VAPOR RECOVERY SYSTEMS AT GASOLINE DISPENSING FACILITIES SEASONAL EFFECTS

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EXECUTIVE SUMMARY

Emissions from gasoline service stations represent a significant inventory component. As automobile emission standards result in lower hydrocarbon exhaust emissions per mile, the relative importance of fueling station emissions increases. Gasoline dispensing facilities (GDF) have been subject to pollution control since the 1970s. These stationary sources are a potentially important source of hydrocarbon compounds (VOC) that interact with nitrogen oxides to form ambient oxidants.

In nonattainment areas, initial control efforts addressed VOC releases through the installation of vapor recovery systems (VRS) for product delivery processes (Phase I) and product dispensing activities (Phase II). In 1985, emissions from GDFs were regulated statewide by mandating the installation of Phase II VRS on GDFs with annual throughput of at least 480,000 gallons. The purpose of this program is to reduce benzene exposure from fuel dispensing activities. More recently, season-specific formulations of gasoline have been rolled-out to fulfill the need for low volatility gasoline in the summer.

This research project was designed to evaluate the interaction between independent variables that potentially influence gasoline dispensing facilities (GDF) emissions and GDF emissions releases. Possible determinants of GDF emissions include vapor recovery system type, underground storage tank pressure distributions, seasonal environmental effects (e.g., ambient temperature and pressure), and fuel RVP. The results of this project indicate:

- Underground storage tank pressure is a primary determinant of VRS leak rate and the proportional associated fugitive emission releases.

- VRS system type influences UST pressure with VRS pressure, temperature and volume characteristics being possible mediating factors.

- Ambient conditions do not directly include VRS behavior or UST pressure distributions. Ambient temperature does, however, determine vehicle fuel tank vapor temperatures and associated evaporative emission releases.

- The importance of underground storage tank pressure in determining of vent line, fugitive, and total facility emissions strongly suggests the importance of maintaining neutral pressure as a strategy to control emissions at gasoline dispensing facilities. Pressure control systems of interest include nozzle and vapor pump designs that maximize the nozzle fill pipe interface seal to obtain the required collection efficiency at a V/L ratio at or below one. The other option is vapor processor methods (e.g., thermal oxidizers, carbon absorption units, selective permeation membranes). Many current certified nozzle and vapor pump designs do not include an effective seal at the nozzle fill neck interface. Rather, they depend on high V/L ratios to achieve greater than 95% collection efficiency at the dispensing point.

TABLE OF CONTENTS

Page

Executive Summary iii

1. INTRODUCTION 1-1
   1.1 Study Objectives 1-1
   1.2 Background 1-1
      1.2.1 Gasoline Dispensing Facilities Vapor Recovery Systems 1-2
   1.3 Study Assumptions and Hypotheses 1-4
   1.4 Study Report Content 1-4

2. MATERIALS AND METHODS 2-1
   2.1 Study Design 2-1
      2.1.1 Test Conditions 2-1
         2.1.1.1 Uncontrolled Test Series 2-1
   2.2 Study Sites 2-3
   2.3 Field Parameter Measurements 2-4
      2.3.1 Meteorological Measurements 2-11
      2.3.2 Hydrocarbon Measurements 2-11
         2.3.2.1 Analytical Procedures for TP-201.2 2-11
         2.3.2.2 Analytical Procedures for TP-201.2B 2-12
      2.3.3 Pressure Measurements 2-13
         2.3.3.1 Analytical Procedures for TP-201.2 2-14
      2.3.4 Temperature Measurements 2-14
         2.3.4.1 Analytical Procedures for TP-201.2 2-14
         2.3.4.2 Analytical Procedures for Ancillary Temperature Readings ... 2-15
      2.3.5 Volume Measurements 2-15
         2.3.5.1 Analytical Procedures for TP-201.2 2-15
      2.3.6 Data Acquisition System 2-16
   2.4 Determination of Vehicle Matrix for TP-201.2A 2-16
   2.5 Vehicle Leak Check Test 2-16
   2.6 Pre-Test and Post-Test Measurements for Static Pressure, Dynamic Pressure and A/L Ratio 2-16
   2.7 Quality Assurance/Quality Control 2-17

3. RESULTS 3-1
   3.1 Balance Vapor Recovery Systems 3-1
      3.1.1 Winter Conditions 3-1
         3.1.1.1 Hydrocarbon Behavior 3-2
         3.1.1.2 Volume Behavior 3-2
         3.1.1.3 Pressure Behavior 3-2
         3.1.1.4 Temperature Behavior 3-3
         3.1.1.5 Ambient Conditions 3-3

3.1.1.6 Vehicle Conditions 3-4
3.1.2 Spring Conditions 3-4
3.1.2.1 Hydrocarbon Behavior 3-4
3.1.2.2 Volume Behavior 3-4
3.1.2.3 Pressure Behavior 3-5
3.1.2.4 Temperature Behavior 3-5
3.1.2.5 Ambient Conditions 3-5
3.1.2.6 Vehicle Conditions 3-6
3.2 Vacuum Assist Vapor Recovery Systems 3-6
3.2.1 Winter Conditions 3-6
3.2.1.1 Hydrocarbon Behavior 3-6
3.2.1.2 Volume Behavior 3-7
3.2.1.3 Pressure Behavior 3-7
3.2.1.4 Temperature Behavior 3-8
3.2.1.5 Ambient Conditions 3-8
3.2.1.6 Vehicle Conditions 3-8
3.3 Evaluation of Independent and Dependent Variable Relationships 3-9
3.3.1 Ambient Pressure and Temperature Effects 3-9
3.3.2 Vapor Recovery System Design Effects 3-10
3.3.3. Fuel Effects 3-11
3.3.4 Vapor Recovery System Dynamics Effects 3-11

4. DISCUSSION 4-1
4.1 Vapor Recovery System Performance 4-2
4.2 Ambient Conditions 4-4
4.3 Causal Factors Affecting Emissions 4-4
4.4 Interpretation Issues 4-5

5. SUMMARY AND CONCLUSIONS 5-1
5.1 Summary 5-1
5.2 Conclusions 5-2

6. RECOMMENDATIONS 6-1

7. REFERENCES 7-1

APPENDICES

A BALANCE SYSTEM (ARCO) WINTER DATA
B VACUUM ASSIST (SHELL) WINTER DATA
C BALANCE SYSTEM (ARCO) SPRING DATA
D BAY AREA AIR QUALITY MANAGEMENT DISTRICT PERFORMANCE DATA
E 100 CAR TEST DATA SHEETS
F PROJECT QAPP
G AIR RESOURCES BOARD CERTIFICATION AND TEST PROCEDURES

H STATISTICS DEFINITIONS

FIGURES AND TABLES

Figures | Page

1-1 General layout of a GDF vapor recovery system 1-3
2-1 Field Measurement Program Diagram 2-6
2-2 Field Measurement Set-up and Configuration for Test Point One 2-7
2-3 Field Measurement Set-up and Configuration for Test Point Two 2-8
2-4 Field Measurement Set-up and Configuration for Test Point Three 2-9
3-1 Balance System Nozzle Emissions (ppm) for Winter Conditions 3-12
3-2 Balance System Return Emissions (ppm) for Winter Conditions 3-13
3-3 Balance System Vent Emissions (ppm) for Winter Conditions 3-14
3-4 Balance System Nozzle Mass Emissions for Winter Conditions 3-15
3-5 Balance System Return Mass Emissions for Winter Conditions 3-16
3-6 Balance System Vent Mass Emissions for Winter Conditions 3-17
3-7 Balance System Nozzle Volume for Winter Conditions 3-18
3-8 Balance System Return Volume for Winter Conditions 3-19
3-9 Balance System Vent Volume for Winter Conditions 3-20
3-10 Balance System Nozzle Pressure for Winter Conditions 3-21
3-11 Balance System Return Pressure for Winter Conditions 3-22
3-12 Balance System Vent Pressure for Winter Conditions 3-23
3-13 Balance System Nozzle Temperature for Winter Conditions 3-24
3-14 Balance System Return Temperature for Winter Conditions 3-25
3-15 Balance System Vent Temperature for Winter Conditions 3-26
3-16 Balance System Ambient Pressure for Winter Conditions 3-27
3-17 Balance System Ambient Temperature for Winter Conditions 3-28
3-18 Balance System Underground Storage Tank Pressure for Winter Conditions 3-29
3-19 Balance System Leak Rate for Winter Conditions 3-30
3-20 Balance System Vehicle Tank Temperature for Winter Conditions 3-31
3-21 Balance System Nozzle Emissions (ppm) for Spring Conditions 3-32
3-22 Balance System Return Emissions (ppm) for Spring Conditions 3-33
3-23 Balance System Vent Emissions (ppm) for Spring Conditions 3-34
3-24 Balance System Nozzle Mass Emissions for Spring Conditions 3-35
3-25 Balance System Return Mass Emissions for Spring Conditions 3-36
3-26 Balance System Vent Mass Emissions for Spring Conditions 3-37
3-27 Balance System Nozzle Volume for Spring Conditions 3-38
3-28 Balance System Return Volume for Spring Conditions 3-39
3-29 Balance System Vent Volume for Spring Conditions 3-40
3-30 Balance System Nozzle Pressure for Spring Conditions 3-41
3-31 Balance System Return Pressure for Spring Conditions 3-42
3-32 Balance System Vent Pressure for Spring Conditions 3-43
3-33 Balance System Nozzle Temperature for Spring Conditions 3-44
3-34 Balance System Return Temperature for Spring Conditions 3-45
3-35 Balance System Vent Temperature for Spring Conditions 3-46
3-36 Balance System Ambient Pressure for Spring Conditions 3-47
3-37 Balance System Ambient Temperature for Spring Conditions 3-48

3-38 Balance System Underground Storage Tank Pressure for Spring Conditions 3-49
3-39 Balance System Leak Rate for Spring Conditions..... 3-50
3-40 Balance System Vehicle Tank Temperature for Spring Conditions..... 3-51
3-41 Vacuum Assist System Nozzle Emissions (ppm) for Winter Conditions..... 3-52
3-42 Vacuum Assist System Return Emissions (ppm) for Winter Conditions 3-53
3-43 Vacuum Assist System Vent Emissions (ppm) for Winter Conditions 3-54
3-44 Vacuum Assist System Nozzle Mass Emissions for Winter Conditions..... 3-55
3-45 Vacuum Assist System Return Mass Emissions for Winter Conditions..... 3-56
3-46 Vacuum Assist System Vent Mass Emissions for Winter Conditions 3-57
3-47 Vacuum Assist System Nozzle Volume for Winter Conditions 3-58
3-48 Vacuum Assist System Return Volume for Winter Conditions 3-59
3-49 Vacuum Assist System Vent Volume for Winter Conditions..... 3-60
3-50 Vacuum Assist System Nozzle Pressure for Winter Conditions 3-61
3-51 Vacuum Assist System Return Pressure for Winter Conditions 3-62
3-52 Vacuum Assist System Vent Pressure for Winter Conditions..... 3-63
3-53 Vacuum Assist System Nozzle Temperature for Winter Conditions..... 3-64
3-54 Vacuum Assist System Return Temperature for Winter Conditions 3-65
3-55 Vacuum Assist System Vent Temperature for Winter Conditions 3-66
3-56 Vacuum Assist System Ambient Pressure for Winter Conditions..... 3-67
3-57 Vacuum Assist System Ambient Temperature for Winter Conditions..... 3-68
3-58 Vacuum Assist System Underground Storage Tank Pressure for Winter Conditions.. 3-69
3-59 Vacuum Assist System Leak Rate for Winter Conditions..... 3-70
3-60 Vacuum Assist System Vehicle Tank Temperature for Winter Conditions 3-71
4-1 Balance System UST Pressure as a Function of Ambient Pressure Scattergram for Winter Conditions 4-9
4-2 Balance System UST Pressure as a Function of Ambient Pressure Regression for Winter Conditions 4-10
4-3 Balance System UST Pressure Residuals as a Function of Ambient Pressure for Winter Conditions 4-11
4-4 Balance System UST Pressure as a Function of Ambient Pressure Scattergram for Spring Conditions..... 4-12
4-5 Balance System UST Pressure as a Function of Ambient Pressure Regression for Spring Conditions..... 4-13
4-6 Balance System UST Pressure Residuals as a Function of Ambient Pressure for Spring Conditions..... 4-14
4-7 Vacuum Assist System UST Pressure as a Function of Ambient Pressure Scattergram for Winter Conditions..... 4-15
4-8 Vacuum Assist System UST Pressure as a Function of Ambient Pressure Regression for Winter Conditions..... 4-16
4-9 Vacuum Assist System UST Pressure Residuals as a Function of Ambient Pressure for Winter Conditions..... 4-17
4-10 Balance System UST Pressure as a Function of Ambient Temperature Scattergram for Winter Conditions..... 4-18
4-11 Balance System UST Pressure as a Function of Ambient Temperature Regression for Winter Conditions..... 4-19
4-12 Balance System UST Pressure Residuals as a Function of Ambient Temperature for Winter Conditions..... 4-20
4-13 Balance System UST Pressure as a Function of Ambient Temperature Scattergram for Spring Conditions..... 4-21

4-14 Balance System UST Pressure as a Function of Ambient Temperature Regression for Spring Conditions 4-22
4-15 Balance System UST Pressure Residuals as a Function of Ambient Temperature for Spring Conditions 4-23
4-16 Vacuum Assist System UST Pressure as a Function of Ambient Temperature Scattergram for Winter Conditions 4-24
4-17 Vacuum Assist System UST Pressure as a Function of Ambient Temperature Regression for Winter Conditions 4-25
4-18 Vacuum Assist System UST Pressure Residuals as a Function of Ambient Temperature for Winter Conditions 4-26
4-19 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature Scattergram for Winter Conditions 4-27
4-20 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature Regression for Winter Conditions 4-28
4-21 Balance System Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Winter Conditions 4-29
4-22 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature Scattergram for Spring Conditions 4-30
4-23 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature Regression for Spring Conditions 4-31
4-24 Balance System Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Spring Conditions 4-32
4-25 Vacuum Assist System Vehicle Tank Temperature as a Function of Ambient Temperature Scattergram for Winter Conditions 4-33
4-26 Vacuum Assist System Vehicle Tank Temperature as a Function of Ambient Temperature Regression for Winter Conditions 4-34
4-27 Vacuum Assist System Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Winter Conditions 4-35
4-28 Balance System UST Pressure as a Function of Return Volume Scattergram for Winter Conditions 4-36
4-29 Balance System UST Pressure as a Function of Return Volume Regression for Winter Conditions 4-37
4-30 Balance System UST Pressure Residuals as a Function of Return Volume for Winter Conditions 4-38
4-31 Balance System UST Pressure as a Function of Return Volume Scattergram for Spring Conditions 4-39
4-32 Balance System UST Pressure as a Function of Return Volume Regression for Spring Conditions 4-40
4-33 Balance System UST Pressure Residuals as a Function of Return Volume for Spring Conditions 4-41
4-34 Vacuum Assist System UST Pressure as a Function of Return Volume Scattergram for Winter Conditions 4-42
4-35 Vacuum Assist System UST Pressure as a Function of Return Volume Regression for Winter Conditions 4-43
4-36 Vacuum Assist System UST Pressure Residuals as a Function of Return Volume for Winter Conditions 4-44
4-37 Balance System Leak Rate as a Function of UST Pressure Scattergram for Winter Conditions 4-45
4-38 Balance System Leak Rate as a Function of UST Pressure Regression for Winter Conditions 4-46

4-39 Balance System Leak Rate Residuals as a Function of UST Pressure for Winter Conditions 4-47
4-40 Balance System Leak Rate as a Function of UST Pressure Scattergram for Spring Conditions 4-48
4-41 Balance System Leak Rate as a Function of UST Pressure Regression for Spring Conditions 4-49
4-42 Balance System Leak Rate Residuals as a Function of UST Pressure for Spring Conditions 4-50
4-43 Vacuum Assist System Leak Rate as a Function of UST Pressure Scattergram for Winter Conditions 4-51
4-44 Vacuum Assist System Leak Rate as a Function of UST Pressure Regression for Winter Conditions 4-52
4-45 Vacuum Assist System Leak Rate Residual as a Function of UST Pressure for Winter Conditions 4-53
4-46 Balance System Vent Emissions as a Function of UST Pressure Scattergram for Winter Conditions 4-54
4-47 Balance System Vent Emissions as a Function of UST Pressure Regression for Winter Conditions 4-55
4-48 Balance System Vent Emissions Residuals as a Function of UST Pressure for Winter Conditions 4-56
4-49 Balance System Vent Emissions as a Function of UST Pressure Scattergram for Spring Conditions 4-57
4-50 Balance System Vent Emissions as a Function of UST Pressure Regression for Spring Conditions 4-58
4-51 Balance System Vent Emissions Residuals as a Function of UST Pressure for Spring Conditions 4-59
4-52 Vacuum Assist System Vent Emissions as a Function of UST Pressure Scattergram for Winter Conditions 4-60
4-53 Vacuum Assist System Vent Emissions as a Function of UST Pressure Regression for Winter Conditions 4-61
4-54 Vacuum Assist System Vent Emissions Residuals as a Function of UST Pressure for Winter Conditions 4-62
4-55 Balance System Vent Emissions as a Function of Leak Rate Scattergram for Winter Conditions 4-63
4-56 Balance System Vent Emissions as a Function of Leak Rate Regression for Winter Conditions 4-64
4-57 Balance System Vent Emissions Residuals as a Function of Leak Rate for Winter Conditions 4-65
4-58 Balance System Vent Emissions as a Function of Leak Rate Scattergram for Spring Conditions 4-66
4-59 Balance System Vent Emissions as a Function of Leak Rate Regression for Spring Conditions 4-67
4-60 Balance System Vent Emissions Residuals as a Function of Leak Rate for Spring Conditions 4-68
4-61 Vacuum Assist System Vent Emissions as a Function of Leak Rate Scattergram for Winter Conditions 4-69
4-62 Vacuum Assist System Vent Emissions as a Function of Leak Rate Regression for Winter Conditions 4-70

4-63 Vacuum Assist System Vent Emissions Residuals as a Function of Leak Rate for Winter Conditions 4-71

Tables

2-1 Vapor Recovery System Test Conditions 2-2
2-2 Temperature and Fuel Specifications 2-2
2-3 Independent/dependent Variables 2-3
2-4 Field Test Locations 2-4
2-5 Vapor Recovery Specifications 2-4
2-6 Hydrocarbon Analyzer Specifications 2-9
2-7 Pressure Transducers 2-10
2-8 Vehicle Test Matrix 2-13
2-9 ARB Performance Tests 2-13
3-1 Field Sampling, Product Delivery and System Integrity Check Schedule 3-72
3-2 Balance Winter Conditions Sampling Data 3-73
3-3 Balance Winter Conditions Descriptive Statistics for Nozzle Hydrocarbons (ppm) 3-74
3-4 Balance Winter Conditions Descriptive Statistics for Return Hydrocarbons (ppm) 3-75
3-5 Balance Winter Conditions Descriptive Statistics for Vent Hydrocarbons (ppm) 3-76
3-6 Balance Winter Conditions Descriptive Statistics for Nozzle Hydrocarbons (mass) 3-77
3-7 Balance Winter Conditions Descriptive Statistics for Return Hydrocarbons (mass) 3-78
3-8 Balance Winter Conditions Descriptive Statistics for Vent Hydrocarbons (mass) 3-79
3-9 Balance Winter Conditions Descriptive Statistics for Nozzle Pressure ("Hg) 3-80
3-10 Balance Winter Conditions Descriptive Statistics for Return Pressure ("Hg) 3-81
3-11 Balance Winter Conditions Descriptive Statistics for Vent Pressure ("Hg) 3-82
3-12 Balance Winter Conditions Descriptive Statistics for Nozzle Volume (ft^3/sec) 3-83
3-13 Balance Winter Conditions Descriptive Statistics for Return Volume (ft^3/sec) 3-84
3-14 Balance Winter Conditions Descriptive Statistics for Vent Volume (ft^3/sec) 3-85
3-15 Balance Winter Conditions Descriptive Statistics for Nozzle Temperature (R) 3-86
3-16 Balance Winter Conditions Descriptive Statistics for Return Temperature (R) 3-87
3-17 Balance Winter Conditions Descriptive Statistics for Vent Temperature (R) 3-88
3-18 Balance Winter Conditions Descriptive Statistics for UST Pressure ("H2O) 3-89
3-19 Balance Winter Conditions Descriptive Statistics for Leak Rate (CFM) 3-90
3-20 Balance Winter Conditions Descriptive Statistics for Ambient Pressure ("H2O) 3-91
3-21 Balance Winter Conditions Descriptive Statistics for Ambient Temperature (F) 3-92
3-22 Balance Winter Conditions Descriptive Statistics for Vehicle Tank Temperature (F) 3-93
3-23 Vacuum Assist Winter Conditions Sampling Data 3-94
3-24 Vacuum Assist Winter Conditions Descriptive Statistics for Nozzle Hydrocarbons (ppm) 3-95
3-25 Vacuum Assist Winter Conditions Descriptive Statistics for Return Hydrocarbons (ppm) 3-96
3-26 Vacuum Assist Winter Conditions Descriptive Statistics for Vent Hydrocarbons (ppm) 3-97
3-27 Vacuum Assist Winter Conditions Descriptive Statistics for Nozzle Hydrocarbons (mass) 3-98
3-28 Vacuum Assist Winter Conditions Descriptive Statistics for Return Hydrocarbons (mass) 3-99
3-29 Vacuum Assist Winter Conditions Descriptive Statistics for Vent Hydrocarbons (mass) 3-100

3-30 Vacuum Assist Winter Conditions Descriptive Statistics for Nozzle Pressure ("Hg) 3-101
3-31 Vacuum Assist Winter Conditions Descriptive Statistics for Return Pressure ("Hg) 3-102
3-32 Vacuum Assist Winter Conditions Descriptive Statistics for Vent Pressure ("Hg).....3-103
3-33 Vacuum Assist Winter Conditions Descriptive Statistics for Nozzle Volume (ft^3/sec) 3-104
3-34 Vacuum Assist Winter Conditions Descriptive Statistics for Return Volume (ft^3/sec) 3-105
3-35 Vacuum Assist Winter Conditions Descriptive Statistics for Vent Volume (ft^3/sec) ...3-106
3-36 Vacuum Assist Winter Conditions Descriptive Statistics for Nozzle Temperature (R) .3-107
3-37 Vacuum Assist Winter Conditions Descriptive Statistics for Return Temperature (R) .3-108
3-38 Vacuum Assist Winter Conditions Descriptive Statistics for Vent Temperature (R).....3-109
3-39 Vacuum Assist Winter Conditions Descriptive Statistics for UST Pressure ("H2O) 3-110
3-40 Vacuum Assist Winter Conditions Descriptive Statistics for Leak Rate (CFM) 3-111
3-41 Vacuum Assist Winter Conditions Descriptive Statistics for Ambient Pressure ("H2O) 3-112
3-42 Vacuum Assist Winter Conditions Descriptive Statistics for Ambient Temperature (F) 3-113
3-43 Vacuum Assist Winter Conditions Descriptive Statistics for Vehicle Tank Temperature (F) 3-114
3-44 Balance Spring Conditions Sampling Data.....3-115
3-45 Balance Spring Conditions Descriptive Statistics for Nozzle Hydrocarbons (ppm).....3-116
3-46 Balance Spring Conditions Descriptive Statistics for Return Hydrocarbons (ppm).....3-117
3-47 Balance Spring Conditions Descriptive Statistics for Vent Hydrocarbons (ppm) 3-118
3-48 Balance Spring Conditions Descriptive Statistics for Nozzle Hydrocarbons (mass) 3-119
3-49 Balance Spring Conditions Descriptive Statistics for Return Hydrocarbons (mass) 3-120
3-50 Balance Spring Conditions Descriptive Statistics for Vent Hydrocarbons (mass).....3-121
3-51 Balance Spring Conditions Descriptive Statistics for Nozzle Pressure ("Hg) 3-122
3-52 Balance Spring Conditions Descriptive Statistics for Return Pressure ("Hg) 3-123
3-53 Balance Spring Conditions Descriptive Statistics for Vent Pressure ("Hg) 3-124
3-54 Balance Spring Conditions Descriptive Statistics for Nozzle Volume (ft^3/sec).....3-125
3-55 Balance Spring Conditions Descriptive Statistics for Return Volume (ft^3/sec).....3-126
3-56 Balance Spring Conditions Descriptive Statistics for Vent Volume (ft^3/sec) 3-127
3-57 Balance Spring Conditions Descriptive Statistics for Nozzle Temperature (R).....3-128
3-58 Balance Spring Conditions Descriptive Statistics for Return Temperature (R) 3-129
3-59 Balance Spring Conditions Descriptive Statistics for Vent Temperature (R) 3-130
3-60 Balance Spring Conditions Descriptive Statistics for UST Pressure ("H2O).....3-131
3-61 Balance Spring Conditions Descriptive Statistics for Leak Rate (CFM).....3-132
3-62 Balance Spring Conditions Descriptive Statistics for Ambient Pressure ("H2O).....3-133
3-63 Balance Spring Conditions Descriptive Statistics for Ambient Temperature (F) 3-134
3-64 Balance Spring Conditions Descriptive Statistics for Vehicle Tank Temperature (F)...3-135
3-65 Regression Analysis UST Pressure as a Function of Ambient Pressure for Balance System Winter Conditions.....3-136
3-66 Regression Analysis UST Pressure as a Function of Ambient Pressure for Balance System Spring Conditions.....3-137
3-67 Regression Analysis UST Pressure as a Function of Ambient Pressure for Vacuum Assist Winter Conditions.....3-138
3-68 Regression Analysis UST Pressure as a Function of Ambient Temperature for Balance System Winter Conditions.....3-139
3-69 Regression Analysis UST Pressure as a Function of Ambient Temperature for Balance System Spring Conditions.....3-140
3-70 Regression Analysis UST Pressure as a Function of Ambient Temperature for Vacuum Assist Winter Conditions.....3-141

3-71 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature for Balance System Winter Conditions 3-142
3-72 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature for Balance System Spring Conditions 3-143
3-73 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature for Vacuum Assist Winter Conditions 3-144
3-74 Regression Analysis UST Pressure as a Function of Return Volume for Balance System Winter Conditions 3-145
3-75 Regression Analysis UST Pressure as a Function of Return Volume for Balance System Spring Conditions 3-146
3-76 Regression Analysis UST Pressure as a Function of Return Volume for Vacuum Assist System Winter Conditions 3-147
3-77 Regression Analysis Leak Rate as a Function of UST Pressure for Balance System Spring Conditions 3-148
3-78 Regression Analysis Leak Rate as a Function of UST Pressure for Vacuum Assist System Winter Conditions 3-149
3-79 Regression Analysis Leak Rate as a Function of UST Pressure for Vacuum Assist System Winter Conditions 3-150
3-80 Regression Analysis Vent Emissions as a Function of UST Pressure for Balance System Winter Conditions 3-151
3-81 Regression Analysis Vent Emissions as a Function of UST Pressure for Balance System Spring Conditions 3-152
3-82 Regression Analysis Vent Emissions as a Function of UST Pressure for Vacuum Assist System Winter Conditions 3-153
3-83 Regression Analysis Vent Emissions as a Function of Leak Rate Balance System Winter Conditions 3-154
3-84 Regression Analysis Vent Emissions as a Function of Leak Rate Balance System Spring Conditions 3-155
3-85 Regression Analysis Vent Emissions as a Function of Leak Rate Vacuum Assist System Winter Conditions 3-156

Section 1

INTRODUCTION

1.1 STUDY OBJECTIVES

This research project was designed to quantify hydrocarbon emissions at gasoline dispensing facilities (GDF) and to evaluate which variables influence the magnitude of GDF emissions. Specifically, there were four objectives for this project:

1. Assess the effectiveness of balance and vacuum assist Stage II vapor recovery systems (VRS) in reducing emissions under a variety of seasonal, gasoline characteristics, and GDF conditions.

2. Identify and characterize the parameters that influence GDF emissions, develop correlations between these parameters, facility emissions and Stage II system performance, and derive a mathematical expression, which relates facility emissions with the parameters that influence GDF emissions.

3. Derive emission factors for the different emittant sources at GDFs for a variety of Stage II VRS.

4. Improve the Certification and Test Procedures (C&TP) by develop a standardized methodology for determining GDF emissions and Stage II vapor recovery system efficiency.

1.2 BACKGROUND

Emissions from gasoline service stations represent a significant inventory component. As automobile emission standards result in lower hydrocarbon exhaust emissions per mile, the relative importance of fueling station emissions increases. Gasoline dispensing facilities (GDF) have been subject to pollution control since the 1970s. These stationary sources are a potentially important source of hydrocarbon compounds (VOC) that interact with nitrogen oxides to form ambient oxidants. In nonattainment areas, initial control efforts addressed VOC releases through the installation of vapor recovery systems (VRS) for product delivery processes (Phase I) and product dispensing activities (Phase II). In 1985, emissions from GDFs were regulated statewide by mandating the installation of Phase II VRS on GDFs with annual throughput of at least 480,000 gallons. The purpose of this program is to reduce benzene exposure from fuel dispensing activities. More recently, season-specific formulations of gasoline have been rolled-out to fulfill the need for low volatility gasoline in the summer.

1.2.1 Gasoline Dispensing Facilities Vapor Recovery Systems

At GDFs, vapor recovery is a general term describing methods for preventing the release of VOC emissions into the atmosphere during product unloading or customer refueling events. Figure 1-1 illustrates the general layout of a GDF vapor recovery system. Phase I vapor recovery controls emissions (i.e., transfer emissions) during product deliveries by capturing the vapors in the delivery truck and returning them to the terminal for processing. Phase II vapor recovery, which controls emissions (i.e., transfer emissions) from vehicle fueling operations, captures vapors at the vehicle fill pipe and returns them to the facility underground storage tanks (UST). Two types of Phase II systems have been developed: (1) balance systems and (2) vacuum assist systems. Balance systems operate on the principle of positive displacement during refueling. Vacuum in the storage tank is created when fuel is removed, while at the same time, positive pressure is created in the vehicle fuel tank by incoming liquid gasoline. Saturated vapor is therefore forced out and pulled through the nozzle, vapor passage, and into the UST. The specific process under which balance systems function is a vapor path is established between the dispensing nozzle and the underground vapor return line connected to the dispenser via a coaxial hose. Fuel passes through the inner hose, while vapor is shunted through the outer hose. A bellows surrounding the nozzle spout completes the vapor return path from the vehicle fill pipe opening to the UST. During fueling, the bellows faceplate is pressed tight against the fill pipe opening so that vapors displaced from the fuel tank by the dispensed gasoline are forced back through the vapor return path and into the UST.

In a vacuum assist vapor recovery system, as soon as gasoline is dispensed a vacuum generating device (i.e., an in-line turbine or a vacuum pump) is used to create a suction which pulls vapors from the vehicle tank into the UST via a coaxial hose. In theory, a tight seal at the nozzle/fillpipe interface is not necessary for effective recovery. Vacuum assist systems vary in their design, their choice of vacuum creating devices, and collected vapor to air ratios, a fundamental metric measuring the vapor recovery efficiency of a vacuum assist system.

Some vacuum assist systems are equipped with a vacuum pump that is designed to collect a vapor volume larger than the space available for vapor storage above the liquid in the UST. Excess air along with the saturated vapor is drawn in due to loose fitting nozzles or the varying volumes of fuel dispensed while the vacuum remains constant. To offset this phenomena, an on-line processor, such as a high efficiency incinerator, is used to convert excess vapor into mainly carbon dioxide and water and possibly uncombusted gasoline vapors. The processor may be activated when the internal pressure of the storage tank reaches atmospheric or, in other processor systems, the processor is ignited when the vapor pressure in the return lines exceeds a designated amount (e.g., one inch water column).

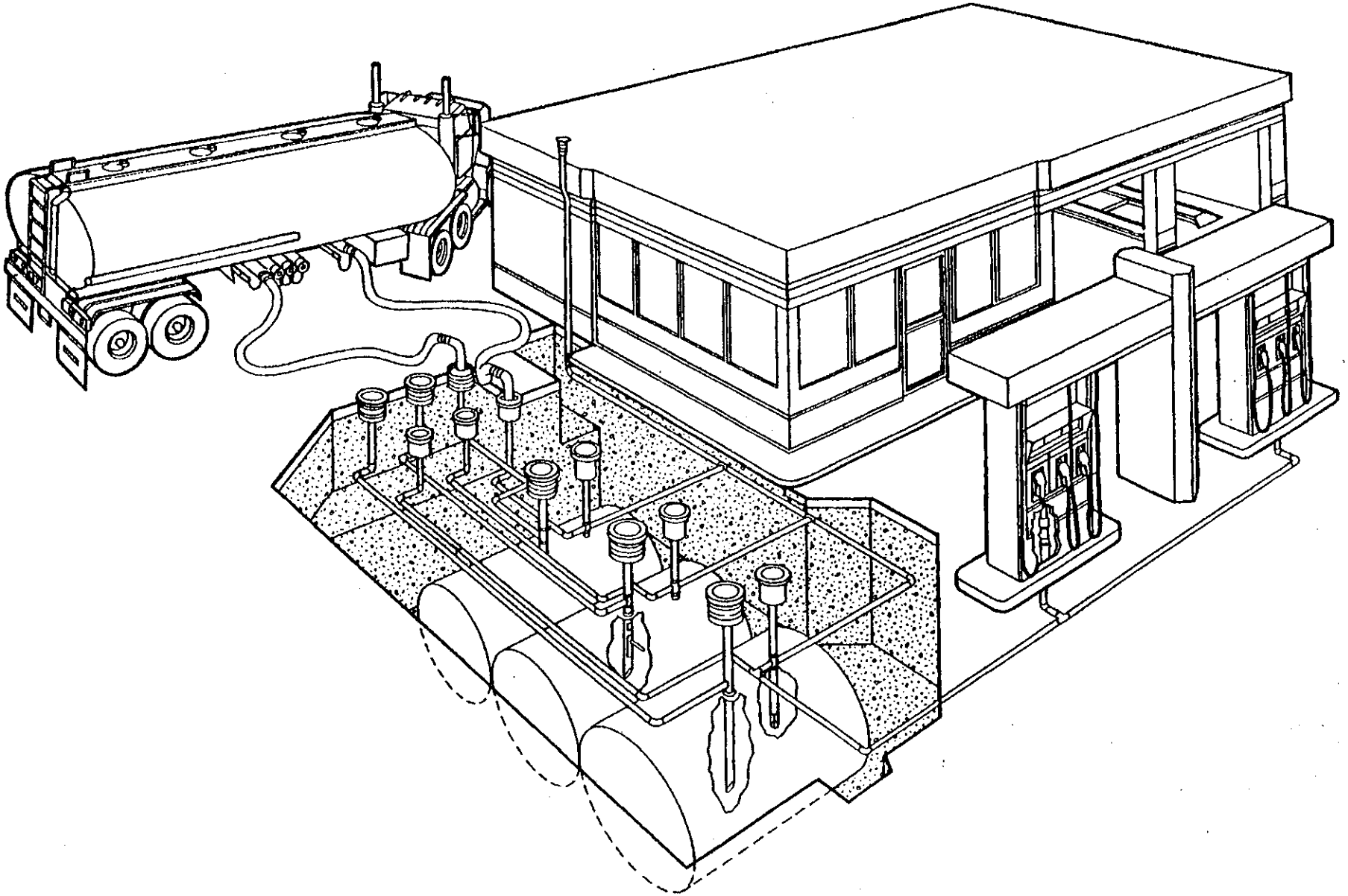


Figure 1-1 Typical Layout of Gasoline Dispensing Facility

Other vacuum assist system designs do not rely on processors. These systems use fluid driven pump units or rely exclusively on an electronically driven vacuum pump unit to generate (1) the prerequisite vacuum and (2) the control of air/liquid (A/L) ratio specifications based on the dispensing rate. In these systems, since the flow of fuel to the UST, directly or indirectly, regulates the vacuum produced at the vehicle fillpipe, the A/L ratio should be approximately one to one, eliminating the need for system processors.

As previously described, balance and vacuum assist systems are further differentiated by nozzle type. Balance nozzles integrate bellows or boots which surround the nozzle to form a seal at the nozzle/car interface. In contrast, assist nozzles may be bootless or may contain a bell or minibellows surrounding the nozzle design. While balance and vacuum assist systems attempt to control all VOC releases, spillage and fugitive emissions may occur at GDFs as part of both product delivery and dispensing activities.

Since 1990, pressure/vacuum valves have been added to the top of the UST vent line to reduce UST fugitive emissions. For example, since balance systems operate near atmospheric pressure, a P/V valve installed at the vent line riser can provide effective control of system emissions. Recent research activities suggest these devices are very effective in controlling vent line fugitive emissions (Shearer et. al., 1994).

1.3 STUDY ASSUMPTIONS AND HYPOTHESES

The hypothesis that this research project is intended to evaluate is that several determinant parameters (e.g., ambient weather conditions, UST pressure) defined as study independent variables are the predominant factors that govern emissions (i.e., dependent variables) at GDFs. The specific inventory of independent variables that account for the majority of variance in the dependent measures is to be determined in the initial phase of this study. However, based on published literature, the specific thesis that this project will validate or invalidate is that internal VRS pressure, mediated by VRS design parameters and ambient meteorological conditions, is predominant predictor of GDF emissions.

1.4 STUDY REPORT CONTENT

The content of this report includes only data collected at three of the test sites for the uncontrolled test series. Two winter condition sites are reported, a balance VRS location and a vacuum assist VRS locale. Both sites used winter fuel during the test period. One spring site is reported, a balance VRS facility. Summer fuel was being dispensed during the on-site testing. The results of the other proposed test sites are not included in this report.

Section 2

MATERIALS AND METHODS

2.1 STUDY DESIGN

The study design of a research project specifies the test conditions that allow the specific objectives of the research project to be realized. For this project, the specifics of the test conditions articulate how the research project was executed.

2.1.1 Test Conditions

As defined in the project RFP, there were two basic test conditions for this project, which were called test series: the uncontrolled test series and the controlled test series. Each test series had unique yet related study designs. Due to several factors, only a portion of the uncontrolled test series was executed during this research project. For this reason, only the study design for the uncontrolled test series is described below.

2.1.1.1 Uncontrolled Test Series

The uncontrolled test series was designed to evaluate the influence of a range of parameters (i.e., independent variables) on different GDF emission sources (i.e., dependent variables). The goal of this empirical evaluation was to determine which independent variables predict (i.e., account for the variance) GDF emissions. This relationship was to be expressed as a mathematical expression or multivariate regression model. The specific objectives of the uncontrolled test series were therefore:

1. Quantify GDF emissions including transfer, vent line, spillage and fugitive sources for two types of VRS: balance and vacuum assist (Tables 2-1 and 2-2).

2. Quantify GDF emissions including transfer, vent line, spillage and fugitive sources for two ambient temperature conditions and two types of fuel (Table 2-2).

3. Develop correlations between VRS type emission sources and a range of independent variables that are postulated to influence emission rate and magnitude.

4. Derive emission factors in pounds/1000 gallons dispensed for the VRS type emission sources, including transfer, vent line, spillage and fugitive sources.

5. Determine the relative importance of each independent variable on the efficiency of specific VRS performance.

Based on these objectives and the executed work for this study, there were a total of three field test conditions for the uncontrolled test series. The location of the GDFs was in the east San Francisco Bay area. These test locations have product throughput of no less than 100,000 gallons per month (at least 16 nozzles).

Table 2-1
Vapor Recovery System Test Conditions

Test Mode	VRS Type	Vent Valve	Assist Pump Location	Bell	Incinerator
1	Balance	Yes	N/A	No	No
2	Vacuum Assist	Yes	Dispenser	No	No

Table 2-2
Temperature and Fuel Type Specifications

Test Mode	Ambient Temperature	Fuel Type
1,2,	40 ± 10° F	Winter
1	60 ± 10° F	Spring

Independent and Dependent Variables

Table 2-3 specifies the array of independent and dependent variables that were measured or monitored in the field for each of the test conditions:

Table 2-3
Independent/Dependent Variables

Variable	Independent or Dependent	VRS System Type	Measurement Team
Ambient Temperature and Pressure	Independent	BA	AVES
Site Location	Independent	BA	AVES
Static Pressure	Independent	BA	BAAQMD
UST Gauge Pressure	Independent	BA	AVES
Vehicle Fuel Tank Temperature in Vapor	Independent	BA	AVES
UST Ullage Capacity	Independent	BA	AVES
Air/Liquid Ratio	Independent	A	BAAQMD
Dynamic Back Pressure	Independent	B	BAAQMD
Station Design	Independent	BA	AVES
Vent emissions	Dependent	BA	AVES
Fugitive emissions	Dependent	BA	AVES
Bulk fuel deliveries	Dependent	BA	AVES

Where:]

B = Balance
A = Vacuum Assist
AVES = AeroVironment Environmental Services
BAAQMD = Bay Area Air Quality Management District

Based on the work executed for the study, the independent variables evaluated were ambient temperature and pressure, system type, and system static pressure (a measure of system tightness).

Development of Emission Factors for GDFs

The emissions data collected in the uncontrolled test series were used to derive emission factors for the balance and Gilbarco vacuum assist VRS evaluated relative to independent/dependent variable interactions. The emission factors are reported in Section 3 of this report.

Development of Variable Correlations

Regression analysis were used to correlate the independent and dependent variables.

2.2 STUDY SITES

The criteria for selecting the GDF measurement sites included the following characteristics:

- Proximity to both Sacramento and the San Francisco Bay area.
- A product throughput of at least 100,000 gallons per month (> 16 nozzles).
- The presence of tank level monitors on the GDF underground storage tank or a computerized tracking system for product volume.
- The sites contained the balance or Gilbarco vacuum assist VRS required for the study.

Based on these criteria, Table 2-4 lists the site location used for the field study.

Table 2-4
Field Test Locations

Vapor Recovery System Type	WSPA Member Company	Address	Test Dates
Balance	ARCO	3000 Travis Boulevard Fairfield, CA	12/8/98-12/9/98 5/28/99-5/30/99
Gilbarco Vacuum Assist	Shell	3621 San Pablo Dam Road El Sobrante, CA	2/5/99- 2/6/99

Table 2-5
Vapor Recovery Specifications

VRS Type	Manufacturer	Nozzle
Balance	Tolkeim 162 L-1-RC-TW (Executive Order 52)	Emco Wheaton A4001 16 nozzles
Vacuum Assist	Gilbarco VaporVac AL121OC (Executive Order G-70-150) OPW P/V Valve 523LPS-2250	OPW 11VA 27 19 Nozzles Emco Wheaton 4505 5 Nozzles

2.3 FIELD PARAMETER MEASUREMENTS

The field measurement process targeted a suite of parameters as specified by the Air Resources Board's Certification and Test Procedures (C & TP). For this project, there were four relevant certification and test procedures:

TP-201.2 - Determination of Efficiency of Phase II Vapor Recovery Systems of Dispensing Facilities: The purpose of this test procedure is to determine the percent vapor recovery efficiency for a vapor recovery system at a GDF. The percent vapor recovery efficiency is the percent of vapors displaced by dispensing which are recovered by a vapor recovery system rather that emitted to the atmosphere.

TP-201.2A - Determination of Vehicle Matrix for Phase II Vapor Recovery Systems of Dispensing Facilities: The purpose of this test procedure is to ensure that the sample of vehicles to be used in TP-201.2 is made up of vehicles representative of the on road vehicle population in terms of vehicle miles traveled. This calculation procedure produces such a representative vehicle matrix.

Proposed TP-201.2B - Determination of Flow Versus Pressure for Equipment in Phase II Vapor Recovery Systems of Dispensing Facilities: The TP-201.2B test procedure used for this project is a proposed procedure (Proposed Draft Date: 1/95) that has not been formally integrated into the ARB vapor recovery test procedures. The purpose of this proposed test procedure is to determine fugitive emission profiles for dominant fugitive emission sources (i.e., idle nozzles, UST overfill drains, P/V valves) and the vapor recovery efficiency at GDFs. This is in contrast to the current adopted TP-201.2B procedure that develops flow vs. pressure profiles for the entire GDF as opposed to specific GDF fugitive emission sources.

The mass flux of fugitive emissions from a dispensing facility is the product of the volumetric flow rate and the flow-weighted mass per volume concentrations. The volumetric flow rate is based on data for pressure vs. time from the facility and data for flow vs. pressure from a model of the facility. The model flow vs. pressure data provides a conversion for the facility pressure vs. time data to flow vs. time data. In contrast to the field based hydrocarbon test procedures, the flow/pressure simulation model for TP-201.2B was executed in the Acurex laboratory as a bench top experiment with site-specific pressure signatures provided by the BAAQMD performance tests.

The specifics of these test procedures are contained in the project QAPP located in Appendix E. For the purposes of this project and as specified in TP-201.2, there were three test locations at each of the two field test sites where hydrocarbon concentration (measured as propane), VRS vent pressure, VRS temperature, and VRS vapor volume (measured as flow) were quantified:

- Test Point 1 - The nozzle fill neck interface
- Test Point 2 - The dispenser vapor return line
- Test Point 3 -The UST vent line riser outlet

Figure 2-1 illustrates the field measurement program and it's various elements (Appendix B, Figure 1, TP-201.2). Figures 2-2, 2-3 and 2-4 specify the measurement locations for each of the recorded parameters at test points 1-3. All procedures were executed in the field with the exception of the flow/pressure simulation model for TP-201.2B which was executed in the Acurex laboratory as a bench top experiment with site-specific pressure signatures provided by the BAAQMD performance tests. Apart from the VRS measurement protocols, general site characteristics were assessed including underground storage tank pressure and meteorological metrics.

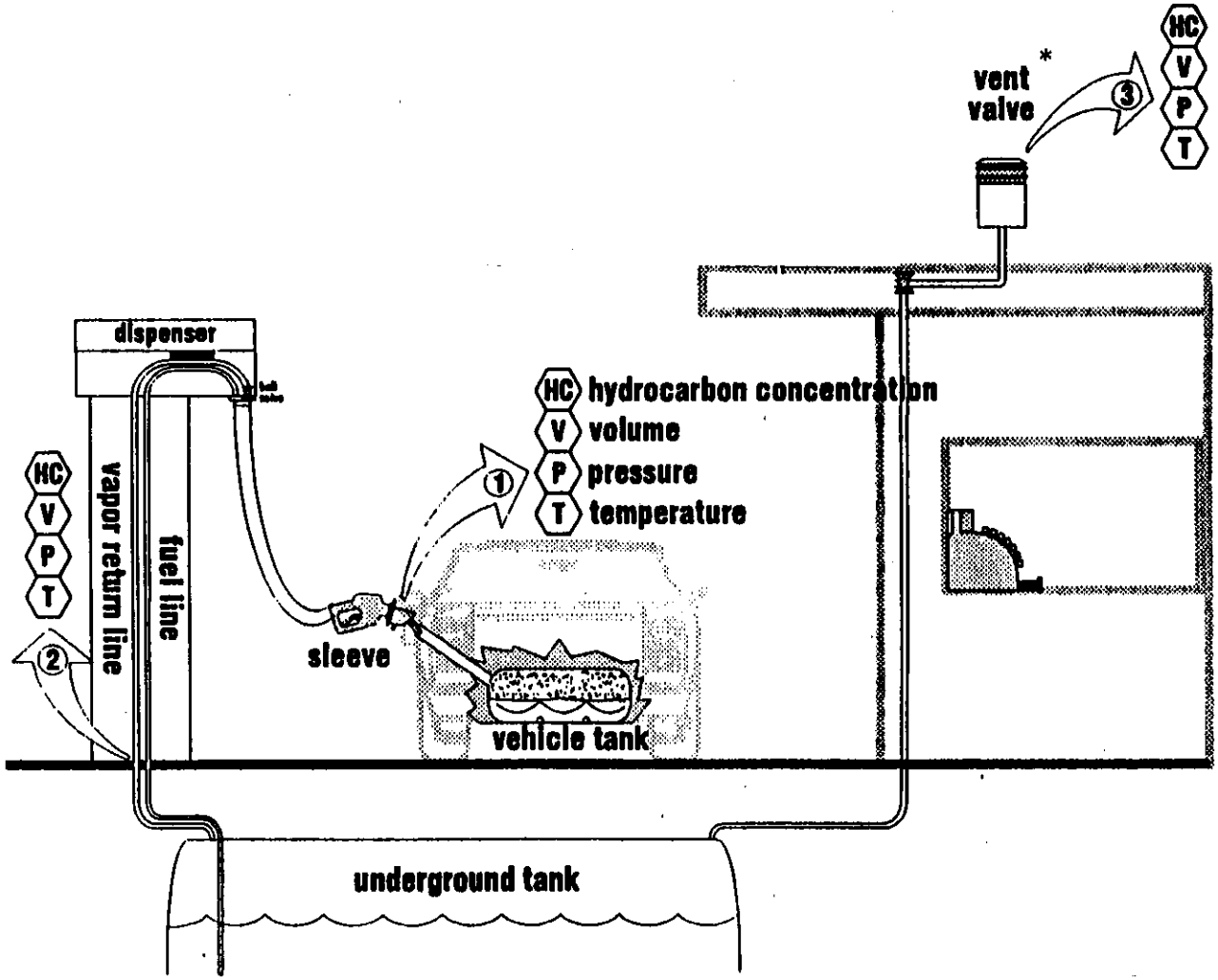


Figure 2-1 Field Measurement Program

* Test Points 1 & 2 represent actual test locations. Test Point 3 test location is illustrated in Figure 2-4.

Source: ARB Certification and Test Procedure TP-201.2

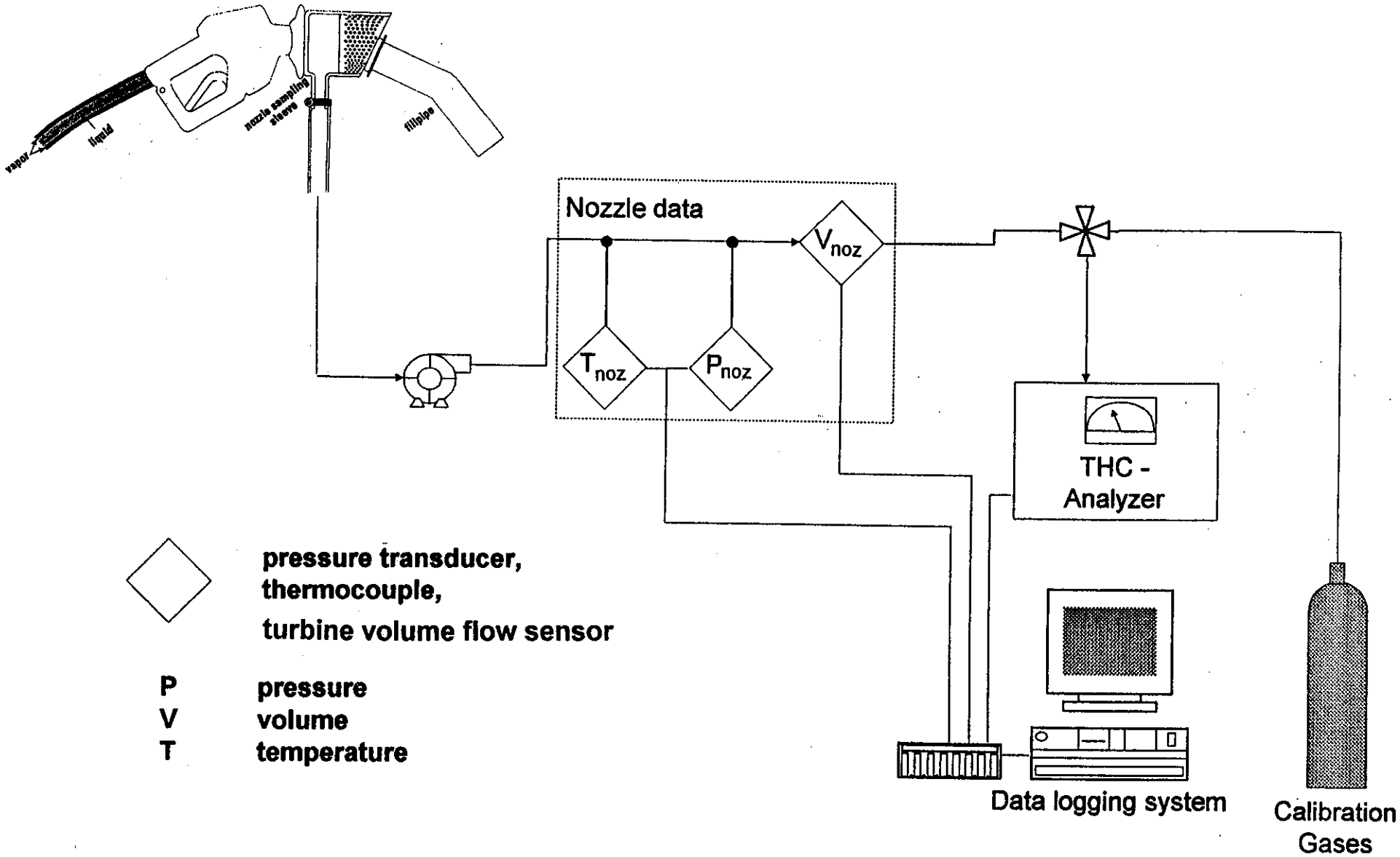


Figure 2-2 Field Measurement Set-up and Configuration for Test Point One

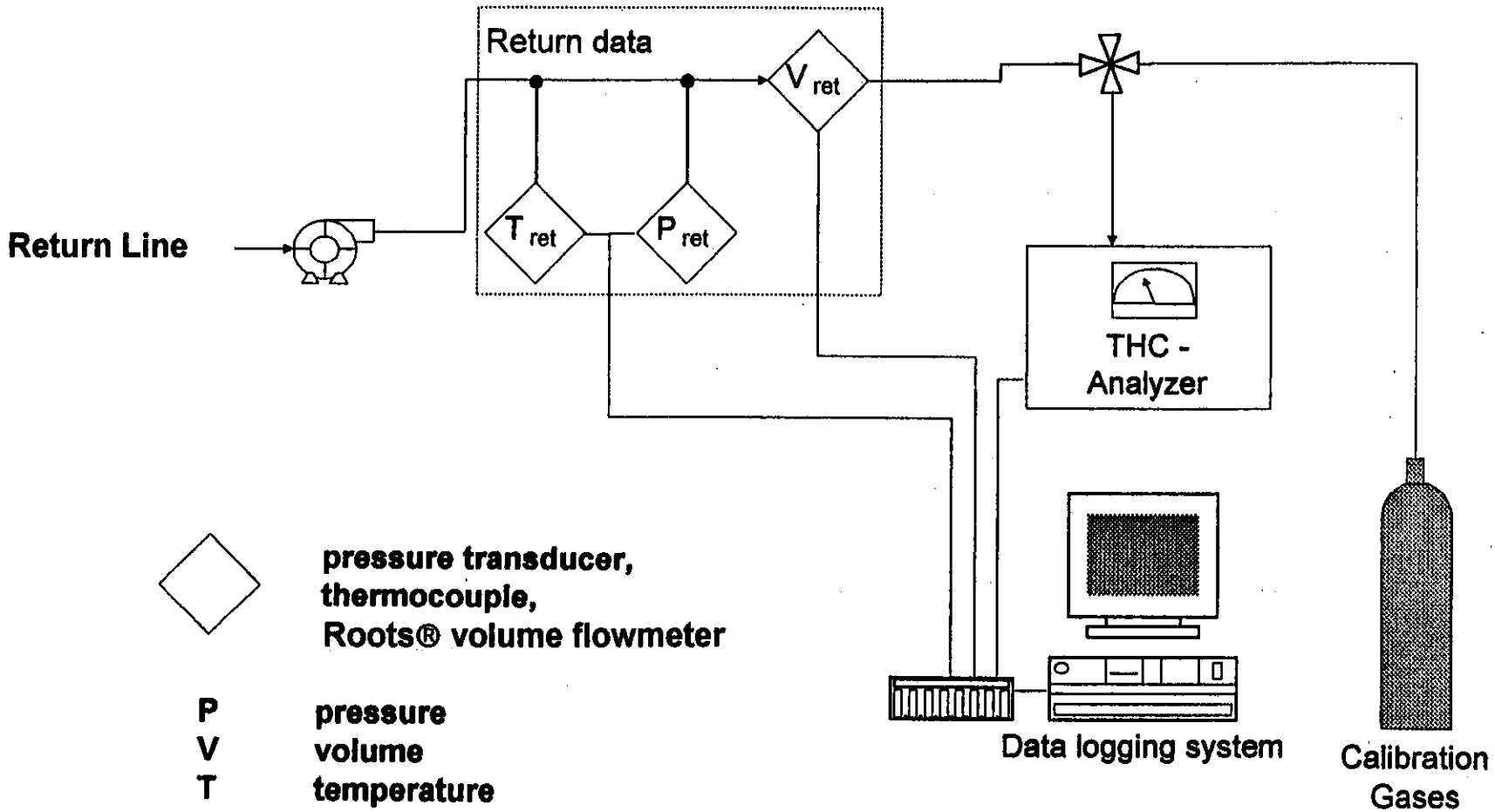


Figure 2-3 Field Measurement Set-up and Configuration for Test Point Two

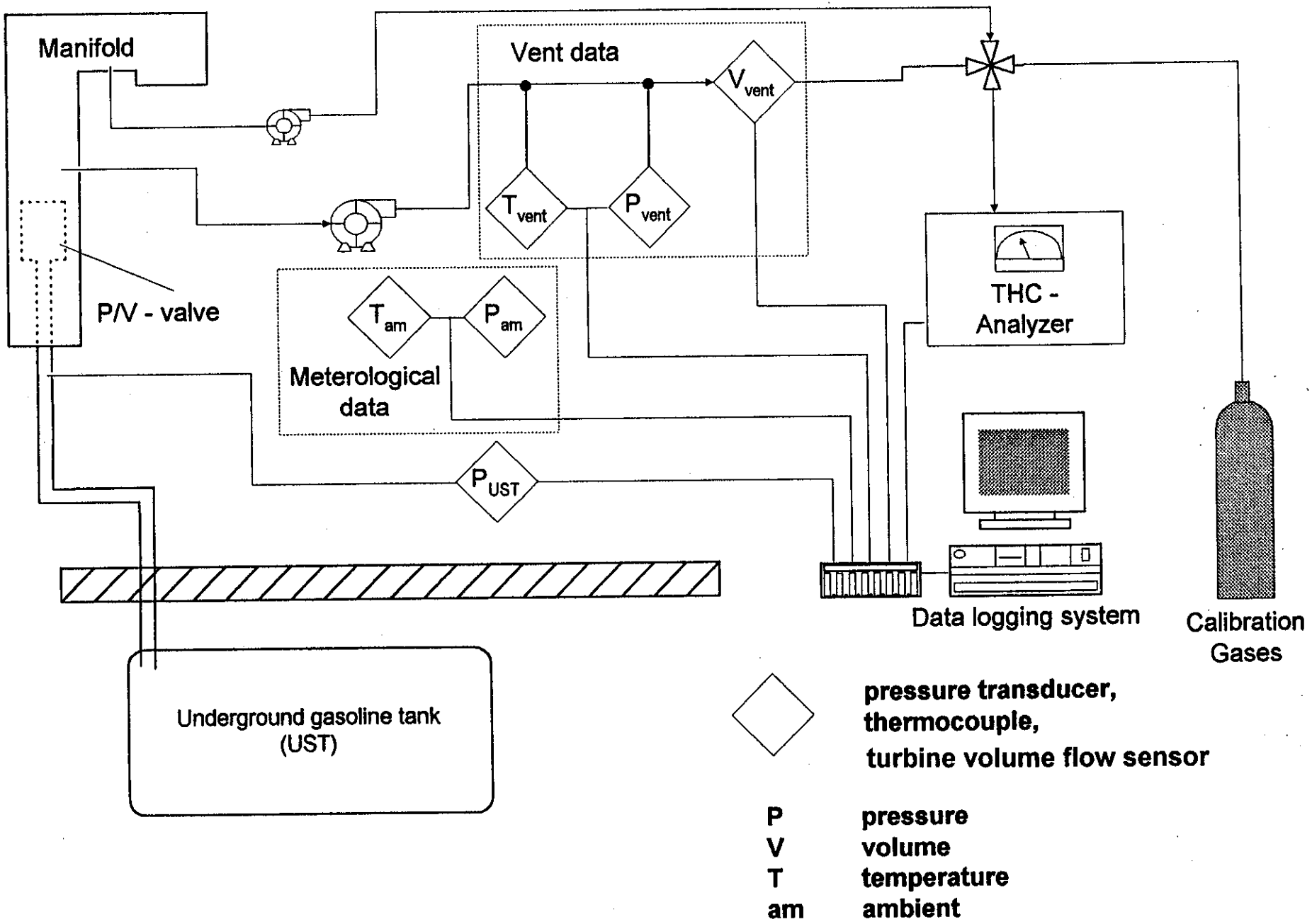


Figure 2-4 Field Measurement Set-up and Configuration for Test Point Three

With the exception of test point three (the vent line), all field measurement procedures were executed in conformity with the C & TPs. For test point three, the field measurement sample train consisted of a PVC manifold with sample ports that was placed over vent line riser. Discrete sample ports existed for temperature, pressure, and volume/hydrocarbon sampling functions. This method was developed, validated, and field tested at previous field test sites by the project researchers (AeroVironment, 1994).

The primary objective of the vent line monitoring methodology was to develop a nonintrusive measurement system that did not affect vapor or airflow in and out of the vent line. Previous studies have been critiqued for using instrumentation, such as flowmeters, attached to the vent line outlet that increase or decrease vent line VOC emissions relative to baseline conditions. The range of parameters necessary to describe GDF system characteristics impose demanding requirements for an ideal monitoring system. The monitoring system must be able to measure a wide range of flow rates (e.g., -50 to +50 liters per minute), vent line pressure values (e.g., -1 to +1 inch of water column [w.c.]) and VOC vent line concentrations (1-40,000 ppm). These measurements must not skew the calculated vent line VOC emission factors.

For the monitoring system to generate valid data, the following critical system performance requirements were established:

1. The sample train must not perturb normal UST in-breathing and out-breathing. The sample manifold was designed to minimize positive and negative pressures that could potentially impact VOC emissions from the vent line. Too high a sample rate could potentially influence UST emissions.

2. The sample line flow rate (100 lpm) must be higher than the greatest anticipated flow rate from the UST vent line. If the UST emission flow rate exceeded the sample line flow rate, the sampling system would not capture 100 percent of the vent line VOC emissions and underestimate vent line VOC emissions using Equation (2-1).

In order to measure VOC emissions from the vent line without affecting vent line flow, a nonperturbing and nonintrusive monitoring system was used for this study. Instead of putting a flowmeter on the vent line that could impose a restriction on flow, an open sampling manifold attached to an air pump was installed on the vent line. Air was drawn at 100 liters per minute (lpm) through a sample port in the manifold such that any air or vapors expelled from the vent would be captured in the manifold and drawn into the sampling system. The VOC concentration and flow rate in the sample line were continuously monitored using a flame ionization detector hydrocarbon analyzer and a turbine flow sensor respectively. A data logger scanned the instantaneous VOC analyzer output and flowmeter sample rate data every second to calculate one-minute averages for flow rate, and VOC concentration calibrated to propane. These one-

minute VOC and flow rate averages were used to calculate one-minute average VOC emission rates using the following expression:

VOC concentration (mg/m^3) x flow rate (m^3/min) = VOC emission rate (mg/min) (2-1)

2.3.1 Meteorological Measurements

At each site, ambient meteorological measurements were data logged continuously during the C & TP measurement program. The location of the meteorological instrumentation was directly adjacent to the field test van to facilitate data logging ease. However, recognizing potential interferences from the field test van, the meteorological tower was be far enough away (i.e., six feet above the top of the van) to minimize external interferences.

Ambient temperature values were assessed using an Omega K-type thermocouple probe assembly with a transjoint (TJ48-CASS-14G-12—BX-OST-M) integrated with an Action Instruments TC temperature signal conditioner (Model 4351-2000). A K-type thermocouple is a temperature measurement sensor that consists of two dissimilar metals joined together at one end (a junction) that produces a small thermoelectric voltage when the junction is heated. The voltage output is proportional to the difference in temperature between the hot junction and the lead wires. The change in thermoelectric voltage is interpreted by the TC temperature signal conditioner, a pulse accumulator device which conditions the temperature resistance signal. The conditioned signal is a voltage output with a 0-5 volt scale. . The signal conditioner output was calibrated to degrees Rankine prior to field deployment. The TC temperature signal conditioner output served as input into the field data acquisition system, with a temperature value recorded every second.

Ambient pressure was recorded using an Omega Model PX02 absolute pressure barometer. As with temperature, a pressure value was determined every second and subsequently data logged.

2.3.2 Hydrocarbon Measurements

The hydrocarbon measurements were performed according to the procedures specified in ARB C & TPs.

2.3.2.1 Analytical Procedures for TP-201.2

As specified in the C & TPs, the hydrocarbon measurements were performed according to EPA reference method 25A. EPA Method 25A describes the determination of total gaseous organic compound emissions using a flame ionization detector. The principle of operation for the flame ionization detector method (EPA 25A) is that a hydrocarbon gas sample is extracted from the source through a sample line and a glass fiber filter

and subsequently fed to the flame ionization analyzer. Results are reported as volume concentration equivalents of the calibration gas or as carbon equivalents.

The specifications of the hydrocarbon analyzers used for this project are tabulated in Table 2-6. The hydrocarbon sample trains for sample points one and two are described in TP-201.2 (Appendix H). The vent line hydrocarbon sample train was previously discussed.

Table 2-6
Hydrocarbon Analyzer Specifications

Instrument Model Number	Analytical Method	Test Points	Operating Range (ppm as C_3)	Use
Beckman Model 400A	FID	1	1,000	Concentrations at vent line outlet
California Analytical Model 100	NDIR	2	1,000,000 (0-100%)	Concentrations at return line
Ratfisch Model RS 55CA	FID	1	1,000	Concentrations at nozzle/sleeve

In addition, an ancillary hydrocarbon detection procedure (measured as percent LEL) was executed at test point one for the purposes of assessing leakage at the vehicle/nozzle interface. This consisted of using a Thermo Environmental Instruments GT-105 combustible gas meter.

The duration of the hydrocarbon assessment procedures consisted of measuring hydrocarbon releases at the three sample points for 100 refueling car events. The hydrocarbon data was data logged into the data acquisition system with a data point collected every second.

2.3.2.2 Analytical Procedures for TP-201.2B

The objective of this TP-201.2B is to estimate site-specific fugitive emissions by determining the flow leaving the facility as a function of VRS pressure signatures. Fugitive emission sources include UST vent lines equipped with P/V valves, "closed" idle nozzle check valves and "closed" overfill drain valves.

Several parameters need to be quantitatively measured to produce a value for fugitive mass flux including:

Facility VRS volumetric leak flow rate
Facility VRS pressure profiles
Hydrocarbon concentrations (hydrocarbon mass/volume of hydrocarbon emitted
Facility VRS temperate profiles

To generate the pressure and flow values, the BAAQMD executed two inch static pressure performance tests (C & TP TP-201.3) at each field test sites. This procedure pressurizes the entire vapor recovery system to two inches water column. After five minutes, the VRS pressure is noted and compared to allowable levels. Using standard engineering principles, the volumetric leak flow rate (Q) can be calculated. This value, coupled with the flow-weighted hydrocarbon mass per volume concentration yields the mass flux of fugitive emissions leaving the GDF for the TP-201.3 pressure conditions.

Hydrocarbon concentrations (mass/volume) were assayed at the vent line upstream from the P/V valves rather than downstream. The lack of downstream hydrocarbon data as excluded the calculation of fugitive emissions for this project. The UST pressure dependent Q values were used as a surrogate for facility fugitive emissions. Facility pressure and temperature profiles were collected during the execution of TP-201.2. These include maximum and minimum facility throughputs and product bulk drops.

As specified in the proposed TP-201.2B test procedure used for this project (Proposed Draft Date: 1/95), to model the facility to yield a facility specific Q value, a PVC pipe was pressurized to 2" WC and a hole was subsequently drilled in it of a size yielding the same average leak flow that occurred during the BAAQMD administered five minute pressure decay test on the VRS in which the pressure dropped from 2 "WC to 1.96 "WC. (as determined by TP-201.3). Having simulated the site-specific field leak rate (Q) , the PVC pipe was pressurized for a range of values to yield sufficient pressure/flow data points to estimate a pressure/flowrate function for the test site. With the facility model, volumetric leak flow rates (Q) were determined for the empirical time dependent pressure profile conditions found at the field test site.

2.3.3 Pressure Measurements

Based the specifications of TP-201.2, pressure readings were taken at the vent line outlet, the return line and nozzle concurrent with the hydrocarbon measurements. The specific locations for the pressure transducers on the sample manifolds were upstream from the hydrocarbon vapor sampling lines. In the case of sample point three, the pressure sampling line was ambient relative to the P/V valve. The pressure transducers that were used are tabulated in Table 2-7. Concurrent with the vent line pressure values, underground storage tank (UST) pressure conditions were assessed by suspending a pressure transducer down the vent line riser to a location approximately 2 feet below grade. This location served as a surrogate for measuring in situ UST pressure because of a lack of access to the actual UST.

Table 2-7
Pressure Transducers

Transducer Make	Model	Range
Omega	PX654-01BD5V	± 1.0 in. WC
Omega	PX240	±0 2.5 in. WC
Omega	PX654-50BD5V	±0 5.0 in. WC
Omega	PX654-10BD5V	±0 10.0 in. WC

2.3.3.1 Analytical Procedures for TP-201.2

As is apparent from Table 2-7, ranges of differential Omega pressure transducers were available for the field technicians. The specific transducer used depended on the vapor recovery system pressure profile at the time of the test. Initial pressure values were observed prior to initiation of actual field data acquisition. In addition, for the vacuum assist test site, archival VRS pressure data was available from Gilbarco to aid in the selecting the appropriate pressure sensor. For the ARCO site, vent pressure was measured using an Omega PX654-50BD5V (±0 5.0 in. WC), the return line pressure was measured using an Omega PX654-50BD5V, at the nozzle pressure was evaluated using a Omega PX654-50BD5V. At the Shell vacuum assist site, vent pressure was measured using an Omega PX654-50BD5V (±0 5.0 in. WC), the return line pressure was measured using an Omega PX654-50BD5V, at the nozzle pressure was evaluated using a Omega PX654-50BD5V. For both sites, UST pressure was quantified using an Omega PX240 (±0 2.5 in. WC). The pressure values were recorded every second and data logged using the test van data acquisition system.

2.3.4 Temperature Measurements

Based on the specifications of the study design document and the relevant C & TPs, temperature was continuously recorded at the three test points. In addition, the temperature of the vehicle fuel tank vapor was recorded.

2.3.4.1 Analytical Procedures for TP-201.2

Temperature was measured using an Omega K-type thermocouple probe assembly with a transjoint (TJ48-CASS-14G-12—BX-OST-M) integrated with an Action Instruments TC temperature signal conditioner (Model 4351-2000). The temperature signal conditioner was used to convert the thermocouple probe output into a voltage signal that can be input into the field test van data acquisition system. The range of the K-type thermocouple probe is 0-200 °F. The specific location of the thermocouple probe was upstream from the hydrocarbon measurement sample port. A temperature value was recorded every second and fed into the data acquisition system.

2.3.4.2 Analytical Procedures for Ancillary Temperature Readings

Vehicle fuel tank temperature was measured using an Omega K-type thermocouple 24 inch handle probe (3/16" diameter) (Model No. KHIN-316) wired into a Omega handheld thermometer (Model No. HH-25K). This was executed immediately after the vehicle driver had agreed to participate in the study. The temperature probe was inserted into the vehicle fuel tank fillneck, allowed to equilibrate for 3-5 seconds, and temperature had recorded on a data acquisition sheet.

2.3.5 VOLUME MEASUREMENT

Pursuant to the C & TPs specifications, the volume of hydrocarbon vapor was measured at test points one, two and three. While TP-201.2 specifies the use of rotary positive displacement gas volume meters (e.g., ROOTS® meters) to measure vapor volume. Previous research has demonstrated that these devices may impede the flow of hydrocarbon vapors thus underreporting hydrocarbon vapor volume after correcting for temperature and pressure. An alternative method to quantify hydrocarbon vapor volume was developed and validated by AeroVironment Inc. (1994) using turbine flow sensors. This method was used to assay hydrocarbon vapor volume at test points two and three. A ROOTS® meter was used at test point one to measure hydrocarbon vapor.

2.3.5.1 Analytical Procedures for TP-201.2

A MacMillian 100 Flo-Sen turbine flow sensor was used to measure hydrocarbon vapor volume at the outlet of the UST vent line on the ambient side of the P/V valve and in the return vapor line. The range of the flow sensor is 0-100 liters per minute. The principle of operation for the flow sensors is that a Pelton type turbine wheel is used to determine the flow rate of the hydrocarbon vapor. As the turbine wheel rotes in response to gas flow rate, electric pulses are generated. Processing circuitry provides a D.C. voltage output (0-5 V) that is proportional to flow rate. This voltage output signal was data logged each second and stored in the field test van data acquisition system. Vapor recovery system pressure and temperature was measured at the inlet of the flow sensor.

At test point one, a ROOTS® meter Model No. 3M 175 (Serial No. 9638385) was used to measure hydrocarbon volume. The meter was coupled with a Veeder-Root solid state 100:1 single bi-directional pulser (part No. 767181-326). As was the case with the turbine flow sensors, the pulses were converted to a D.C. voltage output (0-5 V) proportional to flow rate. These data were logged in one second intervals using the field test van data acquisition system.

2.3.6 Data Acquisition System

All of the collected independent and dependent measure parameters were datalogged at one second intervals using a personal computer (PC) based data acquisition system. The PC is equipped with a 75 megahertz Pentium CPU processor and a standard I/O board (Model C10-DAS1-602/16 made by Computer Board) with 16 single ended channels. The data logging computer software is Laboratory Notebook. In addition to PC based data acquisition, strip chart records were also used to record the continuous independent and dependent variables.

2.4 DETERMINATION OF VEHICLE MATRIX FOR (TP 201.2A)

TP-201.2A specifies the definition of a vehicle matrix which identifies which vehicles (make and year) will be used to measure station hydrocarbon temperature, pressure, volume and concentration at the three sample points. The vehicle matrix used for this project is illustrated in Table 2-8. Within each cell are the numbers of vehicles to be sampled for the 100 car test. Appendix E contains the field data sheets for each of field test locations.

Table 2-8
Vehicle Matrix

Vehicle Year	Chrysler	Ford	GM	Toyota	Honda	Other
1994 - 1997	2	5	4	3	2	5
1991 –1993	2	4	4	3	2	6
1989 – 1992	2	5	4	3	2	5
1984 - 1988	2	4	4	2	2	6
< 1984	2	3	4	2	1	5

2.5 VEHICLE LEAK CHECK TEST

Prior to initiating station parameter sampling at check points 1-3, a procedure is required to check for leaks in the vehicle fuel tank and associated plumbing. This was executed using a manual compression procedure described in TP-201.2.

2.6 PRE-TEST AND POST-TEST MEASUREMENTS FOR STATIC PRESSURE, DYNAMIC PRESSURE AND A/L TESTS

As specified in the uncontrolled test series study design, prior to and following the execution of C &TPs, the balance and Gilbarco vacuum assist vapor recovery systems were evaluated for ARB specified performance. These tests determine if the VRS is functioning according to manufacturers design and ARB mandated performance

specifications. The sequence of the pre-test events (Table 3-1) included an initial performance screen (and maintenance if necessary) by Service Station Maintenance Inc. to verify the VRS was operating properly. Second, three performance tests were executed by BAAQMD staff who are specially trained to execute these tests. The specific performance tests executed by the BAAQMD staff are tabulated in Table 2-9.

Table 2-9
ARB Performance Tests

Variable	Measurement Methodology	System Type
Static Pressure	ARB TP-201.3	All types
Dynamic Back Pressure	ARB TP-201.4	Balance
Air/Liquid Ratio	ARB TP-201.5	Vacuum Assist

If the particular VRS that was tested did not pass the performance tests before the hydrocarbon emission testing was initiated, the VRS was immediately serviced by Service Station Maintenance to bring the system back into compliance. Specifically, nozzles 3, 6 and 7 were serviced to bring into adequate A/L tolerances. Given that the BAAQMD staff were not mandated to return for pre-test follow-up performance testing after the system had been serviced, the post-test performance testing was used to validate that the vapor recovery service call successfully brought the system into compliance prior to beginning the ORVR test series. This was not the ideal method to validate system performance. However, it was the sole path available to the principal investigator to validate system performance criteria given that the BAAQMD was only contracted to execute a single pre- and post-test performance test at each field location.

The performance data for each of the performance tests were logged onto ARB sanctioned data sheets and is included in Appendix B. These data confirm that (as tabulated in the post-test BAAQMD data forms) the pre-test maintenance and procedures successfully brought all VRS elements into acceptable working order prior to executing the field testing.

