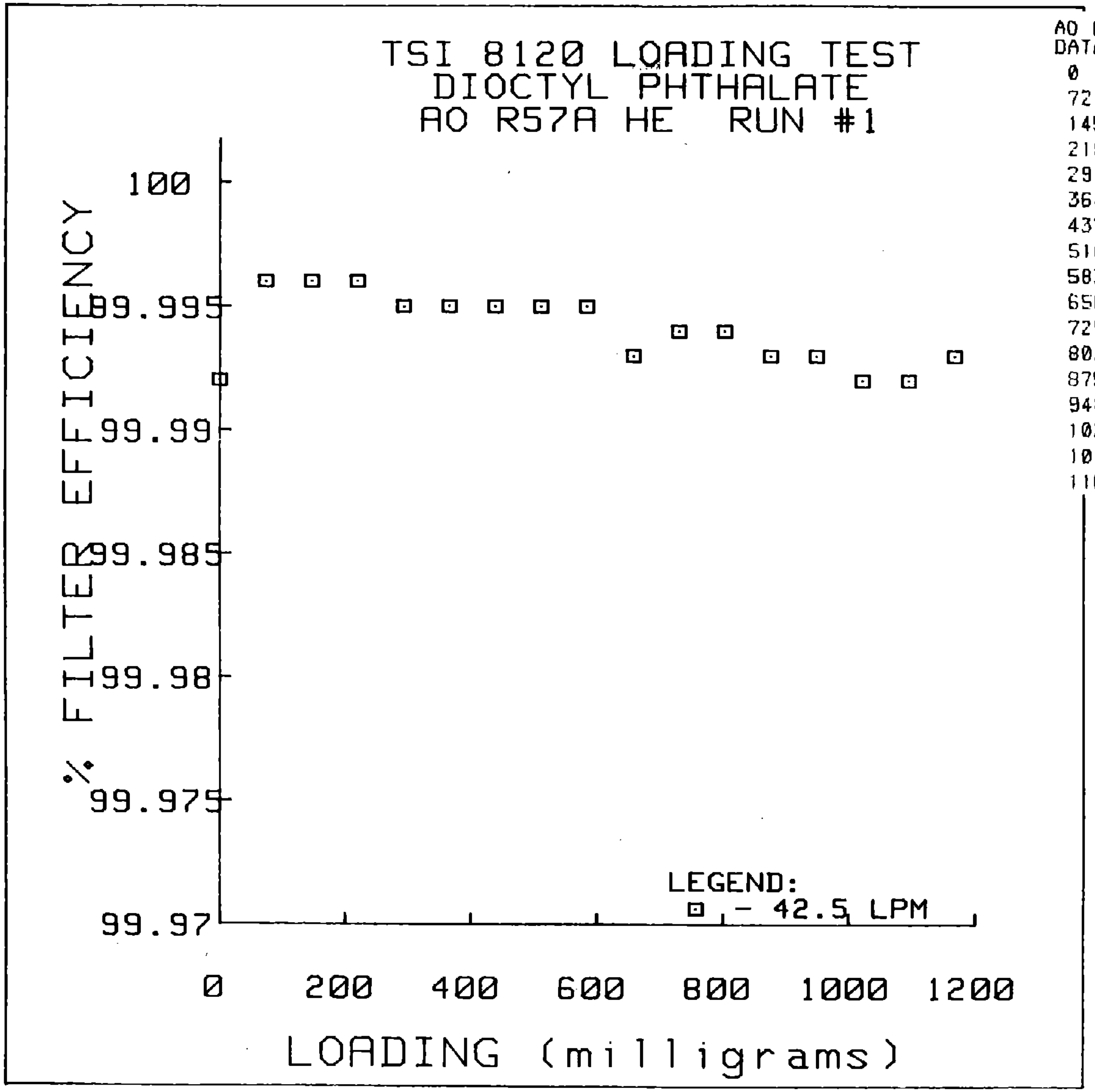
Figure 20



TSI 8110 DOP LOADING TEST WILLSON T20 #2
DATA FOR 42.5 LPM

0	95.78
54.4807	82.2
108.9614	80.7
163.4422	80.2
217.9229	80
272.4036	79.6
326.8843	79.1
381.365	78.9
435.8458	79.4
490.3265	78.5
544.8072	78.6

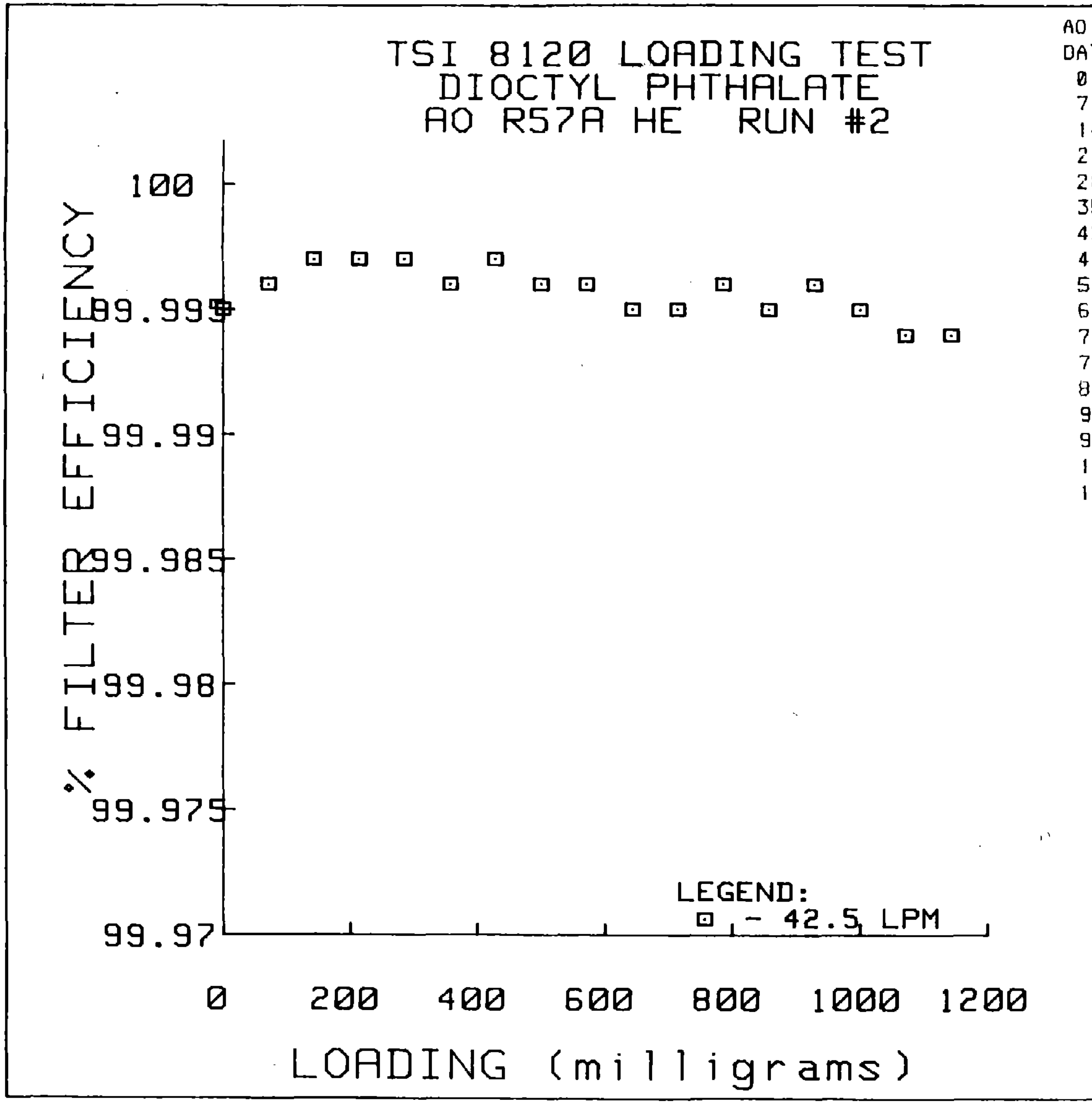
Figure 21



AO R57A HIGH CONC. DOP RUN #1 ON TSI 8120
DATA FOR 42.5 LPM

0	99.992	
72.9278	99.996	
145.8556	99.996	
218.7834	99.996	
291.7112	99.995	
364.639	99.995	
437.566	99.995	
510.4946	99.995	
583.4224	99.995	
656.3502	99.993	
729.278	99.994	
802.2058	99.994	
875.1336	99.993	
948.0614	99.993	
1020.9892		99.992
1093.917	99.992	
1166.8448		99.993

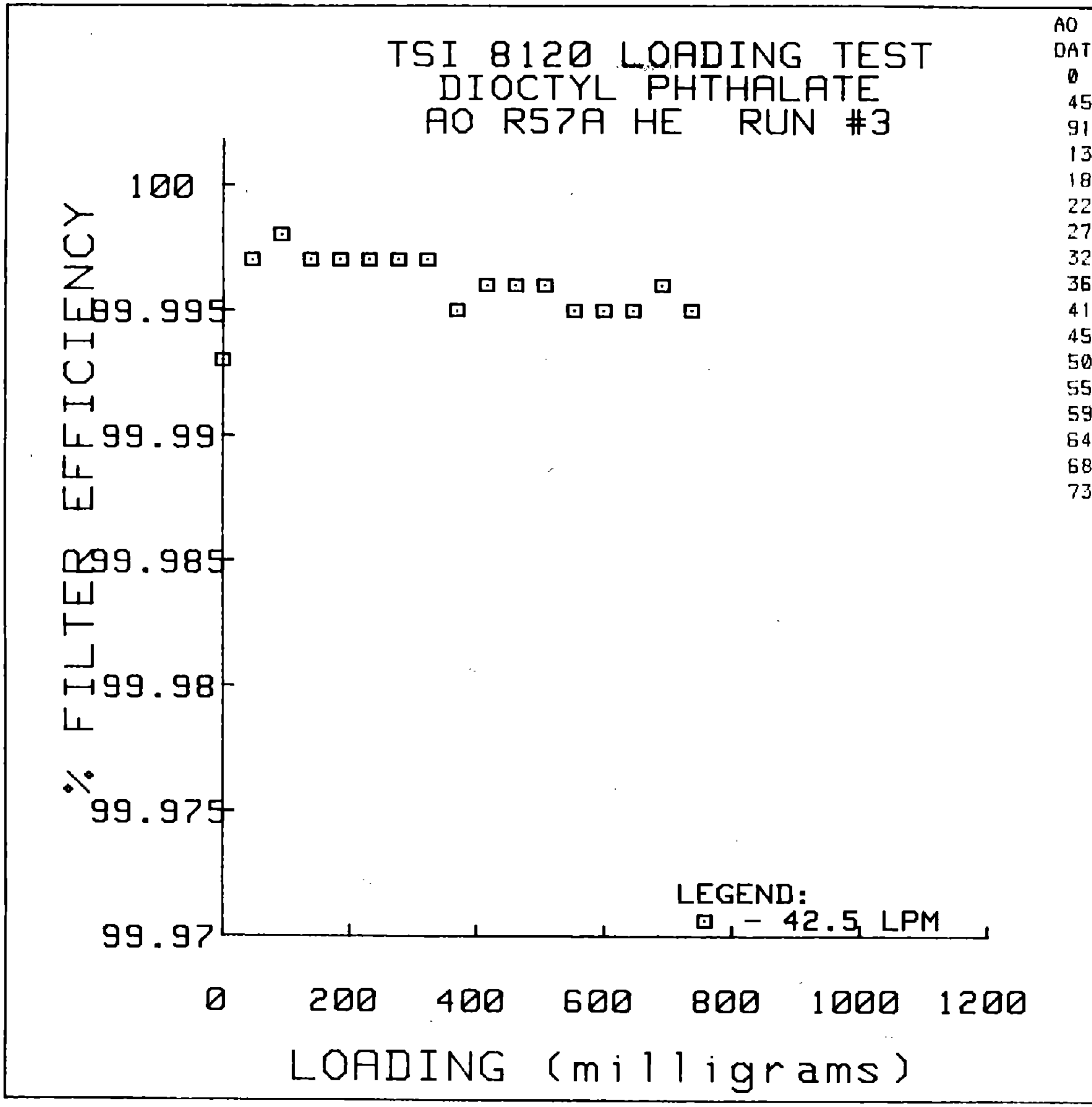
Figure 22



AO R57A HIGH CONC. DOP RUN #2 ON TSI 8120
DATA FOR 42.5 LPM

0	99.995
71.3809	99.996
142.7617	99.997
214.1426	99.997
285.5234	99.997
356.9043	99.996
428.2851	99.997
499.666	99.996
571.0468	99.996
642.4277	99.995
713.8085	99.995
785.1894	99.996
856.5702	99.995
927.9511	99.996
999.3319	99.995
1070.7128	99.994
1142.0936	99.994

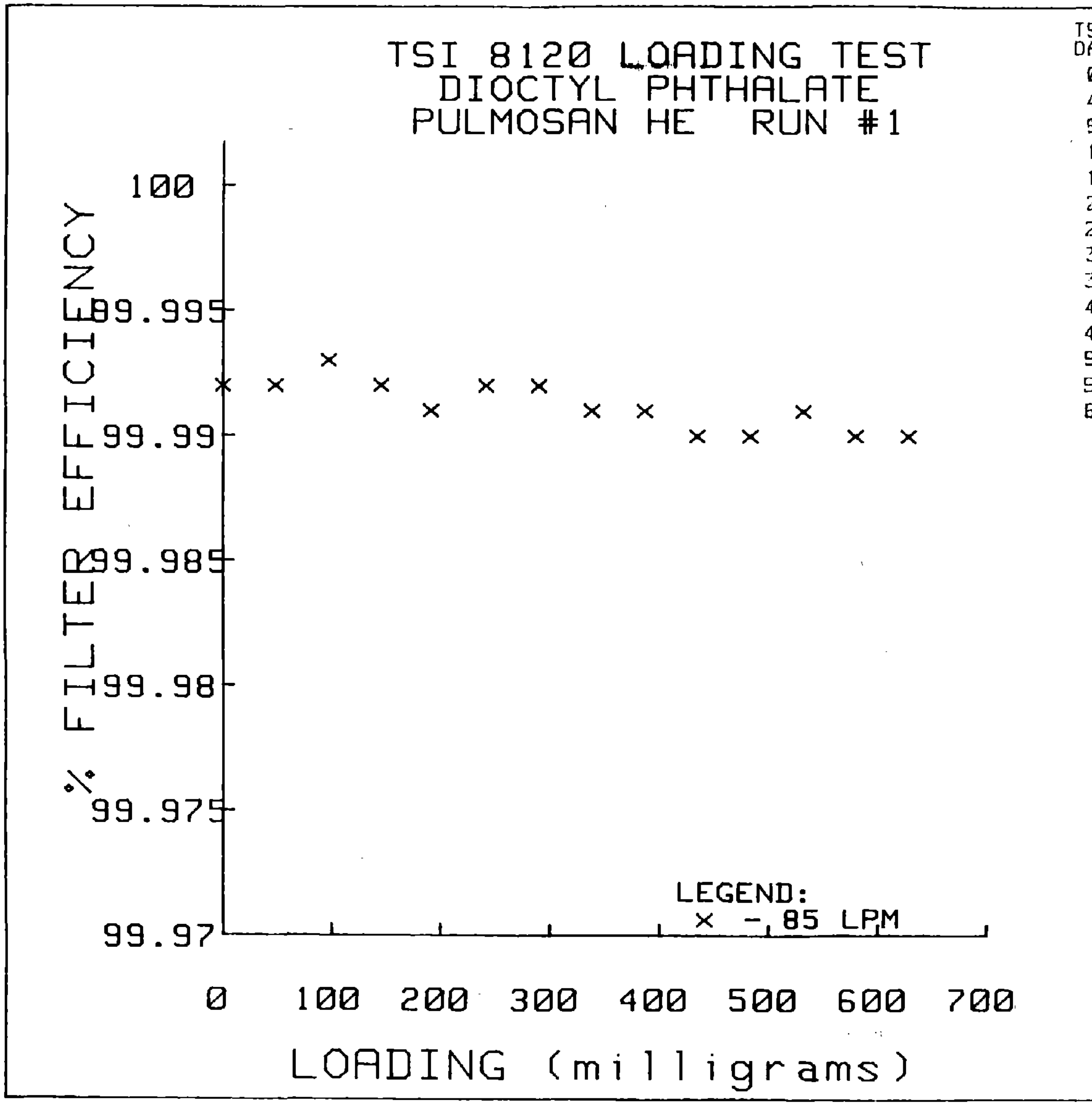
Figure 23



AO R57A HIGH CONC. DOP RUN #3 ON TSI 8120
DATA FOR 42.5 LPM

0	99.993
45.9752	99.997
91.9503	99.998
137.9255	99.997
183.9006	99.997
229.8758	99.997
275.8509	99.997
321.8261	99.997
367.8013	99.995
413.7764	99.996
459.7516	99.996
505.7267	99.996
551.7019	99.995
597.677	99.995
643.6522	99.995
689.6273	99.996
735.6025	99.995

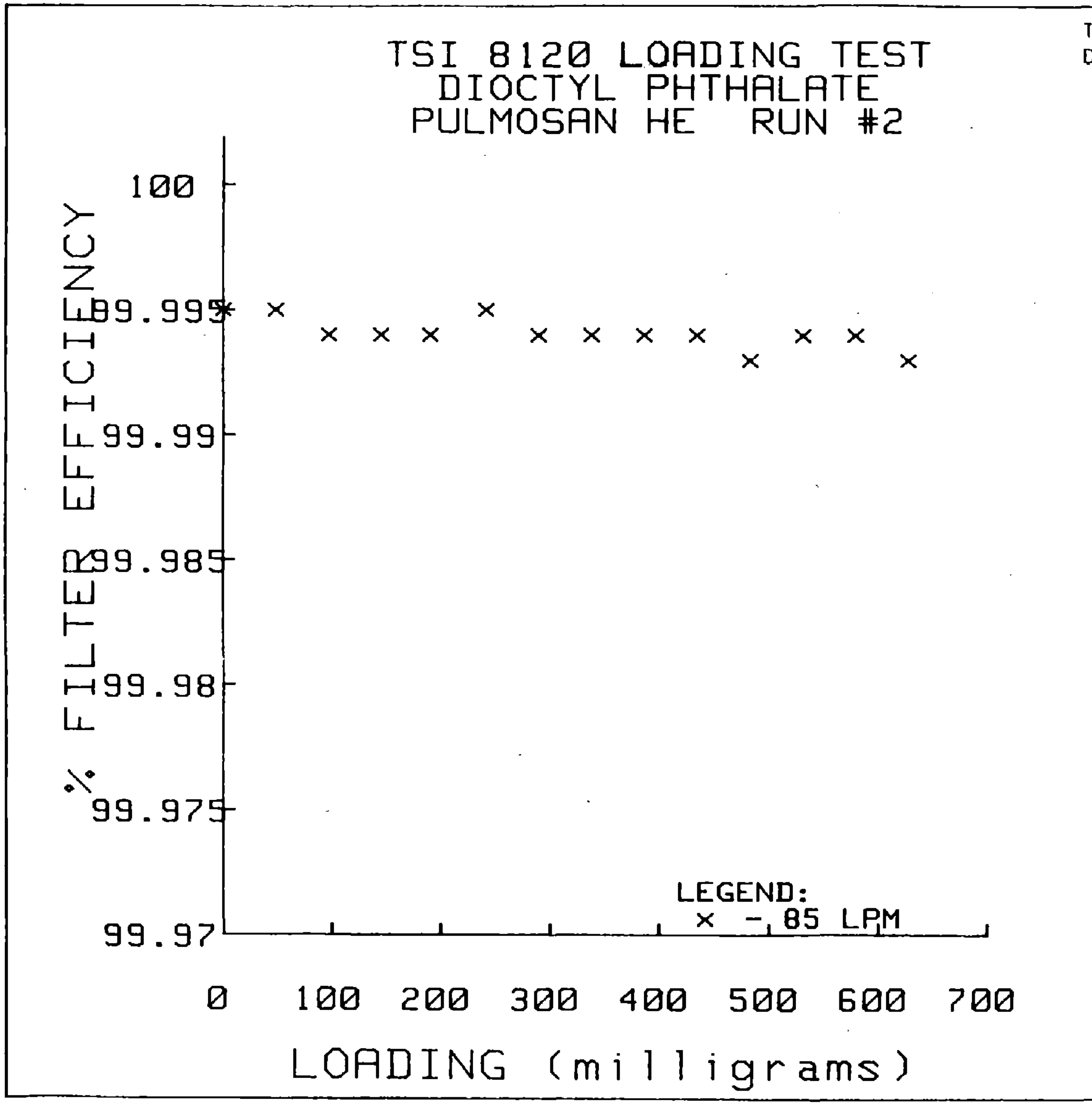
Figure 24



TSI 8120 DOP LOADING TEST PULMOSAN HE #1
DATA FOR 85 LPM

0	99.992
48.2627	99.992
96.5255	99.993
144.7882	99.992
190.051	99.991
241.3137	99.992
289.5765	99.992
337.8392	99.991
386.1019	99.991
434.3647	99.99
482.6274	99.99
530.8902	99.991
579.1529	99.99
627.4156	99.99

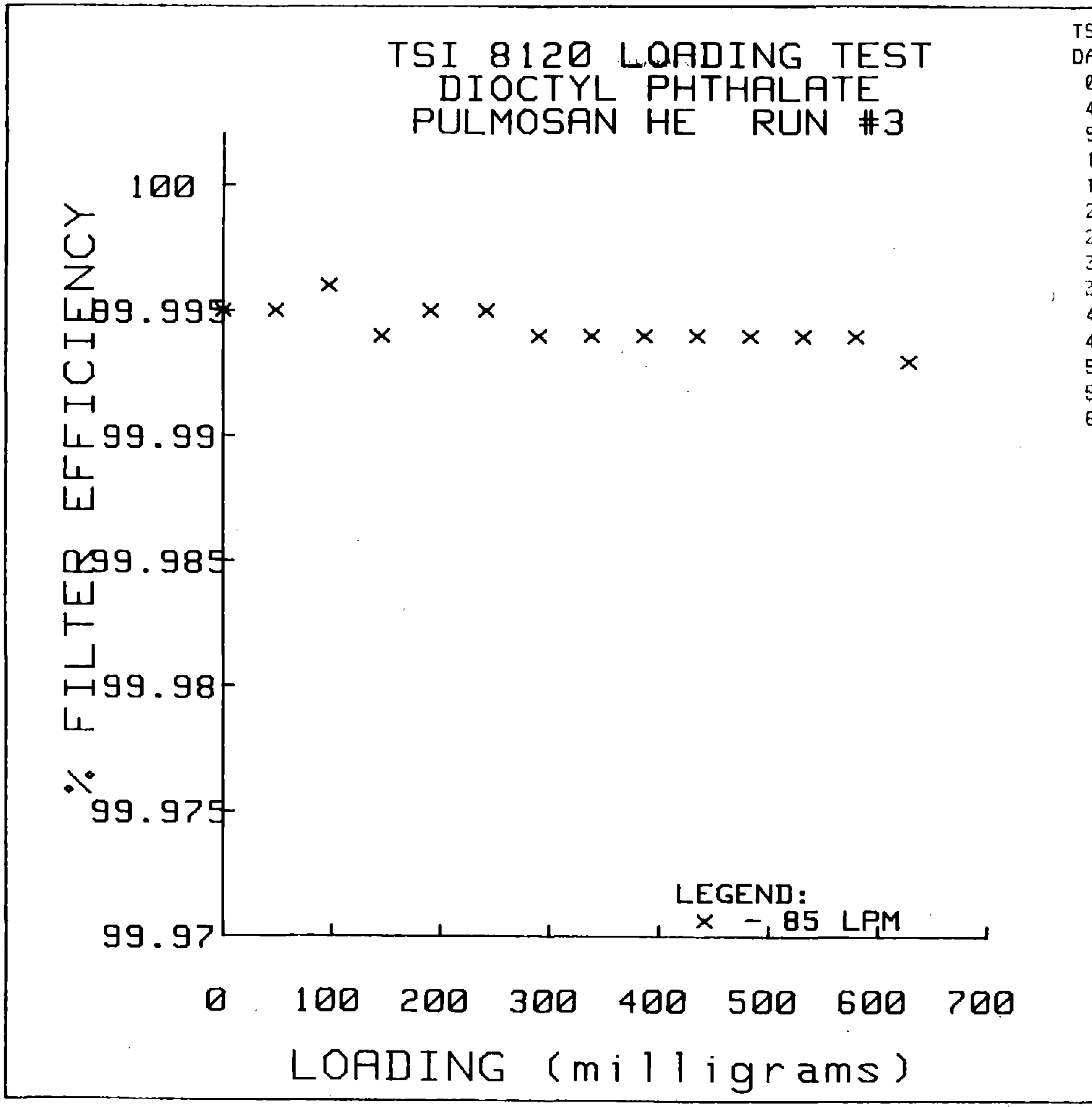
Figure 25



TSI 8120 DOP LOADING TEST PULMOSAN HE #2
DATA FOR 85 LPM

0	99.995
48.2627	99.995
96.5255	99.994
144.7882	99.994
190.051	99.994
241.3137	99.995
289.5765	99.994
337.8392	99.994
386.1019	99.994
434.3647	99.994
482.6274	99.993
530.8902	99.994
579.1529	99.994
627.4156	99.993

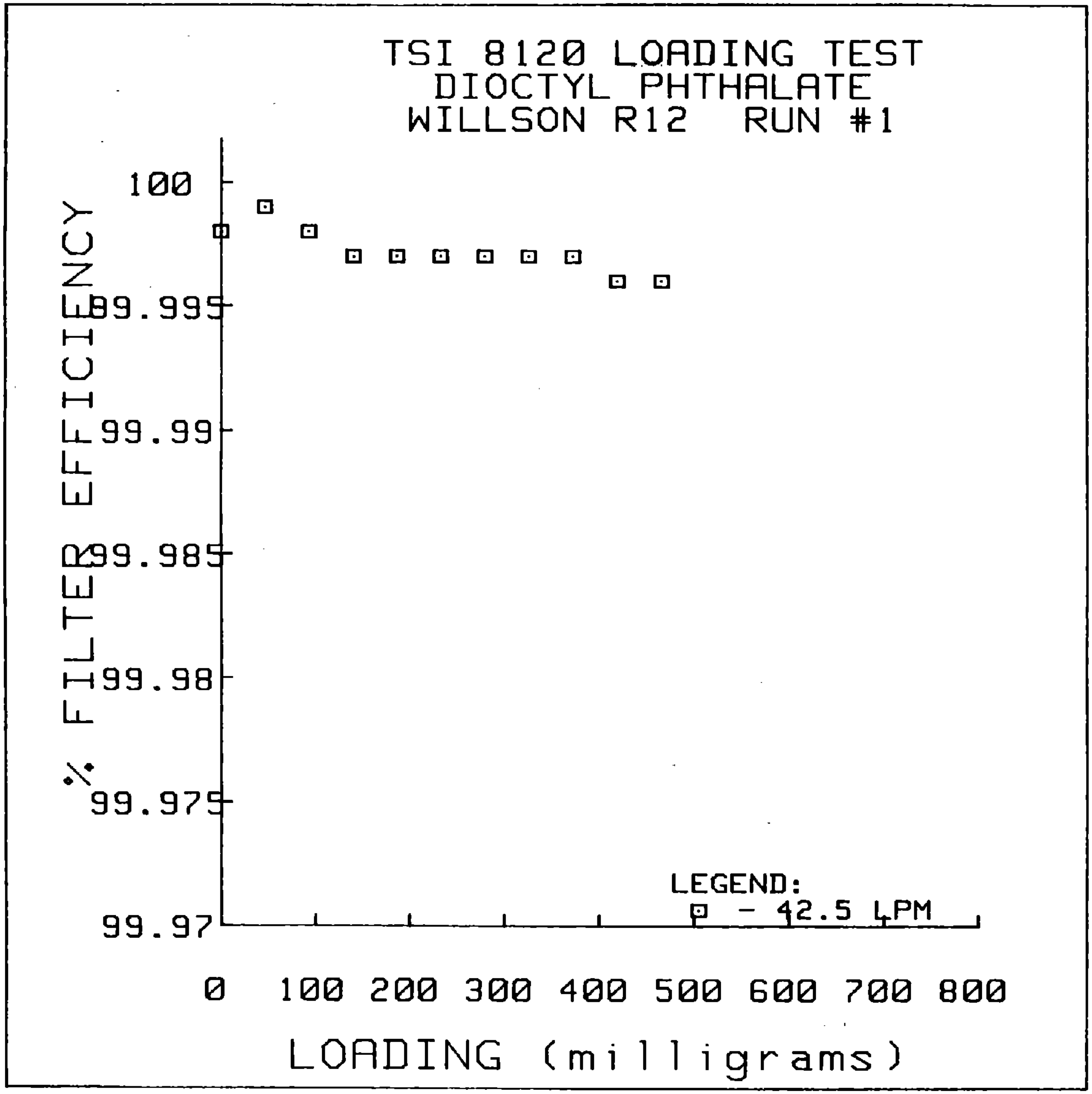
Figure 26



TSI 8120 DOP LOADING TEST PULMOSAN HE #3
DATA FOR 85 LPM

0	99.995
48.2627	99.995
96.5255	99.996
144.7882	99.994
190.051	99.995
241.3137	99.995
289.5765	99.994
337.8392	99.994
386.1019	99.994
434.3647	99.994
482.6274	99.994
530.8902	99.994
579.1529	99.994
627.4156	99.993

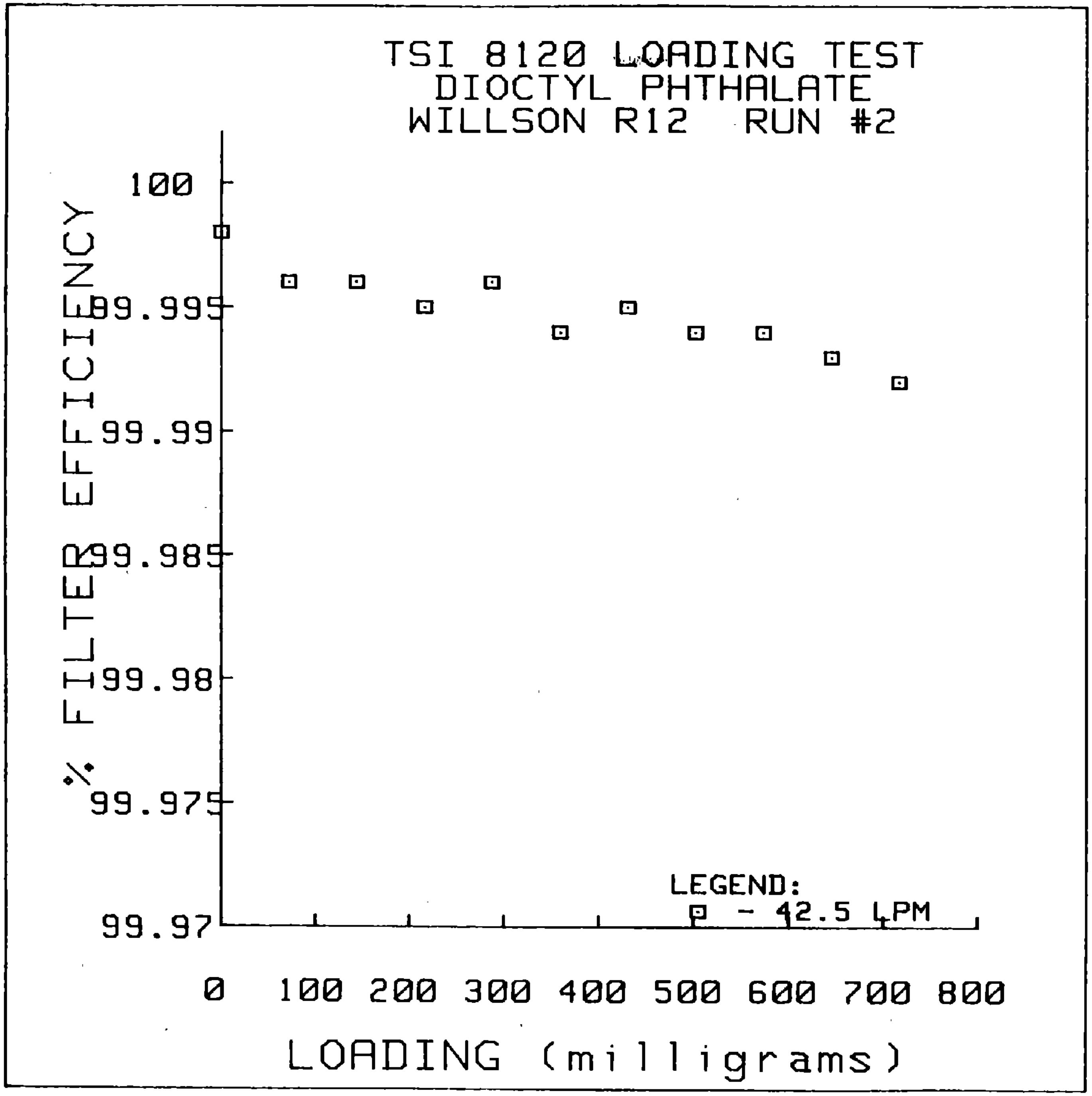
Figure 27



TSI 8120 ART WILLSON R12 HE #1
DATA FOR 42.5 LPM

0	99.998
46.5599	99.999
93.1197	99.998
139.6796	99.997
186.2395	99.997
232.7994	99.997
279.3592	99.997
325.9191	99.997
372.479	99.997
419.0389	99.996
465.5987	99.996

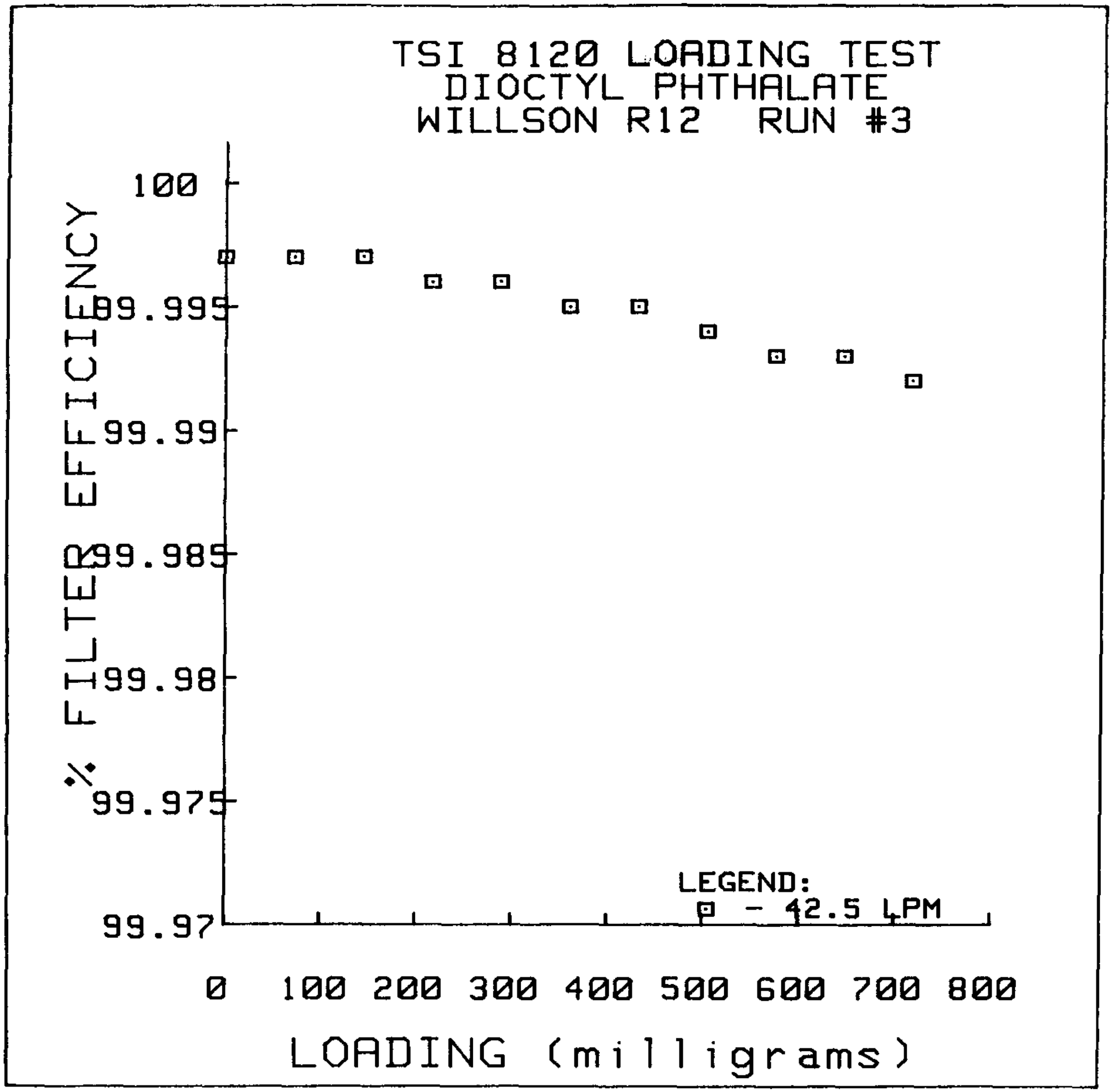
Figure 28



TSI 8120 ART WILLSON R12 HE #2
DATA FOR 42.5 LPM

0	99.998
71.6101	99.996
143.2202	99.996
214.8303	99.995
286.4404	99.996
358.0505	99.994
429.6605	99.995
501.2706	99.994
572.8807	99.994
644.4908	99.993
716.1009	99.992

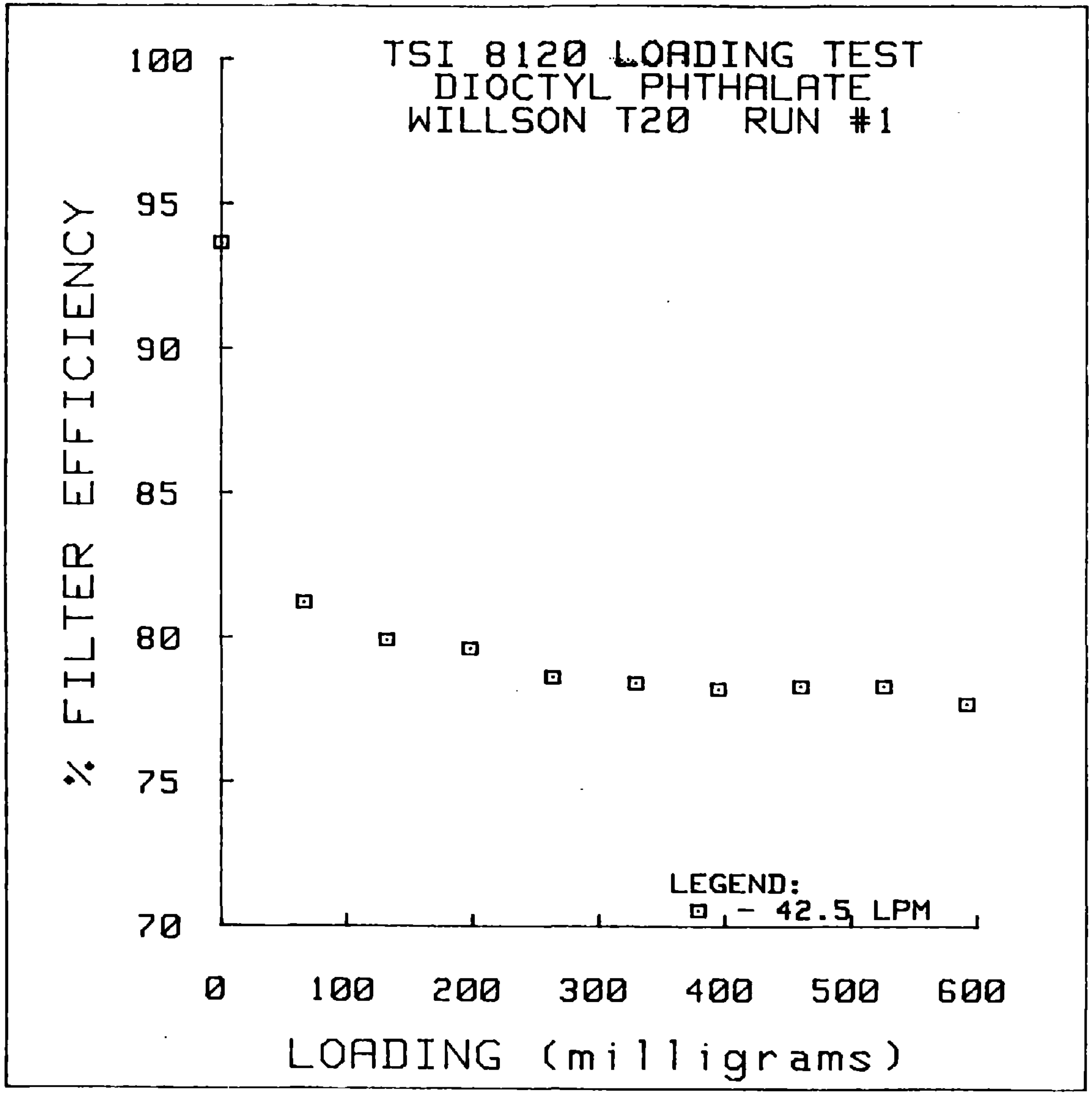
Figure 29



TSI 8120 ART WILLSON R12 HE #3
DATA FOR 42.5 LPM

0	99.997
71.6101	99.997
143.2202	99.997
214.8303	99.996
286.4404	99.996
358.0505	99.995
429.6605	99.995
501.2706	99.994
572.8807	99.993
644.4908	99.993
716.1009	99.992