2.7 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance was executed prior to the initiation of field activities and during the field data acquisition process. Before the deployment of the field measurement van, each pressure sensor, temperature thermocouple, turbine flow sensor, ROOTS® meter, and hydrocarbon analyzer was evaluated for accuracy and precision based on manufacturer specifications. In addition, the test site P/V valve was evaluated for leak rate and cracking pressure.

Pressure transducers were checked at 0, ±50% and ±100% of scale using known pressure conditions and subsequently calibrated to voltage output values (1-5 V) using a linear regression model. Thermocouples were calibrated using ice bath, mouth, and hot water conditions and a reference temperature value. The thermocouple output in

degrees Fahrenheit was calibrated to voltage output (0-5 V) using a linear regression model. The turbine flow sensor and ROOTS® meter were calibrated against a primary flow gas meter (Rodwell 445603) and subsequently used to establish a flow/voltage relationship using a linear regression model. The Beckman Model 400A Hydrocarbon FID analyzer, California Analytical Model 100 Hydrocarbon NDIR analyzer, and Ratfisch Model RS 55CA Hydrocarbon FID analyzer were calibrated using reference gases (Praxair Distribution) at 0%, 50% and 90% of span range. The test site P/V valve was evaluated by exerting a known pressure onto the valve and recording flow rate in liters per minute. The cracking pressure was notated and compared to manufacturer specifications.

During the field measurement period that transpired over five days, the pressure, temperature and volume meters were not recalibrated. However, the Beckman Model 400 Hydrocarbon FID analyzer, California Analytical Model 100 Hydrocarbon NDIR analyzer, and Ratfisch Model RS 55CA Hydrocarbon FID analyzer were calibrated as specified in Part 60, Appendix A, Method 25A. Immediately prior to the initiation of testing, a zero gas (less than 0.1 ppmv), mid-range span gas (45-55 percent of the applicable span value) and a high-level calibration gas (80-90 percent of the applicable span value) were used to evaluate the accuracy the hydrocarbon analyzer. This QA/QC check was also executed at the end of each testing day and during the actual testing approximately once every three hours.

Section 3

RESULTS

As described in Section One of this report, only the data collected at three of the uncontrolled test series are reported in this section. A description of the field data is provided. In addition, a narrative of the causal relationships between the study independent and dependent variables is included based on the statistical analysis.

3.1 BALANCE VAPOR RECOVERY SYSTEMS

Table 3-1 tabulates the sample times, product delivery events, and system integrity checks for the uncontrolled balance test series for winter and spring conditions. The 100 car testing occurred over two 2-day periods, December 9-10 1997 and May 29-30, 1998. Each sampling event (i.e., one car) transpired over a 1-4 minute time period. The recorded hydrocarbon concentrations, temperature, pressure and volume parameters at test points 1-3 are therefore not continuous data sets but rather 100 discrete sampling events (100 cars each for the winter and spring conditions). The testing occurred at dispenser 8, nozzle 15. The remaining dispensers operated as usual. Fuel RVP for the tested dispenser was 12.28.

Product deliveries occurred on both sample days. On 9 December, unleaded fuel was downloaded at 16:30 hours. The following day, both unleaded and premium products were delivered at 13:40 hours.

System integrity checks were done prior to and following the 100 car tests. In pre-test evaluation, static pressure and dynamic pressure testing were executed by both Service Station Maintenance Inc. and the Bay Area Air Quality Management District (BAAQMD). Prior to the inception of site testing for seasonal effects (two days before), Service Station Maintenance evaluated the site for system integrity. Once the site was designated "tight", the BAAQMD "officially" tested the site for pre-sampling certification. As is apparent from the test results (Appendix D), the ARCO site passed both static pressure testing and allowable dynamic back pressure for each of the station nozzles. As a frame of reference, the allowed dynamic back pressure values for a Tokheim balance system are 0.15, 0.45, and 0.95 at nitrogen flowrates of 20, 60, and 100 CFH, respectively.

3.1.1 Winter Conditions

Table 3-2 tabulated the volumes of fuel delivered and the total testing time for this test series. For winter fuel and meteorological conditions, descriptive statistics are tabulated in Tables 3-3 through 3-22. The data for this testing period are also illustrated in Figures 3-1 through 3-20.

3.1.1.1 Hydrocarbon Behavior

Hydrocarbon readings varied between sample points (Figures 3-1 to 3-6). At test point 1 (the vehicle/nozzle interface), hydrocarbon concentrations ranged from 0-10,380 parts per million (ppm) over the 100 car sampling period (Table 3-3). Definition oF the descriptive statistics terms are listed in Appendix H. Hydrocarbon mass transfer rate fluctuated between 0 and 0.007 pounds per minute (lb/min) (Table 3-6). Over the two day sampling period, test point one hydrocarbon behavior peaked on four different occasions with each peak event lasting over a 1-2 hour period. As expected, test point 2 (return line) contained the highest hydrocarbon concentrations and mass. With the exception of a single no concentration excursion midway through the 100 car test, concentrations were fairly homogeneous within a band between 35,000 and 55,000 ppm. The range was between 0-103,797 ppm (Table 3-4). Mass values mirrored the concentration data with the majority of readings between 0.25-0.40 lb/min (Table 3-7). The peak mass return line observation was 0.51 lb/sec. Test point 3, the vent line, manifested lower hydrocarbon emissions by several orders of magnitude compared to test points 1 and 2. Vent emission concentrations ranged from 0 to 1146 ppm (Table 3-5). Peak values occurred during the initial 25% of the 100 car test. Following that point, vent line emission concentrations were less than 10 ppm. Mass emissions at test point 3 were low ranging from 0 to 0.2 lb/min (Table 3-8). Mass emissions tracked the hydrocarbon concentration pattern with an initial peak followed by a long plateau of emissions less than 0.001 lb/min. in contrast to the other vapor recovery system test points.

3.1.1.2 Volume Behavior

Hydrocarbon vapor flow data (Tables 3-12 to 3-14) for the three test points was roughly equivalent with volumes of approximately 0.10 cubic feet per second (ft^3/sec) for the duration of the 100 car test. The exception to this pattern was a reduction in measured volume to approximately 0.01 ft^3/sec for 30 minute period midway through the 100 car test (Figures 3-7 to 3-9). The range of observed volume values for test points 1-3 was 0.0065 - 0.1240 ft^3/sec, 0.0061 - 0.1185 ft^3/sec, and 0.0072 - 0.0959 ft^3/sec respectively.

3.1.1.3 Pressure Behavior

Vapor recovery system pressure for test points one and three was approximately constant over the time period of the 100 car test. With the exception of a pressure drop to –0.40 inches mercury ("Hg) at cars 50-53 at the beginning of day 2 sampling, the pressure hovered around 0.65 "Hg for both the nozzle and vent locations (Figures 3-10 and 3-12). The range of observed pressure values at test point 1 was –0.386 to +1.049 "Hg (Table 3-9). Test point 3 yielded a range of –0.405 to +0.916 "Hg (Table 3-11). The pressure behavior at test point 2 was variant with increases or decreases in pressure of 1-2 "Hg for one hour periods (Figure 3-11). The majority of pressure values were positive with the exception of the negative pressure excursion when fueling cars

50-53. The range of pressure values for the return lines was –0.058 to +4.172 "Hg (Table 3-10).

In contrast to test points 1-3, the majority of underground storage tank (UST) pressure values were negative (Figure 3-18). The range of UST pressure reading were from –9.57 to +4.474 "H_2O (Table 3-18). While the range is broad, with the exception of the negative pressure drops for cars 50-53, testing for 95 of 100 cars experienced UST pressure of –2.0 – 1.0 "H_2O. The positive UST pressure values from +2.50 to +4.474 "H_2O occurred for a single car (car 5).

The calculated system leak rate (Q), a direct function of UST pressure, ranged from –0.371 to +0.246 cubic feet per minute (CFM) (Table 3-19). The methods to calculate are described in Section 2.3.3.3 and the proposed TP-201.2B (Proposed Draft Date: 1/95). Because leaks do not occur at negative UST pressure, the effective leak rate range was 0 to +0.246 CFM. Leaks did occur through the duration of the 100 car test with the majority occurring between cars 45-100 (Figure 3-19).

3.1.1.4 Temperature Behavior

The temperature values (R) for test points 1-3 were bimodal with peaks occurring during the early and late phases of the 100 car test (Figures 3-13 through 3-15). This distribution tracked ambient temperatures. For test point one, temperature reading ranged from 560.9 – 587.5 R (Table 3-15). Temperatures were cooler for the return line with observations from 511.8 – 532 R (Table 3-16). Vent line temperature demonstrated the highest values ranging from 579.2 – 602.0 R (Table 3-17). Note that while temperatures were measured in degrees Fahrenheit, for temperature data analysis, temperature values were converted to Rankine units based on the specifications of the ARB Certification and Test Procedures. Rankine units are used as an absolute temperature scale. Temperature in degrees Rankine is equal to degrees Fahrenheit plus 459.67.

3.1.1.5 Ambient Conditions

Ambient conditions for the Fairfield site were characterized as winter circumstances. Temperatures were bimodal with peaks occurring during the first quarter and last quarter of the 100 car testing (Figure 3-17). Ambient temperatures ranged from 51.9 to 69.5 °F (Table 3-21). Due to problems with the ambient pressure transducer, ambient pressure reading were derived from Travis Air Force Base, five miles east of the test site. These values were hourly which is reflected in the pressure readings distribution (Figure 3-16). The ambient pressure values ranged from 29.2 to 30.4 "Hg (Table 3-20). Pressure readings were in a band between 30.2 – 30.4 'Hg with exception of a drop in pressure to 29.29 'Hg for cars 11-23.

3.1.1.6 Vehicle Conditions

As hypothesized at the onset of the study, vehicle tank temperatures track ambient temperatures. The observed distributions for these data were bimodal with dominant maximums visible during the early and later stages of the 100 car test. (Figure 3-20). The range of vehicle tank temperatures was from 50 – 80.5 °F (Table 3-18).

3.1.2 Spring Conditions

Table 3-44 contains the total fuel delivered to the 100 cars and the total sampling time. For spring fuel and meteorological conditions, descriptive statistics are tabulated in Tables 3-45 through 3-64. The data for this testing period are also illustrated in Figures 3-21 through 3-40.

3.1.2.1 Hydrocarbon Behavior

Hydrocarbon readings for sample points 1-3 were comparable to the winter conditions (Figures 3-1 to 3-6). The nozzle hydrocarbon concentrations ranged from 0-9904 ppm (Table 3-45) and mass values were 0 – 0072 lb/min (Table 3-45). The distribution of hydrocarbon values at the nozzle was multimodal with a peak averaging approximately 4000 ppm and 0.002 lb/min (Figures 3-21 and 3-24). The single peak above these levels registered hydrocarbon concentrations in the 9900 ppm range and a mass value in excess of 0.005 lb/min during the fueling of car 72. Test point two hydrocarbon data yielded a concentration range of 233,257 – 499,453 ppm (Table 3-46) and mass values between 0.0183 – 0.4822 lb/min (Table 3-49). Peak concentrations were disperse throughout the 100 car test (Figure 3-22). Mass maximums were also distributed across the test period with a single atypical minimum (for the test period) of approximately 0.19 lb/min at vehicle 69 (Figure 3-25). Vent line emissions were consistent with winter conditions by demonstrating an early peak followed by a bimodal lower plateau beginning at cars 15 and 55 for the duration of the testing (Figure 3-23). In contrast, mass emissions at test point 3 displayed 0 mass emissions throughout the test cycle due to 0 volume outflow (Figure 3-26). The range of observed vent line hydrocarbons was 0-88 ppm (Table 3-47).

3.1.2.2 Volume Behavior

Hydrocarbon vapor flow data for test points 1 and 2 were in the same range (0.11 – 0.12 ft^3/5sec) and exhibited little variability with the exception of a minimum at car 69 (Figures 3-27 and 3-28). The ranges were 0.0076 – 0.1094 ft^3/5sec and 0.0069 – 0.13398 ft^3/5sec for the nozzle and return line respectively (Tables 3-54 and 3-55). Vent line volumes were variable but negative in value throughout the duration of the 100 car test (Figure 3-29 and Table 3-56).

3.1.2.3 Pressure Behavior

In contrast to winter conditions, vapor recovery system pressure values were higher for all three test points. Nozzle pressure readings ranged from +0.889 to +3.009 "Hg (Table 3-51). Pressure values were homogeneous until car 69 triggered a deep pressure reduction followed by unstable pressure conditions (Figure 3-30). Test point 2 experienced the same minimum behavior at car 69 (Figure 3-31). On either side of this event, pressure distributions were within a band between +3.3 to +3.5 'Hg. The observed return line pressure range was +0.880 to +3.958 "Hg (Table 3-52). Vent line pressure values were also fairly constant between +3.3 to +3.4 "Hg (Figure 3-32). The exception to this pattern was a dramatic pressure drop at car 69. Pressure range for test point three was +0.880 to +3.958 (Table 3-53).

UST pressure values were negative ranging from -0.891 to -0.153 "H_2O (Table 3-60). The distributions were multi-modal with peaks dispersed throughout the 100 car test period (Table 3-38). These pressure values were similar to the winter test period without the negative pressure excursion below –9.0 "H_2O.

The calculated system leak rate (Q) ranged from –0.102 to +0.039 CFM (Table 3-61). Negative leak rates do not produce outflowing of system vapor from fugitive sources. Though these data do support the value of negative UST pressure in controlling system hydrocarbon emissions, the leak rates were not constant, demonstrating continual movement based on associated UST pressure values (Figure 3-39).

3.1.2.4 Temperature Behavior

Though ambient temperature characteristics were higher compared to winter sampling conditions, VRS temperature profiles were in the same range as the winter testing. Test point 1 yielded a range of 556.1 – 595.2 R (Table 3-57). The distributions over the 100 car test demonstrated a gradual increase in temperature values with the exception of a large minimum at car 69 (Figure 3-33). This is reflected ambient temperature readings. Return line temperatures were lower as the hydrocarbon vapor cools relative to the proximity of the vehicle fuel tank. The distributions were multi-modal showing a gradual increase in temperature over the duration of the testing (Figure 3-34). Test point 2 temperature ranges were 517.9 – 540.5 R (Table 3-58). Like the winter testing at the VRS balance site, vent line temperatures exhibited an increase in temperature profiles relative to the return line (Figure 3-35). The temperature readings also increased as a function of time as the 100 car testing progressed. The temperature range at test point 3 was 551.3 – 592.7 R (Table 3-59).

3.1.2.5 Ambient Conditions

Spring ambient conditions at the Fairfield site were characteristically different than the winter testing. Temperatures demonstrated an increase over time, starting out at approximately 58 °F and finishing in the mid 70's (Figure 3-37). The range in ambient

temperature conditions was 58.4 – 77.83 °F (Table 3-63). Ambient pressure exhibited a modest ranged from 30.01 – 30.06 "Hg (Table 3-62). The pressure distributions were mono-modal with the maximum occurring during the middle of the 100 car test period (Figure 3-36).

3.1.2.6 Vehicle Conditions

Vehicle tank temperatures reflect the gradual increase in ambient temperatures over the duration of the 100 car testing. Beginning with a maximum of 92 °F followed by minimum of 56 °F, the distribution of the tank temperature values increases as the testing progresses (Figure 3-40). The range of these values was from 43.4 – 51.6 °F (Table 3-64).

3.2 VACUUM ASSIST VAPOR RECOVERY SYSTEMS

The testing schedule, product delivery events and system integrity testing for the vacuum assist test site are recorded in Table 3-1. Using dispenser number 3, testing occurred over a two day period, February 5-6, 1998. A product delivery occurred at 22:20 hours on first day of testing.

System integrity checks were done prior to and immediately following the seasonal testing. In pre-test evaluation, static pressure, dynamic pressure and A/L testing was executed by both Service Station Maintenance Inc. and the Bay Area Air Quality Management District (BAAQMD). Prior to the inception of site testing (several days before), Service Station Maintenance evaluated the site for system integrity. Once the site was designated "tight", the BAAQMD "officially" tested the site for pre-sampling certification. As is apparent from the test results (Appendix D), several of the site nozzles failed the A/L testing during the pre-test system integrity checks. As a frame of reference, the allowed A/L values for the Gilbarco VaporVac system are 1.00-1.20. The malfunctioning nozzles were repaired by Service Station Maintenance and checked for appropriate A/L values prior to the inception of seasonal testing. Post test system integrity was executed by BAAQMD. All post-testing data were within acceptable ranges. This observation confirms that the nozzle A/L values were repaired prior to the inception of seasonal testing.

3.2.1 Winter Conditions

For winter fuel and meteorological conditions, descriptive statistics are tabulated in Tables 3-24 through 3-43. The data for this testing period are also illustrated in Figures 3-41 through 3-60.

3.2.1.1 Hydrocarbon Behavior

As hypothesized, hydrocarbon concentration and emission data were different for the tested vacuum assist system when contrasted to the balance system readings. Yet, the

relative hydrocarbon behavior between the three test points was similar. At test point 1, hydrocarbon concentrations ranged from 0-19,957 ppm over the 100 car sampling period (Table 3-24). The temporal distributions at the nozzle exhibited a band of concentrations between 100-500 ppm until car 79 (Figure 3-41). At that point, peaks in excess of 19,000 ppm were observed. Hydrocarbon mass transfer rate fluctuated between 0 and 0.014 lb/min (Table 3-27). Nozzle hydrocarbon mass distributions mirrored the concentration data (Figure 3-44). On average, return line concentration data were higher than the winter balance data. The vacuum assist mass distributions were multi-modal though a dominant peak plateau was visible during the mid section of the 100 car testing (Figure 3-45). The range of mass values was 0 – 42.709 lb/min with number peaks in excess of 25.0 lb/min (Table 3-28). Vent line emission concentrations ranged from 0 – 2034 ppm (Table 3-29). These values are in excess of the balance VRS and are a direct function of UST positive pressure values characteristic of vacuum assist VRS. The vent concentration distributions reveal two sets of hydrocarbon data during the first and last 25% of the 100 car testing (Figure 3-43). The mid 50% of the testing exhibited an extended string of 0 ppm hydrocarbon concentration data. The corresponding vent mass emission distributions mirrored the vent concentration data (Figure 3-46). Most mass peak values were in the 0.0004 lb/min range. The range of vent mass emissions was –6.45 – 0.0013 lb/min (Table 3-29).

3.2.1.2 Volume Behavior

Hydrocarbon vapor flow data varied as a function of test location. Nozzle flow values ranged from 0.006 – 0.116 ft^3/sec (Table 3-33). The volume distributions at test point 1 were similar to the balance VRS winter conditions. From cars 10-100, the majority of values, were in the 0.115 ft^3/sec range (Figure 3-47). The exception to this pattern was a minimum of approximately 0.025 ft^3/sec. Return line volume data ranged from 0.0026 – 5.68 ft^3/sec (Table 3-34). These values were in excess of the winter balance VRS data. The volume distributions at test point 2 displayed five separate peak events followed by significant drops in flow volume (Figure 3-48). Vent line volume characteristics were similar in pattern to the nozzle values. Volume data were fairly uniform with flow in the 0.1075 ft^3/sec range (Figure 3-49). The exception was a maximum peak during the early phases of the 100 car testing. The observed test point 3 volume range was 0.106 – 0.119 ft^3/sec (Table 3-35).

3.2.1.3 Pressure Behavior

Vapor recovery system pressure for test points one and three were predictably higher for the vacuum assist VRS. Test point one pressure ranges were 0.468 – 1.575 "Hg (Table 3-30). Nozzle pressure distributions were within a band from 1.24 – 1.26 " Hg with the exception of two peaks during the beginning and end of the 100 car testing (Figure 3-50). Return pressure readings were multi-modal with a general trend of lower pressures during the mid portions of the field testing (Figure 3-51). The observed pressure range at test point 2 was 1.62 – 5.0 "Hg (Table 3-31). Vent line pressure distributions displayed and early minimum pressure dip to less than 0.70 "Hg followed

by a fairly uniform series of pressure readings in the 1.00 "Hg range (Figure 3-52). The pressure range associated with these data was 0.46 – 1.1 "Hg (Table 3-32).

UST pressure values were positive except for a series of negative pressure conditions for cars 84-87 (Figure 3-58). The distributions across the entire 100 car testing were multi-modal with the majority of values between -0.25 – 0.75 "H_2O. The range of UST pressure readings were from –0.49 – 2.015 "H_2O (Table 3-39).

The calculated system leak rate ranged from -0.371 to -0.057 CFM for the negative UST pressure values to 0 to +0.125 CFM for the UST values in excess of 0 "H_2O (Table 3-40). The distribution of the leak rate data mirrored UST pressure distributions (Figure 3-59).

3.2.1.4 Temperature Behavior

The temperature values (R) for test points 1-3 were in the same general range as those observed during the winter balance VRS testing. Test point 1 temperature ranges were 562.5 – 597.6 R (Table 3-36). The nozzle temperature distributions mirrored ambient temperature conditions with a series of minimums and maximums occurring over the duration of the 100 ca testing (Figure 3-53). Return line temperature distributions tracked a similar pattern as the nozzle temperature values with maximum peaks occurring during the middle and end of the car test program (Figure 3-54). A prominent minimum was visible at car 84-87. The range of test point 2 temperature values was 510.3 - 527.6 R (Table 3-37). Vent line temperatures increased relative to return line values. The observed range was 563.1 – 592.0 R (Table 3-38). Vent temperature distributions followed the same pattern established by test points 1 and 2 (Figure 3-55). Across the 100 car tests, temperatures reading were multi-modal with dominant peaks visible during the testing of cars 1-25, 26-50 and the final 10% of 100 car test schedule.

3.2.1.5 Ambient Conditions

As earlier described, ambient conditions for the El Sobrante site were characterized as winter circumstances. Temperatures were multi-modal with a minimum trough visible 75% through the 100 car test (Figure 3-57). Ambient temperatures for the February test conditions ranged from 53.9 to 67.0 °F (Table 3-42). Ambient pressure readings were relatively uniform (29.7 – 29.8 "Hg) during the sixty cars tested (Figure 3-56). This was followed by a pressure minimum below 29.4 "Hg. The range of observed ambient pressure readings were 29.37 – 30.075 "Hg (Table 3-41).

3.2.1.6 Vehicle Conditions

Vehicle tank temperatures ranged from 52 – 68 °F (Table 3-43). The temperature distributions exhibited a range of maximums and minimums across the 100 car test cycle (Figure 3-60). While maximums in excess of 60 °F were noted on several occasions, the majority of vehicle tank temperature readings were less than 60 °F.

3.3 EVALUATION OF INDEPENDENT AND DEPENDENT VARIABLE RELATIONSHIPS

To explore the relationship between the project independent and dependent variables, a series of regressions analyses were executed. Definition of the regression output parameters are listed in Appendix H. Four different sets of analyses were conducted with a unique constellation of independent and dependent measures to investigate distinct influences that impact GDF emissions. These include:

- External factors (i.e., ambient temperature and pressure, vehicle fuel tank temperature).
- GDF system design elements (i.e., volume of air returned to the UST).
- Fuel characteristics (i.e., RVP of winter and summer fuels).
- VRS system dynamics (i.e., the influence of UST pressure on VRS leak rate and vent line emissions).

3.3.1 Ambient Pressure and Temperature Effects

To investigate the impact of ambient temperature and pressure on GDF emissions, UST pressure was used as a surrogate for GDF emission release potential. The validity of using UST pressure in the regression model as a surrogate is affirmed by previous work suggesting that GDF VRS system emissions are directly correlated with UST pressure. If ambient pressure and temperature predict variance in UST pressure, these parameters are therefore potential determinants of GDF emissions.

Tables 3-65 through 3-67 contain the results of the regression analysis for UST pressure as a function of ambient pressure. The measure of the strength for the relationship between two variables is the R square value. R^2 provides a measure of the explained variance between the independent and dependent variable. The range of R^2 values is between 0-1 where 0 explains zero percent of the variance between the two variables and 1 explains 100% of the variance. The data suggest that ambient pressure does not influence variance in the dependent measure, UST pressure. R^2 values ranged from 2.09×10^{-5} to 3.11×10^{-2}. Two of the three R^2 values were less than 10^{-4}.

The influence of ambient temperature is tabulated in tables 3-68 to 3-70. This independent variable did not account for significant variance in UST pressure. The range of R^2 values was 1.48×10^{-4} to 1.71×10^{-2}. As was the case for the ambient temperature analysis, two of the three R^2 values were very small ($< 10^{-3}$).

In addition to exploring the relationship between ambient conditions and the potential for VRS emissions, the role of ambient temperature on vehicle tank temperature was investigated. Tables 3-71 through 3-73 illustrate the possible significant influence ambient temperature can have on vehicle evaporative emissions. While two of the

three R^2 values were in the 0.13 range, the data for the winter balance system testing yielded a strong R^2 value: 0.76. The multiple R (i.e., the correlation coefficient R) also indicates a strong association between ambient temperature and vehicle tank temperature for the balance system winter test conditions. The multiple R is the square root of R^2 and measures the strength of the association between the independent and dependent variable with possible values ranging from –1.0 to 1.0. For this relation, the multiple R was 0.87. Both the R and R^2 numbers indicate that statistically, ambient temperature accounts for the majority of the movement in vehicle tank temperatures for one of the three test sites.

3.3.2 Vapor Recovery System Design Effects

To evaluate the possible impacts of VRS design on GDF emission releases, two different approaches were used. First, the influence of delivered hydrocarbon volume into the UST on UST pressure was investigated. Balance and vacuum assist systems each have unique design features that influence air volume introduced into the UST. Because vacuum assist systems deliver larger air volumes into the UST (and hydrocarbon vapor per unit time), it was postulated that greater volumes of return line air could increase UST pressure and subsequent VRS system emissions. To investigate this relationship, the influence of VRS design was explored as an indicator of possible GDF emissions.

The second type of evaluation conducted was to review the different responses each type of vapor recovery systems displayed for individual regression analyses reported in sections 3.3.1, 3.3.2 and 3.3.4. To control for seasonal effects, only the winter dataset was used as a means of comparison.

Tables 3-74 to 3-76 tabulate the regression analysis investigating UST pressure as a function of return line hydrocarbon volume. In contrast to the initial hypothesis, vacuum assist systems did not explain more variance in the observed UST pressure readings for each of the test sites. Of the three regressions executed, the balance system during winter test conditions accounted for the most variance in the UST pressure readings with reported R^2 value of 0.805. The spring balance system testing indicated the opposite results with a very small reported R^2 value (1.00×10^{-8}). The vacuum assist regression analysis yielded an R^2 value of 0.03.

A general comparison of each of the executed regression analysis as a function of VRS type does not indicate a reproducible trend for the tested independent and dependent variables. The vacuum assist system indicated a stronger (yet not significant) relationship between ambient pressure and UST pressure. This is predicted given the importance of induced pressure conditions on the efficacy of vacuum assist system efficiency. Conversely, one of the two balance system tests was more affected by return line hydrocarbon volume than was the tested vacuum assist system. The remaining regression analyses indicated similar responses between the two VRS types. Each was equally influenced by the UST/leak rate relationship. These systems also

demonstrated the lack of causal relationship between UST pressure and leak rate on vent line emissions.

3.3.3 Fuel Effects

Fuel effects were investigated by comparing the influence of seasonal fuel on VRS behavior. Given the higher RVP was winter fuels, It would be expected that winter fuel would yield VRS conditions that would lead to concomitant higher VRS emissions. To control for VRS design differences, only the balance site dataset was used. Furthermore, the balance site was the only location with data for winter and summer fuels.

The comparative regression analyses suggest that fuel effects may be visible for the vent line emission/ UST and leak rate regressions. Winter testing did produce data that was more effective as explaining variance in these relationships. Conversely, spring conditions with their higher temperatures (and associated lower RVP fuels) were more effective at predicting the influence of temperature on UST pressure characteristics. The remaining regression analyses (e.g., ambient pressure effects and the UST pressure/leak rate relationship) were unaffected by seasonal fuel impacts.

3.3.3 Vapor Recovery System Dynamics Effects

VRS system dynamics include the influence of UST pressure on leak rate and vent line hydrocarbon emission concentrations. The basis of these regression equations is to affirm the importance of UST pressure on GDF emissions. In addition, the relationship between leak rate and vent line emissions was explored. As is visible in tables 3-77 through 3-79, leak rate is highly correlated with UST pressure. The regression R^2 values ranged 0.80 to 0.99 indicating that UST pressure is the critical determinant of predicting system leaks and associated fugitive emissions.

While UST pressure is strongly correlated with leak rate, a similar pattern was not observed for the influence of UST pressure or leak rate on vent line emissions. The R^2 values for the UST pressure/vent line concentration relationship were small (<0.009). Leak rate was only moderately more effective at predicting vent line emissions. The R^2 values were no larger than 0.013.

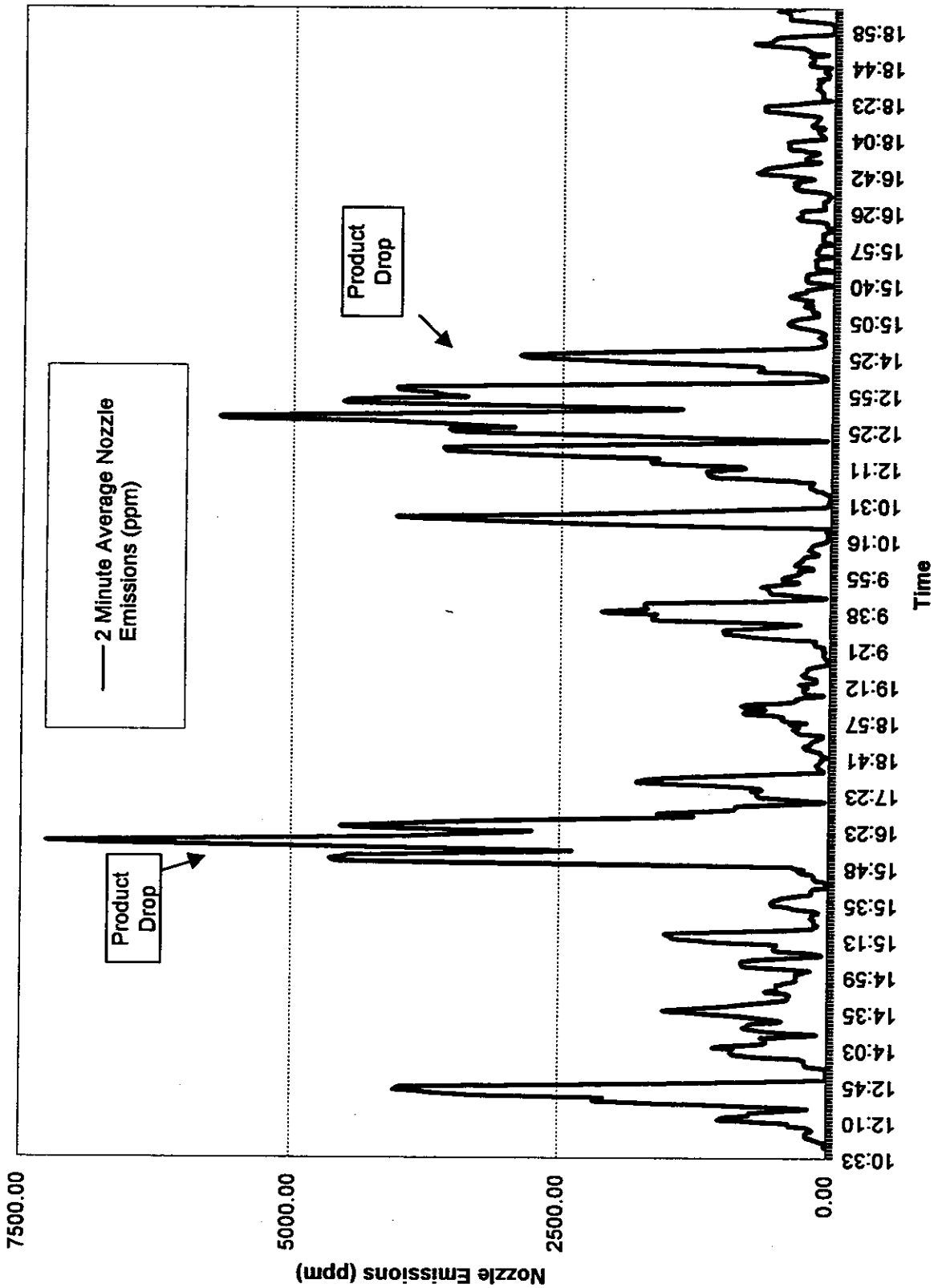


Figure 3-1 Balance System Two Minute Average Nozzle Emissions (ppm) for Winter Conditions

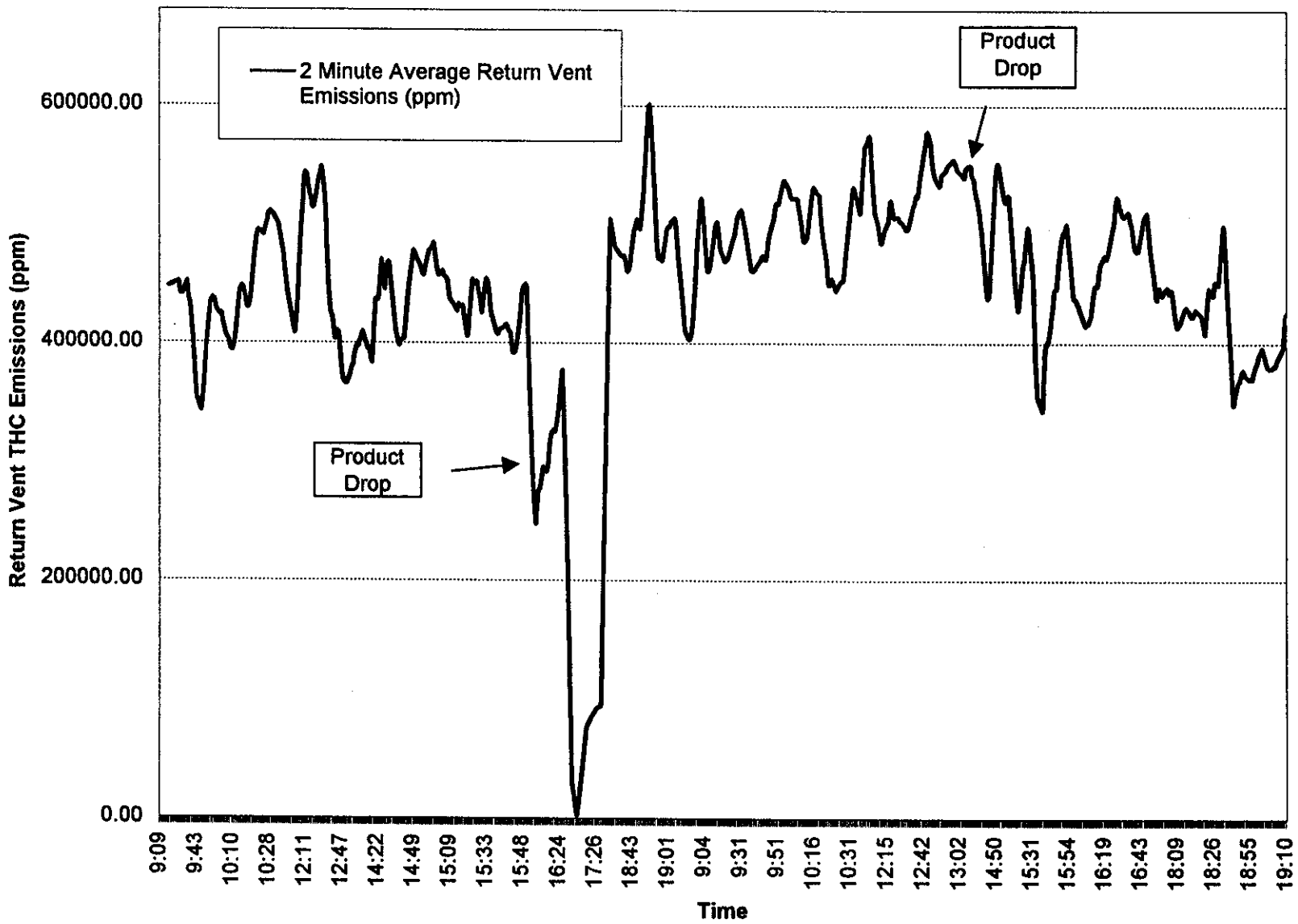


Figure 3-2 Balance System Two Minute Average Return Emissions (ppm) for Winter Conditions

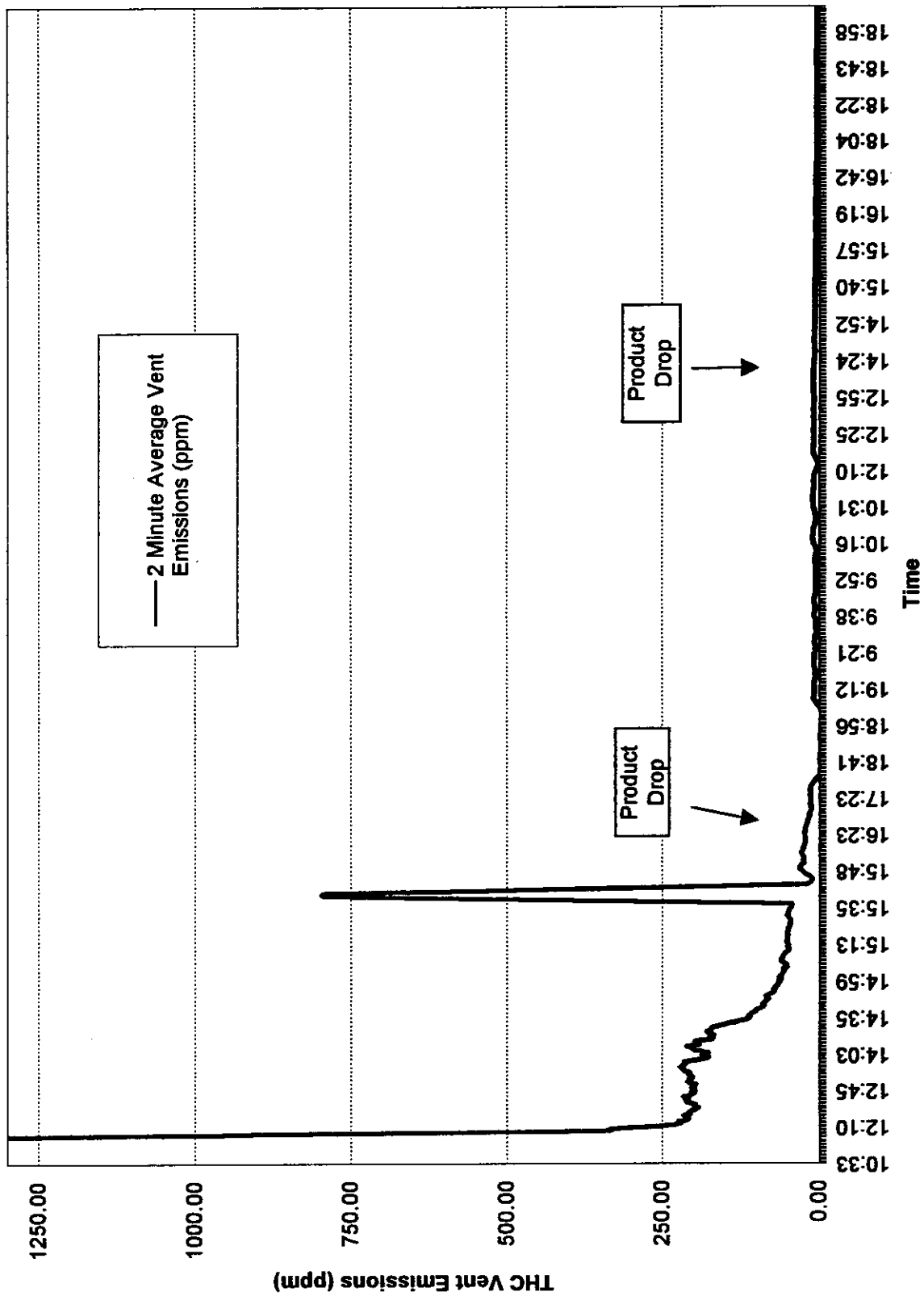


Figure 3-3 Balance System Two Minute Average Vent Emissions (ppm) for Winter Conditions

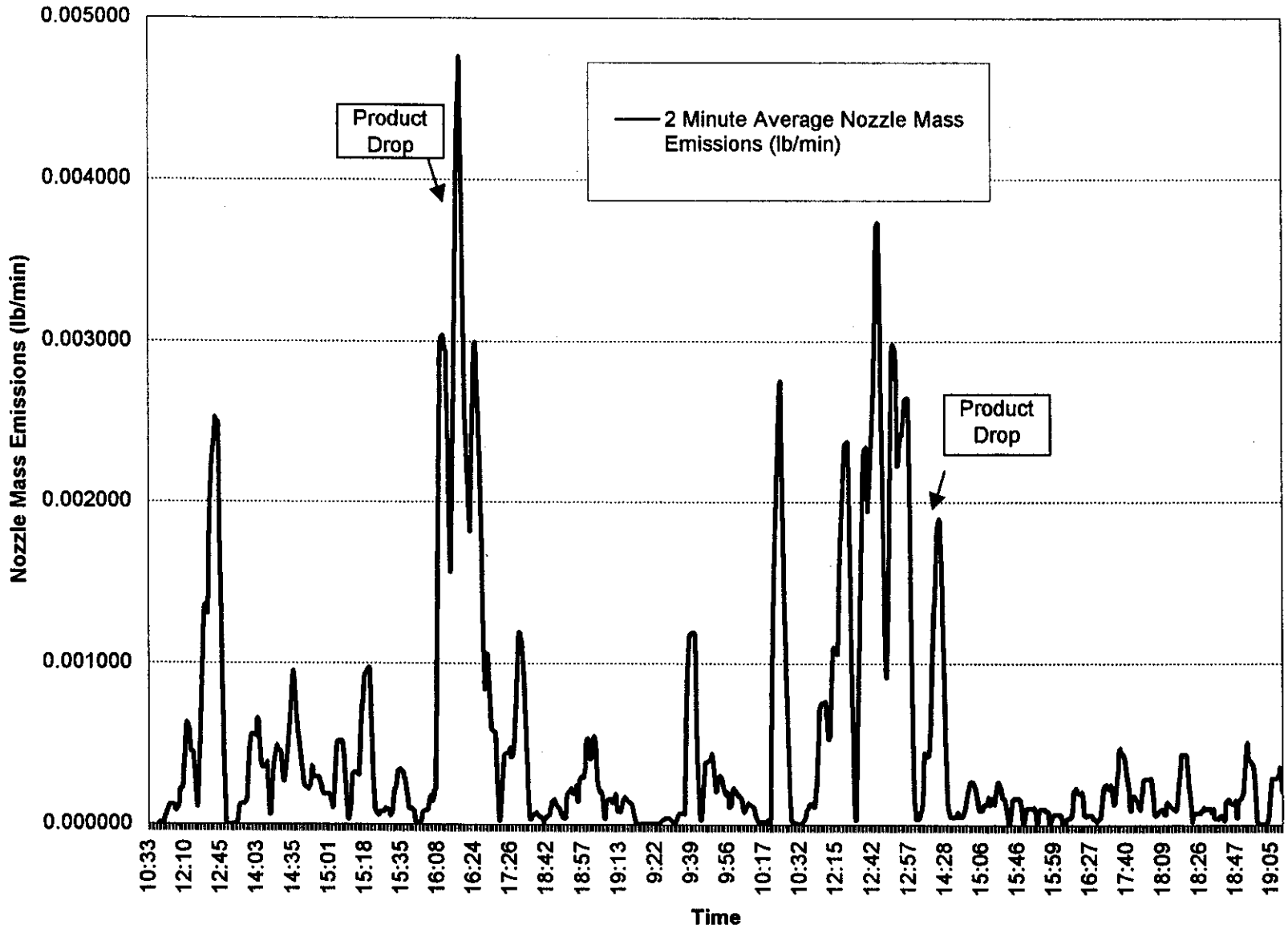


Figure 3-4 Balance System Two Minute Average Nozzle Mass Emissions (lb/min) for Winter Conditions

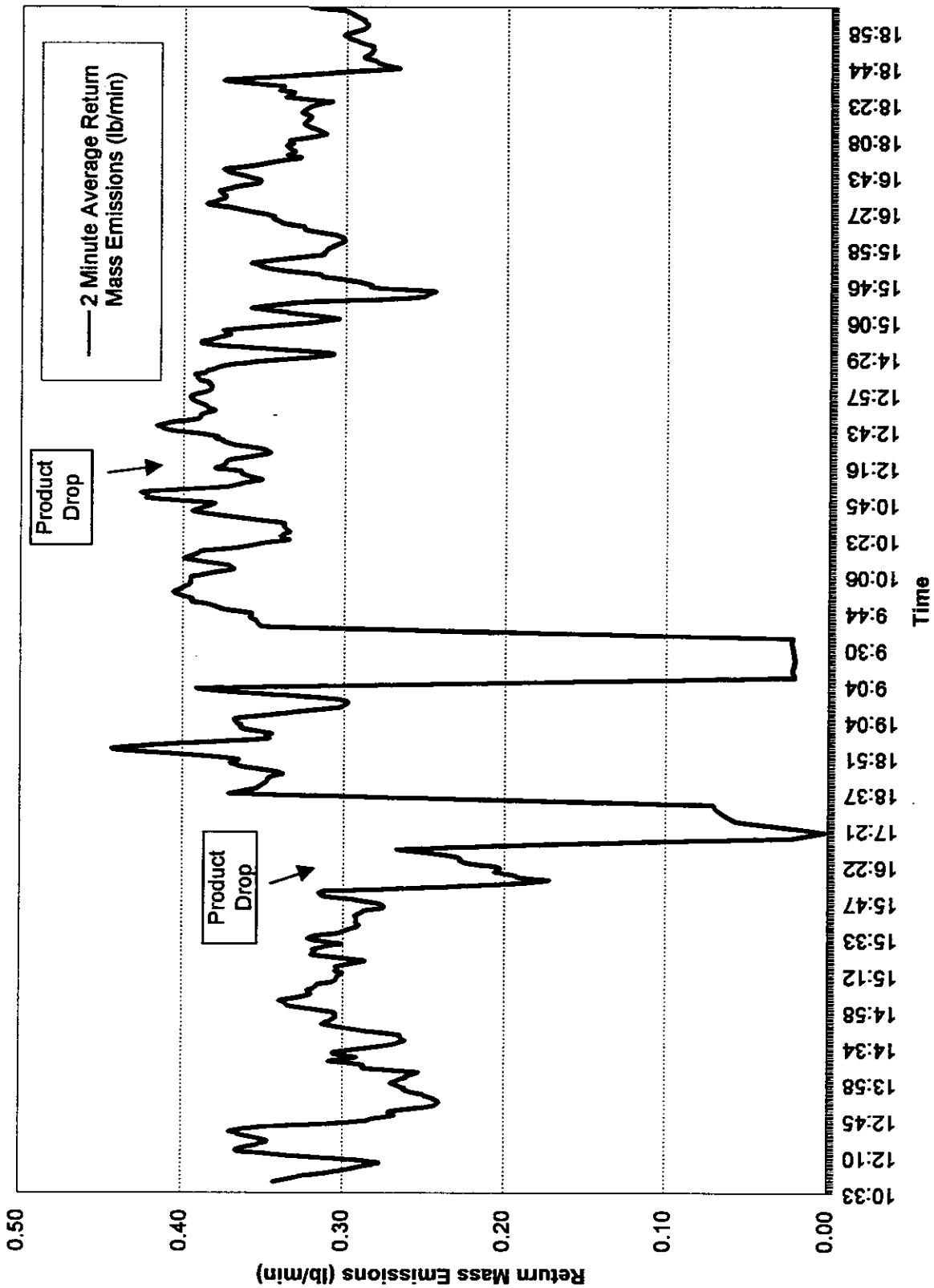


Figure 3-5 Balance System Two Minute Average Return Mass Emissions (lb/min) for Winter Conditions

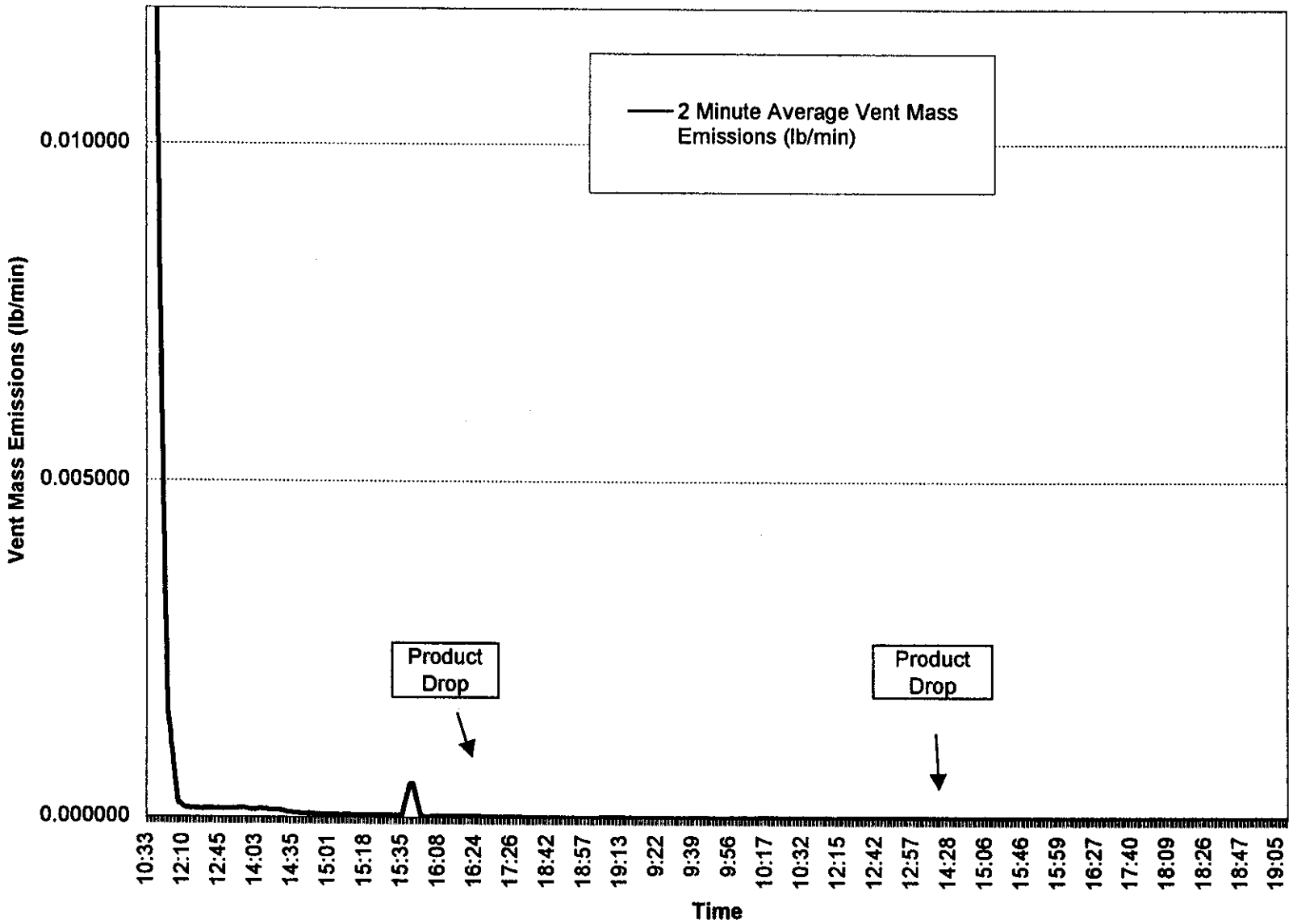


Figure 3-6 Balance System Two Minute Average Vent Mass Emissions (lb/min) for Winter Conditions

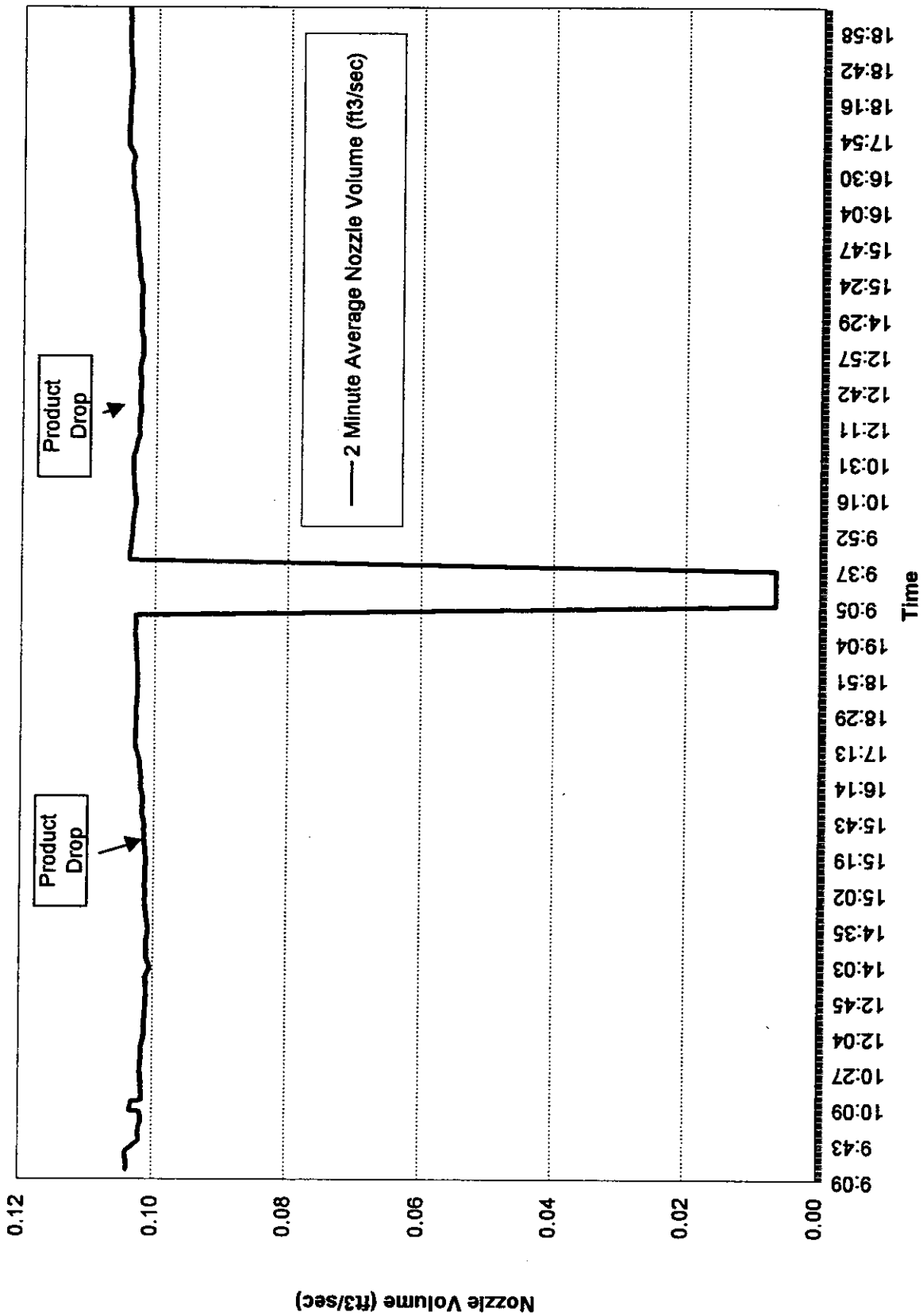


Figure 3-7 Balance System Two Minute Average Nozzle Volume (ft3/sec) for Winter Conditions

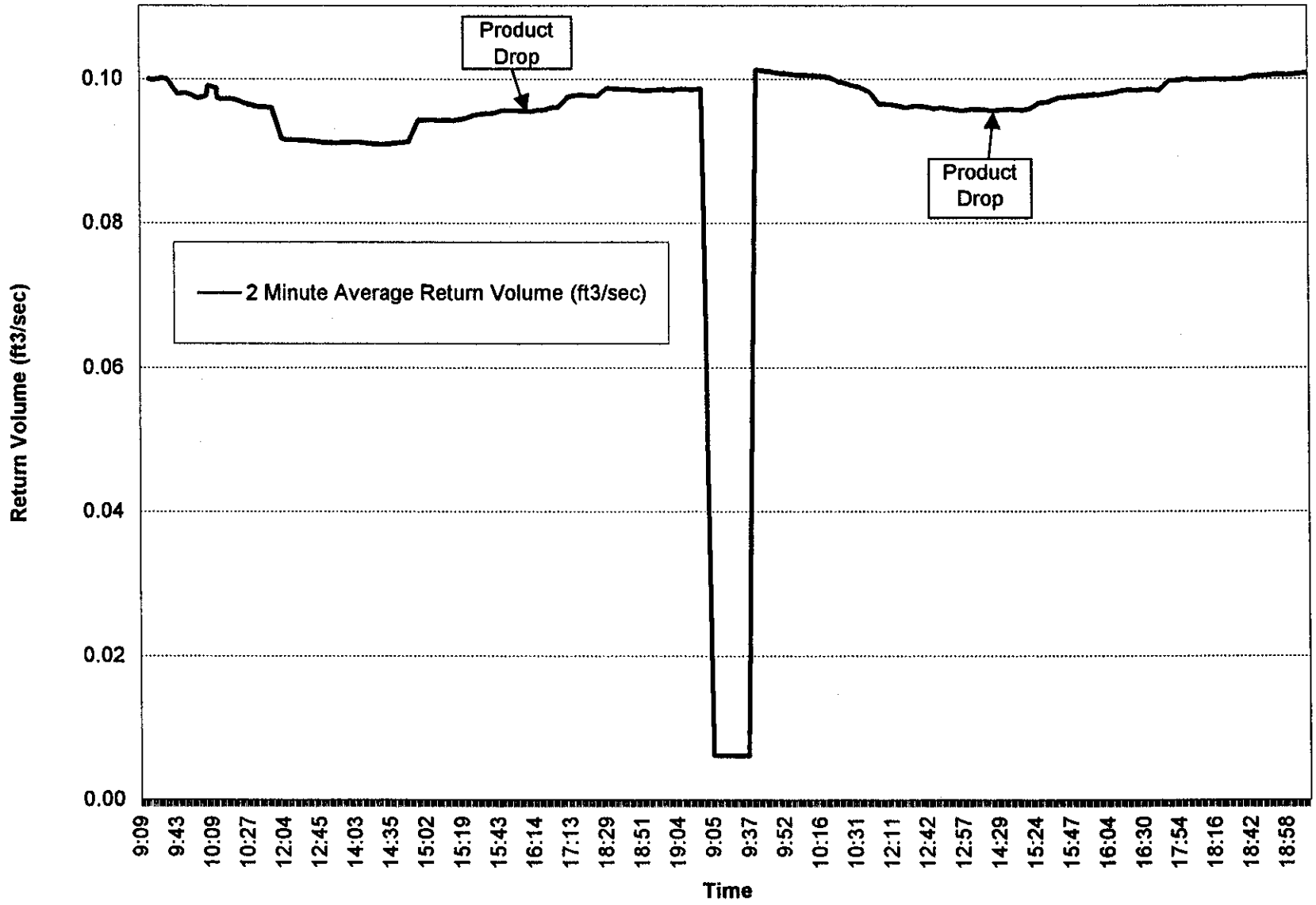


Figure 3-8 Balance System Two Minute Average Return Volume (ft3/sec) for Winter Conditions

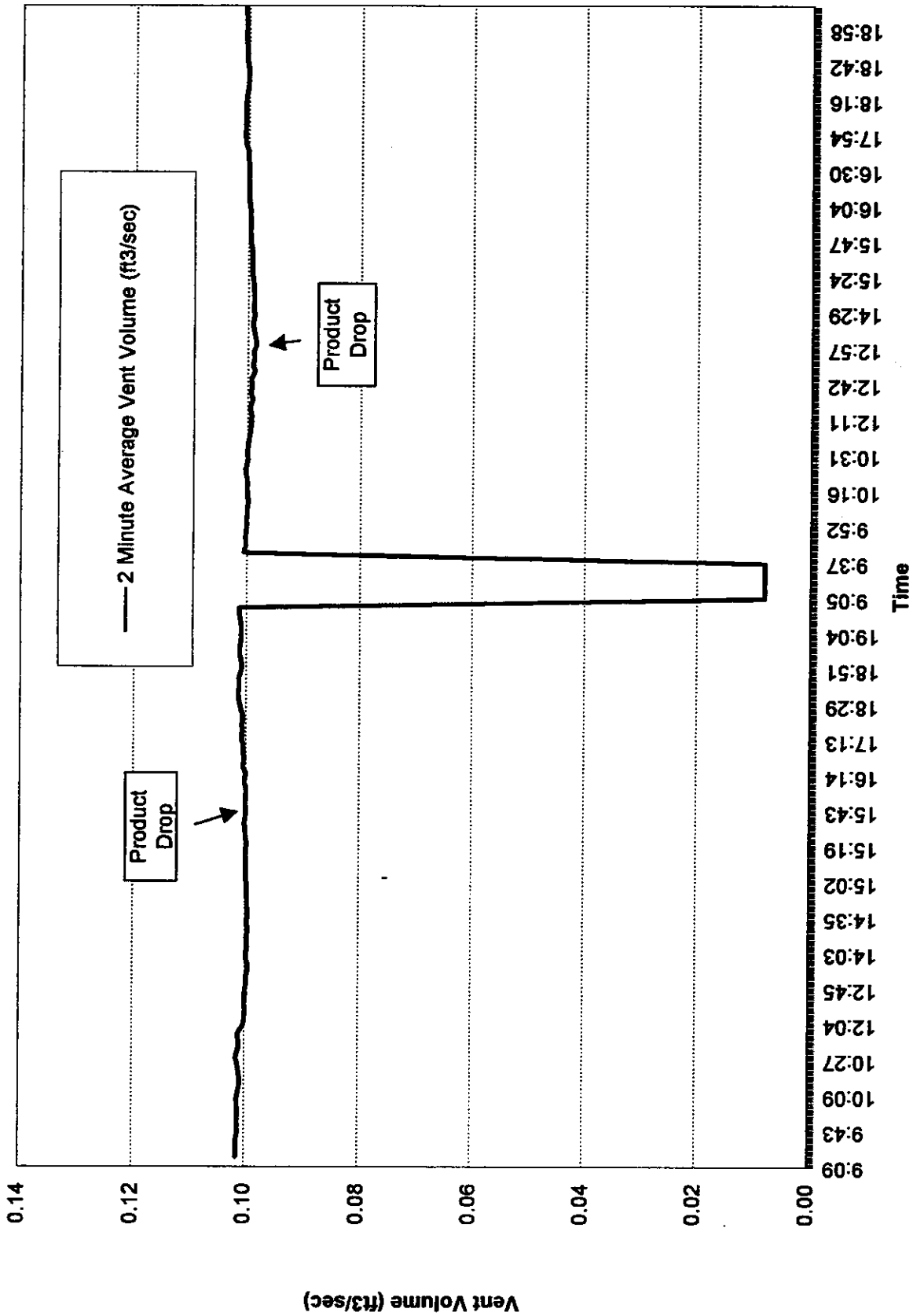


Figure 3-9 Balance System Two Minute Average Vent Volume (ft3/sec) for Winter Conditions

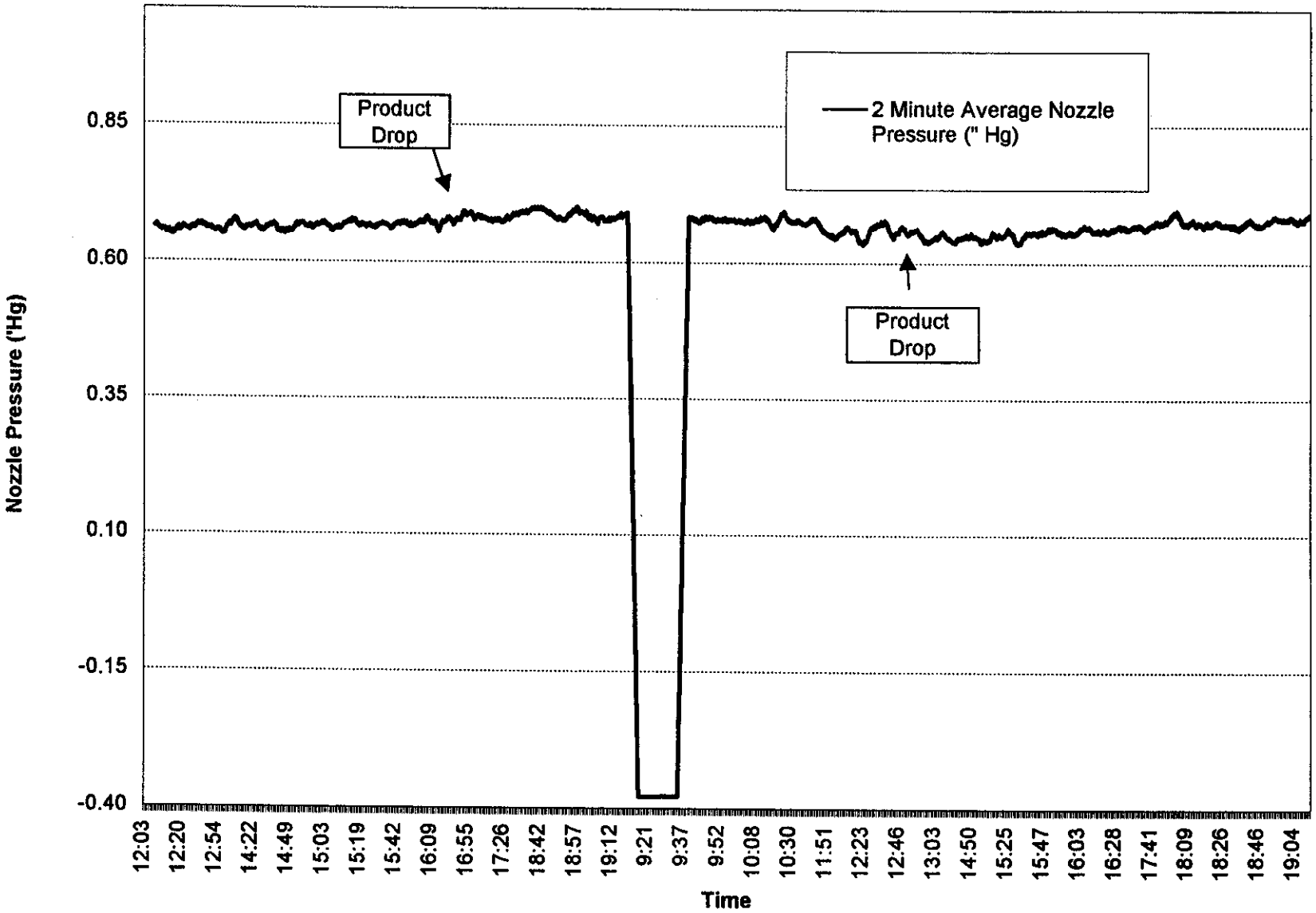


Figure 3-10 Balance System Two Minute Average Nozzle Pressure ("Hg) for Winter Conditions

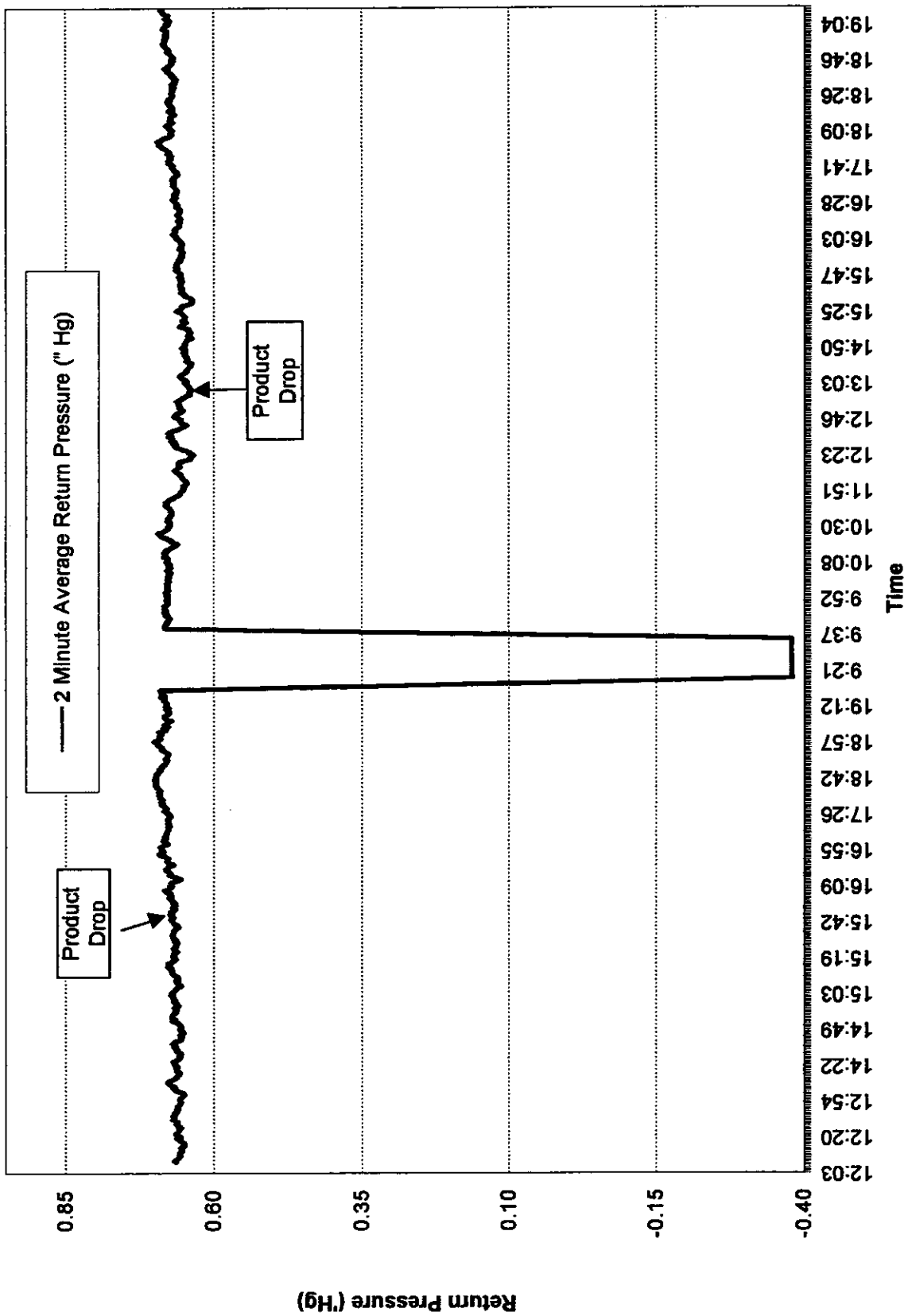


Figure 3-11 Balance System Two Minute Average Return Pressure ("Hg) for Winter Conditions

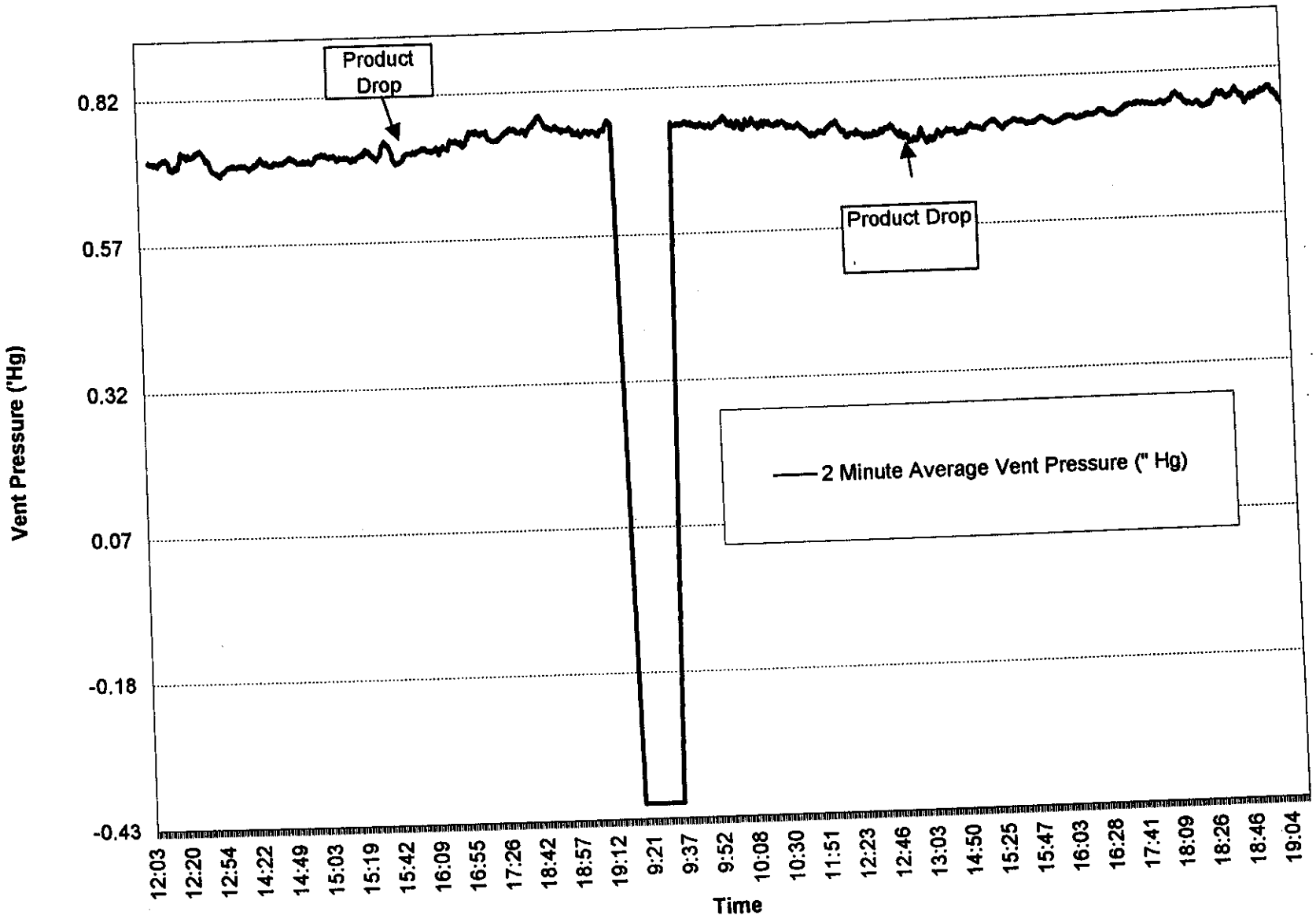


Figure 3-12 Balance System Two Minute Average Vent Pressure ("Hg) for Winter Conditions

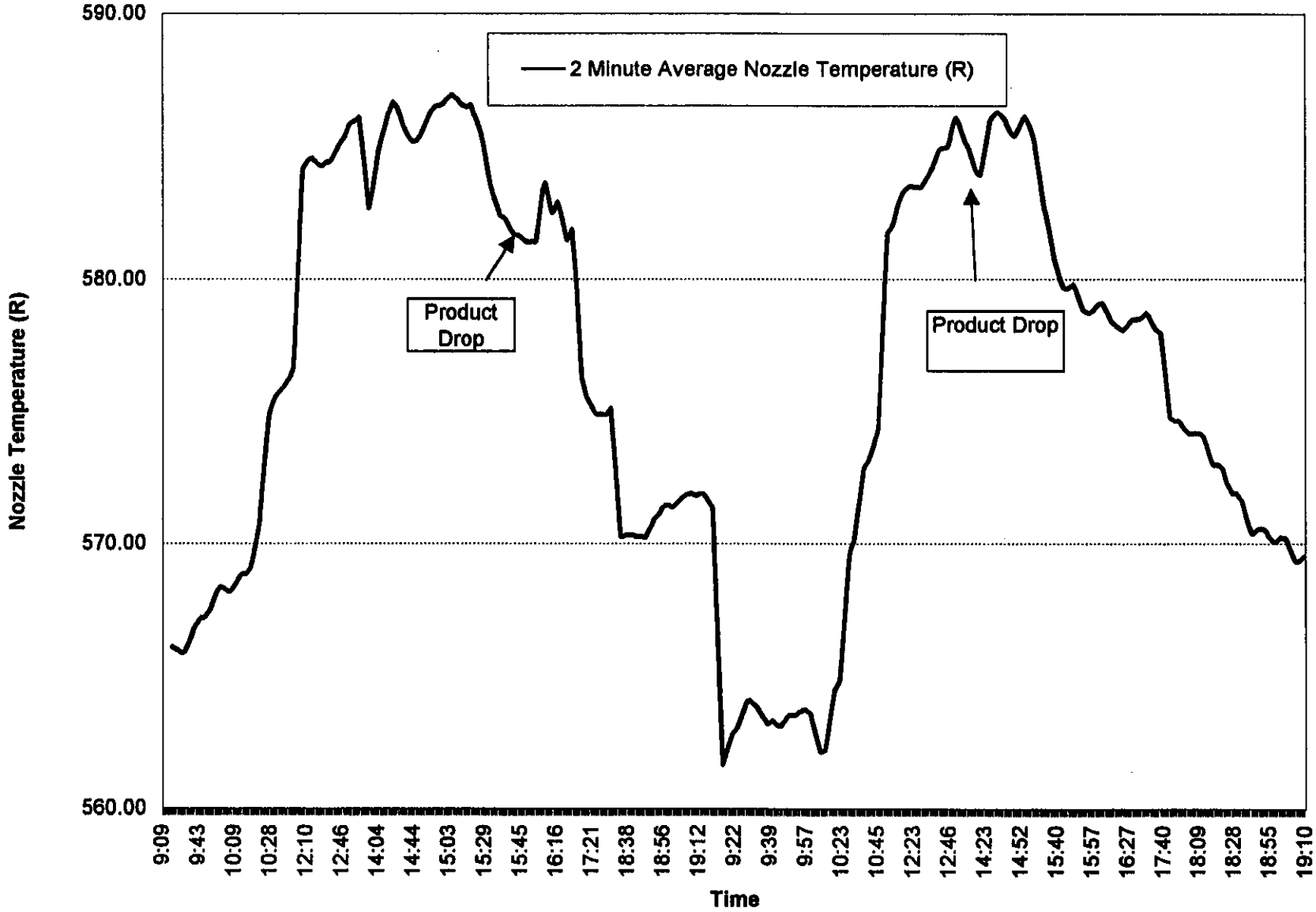


Figure 3-13 Balance System Two Minute Average Nozzle Temperature (R) for Winter Conditions