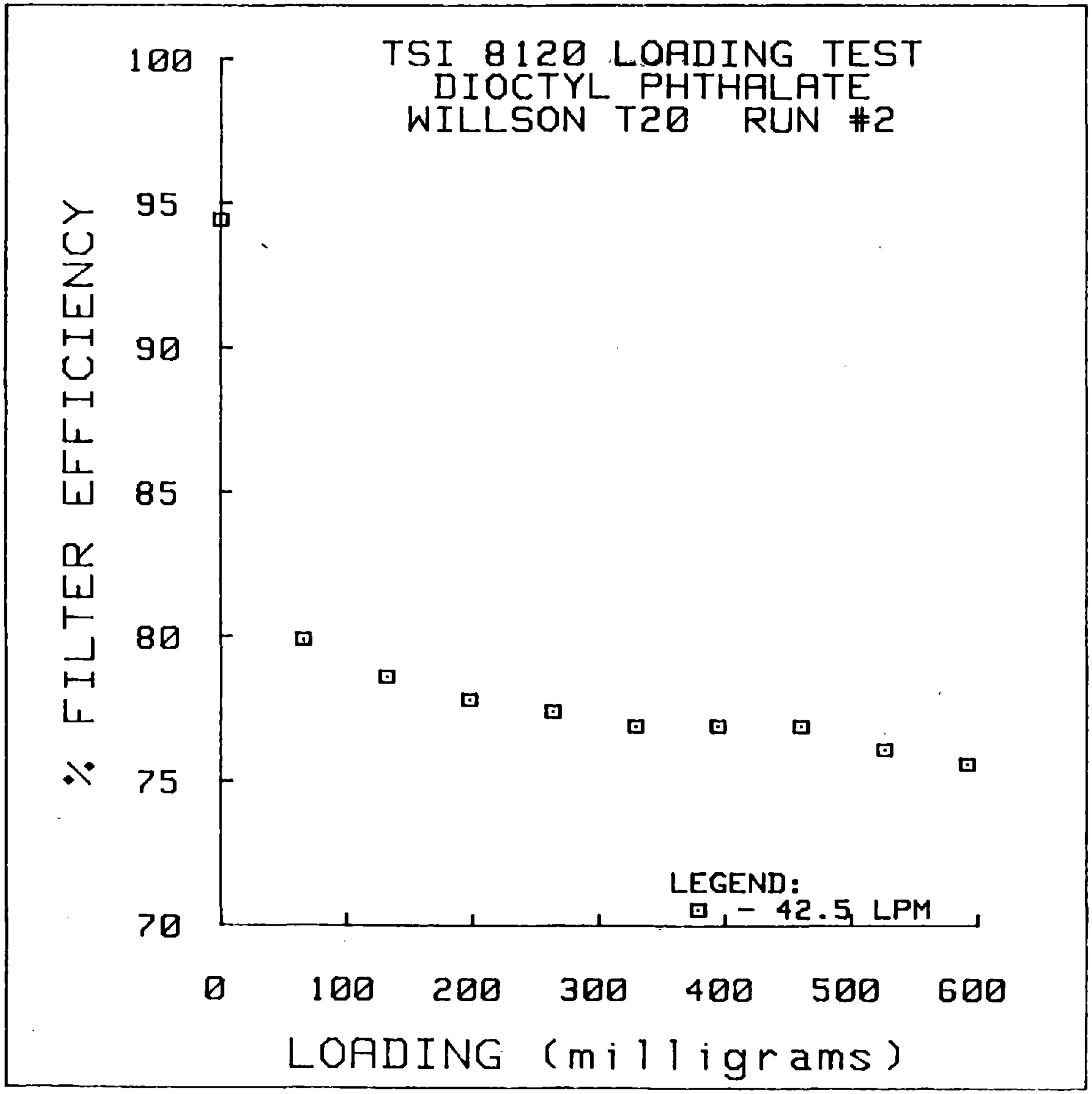
Figure 30



TSI 8120 ART W/DOP WILLSON T20 #1
DATA FOR 42.5 LPM

0	93.64
65.7013	81.2
131.4026	79.9
197.1039	79.6
262.8052	78.6
328.5065	78.4
394.2077	78.2
459.909	78.3
525.6103	78.3
591.3116	77.7

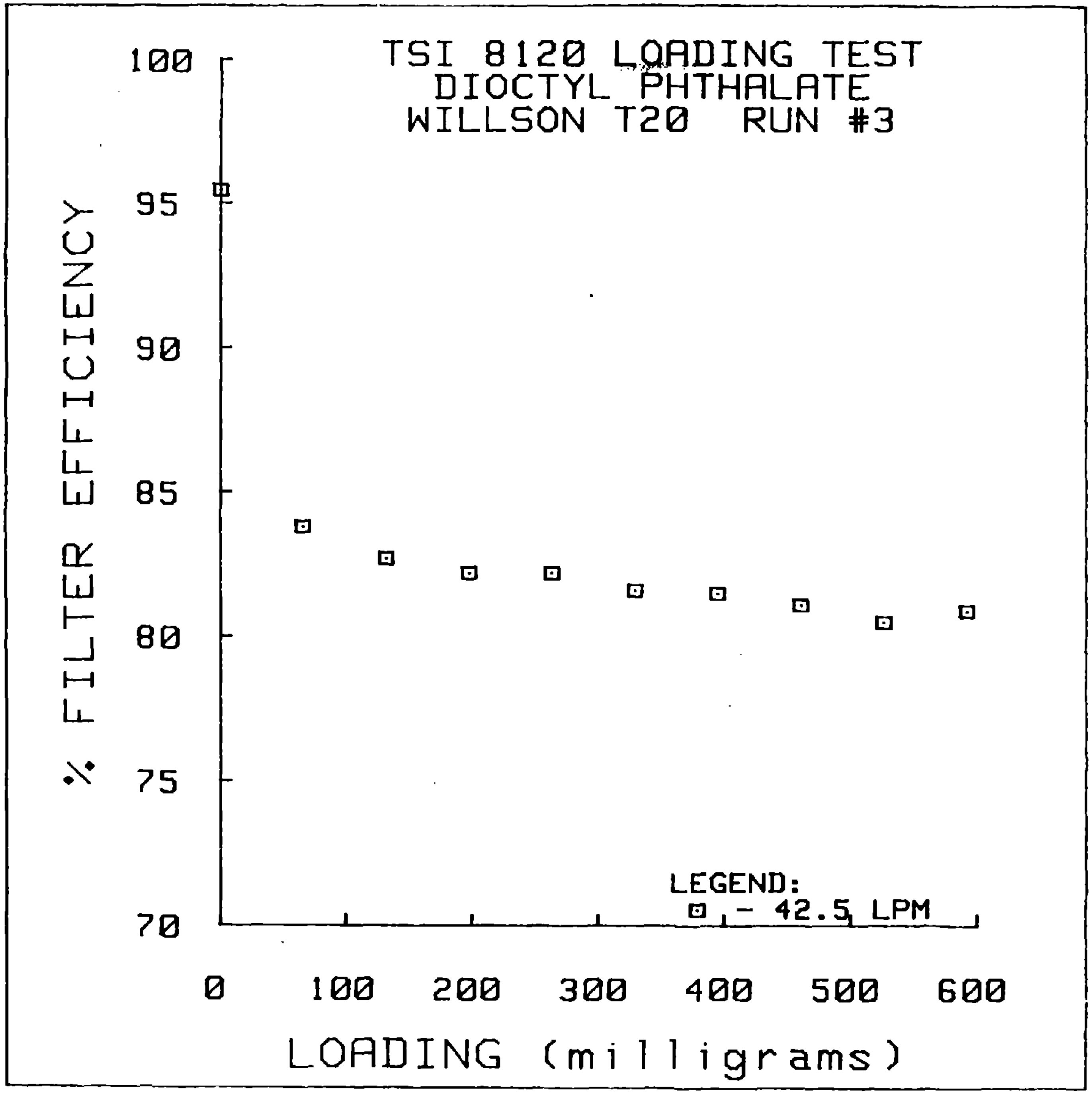
Figure 31



TSI 8120 ART W/DOP WILLSON T20 #2
DATA FOR 42.5 LPM

0	94.41
65.7013	79.9
131.4026	78.6
197.1039	77.8
262.8052	77.4
328.5065	76.9
394.2077	76.9
459.909	76.9
525.6103	76.1
591.3116	75.6

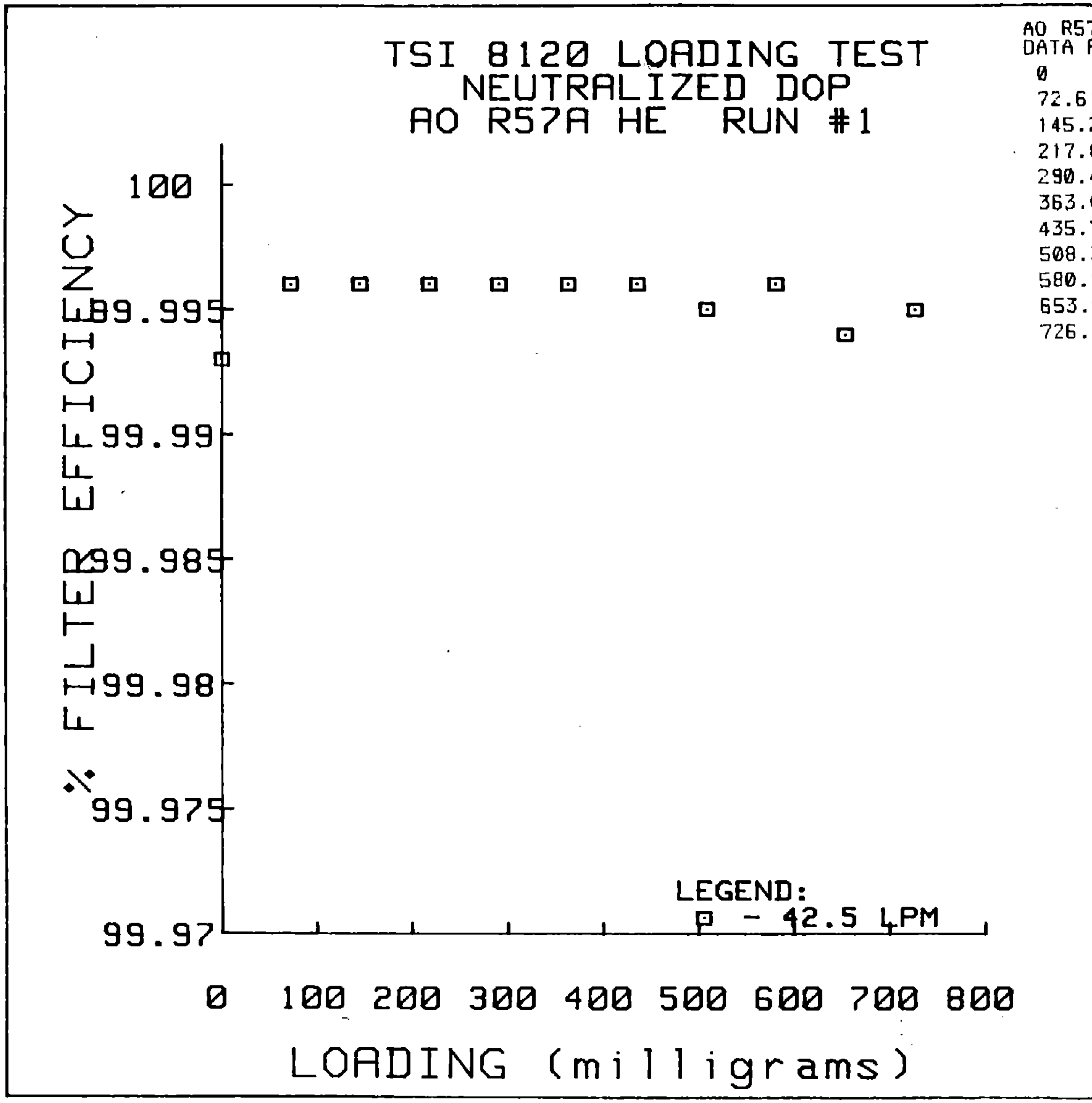
Figure 32



TSI 8120 ART W/DOP WILLSON T20 #3
DATA FOR 42.5 LPM

0	95.44
65.7013	83.8
131.4026	82.7
197.1039	82.2
262.8052	82.2
328.5065	81.6
394.2077	81.5
459.909	81.1
525.6103	80.5
591.3116	80.9

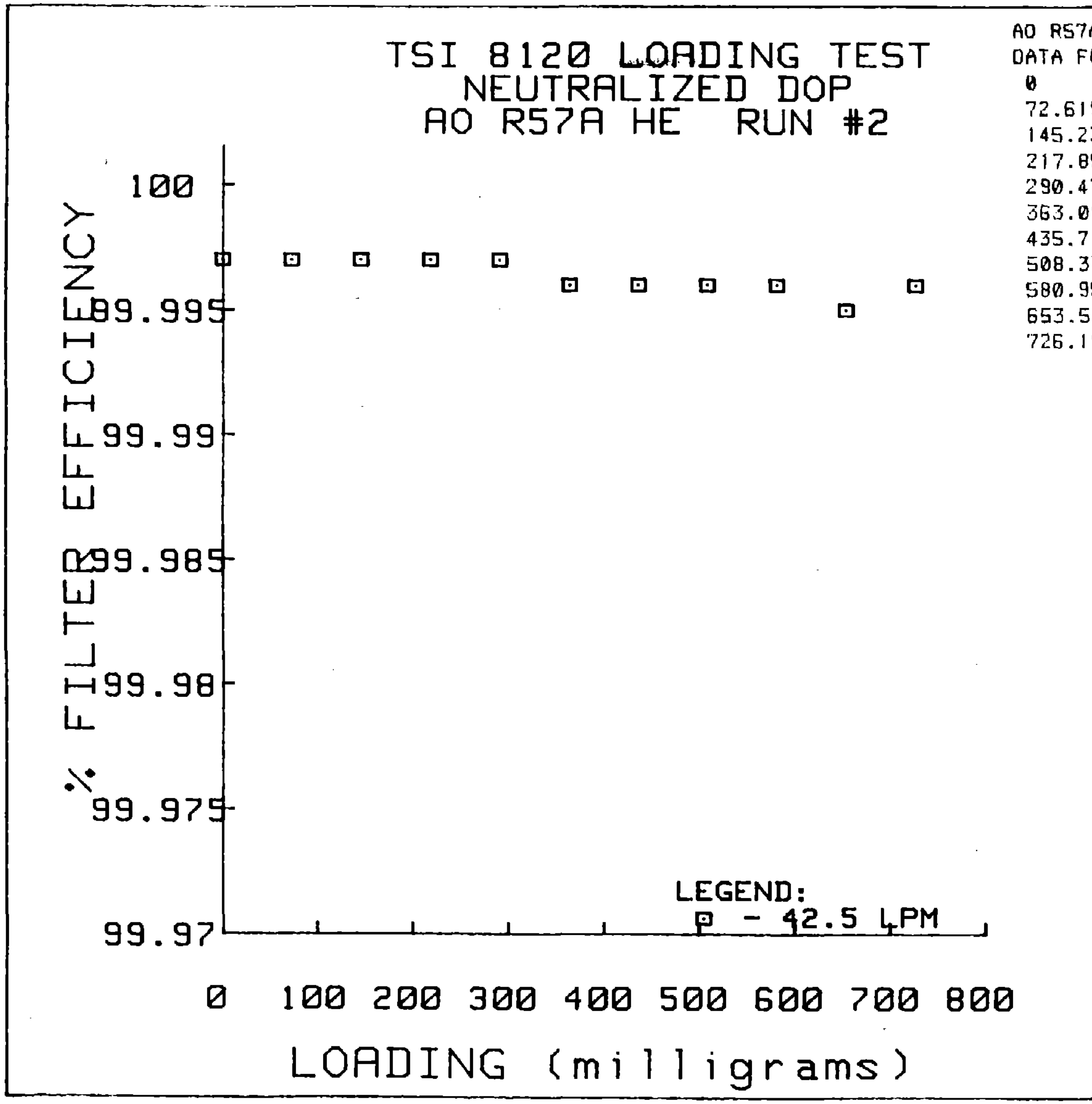
Figure 33



AO R57A HI CONC DOP RUN#1 8120 WITH NEUTRALZ
DATA FOR 42.5 LPM

0	99.993
72.6198	99.996
145.2395	99.996
217.8593	99.996
290.479	99.996
363.0988	99.996
435.7185	99.996
508.3383	99.995
580.958	99.996
653.5778	99.994
726.1975	99.995

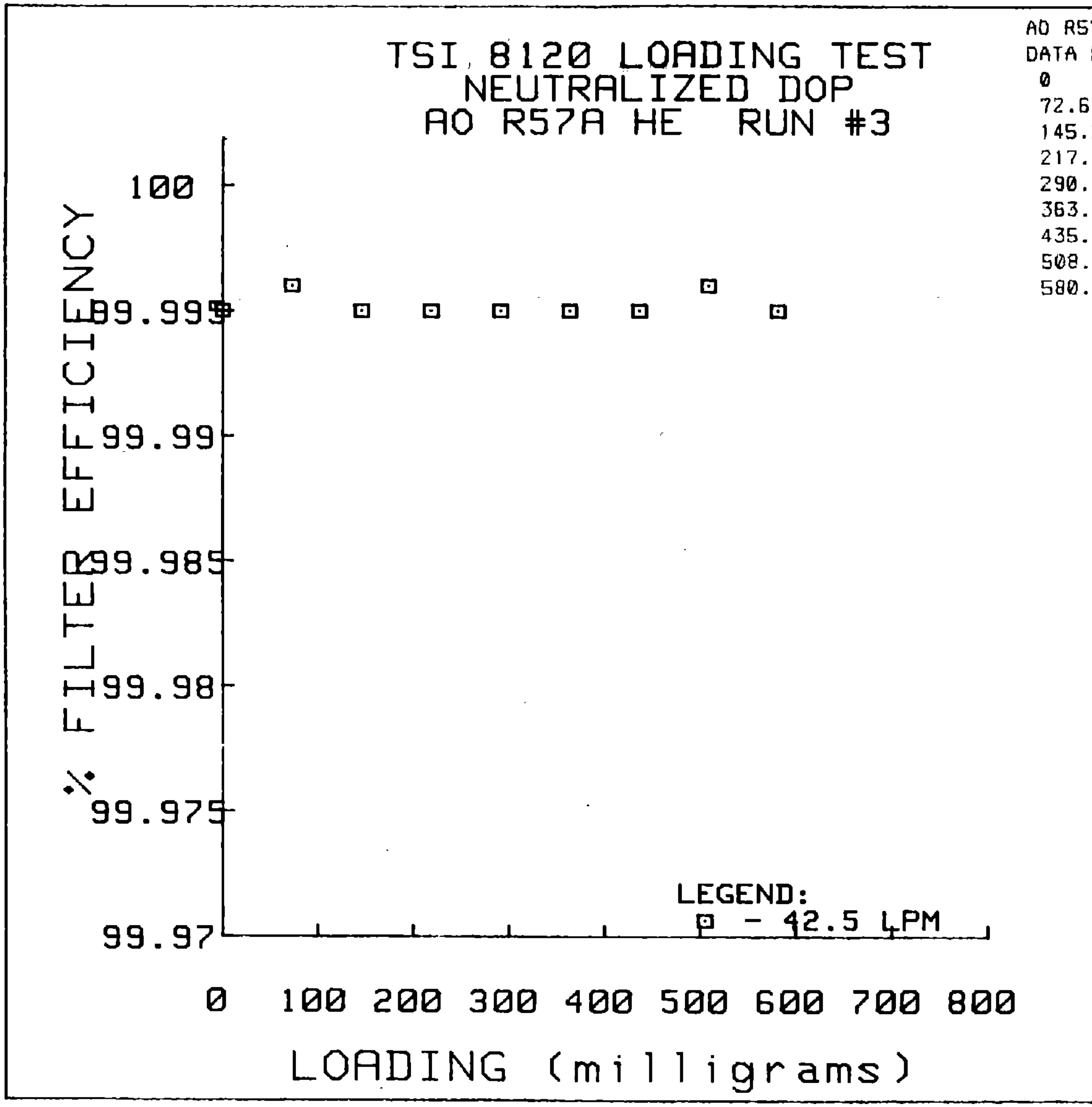
Figure 34



AO R57A HI CONC DOP RUN#2 8120 WITH NEUTRALZ
DATA FOR 42.5 LPM

0	99.997
72.6198	99.997
145.2395	99.997
217.8593	99.997
290.479	99.997
363.0988	99.996
435.7185	99.996
508.3383	99.996
580.958	99.996
653.5778	99.995
726.1975	99.996

Figure 35

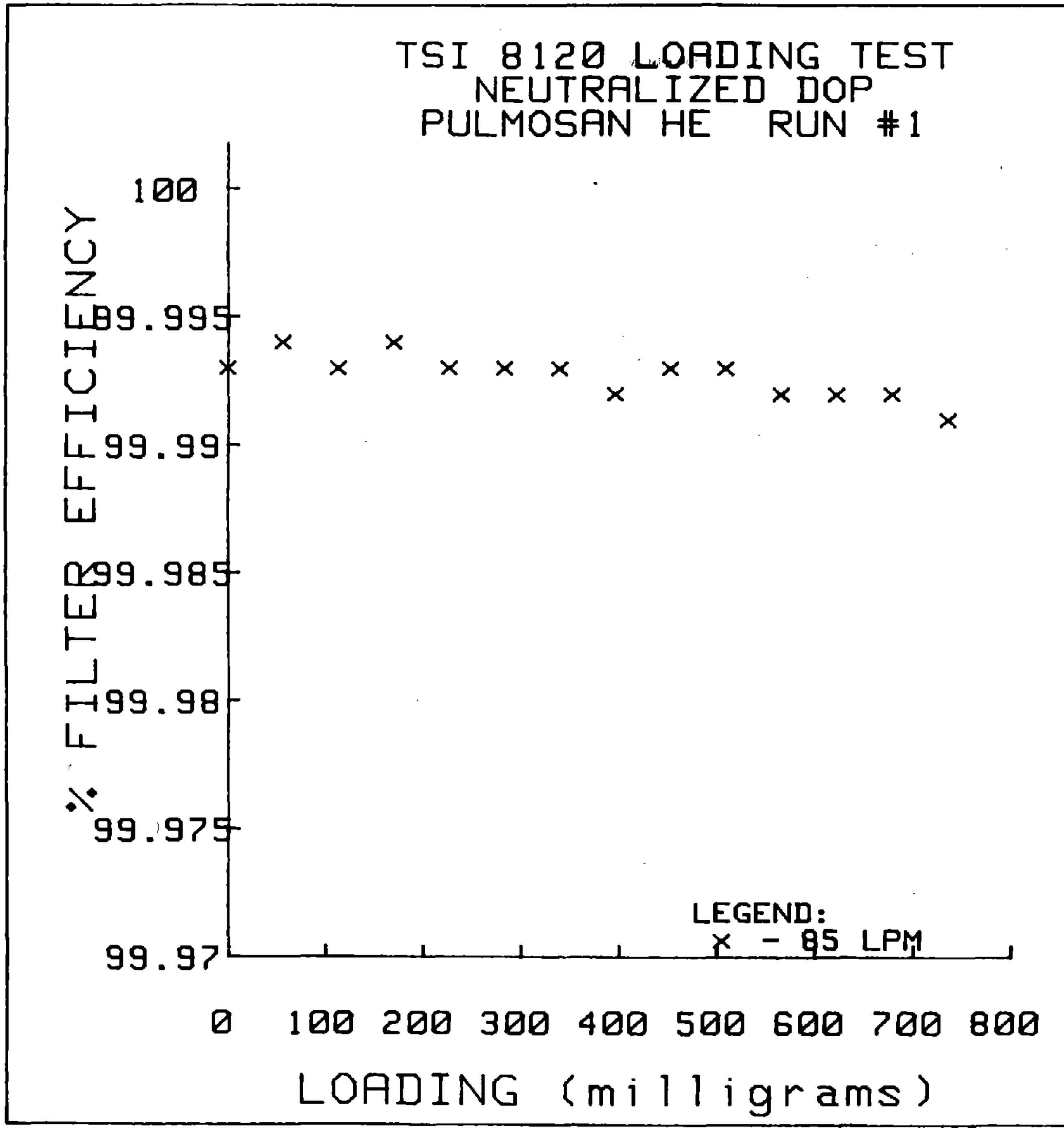


AO R57A HI CONC DOP RUN#3 8120 WITH NEUTRALZ

DATA FOR 42.5 LPM

0	99.995
72.6198	99.996
145.2395	99.995
217.8593	99.995
290.479	99.995
363.0988	99.995
435.7185	99.995
508.3383	99.996
580.958	99.995