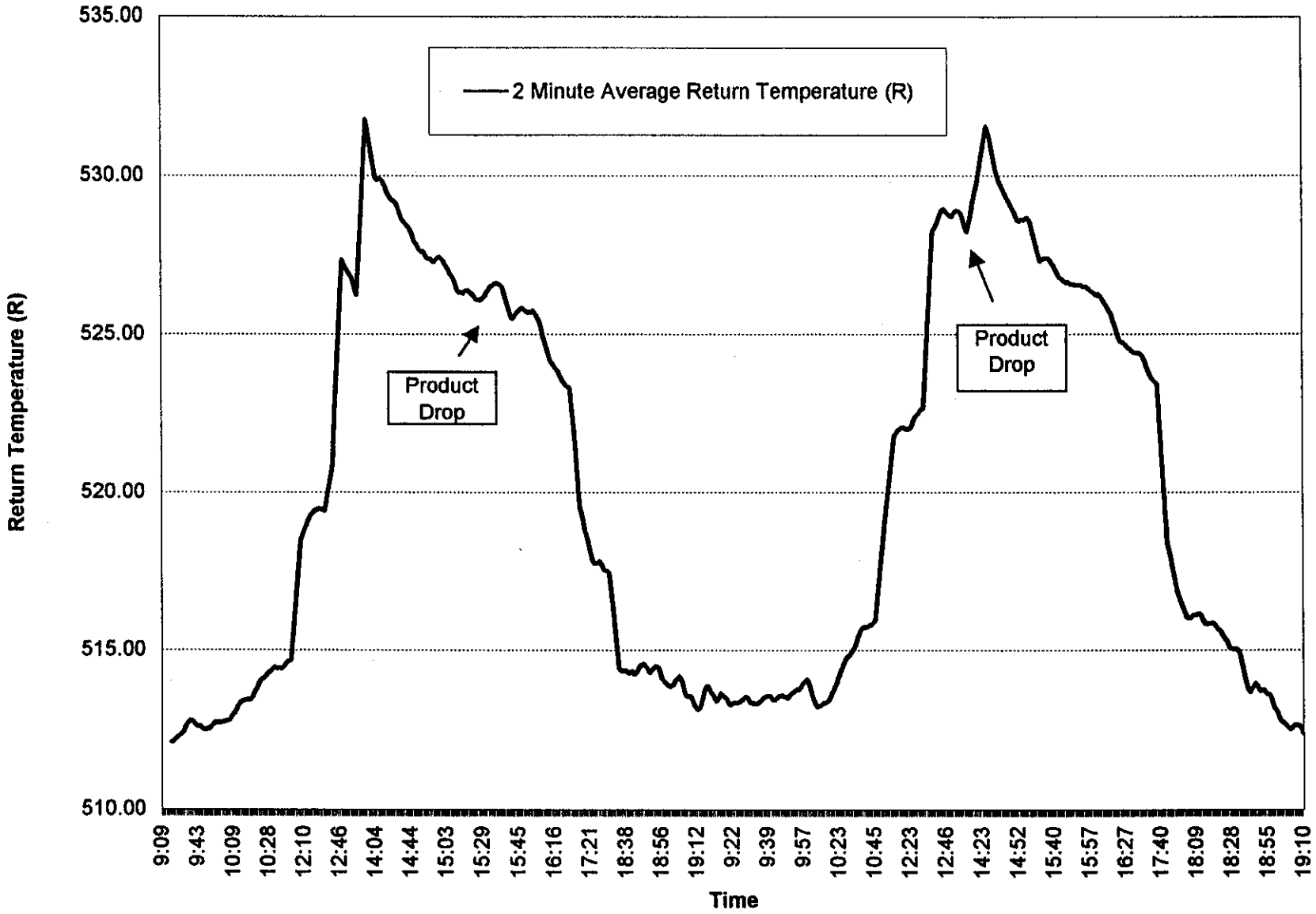


Figure 3-14 Balance System Two Minute Average Return Temperature (R) for Winter Conditions

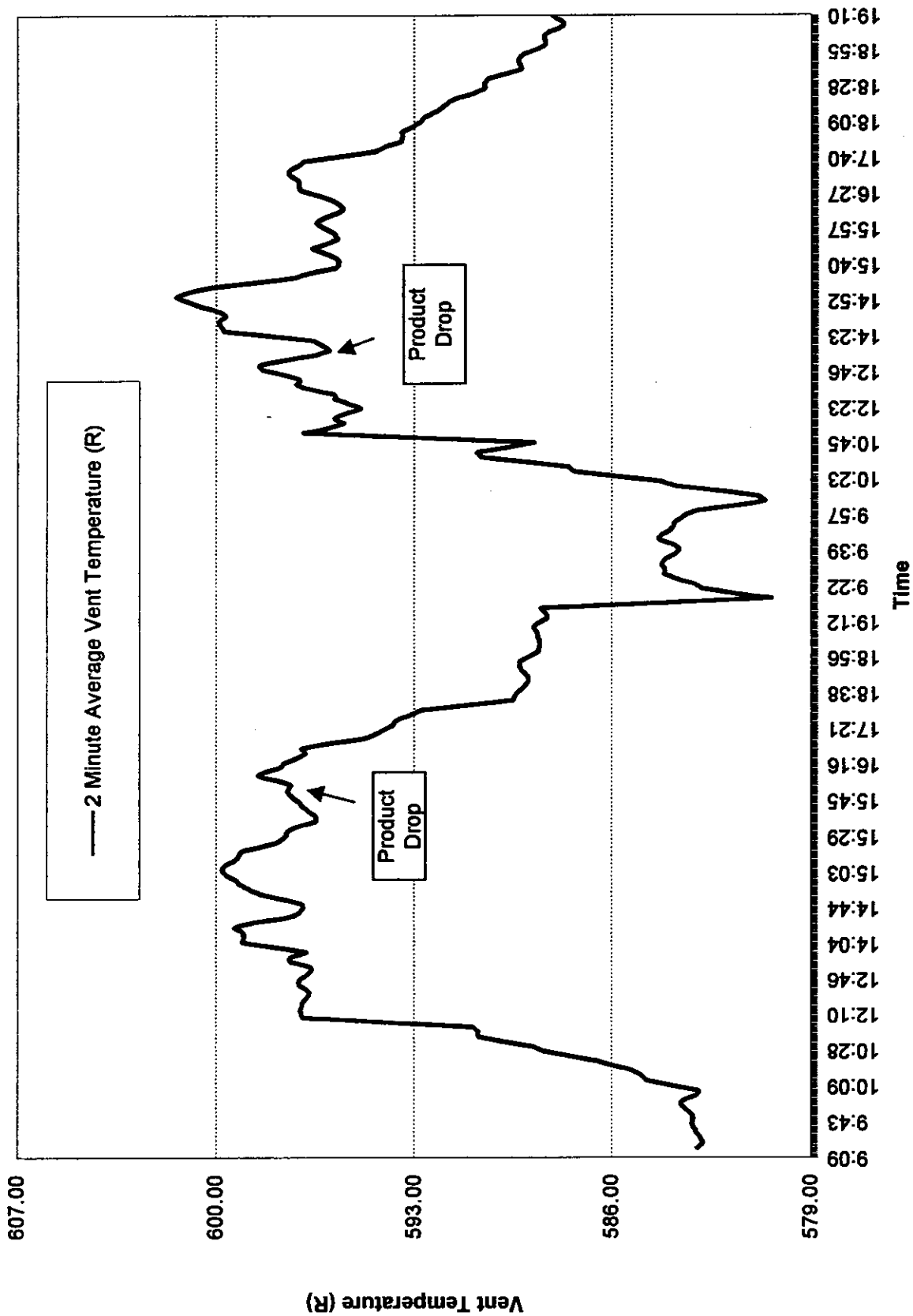


Figure 3-15 Balance System Two Minute Average Vent Temperature (R) for Winter Conditions

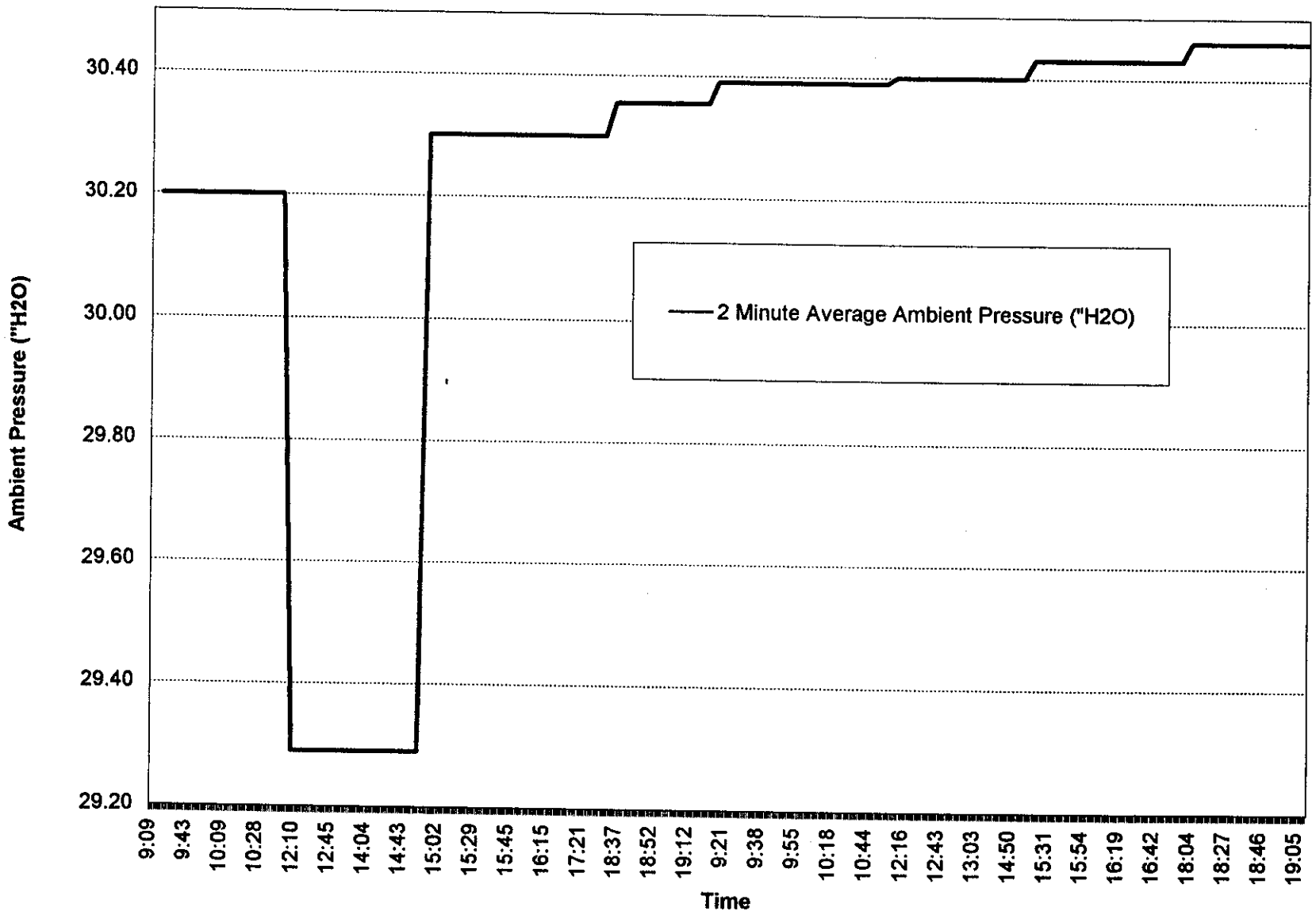


Figure 3-16 Gilbarco Vacuum Assist System Two Minute Average Ambient Pressure ("H2O) for Winter Conditions

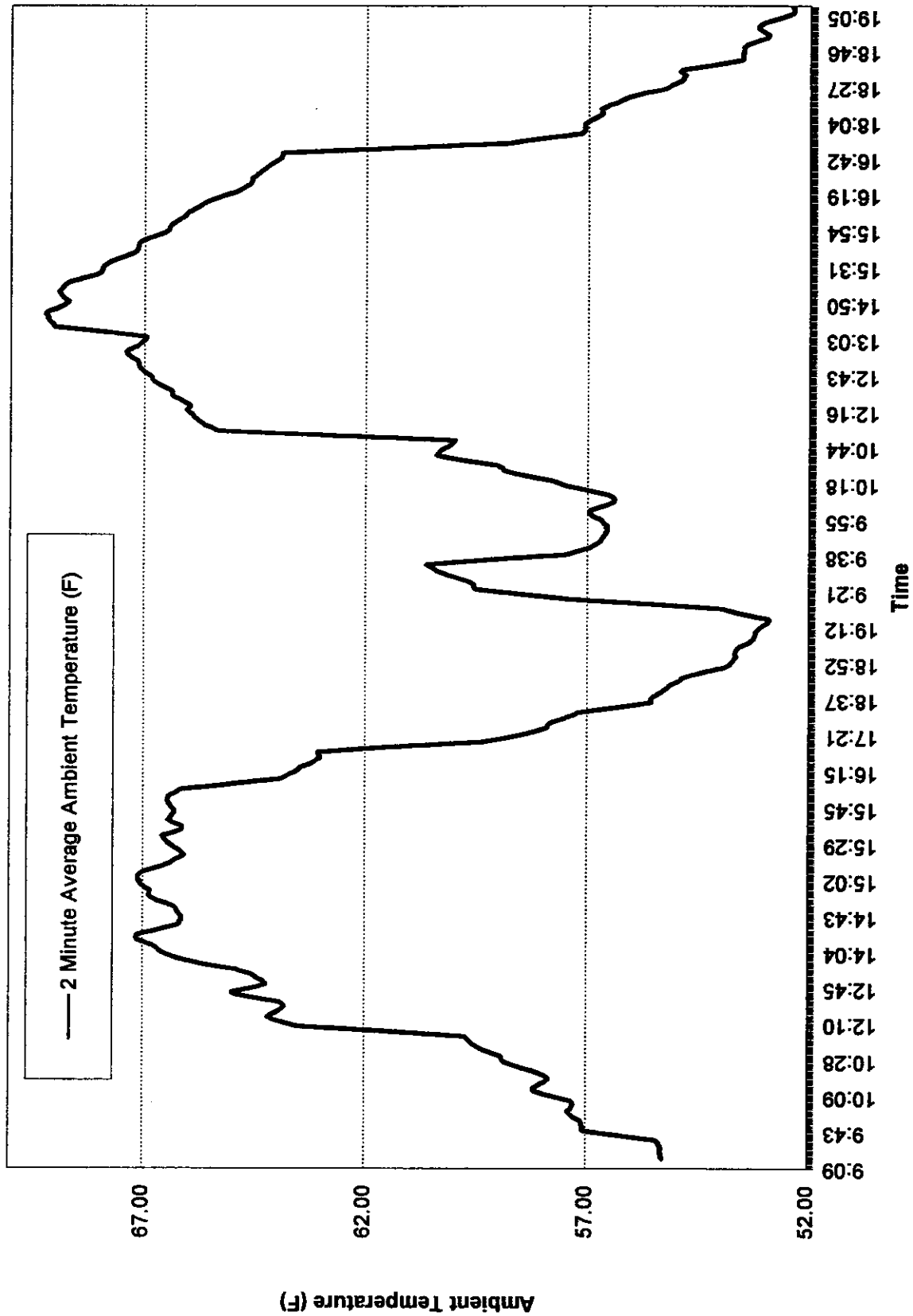


Figure 3-17 Balance System Two Minute Average Ambient Temperature (F) for Winter Conditions

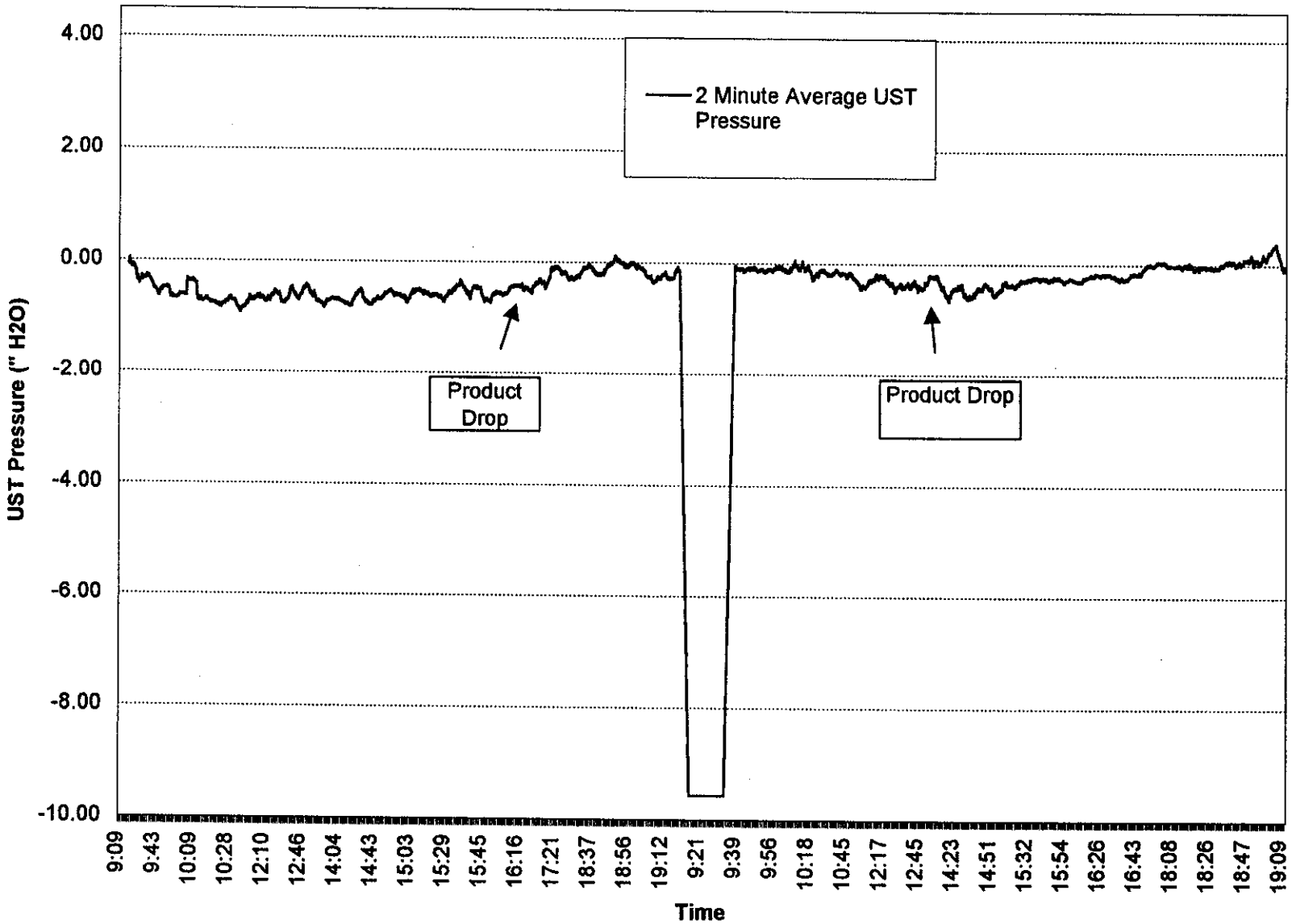


Figure 3-18 Balance System Two Minute Average UST Pressure (" H2O) for Winter Conditions

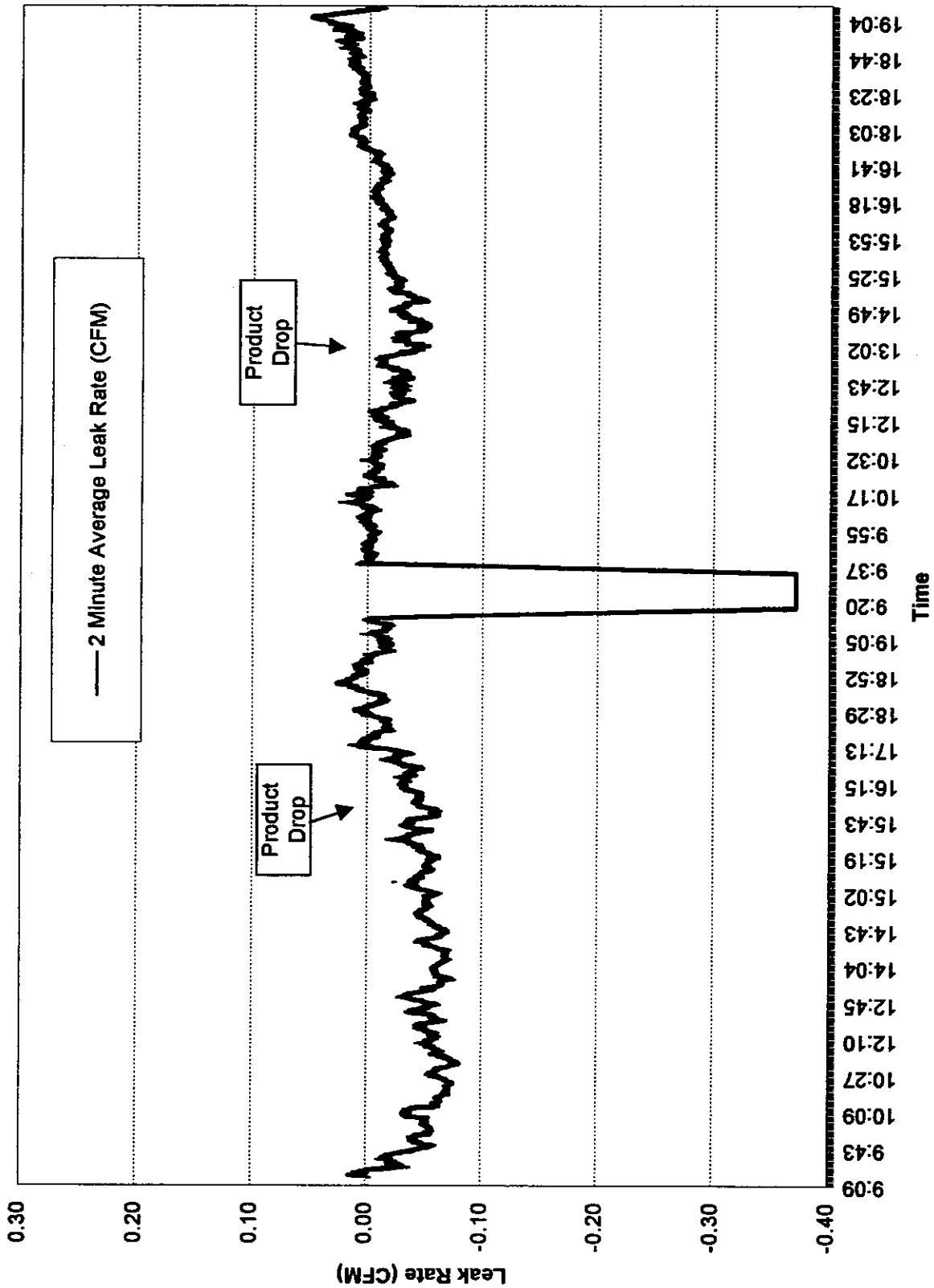


Figure 3-19 Balance System Two Minute Average Leak Rate (CFM) for Winter Conditions

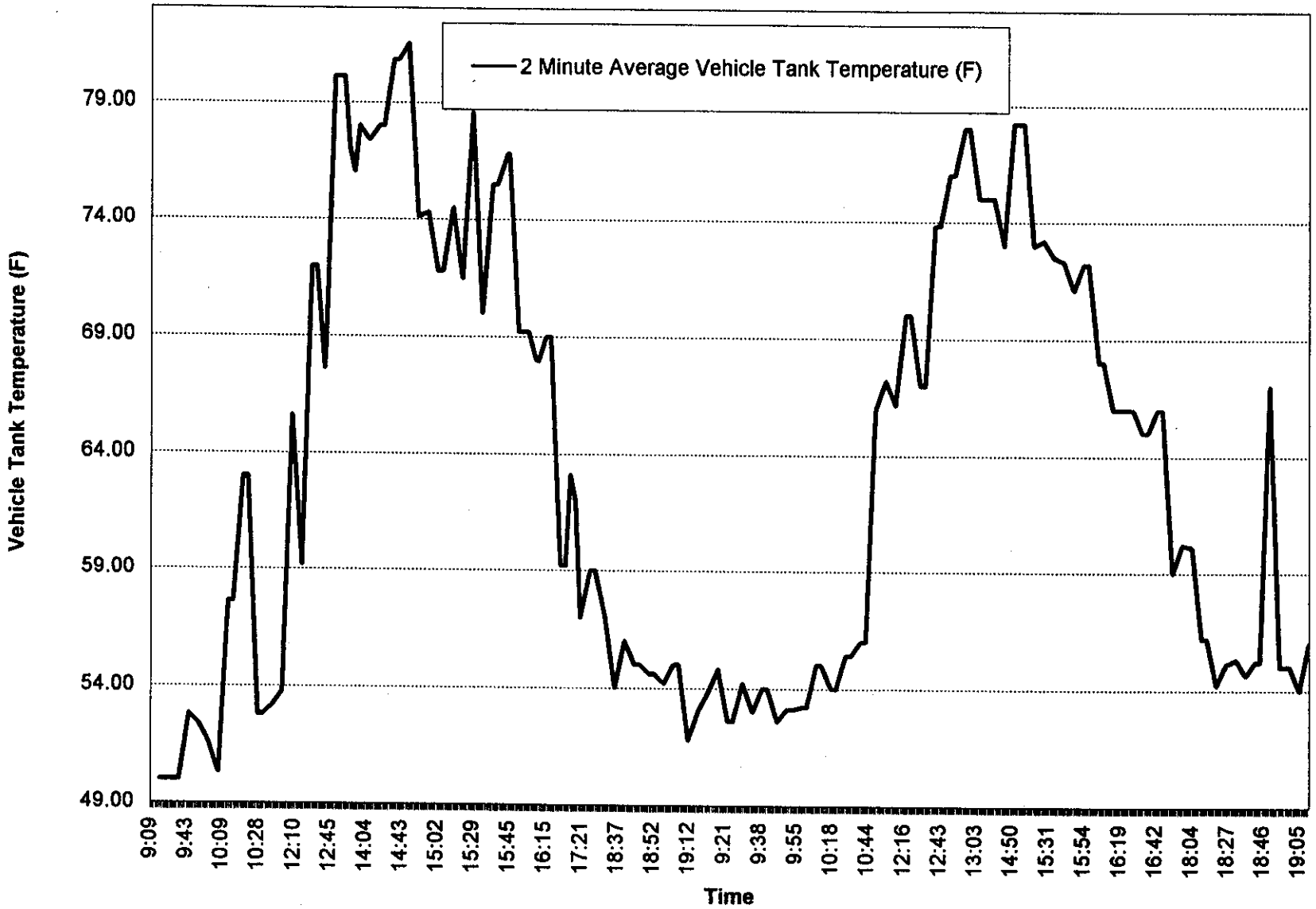


Figure 3-20 Balance System Two Minute Average Vehicle Tank Temperature (F) for Winter Conditions

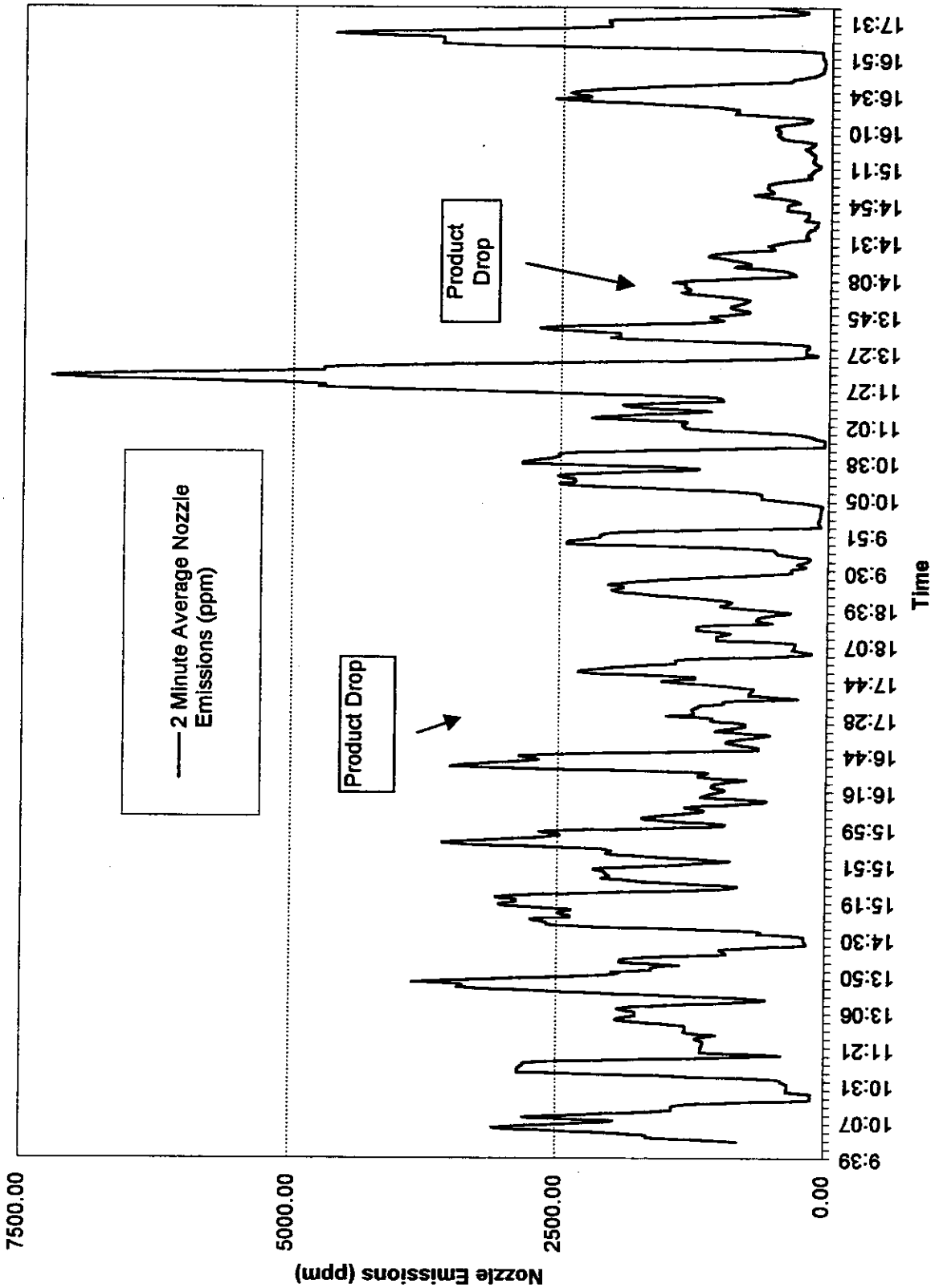


Figure 3-21 Balance System Two Minute Average Nozzle Emissions (ppm) for Spring Conditions

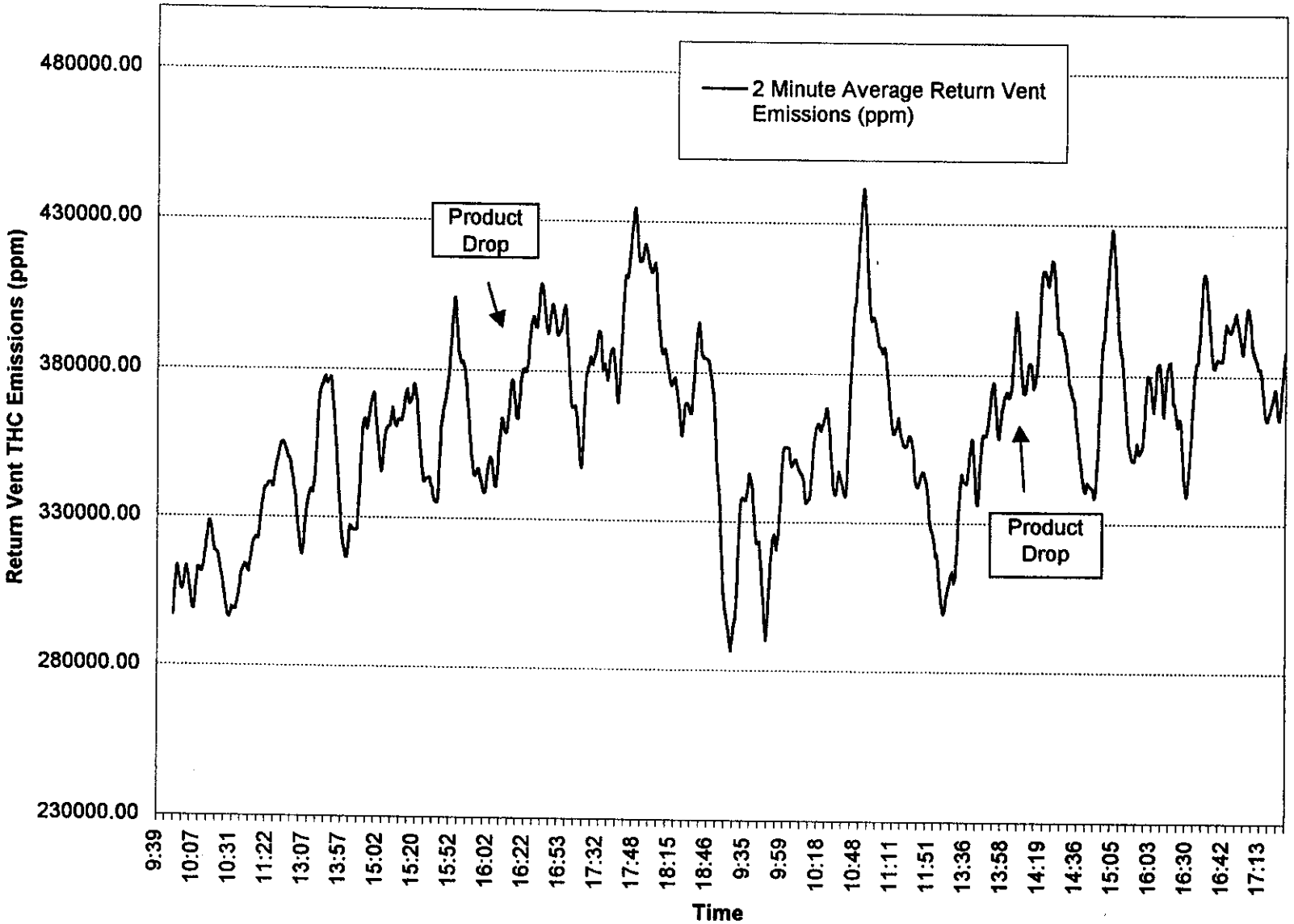


Figure 3-22 Balance System Two Minute Average Return Emissions (ppm) for Spring Conditions

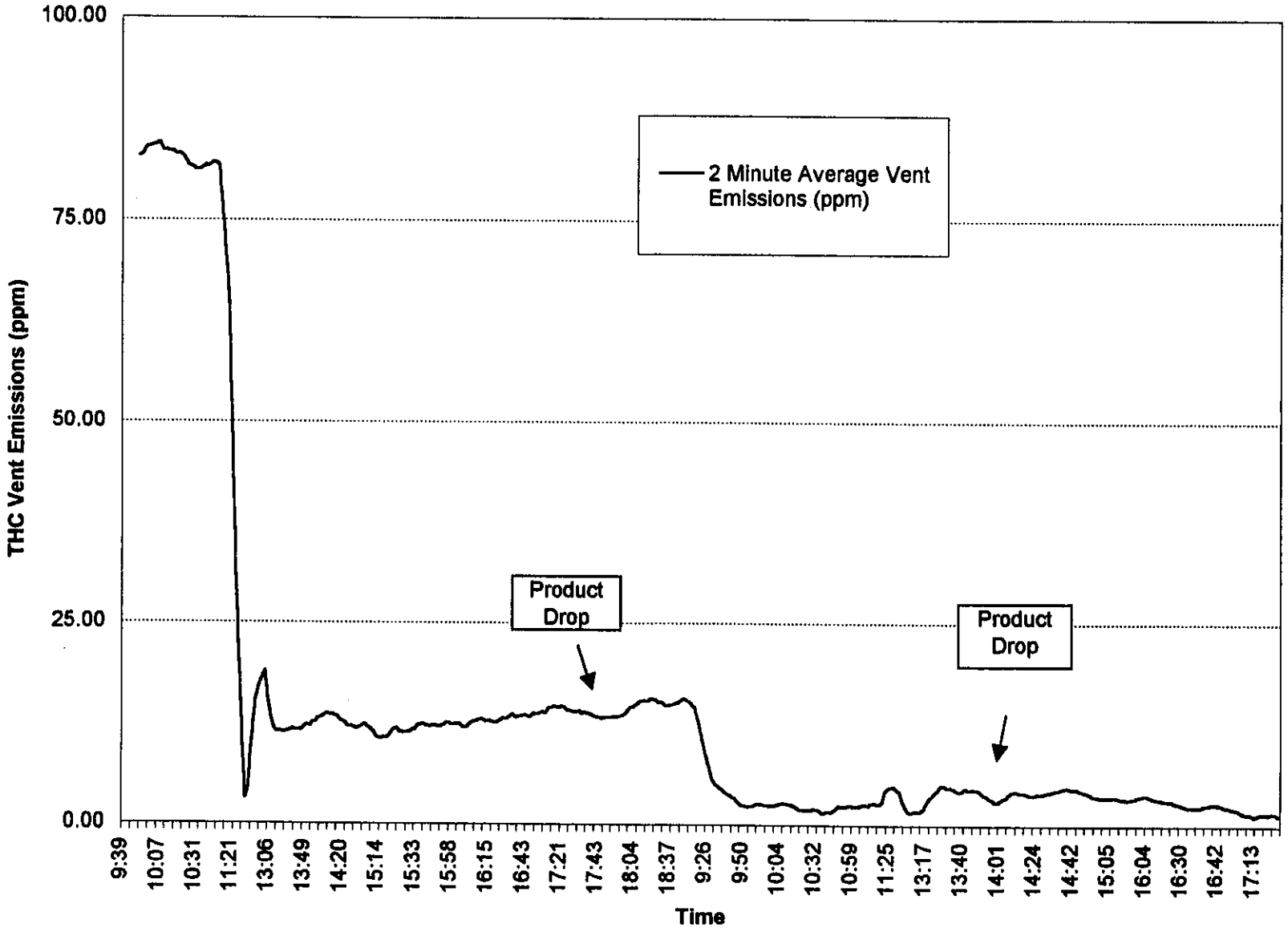


Figure 3-23 Balance System Two Minute Average Vent Emissions (ppm) for Spring Conditions

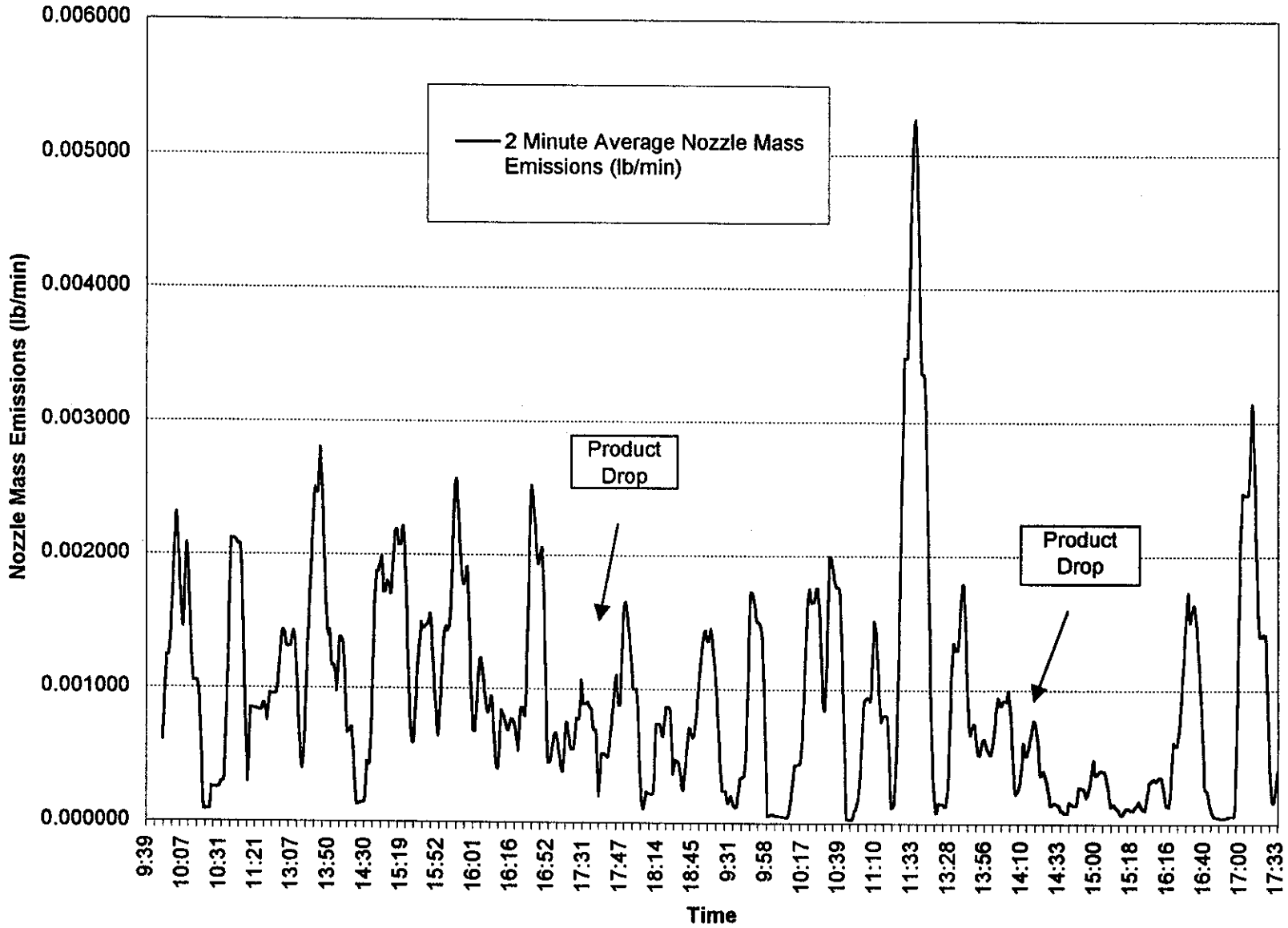


Figure 3-24 Balance System Two Minute Average Nozzle Mass Emissions (lb/min) for Spring Conditions

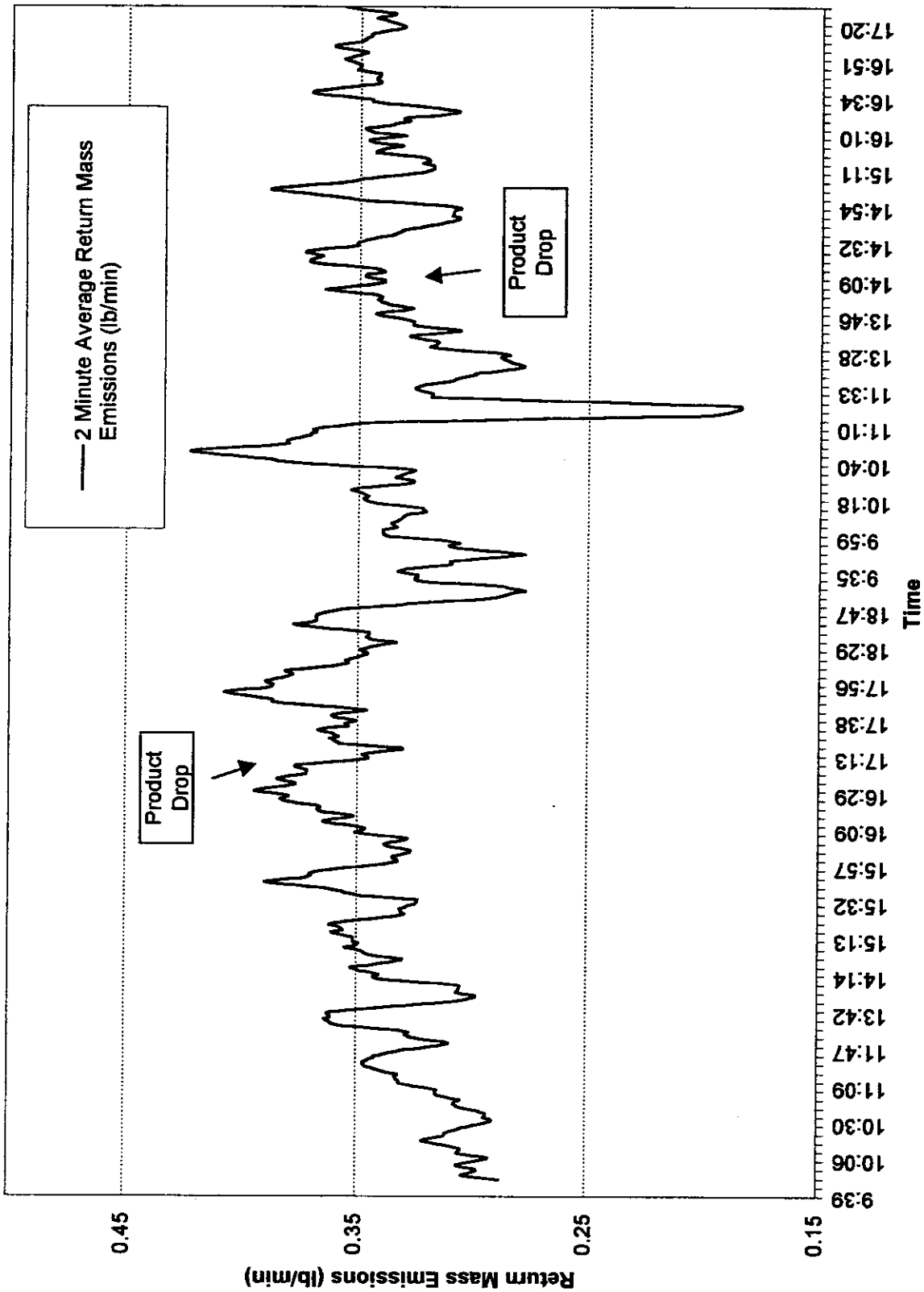


Figure 3-25 Balance System Two Minute Average Return Mass Emissions (lb/min) for Spring Conditions

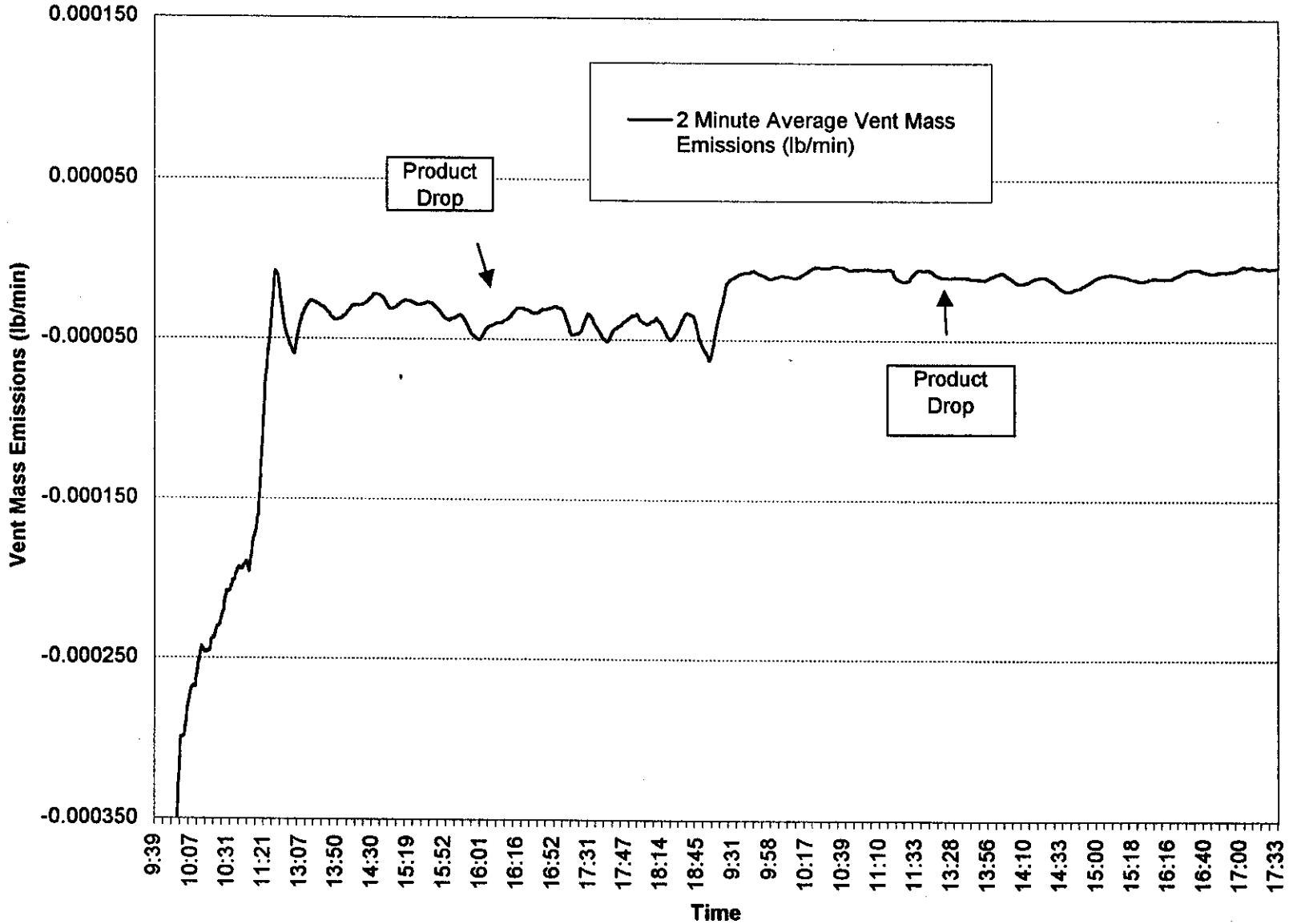


Figure 3-26 Balance System Two Minute Average Vent Mass Emissions (lb/min) for Spring Conditions

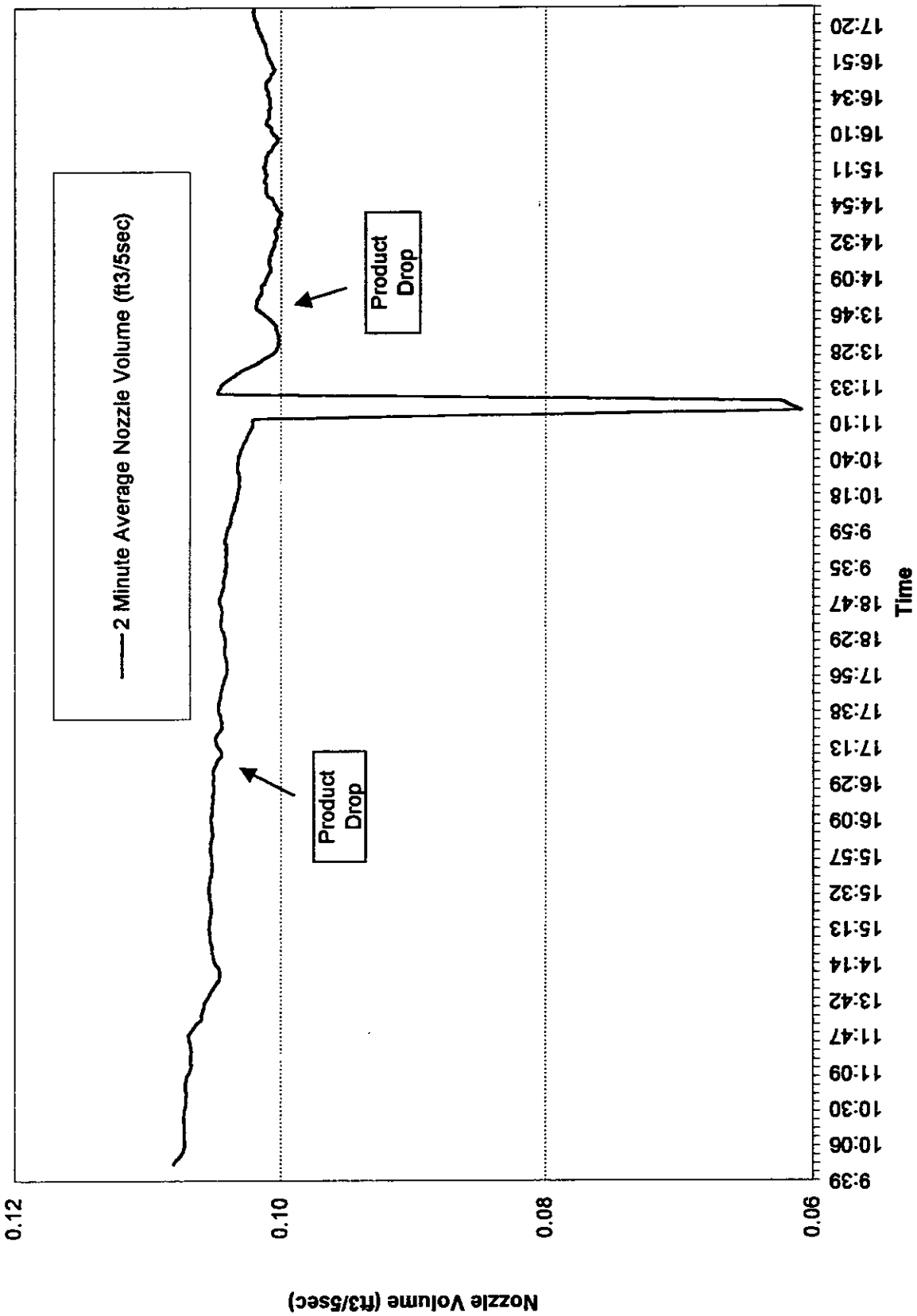


Figure 3-27 Balance System Two Minute Average Nozzle Volume (ft3/sec) for Spring Conditions

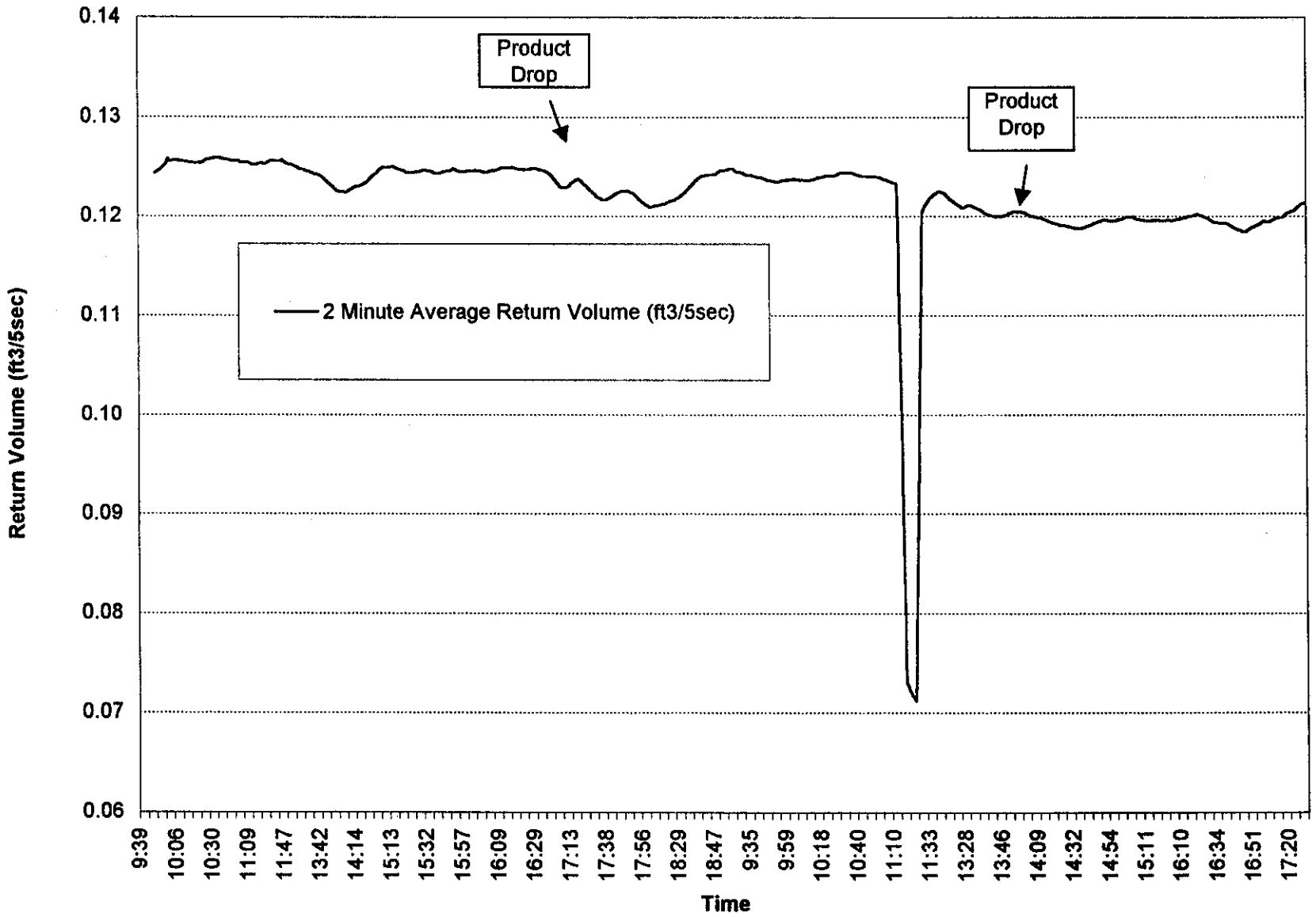


Figure 3-28 Balance System Two Minute Average Return Volume (ft3/sec) for Spring Conditions

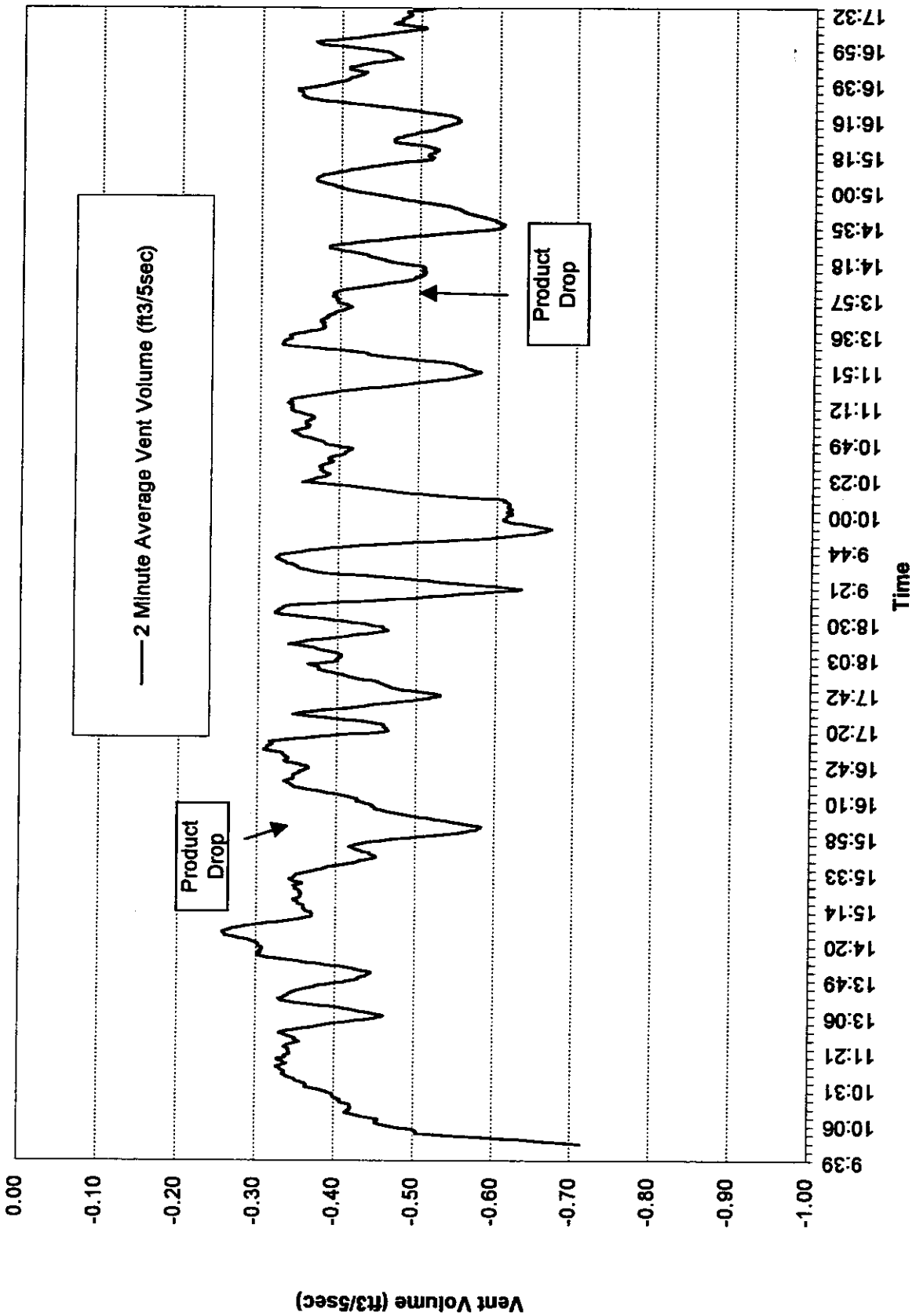


Figure 3-29 Balance System Two Minute Average Vent Volume (ft3/5sec) for Spring Conditions

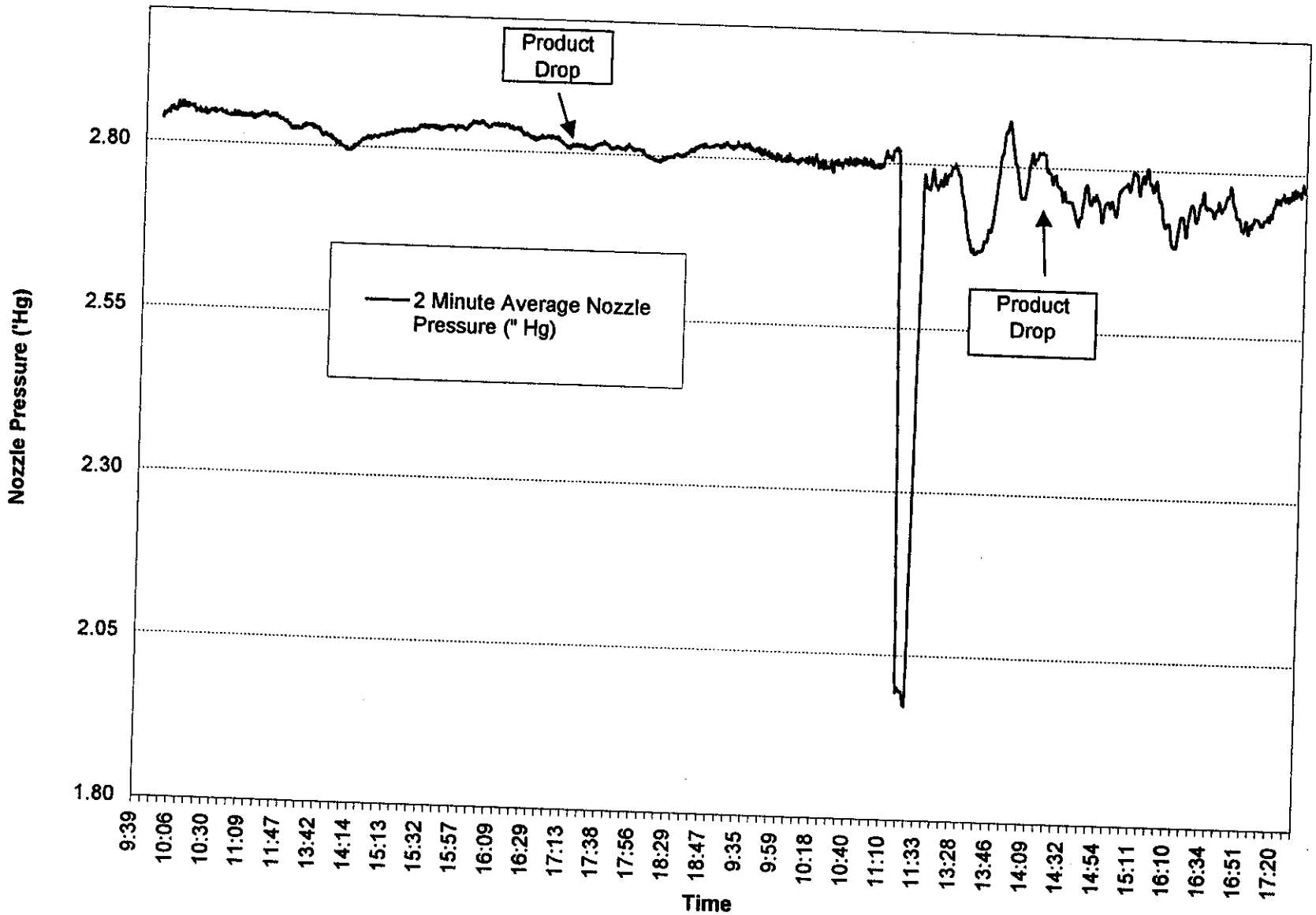


Figure 3-30 Balance System Two Minute Average Nozzle Pressure ("Hg) for Spring Conditions

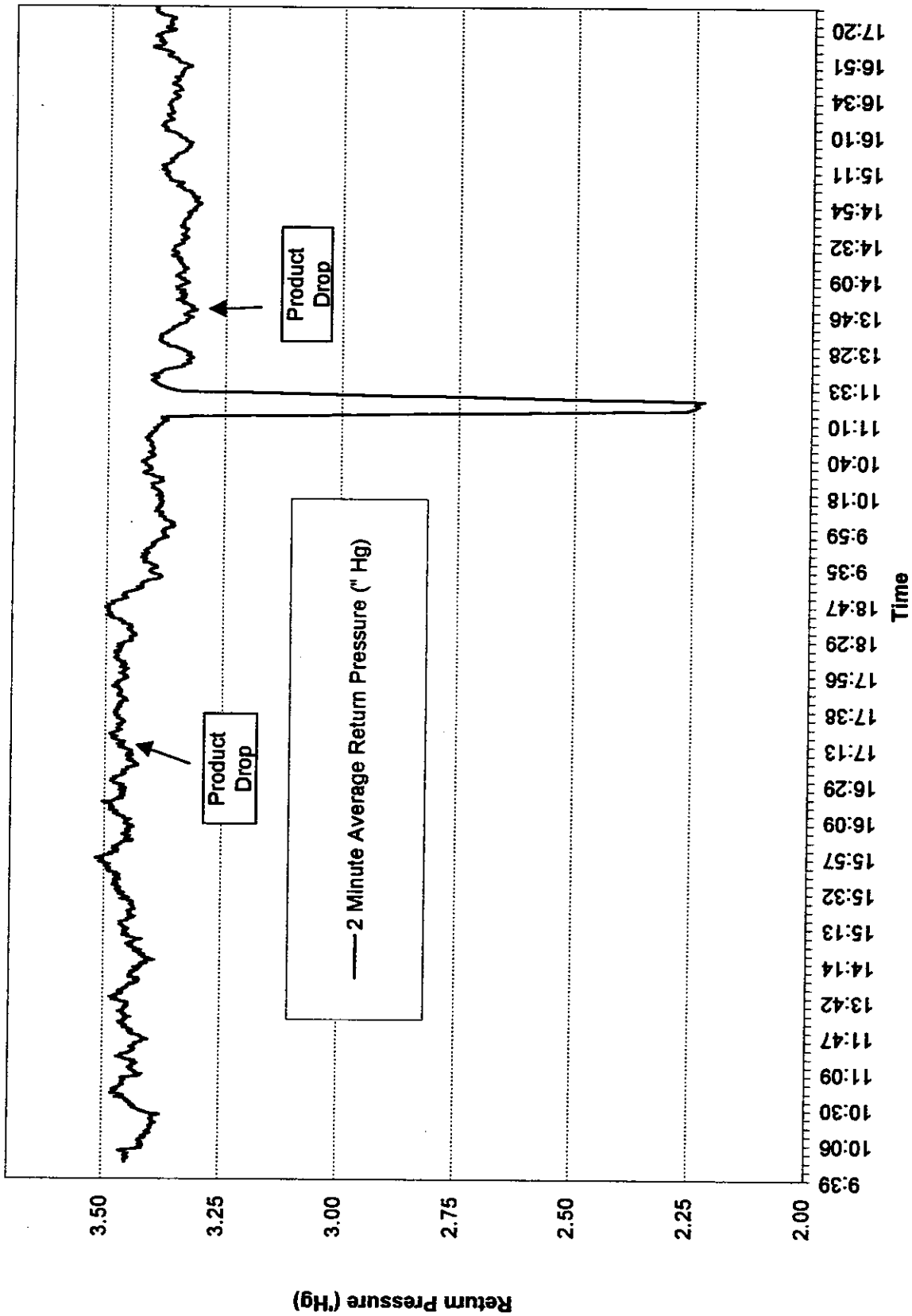


Figure 3-31 Balance System Two Minute Average Return Pressure ("Hg) for Spring Conditions

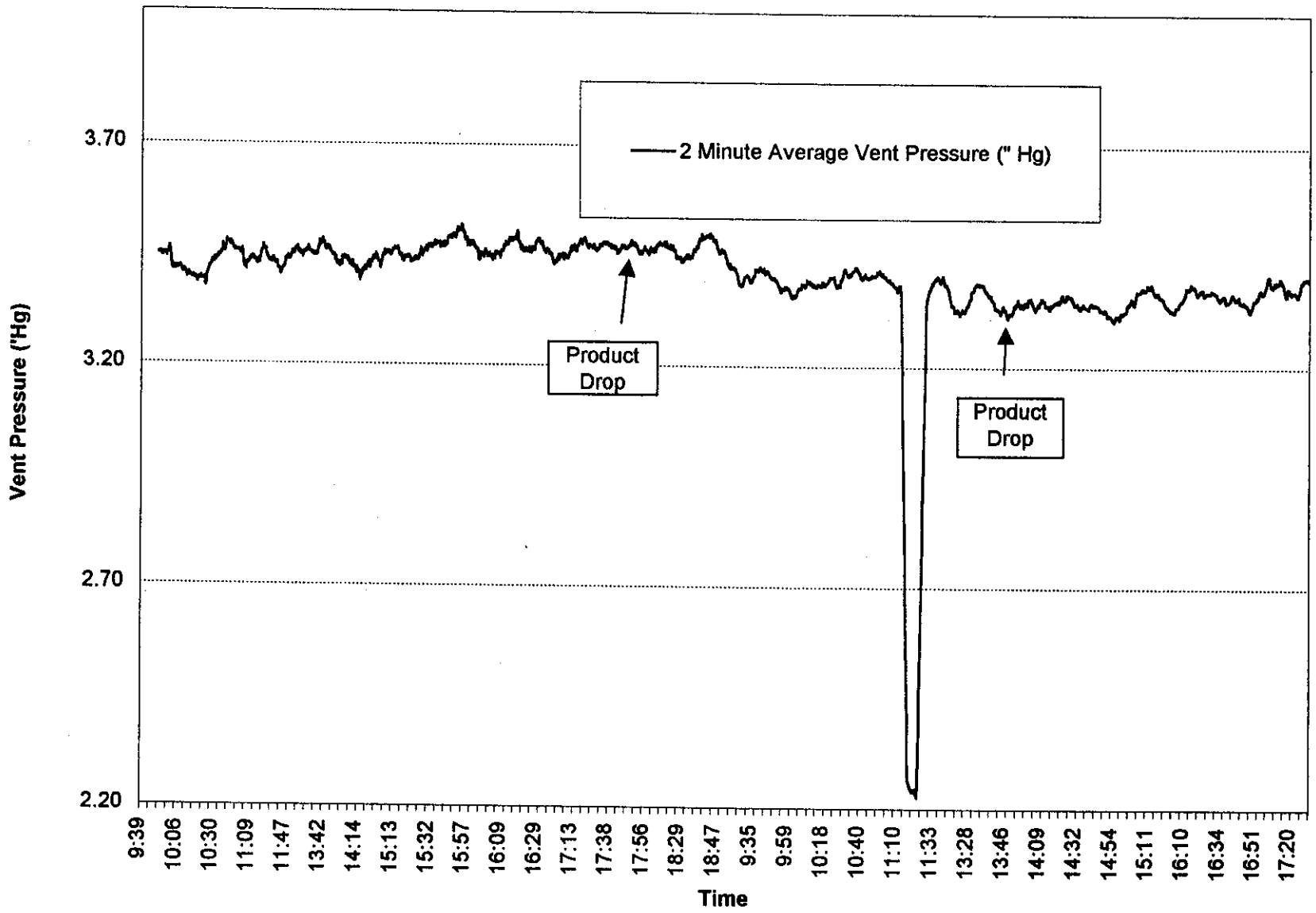


Figure 3-32 Balance System Two Minute Average Vent Pressure ("Hg) for Spring Conditions

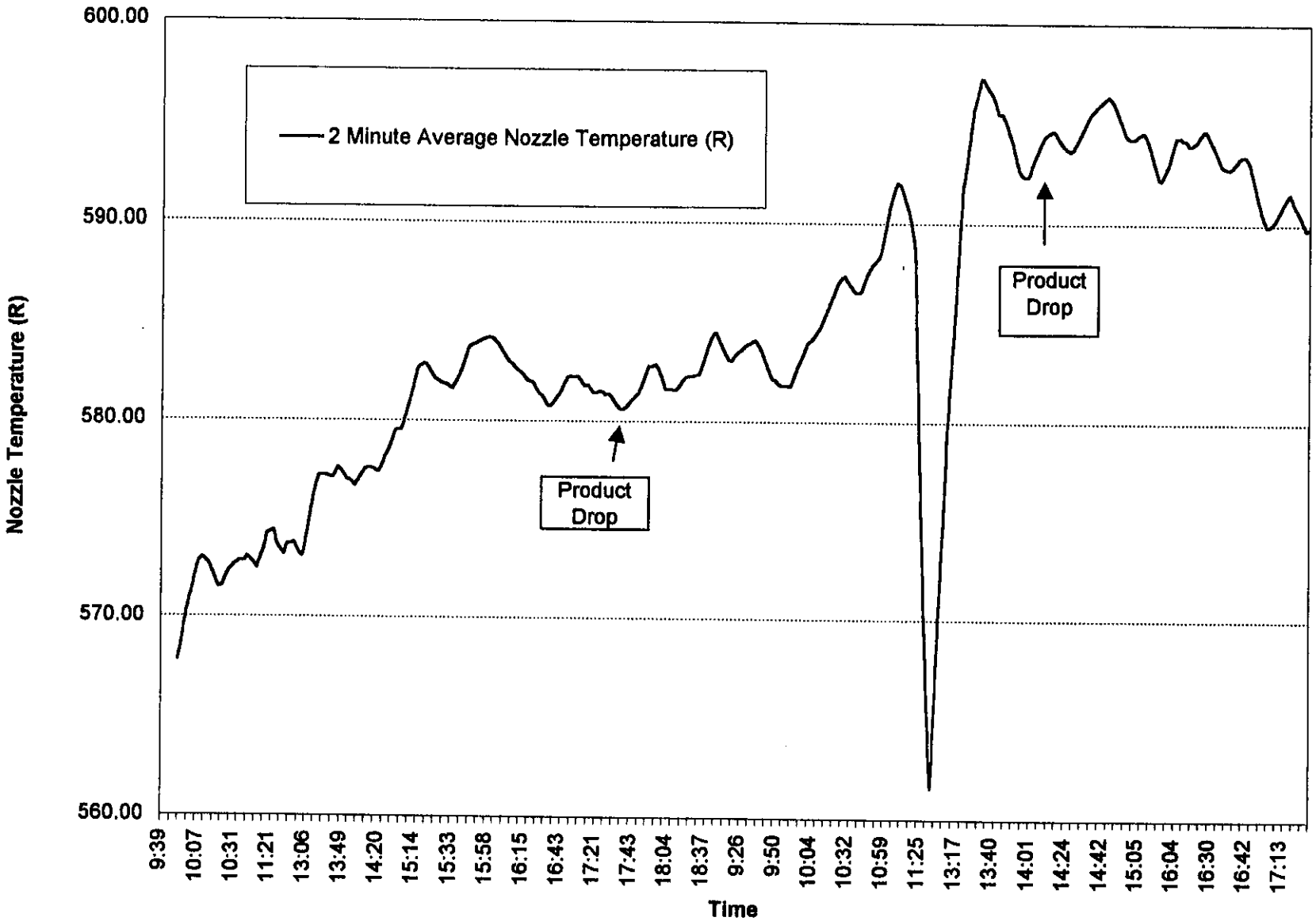


Figure 3-33 Balance System Two Minute Average Nozzle Temperature (R) for Spring Conditions

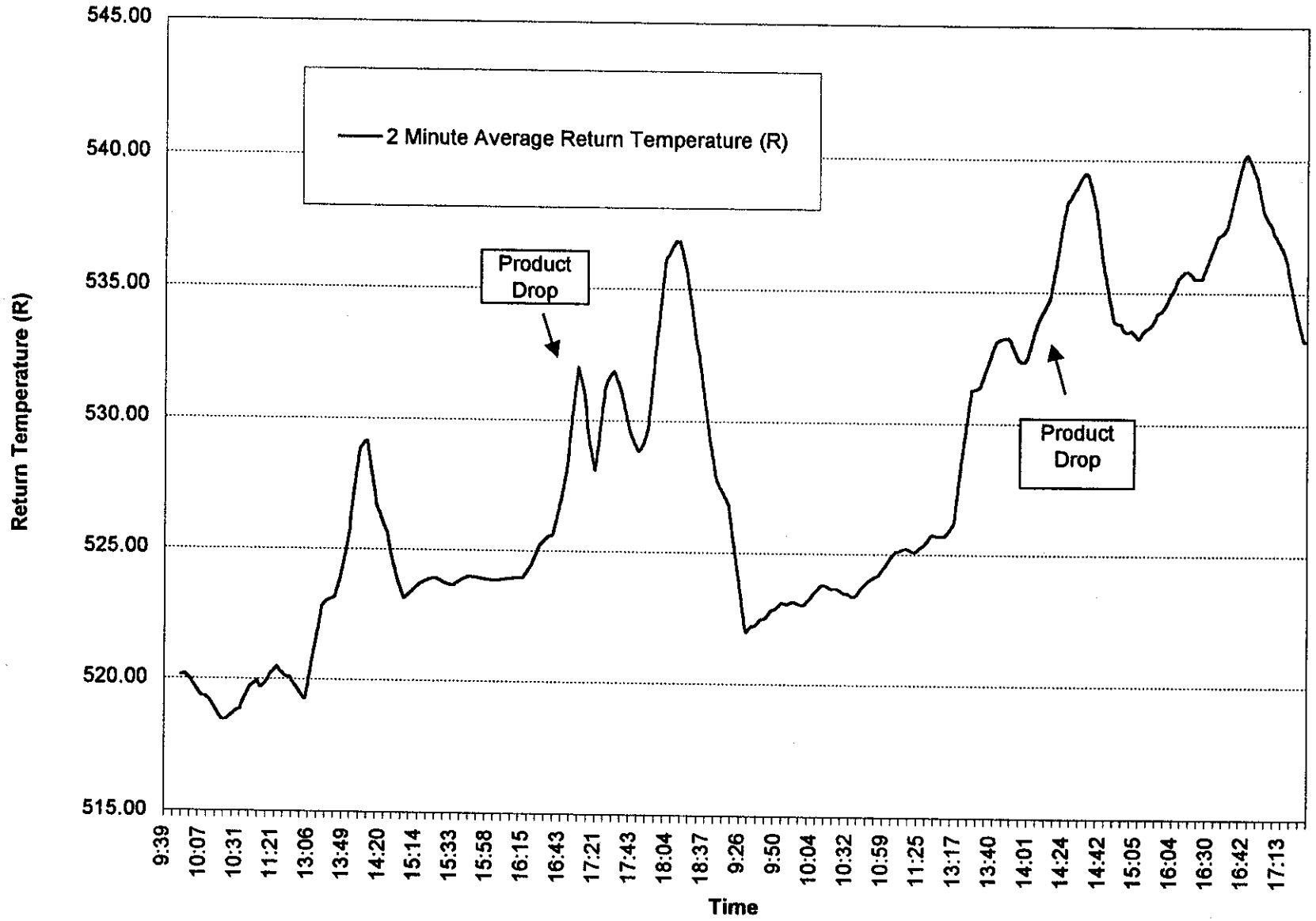


Figure 3-34 Balance System Two Minute Average Return Temperature (R) for Spring Conditions

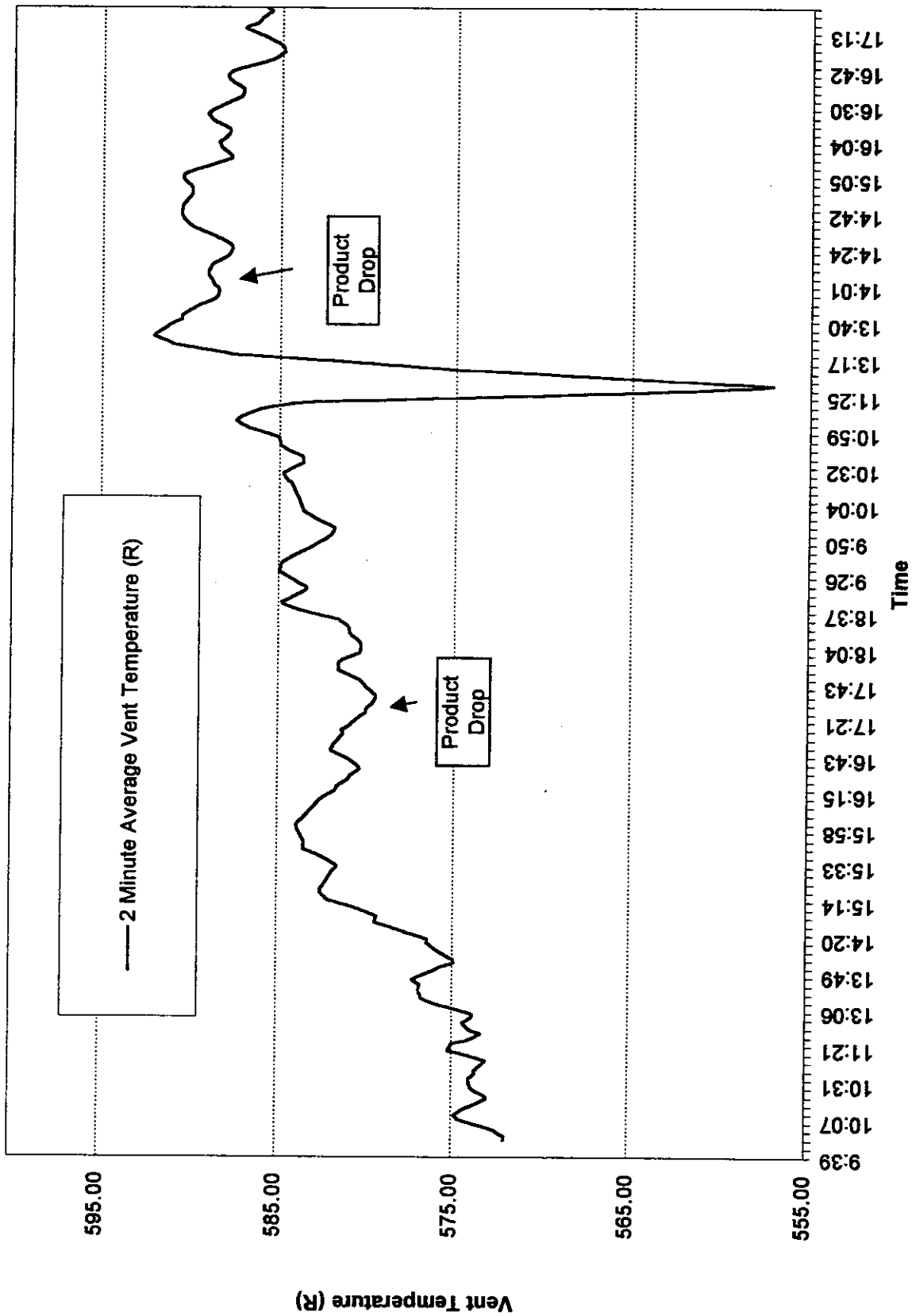


Figure 3-35 Gilbarco Vacuum Assist System Two Minute Average Vent Temperature (R) for Winter Conditions

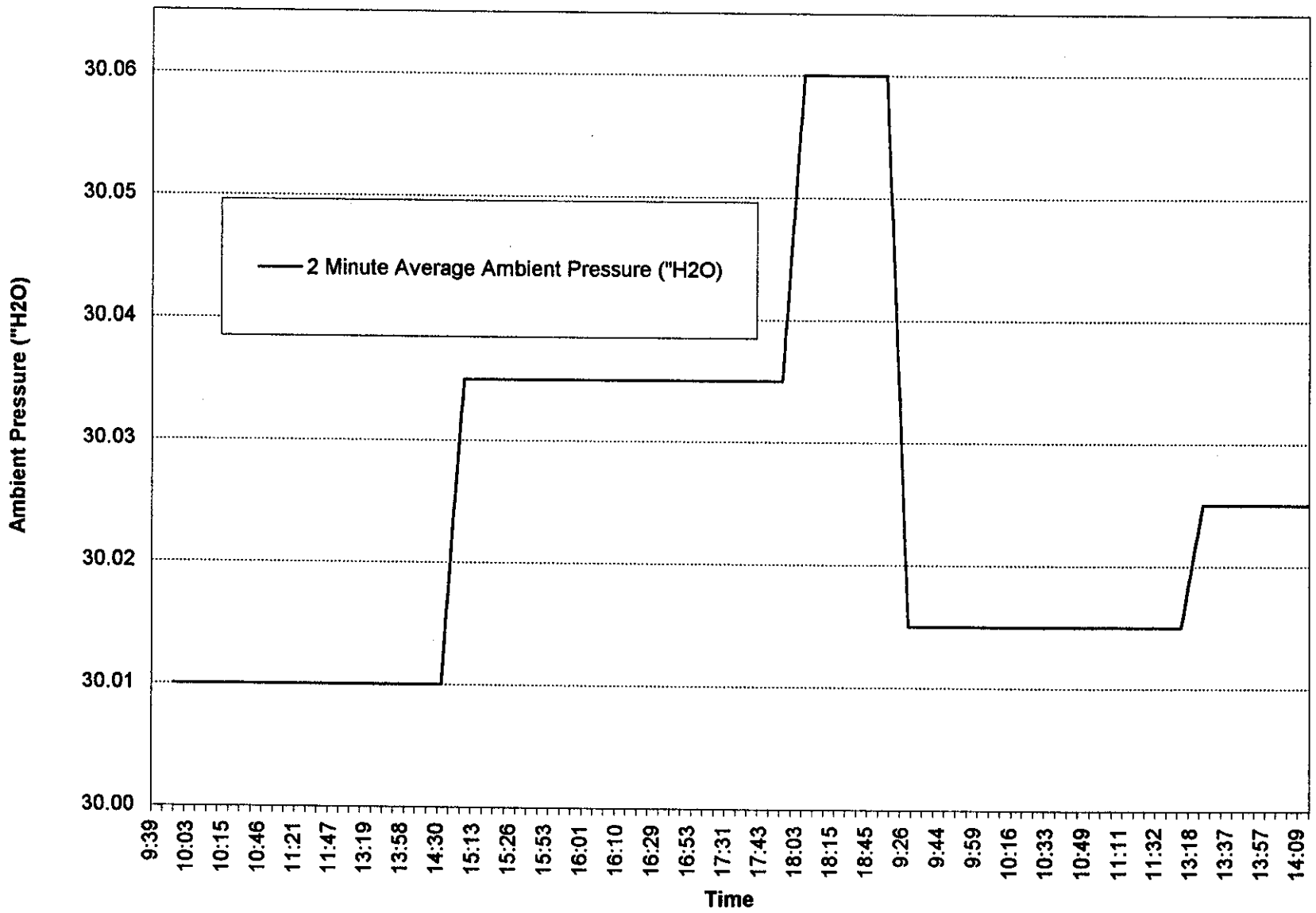


Figure 3-36 Balance System Two Minute Average Ambient Pressure ("H2O) for Spring Conditions

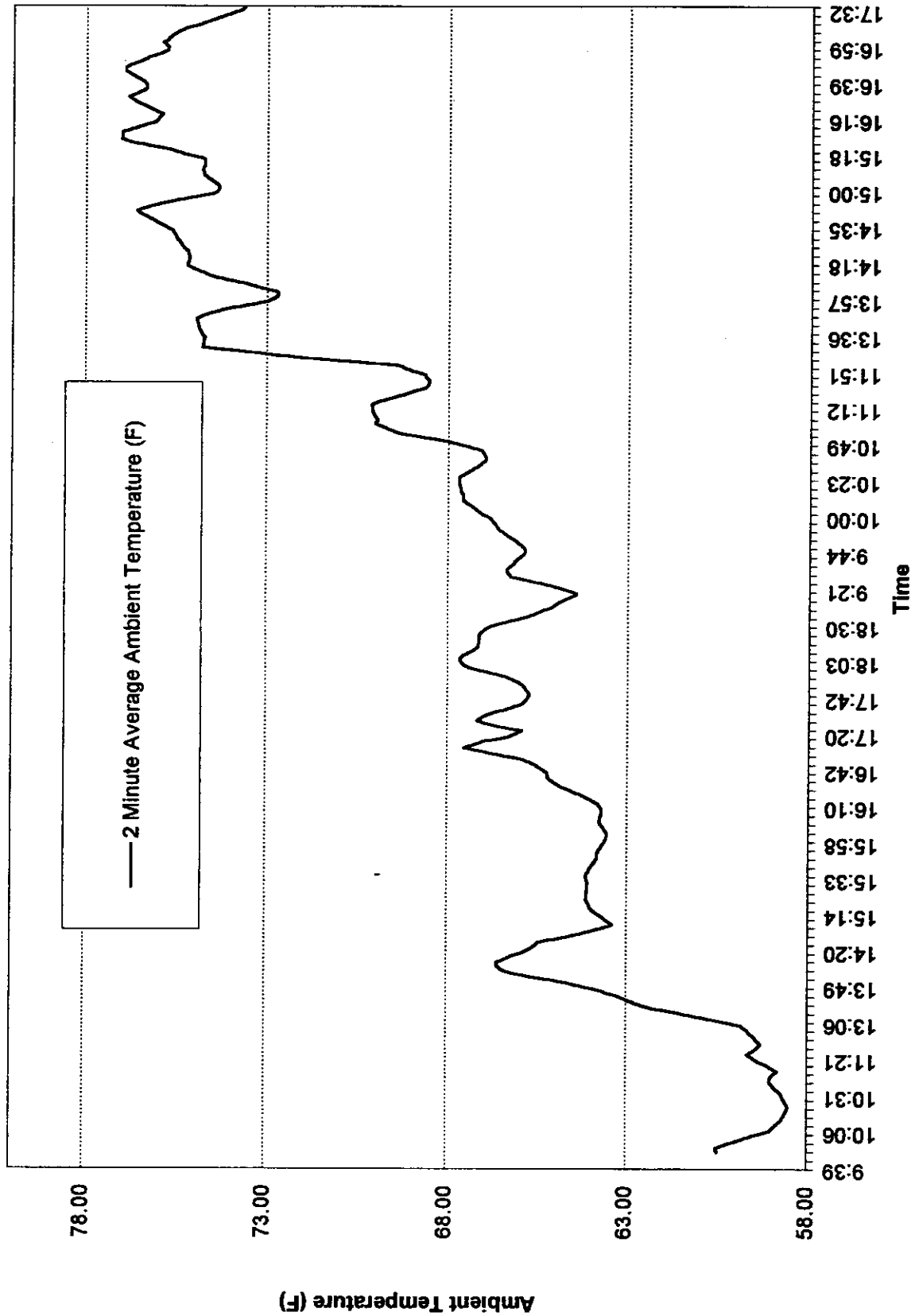


Figure 3-37 Balance System Two Minute Average Ambient Temperature (F) for Spring Conditions

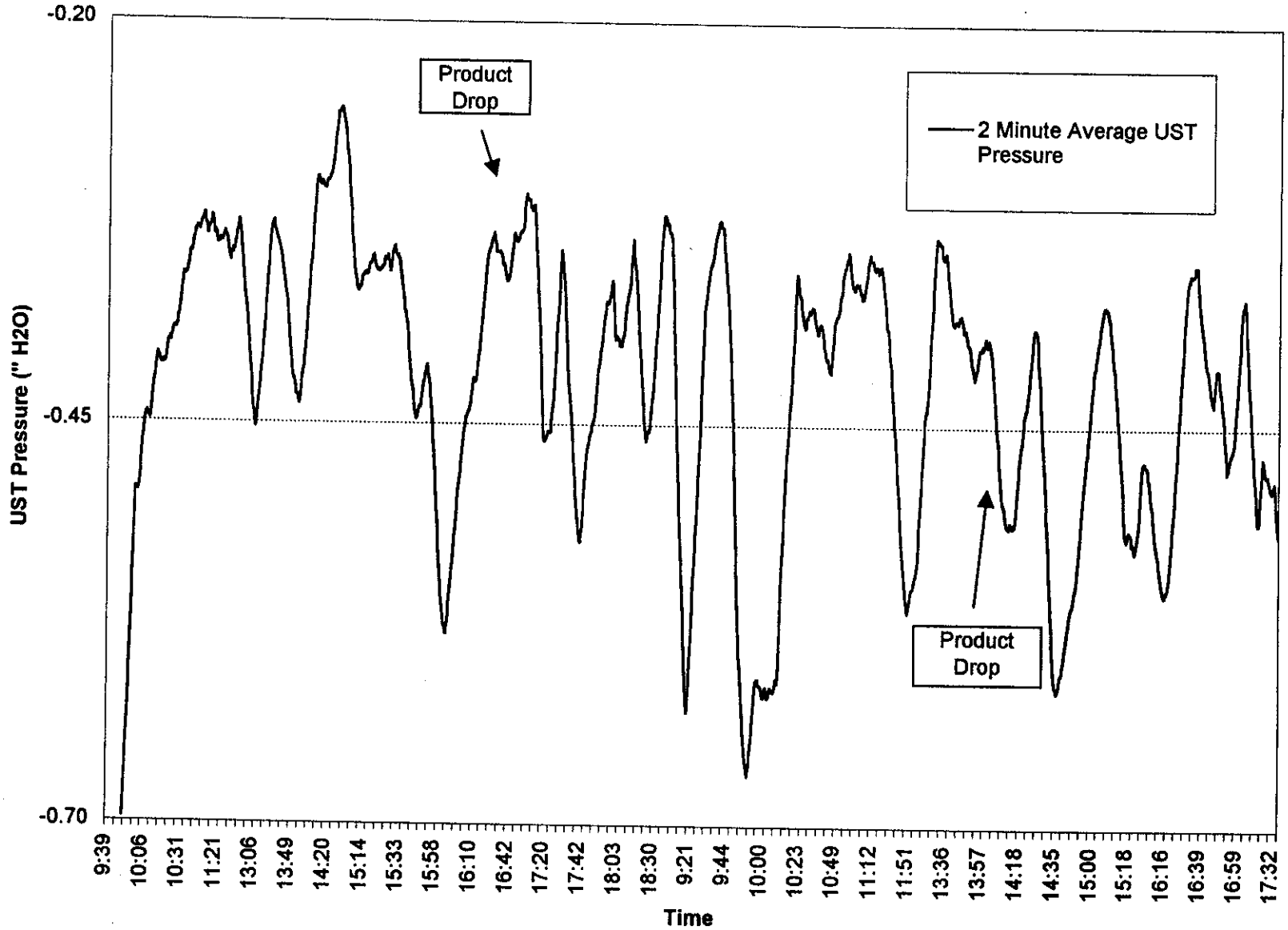


Figure 3-38 Balance System Two Minute Average UST Pressure (" H2O) for Spring Conditions

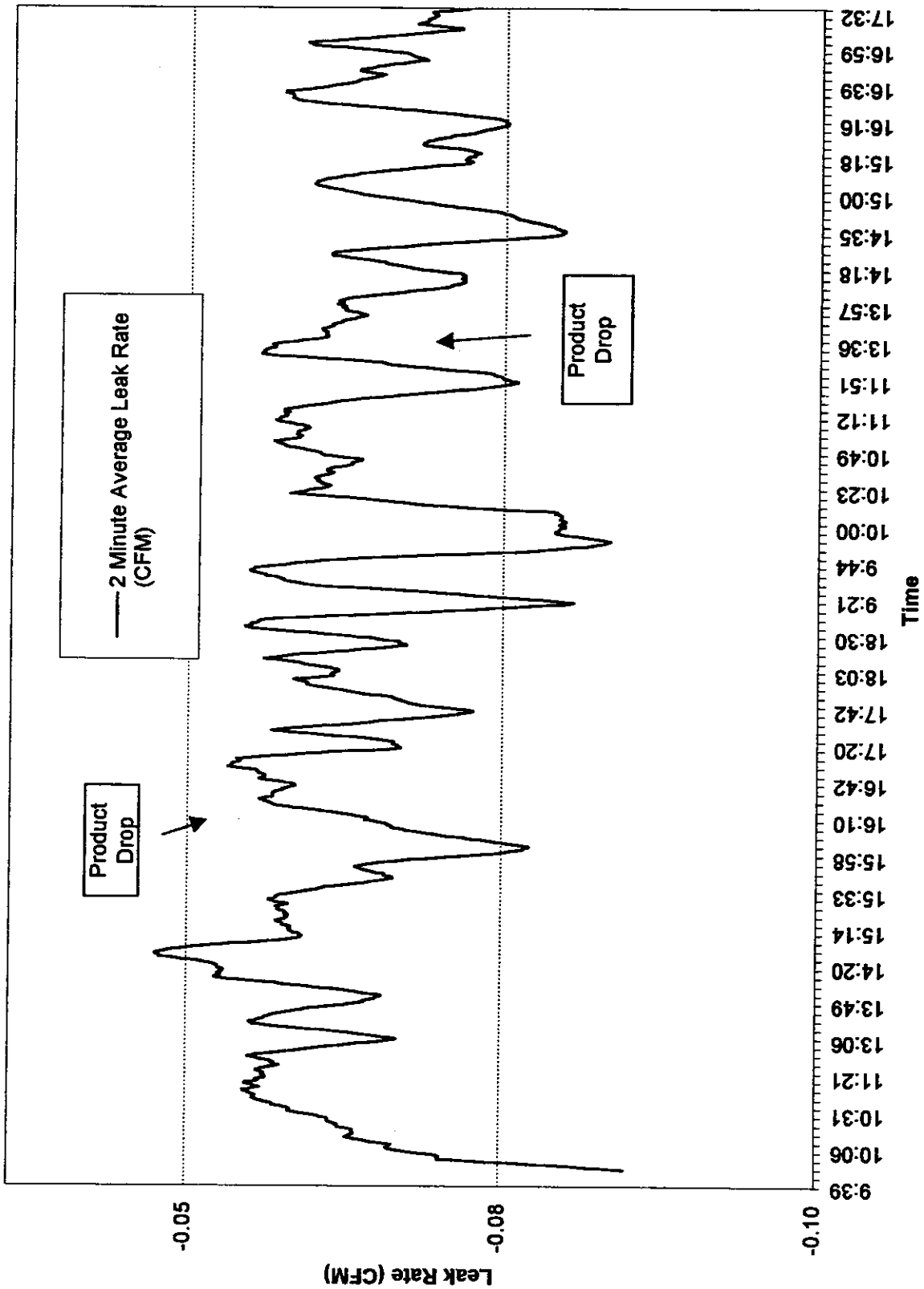


Figure 3-39 Balance System Two Minute Average Leak Rate (CFM) for Spring Conditions

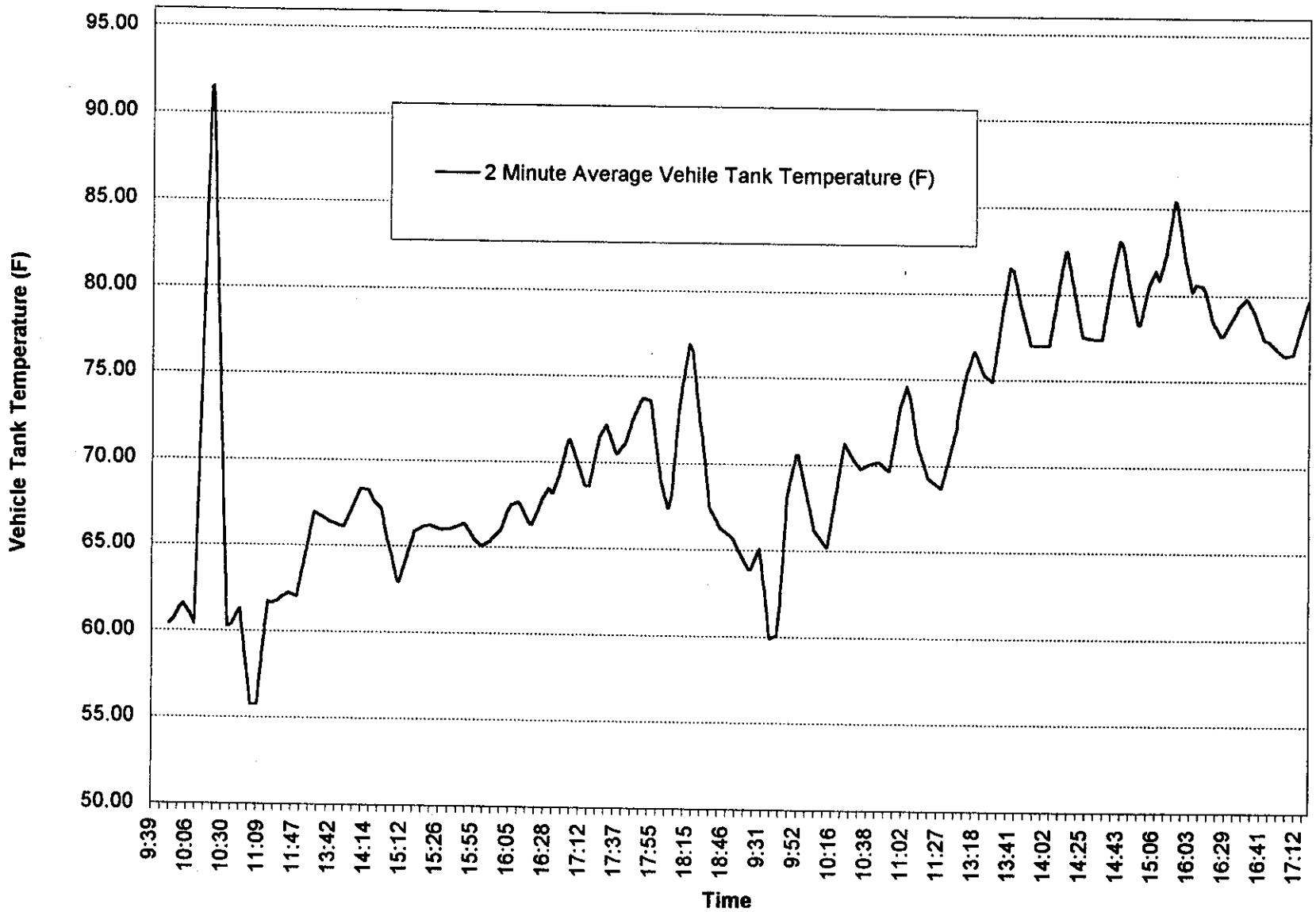


Figure 3-40 Balance System Two Minute Average Vehicle Tank Temperature (F) for Spring Conditions

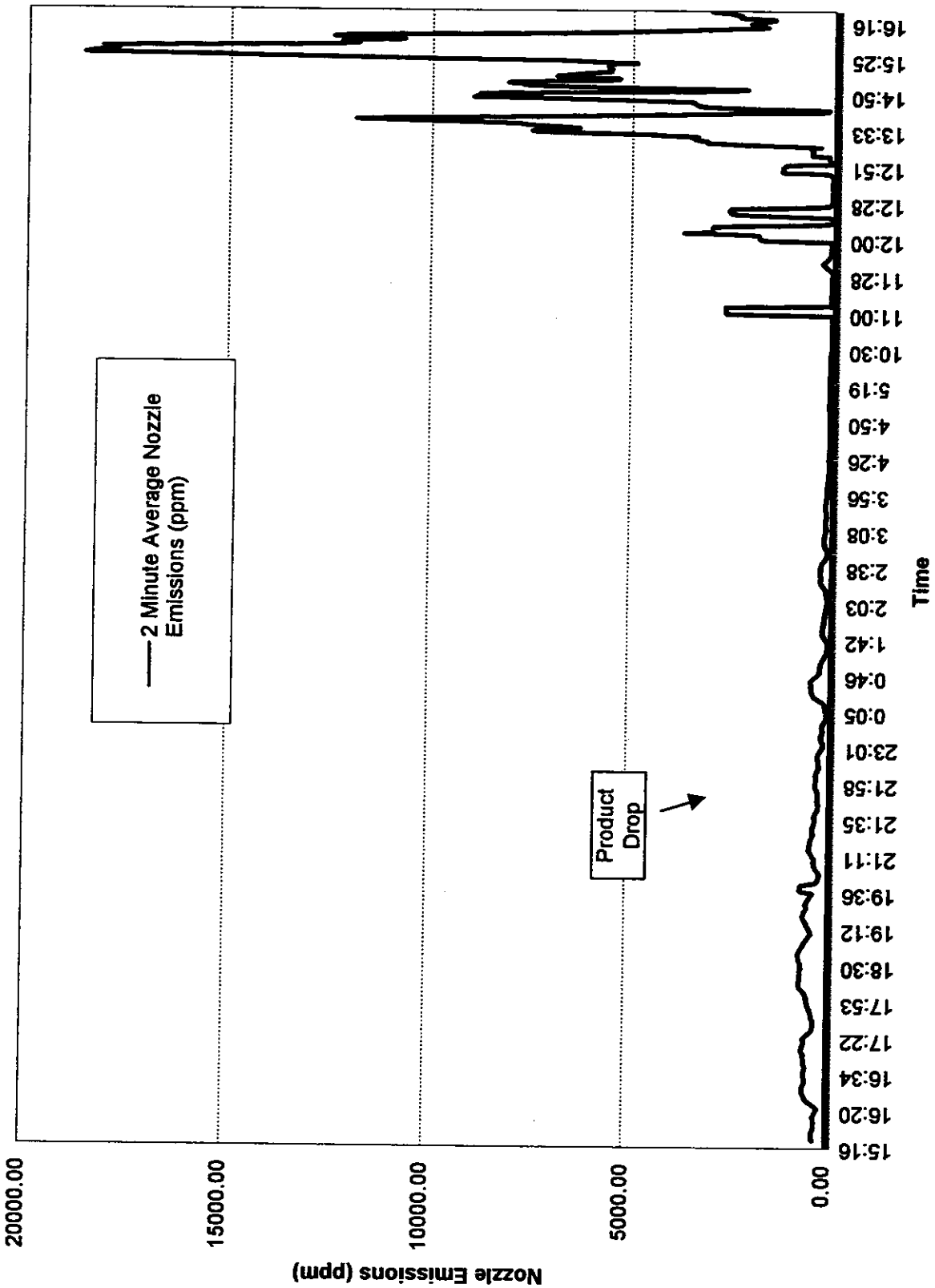


Figure 3-41 Gilbarco Vacuum Assist System Two Minute Average Nozzle Emissions (ppm) for Winter Conditions

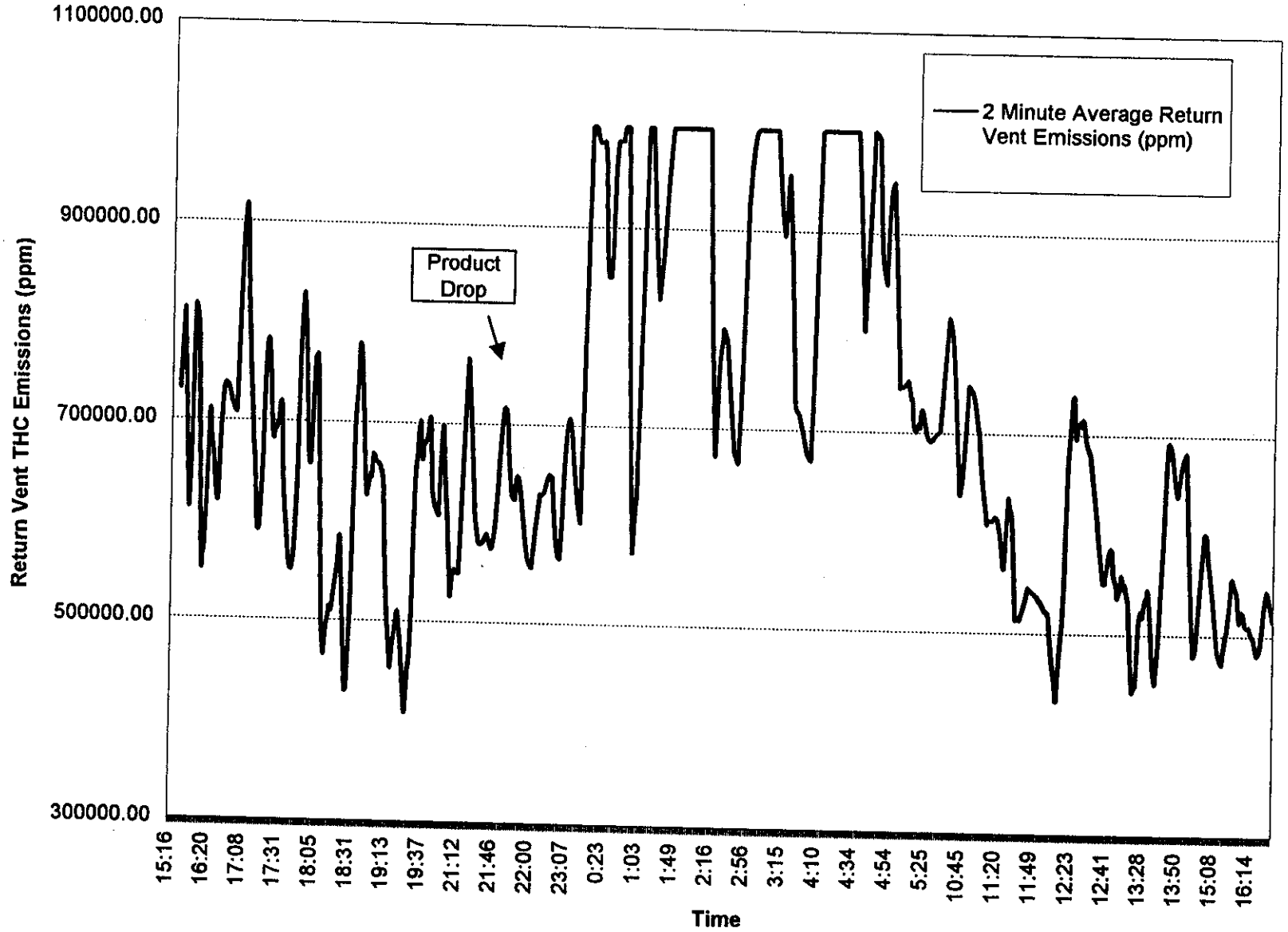


Figure 3-42 Gilbarco Vacuum Assist System Two Minute Average Return Emissions (ppm) for Winter Conditions

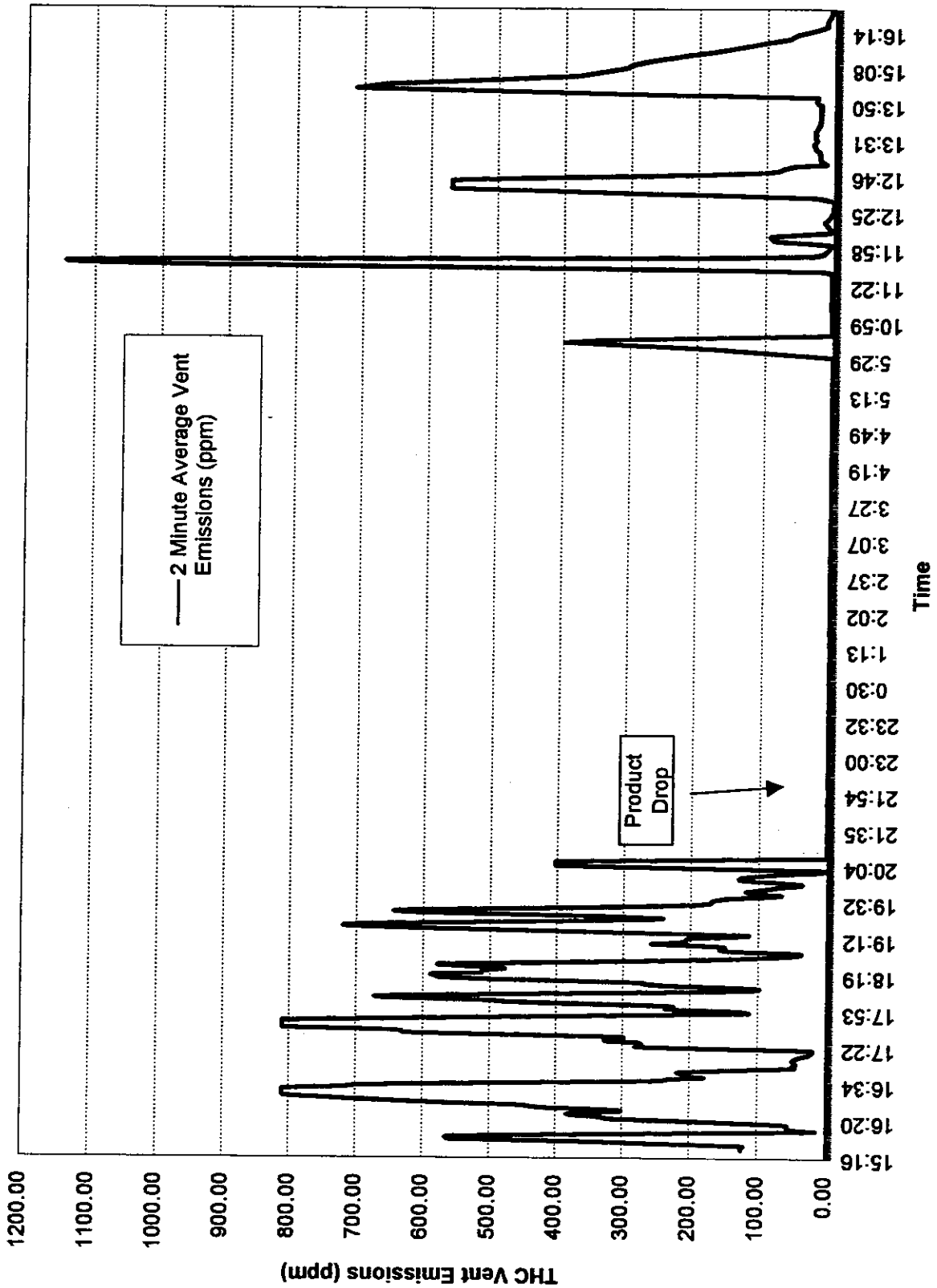


Figure 3-43 Gilbarco Vacuum Assist System Two Minute Average Vent Emissions (ppm) for Winter Conditions

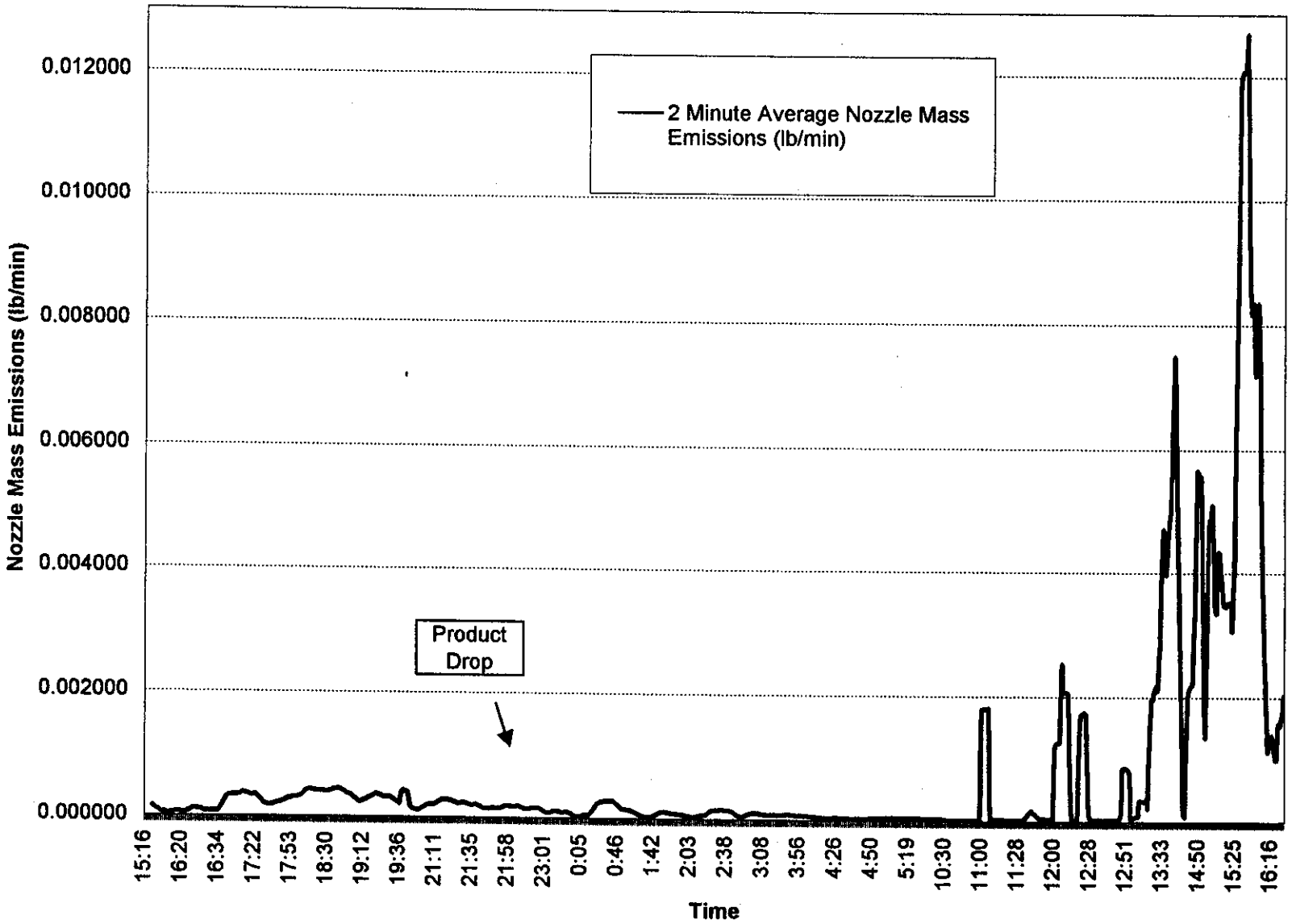


Figure 3-44 Gilbarco Vacuum Assist System Two Minute Average Nozzle Mass Emissions (lb/min) for Winter Conditions

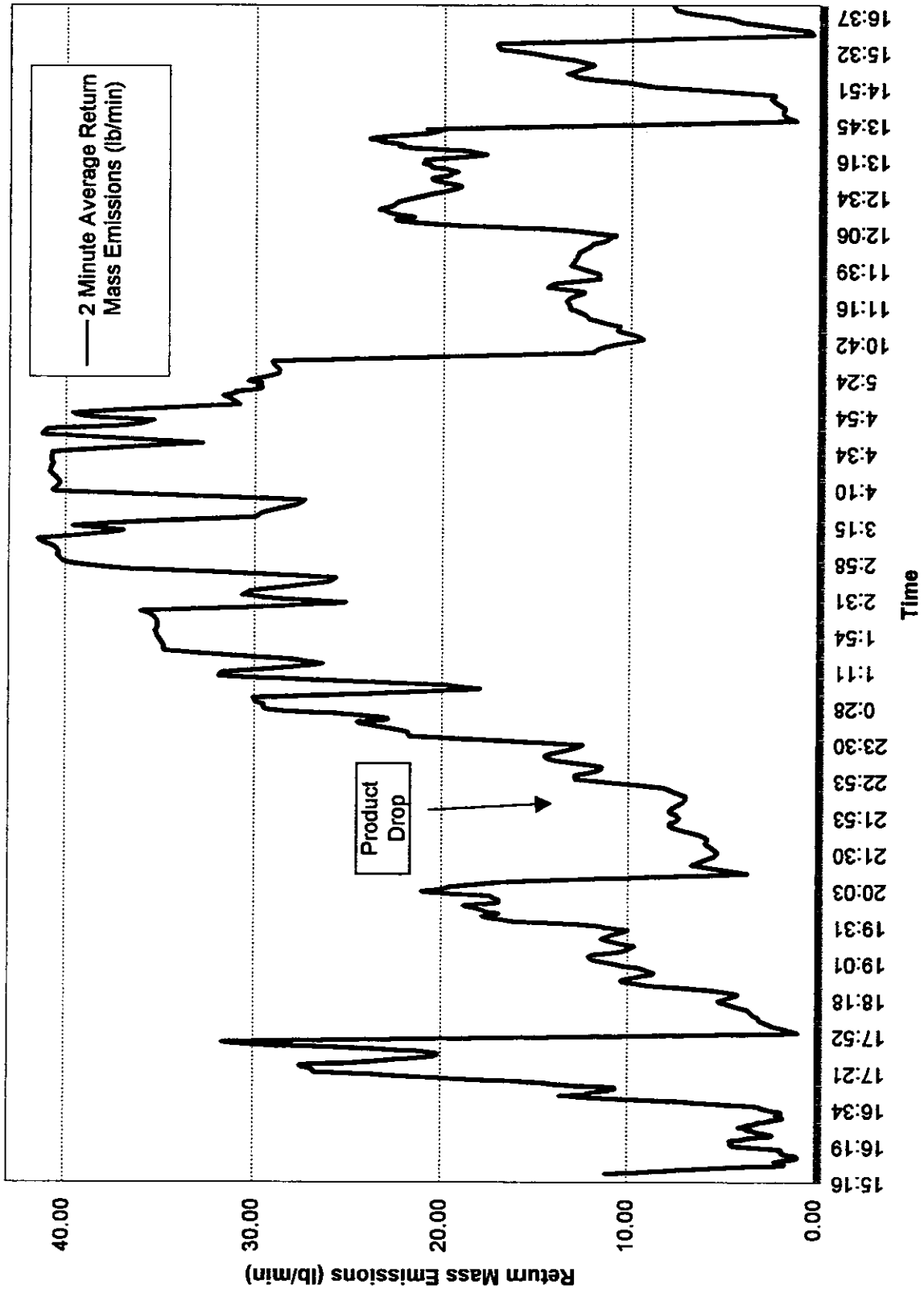


Figure 3-45 Gilbarco Vacuum Assist System Two Minute Average Return Mass Emissions (lb/min) for Winter Conditions

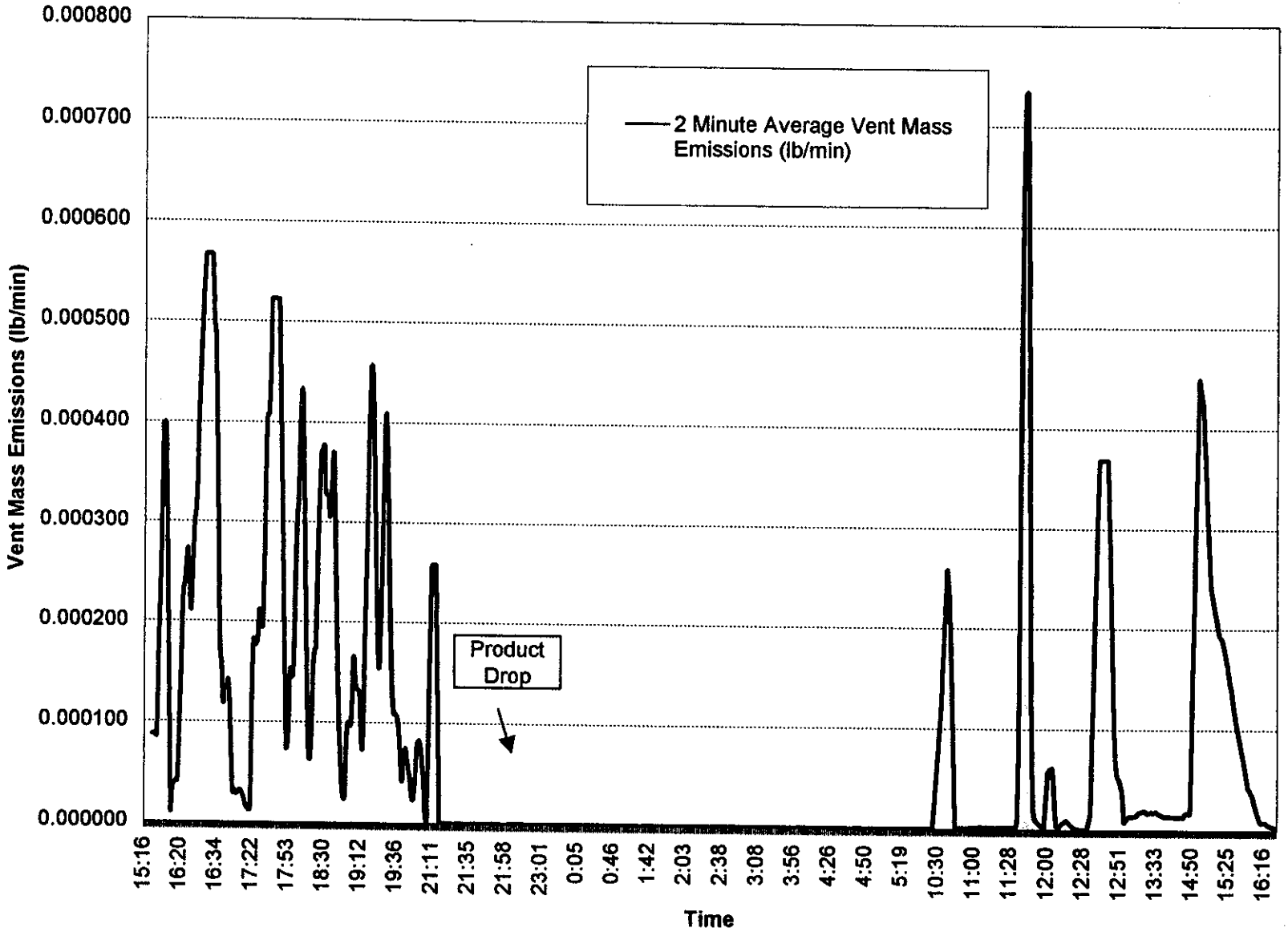


Figure 3-46 Gilbarco Vacuum Assist System Two Minute Average Vent Mass Emissions (lb/min) for Winter Conditions

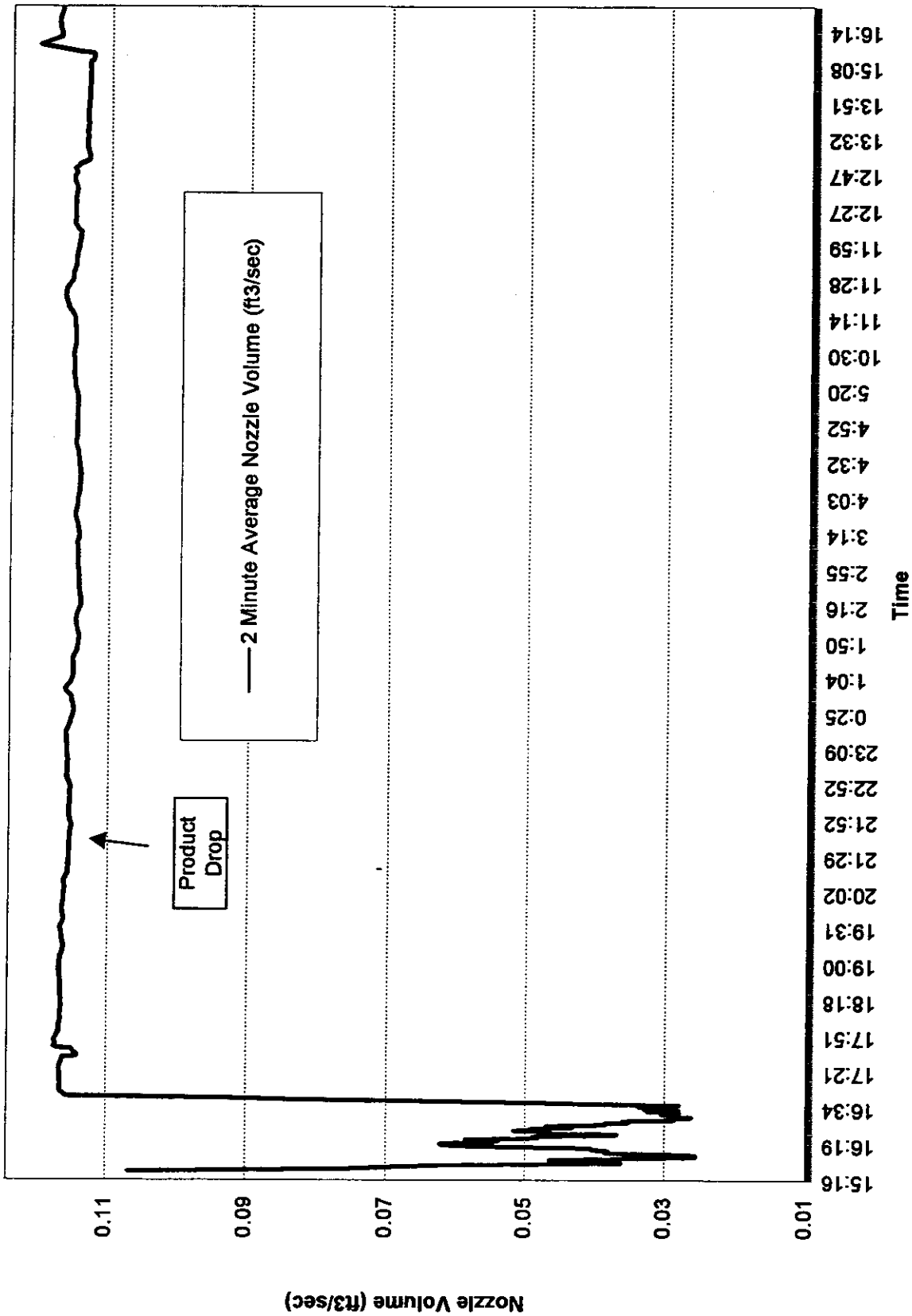


Figure 3-47 Gilbarco Vacuum Assist System Two Minute Average Nozzle Volume (ft3/sec) for Winter Conditions

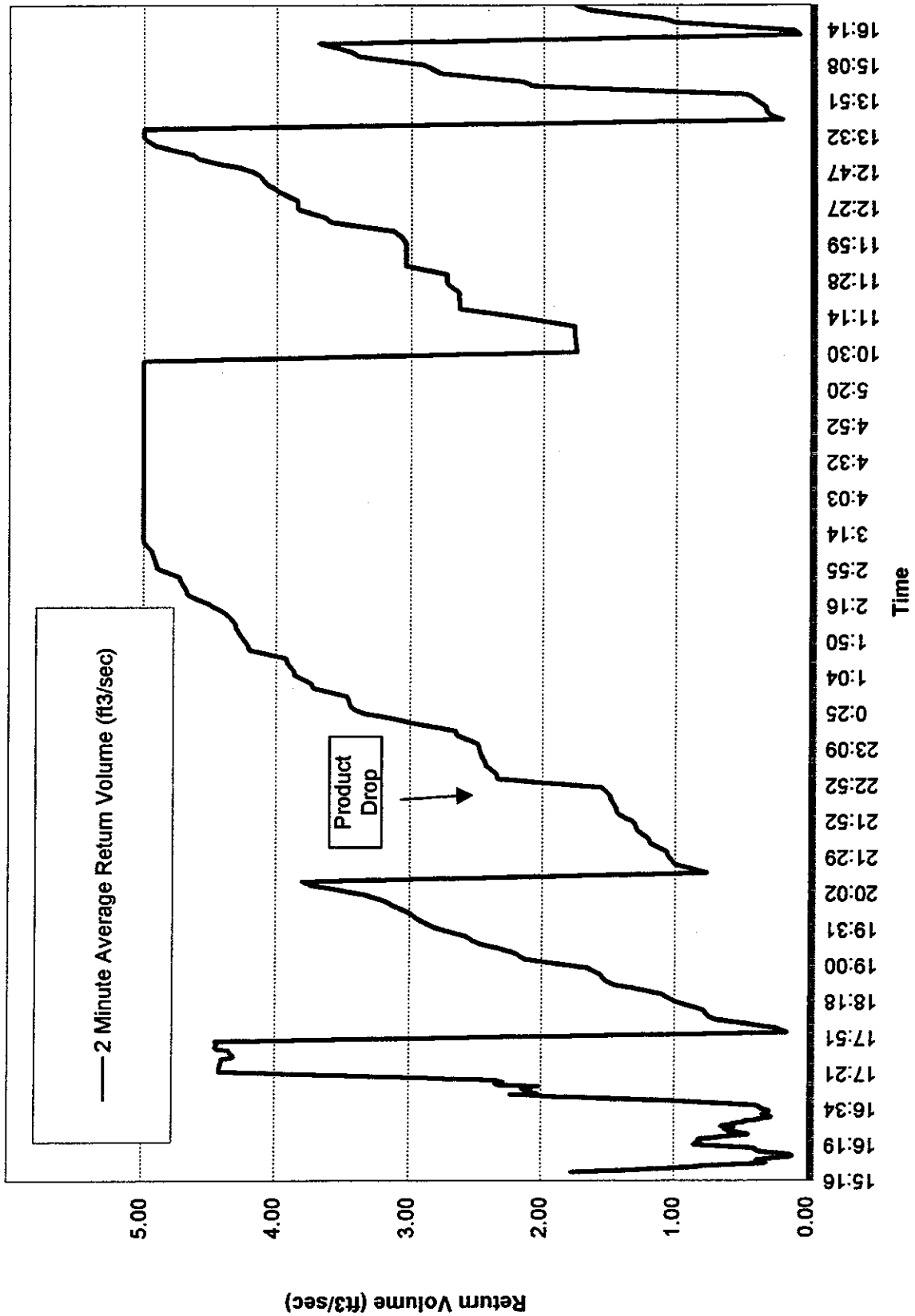


Figure 3-48 Gilbarco Vacuum Assist System Two Minute Average Return Volume (ft3/sec) for Winter Conditions

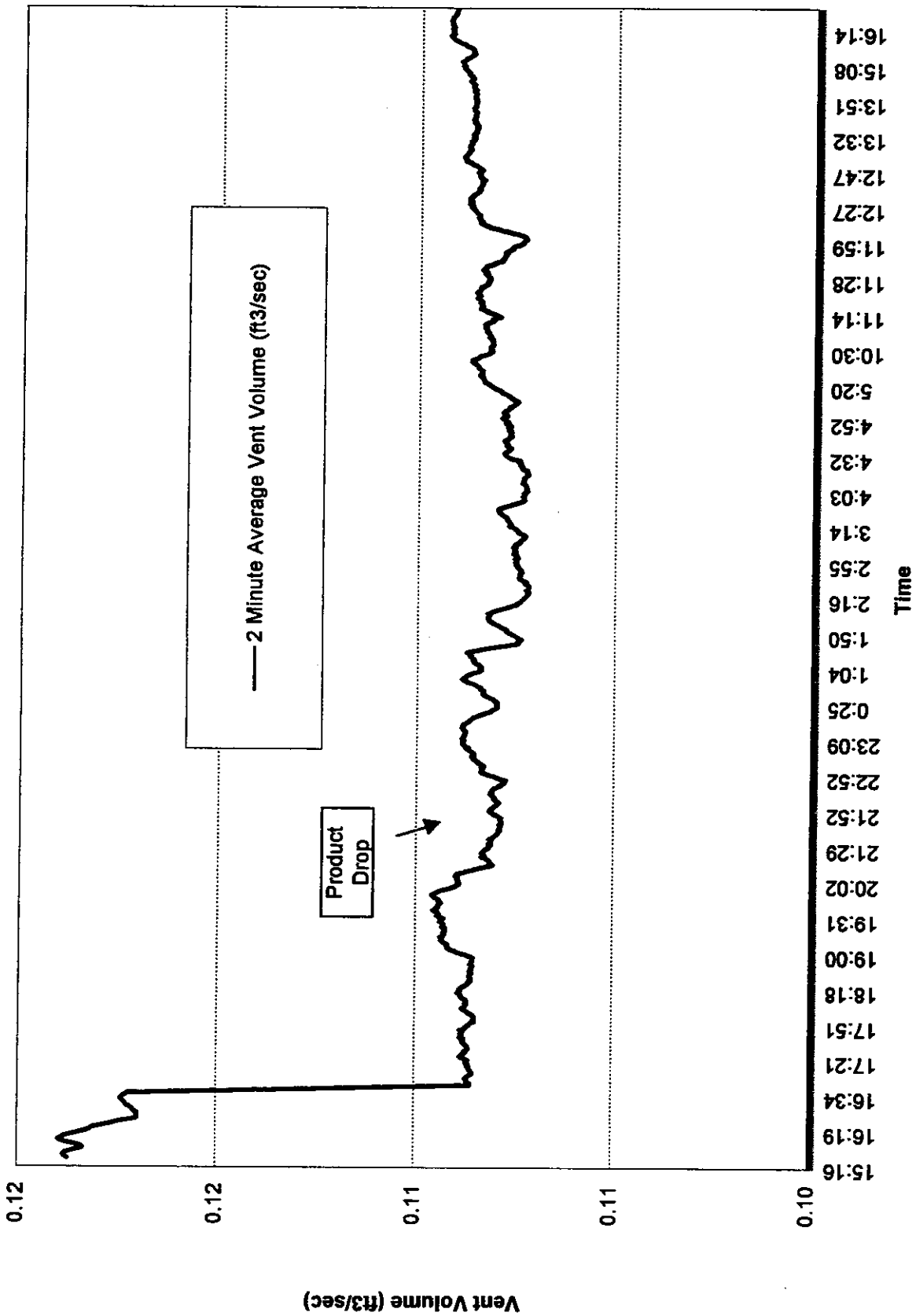


Figure 3-49 Gilbarco Vacuum Assist System Two Minute Average Vent Volume (ft3/sec) for Winter Conditions

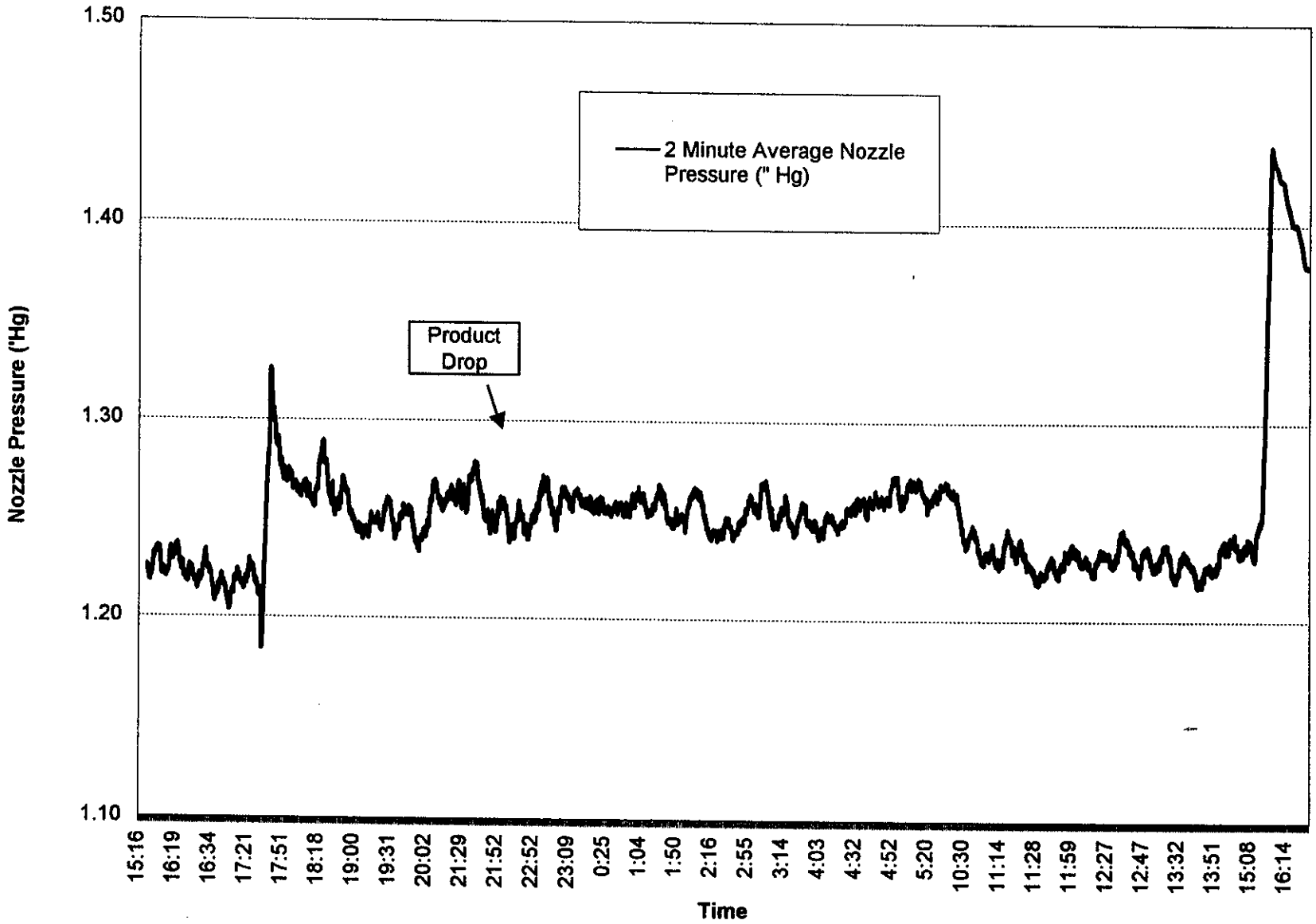


Figure 3-50 Gilbarco Vacuum Assist System Two Minute Average Nozzle Pressure ("Hg) for Winter Conditions

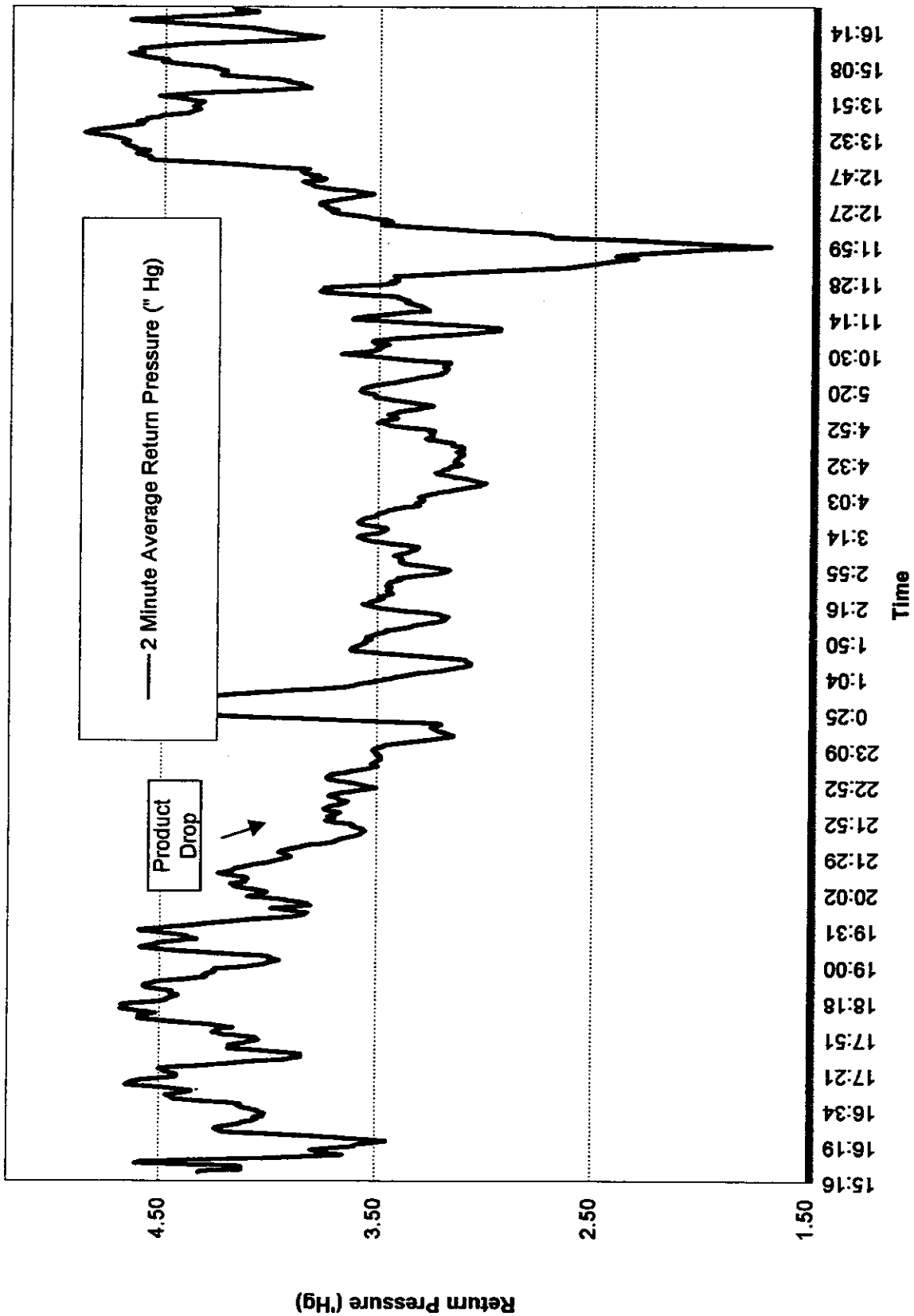


Figure 3-51 Gilbarco Vacuum Assist System Two Minute Average Return Pressure ("Hg) for Winter Conditions

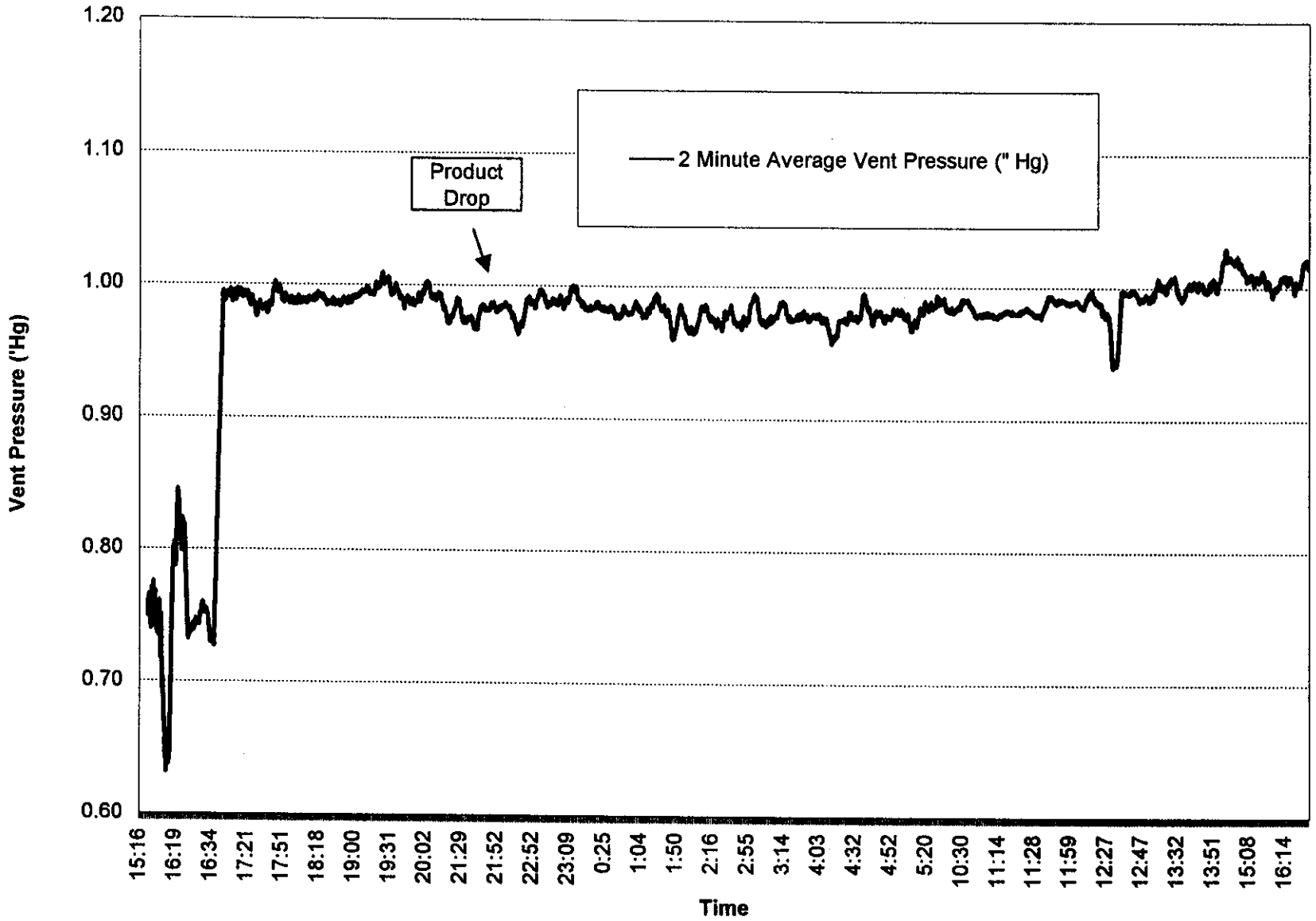


Figure 3-52 Gilbarco Vacuum Assist System Two Minute Average Vent Pressure ("Hg) for Winter Conditions

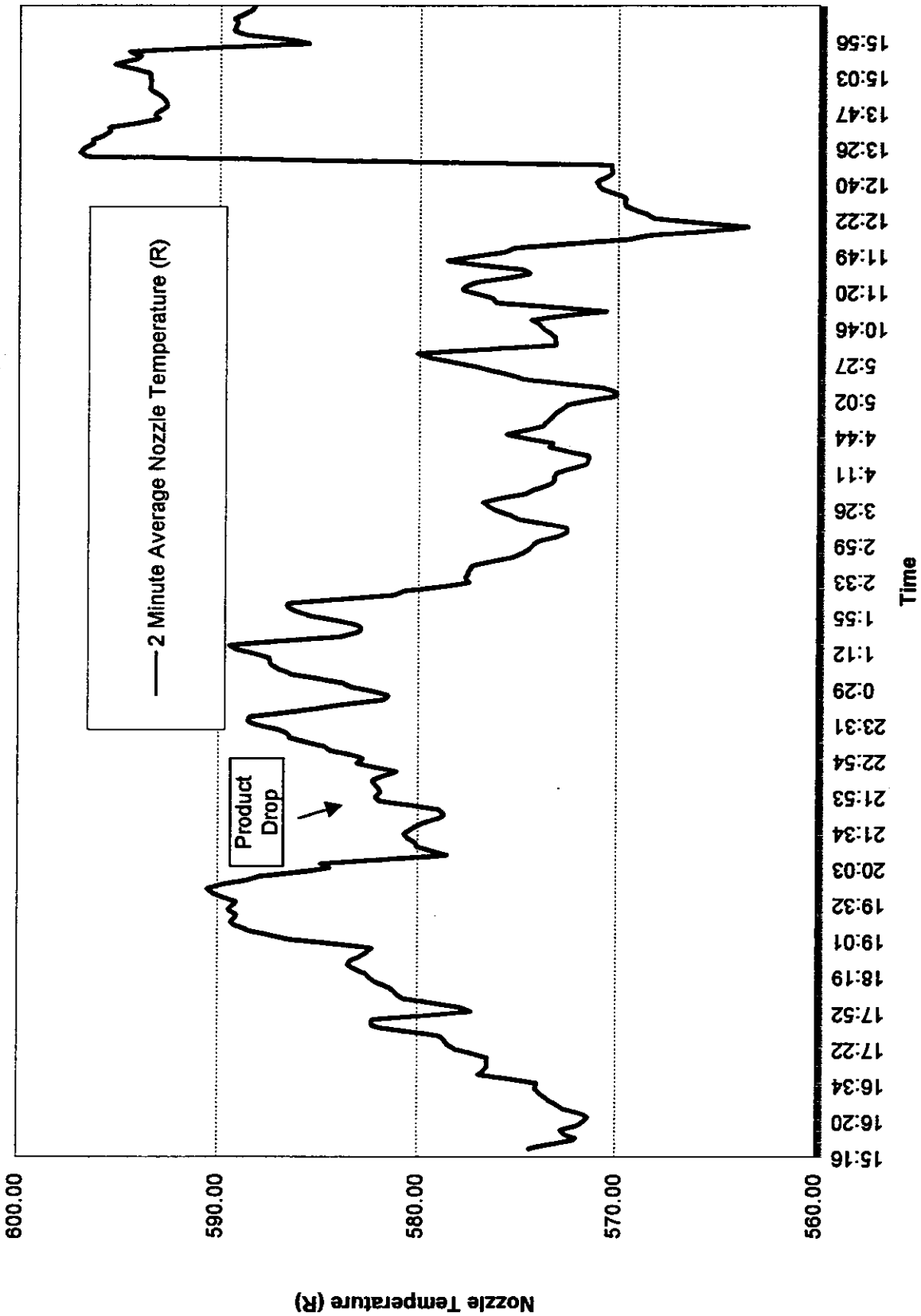


Figure 3-53 Gilbarco Vacuum Assist System Two Minute Average Nozzle Temperature (R) for Winter Conditions