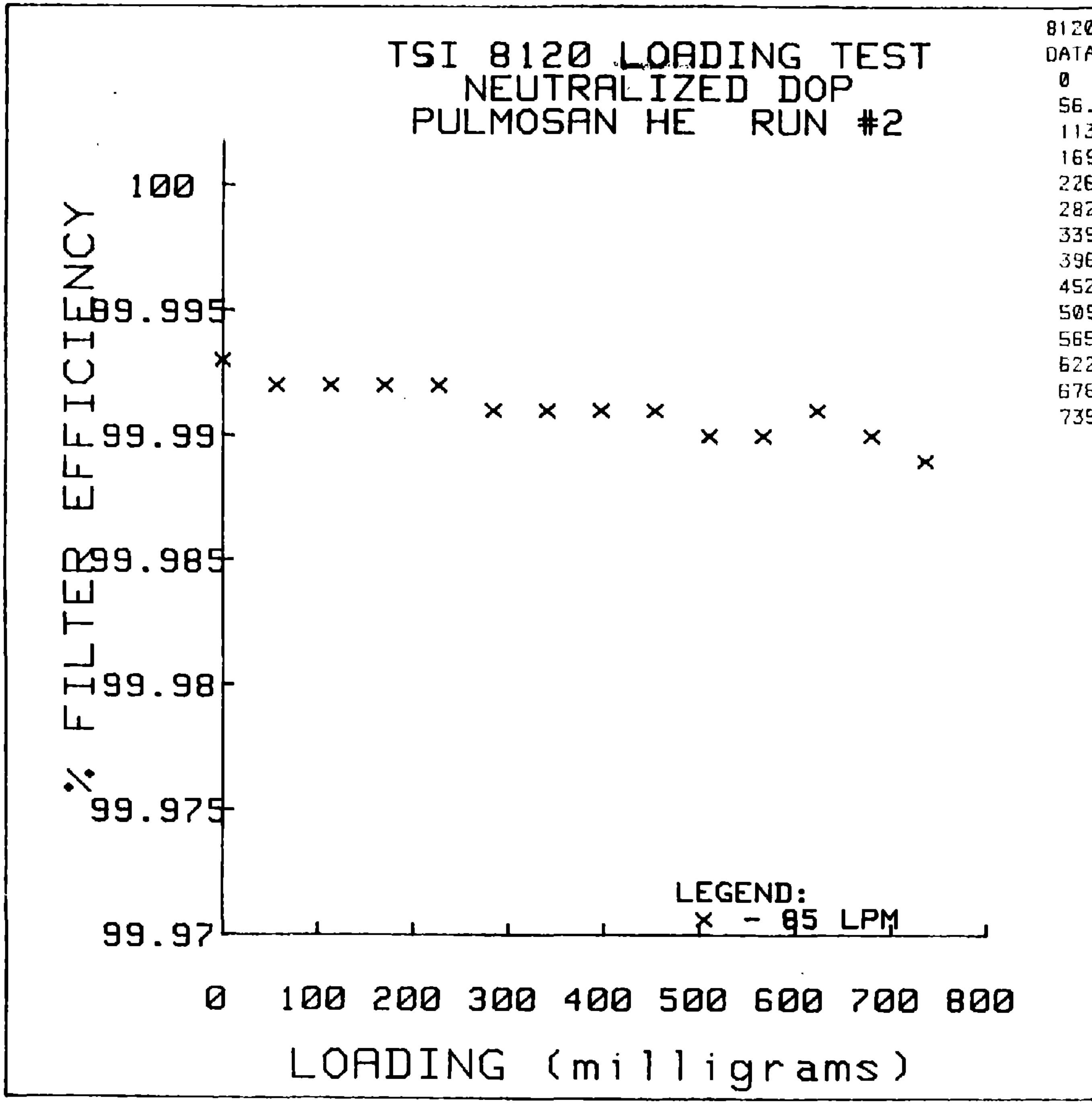
Figure 36



8120 W/ NEUTRIZER DOP LOAD TEST PULMOSAN #1
DATA FOR 85 LPM

0	99.993
56.572	99.994
113.144	99.993
169.716	99.994
226.288	99.993
282.86	99.993
339.432	99.993
396.004	99.992
452.576	99.993
509.148	99.993
565.72	99.992
622.292	99.992
678.864	99.992
735.436	99.991

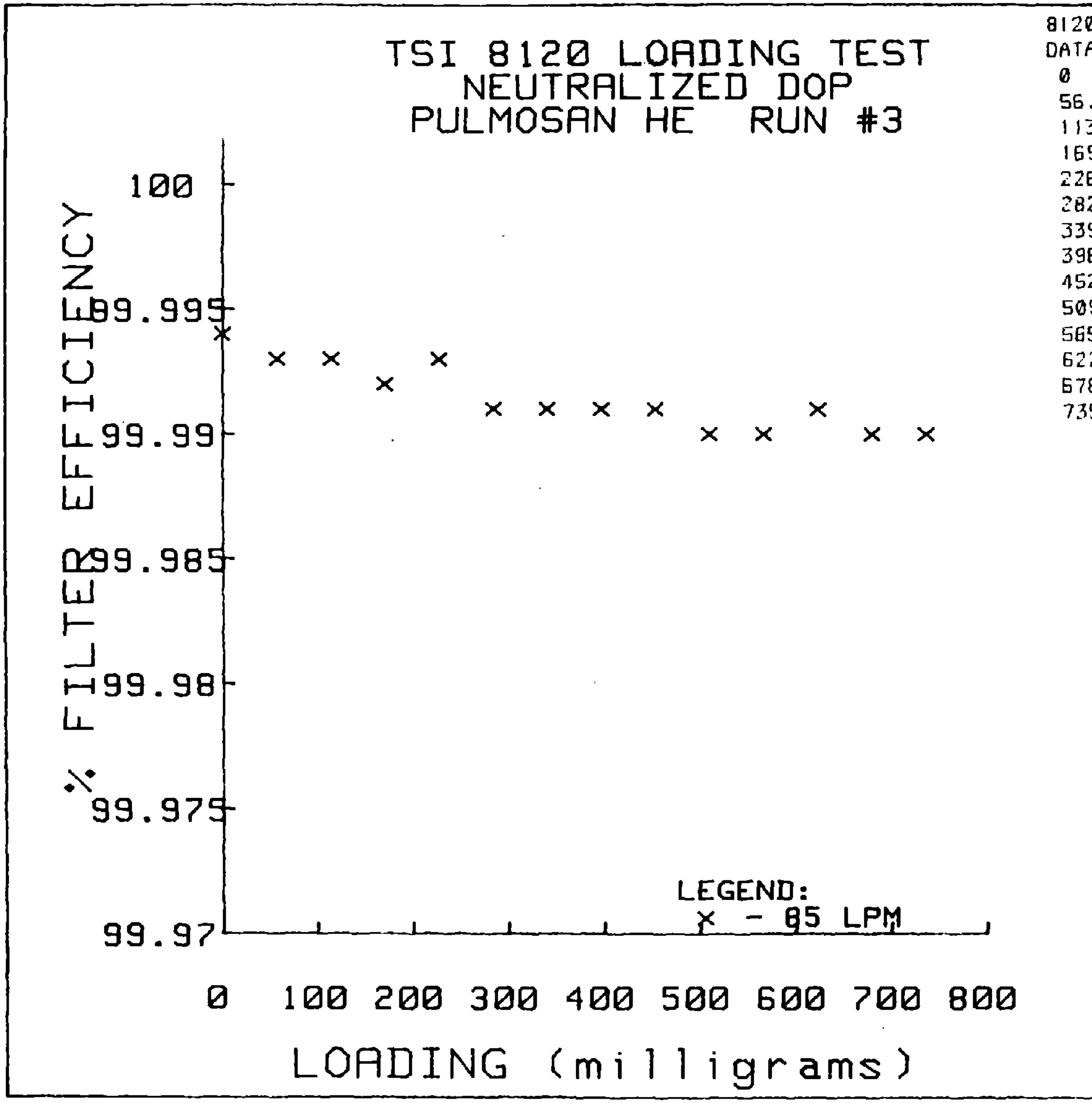
Figure 37



8120 W/ NEUTRIZER DOP LOAD TEST PULMOSAN #2
DATA FOR 85 LPM

0	99.993
56.572	99.992
113.144	99.992
169.716	99.992
226.288	99.992
282.86	99.991
339.432	99.991
396.004	99.991
452.576	99.991
509.148	99.99
565.72	99.99
622.292	99.991
678.864	99.99
735.436	99.989

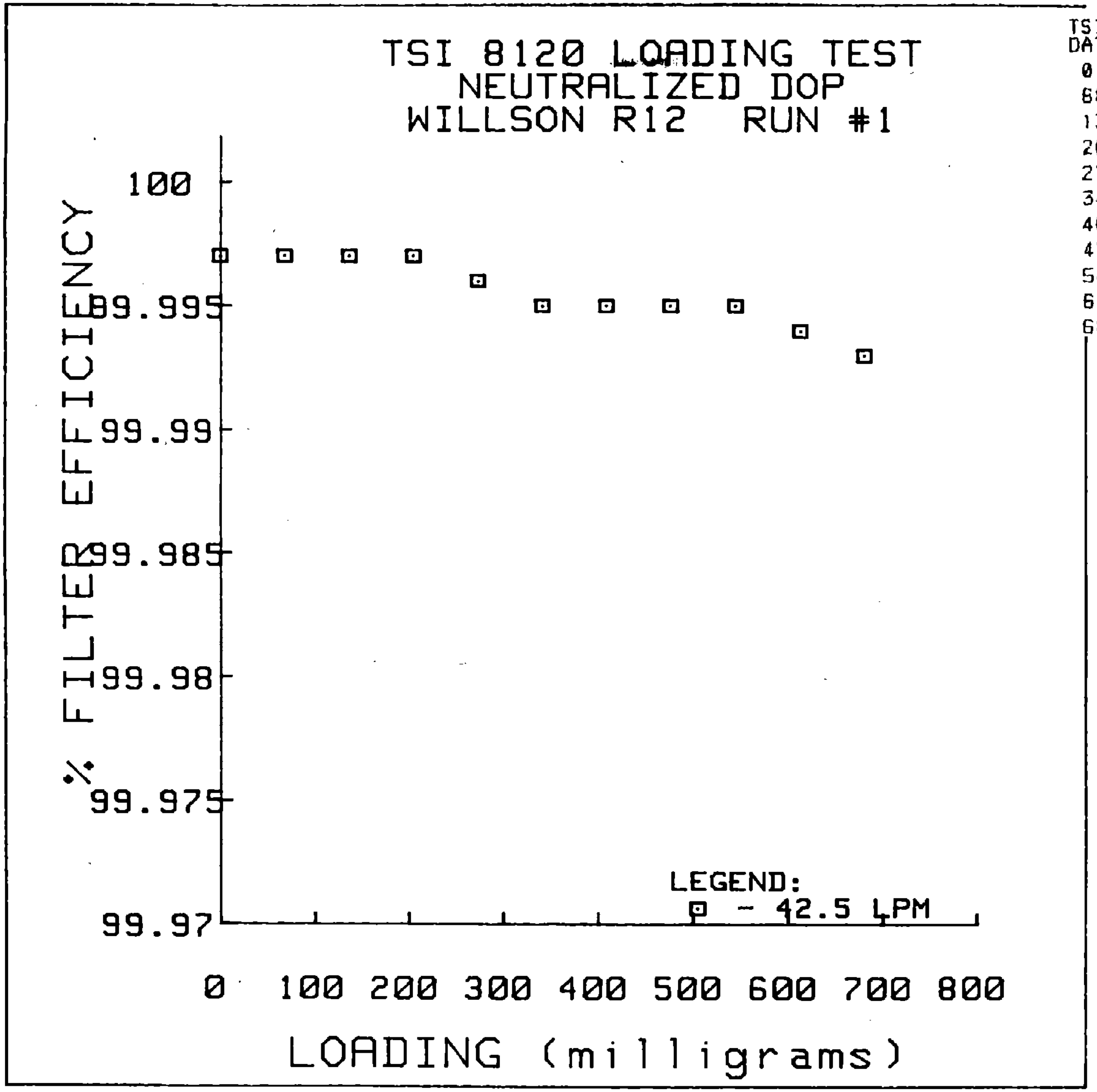
Figure 38



8120 W/ NEUTRIZER DOP LOAD TEST PULMOSAN #3
DATA FOR 85 LPM

0	99.994
56.572	99.993
113.144	99.993
169.716	99.992
226.288	99.993
282.86	99.991
339.432	99.991
396.004	99.991
452.576	99.991
509.148	99.99
565.72	99.99
622.292	99.991
678.864	99.99
735.436	99.99

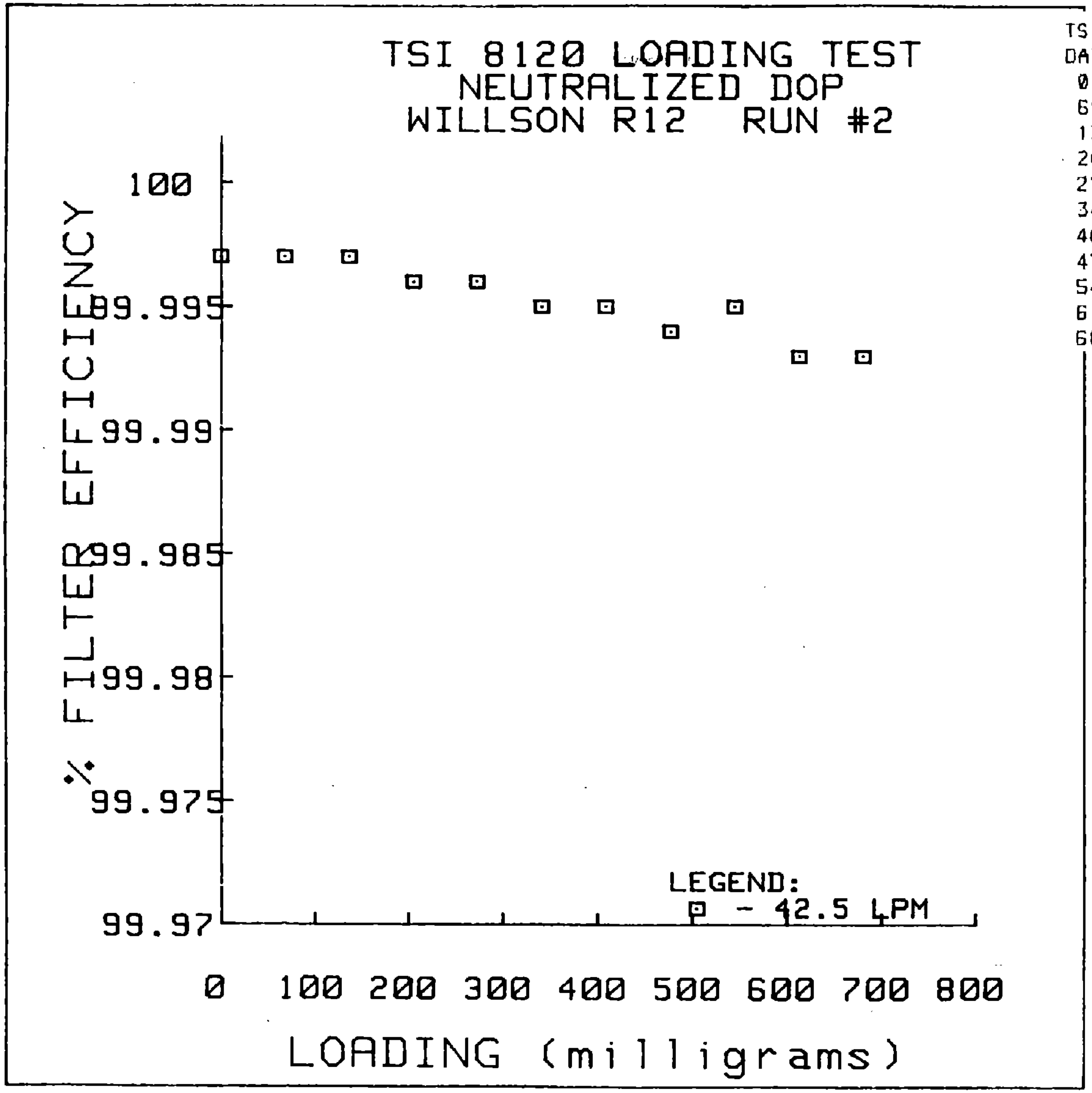
Figure 39



TSI 8120 ART W/ NEUTRALZR WILLSON R12 #1
DATA FOR 42.5 LPM

0	99.997
68.0293	99.997
136.0587	99.997
204.088	99.997
272.1174	99.996
340.1467	99.995
408.1761	99.995
476.2054	99.995
544.2348	99.995
612.2641	99.994
680.2935	99.993

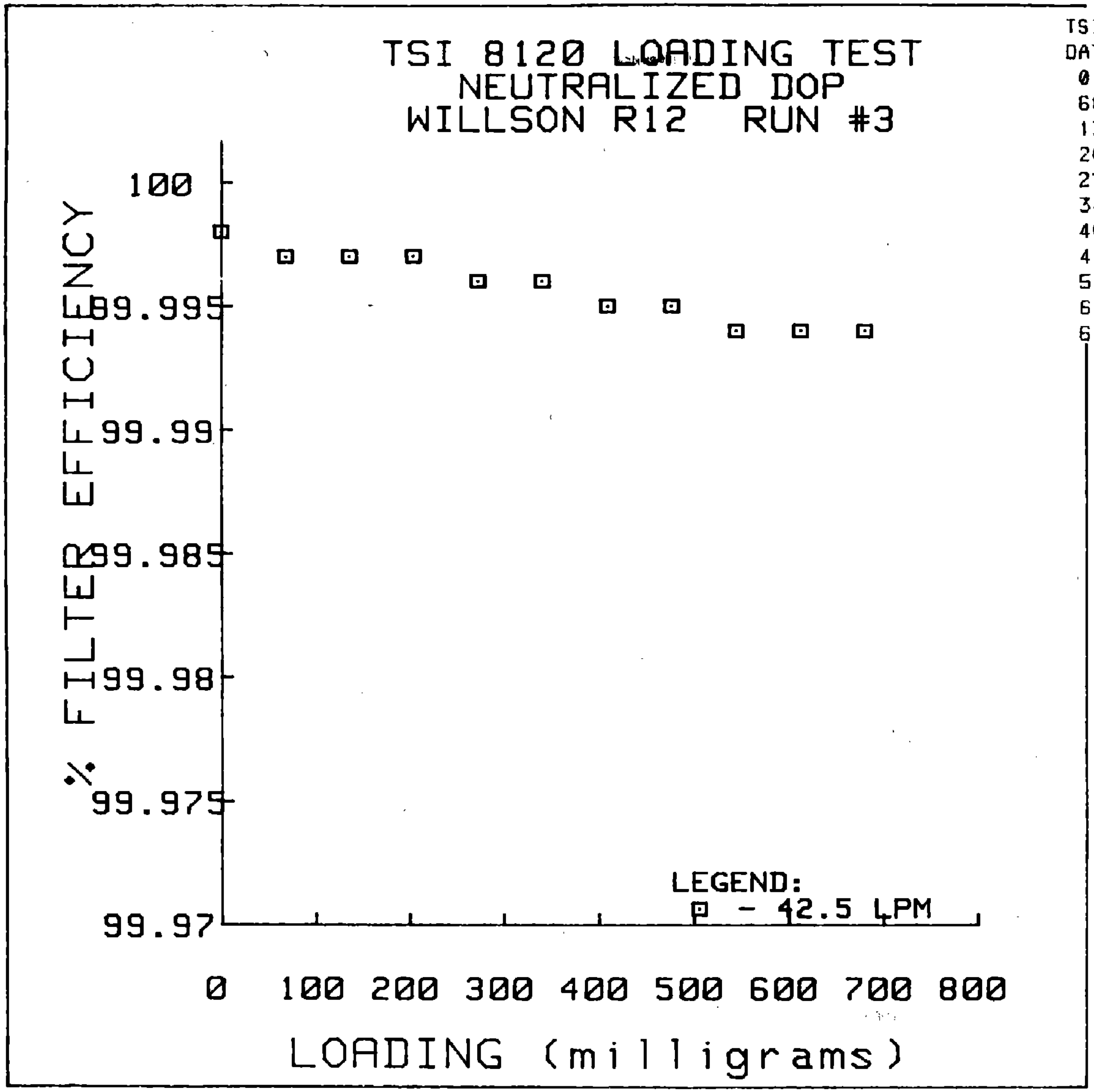
Figure 40



TSI 8120 ART W/ NEUTRALZR WILLSON R12 #2
DATA FOR 42.5 LPM

0	99.997
68.0293	99.997
136.0587	99.997
204.088	99.996
272.1174	99.996
340.1467	99.995
408.1761	99.995
476.2054	99.994
544.2348	99.995
612.2641	99.993
680.2935	99.993