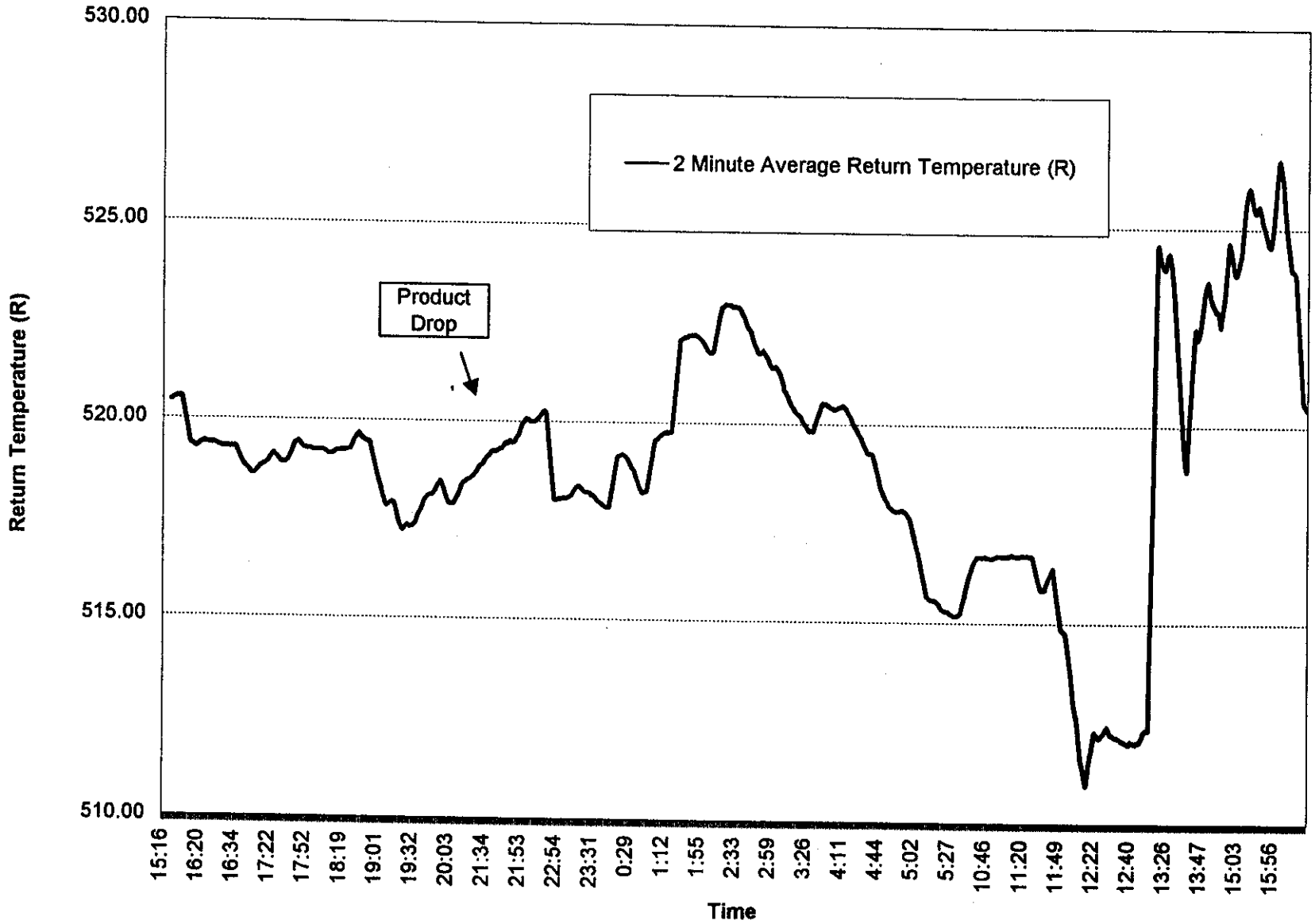


Figure 3-54 Gilbarco Vacuum Assist System Two Minute Average Return Temperature (R) for Winter Conditions

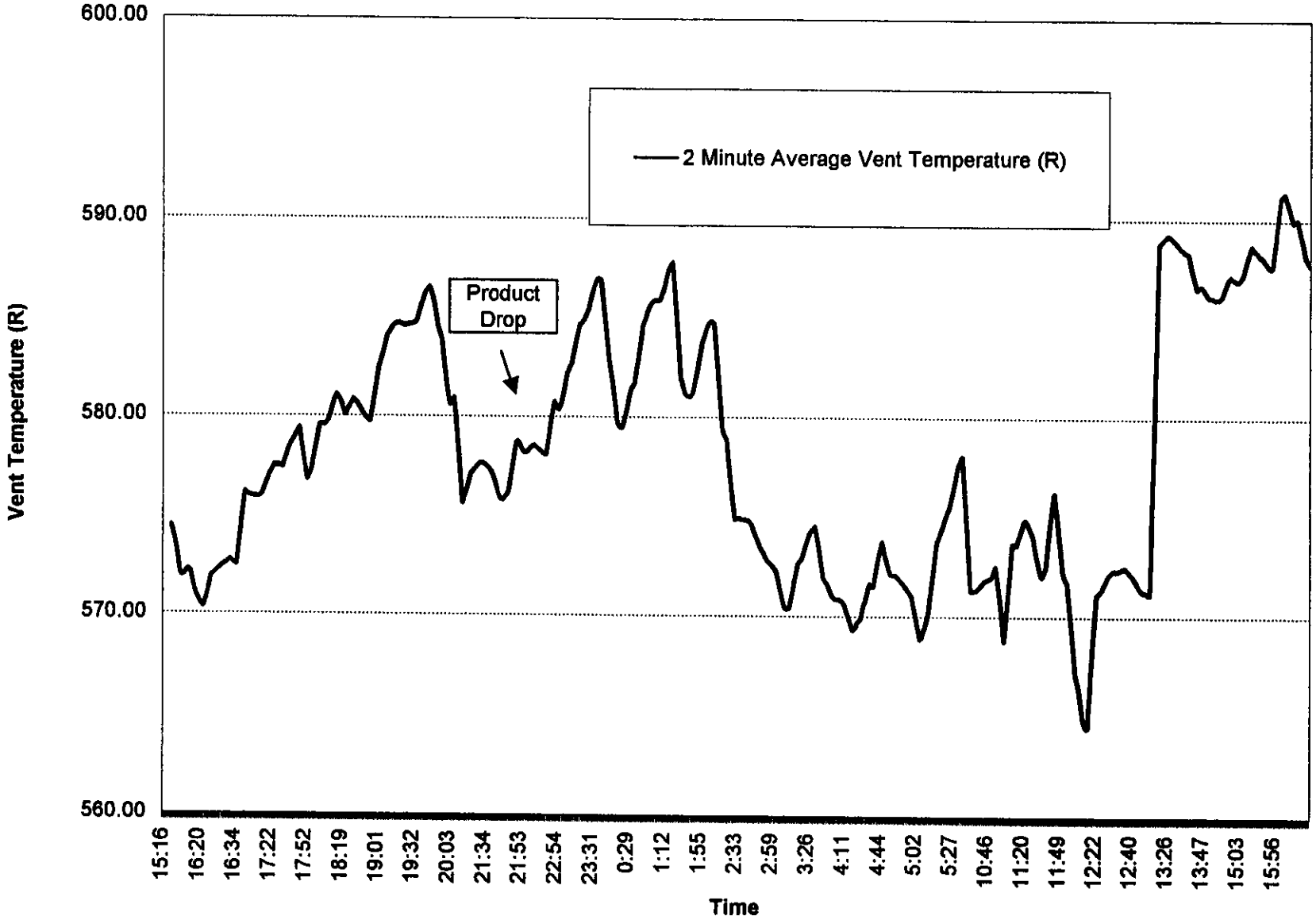


Figure 3-55 Gilbarco Vacuum Assist System Two Minute Average Vent Temperature (R) for Winter Conditions

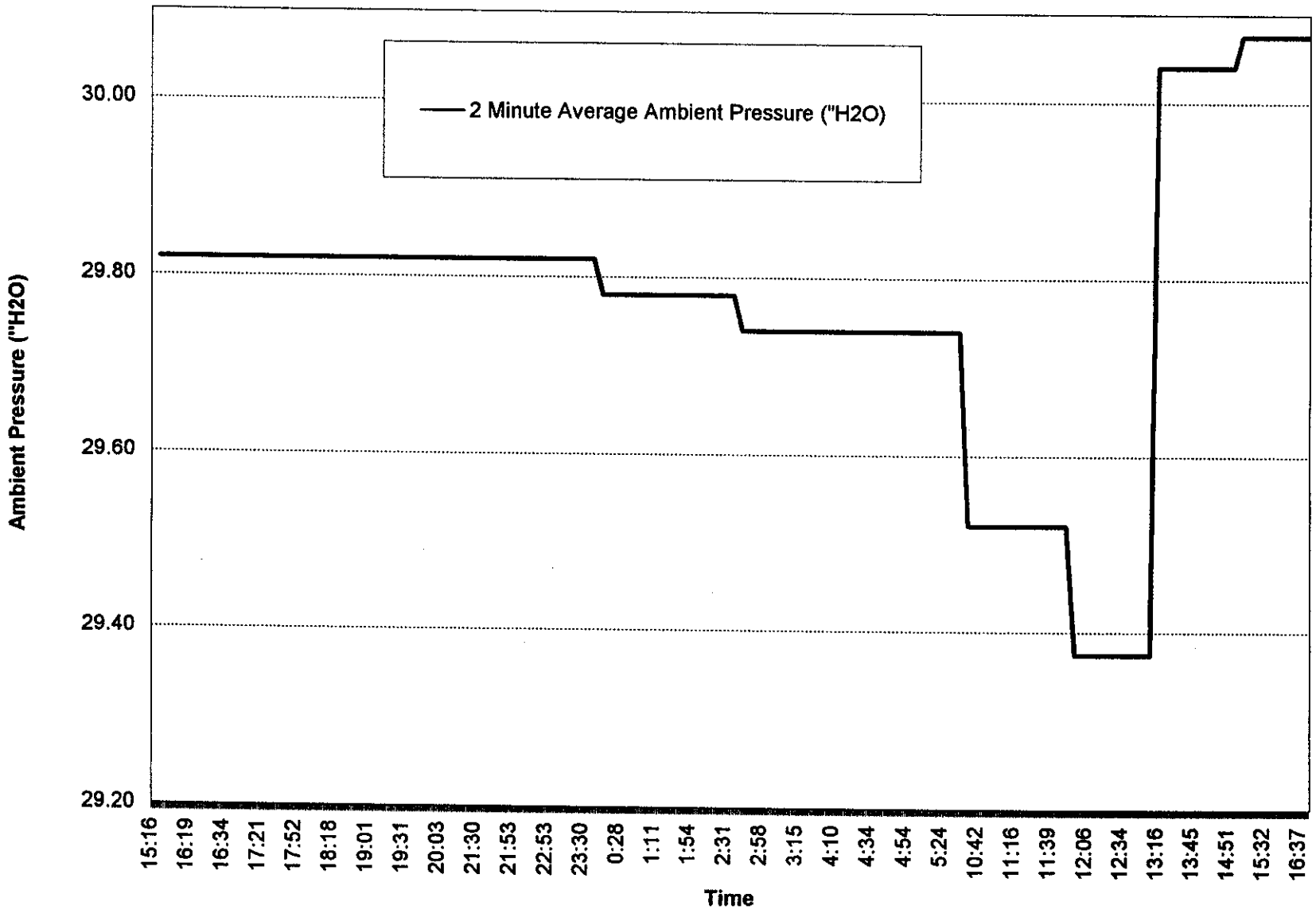


Figure 3-56 Gilbarco Vacuum Assist System Two Minute Average Ambient Pressure ("H2O) for Winter Conditions

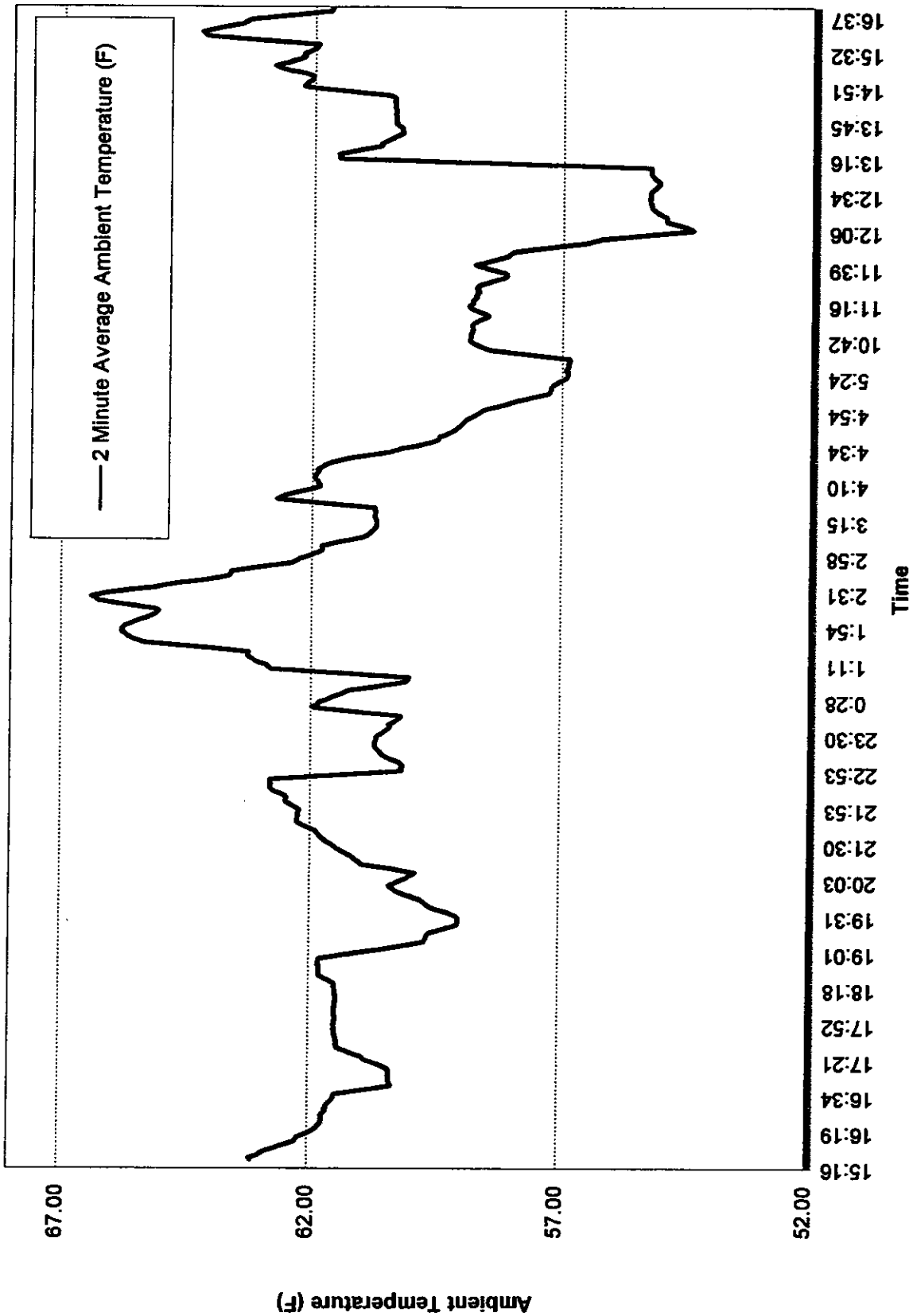


Figure 3-57 Gilbarco Vacuum Assist System Two Minute Average Ambient Temperature (F) for Winter Conditions

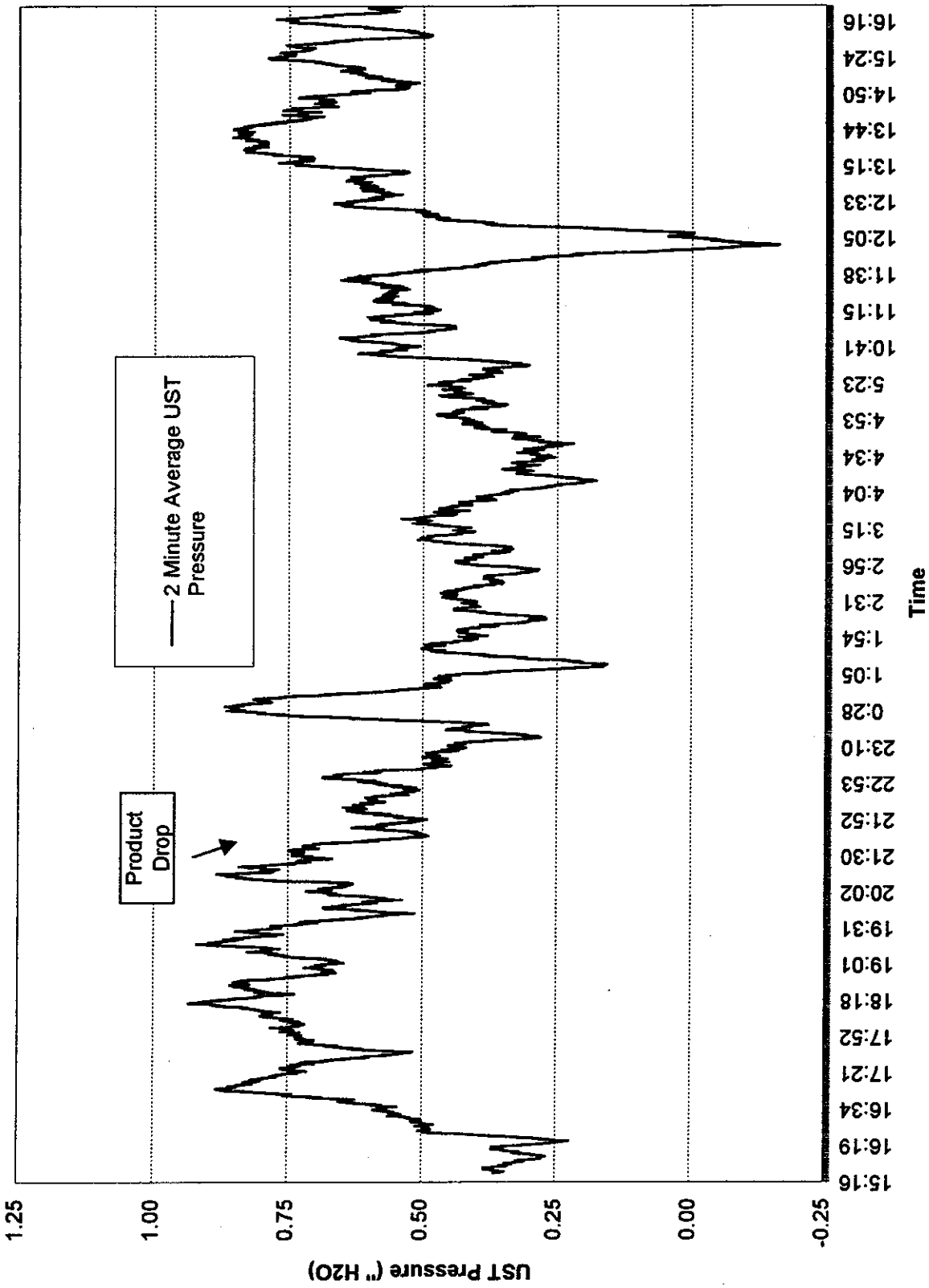


Figure 3-58 Gilbarco Vacuum Assist System Two Minute Average UST Pressure (" H2O) for Winter Conditions

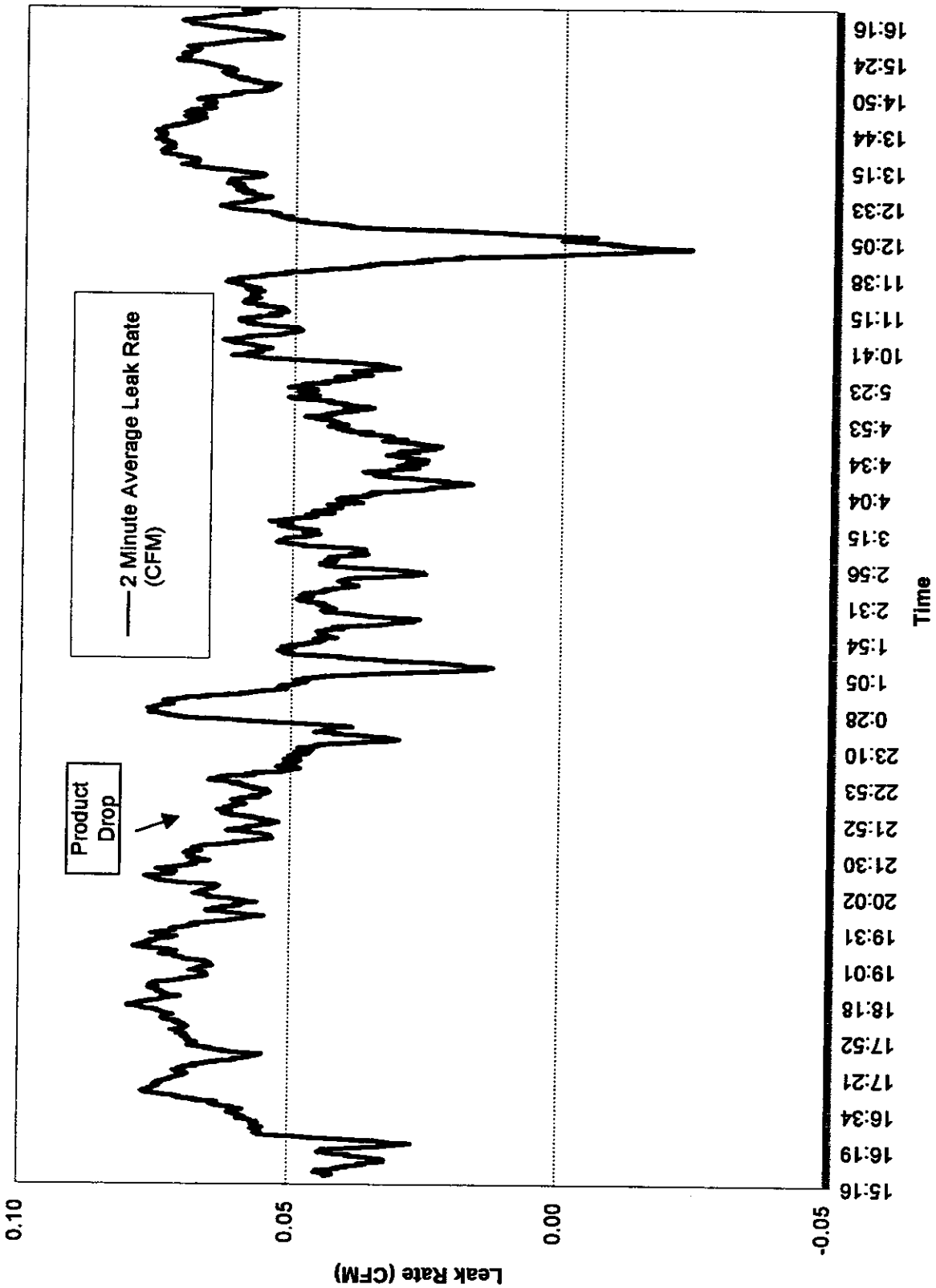


Figure 3-59 Gilbarco Vacuum Assist System Two Minute Average Leak Rate (CFM) for Winter Conditions

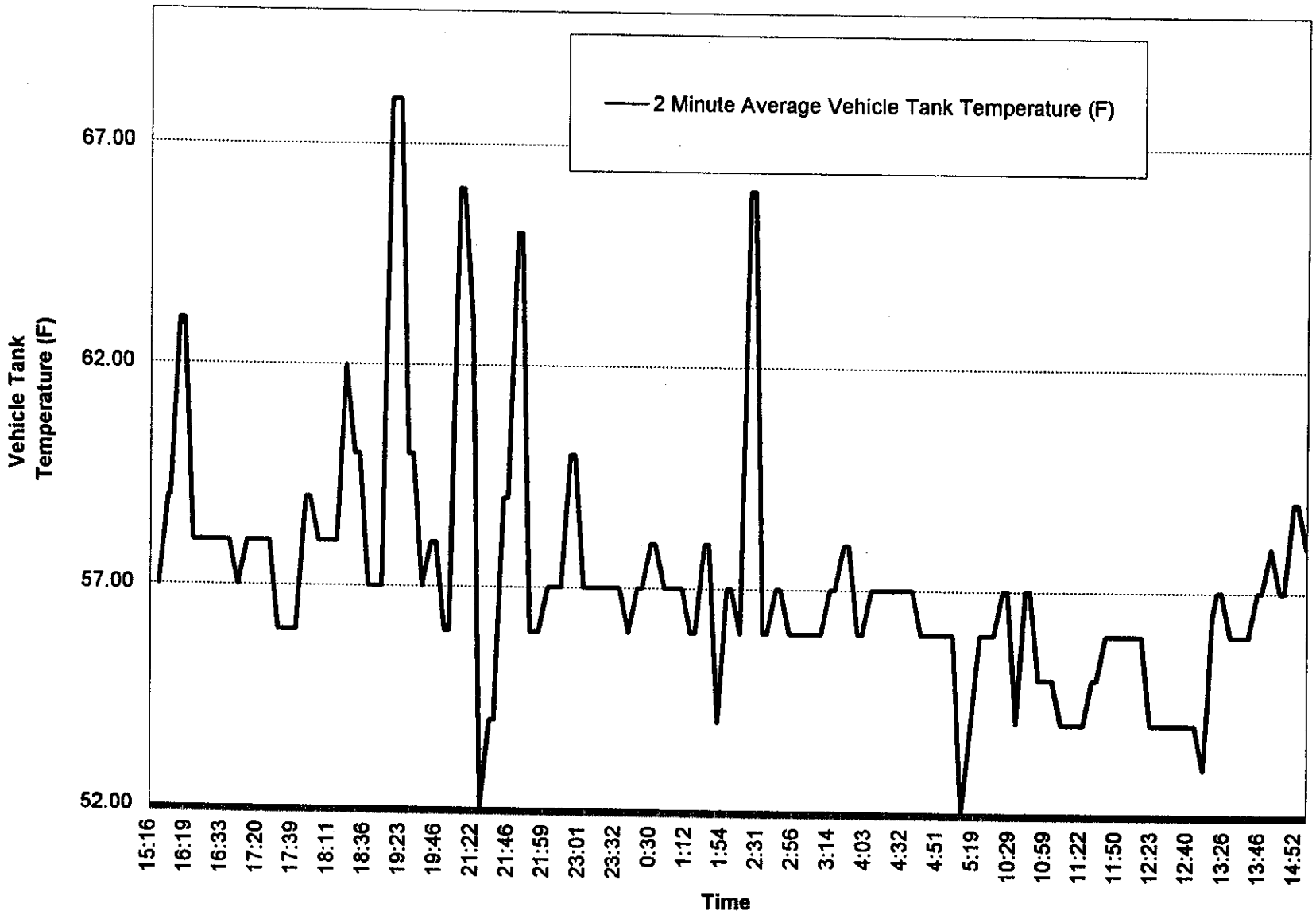


Figure 3-60 Gilbarco Vacuum Assist System Two Minute Average Vehicle Tank Temperature (F) for Winter Conditions

Table 3-1

Sampling, Product Delivery and System Integrity Check Schedule

System Type	Date	Field Testing Time	Dispenser Test Location	System Maintenance, Pressure Integrity and/ A/L Testing or Dynamic Pressure Testing: Service Station Maintenance	System Maintenance, Pressure Integrity & A/L Testing or Dynamic Pressure Testing BAAQMD	Product Delivery Time (gallons delivered)
Balance	2/7	-	All Locations	Testing Occurred	-	-
Balance	2/8	9:00 – 16:00	All Locations	-	Testing Occurred	-
Balance	2/9	9:09-19:22	Dispenser 15		-	16:30 (8652 gallons)
Balance	2/10	9:04 – 19:11	Dispenser 15	-	-	13:40 (7500 gallons)
Balance	2/23	9:00 – 16:00	All Locations	-	Testing Occurred	-
Balance	5/27	-	All Locations	Testing Occurred	-	-
Balance	5/28	10:00 – 14:00	All Locations	-	Testing Occurred	-
Balance	5/29	9:39-18:47	Dispenser 15		-	17:30 (8802 gallons)
Balance	5/30	9:21 – 17:33	Dispenser 15	-	-	14:00 (8600 gallons)
Balance	5/31	9:00 – 13:00	All Locations	-	Testing Occurred	-
Vacuum Assist	2/3	-	All Locations	Testing Occurred	-	-
Vacuum Assist	2/4	10:00 – 10:50 12:30 – 15:00	All Locations	-	Testing Occurred	-
Vacuum Assist	2/4	15:00-17:00	All Locations	Maintenance Occurred	-	-
Vacuum Assist	2/5	15:16 – 24:00	Dispenser 2	-	-	22:20 (9010 gallons)
Vacuum Assist	2/6	0:00 – 5:30 10:39-16:39	Dispenser 2	-	-	-
Vacuum Assist	2/17	11:20 – 12:15 12:30-3:00	All Locations	-	Testing Occurred	-

Table 3-2
Balance System Winter Sampling Data

Total Hydrocarbons Vent Emissions (pounds)	Sampling Time (Minutes)	Gasoline Throughput (Gallons)	Fuel RVP (lbs)	Vent Emission Factor (lbs/1000 gal)
1.48	142	873.64	12.28	0.012

TABLE 3-3

Balance Winter Conditions for Nozzle Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	812.753
Standard Error	15.250
Median	77.900
Mode	0.100
Standard Deviation	1721.700
Sample Variance	2964249.660
Kurtosis	8.648
Skewness	2.932
Range	10379.700
Minimum	0.000
Maximum	10379.700
Sum	10359349.300
Count	12746.000

TABLE 3-4

Balance Winter Conditions for Return Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	445620.459
Standard Error	820.079
Median	456578.000
Mode	0.000
Standard Deviation	97434.267
Sample Variance	9493436438.838
Kurtosis	6.504
Skewness	-2.090
Range	679015.000
Minimum	0.000
Maximum	679015.000
Sum	6290378403.000
Count	14116.000

TABLE 3-5

Balance Winter Conditions for Vent Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	41.112
Standard Error	0.977
Median	7.000
Mode	3.000
Standard Deviation	109.261
Sample Variance	11937.880
Kurtosis	51.299
Skewness	6.328
Range	1156.000
Minimum	-10.000
Maximum	1146.000
Sum	514186.000
Count	12507.000

TABLE 3-6

Balance Winter Conditions for Nozzle Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	0.000518
Standard Error	0.000010
Median	0.000047
Mode	0.000000
Standard Deviation	0.001124
Sample Variance	0.000001
Kurtosis	9.003676
Skewness	2.995567
Range	0.006828
Minimum	0.000000
Maximum	0.006828
Sum	6.606543
Count	12745.000000

TABLE 3-7

Balance Winter Conditions for Return Hydrocarbon Mass (lb/min)
Descriptive Statistics

Statistics	Value
Mean	0.307818
Standard Error	0.000849
Median	0.324600
Mode	0.000000
Standard Deviation	0.095884
Sample Variance	0.009194
Kurtosis	3.002533
Skewness	-1.775177
Range	0.508651
Minimum	0.000000
Maximum	0.508651
Sum	3923.451807
Count	12746.000000

TABLE 3-8

Balance Winter Conditions for Vent Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	2.545195874
Standard Error	0.176439487
Median	0.075462558
Mode	0
Standard Deviation	19.91969767
Sample Variance	396.7943553
Kurtosis	111.9018668
Skewness	10.41842087
Range	278.3636296
Minimum	-0.108545002
Maximum	278.2550846
Sum	32441.06661
Count	12746

TABLE 3-9

Balance Winter Conditions for Nozzle Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	0.624
Standard Error	0.002
Median	0.657
Mode	-0.379
Standard Deviation	0.230
Sample Variance	0.053
Kurtosis	12.566
Skewness	-3.434
Range	1.435
Minimum	-0.386
Maximum	1.049
Sum	7950.848
Count	12746.000

TABLE 3-10

Balance Winter Conditions for Return Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	1.712
Standard Error	0.006
Median	1.725
Mode	0.065
Standard Deviation	0.679
Sample Variance	0.461
Kurtosis	1.288
Skewness	-0.384
Range	4.230
Minimum	-0.058
Maximum	4.172
Sum	21818.005
Count	12746.000

TABLE 3-11

Balance Winter Conditions for Vent Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	0.691
Standard Error	0.002
Median	0.757
Mode	-0.405
Standard Deviation	0.242
Sample Variance	0.059
Kurtosis	14.813
Skewness	-3.881
Range	1.321
Minimum	-0.405
Maximum	0.916
Sum	8805.556
Count	12746.000

TABLE 3-12

Balance Winter Conditions for Nozzle Volume (ft^3/sec)
Descriptive Statistics

Statistics	Value
Mean	0.0989
Standard Error	0.0002
Median	0.1025
Mode	0.0065
Standard Deviation	0.0185
Sample Variance	0.0003
Kurtosis	20.8886
Skewness	-4.7711
Range	0.1175
Minimum	0.0065
Maximum	0.1240
Sum	1396.0927
Count	14116.0000

TABLE 3-13

Balance Winter Conditions for Return Volume (ft^3/sec)
Descriptive Statistics

Statistics	Value
Mean	0.0935
Standard Error	0.0001
Median	0.0972
Mode	0.0061
Standard Deviation	0.0177
Sample Variance	0.0003
Kurtosis	19.8823
Skewness	-4.6086
Range	0.1124
Minimum	0.0061
Maximum	0.1185
Sum	1320.0457
Count	14116.0000

TABLE 3-14

Balance Winter Conditions for Vent Volume (ft^3/sec)
Descriptive Statistics

Statistics	Value
Mean	0.0891
Standard Error	0.0001
Median	0.0923
Mode	0.0072
Standard Deviation	0.0165
Sample Variance	0.0003
Kurtosis	20.4386
Skewness	-4.6995
Range	0.0887
Minimum	0.0072
Maximum	0.0959
Sum	1257.1387
Count	14116.0000

TABLE 3-15

Balance Winter Conditions for Nozzle Temperature (R)
Descriptive Statistics

Statistics	Value
Mean	576.382
Standard Error	0.065
Median	576.446
Mode	570.308
Standard Deviation	7.667
Sample Variance	58.785
Kurtosis	-1.231
Skewness	-0.244
Range	26.551
Minimum	560.954
Maximum	587.505
Sum	8136208.366
Count	14116.000

TABLE 3-16

Balance Winter Conditions for Return Temperature (R)
Descriptive Statistics

Statistics	Value
Mean	520.079
Standard Error	0.053
Median	518.550
Mode	513.431
Standard Deviation	6.344
Sample Variance	40.251
Kurtosis	-1.584
Skewness	0.238
Range	20.574
Minimum	511.841
Maximum	532.414
Sum	7341433.519
Count	14116.000

TABLE 3-17

Balance Winter Conditions for Vent Temperature (R)
Descriptive Statistics

Statistics	Value
Mean	592.457
Standard Error	0.048
Median	594.404
Mode	596.883
Standard Deviation	5.692
Sample Variance	32.395
Kurtosis	-1.102
Skewness	-0.463
Range	22.804
Minimum	579.235
Maximum	602.039
Sum	8363120.582
Count	14116.000

TABLE 3-18

Balance Winter Conditions for UST Pressure ("H_2O) Descriptive Statistics

Statistics	Value
Mean	-0.693
Standard Error	0.017
Median	-0.118
Mode	-9.568
Standard Deviation	1.987
Sample Variance	3.948
Kurtosis	12.399
Skewness	-3.349
Range	14.042
Minimum	-9.568
Maximum	4.474
Sum	-9782.516
Count	14116.000

TABLE 3-19

Balance Winter Conditions for Leak Rate (CFM)
Descriptive Statistics

Statistics	Value
Mean	-0.037
Standard Error	0.001
Median	-0.034
Mode	-0.371
Standard Deviation	0.113
Sample Variance	0.013
Kurtosis	0.653
Skewness	-0.823
Range	0.617
Minimum	-0.371
Maximum	0.246
Sum	-518.878
Count	14116.000

TABLE 3-20

Balance Winter Conditions for Ambient Pressure ("H_2O) Descriptive Statistics

Statistics	Value
Mean	30.236
Standard Error	0.003
Median	30.390
Mode	30.300
Standard Deviation	0.353
Sample Variance	0.125
Kurtosis	3.094
Skewness	-2.179
Range	1.170
Minimum	29.290
Maximum	30.460
Sum	426810.070
Count	14116.000

TABLE 3-21

Balance Winter Conditions for Ambient Temperature (°F)
Descriptive Statistics

Statistics	Value
Mean	61.24
Standard Error	0.04
Median	60.58
Mode	66.45
Standard Deviation	5.18
Sample Variance	26.83
Kurtosis	-1.48
Skewness	-0.13
Range	17.53
Minimum	51.94
Maximum	69.47
Sum	864520.36
Count	14116.00

TABLE 3-22

Balance Winter Conditions for Vehicle Tank Temperature (°F)
Descriptive Statistics

Statistics	Value
Mean	63.5
Standard Error	0.1
Median	63.0
Mode	55.0
Standard Deviation	9.5
Sample Variance	90.7
Kurtosis	-1.4
Skewness	0.3
Range	31.5
Minimum	50.0
Maximum	81.5
Sum	896074.5
Count	14116.0

Table 3-23
Vacuum Assist System Winter Sampling Data

Total Hydrocarbons Vent (pounds)	Sampling Time (Minutes)	Gasoline Throughput (Gallons)	Fuel RVP (lbs)	Vent Emission Factor (lbs/1000 gal)
1.31	193	1100.96	12.2	0.006

TABLE 3-24

Vacuum Assist Winter Conditions for Nozzle Hydrocarbons (ppm) Descriptive Statistics

Statistics	Value
Mean	1079.757
Standard Error	25.293
Median	196.000
Mode	49.000
Standard Deviation	3236.541
Sample Variance	10475197.999
Kurtosis	16.830
Skewness	4.128
Range	20368.000
Minimum	-411.000
Maximum	19957.000
Sum	17679933.000
Count	16374.000

TABLE 3-25

Vacuum Assist Winter Conditions for Return Hydrocarbons (ppm) Descriptive Statistics

Statistics	Value
Mean	700184.687
Standard Error	1380.739
Median	667077.000
Mode	1000610.000
Standard Deviation	176680.654
Sample Variance	31216053422.959
Kurtosis	-0.855
Skewness	0.481
Range	684417.000
Minimum	316193.000
Maximum	1000610.000
Sum	11464824060.000
Count	16374.000

TABLE 3-26

Vacuum Assist Winter Conditions for Vent Hydrocarbons (ppm) Descriptive Statistics

Statistics	Value
Mean	122.990
Standard Error	1.985
Median	2.000
Mode	0.000
Standard Deviation	253.988
Sample Variance	64510.152
Kurtosis	9.756
Skewness	2.710
Range	2044.000
Minimum	-10.000
Maximum	2034.000
Sum	2013834.000
Count	16374.000

TABLE 3-27

Vacuum Assist Winter Conditions for Nozzle Hydrocarbon Mass (lb/min)
Descriptive Statistics

Statistics	Value
Mean	0.000696742
Standard Error	1.65447E-05
Median	0.000106191
Mode	0
Standard Deviation	0.002117074
Sample Variance	4.482E-06
Kurtosis	17.480089
Skewness	4.182201464
Range	0.01399175
Minimum	-0.000257452
Maximum	0.013734299
Sum	11.40845646
Count	16374

TABLE 3-28

Vacuum Assist Winter Conditions for Return Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	18.383
Standard Error	0.095
Median	15.084
Mode	0.000
Standard Deviation	12.124
Sample Variance	146.985
Kurtosis	-1.001
Skewness	0.392
Range	42.709
Minimum	0.000
Maximum	42.709
Sum	300998.538
Count	16374.000

TABLE 3-29

Vacuum Assist Winter Conditions for Vent Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	8.03743E-05
Standard Error	1.29938E-06
Median	1.2836E-06
Mode	0
Standard Deviation	0.00016627
Sample Variance	2.76458E-08
Kurtosis	9.210403495
Skewness	2.674368663
Range	0.001335678
Minimum	-6.45686E-06
Maximum	0.001329221
Sum	1.316048519
Count	16374

TABLE 3-30

Vacuum Assist Winter Conditions for Nozzle Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	1.254
Standard Error	0.001
Median	1.248
Mode	1.248
Standard Deviation	0.071
Sample Variance	0.005
Kurtosis	2.155
Skewness	0.365
Range	1.107
Minimum	0.468
Maximum	1.575
Sum	19822.160
Count	15805.000

TABLE 3-31

Vacuum Assist Winter Conditions for Return Pressure ("Hg) Descriptive Statistics

Statistics	Value
Mean	3.759
Standard Error	0.005
Median	3.701
Mode	5.000
Standard Deviation	0.611
Sample Variance	0.373
Kurtosis	0.114
Skewness	-0.077
Range	3.377
Minimum	1.623
Maximum	5.000
Sum	59405.896
Count	15805.000

TABLE 3-32

Vacuum Assist Winter Conditions for Vent Pressure ("Hg) Descriptive Statistics

Statistics	Value
Mean	0.979
Standard Error	0.000
Median	0.992
Mode	1.017
Standard Deviation	0.062
Sample Variance	0.004
Kurtosis	5.781
Skewness	-1.837
Range	0.457
Minimum	0.644
Maximum	1.102
Sum	15478.740
Count	15805.000

TABLE 3-33

Vacuum Assist Winter Conditions for Nozzle Volume (ft^3/sec) Descriptive Statistics

Statistics	Value
Mean	0.1068
Standard Error	0.0001
Median	0.1110
Mode	0.0065
Standard Deviation	0.0192
Sample Variance	0.0004
Kurtosis	19.1535
Skewness	-4.4862
Range	0.1099
Minimum	0.0065
Maximum	0.1164
Sum	1748.6956
Count	16374.0000

TABLE 3-34

Vacuum Assist Winter Conditions for Return Volume (ft^3/sec)
Descriptive Statistics

Statistics	Value
Mean	3.3058
Standard Error	0.0134
Median	3.2757
Mode	5.6757
Standard Deviation	1.7064
Sample Variance	2.9119
Kurtosis	-1.2049
Skewness	-0.2544
Range	5.6752
Minimum	0.0026
Maximum	5.6778
Sum	53570.6767
Count	16205.0000

TABLE 3-35

Vacuum Assist Winter Conditions for Vent Volume (ft^3/sec) Descriptive Statistics

Statistics	Value
Mean	0.1090
Standard Error	0.0000
Median	0.1085
Mode	0.1086
Standard Deviation	0.0025
Sample Variance	0.0000
Kurtosis	8.8497
Skewness	3.0860
Range	0.0137
Minimum	0.1058
Maximum	0.1194
Sum	1784.0491
Count	16374.0000

TABLE 3-36

Vacuum Assist Winter Conditions for Nozzle Temperature (R) Descriptive Statistics

Statistics	Value
Mean	580.394
Standard Error	0.059
Median	579.613
Mode	573.231
Standard Deviation	7.533
Sample Variance	56.750
Kurtosis	-0.760
Skewness	0.346
Range	35.077
Minimum	562.513
Maximum	597.590
Sum	9503373.749
Count	16374.000

TABLE 3-37

Vacuum Assist Winter Conditions for Return Temperature (R) Descriptive Statistics

Statistics	Value
Mean	519.060
Standard Error	0.024
Median	519.196
Mode	519.245
Standard Deviation	3.088
Sample Variance	9.536
Kurtosis	0.498
Skewness	-0.213
Range	17.343
Minimum	510.300
Maximum	527.644
Sum	8499093.155
Count	16374.000

TABLE 3-38

Vacuum Assist Winter Conditions for Vent Temperature (R) Descriptive Statistics

Statistics	Value
Mean	578.153
Standard Error	0.050
Median	577.401
Mode	571.997
Standard Deviation	6.362
Sample Variance	40.478
Kurtosis	-1.070
Skewness	0.260
Range	28.901
Minimum	563.124
Maximum	592.025
Sum	9466673.989
Count	16374.000

TABLE 3-39

Vacuum Assist Winter Conditions for UST Pressure ("H_2O) Descriptive Statistics

Statistics	Value
Mean	0.542
Standard Error	0.003
Median	0.457
Mode	0.468
Standard Deviation	0.428
Sample Variance	0.183
Kurtosis	-0.646
Skewness	0.450
Range	2.505
Minimum	-0.490
Maximum	2.015
Sum	8873.300
Count	16374.000

TABLE 3-40

Vacuum Assist Winter Conditions for Leak Rate (CFM) Descriptive Statistics

Statistics	Value
Mean	0.053
Standard Error	0.000
Median	0.055
Mode	0.056
Standard Deviation	0.032
Sample Variance	0.001
Kurtosis	0.395
Skewness	-0.689
Range	0.182
Minimum	-0.057
Maximum	0.125
Sum	874.928
Count	16374.000

TABLE 3-41

Vacuum Assist Winter Conditions for Ambient Pressure ("H_2O) Descriptive Statistics

Statistics	Value
Mean	29.773
Standard Error	0.001
Median	29.820
Mode	29.820
Standard Deviation	0.172
Sample Variance	0.030
Kurtosis	0.548
Skewness	-0.549
Range	0.700
Minimum	29.375
Maximum	30.075
Sum	487499.870
Count	16374.000

TABLE 3-42

Vacuum Assist Winter Conditions for Ambient Temperature (°F) Descriptive Statistics

Statistics	Value
Mean	60.69
Standard Error	0.02
Median	60.93
Mode	61.46
Standard Deviation	2.41
Sample Variance	5.79
Kurtosis	0.47
Skewness	-0.43
Range	13.04
Minimum	53.99
Maximum	67.03
Sum	993680.76
Count	16374.00

TABLE 3-43

Vacuum Assist Winter Conditions for Vehicle Tank Temperature (°F) Descriptive Statistics

Statistics	Value
Mean	57.2
Standard Error	0.0
Median	57.0
Mode	57.0
Standard Deviation	2.8
Sample Variance	7.9
Kurtosis	4.2
Skewness	1.8
Range	16.0
Minimum	52.0
Maximum	68.0
Sum	882222.0
Count	15417.0

Table 3-44
Balance System Spring Sampling Data

Total Hydrocarbons Vent (pounds)	Sampling Time (Minutes)	Gasoline Throughput (Gallons)	Fuel RVP (lbs)	Vent Emission Factor (lbs/1000 gal)
0.575	140	913.80	7.8	0.004

TABLE 3-45

Balance Spring Conditions for Nozzle Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	1337.521
Standard Error	38.578
Median	288.000
Mode	88.000
Standard Deviation	2004.959
Sample Variance	4019859.323
Kurtosis	4.120
Skewness	2.065
Range	9910.000
Minimum	-6.000
Maximum	9904.000
Sum	3612645.000
Count	2701.000

TABLE 3-46

Balance Spring Conditions for Return Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	361822.905
Standard Error	843.737
Median	359729.000
Mode	346517.000
Standard Deviation	43849.982
Sample Variance	1922820894.637
Kurtosis	0.072
Skewness	0.144
Range	266196.000
Minimum	233257.000
Maximum	499453.000
Sum	977283666.000
Count	2701.000

Table 3-47
Balance Spring Conditions for Vent Hydrocarbons (ppm)
Descriptive Statistics

Statistics	Value
Mean	14.138
Standard Error	0.420
Median	5.000
Mode	3.000
Standard Deviation	21.852
Sample Variance	477.517
Kurtosis	5.328
Skewness	2.586
Range	88.000
Minimum	0.000
Maximum	88.000
Sum	38187.000
Count	2701.000

TABLE 3-48

Balance Spring Conditions for Nozzle Hydrocarbon Mass (lb/min)
Descriptive Statistics

Statistics	Value
Mean	0.000941908
Standard Error	2.75384E-05
Median	0.000195606
Mode	#N/A
Standard Deviation	0.001431202
Sample Variance	2.04834E-06
Kurtosis	4.266230764
Skewness	2.09722771
Range	0.007196254
Minimum	-4.04489E-06
Maximum	0.007192209
Sum	2.54409238
Count	2701

TABLE 3-49

Balance Spring Conditions for Return Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	0.3374
Standard Error	0.0009
Median	0.3354
Mode	#N/A
Standard Deviation	0.0465
Sample Variance	0.0022
Kurtosis	11.6239
Skewness	-1.6919
Range	0.4639
Minimum	0.0183
Maximum	0.4822
Sum	911.1870
Count	2701.0000

TABLE 3-50

Balance Spring Conditions for Vent Hydrocarbon Mass (lb/min) Descriptive Statistics

Statistics	Value
Mean	-4.26061E-05
Standard Error	1.43456E-06
Median	-1.77308E-05
Mode	0
Standard Deviation	7.45557E-05
Sample Variance	5.55855E-09
Kurtosis	13.80996692
Skewness	-3.51376194
Range	0.00053179
Minimum	-0.00053179
Maximum	0
Sum	-0.115079038
Count	2701

TABLE 3-51

Balance Spring Conditions for Nozzle Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	2.786
Standard Error	0.003
Median	2.804
Mode	2.870
Standard Deviation	0.169
Sample Variance	0.028
Kurtosis	75.280
Skewness	-7.447
Range	2.120
Minimum	0.889
Maximum	3.009
Sum	7524.747
Count	2701.000

TABLE 3-52

Balance Spring Conditions for Return Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	3.395
Standard Error	0.005
Median	3.402
Mode	3.384
Standard Deviation	0.237
Sample Variance	0.056
Kurtosis	71.771
Skewness	-7.163
Range	3.078
Minimum	0.880
Maximum	3.958
Sum	9169.221
Count	2701.000

TABLE 3-53

Balance Spring Conditions for Vent Pressure ("Hg)
Descriptive Statistics

Statistics	Value
Mean	3.395
Standard Error	0.005
Median	3.402
Mode	3.384
Standard Deviation	0.237
Sample Variance	0.056
Kurtosis	71.771
Skewness	-7.163
Range	3.078
Minimum	0.880
Maximum	3.958
Sum	9169.221
Count	2701.000

TABLE 3-54

Balance Spring Conditions for Nozzle Volume (ft^3/5sec)
Descriptive Statistics

Statistics	Value
Mean	0.1031
Standard Error	0.0002
Median	0.1041
Mode	0.1044
Standard Deviation	0.0079
Sample Variance	0.0001
Kurtosis	126.0699
Skewness	-10.8056
Range	0.1018
Minimum	0.0076
Maximum	0.1094
Sum	278.3448
Count	2701.0000

TABLE 3-55

Balance Spring Conditions for Return Volume (ft^3/5sec)
Descriptive Statistics

Statistics	Value
Mean	0.1219
Standard Error	0.0002
Median	0.1233
Mode	#N/A
Standard Deviation	0.0093
Sample Variance	0.0001
Kurtosis	132.2613
Skewness	-11.1860
Range	0.1270
Minimum	0.0069
Maximum	0.1339
Sum	329.1738
Count	2701.0000

TABLE 3-56

Balance Spring Conditions for Vent Volume (ft^3/5sec)
Descriptive Statistics

Statistics	Value
Mean	-0.4281
Standard Error	0.0022
Median	-0.4048
Mode	#N/A
Standard Deviation	0.1125
Sample Variance	0.0127
Kurtosis	0.8566
Skewness	-0.8401
Range	0.7531
Minimum	-0.9076
Maximum	-0.1545
Sum	-1156.2924
Count	2701.0000

TABLE 3-57

Balance Spring Conditions for Nozzle Temperature (R) Descriptive Statistics

Statistics	Value
Mean	584.480
Standard Error	0.152
Median	583.515
Mode	582.000
Standard Deviation	7.897
Sample Variance	62.359
Kurtosis	-0.044
Skewness	-0.419
Range	42.071
Minimum	556.095
Maximum	598.166
Sum	1578679.626
Count	2701.000

TABLE 3-58

Balance Spring Conditions for Return Temperature (R) Descriptive Statistics

Statistics	Value
Mean	528.142
Standard Error	0.117
Median	526.138
Mode	523.896
Standard Deviation	6.099
Sample Variance	37.197
Kurtosis	-1.175
Skewness	0.295
Range	22.545
Minimum	517.997
Maximum	540.542
Sum	1426511.516
Count	2701.000

TABLE 3-59

Balance Spring Conditions for Vent Temperature (R)
Descriptive Statistics

Statistics	Value
Mean	582.449
Standard Error	0.118
Median	583.249
Mode	587.640
Standard Deviation	6.135
Sample Variance	37.634
Kurtosis	3.544
Skewness	-1.286
Range	41.354
Minimum	551.327
Maximum	592.681
Sum	1573194.134
Count	2701.000

TABLE 3-60

Balance Spring Conditions for UST Pressure ("H_2O) Descriptive Statistics

Statistics	Value
Mean	-0.427
Standard Error	0.002
Median	-0.402
Mode	-0.354
Standard Deviation	0.112
Sample Variance	0.013
Kurtosis	0.651
Skewness	-0.800
Range	0.738
Minimum	-0.891
Maximum	-0.153
Sum	-1152.899
Count	2701.000

TABLE 3-61

Balance Spring Conditions for Leak Rate (CFM)
Descriptive Statistics

Statistics	Value
Mean	-0.068
Standard Error	0.000
Median	-0.066
Mode	-0.062
Standard Deviation	0.010
Sample Variance	0.000
Kurtosis	0.045
Skewness	-0.483
Range	0.063
Minimum	-0.102
Maximum	-0.039
Sum	-183.971
Count	2701.000

TABLE 3-62

Balance Spring Conditions for Ambient Pressure ("H_2O)
Descriptive Statistics

Statistics	Value
Mean	30.022
Standard Error	0.000
Median	30.015
Mode	30.010
Standard Deviation	0.014
Sample Variance	0.000
Kurtosis	0.788
Skewness	1.197
Range	0.050
Minimum	30.010
Maximum	30.060
Sum	81090.320
Count	2701

TABLE 3-63

Balance Spring Conditions for Ambient Temperature (°F) Descriptive Statistics

Statistics	Value
Mean	68.07
Standard Error	0.11
Median	66.93
Mode	75.03
Standard Deviation	5.52
Sample Variance	30.45
Kurtosis	-1.07
Skewness	0.14
Range	19.41
Minimum	58.42
Maximum	77.83
Sum	183854.36
Count	2701.00

TABLE 3-64

Balance Spring Conditions for Vehicle Tank Temperature (°F) Descriptive Statistics

Statistics	Value
Mean	71.0
Standard Error	0.1
Median	69.4
Mode	66.4
Standard Deviation	7.4
Sample Variance	54.9
Kurtosis	0.3
Skewness	0.4
Range	43.4
Minimum	51.6
Maximum	95.0
Sum	188446.7
Count	2653.0

Table 3-65 Regression Analysis UST Pressure as a Function of Ambient Pressure for Balance System Winter Conditions

Regression Statistics	
Multiple R	0.00456708
R Square	2.0858E-05
Adjusted R Square	-4.999E-05
Standard Error	1.98698283
Observations	14116

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.162315107	1.162315107	0.294398542	0.587424098
Residual	14114	55723.49412	3.948100759		
Total	14115	55724.65643			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0840257	1.432195209	0.058669166	0.95321645	-2.723268663	2.891320059	-2.723268663	2.891320059
X Variable 1	-0.0256991	0.047364134	-0.542585055	0.587424098	-0.118539114	0.067140972	-0.118539114	0.067140972

Table 3-66 Regression Analysis UST Pressure as a Function of Ambient Pressure for Balance System Spring Conditions

Regression Statistics	
Multiple R	0.02669331
R Square	0.00071253
Adjusted R Square	0.00034229
Standard Error	0.11231437
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.024276608	0.02427661	1.92449755	0.165476237
Residual	2699	34.04658275	0.01261452		
Total	2700	34.07085936			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-6.73861076	4.549802556	-1.48107762	0.13870262	-15.66006058	2.18283907	-15.66006058	2.182839066
X Variable 1	0.21023581	0.151547254	1.38726239	0.16547631	-0.086924611	0.50739622	-0.086924611	0.507396221

Table 3-67 Regression Analysis UST Pressure as a Function of Ambient Pressure for Vacuum Assist Winter Conditions

Regression Statistics	
Multiple R	0.17648217
R Square	0.03114596
Adjusted R Square	0.03108678
Standard Error	0.42164011
Observations	16374

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	93.56833023	93.5683302	526.314151	1.1436E-114
Residual	16372	2910.620394	0.17778038		
Total	16373	3004.188725			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-12.5309533	0.569843488	-21.9901667	1.204E-105	-13.64790726	-11.413999	-13.64790726	-11.4139993
X Variable 1	0.43908756	0.019139413	22.9415377	1.144E-114	0.401572272	0.47660285	0.401572272	0.476602851

Table 3-68 Regression Analysis UST Pressure as a Function of Ambient Temperature for Balance System Winter Conditions

Regression Statistics	
Multiple R	0.012157712
R Square	0.00014781
Adjusted R Square	7.69688E-05
Standard Error	1.986856696
Observations	14116

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8.236659444	8.236659444	2.086498233	0.148628558
Residual	14114	55716.41977	3.94759953		
Total	14115	55724.65643			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.407386786	0.198440647	-2.052940217	0.040096763	-0.796357023	-0.018416548	-0.796357023	-0.018416548
X Variable 1	-0.004663677	0.003228639	-1.44447161	0.148628558	-0.010992241	0.001664887	-0.010992241	0.001664887

Table 3-69 Regression Analysis UST Pressure as a Function of Ambient Temperature for Balance System Spring Conditions

Regression Statistics	
Multiple R	0.130937191
R Square	0.017144548
Adjusted R Square	0.016780392
Standard Error	5.471542095
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1409.479487	1409.479487	47.08030526	8.41872E-12
Residual	2699	80802.04904	29.93777289		
Total	2700	82211.52853			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1588.919376	221.6496109	7.168608911	9.73701E-13	1154.299223	2023.539529	1154.299223	2023.539529
X Variable 1	-50.65730254	7.38282364	-6.861507873	8.41878E-12	-65.13386275	-36.18074232	-65.13386275	-36.18074232

Table 3-70 Regression Analysis UST Pressure as a Function of Ambient Temperature for Vacuum Assist Winter Conditions

Regression Statistics	
Multiple R	0.02893387
R Square	0.00083717
Adjusted R Square	0.00077614
Standard Error	0.42818443
Observations	16374

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.51501336	2.51501	13.7176	0.00021315
Residual	16372	3001.67371	0.18334		
Total	16373	3004.18872			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-2.1377614	0.72351504	-2.9547	0.00313	-3.555928	-0.719595	-3.555928	-0.71959479
X Variable 1	0.00514969	0.00139041	3.70373	0.00021	0.00242435	0.007875	0.002424346	0.007875037

Table 3-71 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature Balance System Winter Conditions

Regression Statistics	
Multiple R	0.87284513
R Square	0.76185861
Adjusted R Square	0.76184174
Standard Error	4.64752562
Observations	14116

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	975288.7262	975288.726	45153.3127	0
Residual	14114	304855.2643	21.5994944		
Total	14115	1280143.99			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-34.8047094	0.464179422	-74.9811553	0	-35.7145632	-33.894856	-35.714563	-33.8948555
X Variable 1	1.60479481	0.007552221	212.493089	0	1.58999144	1.61959817	1.58999144	1.61959817

Table 3-72 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature for Balance System Spring Conditions

Regression Statistics	
Multiple R	0.37511811
R Square	0.1407136
Adjusted R Square	0.14038836
Standard Error	6.86206535
Observations	2644

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	20372.32738	20372.3274	432.64426	4.0925E-89
Residual	2642	124406.3399	47.0879409		
Total	2643	144778.6672			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	54.8489114	0.787923598	69.611967	0	53.3039024	56.3939205	53.3039024	56.39392047
X Variable 1	0.23841742	0.01146232	20.8001024	4.092E-89	0.2159414	0.26089344	0.2159414	0.260893443

Table 3-73 Regression Analysis Vehicle Tank Temperature as a Function of Ambient Temperature for Vacuum Assist System Winter Conditions

Regression Statistics	
Multiple R	0.10983712
R Square	0.01206419
Adjusted R Square	0.0120001
Standard Error	0.42711499
Observations	15417

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	34.34018824	34.3401882	188.24049	1.3696E-42
Residual	15415	2812.115522	0.18242722		
Total	15416	2846.45571			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.42806782	0.070288737	-6.09013388	1.155E-09	-0.56584187	-0.29029376	-0.56584187	-0.29029376
X Variable 1	0.0168323	0.001226837	13.7200761	1.37E-42	0.01442756	0.01923705	0.01442756	0.01923705

Table 3-74 Regression Analysis UST Pressure as a Function of Return Volume for Balance Winter Conditions

Regression Statistics	
Multiple R	0.8975359
R Square	0.8055707
Adjusted R Square	0.80555692
Standard Error	0.87615209
Observations	14116

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	44890.15045	44890.1505	58477.9393	0
Residual	14114	10834.50598	0.76764248		
Total	14115	55724.65643			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-10.1185825	0.039668765	-255.07682	0	-10.19633856	-10.0408264	-10.19633856	-10.0408264
X Variable 1	100.793019	0.416806443	241.822123	0	99.97602267	101.610016	99.97602267	101.6100155

Table 3-75 Regression Analysis UST Pressure as a Function of Return Volume for Balance Spring Conditions

Regression Statistics	
Multiple R	0.0001002
R Square	1.0041E-08
Adjusted R Square	-0.0003705
Standard Error	0.1123544
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.42102E-07	3.421E-07	2.71E-05	0.99584678
Residual	2699	34.07085901	0.0126235		
Total	2700	34.07085936			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Upper 95.0%*
Intercept	-0.4266939	0.028432059	-15.007494	5.859E-49	-0.48244475	-0.3709431	-0.4824447	-0.37094313
X Variable 1	-0.001211	0.232620814	-0.0052058	0.9958468	-0.45734394	0.45492198	-0.4573439	0.45492198

Table 3-76 Regression Analysis UST Pressure as a Function of Return Volume for Vacuum Assist Winter Conditions

Regression Statistics	
Multiple R	0.19106
R Square	0.03650392
Adjusted R Square	0.03644103
Standard Error	0.42615923
Observations	15322

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	105.4125088	105.412509	580.428006	6.5767E-126
Residual	15320	2782.291033	0.18161169		
Total	15321	2887.703542			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.72595467	0.008046135	90.2240251	0	0.710183279	0.74172606	0.710183279	0.741726062
X Variable 1	-0.05076877	0.002107281	-24.092074	6.577E-126	-0.054899292	-0.04663824	-0.054899292	-0.04663824

Table 3-77 Regression Analysis Leak Rate as a Function of UST Pressure for Balance System Winter Conditions

Regression Statistics	
Multiple R	0.89866237
R Square	0.80759405
Adjusted R Square	0.80758042
Standard Error	0.02996548
Observations	14116

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	53.19457181	53.1945718	59241.3214	0
Residual	14114	12.6733869	0.00089793		
Total	14115	65.8679587			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.07543425	0.000267113	-282.405267	0	-0.075957826	-0.07491067	-0.075957826	-0.07491067
X Variable 1	0.03089655	0.00012694	243.395401	0	0.030647729	0.03114537	0.030647729	0.031145367

Table 3-78 Regression Analysis Leak Rate as a Function of UST Pressure for Balance System Spring Conditions

Regression Statistics	
Multiple R	0.99719189
R Square	0.99439166
Adjusted R Square	0.99438958
Standard Error	0.0005659
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.153250182	0.15325018	478548.473	0
Residual	2699	0.000864327	3.2024E-07		
Total	2700	0.154114509			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.02388817	4.27907E-05	-558.25624	0	-0.023972071	-0.0238043	-0.023972071	-0.02380426
X Variable 1	0.06706701	9.69496E-05	691.771981	0	0.066876909	0.06725711	0.066876909	0.067257115

Table 3-78 Regression Analysis Leak Rate as a Function of UST Pressure for Vacuum Assist Winter Conditions

Regression Statistics	
Multiple R	0.94853974
R Square	0.89972763
Adjusted R Square	0.8997215
Standard Error	0.0102066
Observations	16374

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15.3035988	15.3035988	146903.3	0
Residual	16372	1.70554742	0.00010417		
Total	16373	17.0091462			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.01475604	0.00012863	114.716962	0	0.01450391	0.01500817	0.01450391	0.015008166
X Variable 1	0.07137287	0.00018622	383.279645	0	0.07100787	0.07173788	0.07100787	0.071737877

Table 3-80 Regression Analysis Vent Emissions (ppm) as a Function of UST Pressure for Balance Winter Conditions

Regression Statistics	
Multiple R	0.0834614
R Square	0.0069658
Adjusted R Squa	0.0068879
Standard Error	1858.7042
Observations	12746

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	308839680.3	308839680	89.3948574	3.79302E-21
Residual	12744	44027732677	3454781.28		
Total	12745	44336572358			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	395.4765	23.26878018	16.9960135	4.4583E-64	349.8661551	441.086851	349.8661551	441.0868506
X Variable 1	-3.8177209	0.403782888	-9.45488537	3.793E-21	-4.609196783	-3.02624505	-4.609196783	-3.02624505

Table 3-81 Regression Analysis Vent Emissions (ppm) as a Function of UST Pressure for Balance Spring Conditions

Regression Statistics	
Multiple R	0.01654813
R Square	0.00027384
Adjusted R Square	-9.6565E-05
Standard Error	21.8532139
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	353.0616035	353.061604	0.7392985	0.389962034
Residual	2699	1288942.428	477.56296		
Total	2700	1289295.49			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	15.5121401	1.652444948	9.38738693	1.264E-20	12.27195452	18.7523257	12.27195452	18.75232571
X Variable 1	3.21909431	3.743895978	0.85982472	0.389962	-4.122099	10.5602876	-4.122099003	10.56028763

Table 3-82 Regression Analysis Vent Emissions (ppm) as a Function of UST Pressure for Vacuum Assist Winter Conditions

Regression Statistics	
Multiple R	0.09498139
R Square	0.00902146
Adjusted R Square	0.00896094
Standard Error	252.847939
Observations	16374

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9528694.274	9528694.27	149.04402	3.94738E-34
Residual	16372	1046696020	63932.0804		
Total	16373	1056224714			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	92.4698131	3.186548361	29.0188011	1.38E-180	86.22383858	98.7157875	86.22383858	98.71578753
X Variable 1	56.3187608	4.613131265	12.2083586	3.947E-34	47.27653179	65.3609899	47.27653179	65.36098988

Table 3-830 Regression Analysis Vent Emissions (ppm) as a Function of Leak Rate for Balance Winter Conditions

Regression Statistics	
Multiple R	0.01253717
R Square	0.00015718
Adjusted R Square	7.8725E-05
Standard Error	1865.0653
Observations	12746

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6968846.856	6968846.86	2.00342384	0.156968783
Residual	12744	44329603511	3478468.57		
Total	12745	44336572358			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	272.636412	28.36177743	9.61281121	8.3701E-22	217.0430151	328.229809	217.043015	328.2298089
X Variable 1	333.605045	235.6927325	1.41542355	0.15696878	-128.3885539	795.598644	-128.388554	795.598644

Table 3-84 Regression Analysis Vent Emissions (ppm) as a Function of Leak Rate (CFM) for Balance Spring Conditions

Regression Statistics	
Multiple R	0.02640264
R Square	0.0006971
Adjusted R Square	0.00032685
Standard Error	0.00958219
Observations	2701

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.000172874	0.00017287	1.88278405	0.170132087
Residual	2699	0.24781785	9.1818E-05		
Total	2700	0.247990725			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.06827572	0.000219612	-310.892959	0	-0.068706341	-0.06784509	-0.068706341	-0.06784509
X Variable 1	1.1579E-05	8.43895E-06	1.37214578	0.17013209	-4.96799E-06	2.8127E-05	-4.96799E-06	2.81269E-05

Table 85 Regression Analysis Vent Emissions (ppm) as a Function of Leak Rate (CFM) for Balance Winter Conditions

Regression Statistics	
Multiple R	0.1156282
R Square	0.01336988
Adjusted R Square	0.01330962
Standard Error	252.292581
Observations	16374

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14121599.22	14121599.2	221.857913	7.54305E-50
Residual	16372	1042103115	63651.5462		
Total	16373	1056224714			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	74.30214	3.817334382	19.4644044	1.9271E-83	66.81975772	81.7845224	66.81975772	81.78452236
X Variable 1	911.172667	61.17348484	14.8948955	7.543E-50	791.2661151	1031.07922	791.2661151	1031.079218

Section 4

DISCUSSION

As initially proposed, the purpose of this research project was to investigate the causal factors that influence hydrocarbon emissions at gasoline dispensing facilities (GDF). The testing was intended to evaluate a range of independent variables during four sets of seasonal tests thus controlling for both environmental factors (i.e., meteorological parameters) and vapor recover system (VRS) and/or site specific characteristics. The project did not complete the full field testing regime. Of the nineteen proposed field test conditions, three were actually executed: winter field tests for a balance VRS and vacuum assist VRS and one spring field test for a balance VRS. Based on the limited dataset for analysis, the project results are neither sufficiently robust or contain the representativeness to extrapolate to a larger universe of GDF sites. However, for the test sites, an investigation of factors influencing VRS performance is possible.

Emissions at GDFs are influenced by a host of parameters that dynamically interact both diurnally and across geographic locations. The driving forces which govern hydrocarbon emission releases include:

Product Throughput

Tank throughput
Product turnover rate
Fuel delivery and dispensing profile
Initial fuel vapor space ullage volume
Initial fuel volume
Vent line volume

Temperature

Diurnal temperature variation
Temperature of fuel delivered to tank
Temperature of fuel in UST

System Parameters

Elevation of vent line outlet above UST
Slope of UST
UST diameter
UST volume
UST Gauge Pressure

Fuel Characteristics

Fuel air saturation
Fuel Reid Vapor Pressure (RVP)
Saturated vapor concentration

Meteorological Characteristics

Local wind velocity profile
Local barometric pressure changes

Control Technology

Phase I vapor recovery system efficiency
Phase II vapor recovery system efficiency
Vapor/Liquid ratio for Stage II refueling
Pressure/Vacuum (P/V) valve efficiency

To adequately understand emission releases from GDF fugitive sources would require controlling for the dominant variables that influence hydrocarbon emissions. For the testing executed for this project, the following variables were measured:

Variable	Independent or Dependent	VRS System Type
Ambient Temperature and Pressure	Independent	Balance/Vacuum Assist
Site Location	Independent	Balance/Vacuum Assist
VRS System Pressure	Independent	Balance/Vacuum Assist
UST Gauge Pressure	Independent/ Dependent	Balance/Vacuum Assist
VRS System Hydrocarbon Volume	Independent	Balance/Vacuum Assist
VRS System Temperature	Independent	Balance/Vacuum Assist
Vehicle Fuel Tank Temperature in Vapor	Independent	Balance/Vacuum Assist
Station Design	Independent	Balance/Vacuum Assist
Vent emissions	Dependent	Balance/Vacuum Assist
Fugitive emissions	Dependent	Balance/Vacuum Assist
Bulk delivery emissions	Dependent	Balance/Vacuum Assist

4.1 VRS SYSTEM PERFORMANCE

For each of the tested GDFs, pressure, temperature and vapor volume were measured at three locations on the VRS. The test locations included the vehicle/nozzle interface (test point 1), the vapor return line that shunts collected vapors into the UST (test point 2) and the vent line that provides a means for the UST to release pressure buildup (test point 3). The testing occurred over a 100 car refueling matrix to account for the

heterogeneity of vehicle influences on GDF behavior. The primary independent variable was VRS system type: balance and vacuum assist. Each are sufficiently unique in terms of their operating attributes to provide a range of pressure, temperature and vapor volume conditions that potentially affect underground storage tank (UST) pressure and GDF emissions.

Pressure varied across VRS type, test locations, and temporal season. The nozzle/vehicle interface and the vent line were the most stable with pressure readings exhibiting relative uniformity across the 100 car test matrix. For these test locations, pressure magnitude increased as testing moved from winter to spring test conditions. Return line pressure values were highly variable for both the balance and vacuum assist test locations during winter testing. However, the seasonal effect observed at the test points 1 and 3 was not visible at the return line.

Temperature values were strongly correlated with ambient temperature conditions for both winter and spring testing. The observed ranges were similar for each test point, with maximums and minimums mirroring ambient temperature variances. There was a pronounced difference in hydrocarbon vapor temperature in the return line relative to both test points 1 and 3. At the return line, temperatures were markedly lower by approximately 60 R units.

Volume readings were consistent with VRS design specifications. At test point two, the vacuum assist VRS yielded volume amounts in quantities significantly larger (i.e., approximately a factor of five larger) than the balance VRS at the same test measurement locations. Within each test condition (i.e., season and VRS type), volume measurements were relatively homogenous with the exception of return line for the vacuum system. This was the test location with the noticeably larger volume readings, a possible reason for the instability in volume readings.

Hydrocarbon concentration measurements were variant for each of the test locations. For balance VRS, hydrocarbon measurements were in the same range for each test location for both the winter and spring test locations. Per VRS design specifications, the return line hydrocarbon values were higher by 2-3 orders of magnitude relative to the nozzle and vent line locations. This pattern was consistent for both VRS types.

Hydrocarbon mass readings (a function of both hydrocarbon concentration and volume) mirrored a similar pattern to the hydrocarbon concentration data. Nozzle and vent line reading were low though heterogeneous across the 100 car test matrix. Return line hydrocarbon values were in the same range for the balance system tests. For the vacuum assist system, measured return line hydrocarbon mass readings were larger by two orders of magnitude relative to the other test locations.

UST pressure characteristics and the associated leak rates were consistent with previous studies. The balance system exhibited a predominance of negative UST pressure readings with a concomitant lack of leak rate values. The range was largely

between zero and negative one inches water. Season did not appear to influence UST pressure profiles. The vacuum assist system did experience negative pressure excursions. However the majority of the UST pressure readings were between 0.25 and 0.75 "H_2O. These conditions did yield a series of positive leak rates suggesting that fugitive emission releases are more likely for vacuum assist systems compared to balance VRS.

4.2 AMBIENT CONDITIONS

Ambient pressure and temperature conditions were unique to seasonal influences. Pressure variations were more prominent during the winter testing period. The inverse was true for temperature readings with wider temperature deviations during the spring testing. As hypothesized, vehicle tank temperatures were strongly associated with ambient temperature conditions suggesting vehicle evaporative emissions will be more prevalent during spring and summer.

Each test site received as least one product delivery during the 100 car matrix testing. These events triggered modest bursts in UST pressure values. Depending on whether the UST readings were positive or in close proximity to zero pressure, there was a concomitant increase in vent line hydrocarbon concentrations and leak rates associated with the product delivery.

4.3 VRS CAUSAL RELATIONSHIPS

The objective of this research project was to explore causal relationships with respect to which variables influence increases or decreases in VRS system emissions. While the dataset available for analysis is limited in its value to realize this objective, a conceptual model can be constructed that will provide insight into GDF emission dynamics. The model consisted of a series of linear regressions following the influence of predicted independent variables in a linear sequence on dependent measures. The order of analysis was:

- External factors (i.e., ambient temperature and pressure, vehicle fuel tank temperature).
- GDF system design elements (i.e., volume of air returned to the UST).
- Fuel characteristics (i.e., RVP of winter and summer fuels).
- VRS system dynamics (i.e., the influence of UST pressure on VRS leak rate and vent line emissions).

This order was prescribed by the several assumptions. The first is that external factors may influence VRS system dynamics with a focus on UST pressure. The second assumption is that UST pressure is the dominant factor influencing GDF system emissions. The third assumption is that VRS system design specifications will be important determinants of UST pressure.