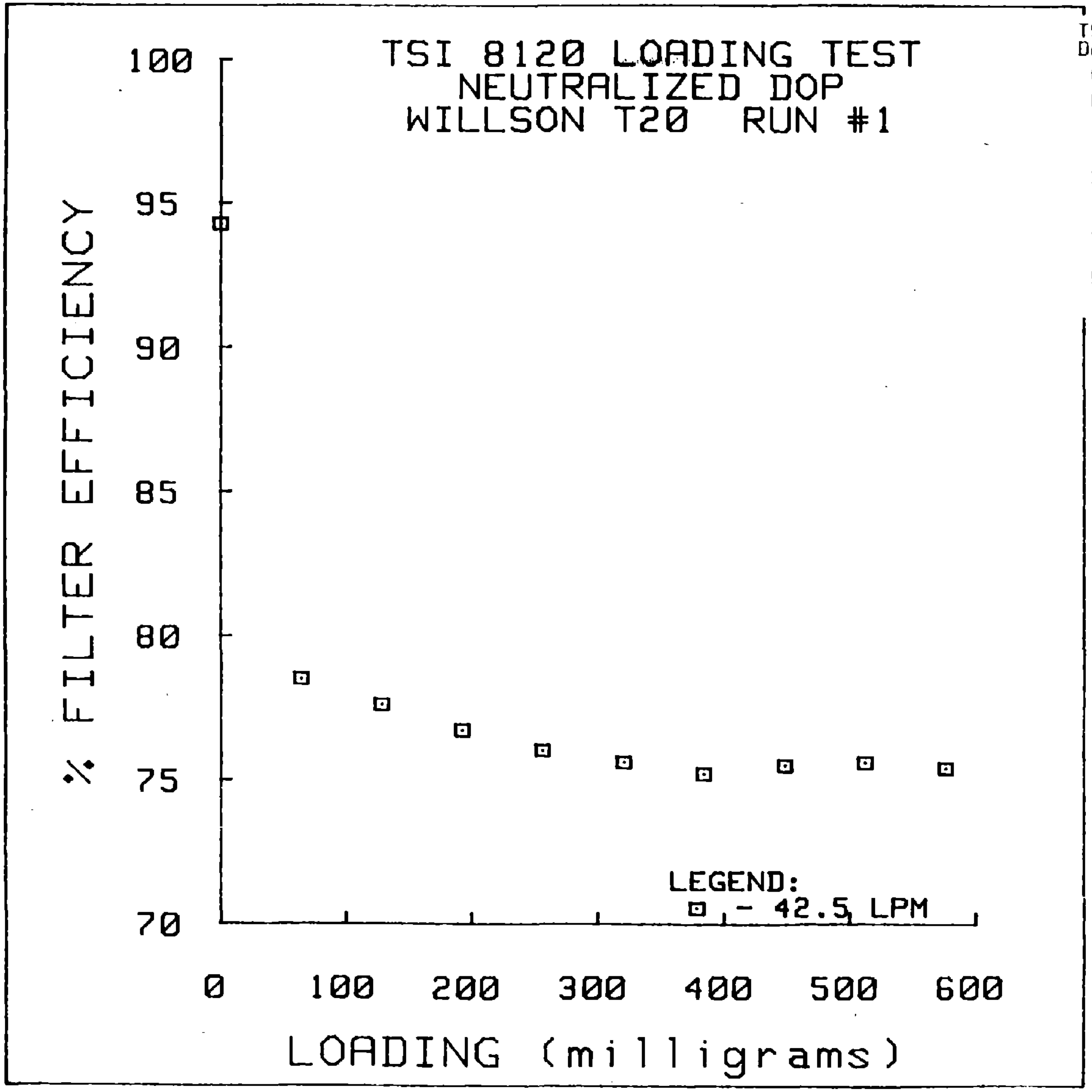
Figure 41



TSI 8120 ART W/ NEUTRALZR WILLSON R12 #3
DATA FOR 42.5 LPM

0	99.998
68.0293	99.997
136.0587	99.997
204.088	99.997
272.1174	99.996
340.1467	99.996
408.1764	99.995
476.2054	99.995
544.2348	99.994
612.2641	99.994
680.2935	99.994

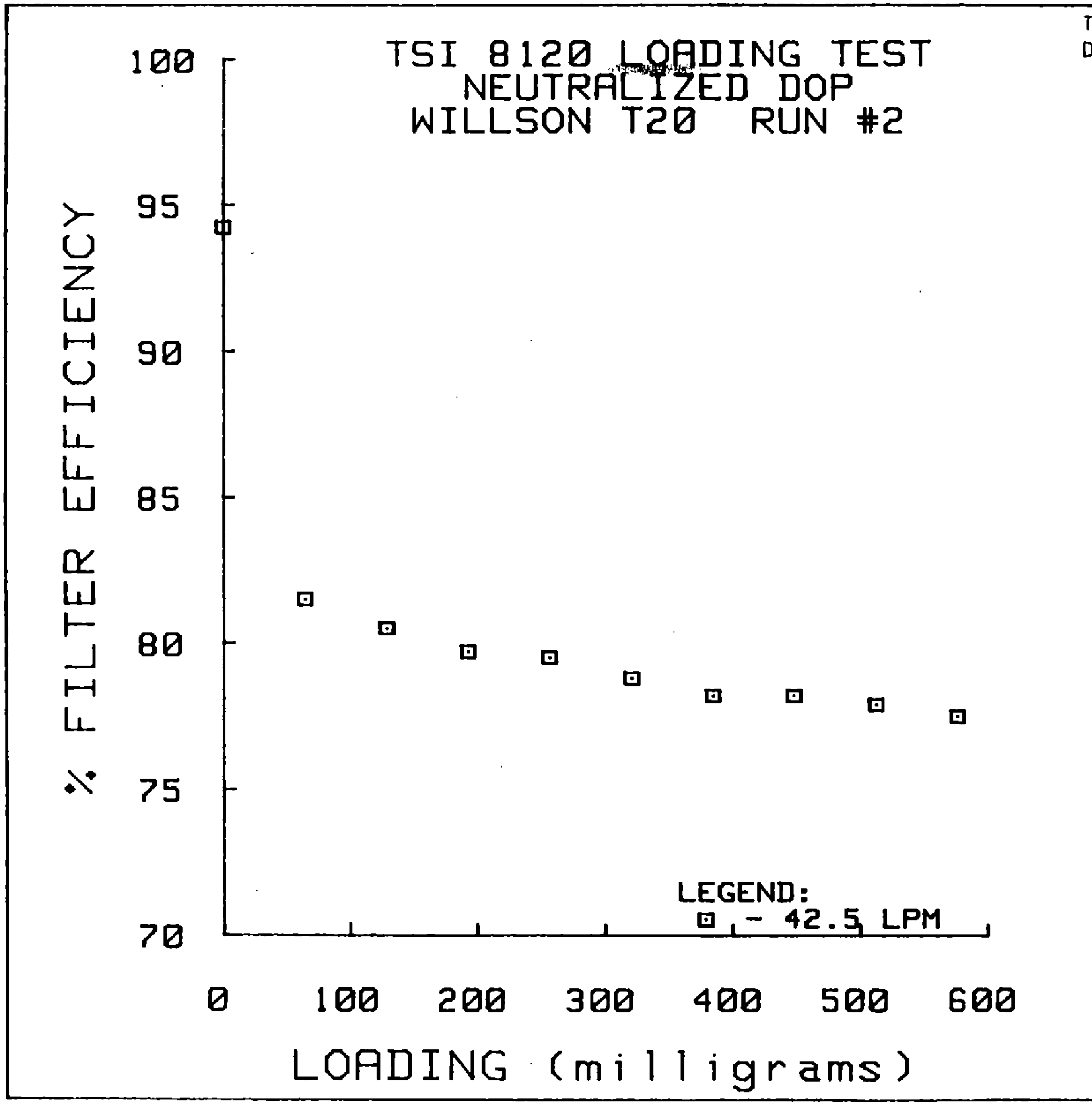
Figure 42



TSI 8120 ART W/DOP & NEUT WILLSON T20 #
DATA FOR 42.5 LPM

0	94.26
64.0222	78.5
128.0444	77.6
192.0665	76.7
256.0887	76
320.1109	75.6
384.1331	75.2
448.1552	75.5
512.1774	75.6
576.1996	75.4

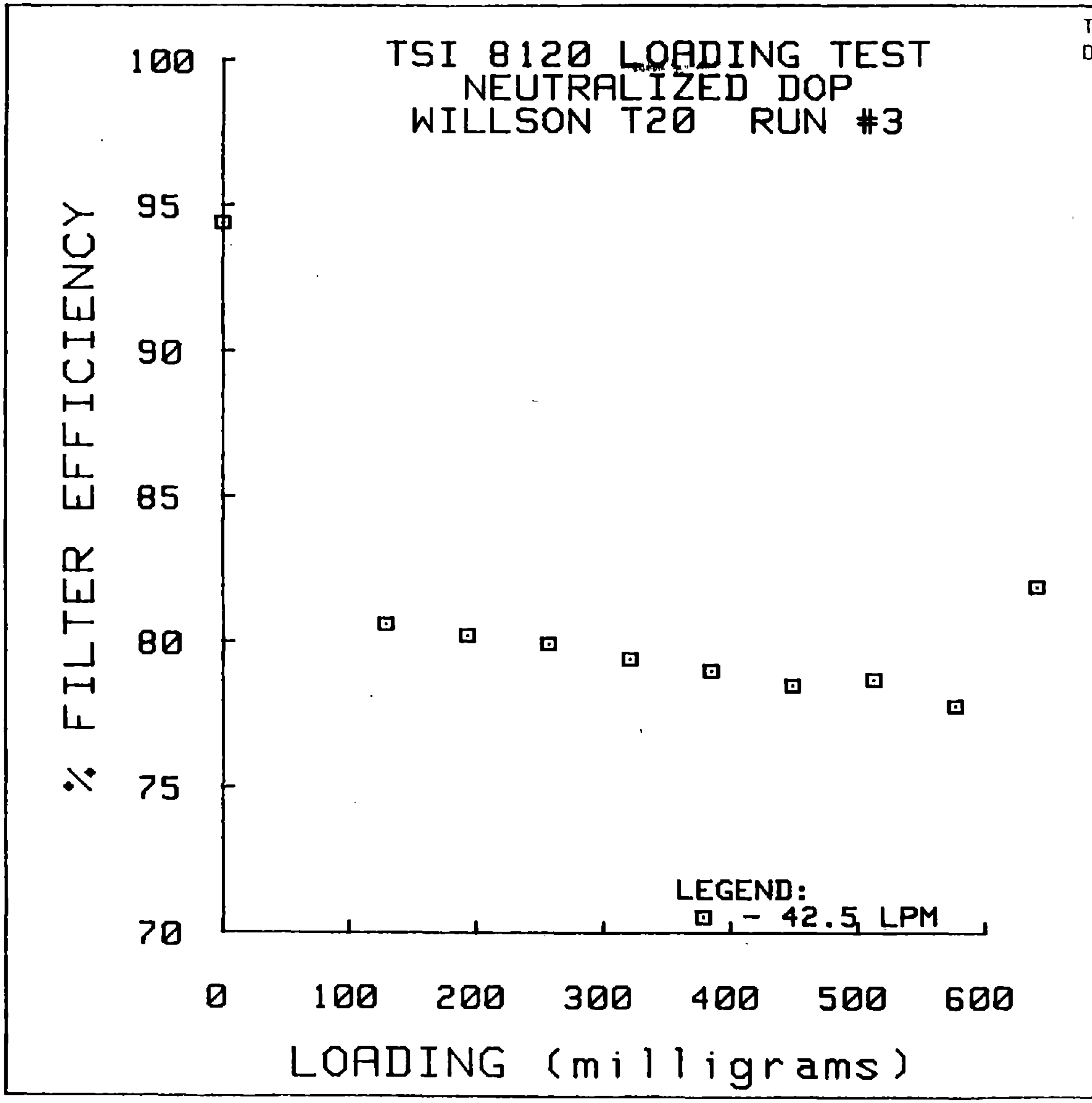
Figure 43



TSI 8120 ART W/DOP & NEUT WILLSON T20 #
DATA FOR 42.5 LPM

0	94.22
64.0222	81.5
128.0444	80.5
192.0665	79.7
256.0887	79.5
320.1109	78.8
384.1331	78.2
448.1552	78.2
512.1774	77.9
576.1996	77.5

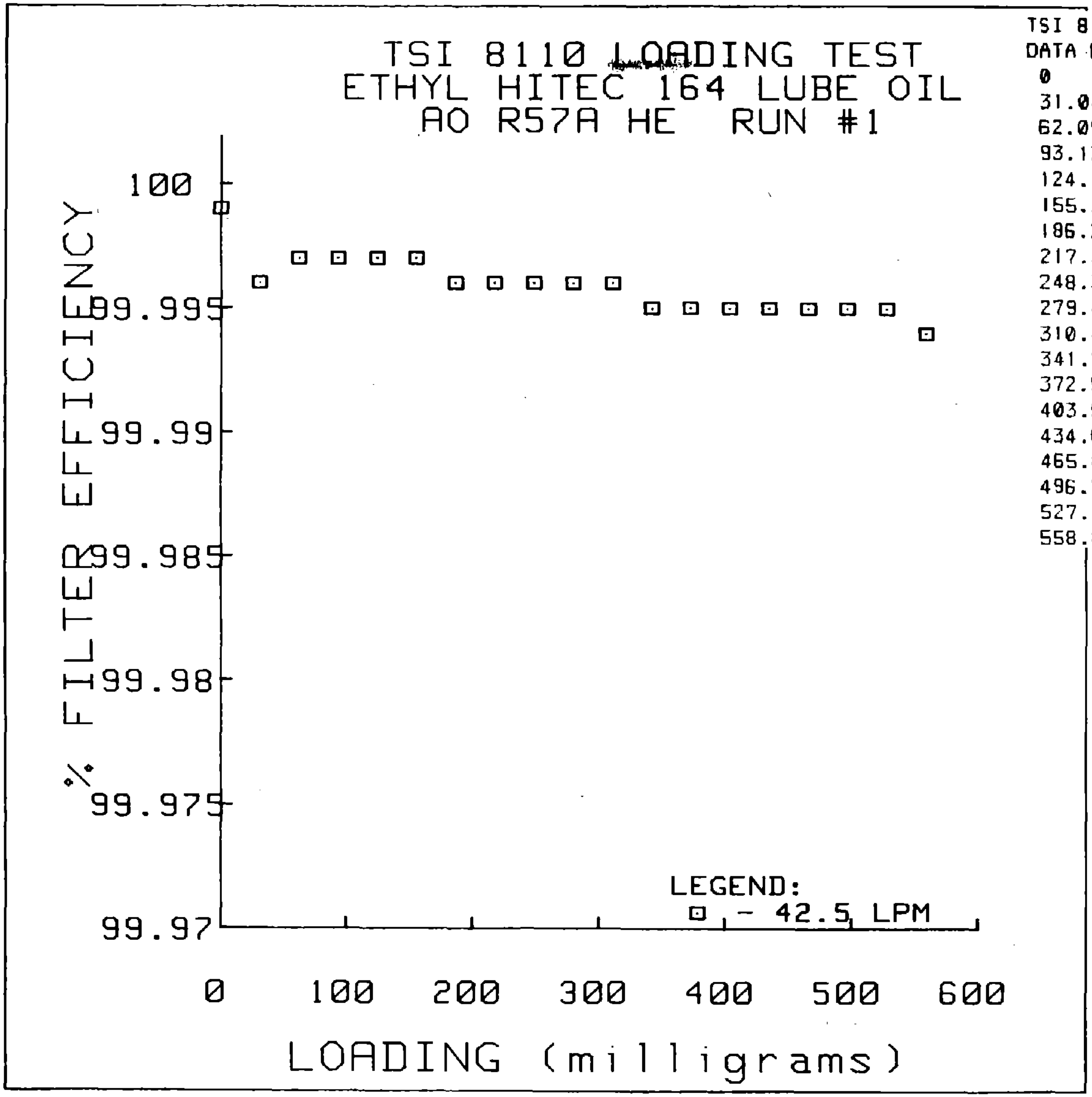
Figure 44



TSI 8120 ART W/DOP & NEUT WILLSON T20 #3
DATA FOR 42.5 LPM

0	94.38
128.0444	80.6
192.0665	80.2
256.0887	79.9
320.1109	79.4
384.1331	79
448.1552	78.5
512.1774	78.7
576.1996	77.8
640.0222	81.9

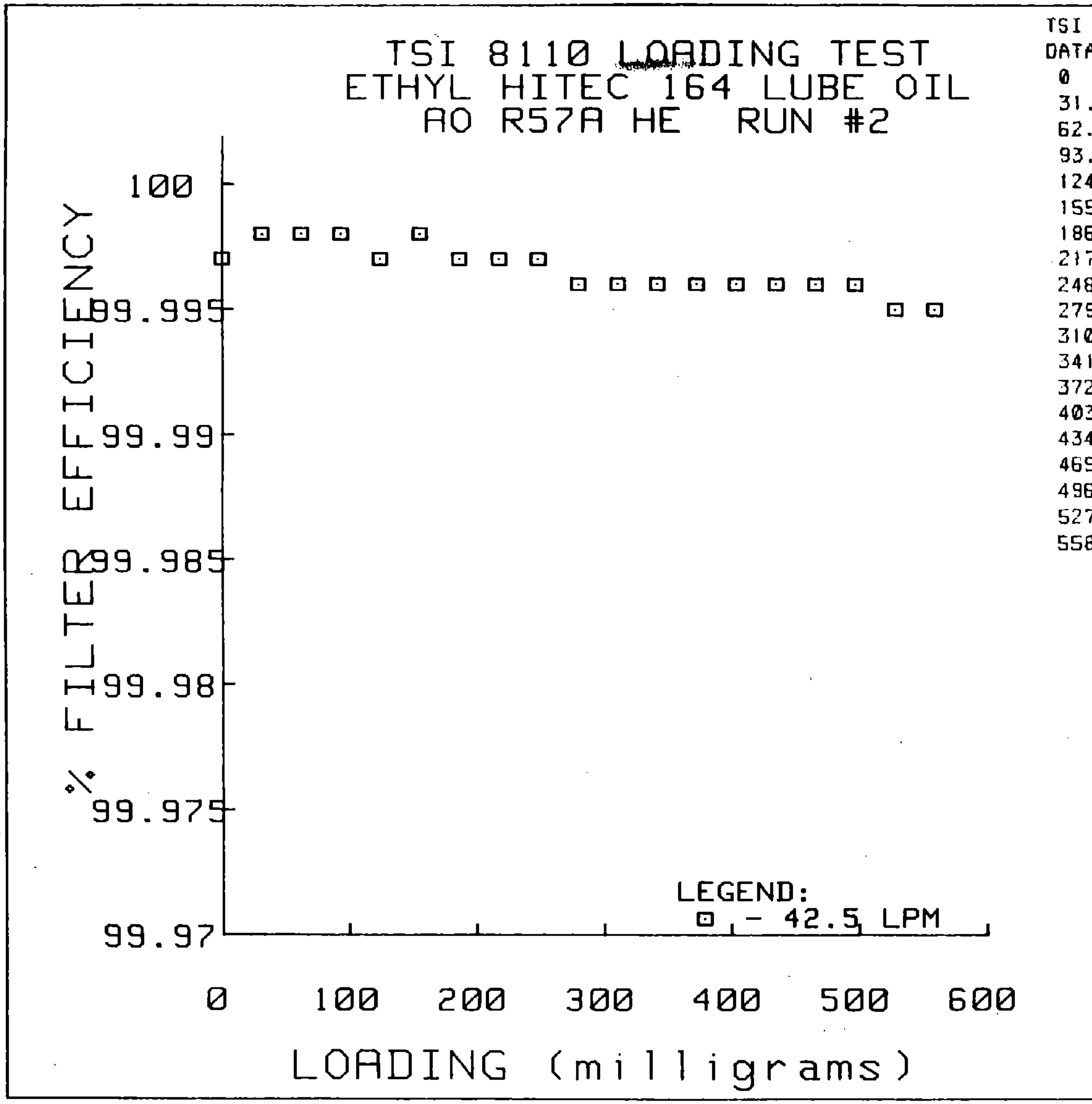
Figure 45



TSI 8110 AFT ETHYL 164 LUBE OIL AO R57A #1
DATA FOR 42.5 LPM

0	99.999
31.0459	99.996
62.0918	99.997
93.1376	99.997
124.1835	99.997
155.2294	99.997
186.2753	99.996
217.3212	99.996
248.367	99.996
279.4129	99.996
310.4588	99.996
341.5047	99.995
372.5506	99.995
403.5964	99.995
434.6423	99.995
465.6882	99.995
496.7341	99.995
527.78	99.995
558.8258	99.994

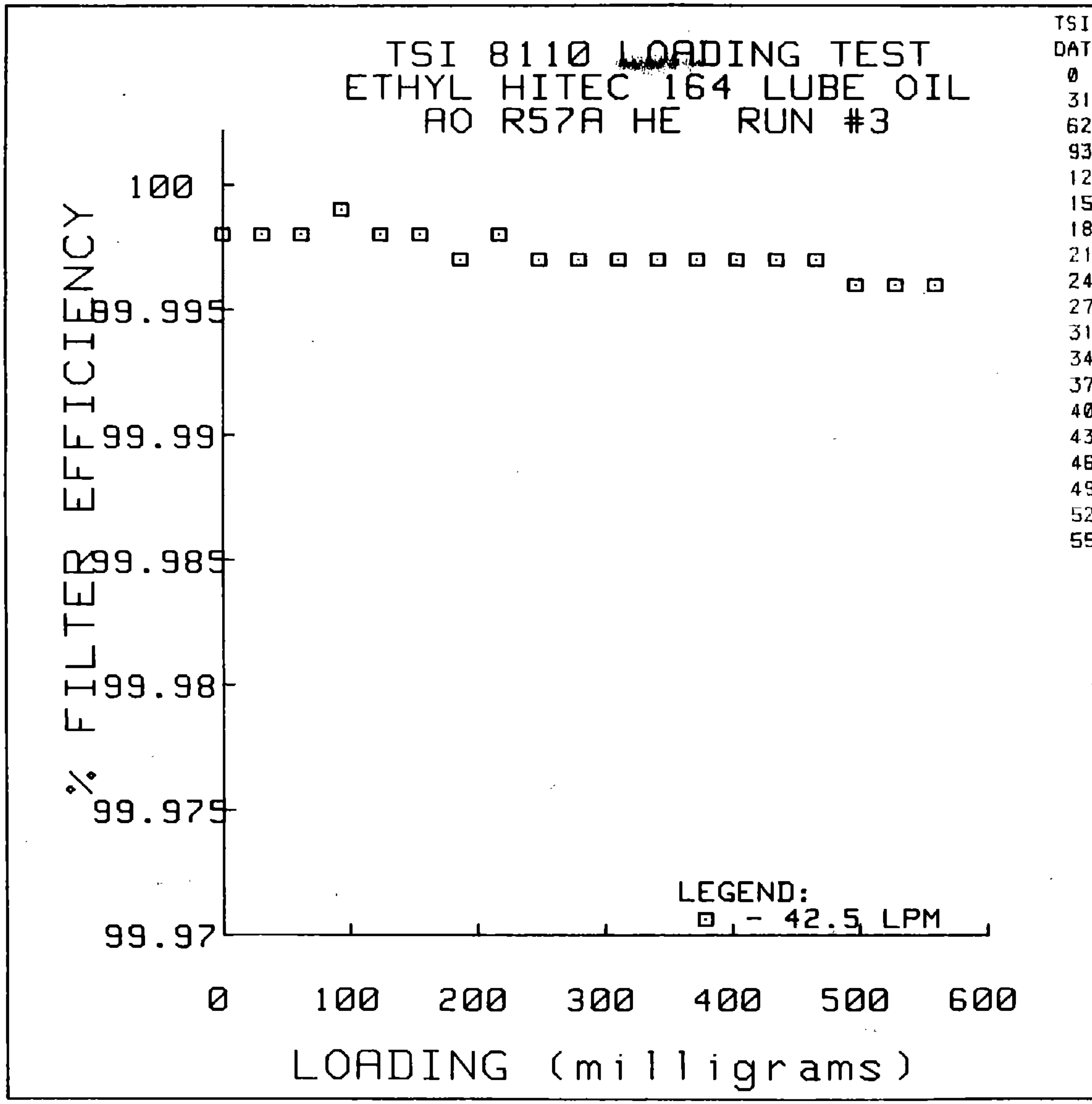
Figure 46



TSI 8110 AFT ETHYL 164 LUBE OIL AO R57A #2
DATA FOR 42.5 LPM

0	99.997
31.0459	99.998
62.0918	99.998
93.1376	99.998
124.1835	99.997
155.2294	99.998
186.2753	99.997
217.3212	99.997
248.367	99.997
279.4129	99.996
310.4588	99.996
341.5047	99.996
372.5506	99.996
403.5964	99.996
434.6423	99.996
465.6882	99.996
496.7341	99.996
527.78	99.995
558.8258	99.995

Figure 47

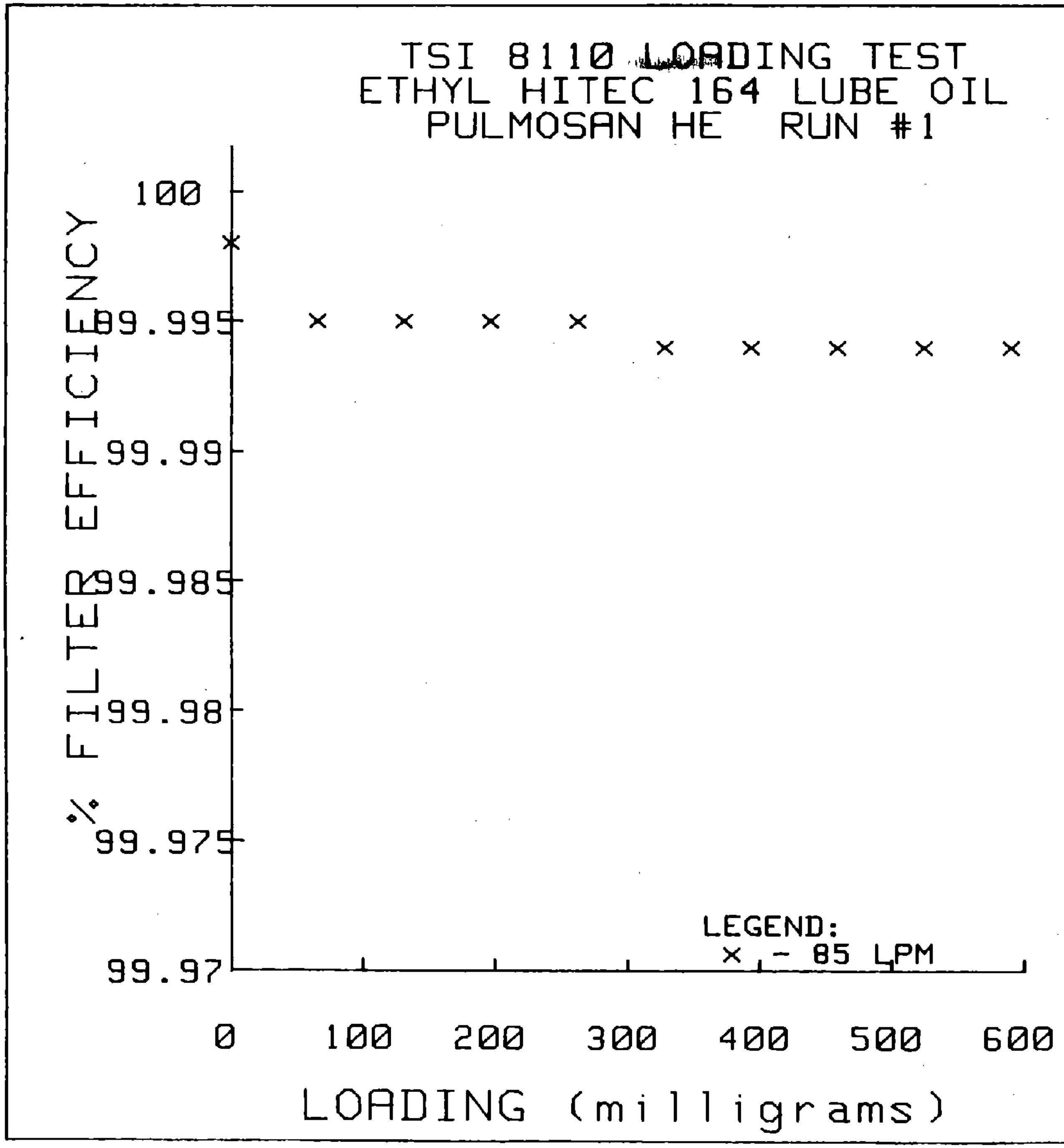


TSI 8110 AFT ETHYL 164 LUBE OIL AO R57A #

DATA FOR 42.5 LPM

0	99.998
31.0459	99.998
62.0918	99.998
93.1376	99.999
124.1825	99.998
155.2294	99.998
186.2753	99.997
217.3213	99.998
248.367	99.997
279.4129	99.997
310.4588	99.997
341.5047	99.997
372.5506	99.997
403.5964	99.997
434.6423	99.997
465.6882	99.997
496.7341	99.996
527.78	99.996
558.8258	99.996

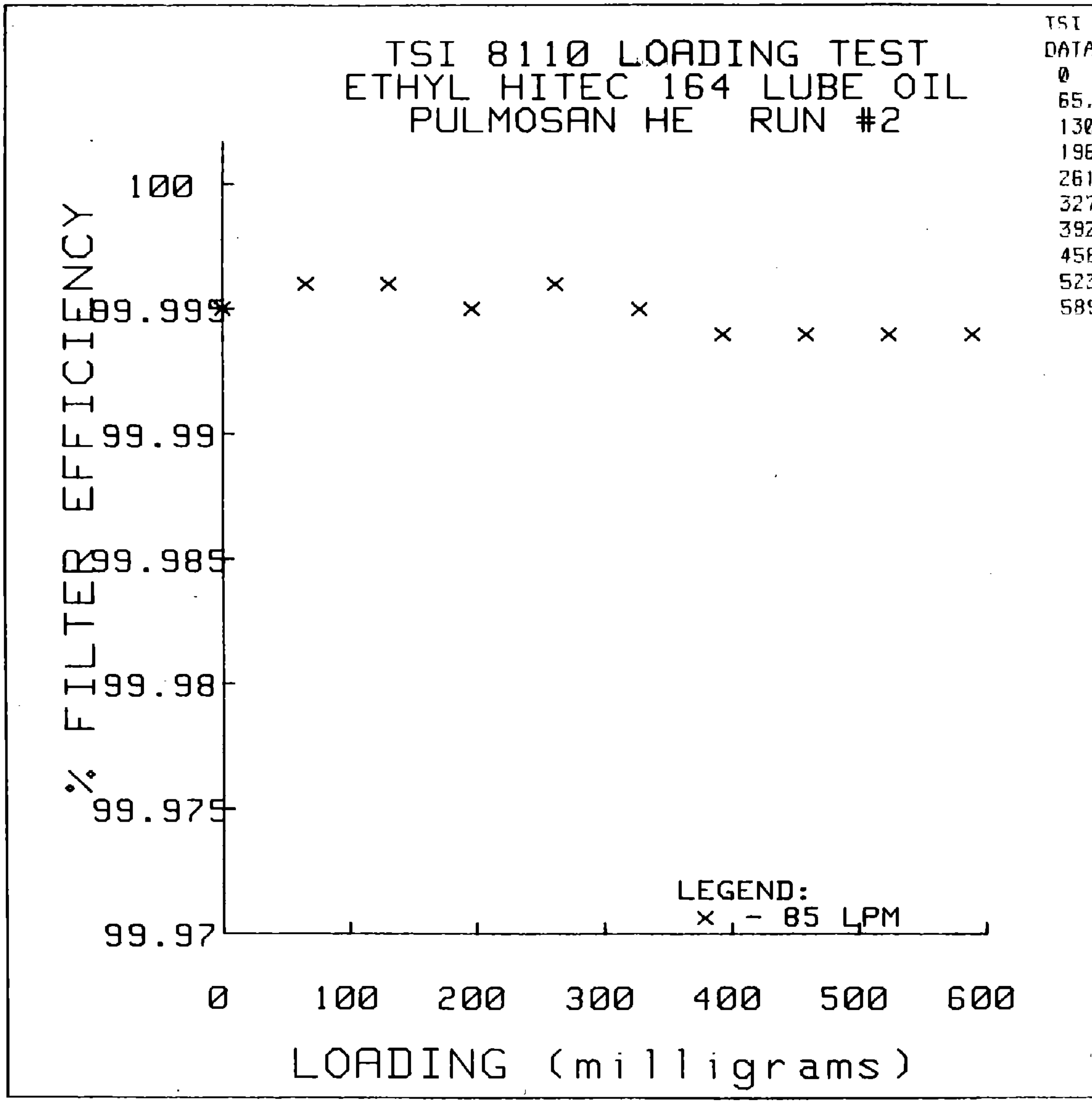
Figure 48



TSI 8110 ETHYL 164 LOADING TEST PULMOSAN #
DATA FOR 85 LPM

0	99.998
65.4937	99.995
130.9873	99.995
196.481	99.995
261.9747	99.895
327.4684	99.994
392.962	99.994
458.4557	99.994
523.9494	99.994
589.443	99.994

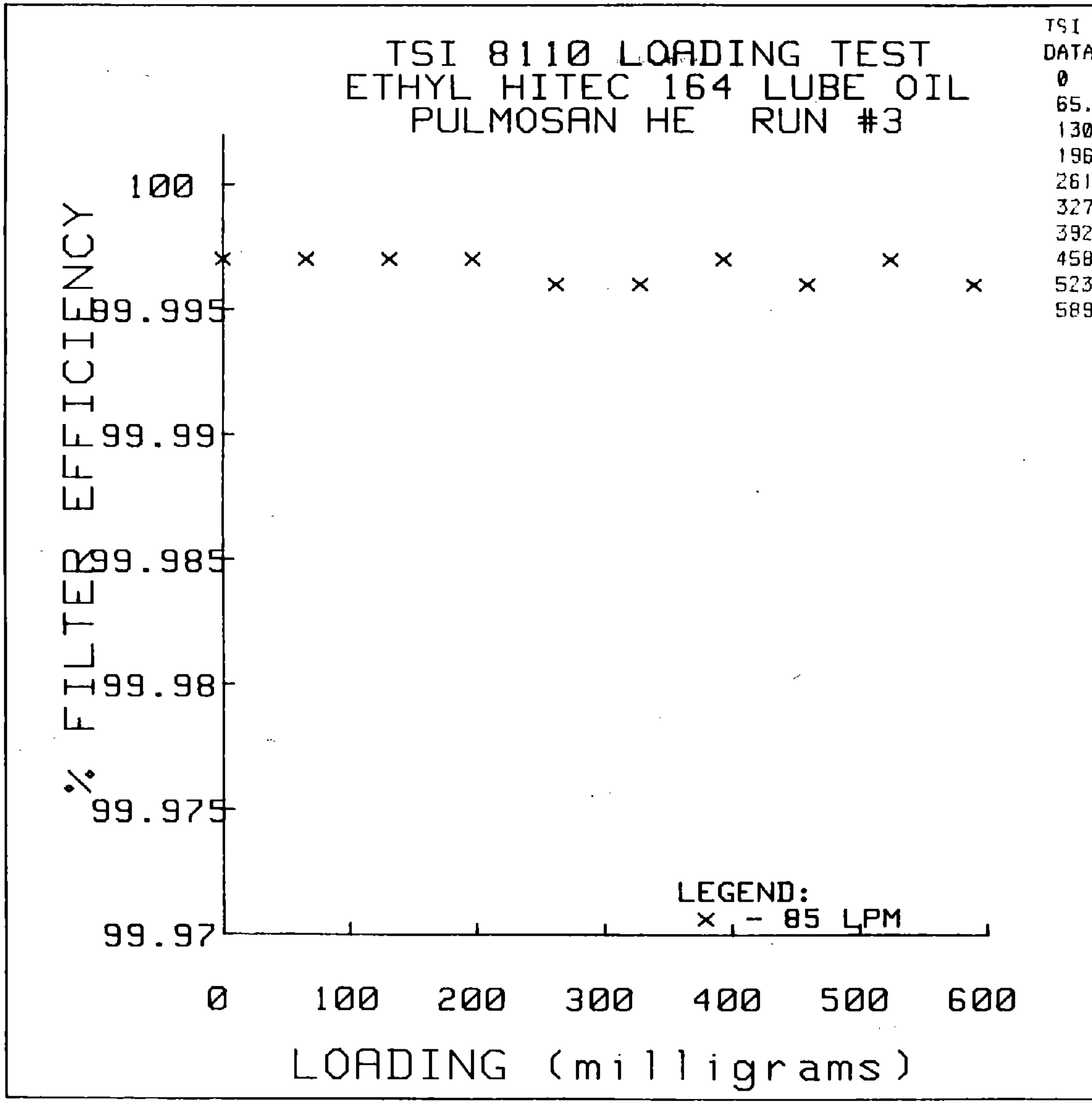
Figure 49



TSI 8110 ETHYL 164 LOADING TEST PULMOSAN #
DATA FOR 85 LPM

0	99.995
65.4937	99.996
130.9873	99.996
196.481	99.995
261.9747	99.996
327.4684	99.995
392.962	99.994
458.4557	99.994
523.9494	99.994
589.443	99.994

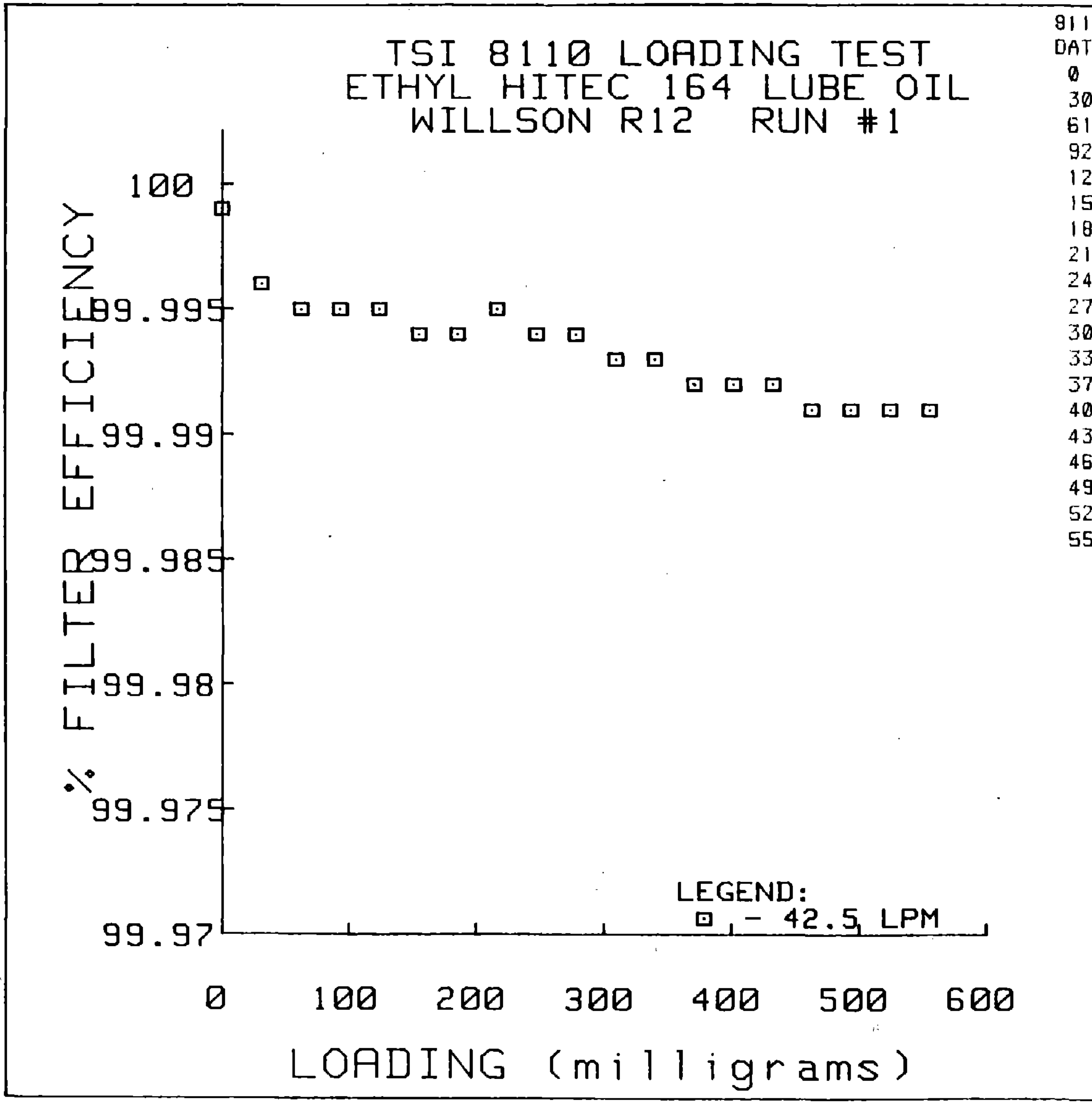
Figure 50



TSI 8110 ETHYL 164 LOADING TEST PULMOSAN #
DATA FOR 85 LPM

0	99.997
65.4937	99.997
130.9873	99.997
196.481	99.997
261.9747	99.996
327.4684	99.996
392.962	99.997
458.4557	99.996
523.9494	99.997
589.443	99.996