External factors did not successfully predict UST variations. For ambient pressure, the linear regression model accounted for less than one percent of the UST variance for the tested balance systems (Figures 4-1, 4-2, 4-4 and 4-5). The vacuum assist system did demonstrate an increased sensitivity to ambient pressure (Figure 4-7 and 4-8). While not a large number, over three percent of the UST variance was attributed to ambient pressure for this system. This is at two orders of magnitude larger than the balance system ambient temperature effects. The larger influence of ambient pressure on vacuum assist systems suggests that USTs with positive pressure characteristics are impacted by temporal variations in ambient pressure to greater degree than negative pressure USTs commonly found in balance VRS settings. Based on the residual plots of the ambient pressure/UST relationship (Figures 4-3, 4-6 and 4-9), the postulated linear relationship between these two variables was sound. However, the lack of significant variance in ambient pressure (i.e., each test site was dominated by 4-5 specific ambient pressure conditions) reduced the strength of the linear model to predict UST pressure as a function of ambient pressure.

Ambient temperature was not a strong predictor of UST pressure. (Figures 4-10 through 4-18). There was, however, marked difference in the ability of ambient pressure to predict UST pressure between VRS type. Spring conditions at the balance site exhibited the greatest explanatory power due to a larger range in observed ambient temperature. While the validity of the linear model is visible when evaluating the residual plots, temperature effects are at best a surrogate for ambient pressure (i.e., greater ambient temperature yields greater UST temperatures which generate greater vapor pressure). However, this hypothesis is not valid given that USTs are both subterranean and insulated from ambient conditions. Therefore, UST pressure is not expected to be impacted by ambient temperature conditions.

Vehicle tank temperature was strongly associated with ambient temperature, an observation based on the proximity of the fuel tank to ambient conditions (Figures 4-19 through 4-27). These relationships would be stronger with respect to variance explanatory power if outliers in the balance spring and vacuum assist winter test conditions were removed. The residual analysis suggests that a collinear variable was excluded from this regression analysis. This assertion is based on the observation that in two cases, the residuals decrease as a function of ambient pressure and increase in the other test condition. Notwithstanding these data, the lack of a relationship between ambient temperature and UST suggests that vehicle tank temperature is unrelated to UST pressure variations.

VRS design specifications did not yield a clear, reproducible relationship with UST pressure. The hypothesis at the onset of the project was that greater volumes of air delivered to the UST by vacuum assist systems relative to balance systems could yield a predictable increase in UST pressure. The regression analysis did not echo these results (Figures 4-28 through 4-36). While vacuum assist systems did generate a broader distribution of return volume data points, balance system return volume during winter test conditions was able to account for 80% of the variance in UST pressure (Figure 4-10). For similar winter test conditions, the vacuum assist system only

produced a weak association with return air volumes and UST pressure. It accounted for approximately 3% of the UST variance (Figure 4-12). The strength of the balance system relationship was certainly influenced by a sole outlier point at the nexus of the x/y axis. If this data point was excluded, the strength of the relationship would have been significantly diminished. Spring test conditions for the balance VRS were even less effective as a predictor of UST pressure as a function of return volume (Figure 4-11). The clusters of data points for the balance systems are consistent with the relatively small range of return volumes observed in these systems. Furthermore, the linear model is appropriate for the return volume/UST pressure regression based on the residual analysis. In all probability, the lack of a strong association of these two variables in the vacuum assist system relative to the winter balance system is probably explained by the outlier in the winter balance system dataset.

Having established possible external influences on UST variance, the conceptual model sought to affirm the role UST pressure in predicting system fugitive emissions. The regression model evaluating leak rate as a function of UST pressure suggested that UST pressure was a very effective predictor of leak rate (Figures 4-37 through 4-45). For each experimental condition, UST pressure accounts for at least 80% of the variance in leak rate values. For the balance system spring test conditions, the explained variance was 99%. However, the curvilinear shape of the regression curves and the residual analysis strongly suggests that the linear model is not appropriate for this relationship and is therefore better described by an exponential or polynomial function. This observation is founded in the fugitive leak dynamics at GDFs. Based on the range and variety of leak sources, leaks are not categorized by a constant geometry. There are different leak flow regimes for different leak sources which vary over time. This situation is further confounded by different flow behaviors (i.e., laminar vs. turbulent flow) at each fugitive leak source. These flow behaviors would be expected to change over time and when UST pressures cross the positive pressure threshold. Thus, while three analyses which regress leak rate as a function of UST pressure have different curve dynamics, they do as a group demonstrate marked flow increases as UST pressure approached positive values.

The UST pressure/leak rate regression findings are supported by previous research that suggests effective control of GDF fugitive emissions can accomplished by a UST pressure management system that maintains neutral UST pressures. Pressure control systems of interest include nozzle and vapor pump designs that maximize the nozzle fill pipe interface seal to obtain the required collection efficiency at a V/L ratio at or below one. The other option is vapor processor methods (e.g., thermal oxidizers, carbon absorption units, selective permeation membranes). Many current certified nozzle and vapor pump designs do not include an effective seal at the nozzle fill neck interface. Rather, they depend on high V/L ratios to achieve greater than 95% collection efficiency at the dispensing point.

While UST pressure is correlated with leak rate, the variance in vent line emissions are not effectively predicted by either UST pressure or system leak rate. The explained

variance for these relationships is 1% or less for the leak rate/vent line emission regression (Figures 4-46 through 4-54). It is even smaller for the UST pressure/vent line emission regression accounting for 0.3 – 0.9% of the predicted variance (Figures 4-55 through 4-65). This result underscores the relative small contribution that vent line emissions make to the total fugitive emission inventory. The scattergram and residual analysis plots for vent line emissions suggest UST pressure outliers are influencing the strength of the reported regression relationships. In addition, clusters of relatively low vent line emission values coupled with clusters of elevated emissions (with little in between) suggest possible experimental measurement error.

Fuel effects were noted on the on the two balance VRS datasets but were not statistically significant. Fuel type influenced vent line emissions as a function of UST pressure and leak rate with higher RVP gasoline having a strong impact. Lower RVP fuel conditions were more affected by summer temperatures with UST pressure responding to diurnal trends in temperature changes.

4.4 INTERPRETATION ISSUES

The lack of a consistent reproducible model that predicts GDF system emissions can be attributed to a variety of factors that highlights the complexity of trying to generate realistic emission factors for gasoline dispensing facilities. Possible interacting elements that influenced the strength of the data interpretation include:

- Experimental Error
- Inadequate variance or dataset robustness
- Length of testing time

The execution of a field project will influence the validity of the dataset. For the current project, the error in the field data collection is a possible contributing effect in terms of introducing a significant error term into the regression model. The initial field test location (Balance Winter Conditions) was problematic in terms of equipment malfunction, deployment of field test apparatus, and execution of field test procedures. The data quality at this location is inconsistent with the initial data points more problematic than the final measurements. The datasets from the vacuum assist winter conditions and the balance spring conditions are not subject to the same level of uncertainties. By the time testing occurred at these locations, the field staff had both formalized their field procedures and reduced equipment malfunction to an acceptable level.

To adequately explore a causal relationship, a variety of conditions are needed to tease out the subtleties of an independent/dependent variable interaction. This was explicitly acknowledged in the project's original experimental design. The current dataset contains information from only three of possible nineteen test sites. For example, only two of four seasons are represented. The lack of a comprehensive

dataset reduces both the robustness of the predictive model and the ability to transfer the study results of a larger universe of GDF sites.

A third issue relative to data interpretation is that the sample period for each experimental condition was too short to adequately investigate the variance implicit in complex systems such as vapor recovery systems. The sampling time for each condition ranged from 140 - 193 minutes. While it would be challenging to measure the baseline parameters at the three test locations (e.g., test points 1-3) for extended periods of time, it may be necessary to comprehensively explore which factors influence GDF emissions.

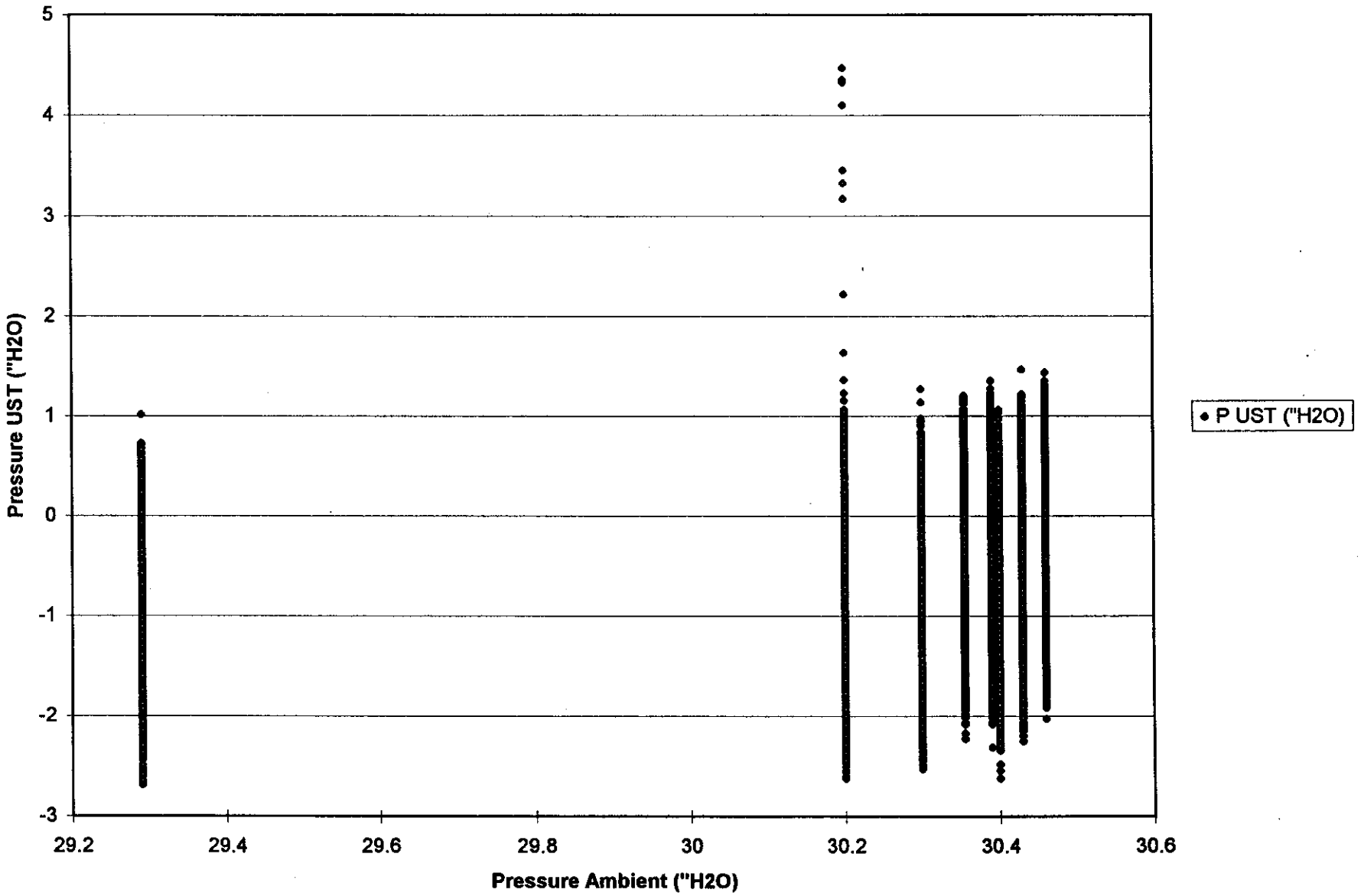


Figure 4-1 Balance System UST Pressure as a Function of Ambient Pressure for Winter Conditions

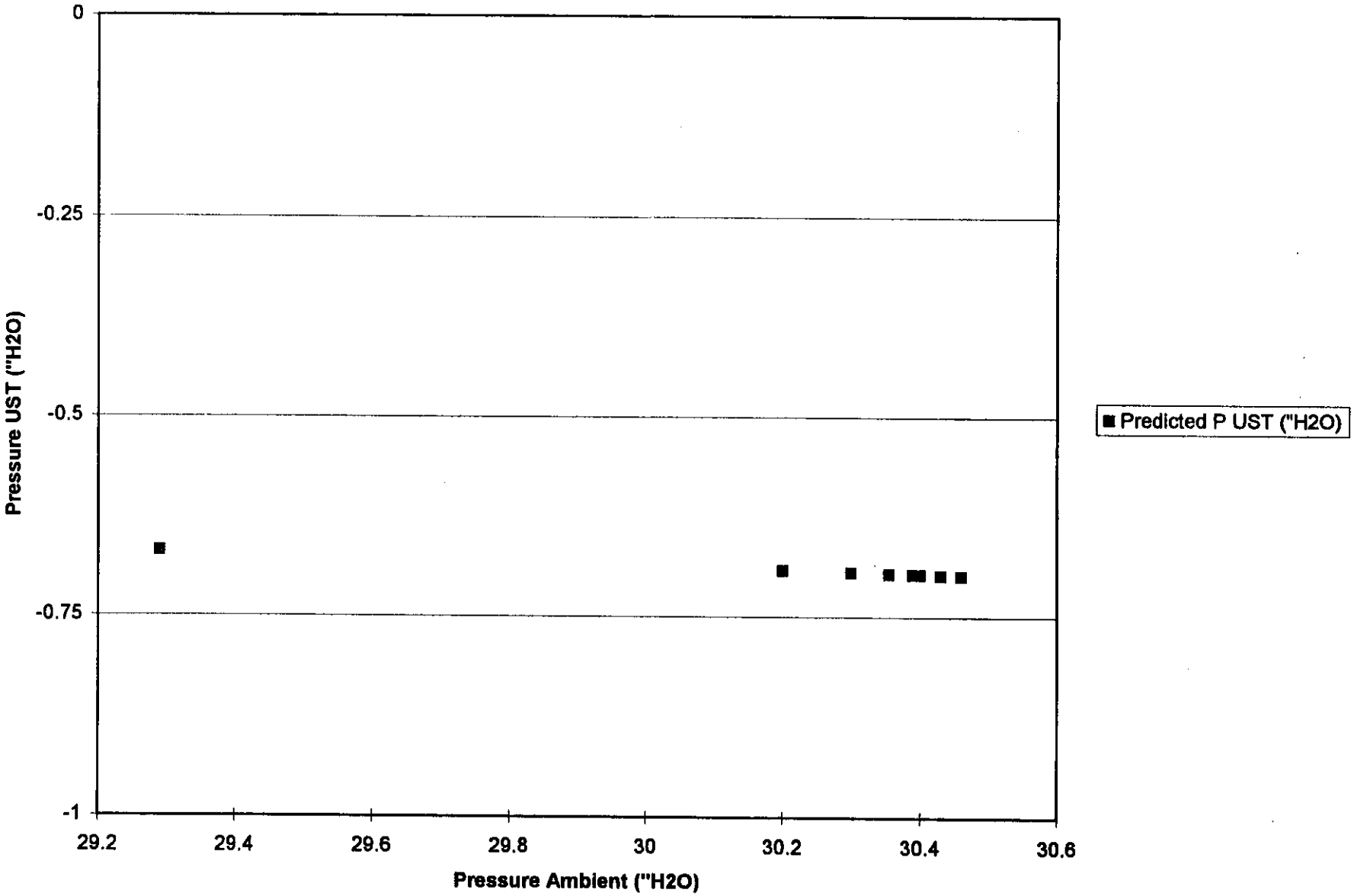


Figure 4-2 Balance System UST Pressure as a Function of Ambient Pressure for Winter Conditions

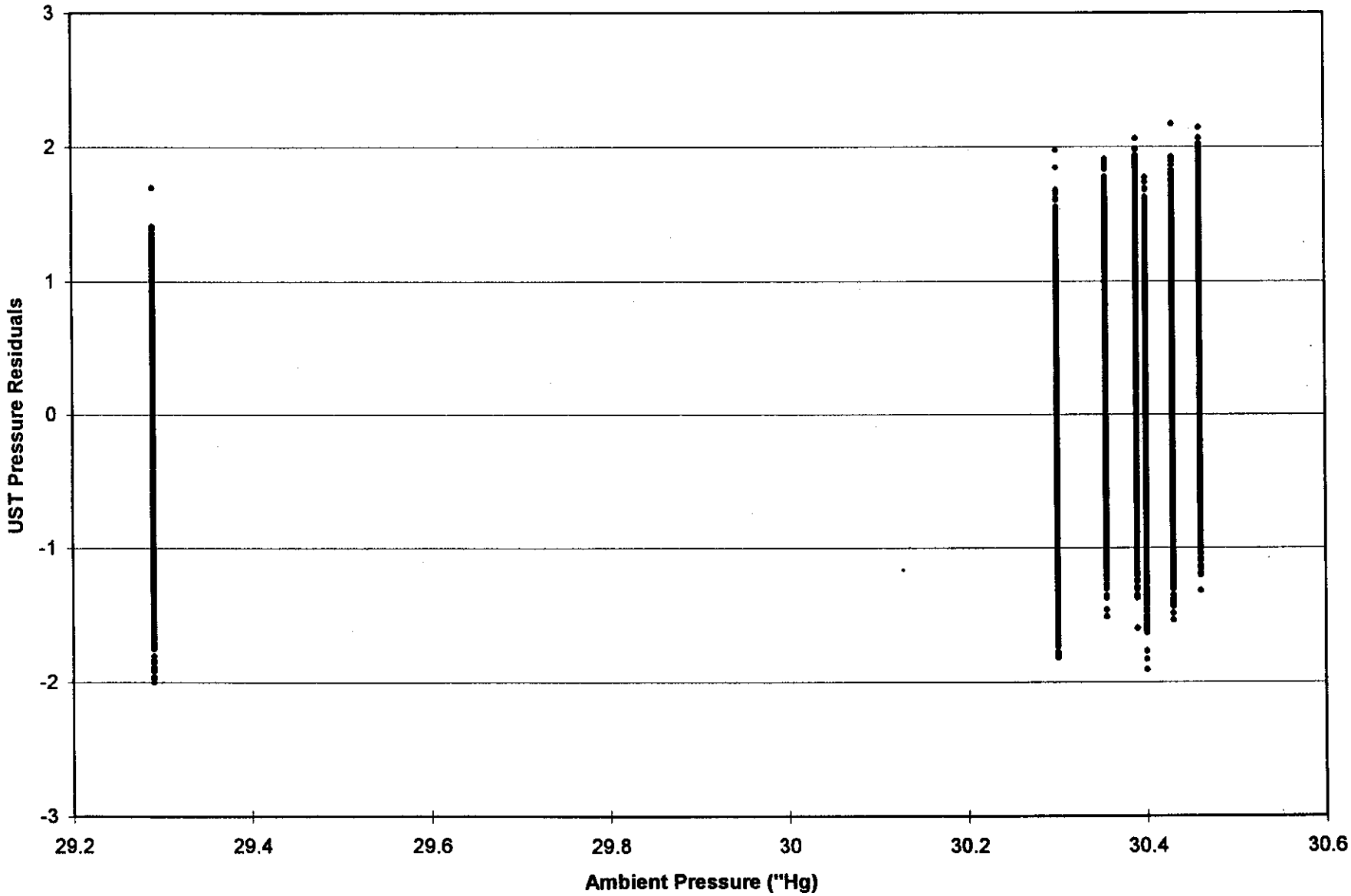


Figure 4-3 Balance System UST Pressure Residuals as a Function of Ambient Pressure for Winter Conditions

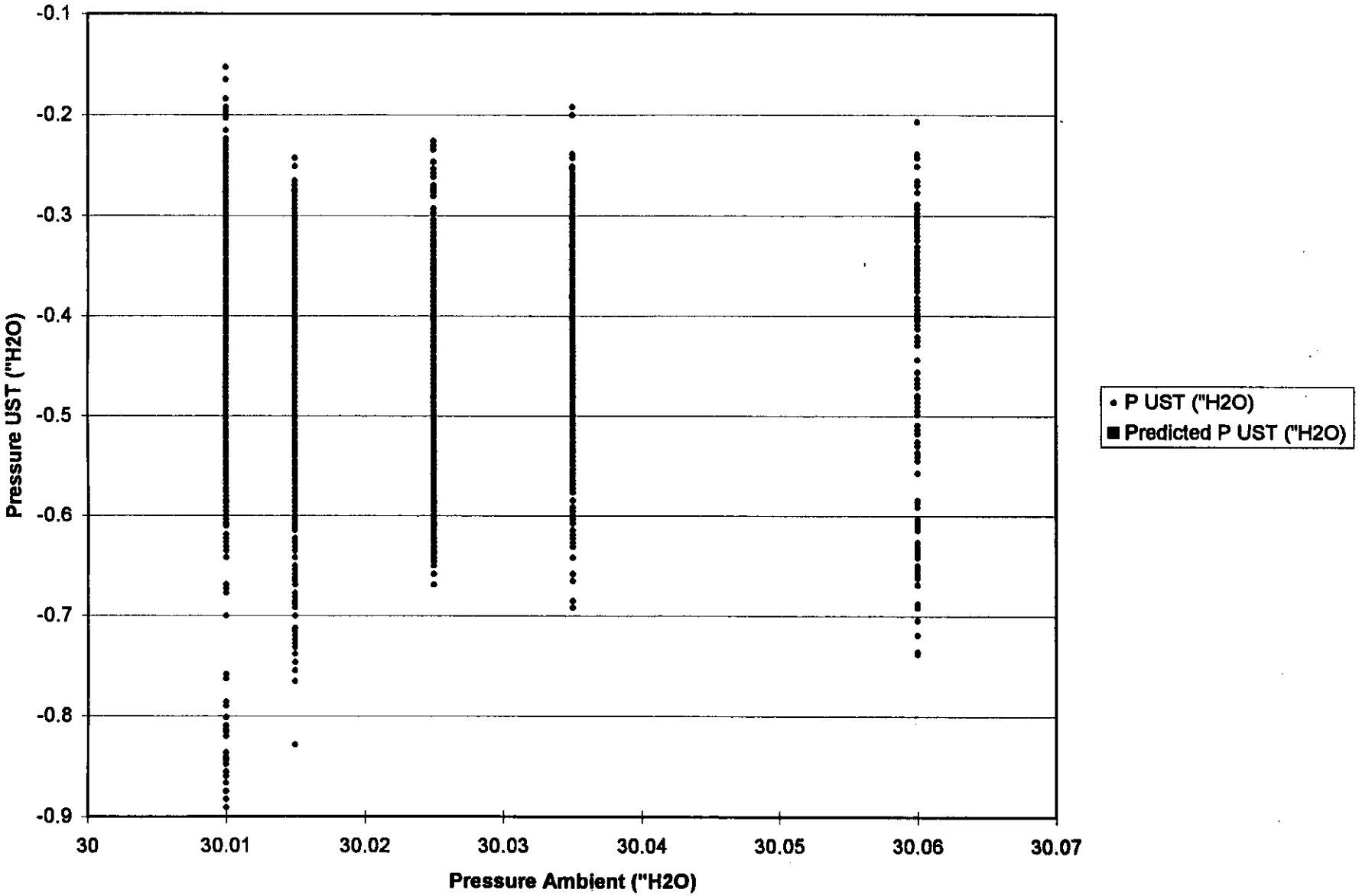


Figure 4-4 Balance System UST Pressure as a Function of Ambient Pressure for Spring Conditions

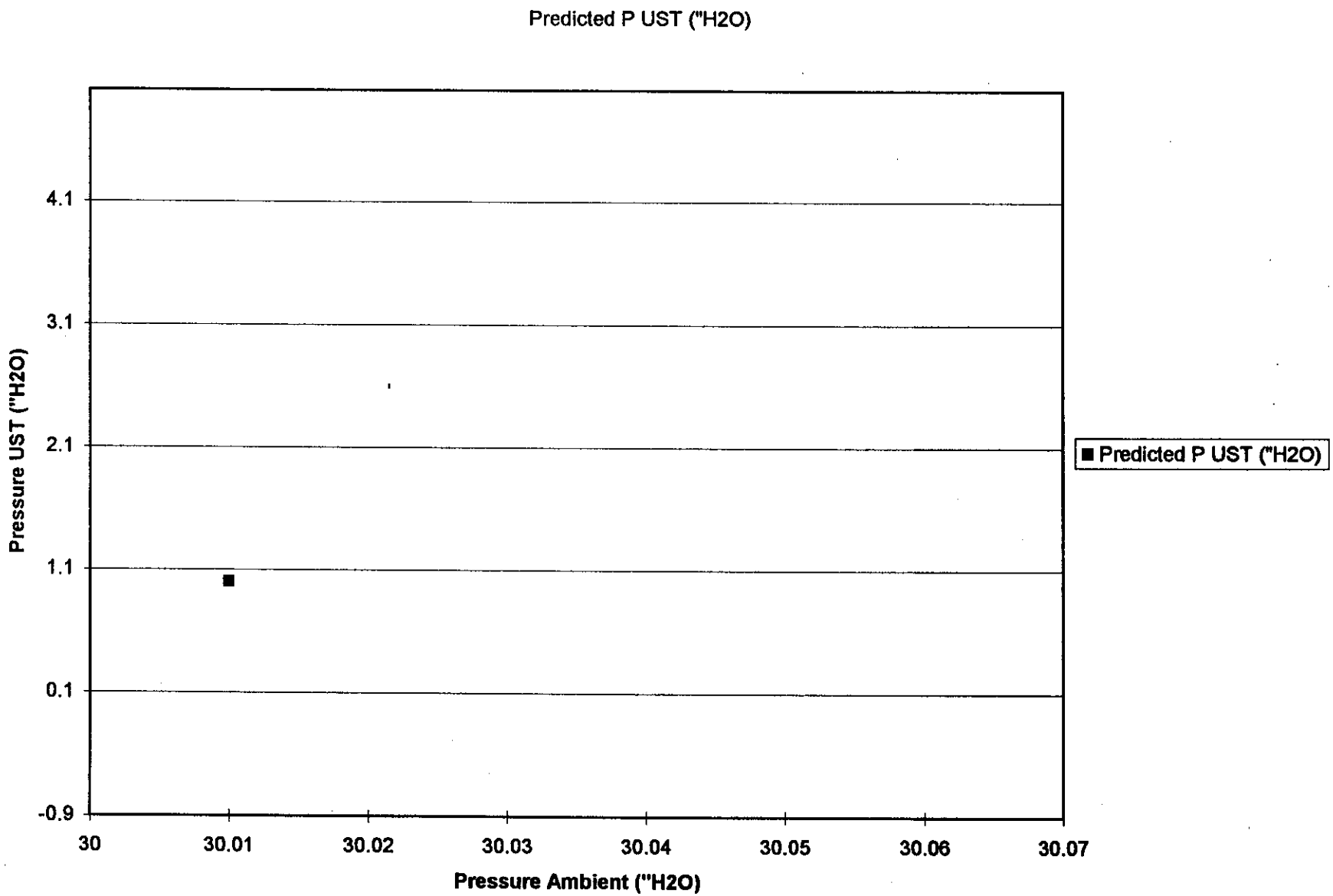


Figure 4-5 Balance System UST Pressure as a Function of Ambient Pressure for Spring Conditions

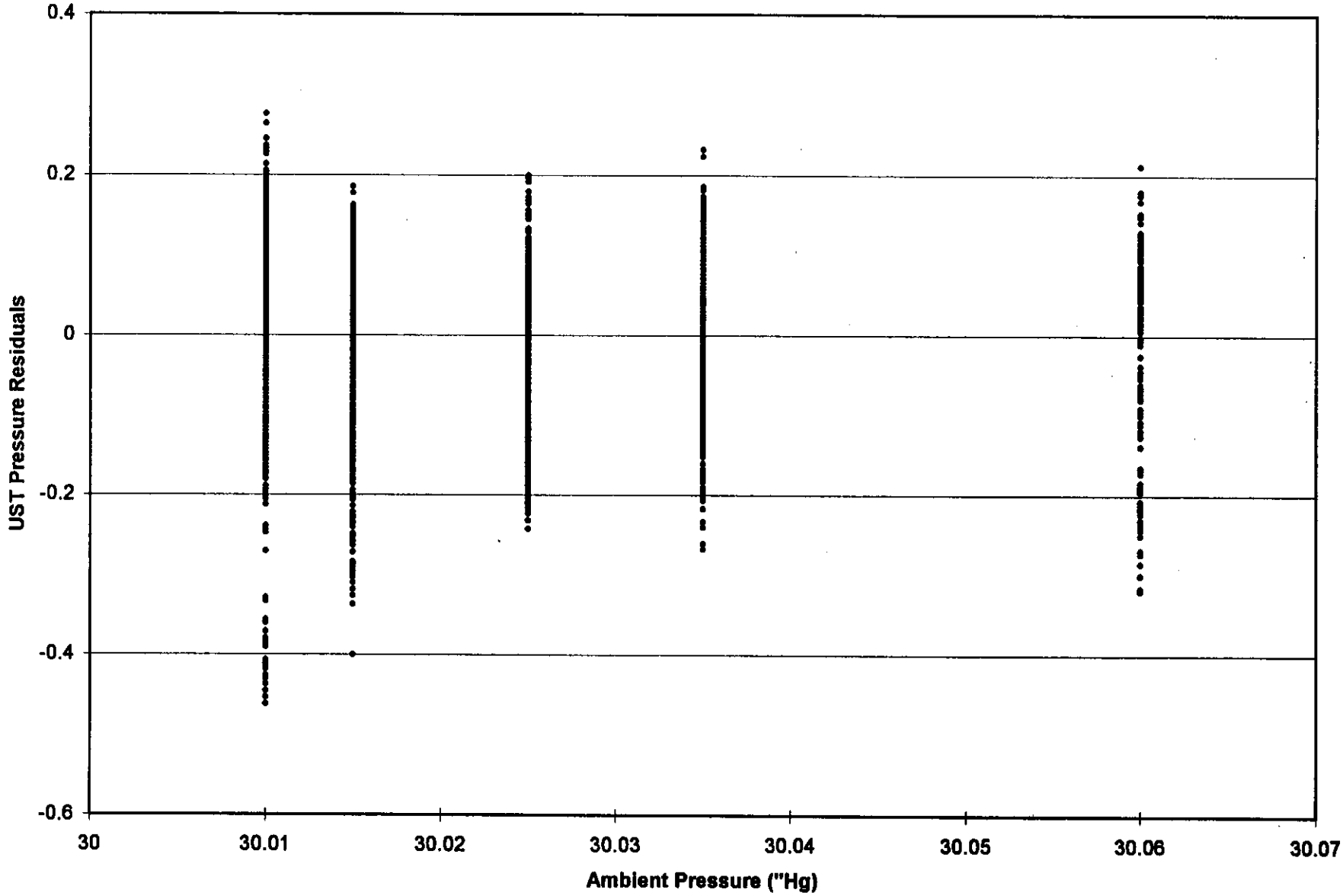


Figure 4-6 Balance System UST Pressure Residuals as a Function of Ambient Pressure for Spring Conditions

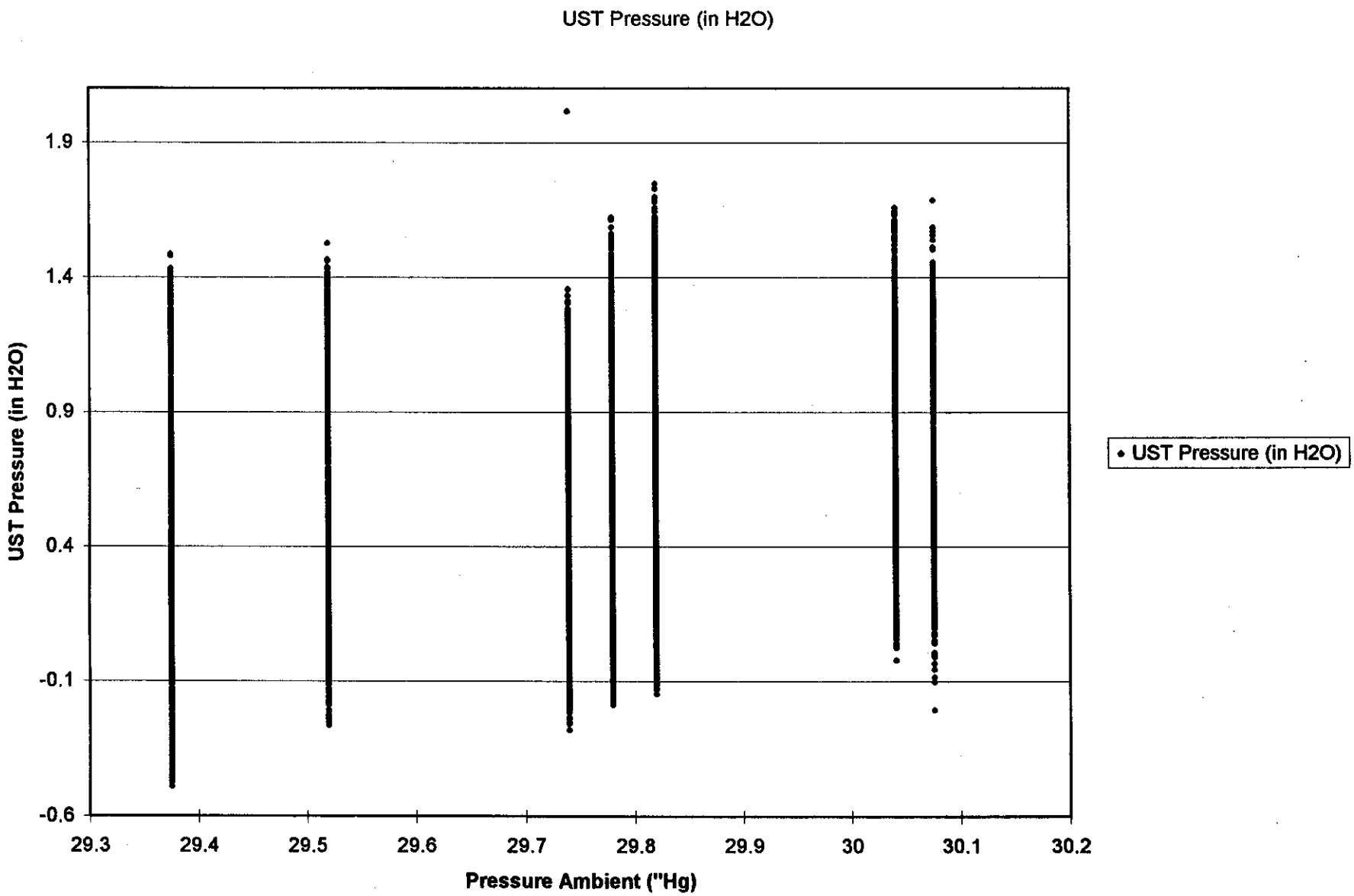


Figure 4-7 Vacuum Assist System UST Pressure as a Function of Ambient Pressure for Winter Conditions

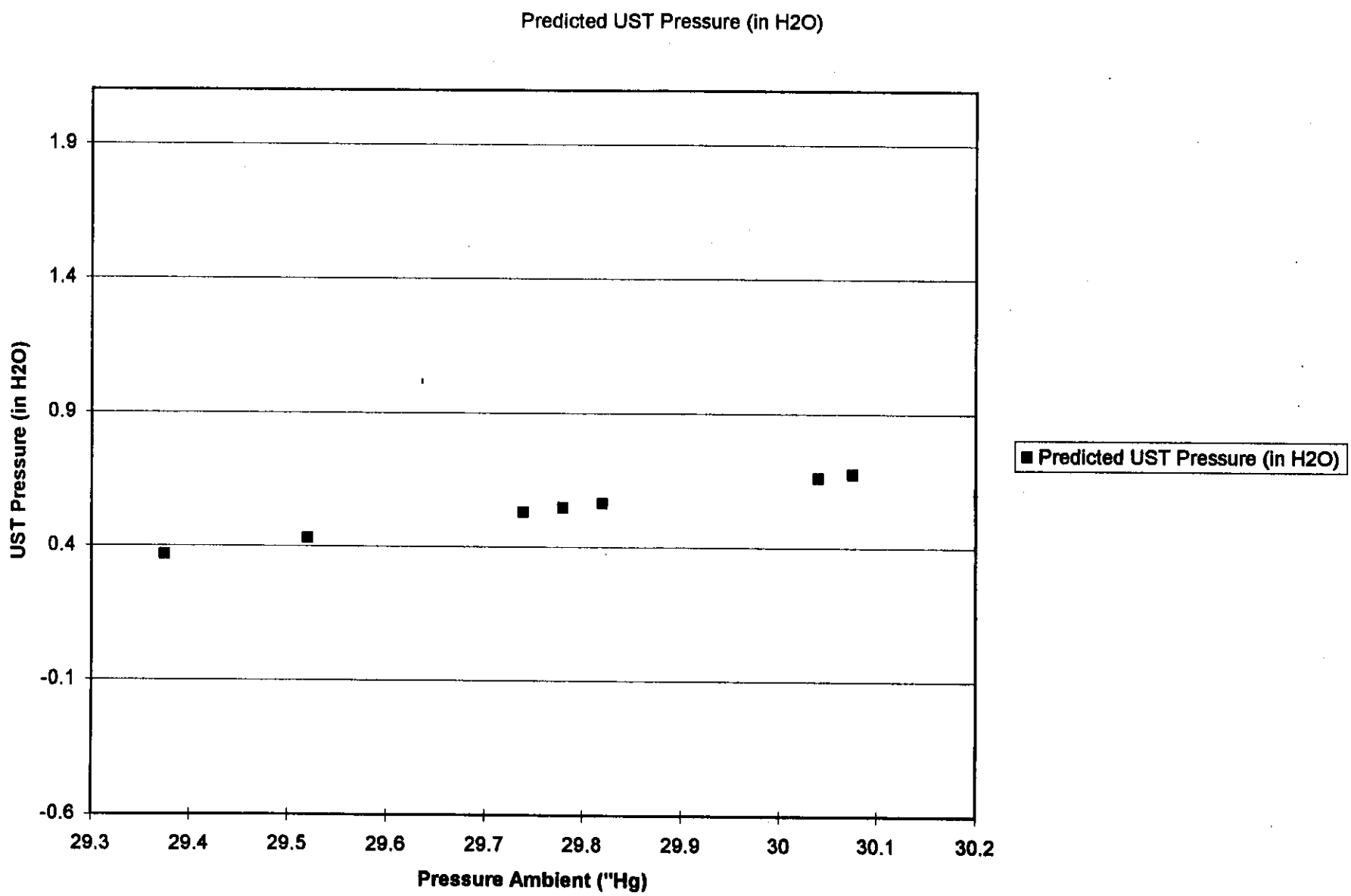


Figure 4-8 Vacuum Assist System UST Pressure as a Function of Ambient Pressure for Winter Conditions

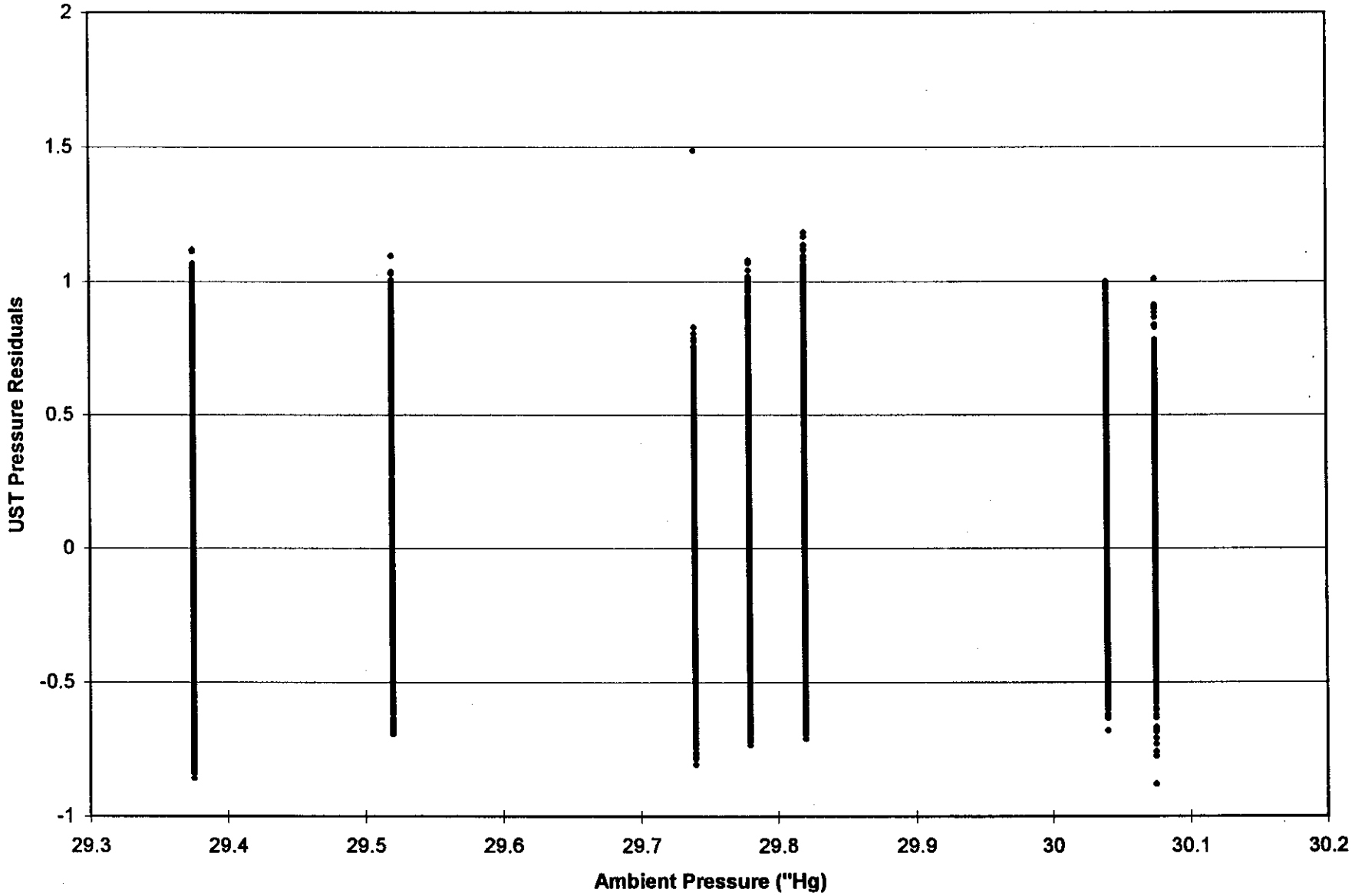


Figure 4-9 Vacuum Assist UST Pressure Residuals as a Function of Ambient Pressure for Winter Conditions

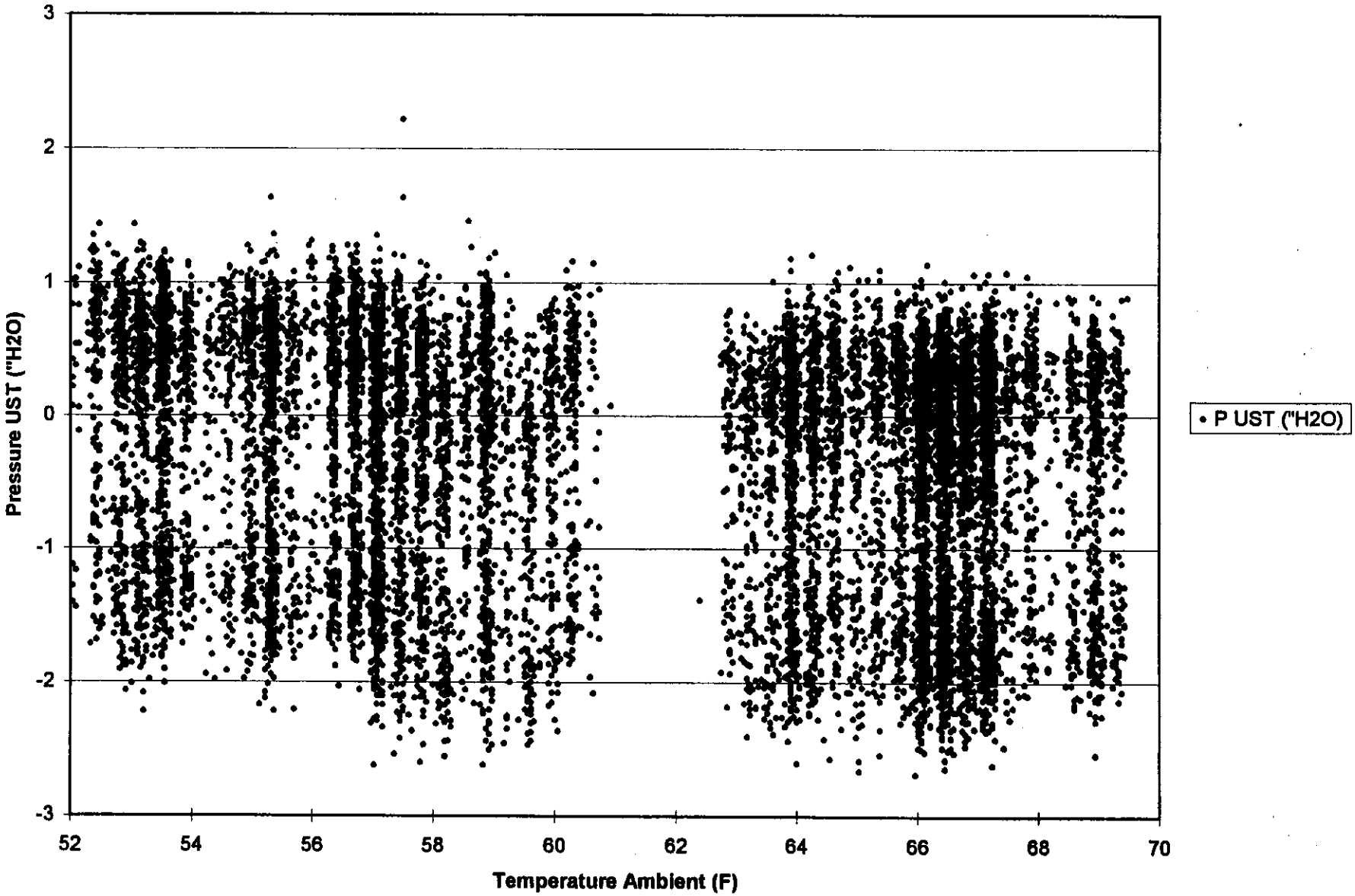


Figure 4-10 Balance System UST Pressure as a Function of Ambient Temperature for Winter Conditions

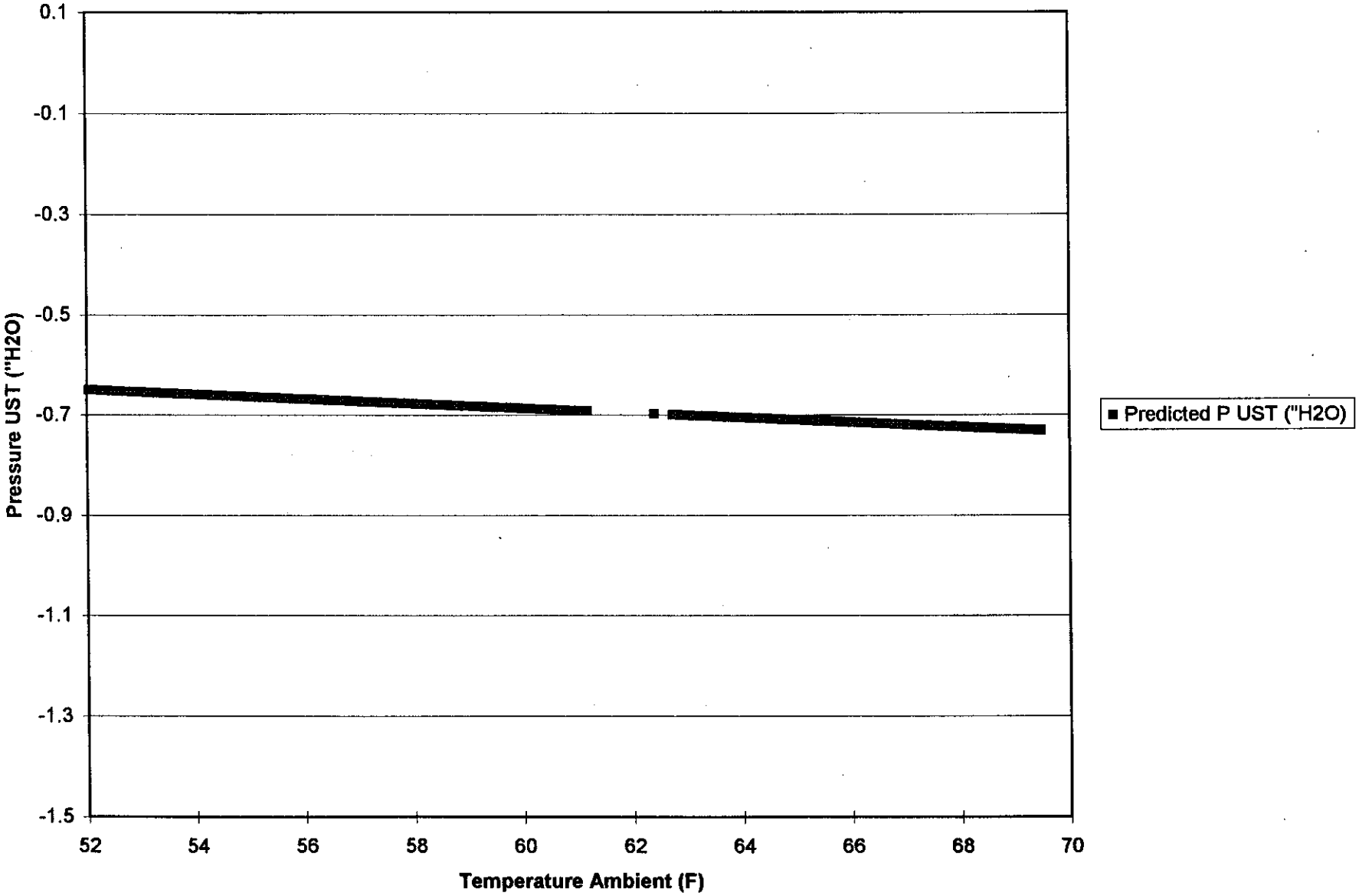


Figure 4-11 Balance System UST Pressure as a Function of Ambient Temperature for Winter Conditions

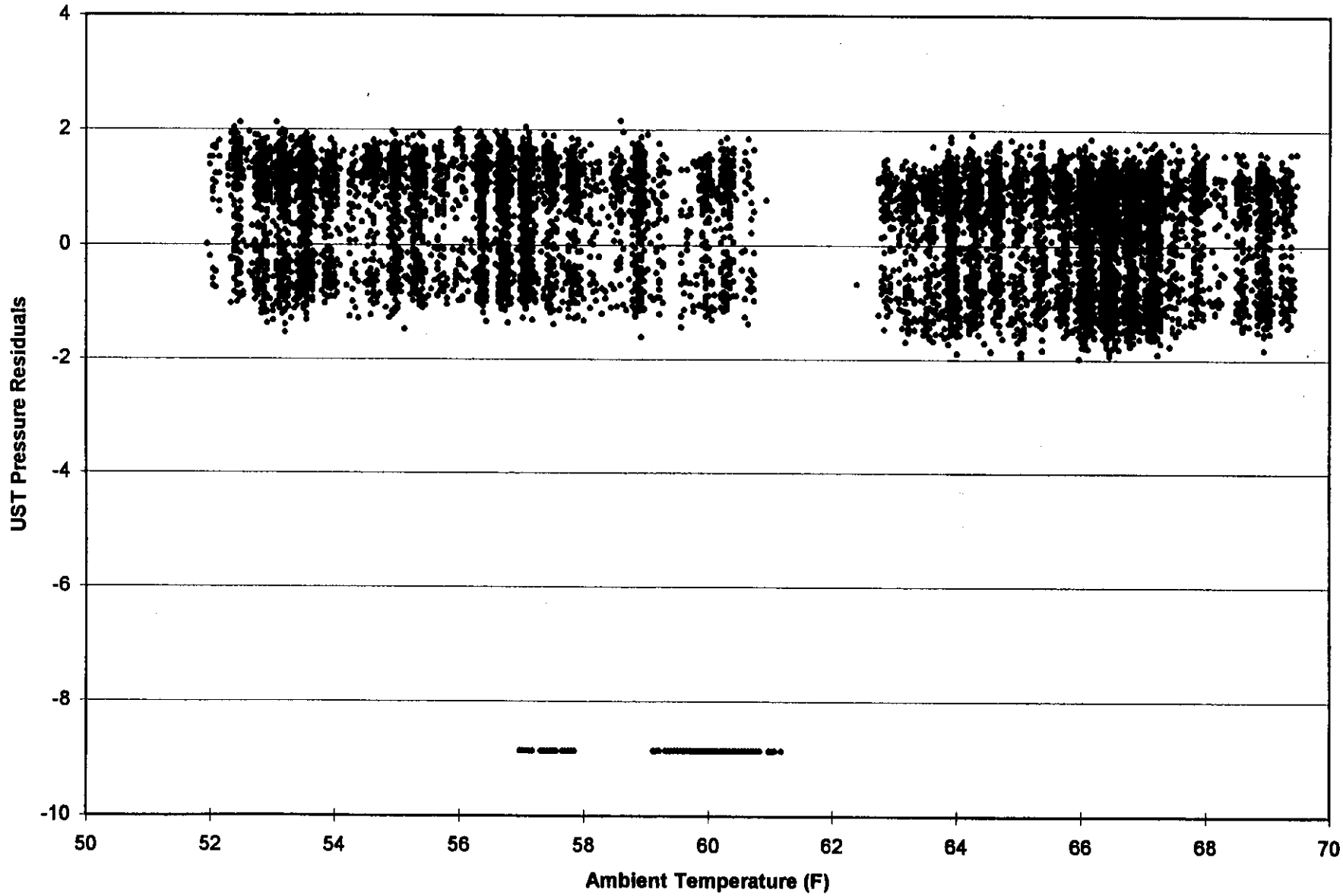


Figure 4-12 Balance System UST Pressure Residuals as a Function of Ambient Temperature for Winter Conditions

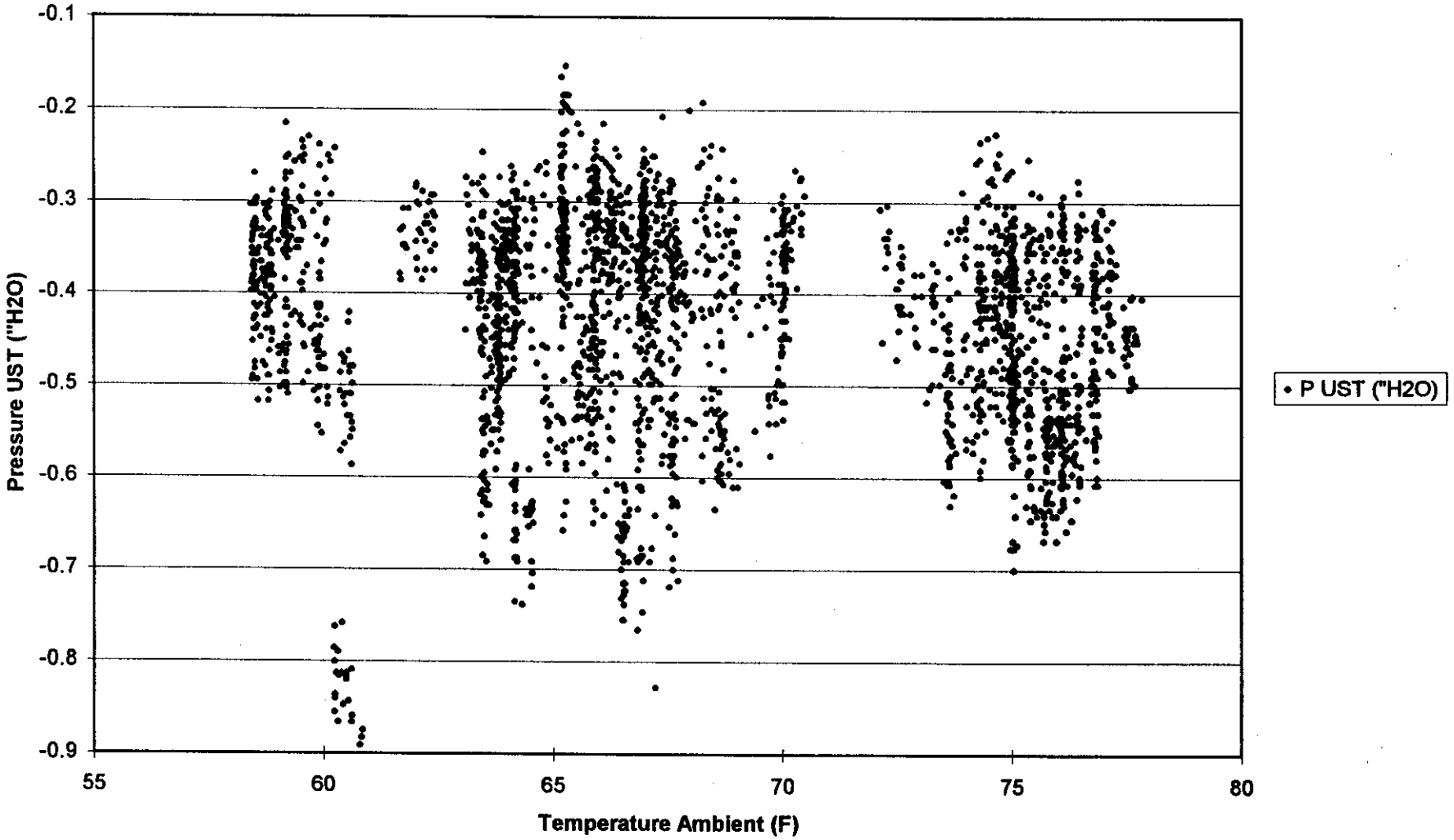


Figure 4-13 Balance System UST Pressure as a Function of Ambient Temperature for Spring Conditions

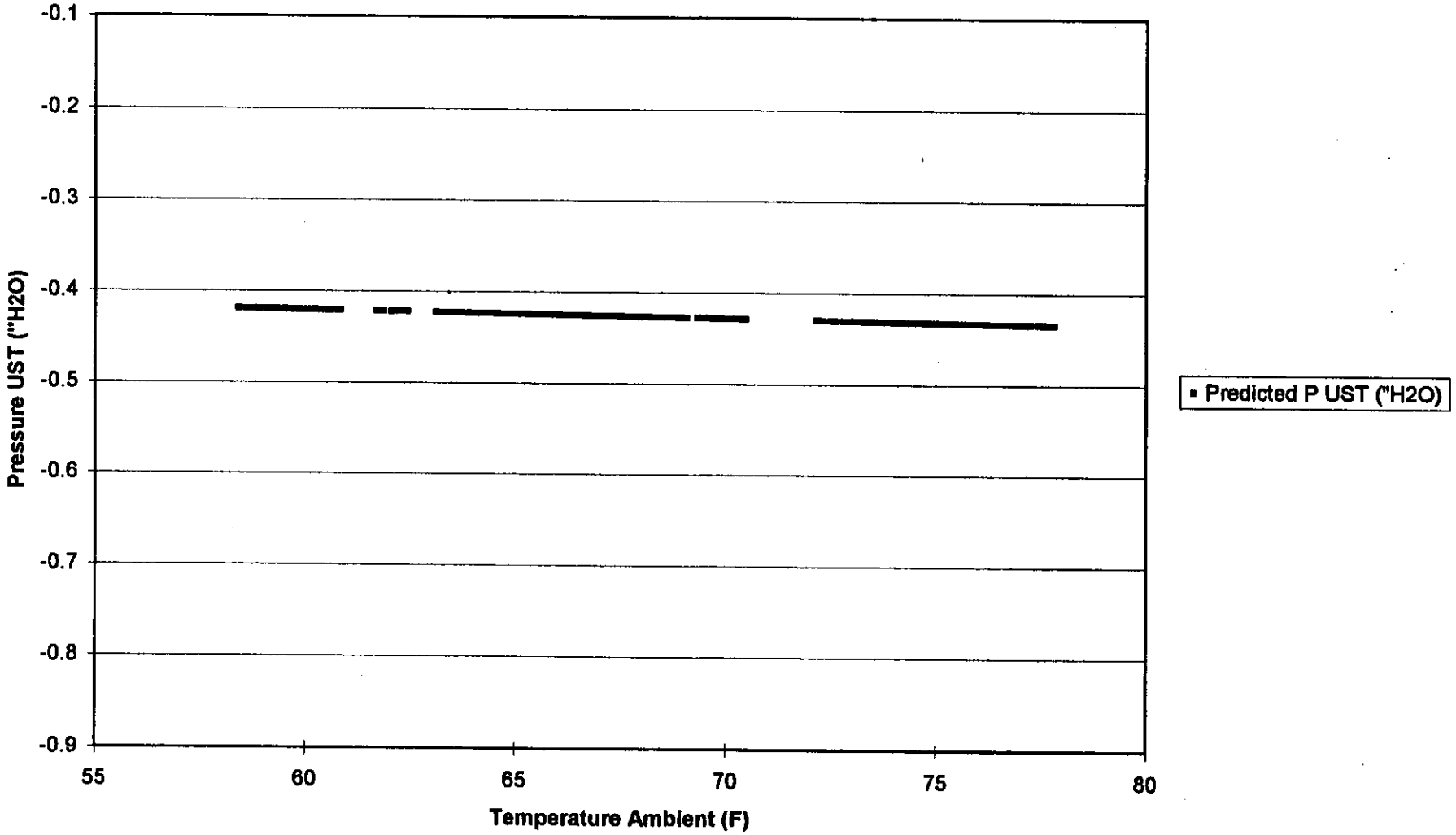


Figure 4-14 Balance System UST Pressure as a Function of Ambient Temperature for Spring Conditions

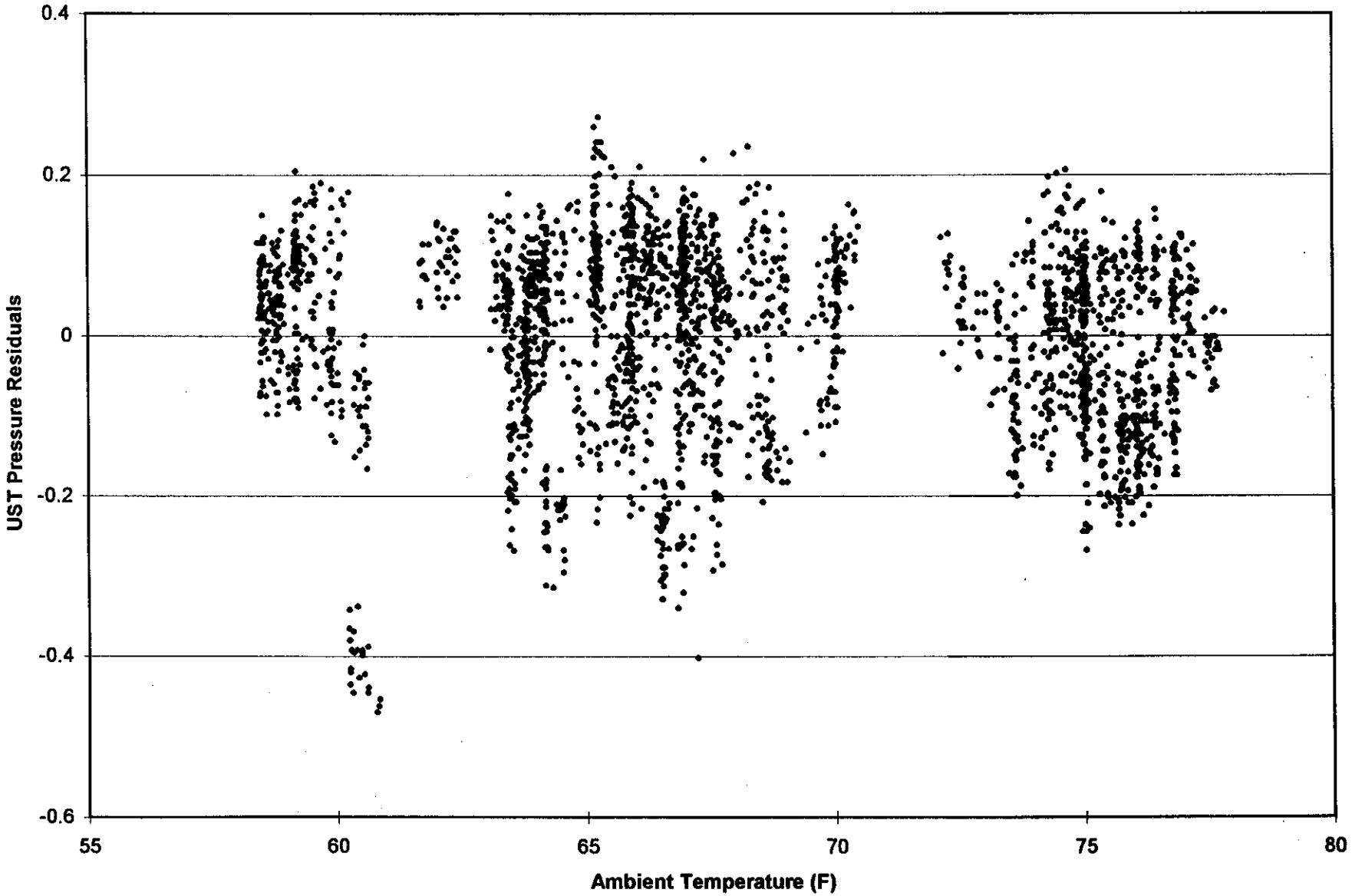


Figure 4-15 Balance System UST Pressure Residuals as a Function of Ambient Pressure for Spring Conditions

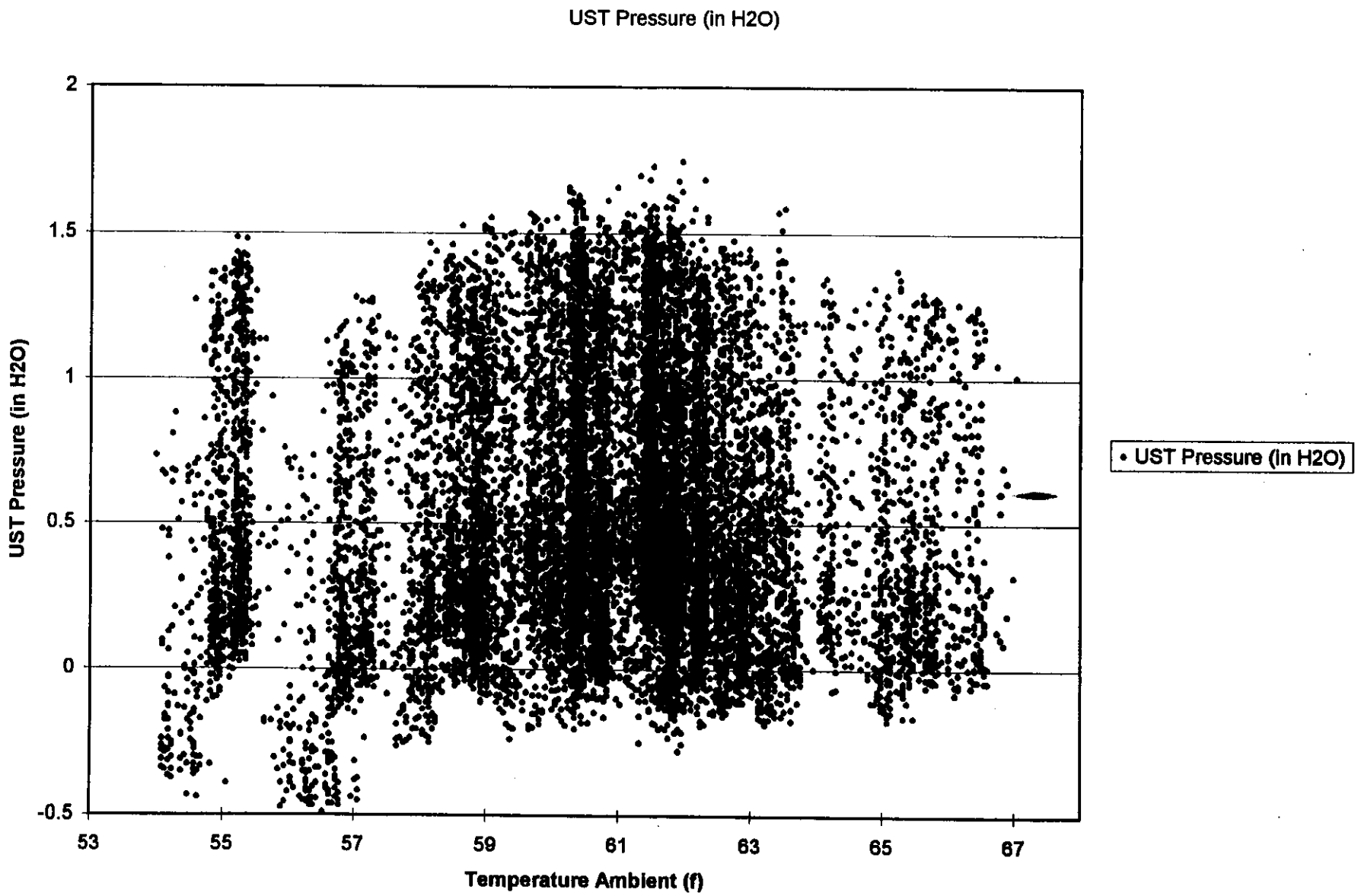


Figure 4-16 Vacuum Assist System UST Pressure as a Function of Ambient Temperature for Winter Conditions

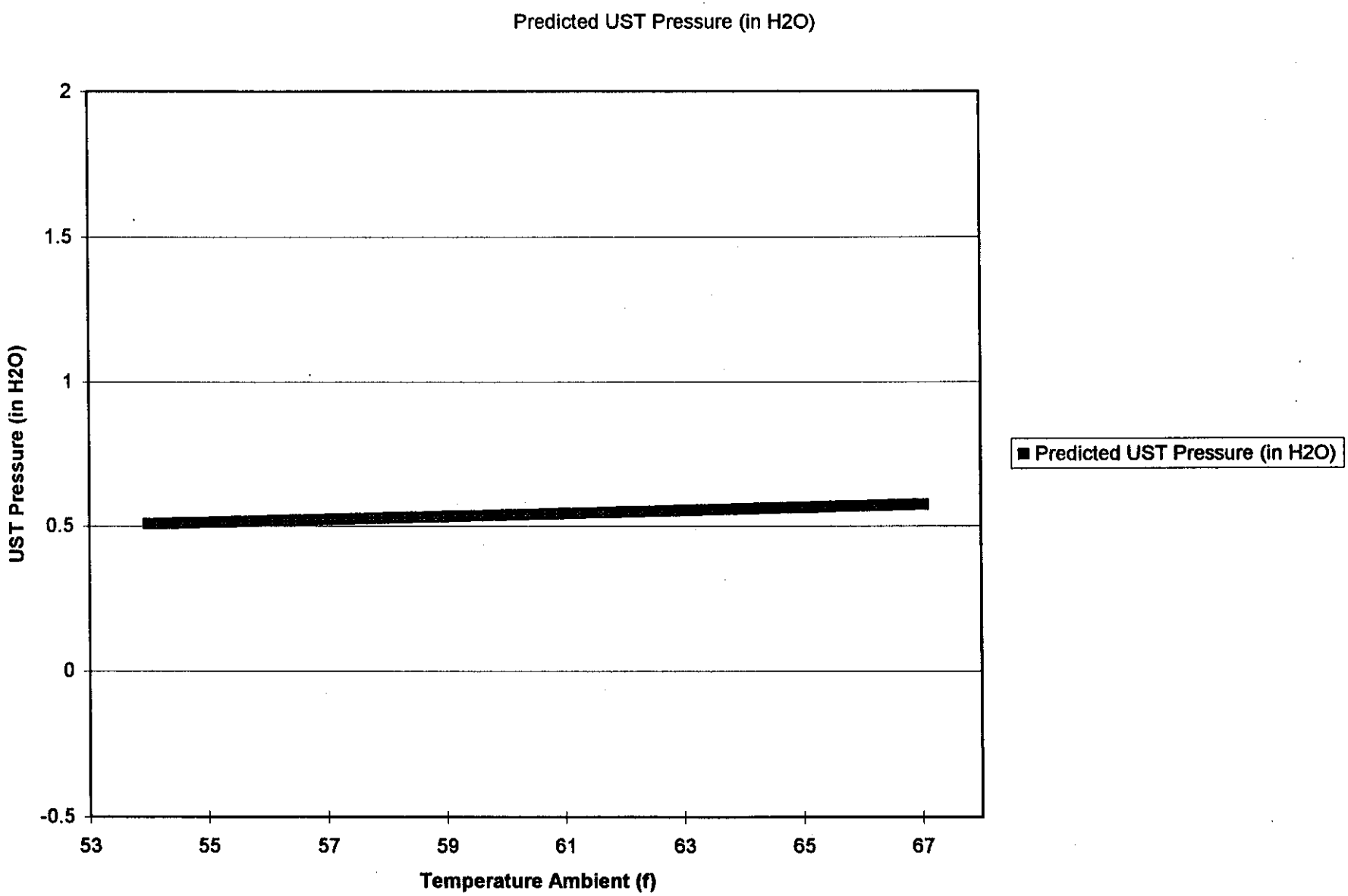


Figure 4-17 Vacuum Assist System UST Pressure as a Function of Ambient Temperature for Winter Conditions

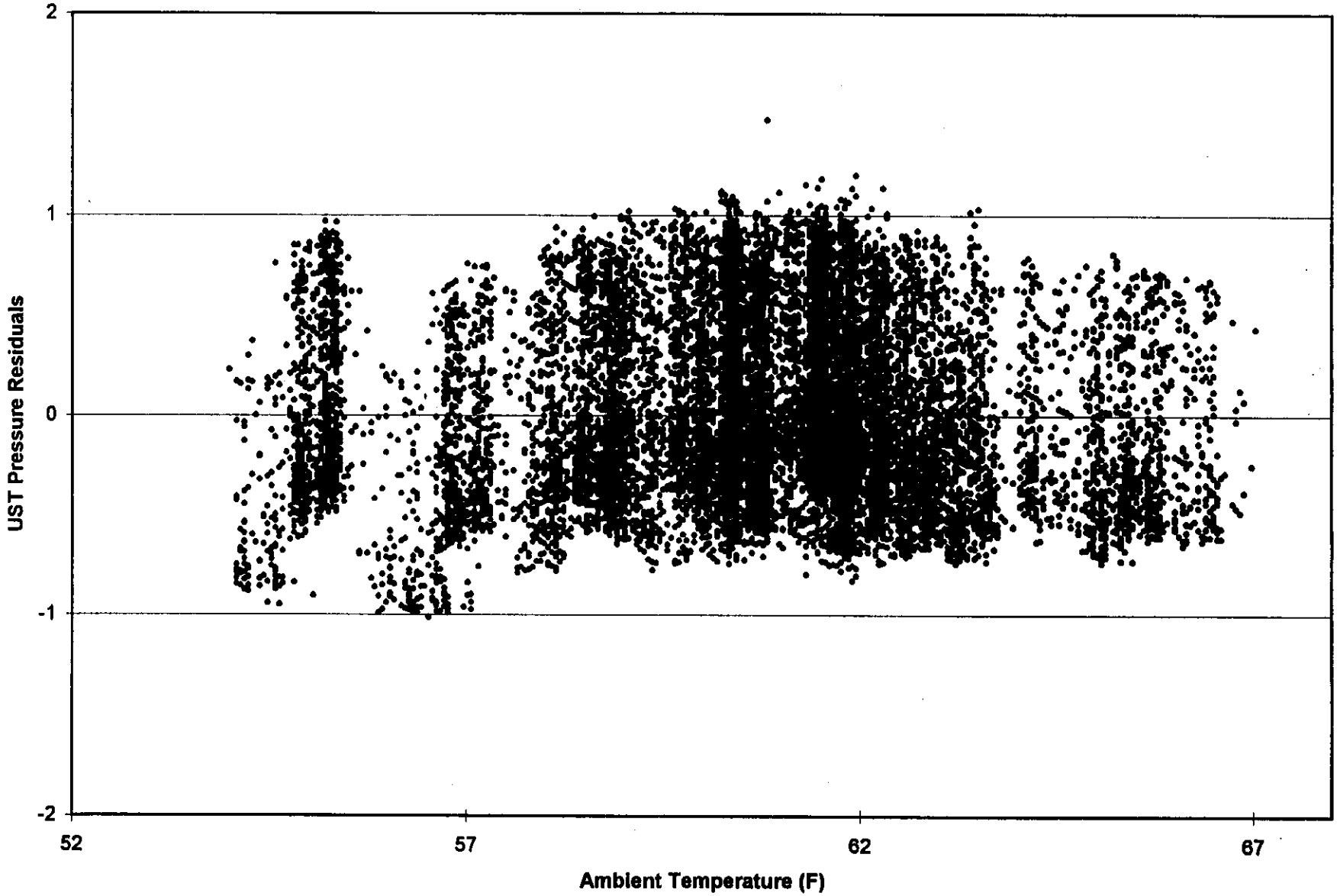


Figure 4-18 Vacuum Assist UST Pressure Residuals as a Function of Ambient Pressure for Winter Conditions