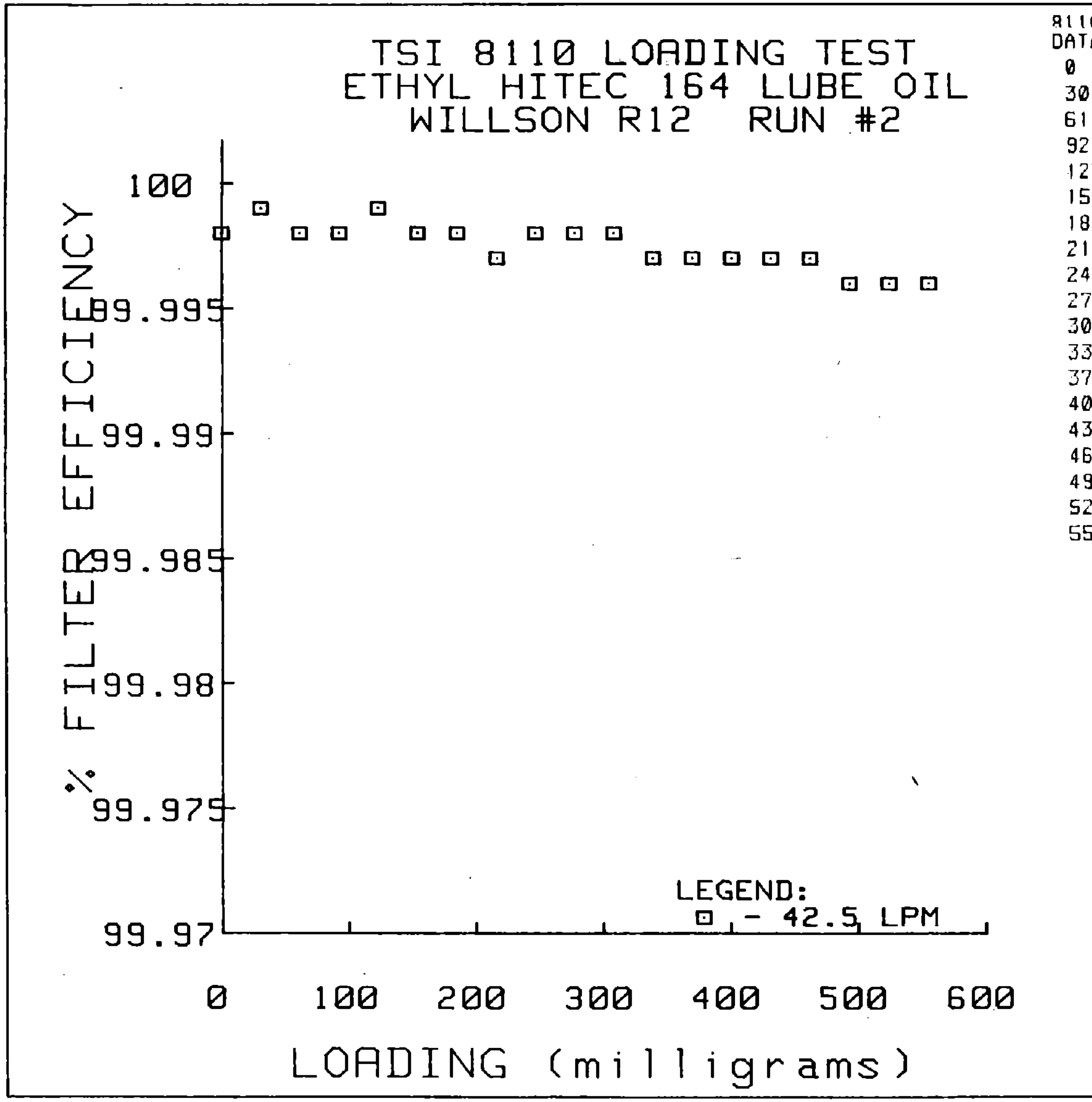
Figure 51



8110 ETHYL 164 LOADING TEST WILLSON R12 #
DATA FOR 42.5 LPM

0	99.999
30.842	99.996
61.684	99.995
92.526	99.995
123.368	99.995
154.21	99.994
185.0521	99.994
215.8941	99.995
246.7361	99.994
277.5781	99.994
308.4201	99.993
339.2621	99.993
370.1041	99.992
400.9461	99.992
431.7881	99.992
462.6301	99.991
493.4722	99.991
524.3142	99.991
555.1562	99.991

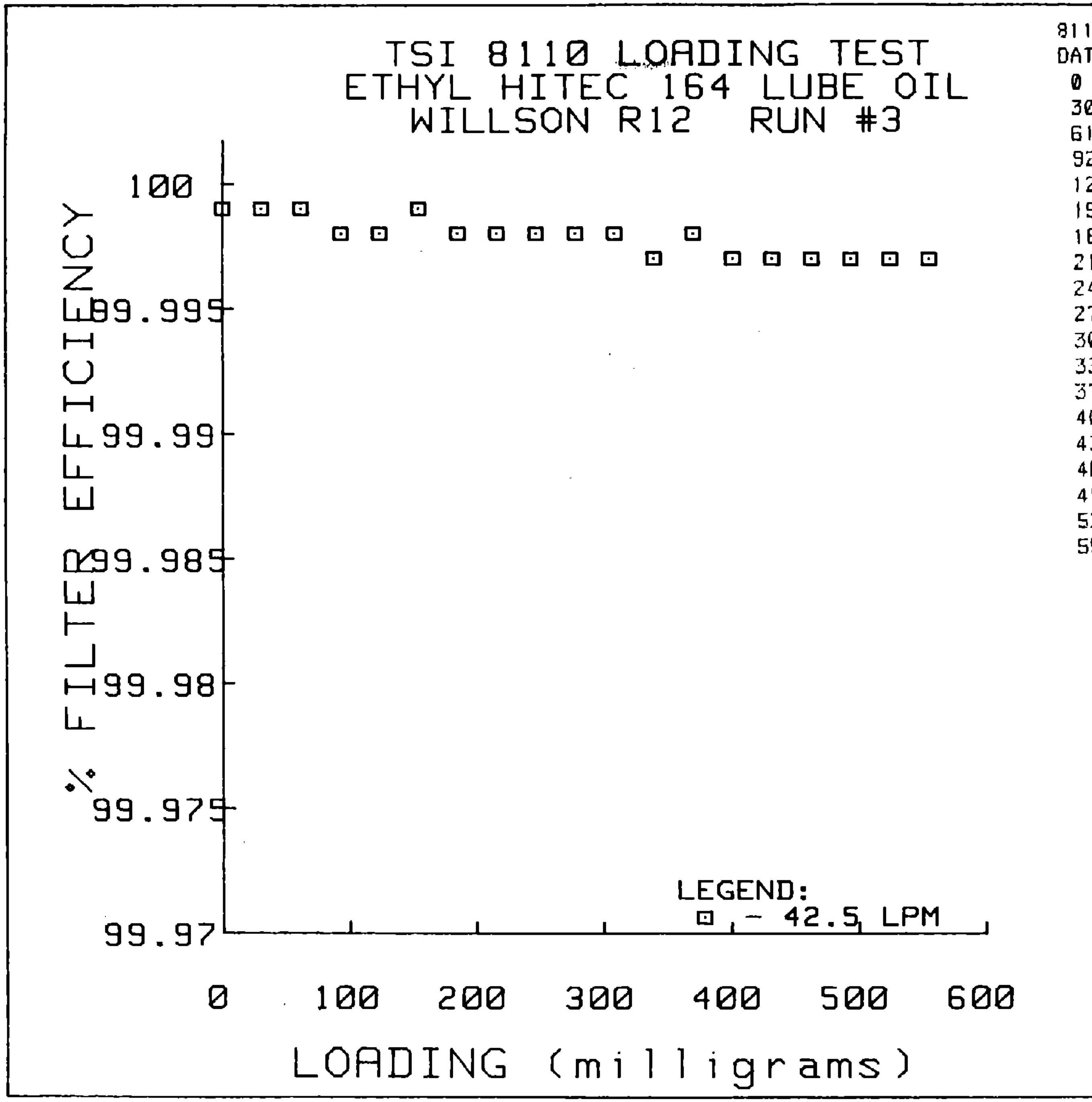
Figure 52



8110 ETHYL 164 LOADING TEST WILLSON R12 #
DATA FOR 42.5 LPM

0	99.998
30.842	99.999
61.684	99.998
92.526	99.998
123.368	99.999
154.21	99.998
185.0521	99.998
215.8941	99.997
246.7361	99.998
277.5781	99.998
308.4201	99.998
339.2621	99.997
370.1041	99.997
400.9461	99.997
431.7881	99.997
462.6301	99.997
493.4722	99.996
524.3142	99.996
555.1562	99.996

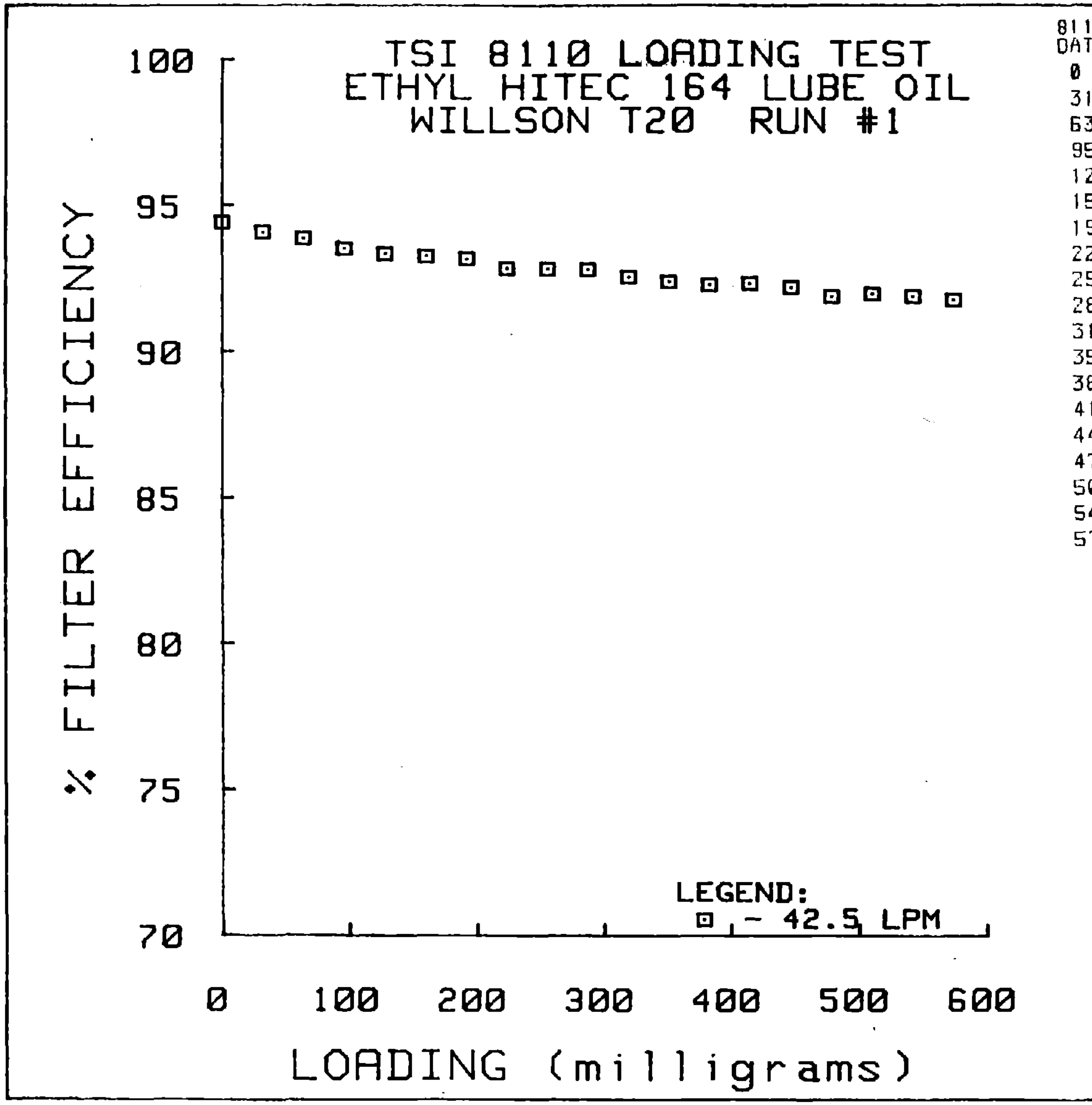
Figure 53



8110 ETHYL 164 LOADING TEST WILLSON R12 #
DATA FOR 42.5 LPM

0	99.999
30.842	99.999
61.684	99.999
92.526	99.998
123.368	99.998
154.21	99.999
185.0521	99.998
215.8941	99.998
246.7361	99.998
277.5781	99.998
308.4201	99.998
339.2621	99.997
370.1041	99.998
400.9461	99.997
431.7881	99.997
462.6301	99.997
493.4722	99.997
524.3142	99.997
555.1562	99.997

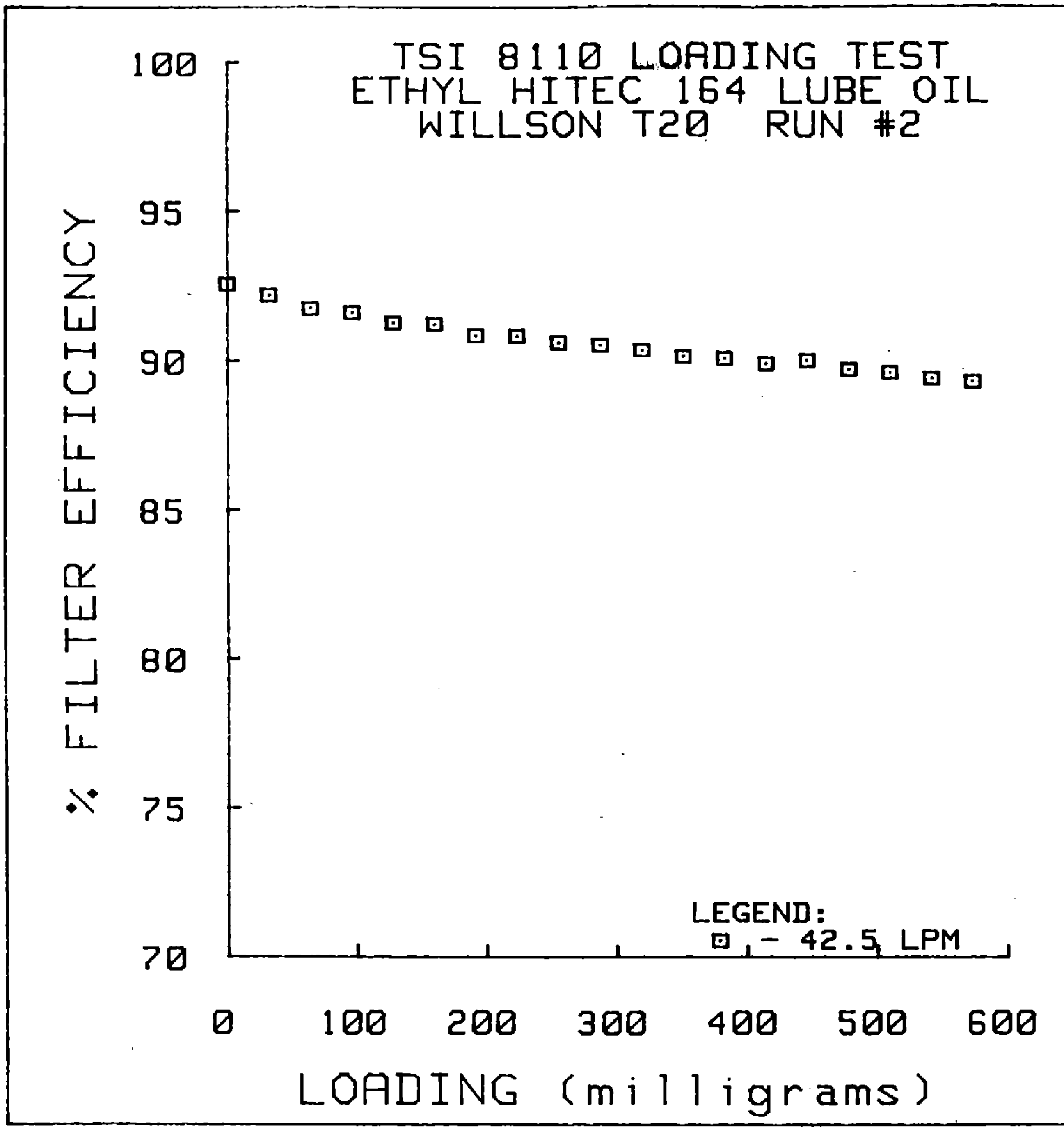
Figure 54



8110 LOADING TEST ETHYL 164 WILLSON T20 #
DATA FOR 42.5 LPM

0	94.42
31.8535	94.08
63.7069	93.87
95.5604	93.51
127.4138	93.33
159.2673	93.26
191.1207	93.17
222.9742	92.84
254.8276	92.81
286.6811	92.8
318.5345	92.55
350.388	92.39
382.2414	92.28
414.0949	92.34
445.9483	92.21
477.8018	91.89
509.6552	91.98
541.5087	91.9
573.3621	91.77

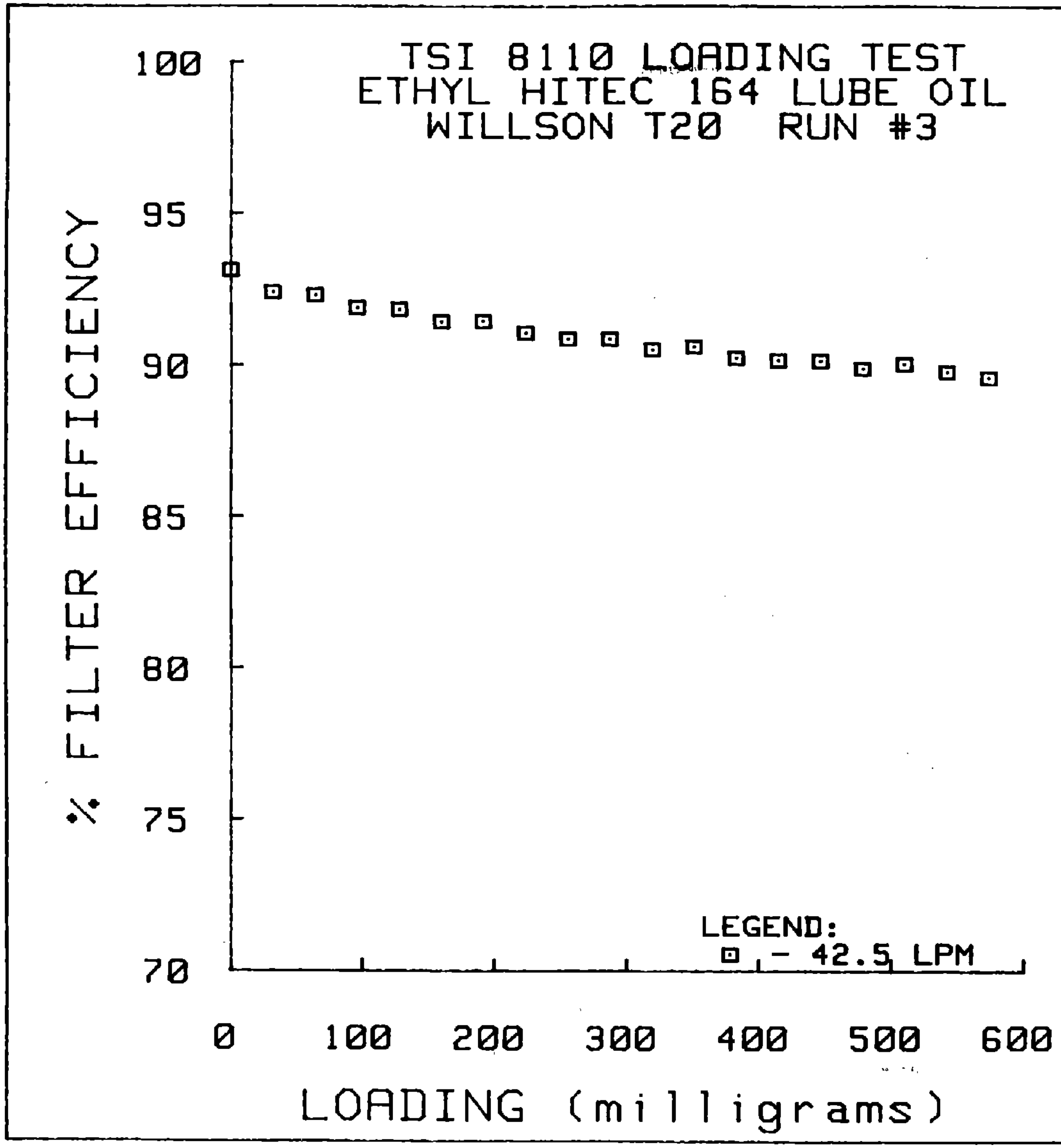
Figure 55



8110 LOADING TEST ETHYL 164 WILLSON T20 #
DATA FOR 42.5 LPM

0	92.55
31.8535	92.19
63.7069	91.74
95.5604	91.61
127.4138	91.26
159.2673	91.21
191.1207	90.82
222.9742	90.8
254.8276	90.58
286.6811	90.52
318.5345	90.35
350.388	90.14
382.2414	90.07
414.0947	89.9
445.9483	90
477.8018	89.7
509.6552	89.6
541.5087	89.4
573.3621	89.3

Figure 56



8110 LOADING TEST ETHYL 164 WILLSON T20 #3
DATA FOR 42.5 LPM

0	93.12
31.8535	92.39
63.7069	92.3
95.5604	91.87
127.4138	91.83
159.2673	91.42
191.1207	91.43
222.9742	91.05
254.8276	90.87
286.6811	90.87
318.5345	90.52
350.388	90.62
382.2414	90.26
414.0949	90.18
445.9483	90.16
477.8018	89.9
509.6552	90.06
541.5087	89.8
573.3621	89.6

Product Code: 7037
DIOCTYL PHTHALATE*

MATERIAL SAFETY DATA SHEET

EASTMAN CHEMICAL PRODUCTS, INC.
EASTMAN KODAK COMPANY
Kingsport, Tennessee 37662

For Health Hazard Information, Call: (615) 229-6094

For Other Information, Call Your Eastman Representative

Eastman Operator: (615) 229-2000

Date of Preparation: 05-19-89

SECTION I. IDENTIFICATION

-- Name:

"KODAFLEX" DOP Plasticizer

-- Synonyms: PM 401; Dioctyl phthalate, Bis(2-ethylhexyl) phthalate, Di-2-ethylhexyl phthalate (DEHP)
-- Formula: $C_{24}H_{38}O_4$
-- Molecular Weight: 390.57

SECTION II. PRODUCT AND COMPONENT HAZARD DATA

A. COMPONENT:	Approx Weight %	CAS Reg No	Eastman Kodak No
Dioctyl phthalate* **	100	117-81-7	904099

See Section VI-A for information on exposure limits.
*Hazardous chemical as defined by OSHA, 29 CFR 1910.1200.
**Chemical subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

B. PRECAUTIONARY LABEL STATEMENT:

WARNING! POSSIBLE CANCER HAZARD - MAY CAUSE CANCER BASED ON ANIMAL DATA

Avoid breathing mist and vapor.
Avoid contact with eyes, skin, and clothing.
Keep container closed.
Use with adequate ventilation.
Wash thoroughly after handling.

FIRST AID: If inhaled, remove to fresh air. Treat symptomatically. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if symptoms persist. Wash skin with soap and plenty of water. Wash clothing before reuse. Destroy contaminated shoes.

Since emptied containers retain product residue, follow label warnings even after container is emptied.