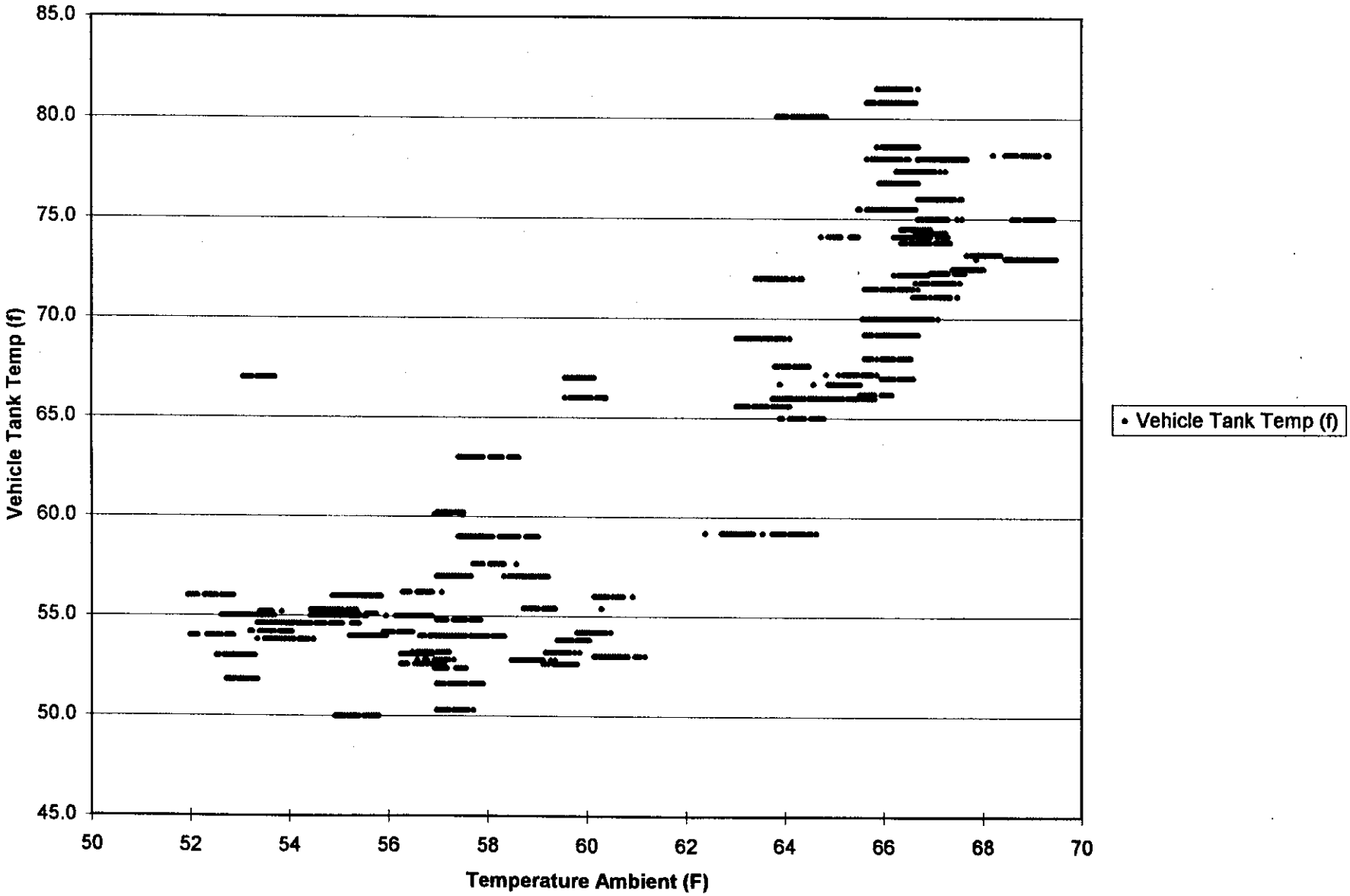


Figure 4-19 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature for Winter Conditions

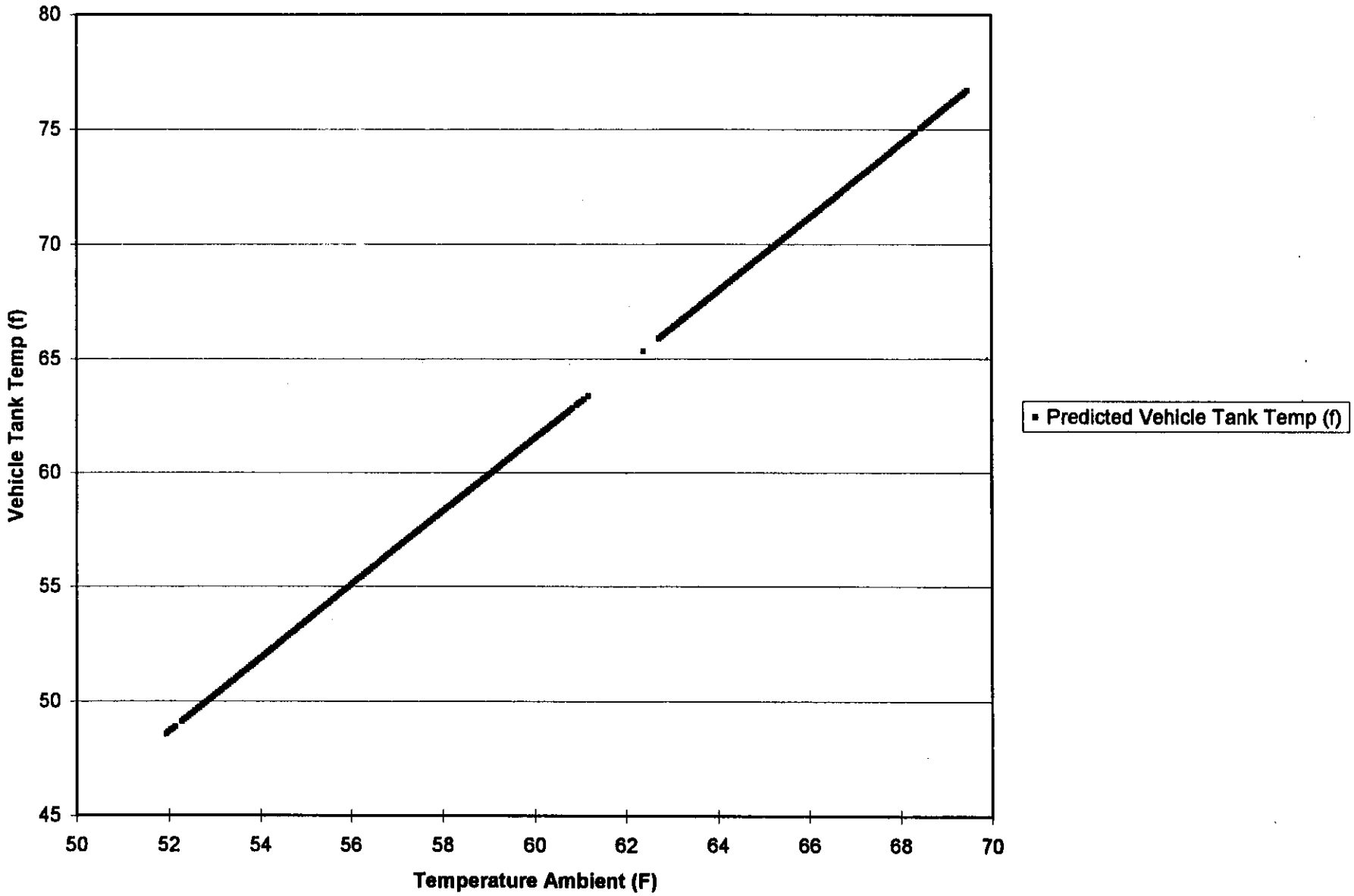


Figure 4-20 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature for Winter Conditions

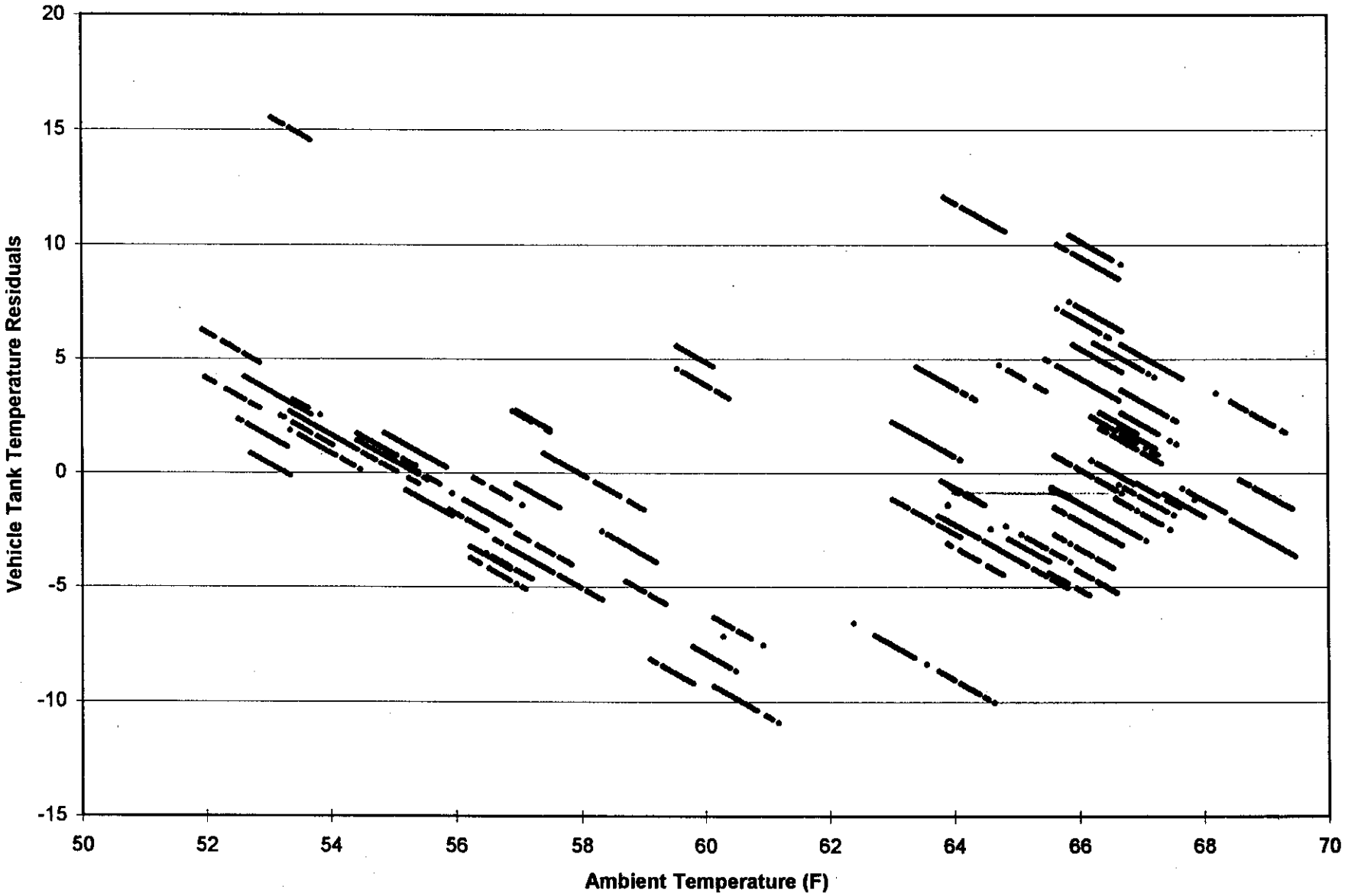


Figure 4-21 Balance System Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Winter Conditions

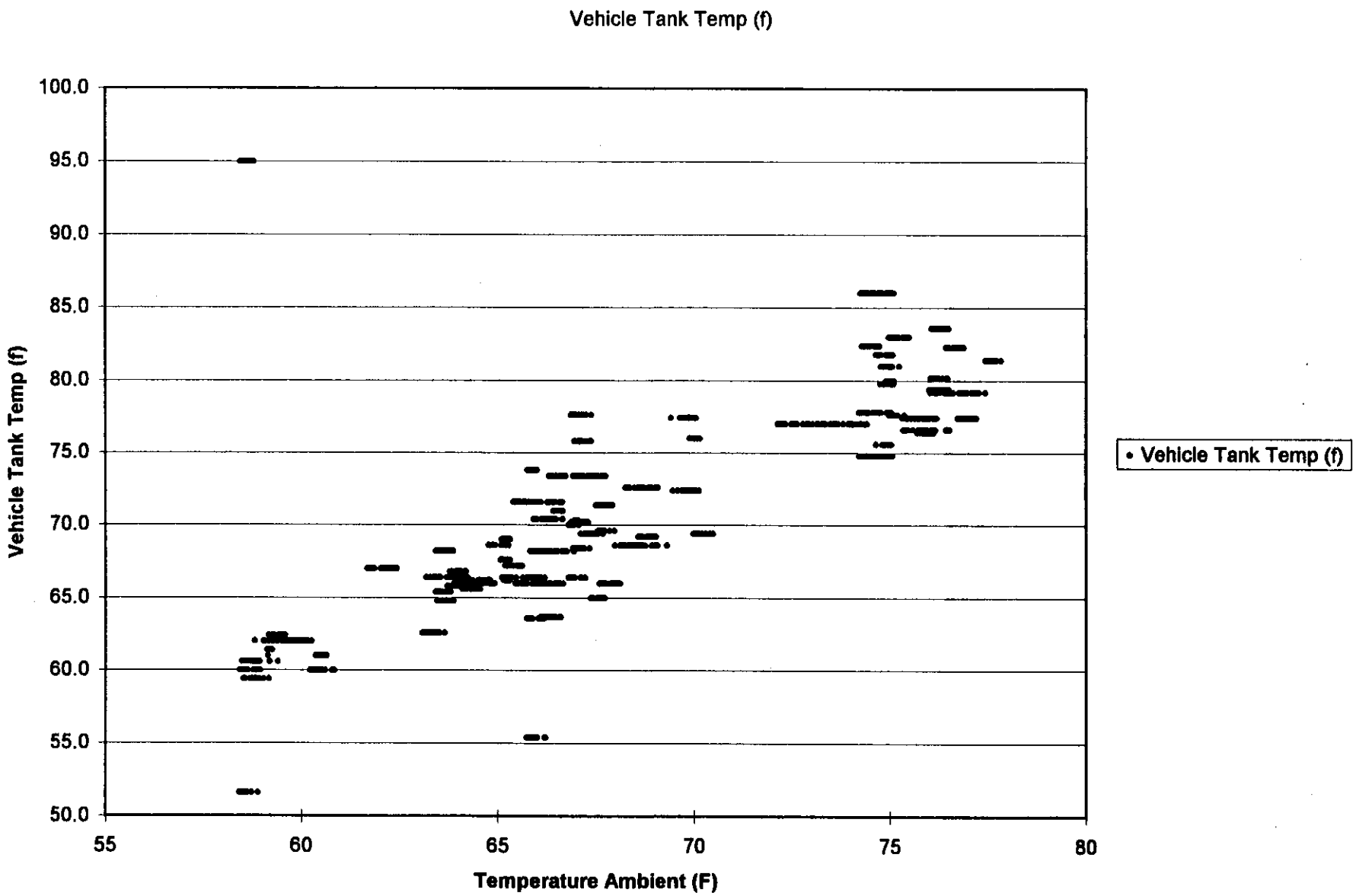


Figure 4-22 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature for Spring Conditions

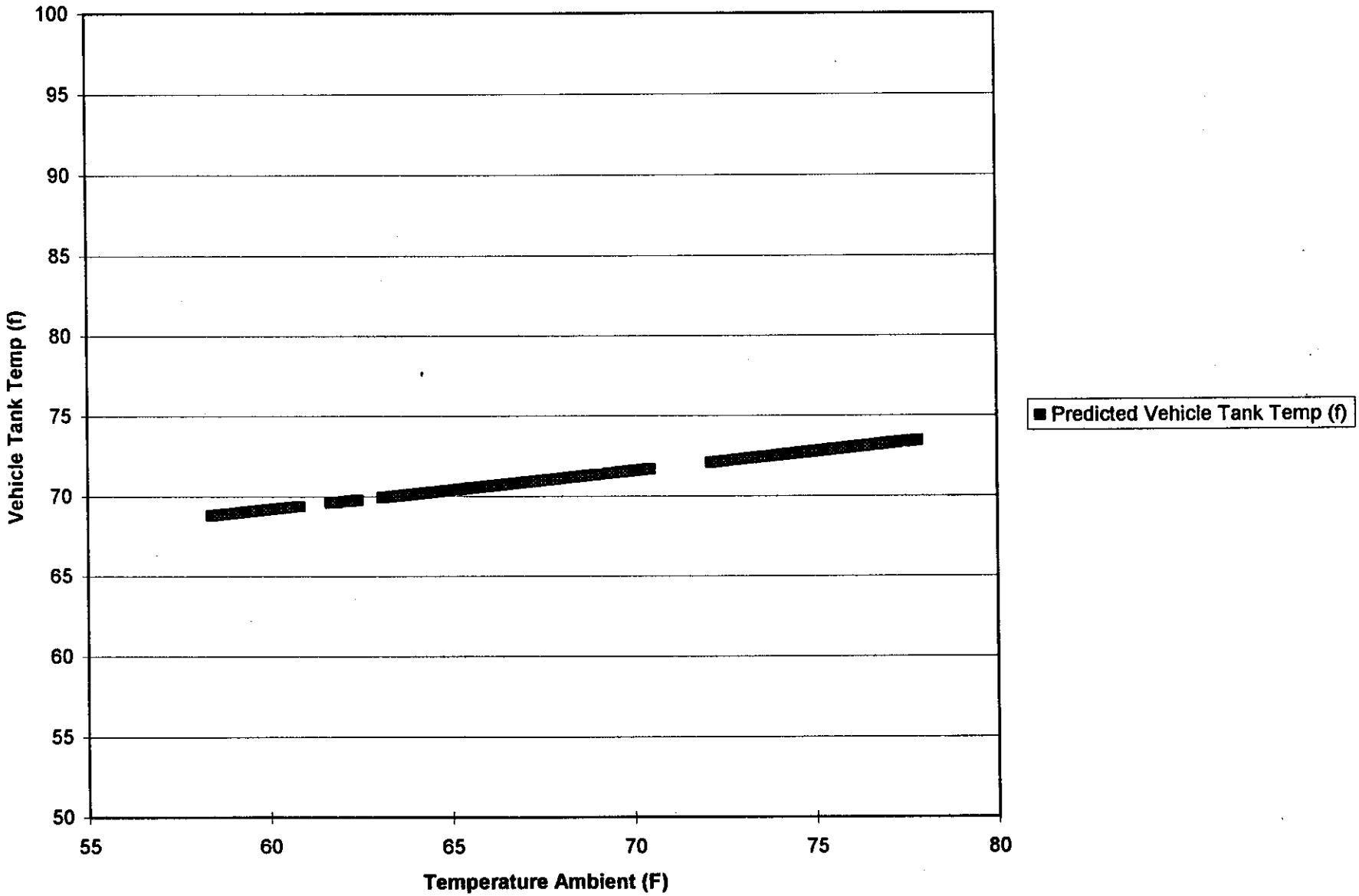


Figure 4-23 Balance System Vehicle Tank Temperature as a Function of Ambient Temperature for Spring Conditions

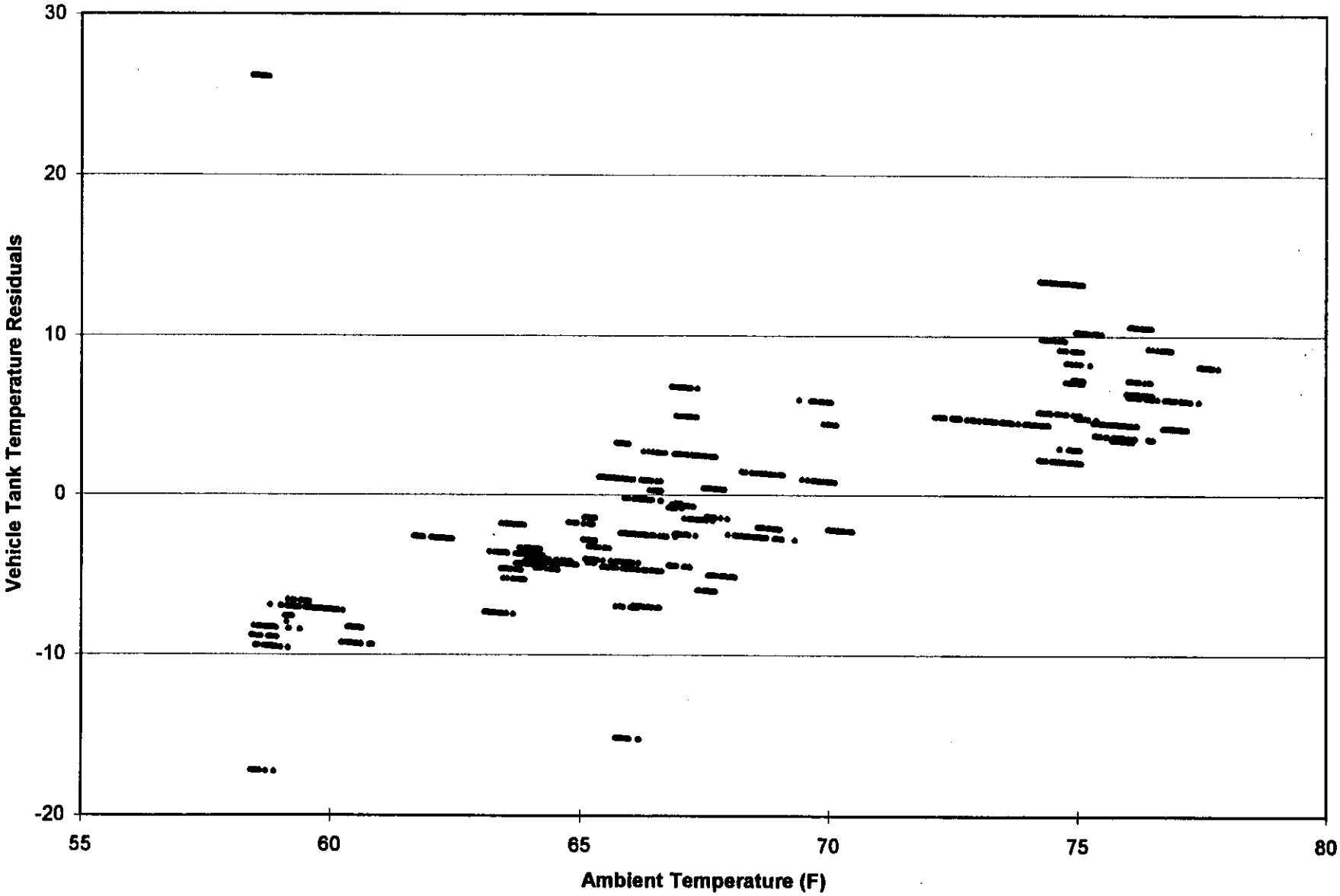


Figure 4-24 Balance System Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Spring Conditions

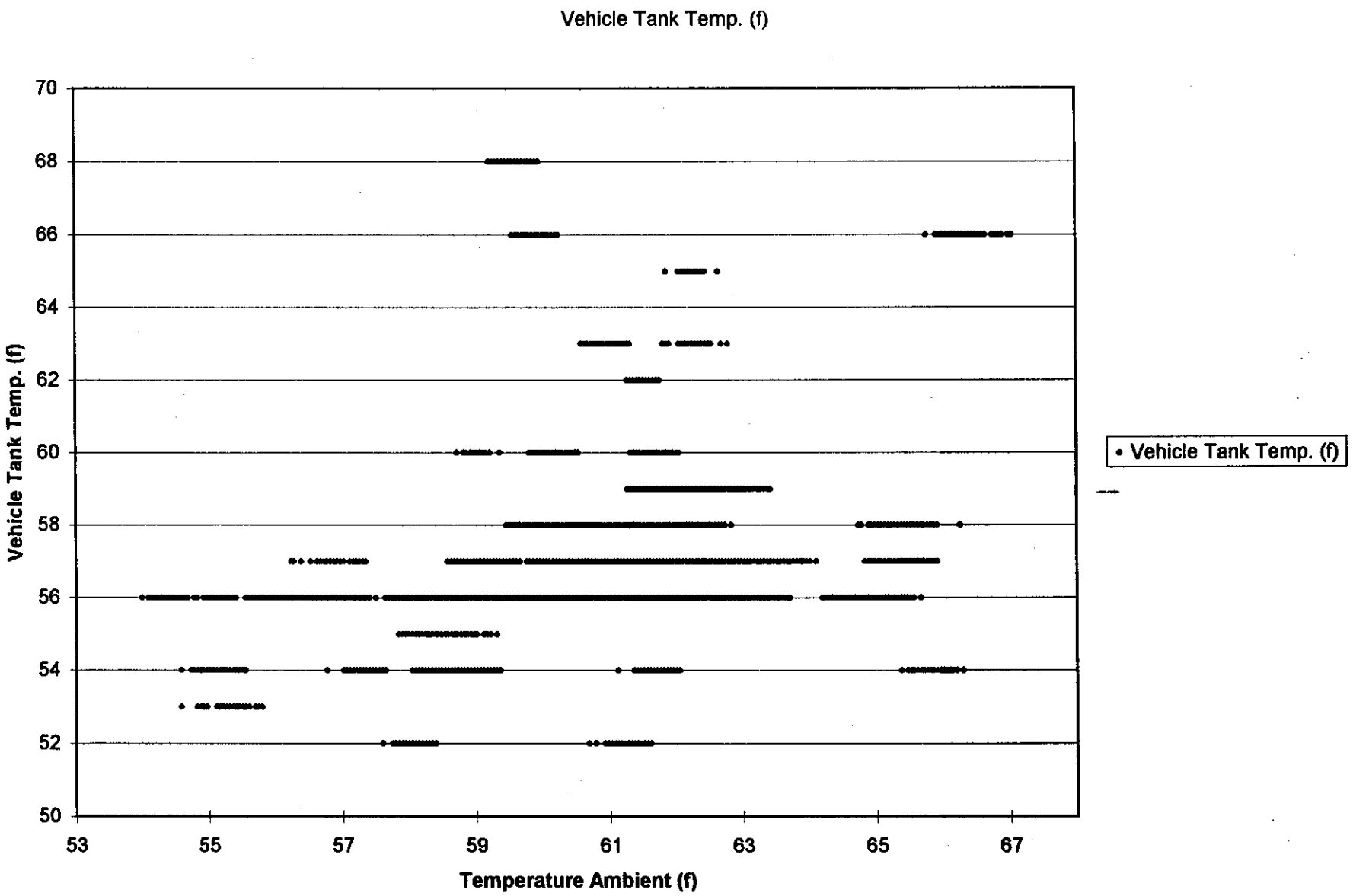


Figure 4-25 Vacuum Assist System Vehicle Tank Temperature as a Function of Ambient Temperature for Winter Conditions

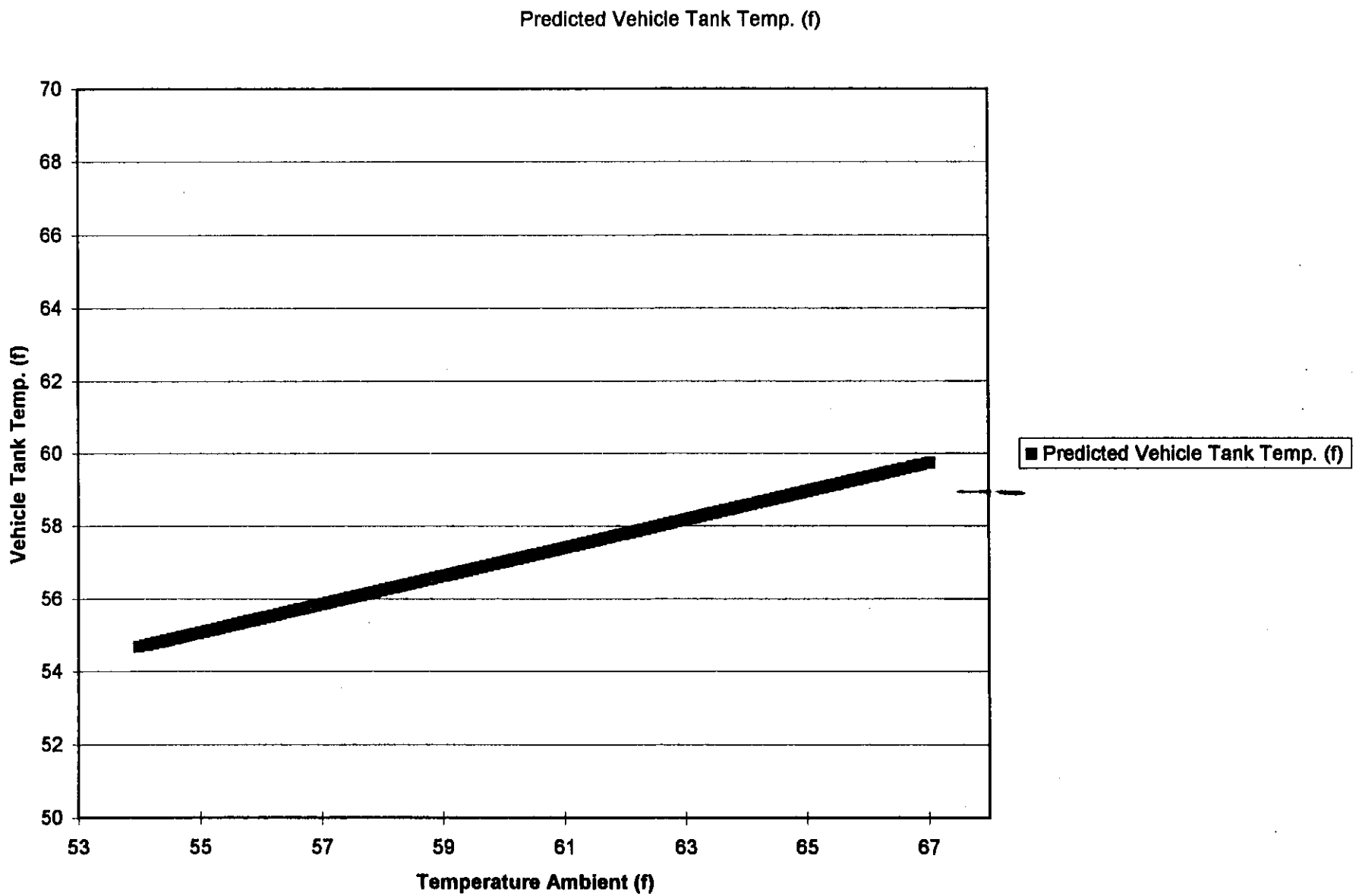


Figure 4-26 Vacuum Assist System Vehicle Tank Temperature as a Function of Ambient Temperature for Winter Conditions

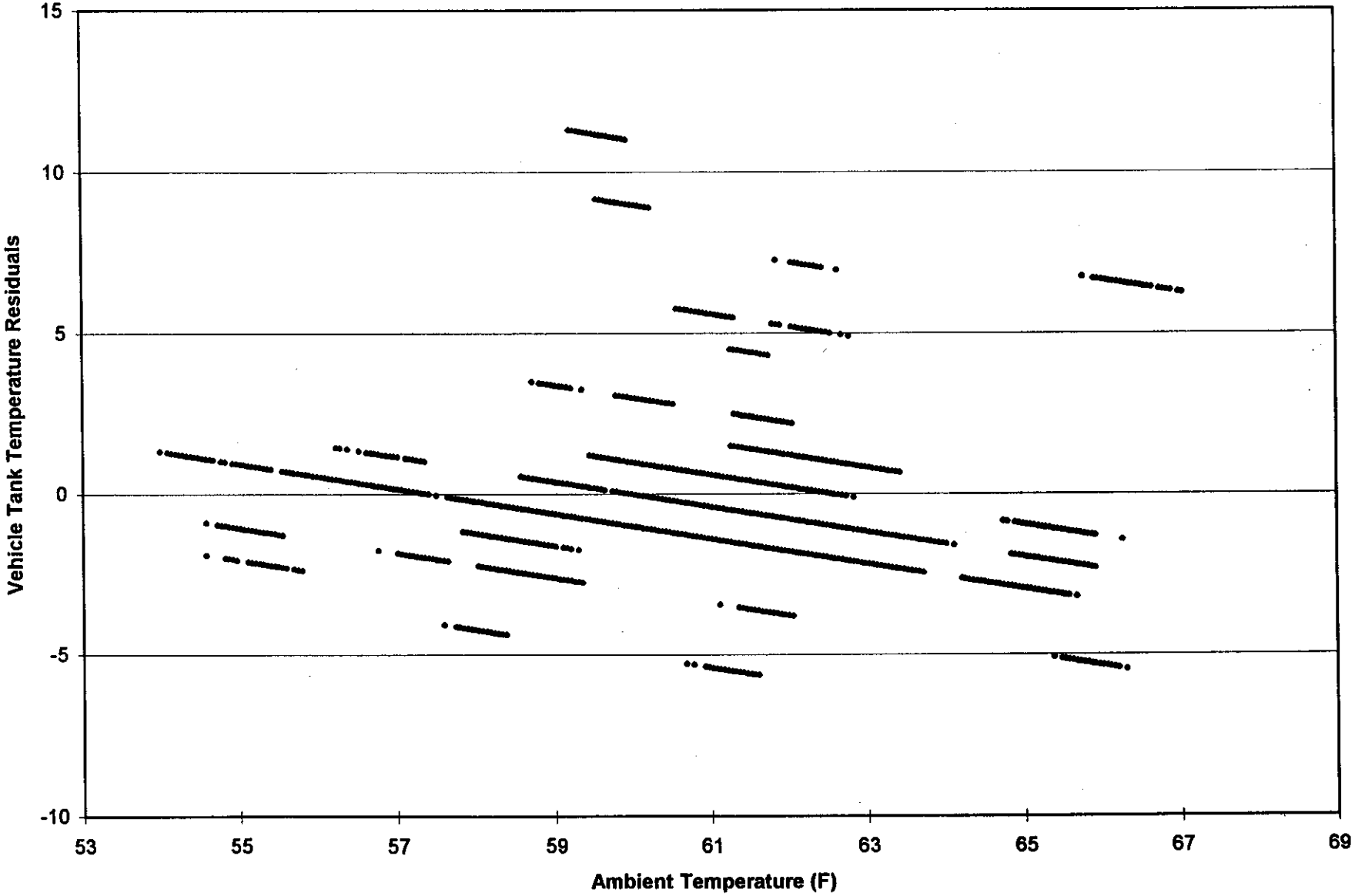


Figure 4-27 Vacuum Assist Vehicle Tank Temperature Residuals as a Function of Ambient Temperature for Winter Conditions

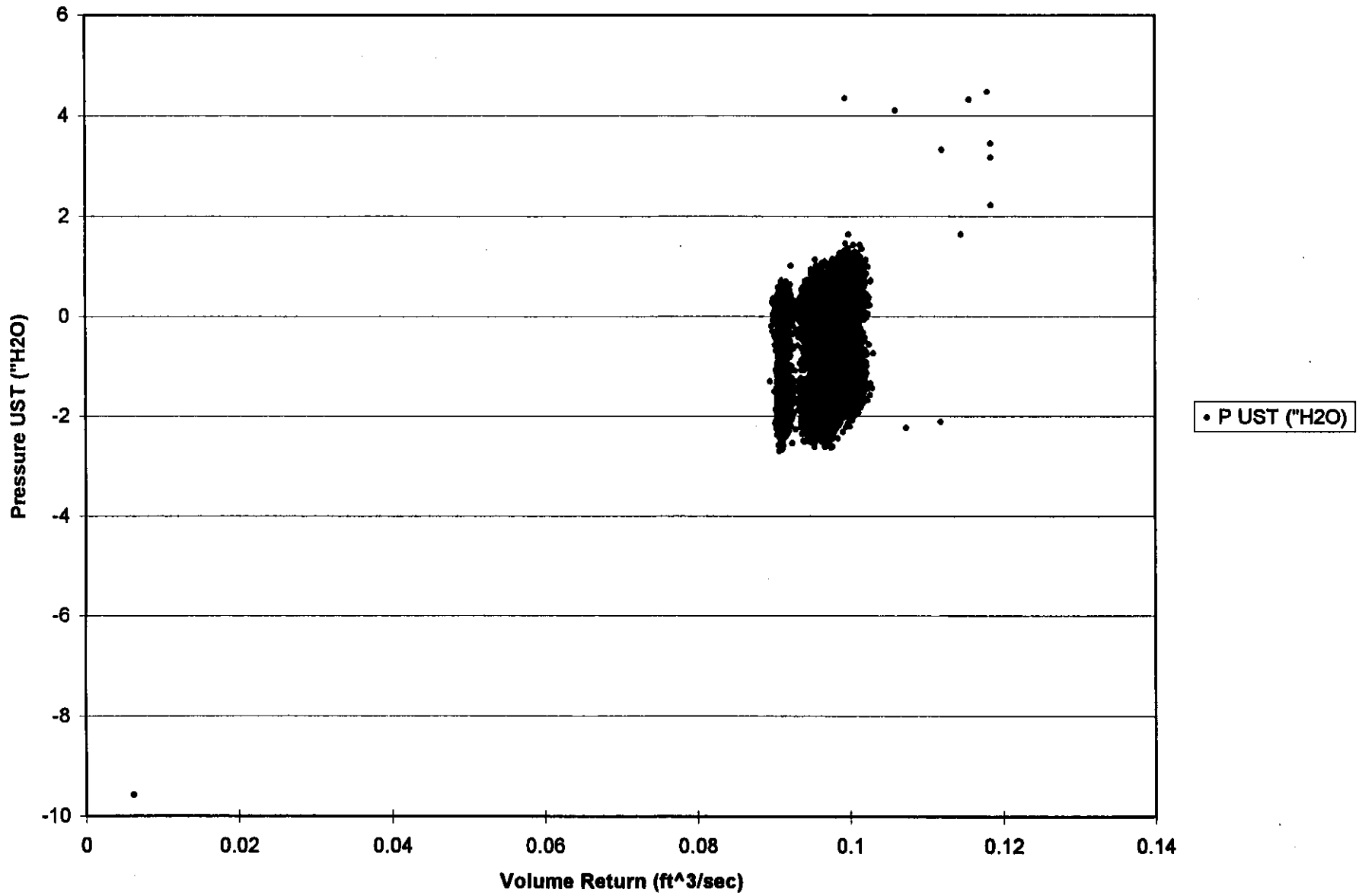


Figure 4-28 Balance System UST Pressure as a Function of Return Line Volume for Winter Conditions

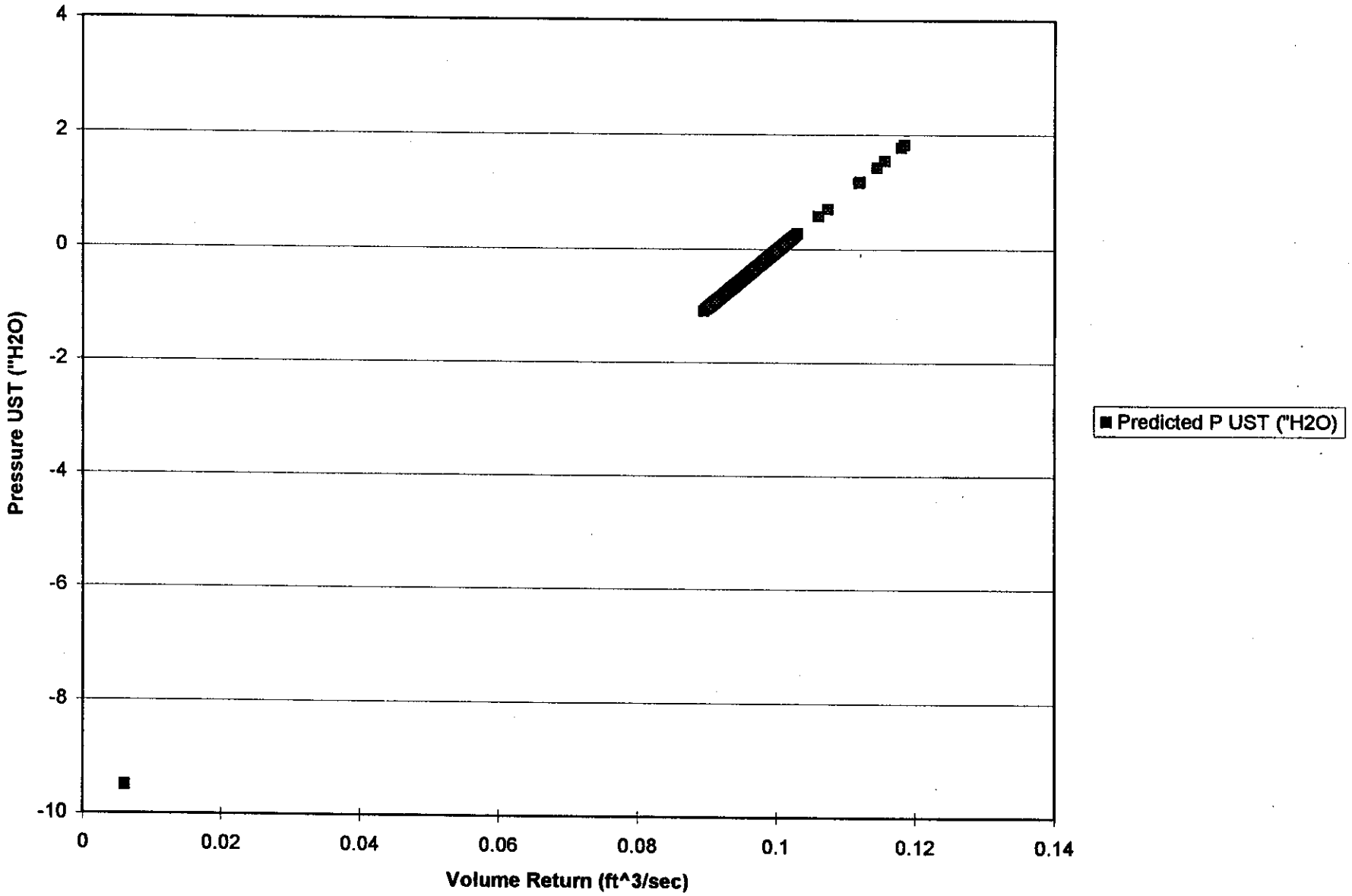


Figure 4-29 Balance System UST Pressure as a Function of Return Line Volume for Winter Conditions

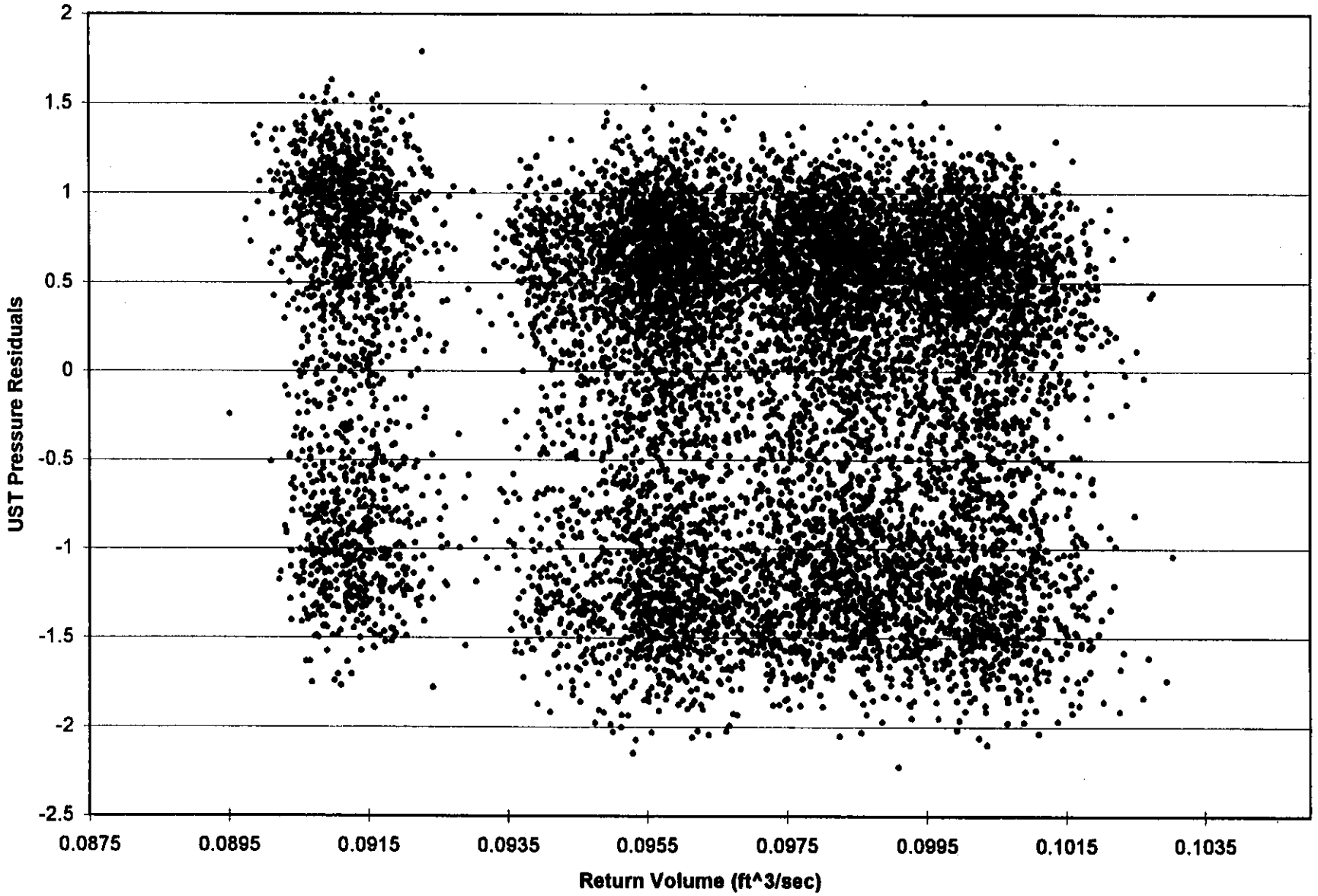
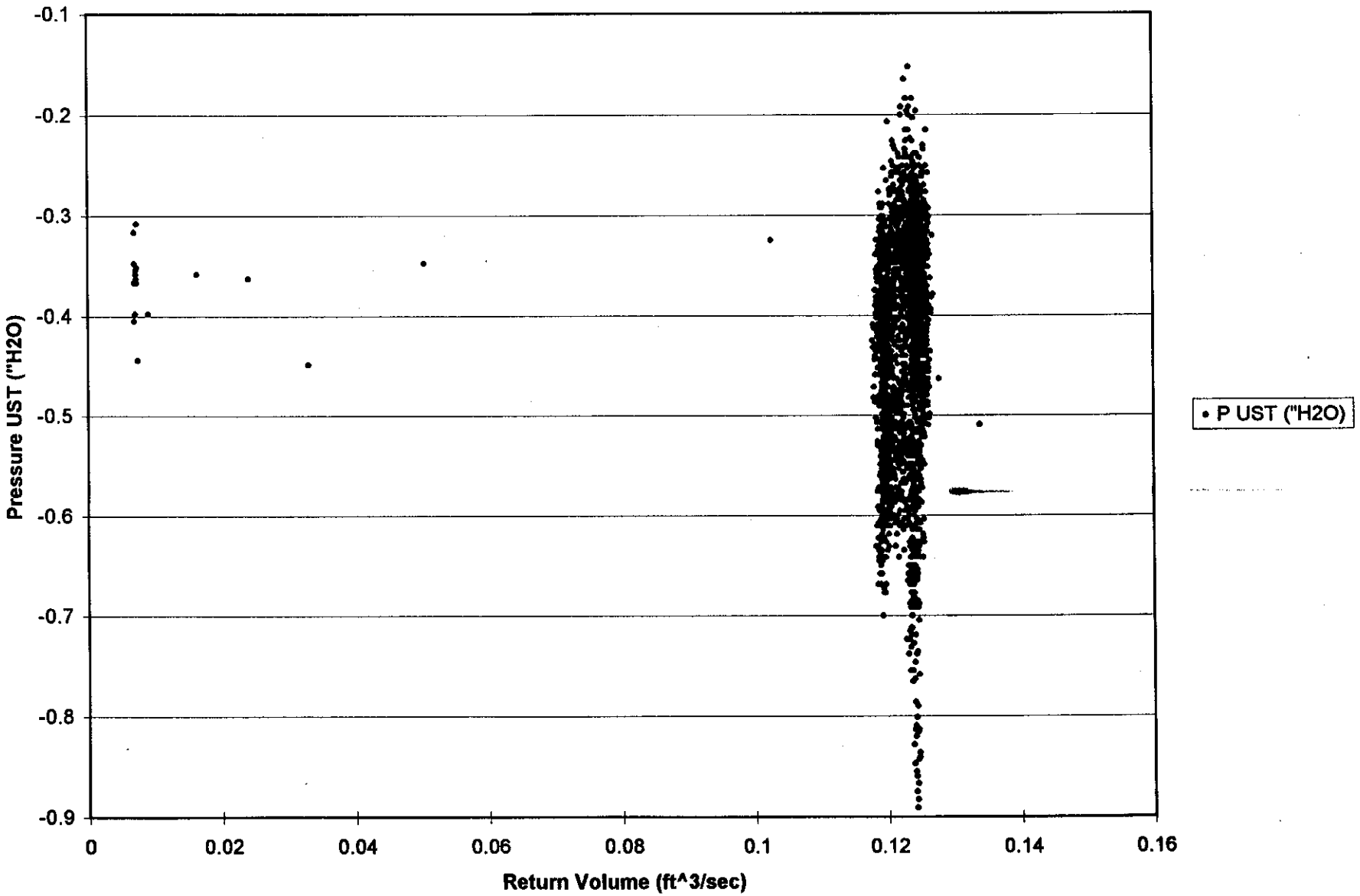
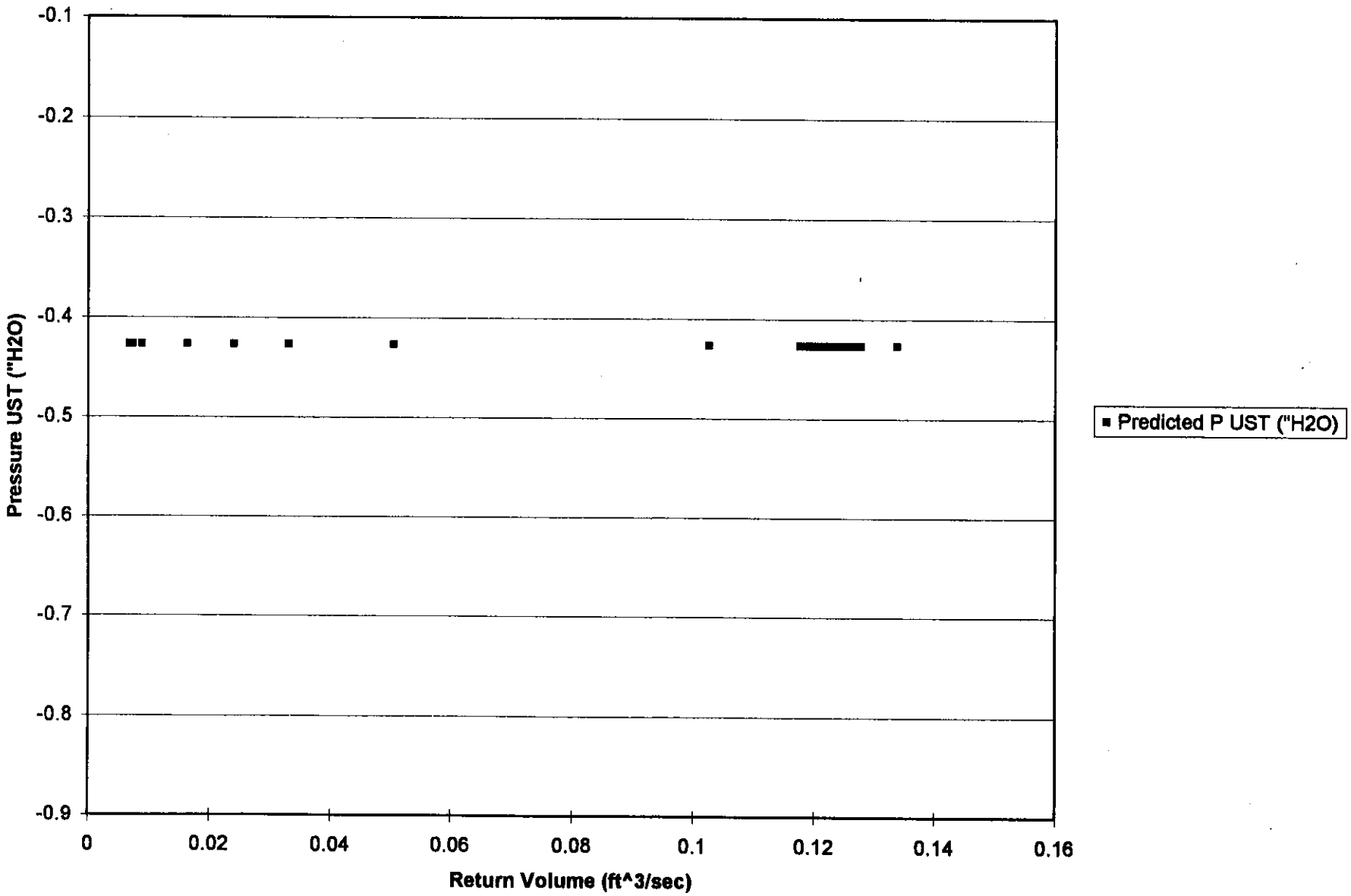


Figure 4-30 Balance System UST Pressure Residuals as a Function of Return Volume for Winter Conditions



Figrue 4-31 Balance System UST Pressure as a Function of Return Volume for Spring Conditions



Figrue 4-32 Balance System UST Pressure as a Function of Return Volume for Spring Conditions

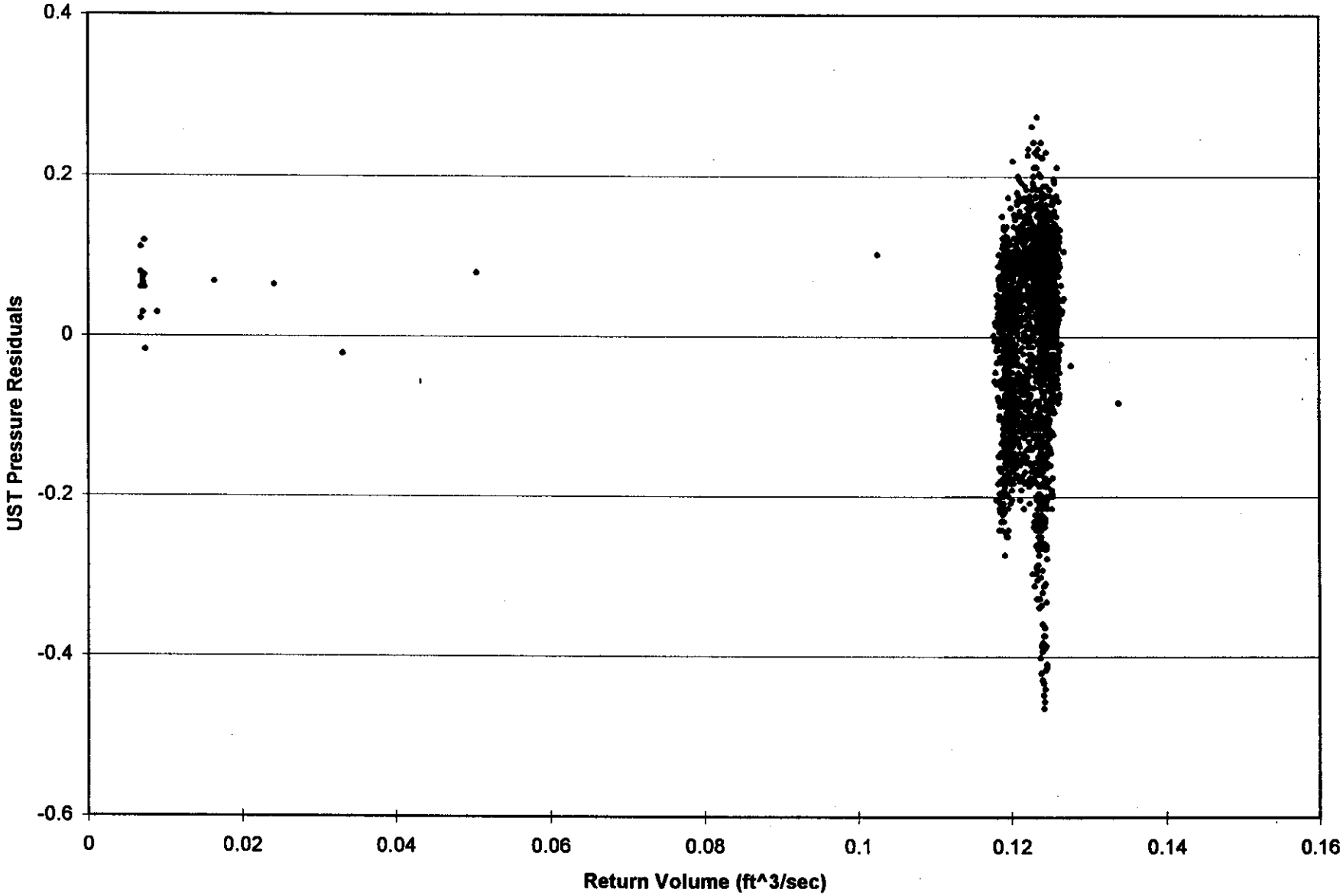


Figure 4-33 Balance System UST Pressure Residuals as a Function of Return Volume for Spring Conditions

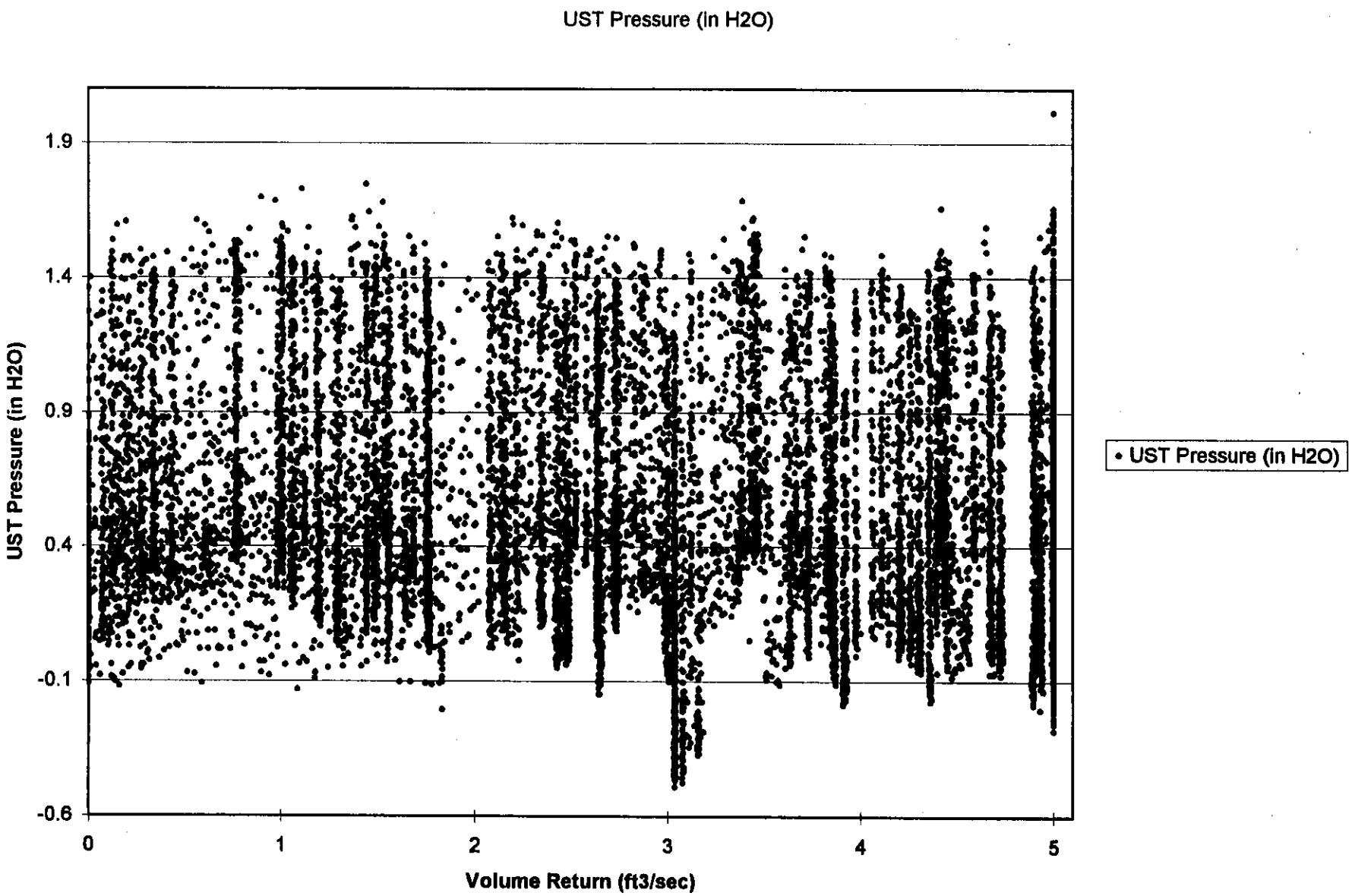


Figure 4-34 Vacuum Assist System UST Pressure as a Function of Return Volume for Winter Conditions

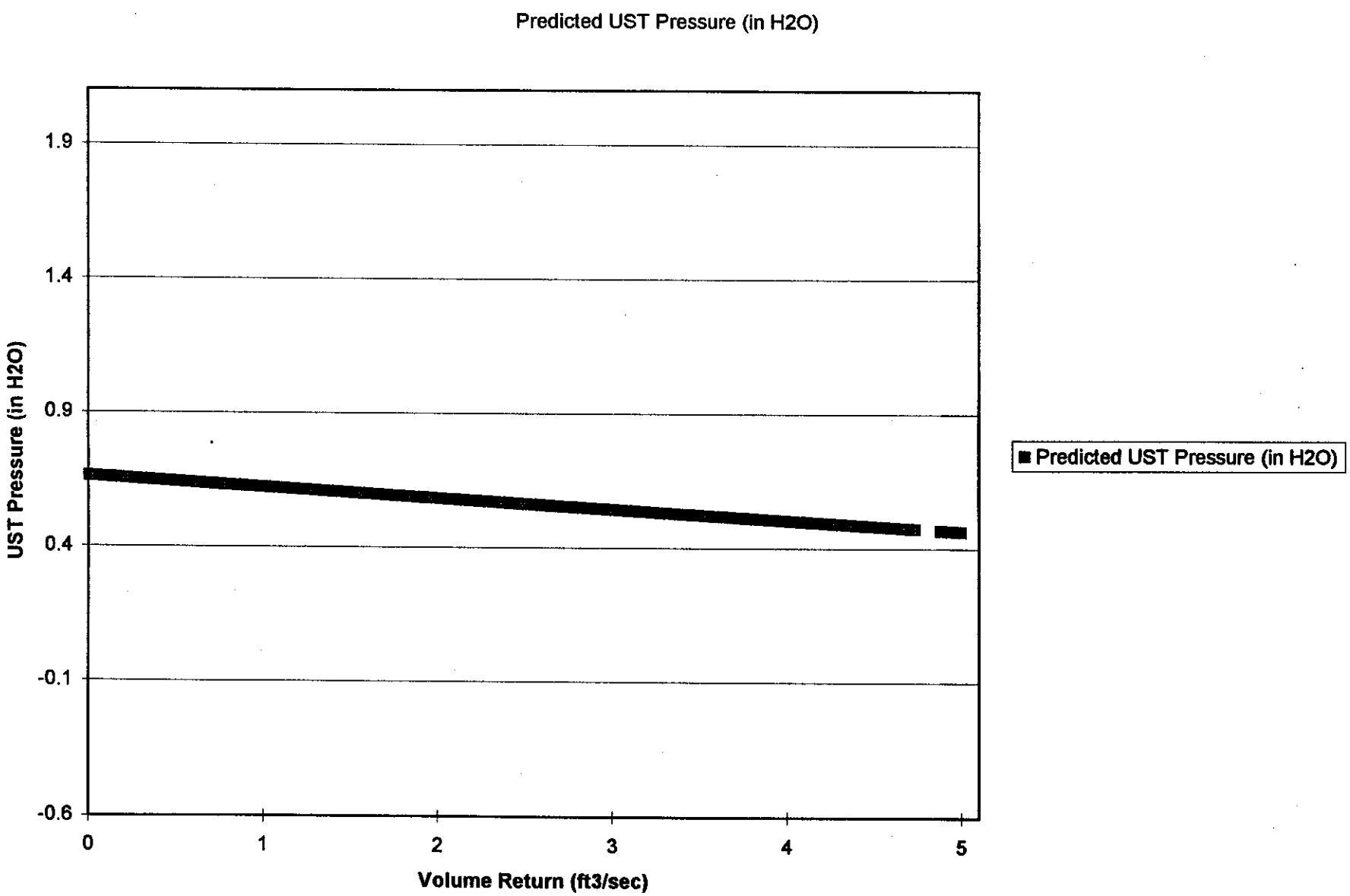


Figure 4-35 Vacuum Assist System UST Pressure as a Function of Return Volume for Winter Conditions

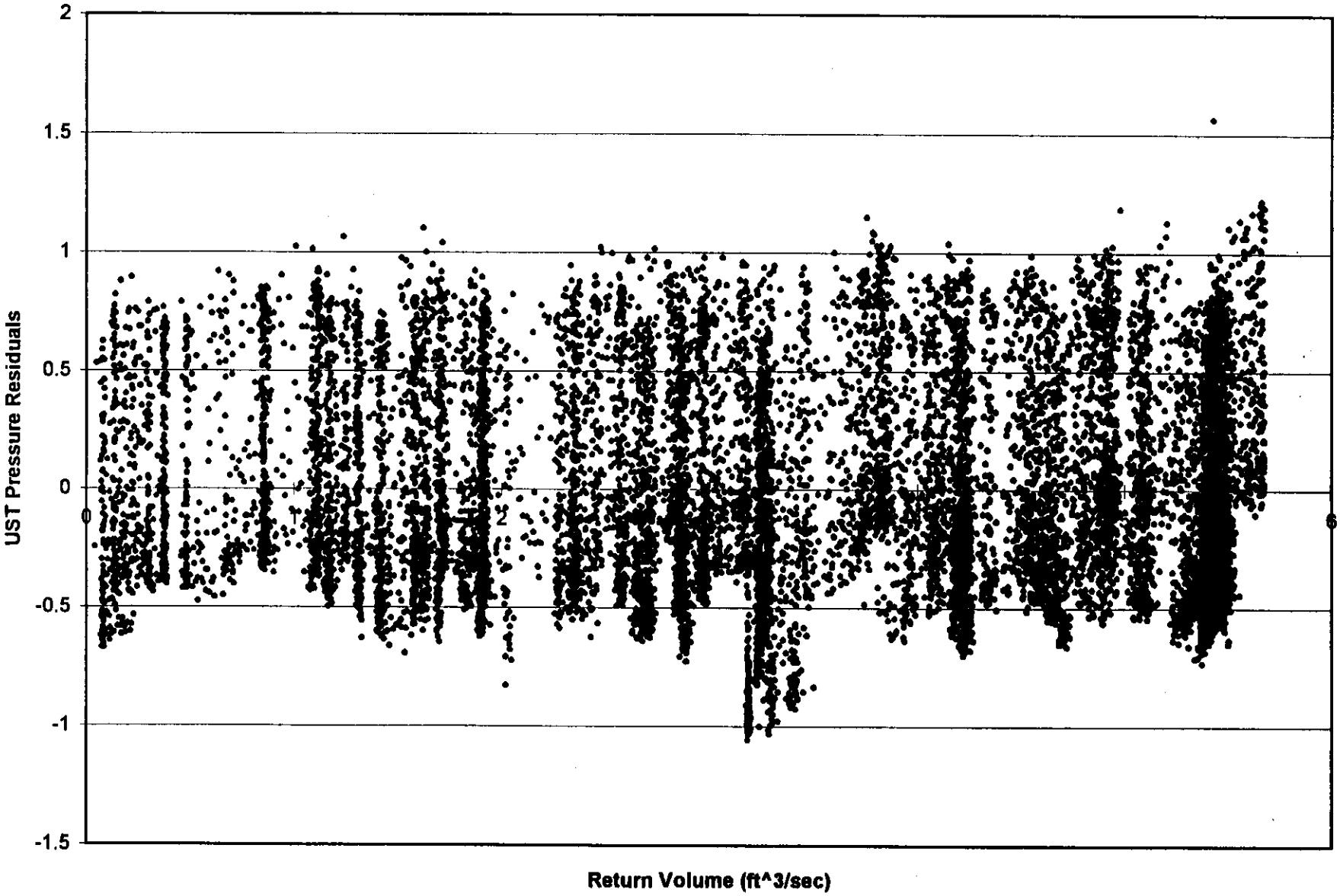


Figure 4-36 Vacuum Assist UST Pressure Residuals as a Function of Return Volume for Winter Conditions

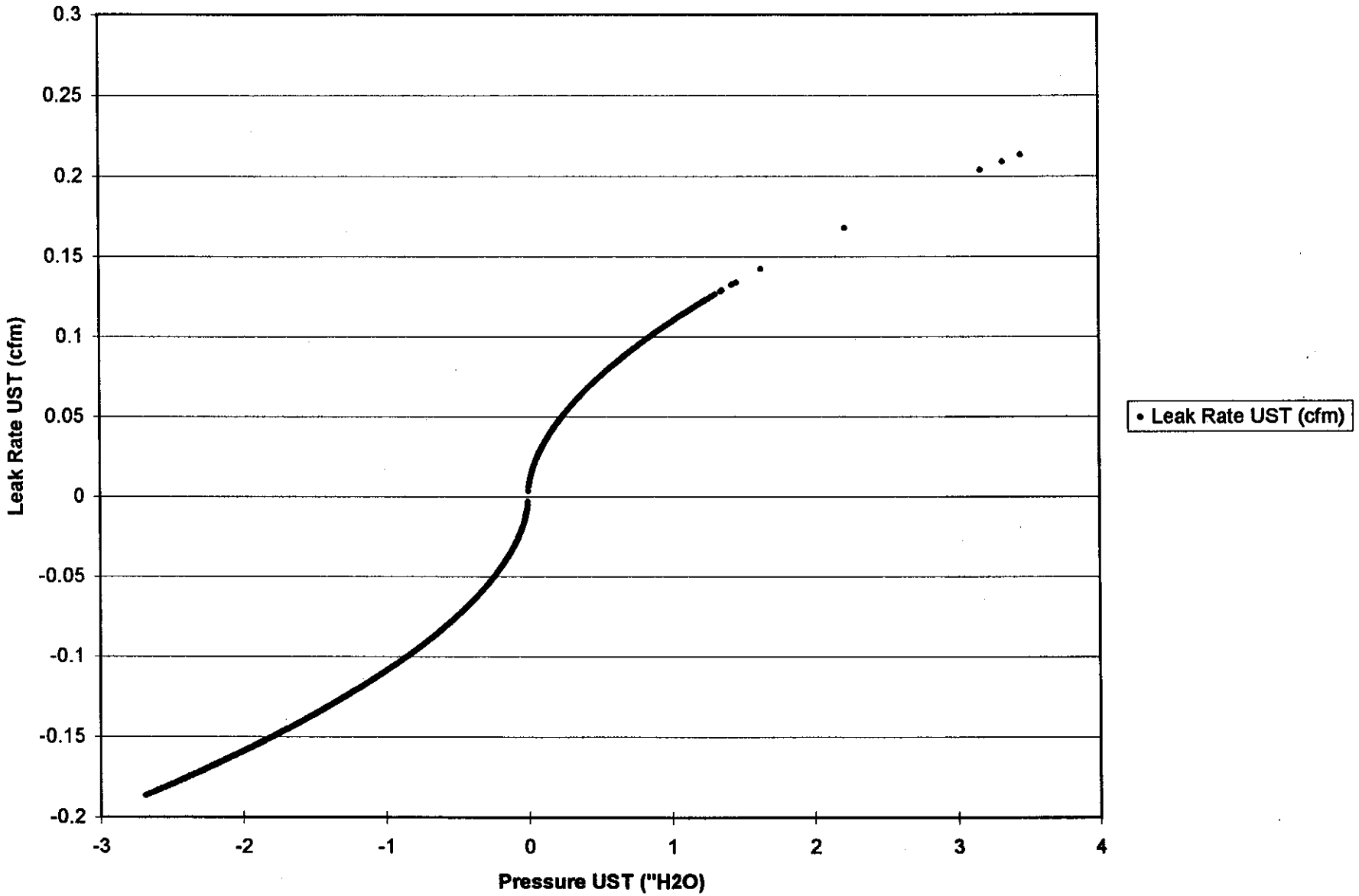


Figure 4-37 Balance System Leak Rate as a Function of UST Pressure for Winter Conditions

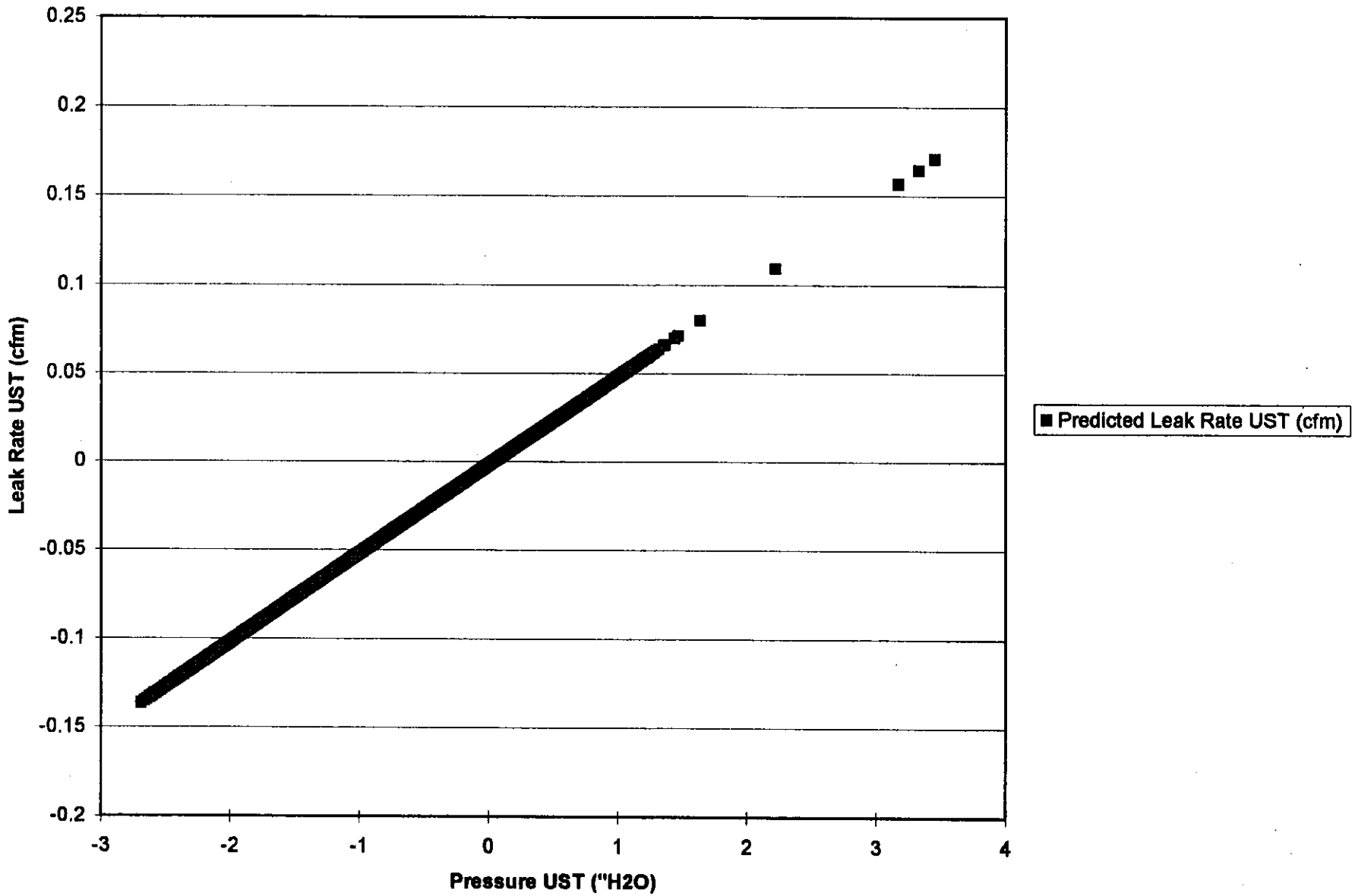


Figure 4-38 Balance System Leak Rate as a Function of UST Pressure for Winter Conditions