FOR MANUFACTURING USE ONLY

SECTION III. PHYSICAL DATA

-- Appearance and Odor: Clear liquid, little or no odor. (1)
-- Boiling Point: 384°C (723°F) (1)
-- Specific Gravity (H_2O = 1): 0.985 at 20°C (68) (1)
-- Vapor Pressure: 7.22 x 10^{-8} mm Hg at 20°C (68°F) (2)
-- Solubility in Water: 340 ug/L at 25°C (Negligible). (1)

SECTION IV. FIRE AND EXPLOSION HAZARD DATA (1)

-- Flash Point: 216°C (420°F), Method Used: Cleveland Open Cup.
-- Autoignition temperature: 391°C (735°F), Method Used: ASTM D 2155.
-- Flammable Limits: LEL 0.31% at 256°C (493°F); 0.28% at 264°C (507°F)
UEL Not determined
-- Extinguishing Agent: Water spray, Dry chemical, CO_2, or Foam.
-- Special Fire-Fighting Procedures: Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.
-- Unusual Fire and Explosion Hazards: None.

SECTION V. REACTIVITY DATA

-- Stability: Stable.
-- Incompatibility: Oxidizing materials can cause a reaction.
-- Hazardous Decomposition Products: As with any other organic material, combustion will produce carbon dioxide and probably carbon monoxide.
-- Hazardous Polymerization: Will not occur.

SECTION VI. TOXICITY AND HEALTH

A. EXPOSURE LIMITS

-- Threshold Limit Value (TLV) 5 mg/m^3-TWA, 10 mg/m^3-STEL, ACGIH, 1988-89.
-- OSHA Permissible Exposure Limit (PEL): 5 mg/m^3, 10 mg/m^3-STEL.
-- A NIOSH industrial hygiene analytical method is available. (3)

B. EXPOSURE EFFECTS

Carcinogenicity Status: This chemical has been listed as a carcinogen or potential carcinogen for hazard communication purposes by: National Toxicology Program (Annual Report on Carcinogens) and International Agency for Research on Cancer (IARC) Monographs. California: WARNING! This chemical is known to the State of California to cause cancer. While DOP may induce liver tumors in rats and mice at high dose levels, it is doubtful that it presents a carcinogenic risk to humans at exposure levels typical of occupational or consumer use. (See Section VI-D).

Inhalation: Harmful if inhaled.

Eyes: Low hazard for usual industrial handling. However, any material that contacts the eye may be irritating or may cause mechanical injury.

Skin: Harmful if absorbed through the skin.

C. FIRST AID

Inhalation: Remove to fresh air. Treat symptomatically.

Eyes: Any material that contacts the eye should be washed out immediately and medical attention obtained if any symptoms are present after washing.

Skin: Immediately wash with soap and plenty of water. Wash clothing before reuse. Destroy contaminated shoes.

D. TOXICITY DATA

Test	Species	Result (4)	Acute Toxicity Classification (5)
Acute oral LD_{50}	Rat	30.6 g/kg	Relatively harmless
Acute oral LD_{50}	Rabbit	33.9 g/kg	
Dermal LD_{50}	Rabbit	>20 mL/kg	
Skin irritation	Rabbit	Slight	
Skin irritation	Human	None	
Skin sensitization	Human	None	
Eye irritation	Rabbit	Slight	

Summary of Data Referable to Carcinogenicity: Dioctyl phthalate (DOP) is the phthalate ester plasticizer whose safety has been most extensively studied. DOP has been used worldwide for more than 40 years with no observed adverse effects on human health.

DOP was tested in a lifetime feeding study in rats and mice by the U.S. National Toxicology Program (NTP). The very low acute and subacute toxicity of DOP enabled the feeding of very large dose levels (3000 to 12,000 ppm in the diet), and, at these doses, it produced liver tumors in both rats and mice. DOP has not shown any evidence for genotoxicity in spite of extensive testing. DOP does produce the proliferation of a subcellular organelle, the peroxisome, and does produce liver enlargement in rodents by forced cell replication. These effects are thought to be closely related to the long-term production of liver tumors in rats and mice.

The Phthalate Esters Panel of the U.S. Chemical Manufacturers Association has sponsored metabolism, mutagenicity, peroxisome proliferation, and other studies of liver effects in rodents in an attempt to understand the mechanism by which DOP produces liver cancer in rats and mice. One outcome of this work has been the elucidation of important species differences between rodents and primates in several key areas. These differences cast doubt on the meaning of the rodent carcinogenicity studies for the prediction of such effects in humans. This program has been carried out in consultation with the U.S. Environmental Protection Agency (EPA). The EPA and the U.S. Food and Drug Administration (FDA) periodically review results generated in this program.

It is generally believed that DOP produces liver tumors in rodents by a "special" mechanism related to its ability to perturb lipid metabolism, to proliferate peroxisomes, or to produce hepatomegaly by forced cell replication. Because these effects are not seen in many other species including primates, it is doubtful that DOP presents a carcinogenic risk to humans at exposure levels typical of occupational or consumer use.

Summary of Data Referable to Reproductive Toxicity: When fed to pregnant mice, malformations in the offspring were observed at a daily dose of 90 mg/kg but not at 70 mg/kg. When fed to pregnant rats at levels that were maternally toxic (670 mg/kg/day), there was no evidence of malformations although embryofetal toxicity was seen (increased resorptions and decreased fetal weights). When DOP was fed to male and female mice at 150 mg/kg/day, it resulted in reduced fertility; however, when fed to male rats, a dose of 900 mg/kg/day was required to produce testicular injury while no injury was seen at 400 mg/kg/day. The significance of these studies to possible human exposure is unknown. Absorption through human skin is extremely slow (approx. 0.0001 $mg/cm^2/hr$) such that immersion of both hands in DOP for an hour could result in the absorption of 0.074 mg or approx. 0.001 mg/kg. (See Section VII-C for proper skin protection.) Inhalation of saturated vapor (0.000095 ppm at 20°C) for a working day would result in an absorbed dose of <0.0002 mg/kg. Inhalation of a respirable aerosol at the TLV of 5 mg/m^3 for a working day would result in an absorbed dose of <0.7 mg/kg. (See Section VII-B for proper respiratory protection.)

SECTION VII. VENTILATION AND PERSONAL PROTECTION

A. VENTILATION

Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. Local exhaust ventilation or an enclosed handling system may be needed to control air contamination below recommended exposure limits (see Section VI-A).

B. RESPIRATORY PROTECTION

An appropriate NIOSH-approved respirator for organic vapor and mist must be worn if exposure is likely to exceed recommended exposure limits (see Section VI-A). If respirators are used, a program should be established to assure compliance with OSHA Standard 29 CFR 1910.134.

C. SKIN AND EYE PROTECTION

Wear safety glasses with side shields (or goggles). Impermeable gloves should be worn. A safety shower, an eye bath, and washing facilities should be available. Wash thoroughly after handling.

SECTION VIII. SPECIAL STORAGE AND HANDLING PRECAUTIONS

Keep from contact with oxidizing materials. Since emptied containers retain product residue, follow label warnings even after container is emptied.

.CTION IX. SPILL, LEAK, AND DISPOSAL PRACTICES

Steps to be Taken in Case Material is Released or Spilled: Small spills may be collected with absorbent materials. For large spills, flush area with water spray. Prevent runoff from entering drains, sewers, or streams. Clean Water Act and Superfund reportable quantity (RQ): 1 lb.

Waste Disposal Method: Incineration. Observe all federal, state, and local laws concerning health and environment.

SECTION X. ENVIRONMENTAL EFFECTS DATA

A. SUMMARY: This material has a low biochemical oxygen demand and little potential to cause oxygen depletion in aqueous systems, a high potential to affect some aquatic organisms, and a high potential to bioconcentrate. The direct, instantaneous discharge to a receiving body of water of an amount of this material which will rapidly produce by dilution a final concentration of 1.0 mg/L or less is not expected to cause adverse environmental effects.

B. OXYGEN DEMAND DATA (6)

-- BOD_5: 0.04 g O_2/g

C. ACUTE AQUATIC EFFECTS

-- 24-,48-,72- and 96-h LC_{50}; Sheepshead minnow: >550 mg/L (7)
-- No observed effect concentration; Sheepshead minnow: 550 mg/L (7)
-- 24-h LC_{50}; Water flea: >68 mg/L (8)
-- 48-h LC_{50}; Water flea: 11 mg/L (8)
-- No discernable effect conc; Water flea: 1.1 mg/L (8)

D. BIOCONCENTRATION POTENTIAL

-- Octanol/water partition coefficient: Log P = 4.88, P = 75,858 (9)

SECTION XI. TRANSPORTATION

DOT Hazard Classification: ORM-E.
Proper DOT Shipping Name: Hazardous Substance Liquid, N.O.S.
NA Number: 9188.

SECTION XII. REFERENCES

1. File data, Material Safety Program, Eastman Chemicals Division, Eastman Kodak Company, Kingsport, Tennessee.

2. J CHEM PHYS 71, 582-587 (1979).

3. NIOSH MANUAL OF ANALYTICAL METHODS, 3rd Edition. Issued by the National Institute for Occupational Safety and Health. U.S. Government Printing Office, Washington, 1984, Method 5020.

4. J IND HYG TOXICOL 27, 130-135 (1945).

5. AM IND HYG ASSOC Q 10, 93-96 (1949).

6. Unpublished data, Health and Environment Laboratories, Eastman Kodak Co., Rochester, New York.

7. BULL ENVIRON CONTAM TOXICOL 27, 596-604 (1981).

8. BULL ENVIRON CONTAM TOXICOL 24, 684-691 (1980).

9. Toxicity Profile for Di-2-Ethylhexyl Phthalate (Draft), ATSDR, USPHS, Atlanta, GA, p.29.

SECTION XIII. HAZARD RATINGS

	Health	Flammability	Reactivity
HMIS* Rating:	1	1	0
NFPA** Rating:	1	1	0

NOTICE: These ratings involve data and interpretations that may vary from company to company and are intended only for rapid, general identification of the magnitude of the specific hazard. TO DEAL ADEQUATELY WITH THE SAFE HANDLING OF THIS MATERIAL, ALL THE INFORMATION CONTAINED IN THIS MSDS MUST BE CONSIDERED. The customer is responsible for determining the proper personal protective equipment needed for its particular use of this material.

*Hazardous Materials Identification System's [HMIS] Revised RAW MATERIALS RATING MANUAL, National Paint & Coatings Association, Fall 1984.

**NFPA 704 Standard System for the Identification of the Fire Hazards of Materials, National Fire Protection Association, 1985.

C/10185A/904099/R-2, S-2, F-1, C-0

MATERIAL SAFETY DATA SHEET

Ethyl Chemicals Group

FOR EMERGENCIES ONLY - Phone 504-344-7147

For Nonemergency Health and Safety Information Phone 504-388-7717

14.0.23

PRODUCT IDENTIFICATION

TRADE NAME:	HiTEC (R) 164 Lube Oil
CHEMICAL NAME:	1-Decene, homopolymer, hydrogenated
CAS NO.:	68037-01-4
CHEMICAL FORMULA:	CnH2n+2
CHEMICAL FAMILY:	Paraffin hydrocarbon

THIS MATERIAL IS IN COMPLIANCE WITH THE TOXIC SUBSTANCES CONTROL ACT (15 USC 2601 - 2629).

COMPONENTS

CHEMICAL NAME	CAS NO.	NOTE+	EXPOSURE LIMIT
Poly Alpha Olefin	68037-01-4	NL	Not established by OSHA/ACGIH.

+NOTE: Carcinogenicity listing of components at concentrations greater than or equal to 0.1% indicated by: @=NTP; #=IARC; &=OSHA; *=OTHER; NL=Not Listed

CHEMICAL AND PHYSICAL PROPERTIES

APPEARANCE/ODOR:	Colorless, odorless liquid.
BOILING POINT:	375-505C/707-941F.
VAPOR PRESSURE:	7mm Hg @ 20C/68F.
SOLUBILITY IN WATER:	Negligible.
SPECIFIC GRAVITY:	0.82 @ 15.6/15.6C.

08/30/89

EMERGENCY PHONE NUMBER TRADE NAME: HiTEC (R) 164 Lube Oil
(504) 344-7147

14.0.23

FIRE AND EXPLOSION HAZARDS

FLASH POINT(METHOD): 224C/435F (PMCC).

FLAMMABLE LIMITS: Not established.

EXTINGUISHING MEDIA: Dry chemical, water spray (fog), foam or carbon dioxide.

HAZARDOUS THERMAL DECOMPOSITION PRODUCTS:
Include oxides of carbon.

SPECIAL FIRE FIGHTING PROCEDURES:
As for petroleum products. Use self-contained breathing apparatus.

UNUSUAL FIRE AND EXPLOSION HAZARDS:
None known.

REACTIVITY DATA

STABILITY: Stable.

HAZARDOUS POLYMERIZATION:
Will not occur.

HEALTH HAZARDS

INHALATION: Inhalation of oil mist or vapors at elevated temperature may cause respiratory irritation.

EYE CONTACT: Not expected to be an eye irritant.

SKIN CONTACT: Not expected to be a skin irritant.

INGESTION: Harmful if aspirated into the lungs-do not induce vomiting.

CHRONIC EFFECTS OF OVEREXPOSURE:
None known.

08/30/89

EMERGENCY PHONE NUMBER (504) 344-7147

TRADE NAME: HiTEC (R) 164 Lube Oil

14.0.23

EMERGENCY FIRST AID PROCEDURES

INHALATION:	If inhaled, remove to fresh air.
EYE CONTACT:	Begin immediate eye irrigation with cool water.
SKIN CONTACT:	Wash contaminated areas with soap and water.
INGESTION:	If swallowed, give two glasses of water. Do not induce vomiting.

EXPOSURE CONTROL INFORMATION

EXPOSURE LIMITS:	Not established by OSHA/ACGIH.
EYE PROTECTION:	Chemical goggles or face shield.
PROTECTIVE GLOVES:	Resistant to chemical penetration.
RESPIRATORY PROTECTION:	NIOSH approved supplied-air respirator when exposed to vapor from heated material.
LOCAL EXHAUST VENTILATION:	At bulk vessel openings when handling heated materials.
MECHANICAL VENTILATION:	Recommended.
OTHER:	If skin contact or contamination of clothing is likely, protective clothing should be worn.

ENVIRONMENTAL PROTECTION

SPILLS OR LEAKS:	Contain any spills with dikes or absorbents to prevent migration and entry into sewers or streams. Take up small spills with dry chemical absorbent. Large spills may be taken up with pump or vacuum and

EMERGENCY PHONE NUMBER (504) 344-7147 TRADE NAME: HiTEC (R) 164 Lube Oil

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ENVIRONMENTAL PROTECTION (Con't)

SPILLS OR LEAKS:	finished off with dry chemical absorbent. May require excavation of contaminated soil.
DISPOSAL METHODS:	Under the CERCLA/RCRA regulations currently in effect, this product is not regulated as a hazardous waste or material. Therefore, it may be disposed of as an industrial waste in a manner acceptable to good waste management practice and in compliance with applicable local, state and federal regulations.
STORAGE REQUIREMENT:	Short term - (less than 24 hours) 65C maximum. Long term - (greater than 24 hours) 50C maximum. Maintain product above 10C for flowability.

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MSDS prepared by: Health & Environment Department
Ethyl Corporation

FOR ADDITIONAL NONEMERGENCY MSDS INFORMATION, CONTACT:

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BATON ROUGE, LA. 70801
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THIS MATERIAL SAFETY DATA SHEET CONTAINS AT LEAST THE INFORMATION REQUIRED BY THE FEDERAL OSHA HAZARD COMMUNICATION RULE, 29 CFR 1910.1200(g) (2).

Ethyl

EXPLANATION OF MATERIAL SAFETY DATA SHEET TERMINOLOGY

PRODUCT IDENTIFICATION

TRADE NAME AND SYNONYMS
The name under which the product is sold and common synonyms.

CHEMICAL NAME AND FORMULA
Chemical descriptive name and the chemical formula.

CAS NO.
Chemical Abstract Service registry number which identifies the product.

SUMMARY OF HAZARDS

Emphasizes major hazard(s) associated with the product. Further details are provided in subsequent sections.

COMPONENTS

COMPONENT NAME
Chemical, generic, or proprietary name that identifies the product or components of a mixture. Inclusion of a component is not necessarily based on hazard criteria.

EXPOSURE LIMIT
The airborne concentration at which most workers can be exposed without any expected adverse effects. Source may be Ethyl guideline, ACGIH TLV® (Threshold Limit Value), or OSHA PEL (Permissible Exposure Limit).

TYPES OF EXPOSURE LIMITS
TWA - the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

STEL (Short-Term Exposure Limit) - a 15 minute time-weighted average exposure which should not be exceeded at any time during a workday even if the 8-hour time-weighted average is within the TLV.

CEILING - the concentration that should not be exceeded during any part of the working exposure.

Peak - The maximum concentration and duration of exposure allowable above the ceiling concentration for an 8-hour shift.

ACGIH - American Conference of Governmental Industrial Hygienists.

OSHA - Occupational Safety and Health Administration.

NIOSH - National Institute of Occupational Safety and Health.

CARCINOGENICITY LISTING
Indicates whether a component is thought to be a cancer hazard based on human experience and animal data.

NTP - National Toxicology Program.

IARC - International Agency for Research on Cancer.

OTHER - May include preliminary data or studies not yet evaluated by the major agencies. Also includes ACGIH and NIOSH listings.

CHEMICAL AND PHYSICAL PROPERTIES

APPEARANCE/ODOR
Description of material at normal temperature and pressure that may be useful in identifying the presence of the product.

BOILING POINT
The temperature at which the vapor pressure of the liquid is equal to the pressure of the atmosphere.

MELTING POINT (FREEZING POINT)
Temperature at which a substance changes from the solid to liquid state

VAPOR PRESSURE
The pressure exerted at any temperature by a vapor existing in equilibrium with its liquid or solid phase.

SOLUBILITY IN WATER
The amount of the product, by weight, that will dissolve in a given weight of water at a specified temperature.

	grams/100 H_2O
Negligible	< 0.1
Slight	0.1 - 1.0
Moderate	1 - 10
Appreciable	> 10
Complete	Soluble in all proportions

SPECIFIC GRAVITY
Ratio of the weight of a volume of the product to the weight of an equal volume of water (liquids/solids) or air (gases).

EVAPORATION RATE
Ratio of the rate of vaporization of the product to the rate of a known material.

PERCENT VOLATILES
The percentage of the product (liquid or solid) that will evaporate at ambient temperature.

POUR POINT
The lowest temperature at which a liquid will flow when the container is inverted.

VISCOSITY
A measure of flow characteristics of a liquid, expressed in units called Centistokes (cSt).

FIRE AND EXPLOSION HAZARDS

FLASH POINT (CLOSED CUP METHOD)
Lowest temperature at which the product will give off enough vapor to ignite.

FLAMMABLE LIMITS
Range of vapor concentration (percent by volume in air) which will burn or explode in the presence of spark of flame. LEL is the lower explosive limit and UEL is the upper explosive limit.

EXTINGUISHING MEDIA
The fire fighting agents which are recommended for use.

HAZARDOUS THERMAL DECOMPOSITION PRODUCTS
Known hazardous products resulting from heating or burning the compound.

SPECIAL FIREFIGHTING PROCEDURES
General firefighting procedures of chemical fires are not described, but special procedures are given, if required.

UNUSUAL FIRE AND EXPLOSION HAZARDS
Hazards not covered by other sections of the MSDS pertaining to chemical reactions in the presence of heat and/or fire.

REACTIVITY DATA

STABILITY
Indicates the susceptibility of the product to dangerous decomposition.

CONDITIONS AND MATERIALS TO AVOID
Gives the conditions and materials that may cause undesirable reactions or instability of the product.

HAZARDOUS DECOMPOSITION PRODUCTS
Describes the hazardous materials produced from a chemical reaction.

HAZARDOUS POLYMERIZATION
Indicates the tendency of the product's molecules to combine in a violent reaction.

HEALTH HAZARDS

Gives the immediate effects of overexposure to the product by skin or eye contact, breathing vapors or dust, and ingestion. Common symptoms which may occur from exposure to the product are given.

CHRONIC EFFECTS
Refers to the effects that may occur after repeated or prolonged over-exposure to the product.

OTHER HEALTH EFFECTS
Includes medical conditions which may be aggravated by exposure to the product.

TOXICITY
Gives numerical results from animal tests on the product. LD_{50} or LC_{50} is the dose level that kills half of the animals tested.

EMERGENCY FIRST AID

Gives emergency and first aid instructions for treating overexposure by inhalation, ingestion, and skin and eye contact.

NOTE TO PHYSICIAN
May give any contraindicated treatment or recommended treatment for a licensed health care professional to conduct.

EXPOSURE CONTROL INFORMATION

EYE PROTECTION
Specification of eyes or face protection beyond normal use of safety glasses.

PROTECTIVE GLOVES
Indicates the need for protective gloves when skin contact may occur.

RESPIRATORY PROTECTION
Specification of the type of respirator recommended for use during routine or emergency situations.

VENTILATION
Specification of the type (local/general) of ventilation recommended to capture contaminants or prevent the build-up of hazardous atmospheres.

OTHER
Specification of other recommended personal protective equipment based on type and degree of hazard.

ENVIRONMENTAL PROTECTION

SPILLS AND LEAKS
Indicates special precautions for clean-up of spills and leaks and preparation of chemical for disposal.

DISPOSAL METHOD
Tells the EPA classification of the product as well as the proper disposal procedure.

EPA
Environmental Protection Agency

RQ
Reportable Quantity - The amount of the product or one of its components that, when spilled, must be reported to the EPA and possibly other regulatory agencies.

RCRA - Resource Conservation and Recovery Act.

CERCLA - Comprehensive Environmental Response, Compensation and Liability Act.

STORAGE REQUIREMENTS
Any unusual requirements or precautions for storage of the product.

ADDITIONAL PRECAUTIONS OR COMMENTS

States or re-emphasizes any special precautions or handling requirements.

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