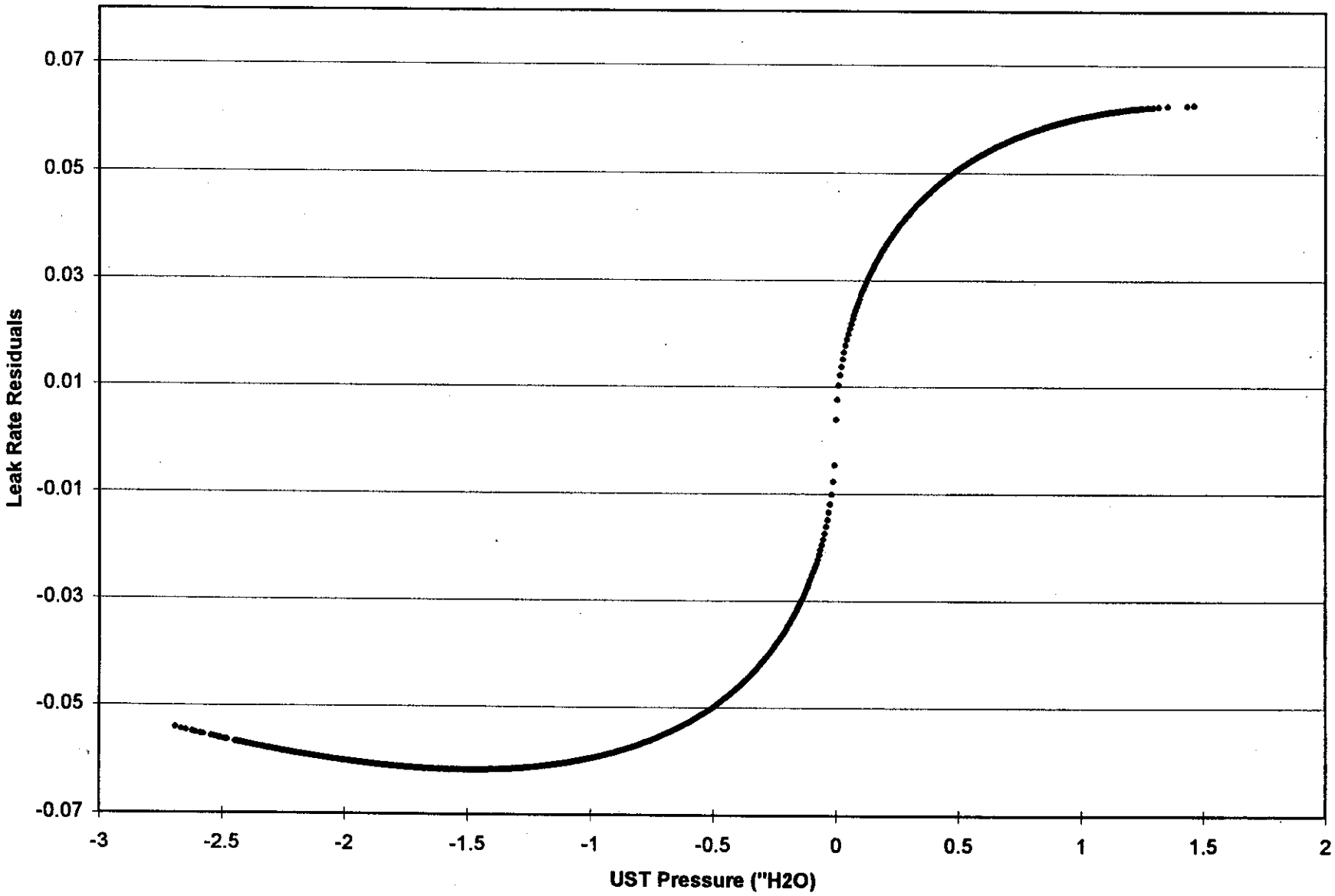


Figure 4-39 Balance System Leak Rate Residuals as a Function of UST Pressure for Winter Conditions

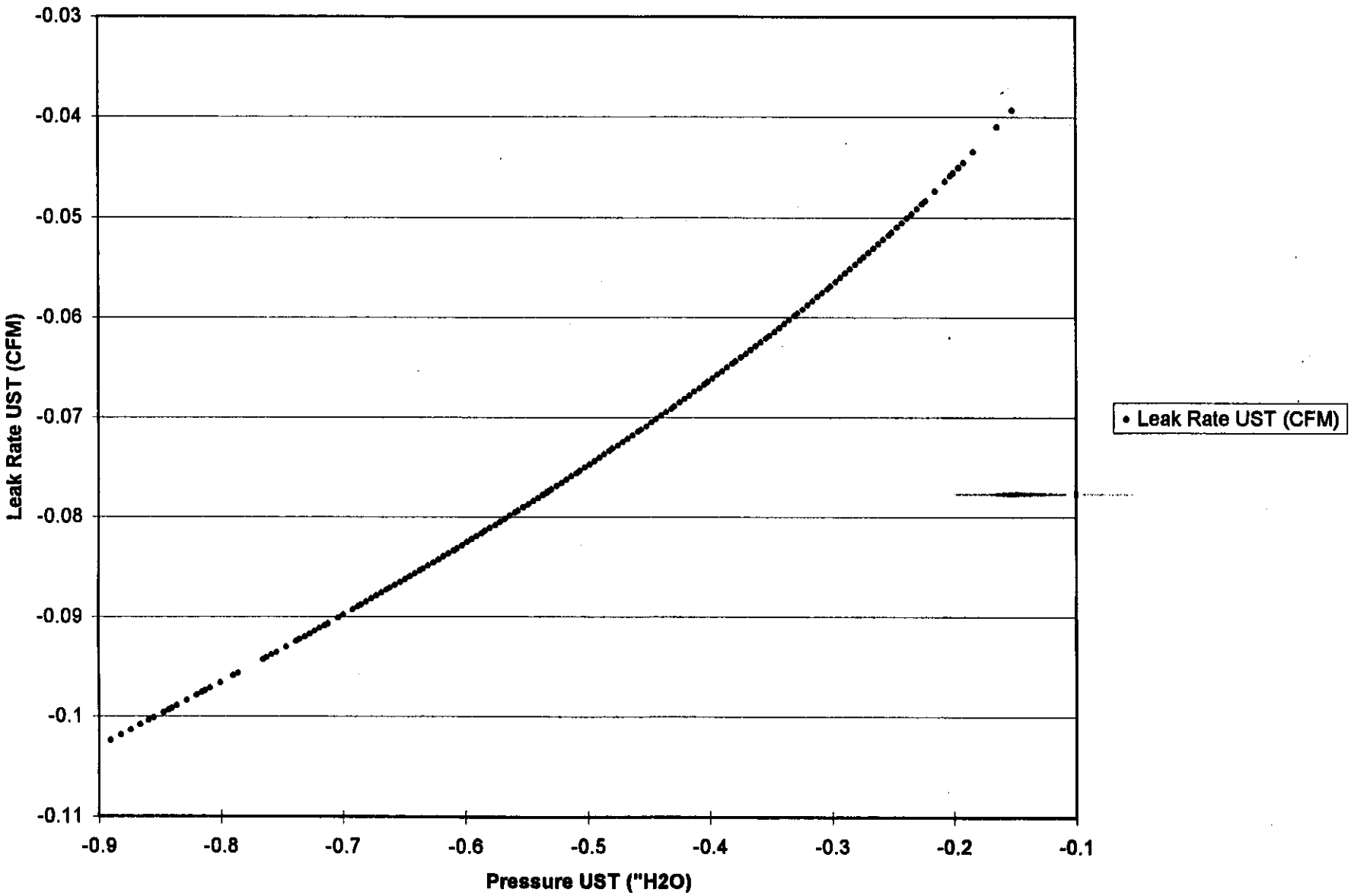


Figure 4-40 Balance System Leak Rate as a Function of UST Pressure for Spring Conditions

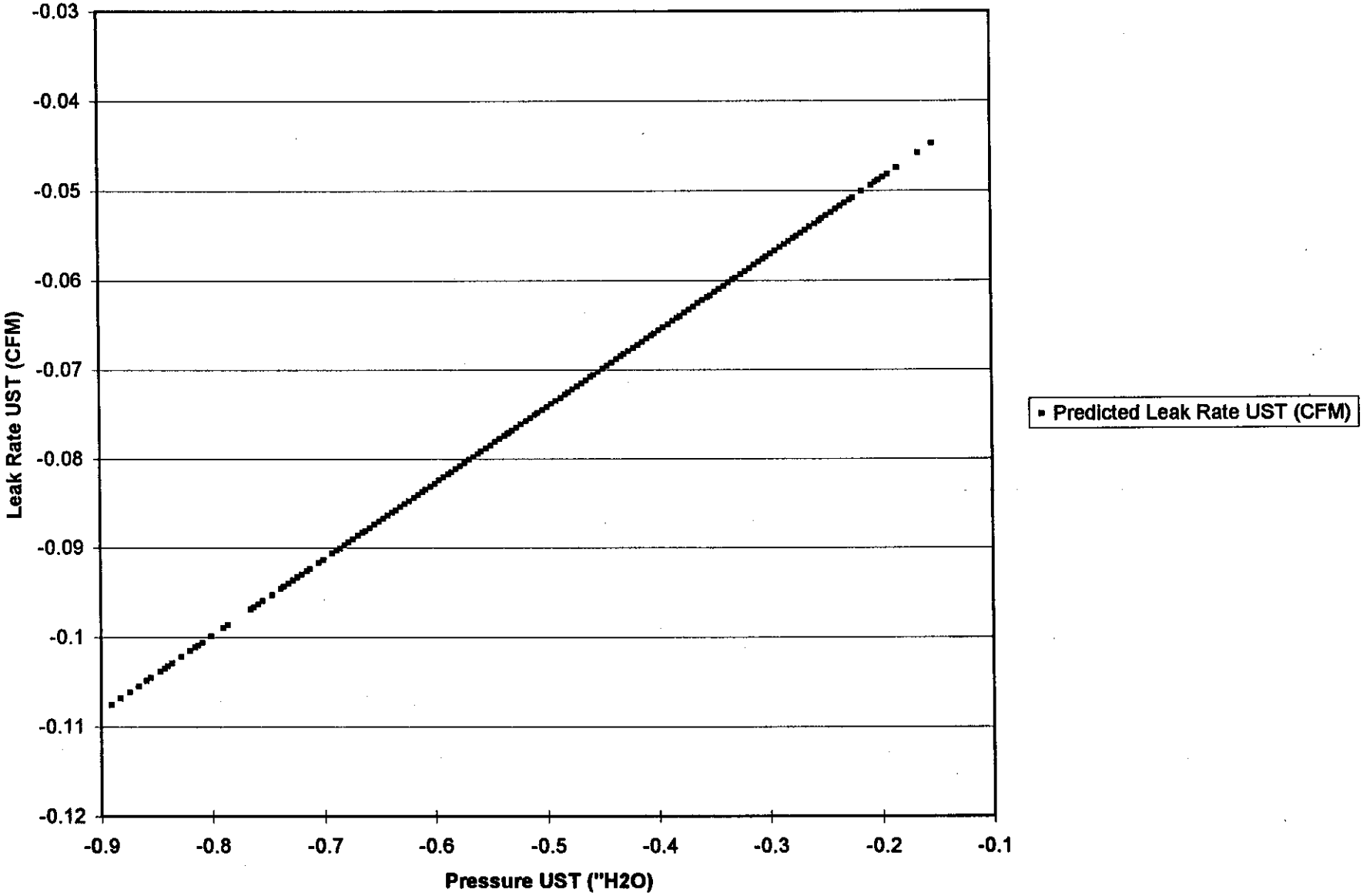


Figure 4-41 Balance System Leak Rate as a Function of UST Pressure for Spring Conditions

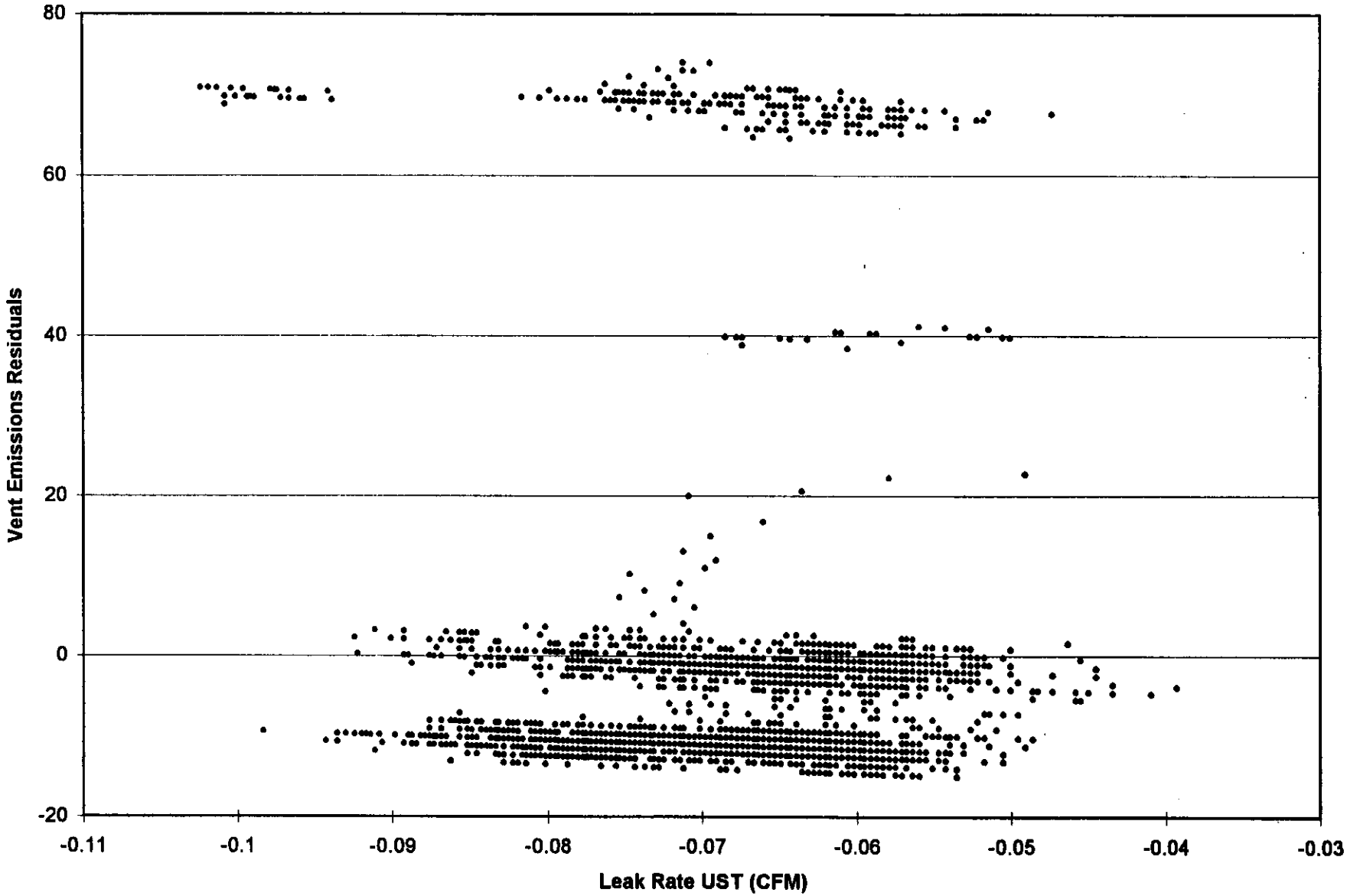


Figure 4-42 Balance System Vent Emission Residuals as a Function of Leak Rate for Spring Conditions

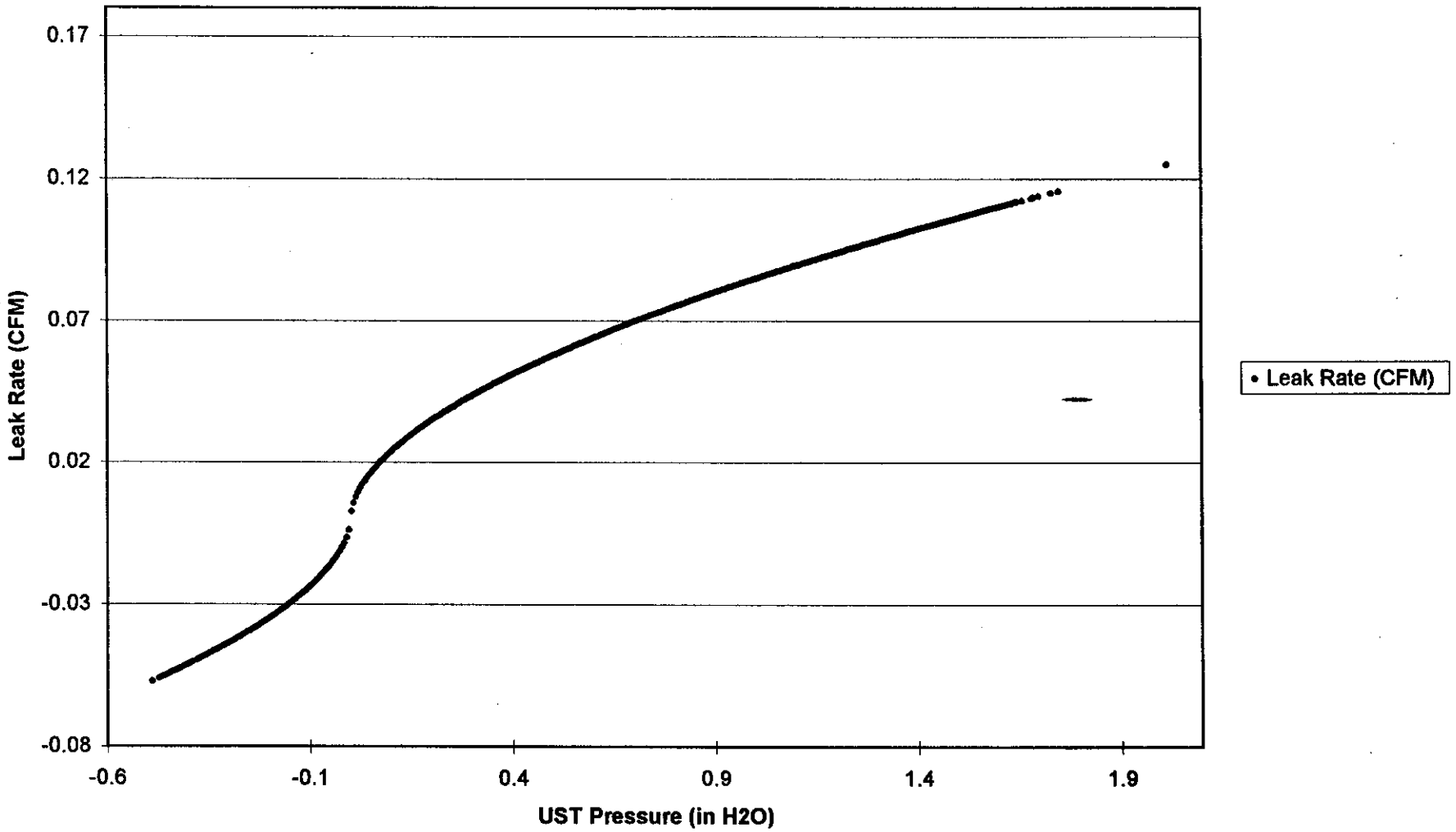


Figure 4-43 Vacuum Assist System Leak Rate as a Function of UST Pressure for Winter Conditions

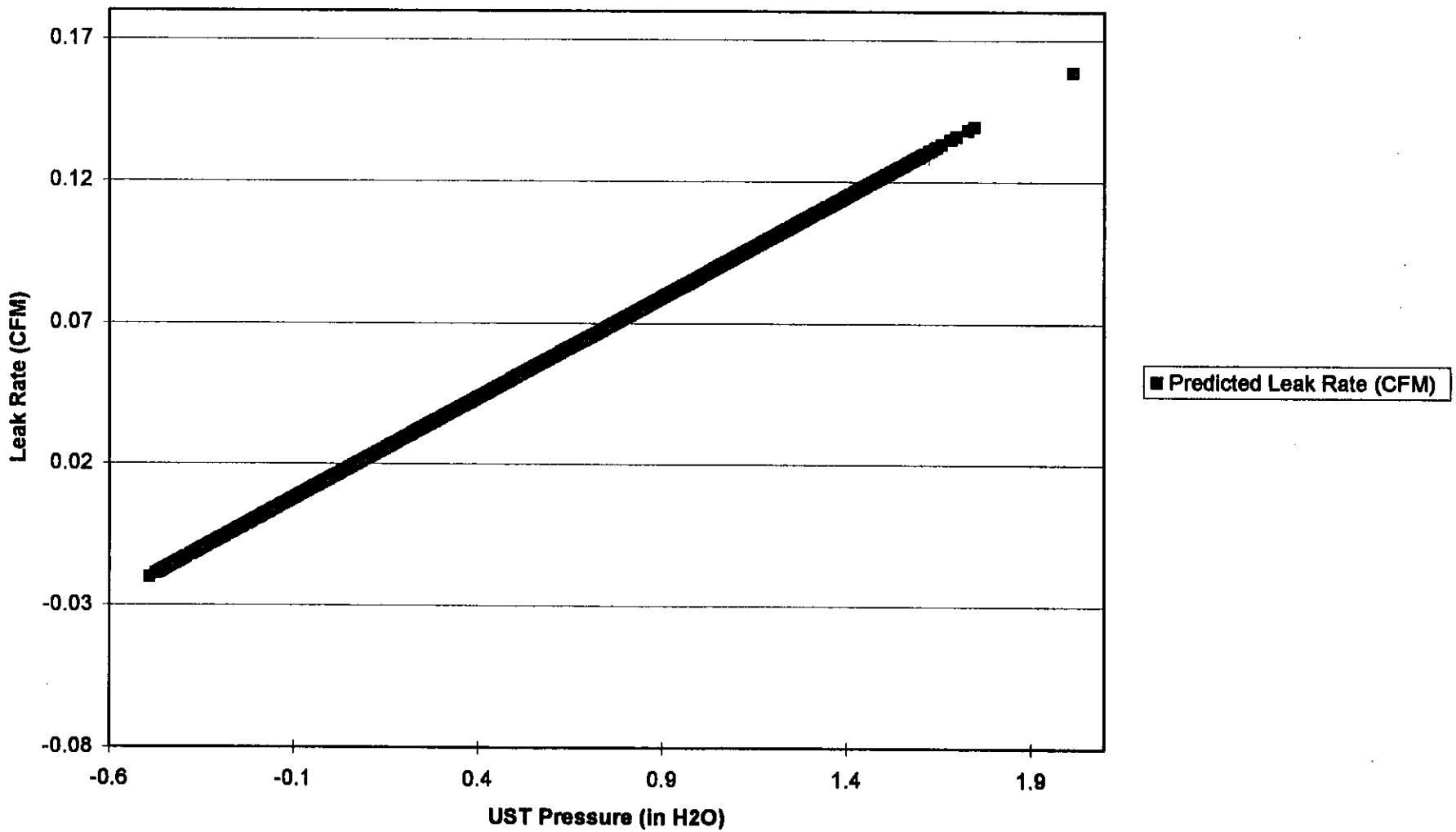


Figure 4-44 Vacuum Assist System Leak Rate as a Function of UST Pressure for Winter Conditions

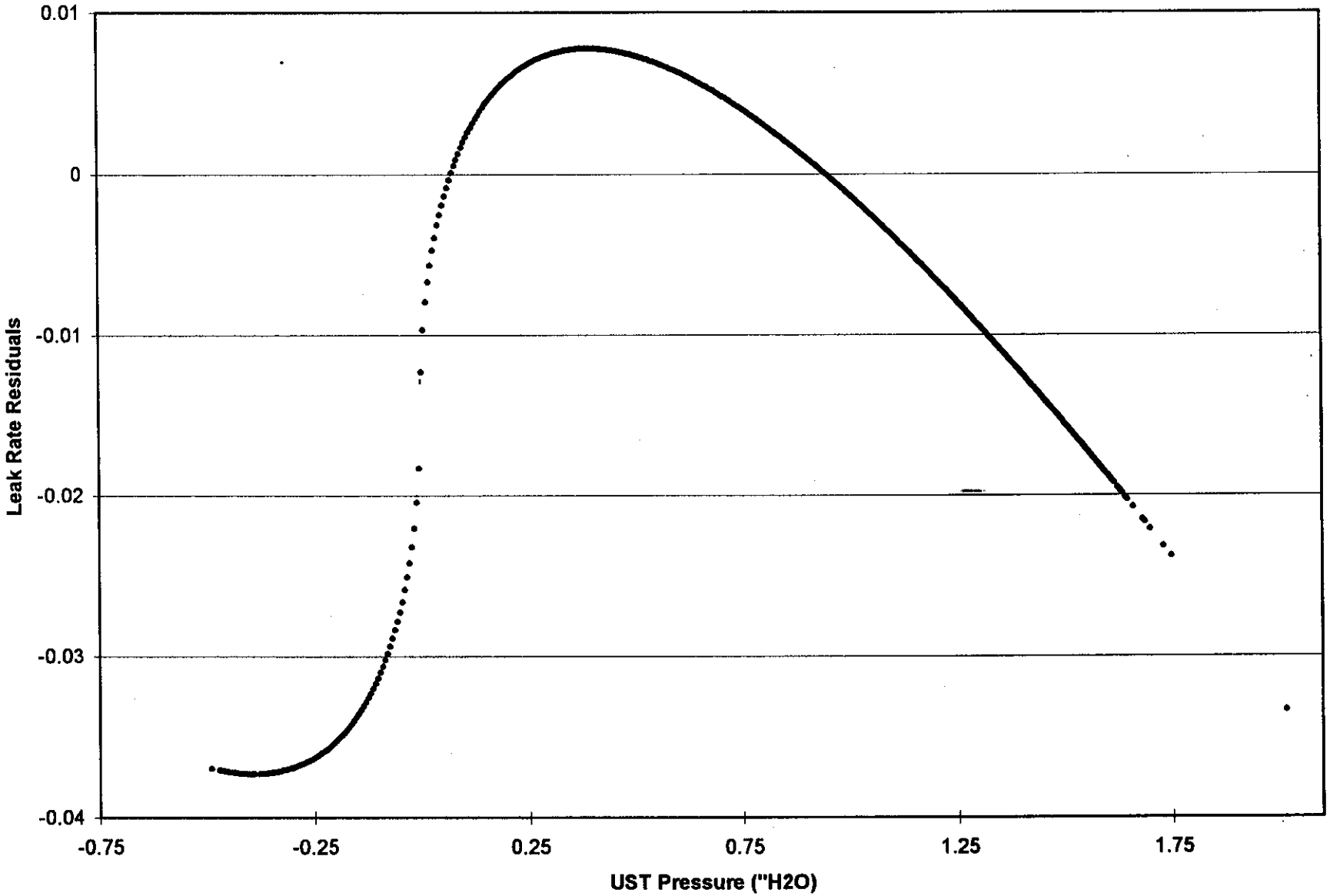


Figure 4-45 Vacuum Assist Leak Rate Residuals as a Function of UST Pressure for Winter Conditions

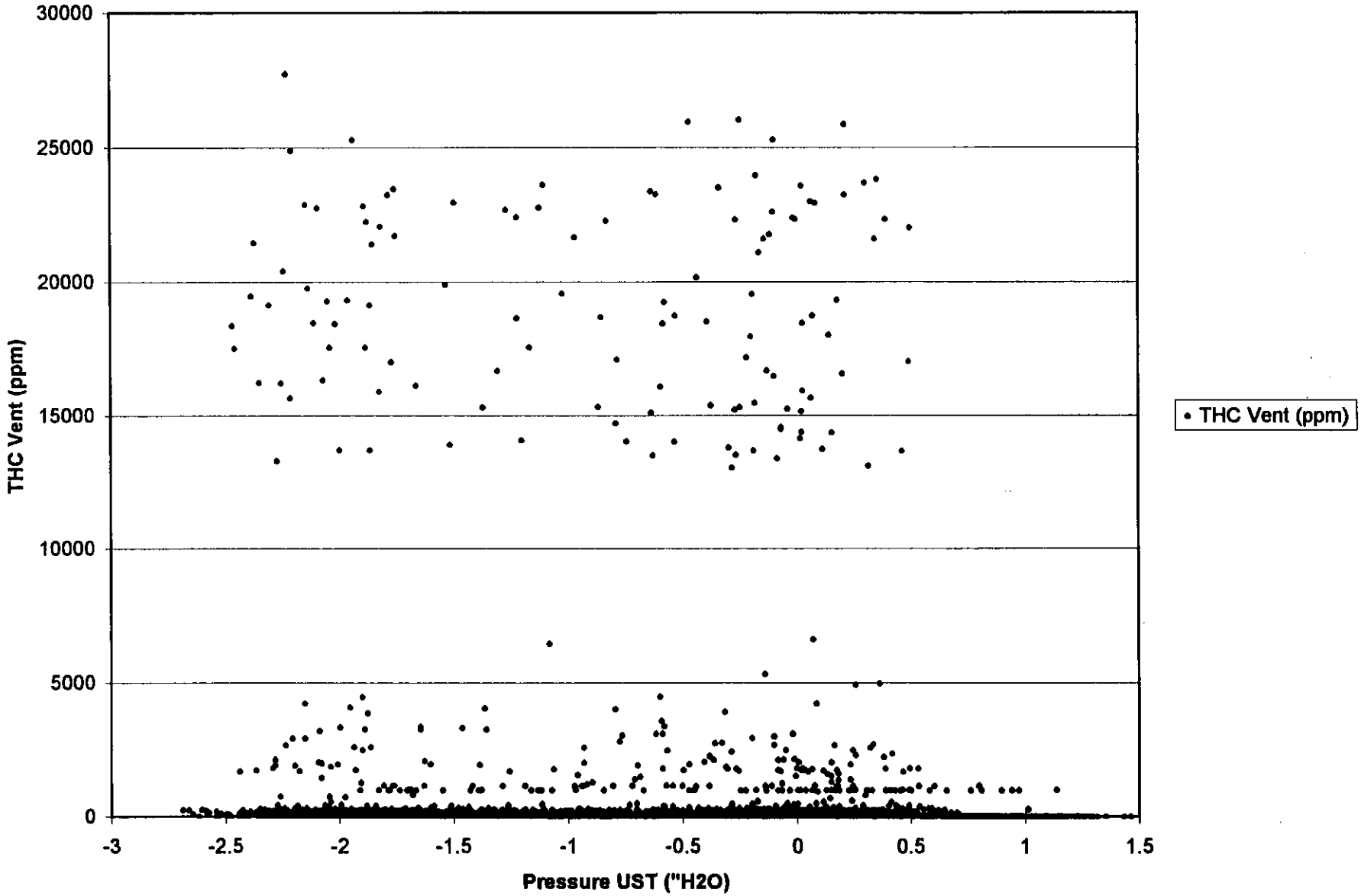


Figure 4-46 Balance System Vent Emissions as a Function of UST Pressure for Winter Conditions

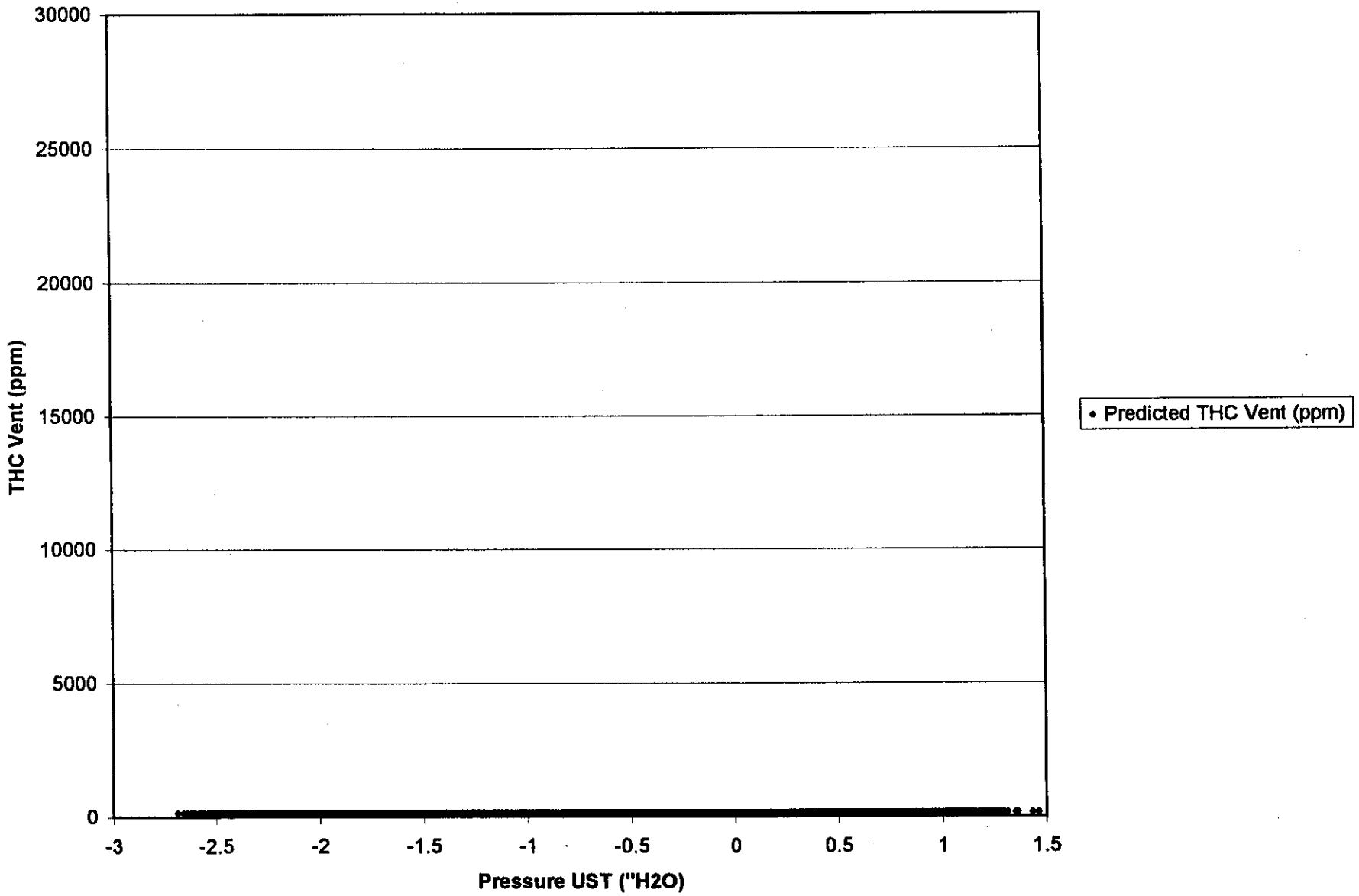


Figure 4-47 Balance System Vent Emissions as a Function of UST Pressure for Winter Conditions

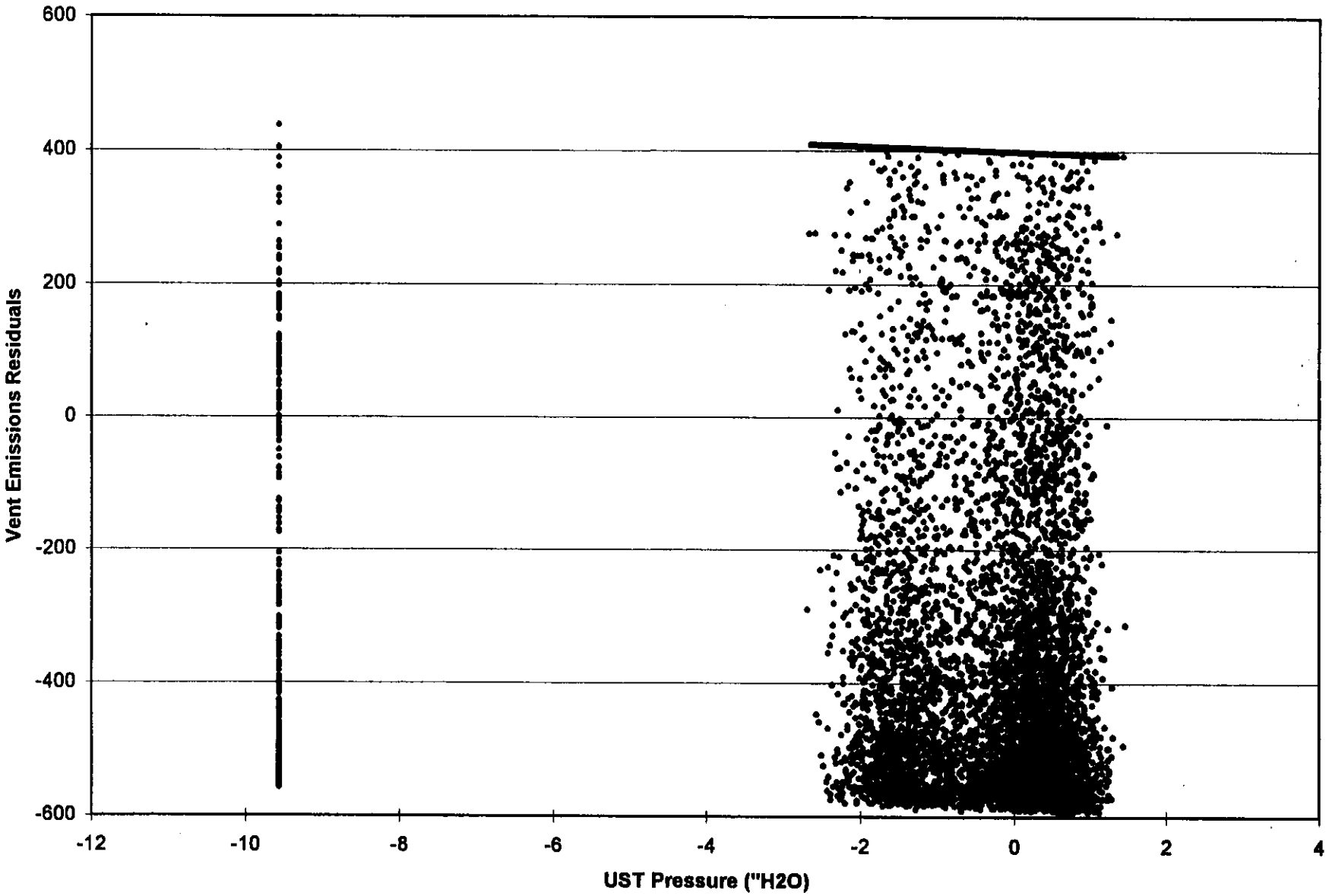


Figure 4-48 Balance System Vent Emissions Residuals as a Function of UST Pressure for Winter Conditions

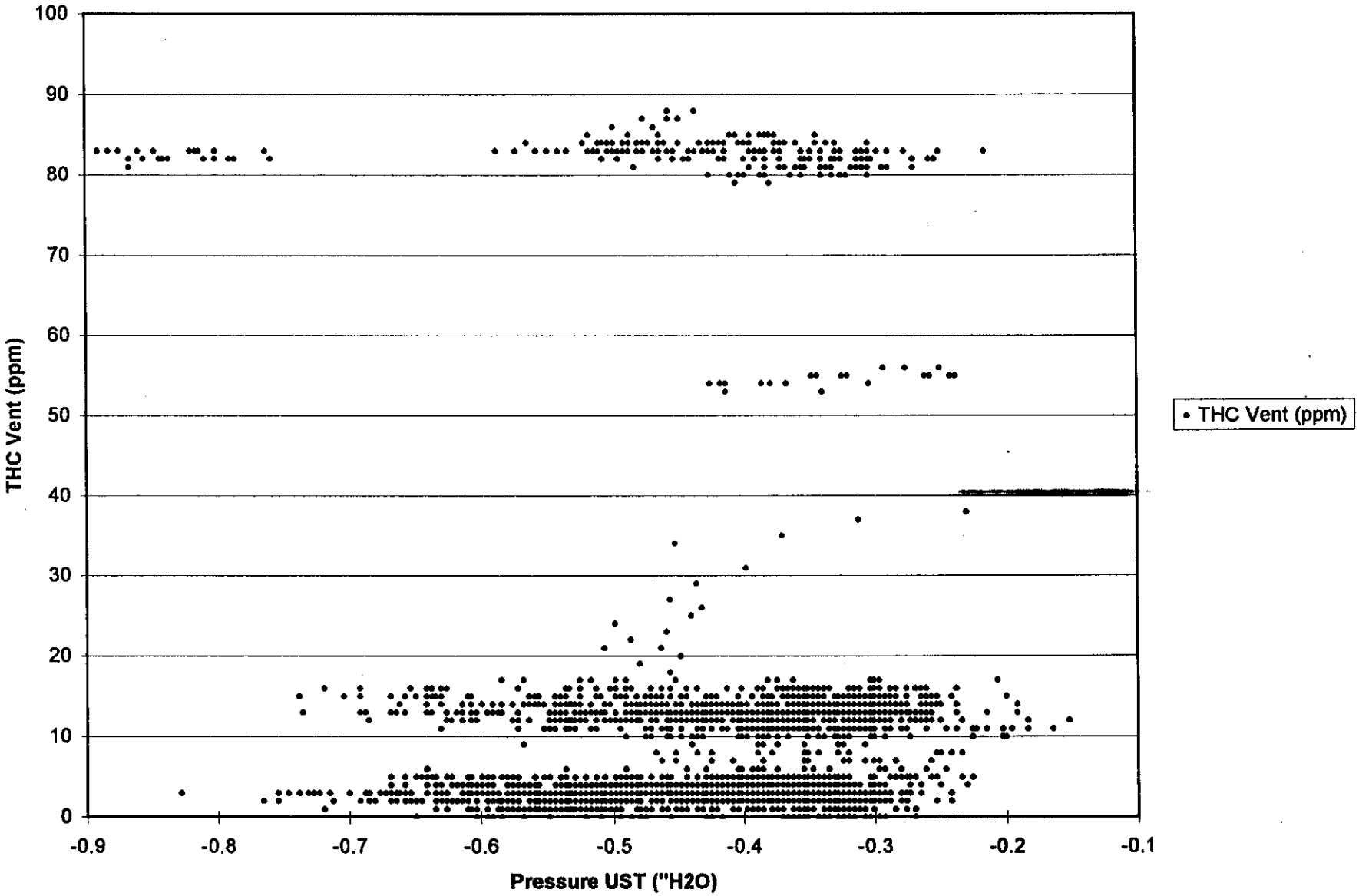


Figure 4-49 Balance System Vent Emissions as a Function of UST Pressure for Spring Conditions

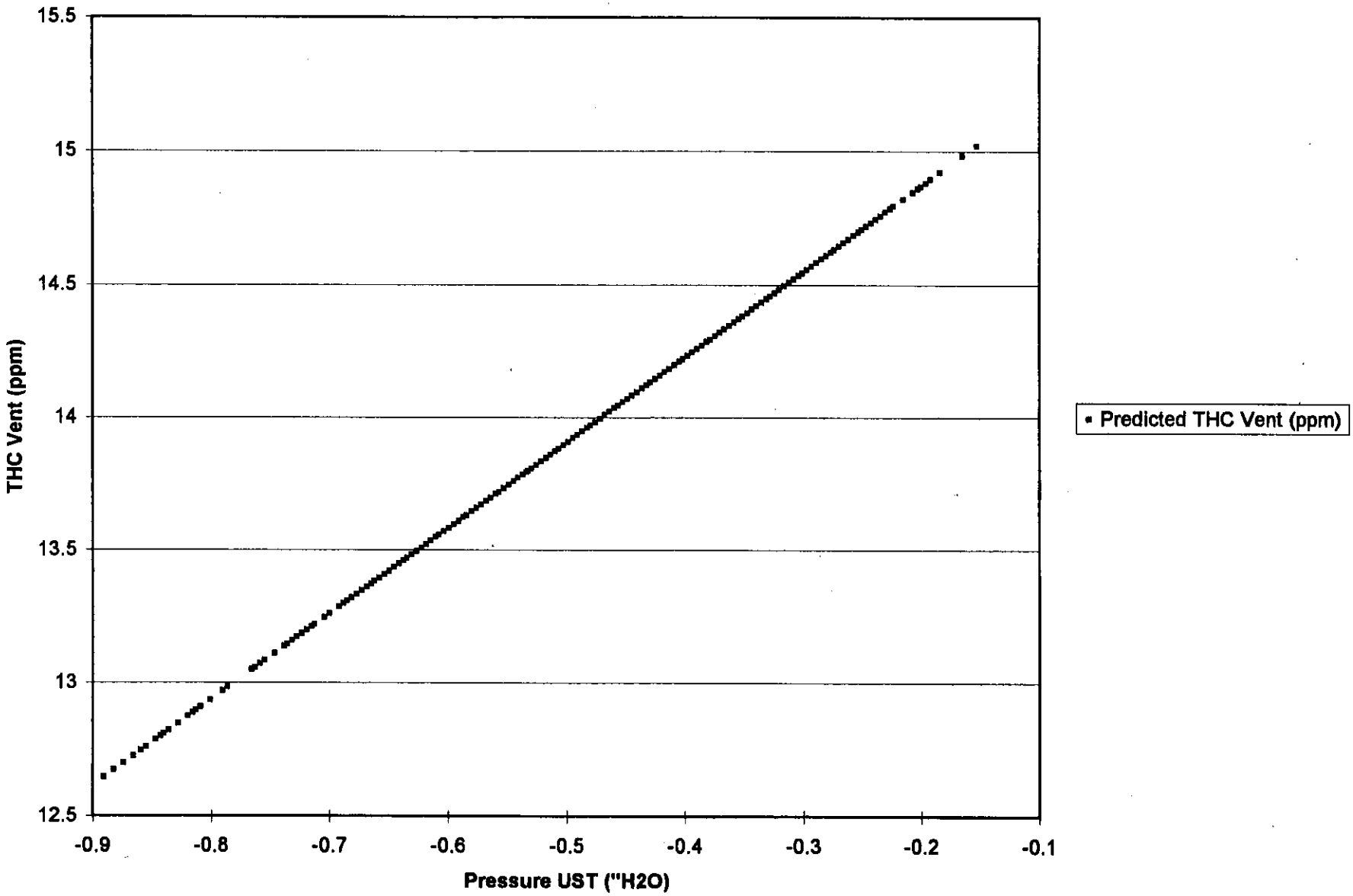


Figure 4-50 Balance System Vent Emissions as a Function of UST Pressure for Spring Conditions

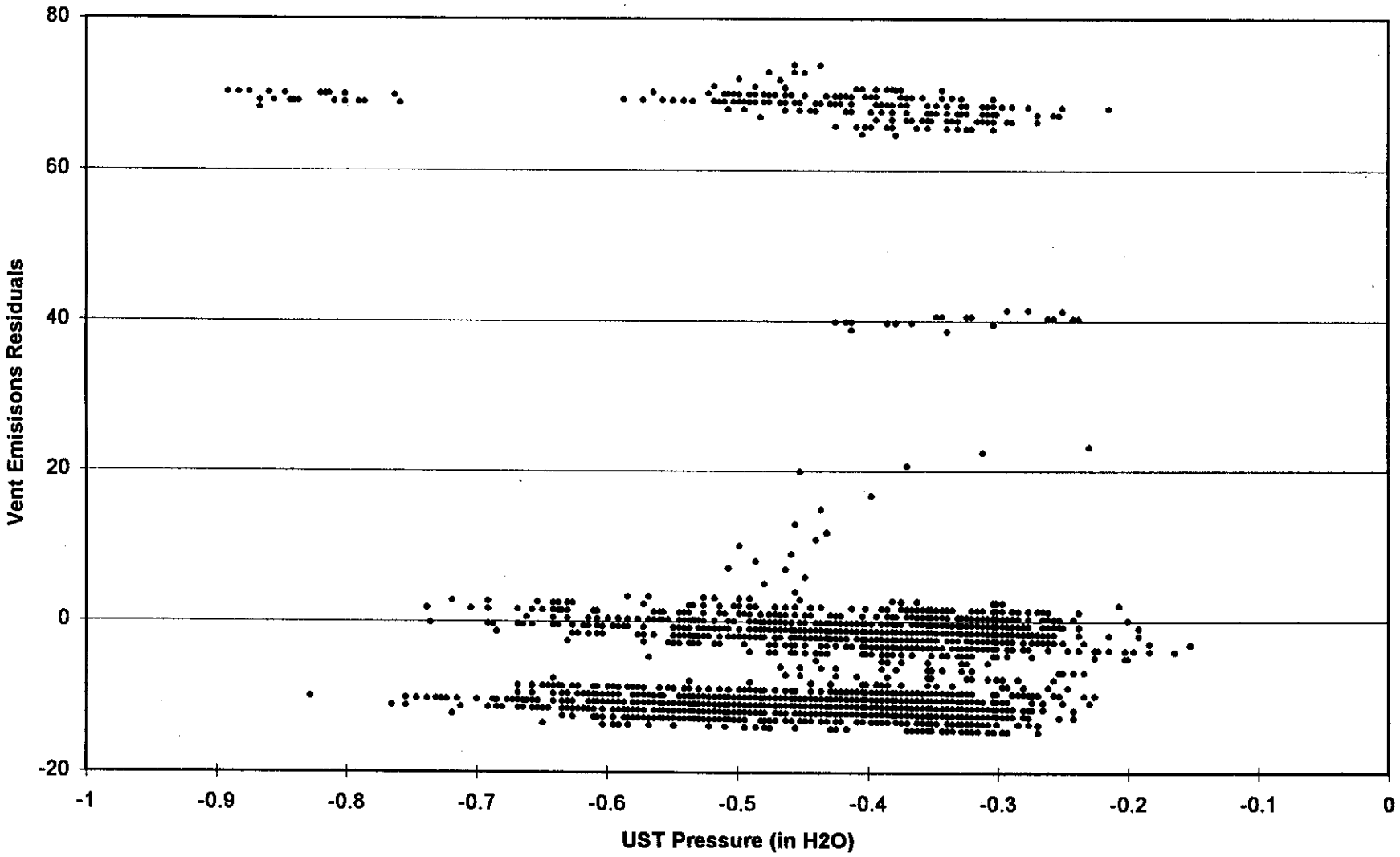


Figure 4-51 Balance System Vent Emission Residuals as a Function of UST Pressure for Spring Conditions

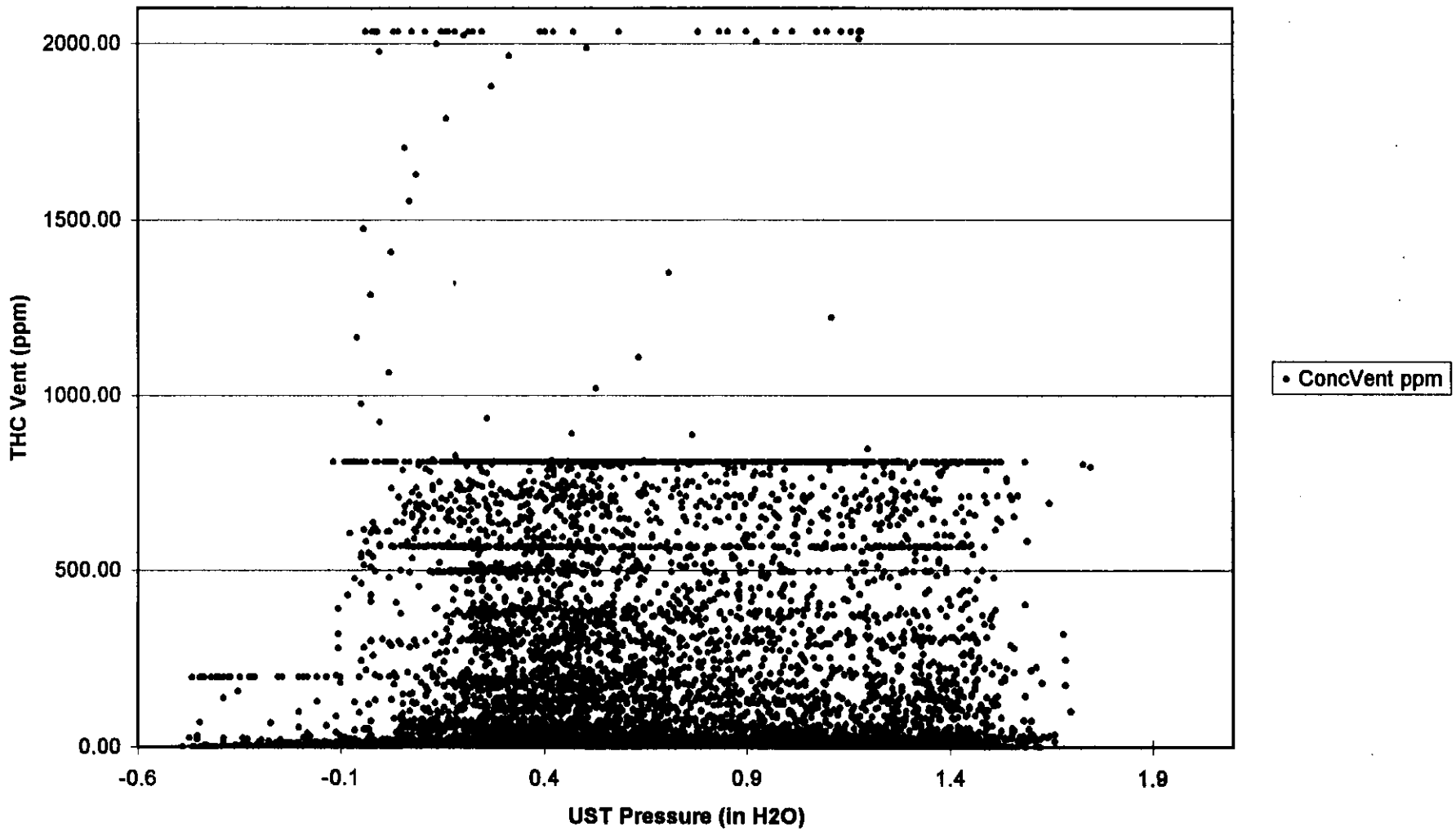


Figure 4-52 Vacuum Assist System Vent Emissions as a Function of UST Pressure for Winter Conditions

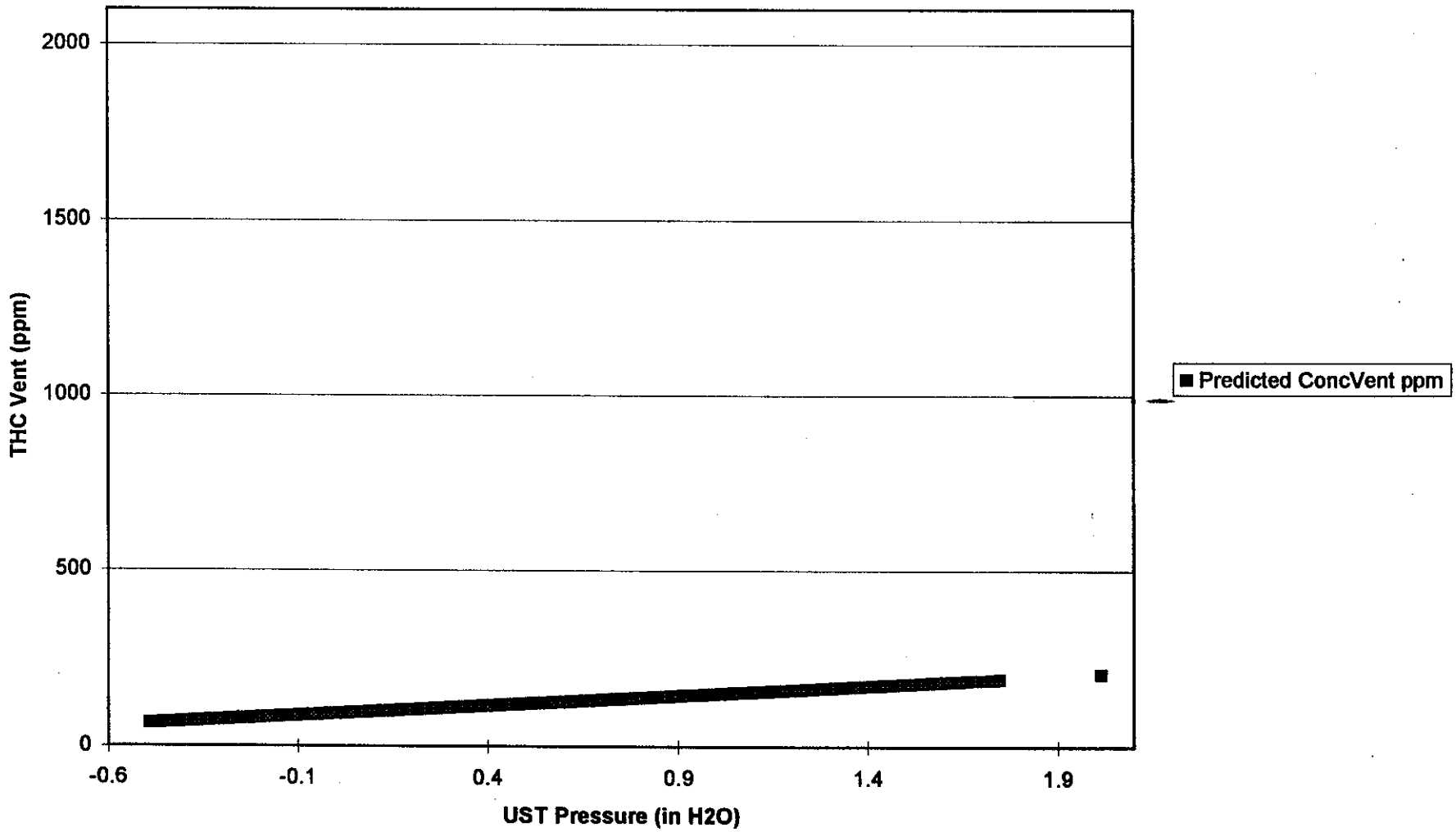


Figure 4-53 Vacuum Assist System Vent Emissions as a Function of UST Pressure for Winter Conditions

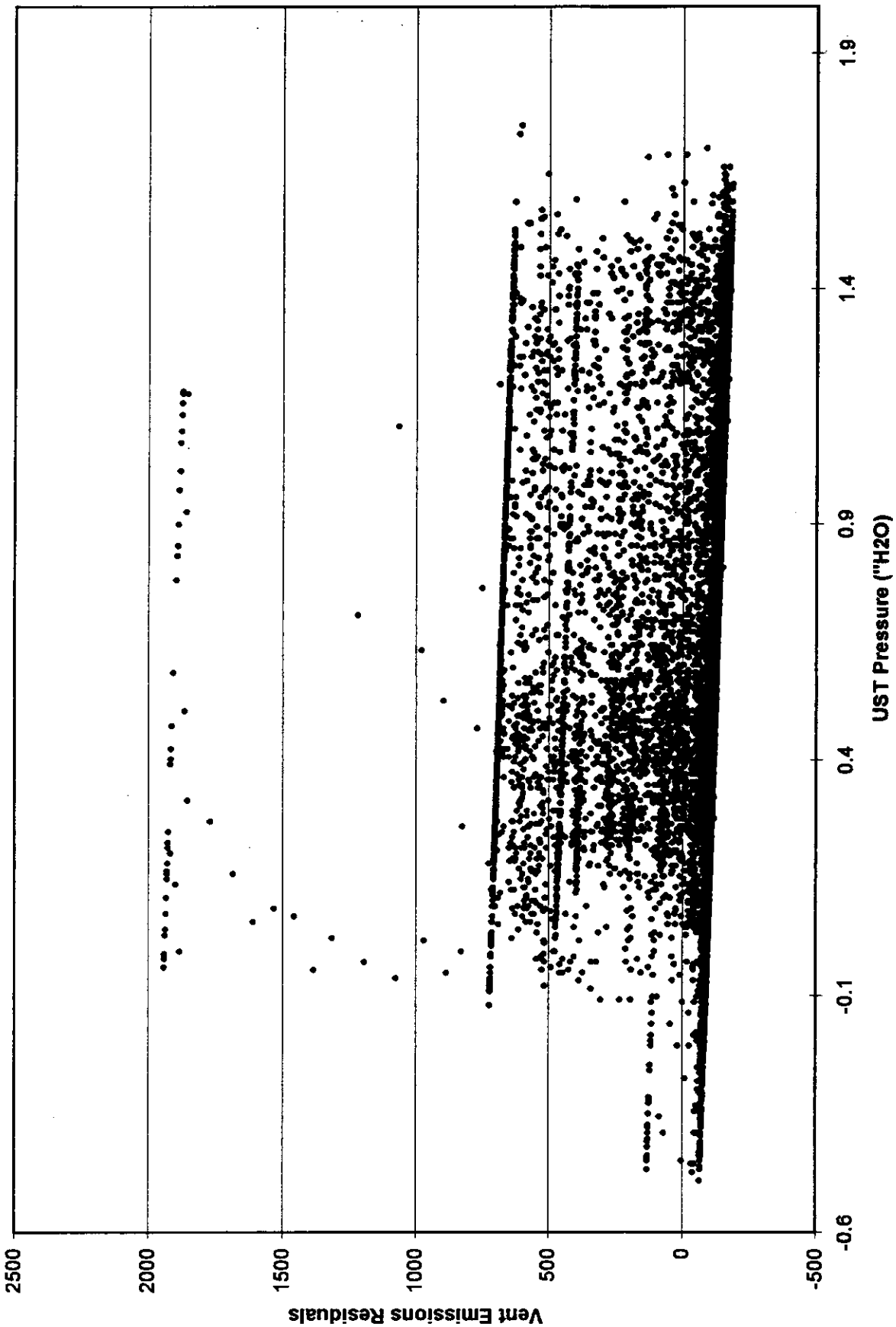


Figure 4-54 Vacuum Assist Vent Emissions Residuals as a Function of UST Pressure for Winter Conditions

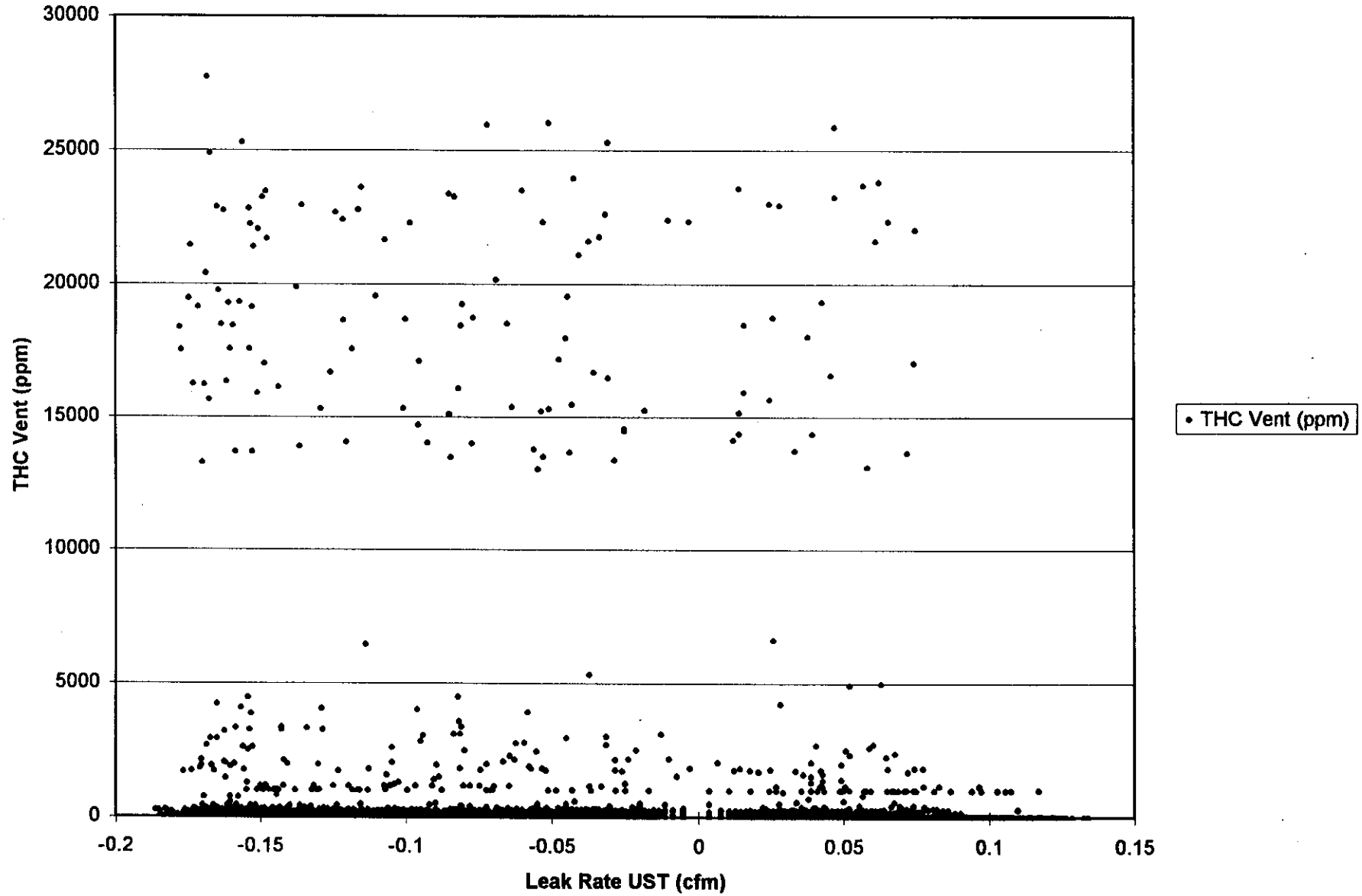


Figure 4-55 Balance System Vent Emissions as a Function of Leak Rate for Winter Conditions

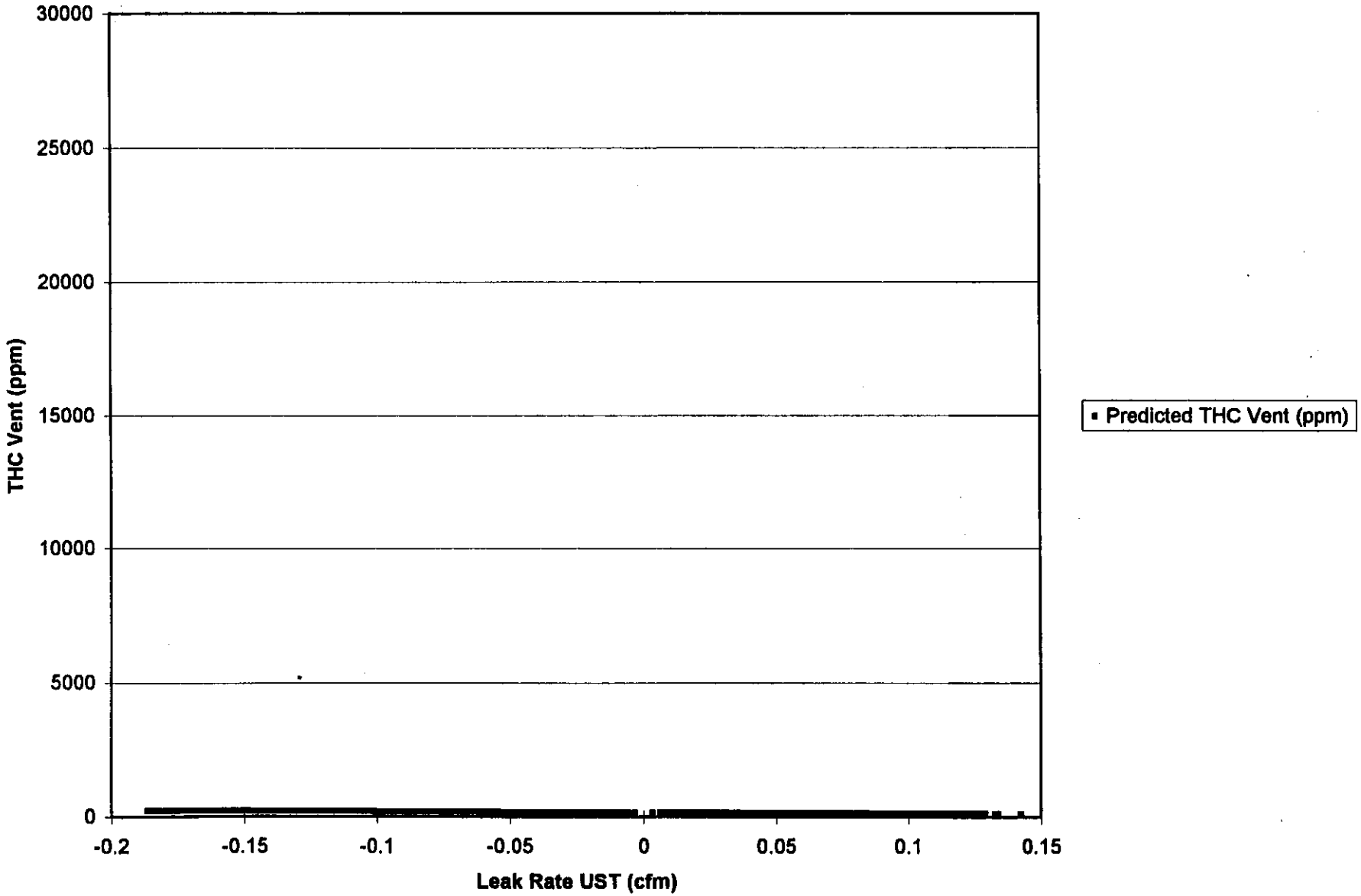


Figure 4-56 Balance System Vent Emissions as a Function of Leak Rate for Winter Conditions

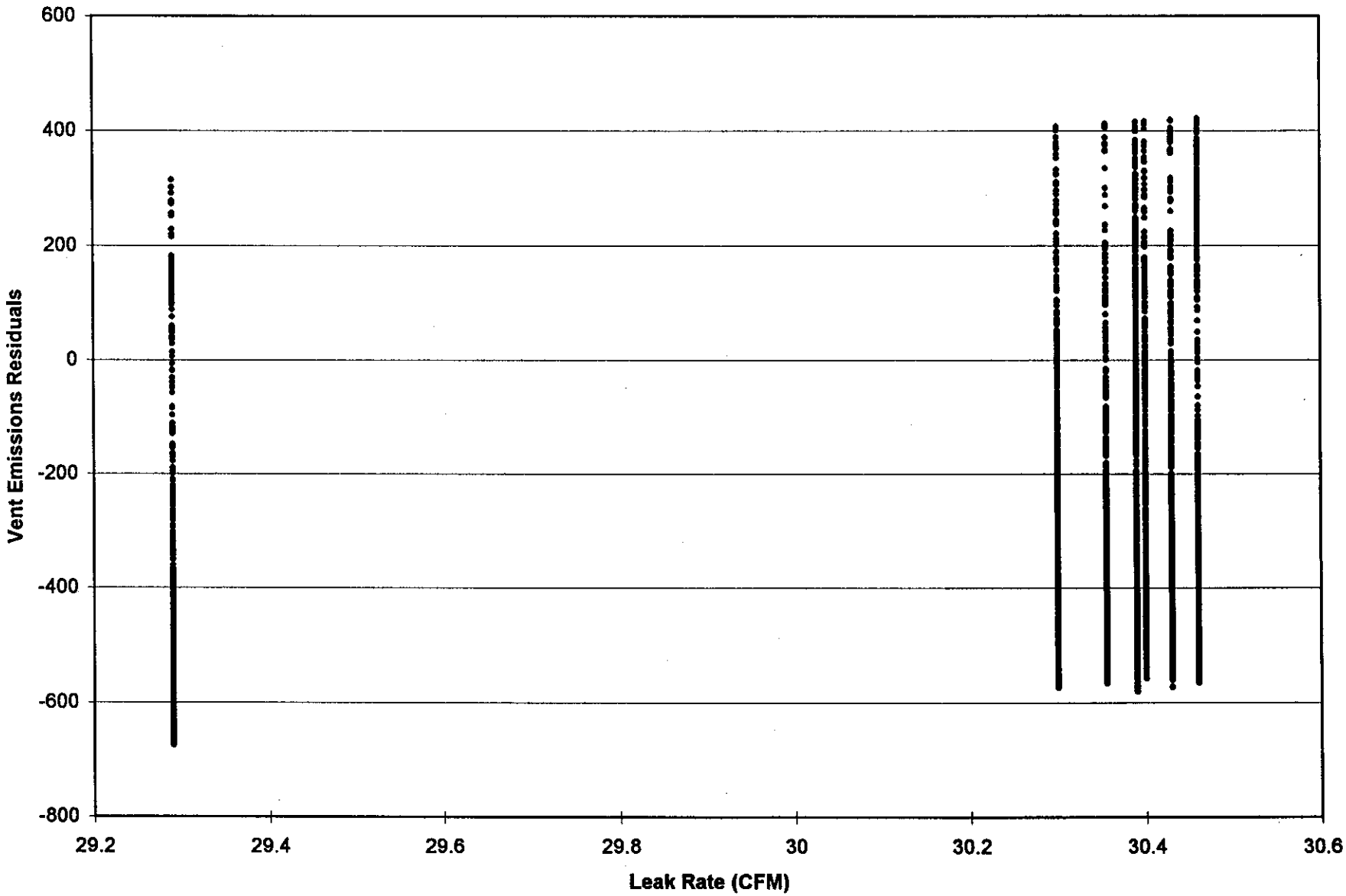


Figure 4-57 Balance System Vent Emissions Residuals as a Function of Leak Rate For Winter Conditions

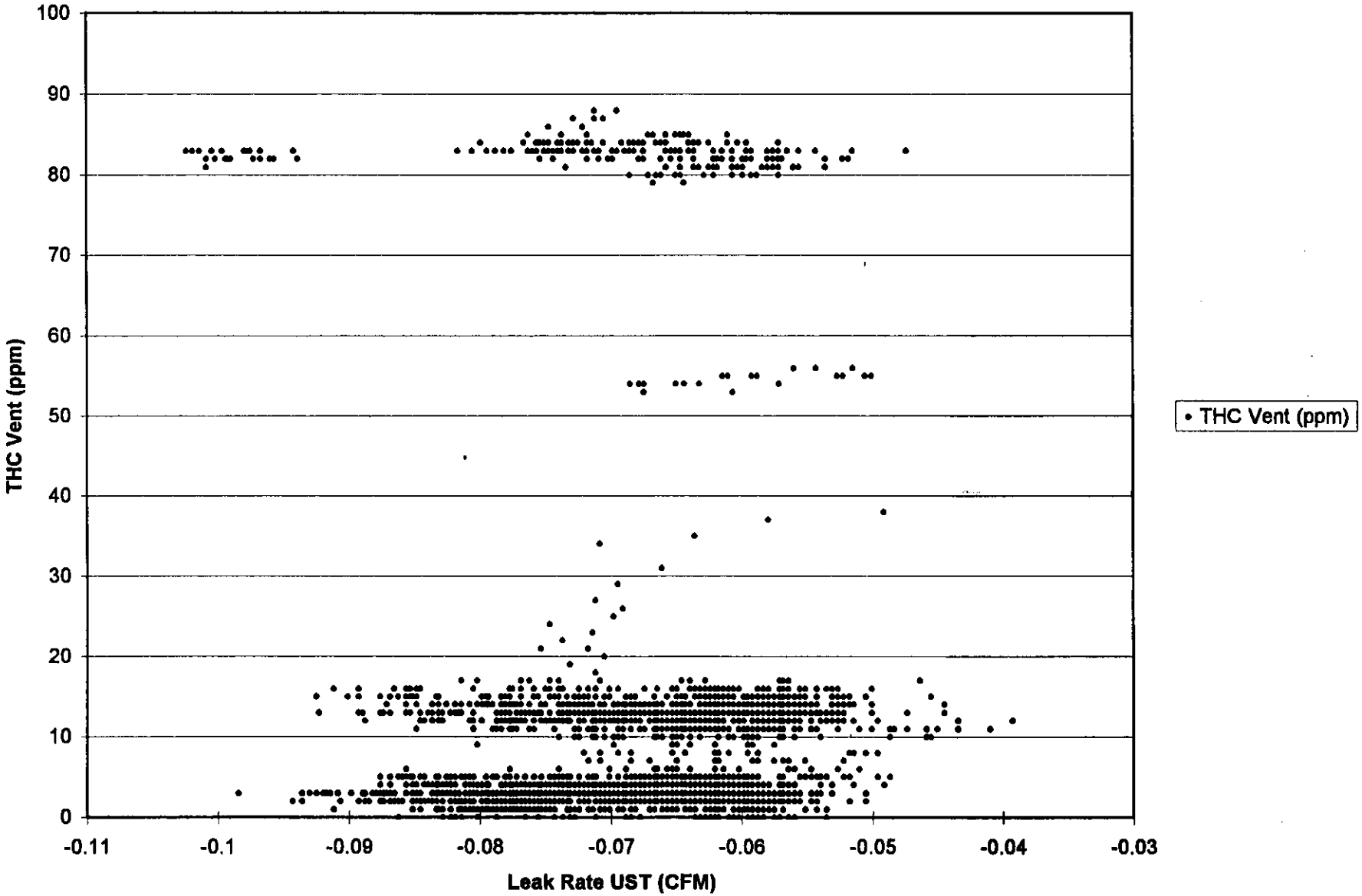


Figure 4-58 Balance System Vent Emissions as a Function of Leak Rate for Spring Conditions

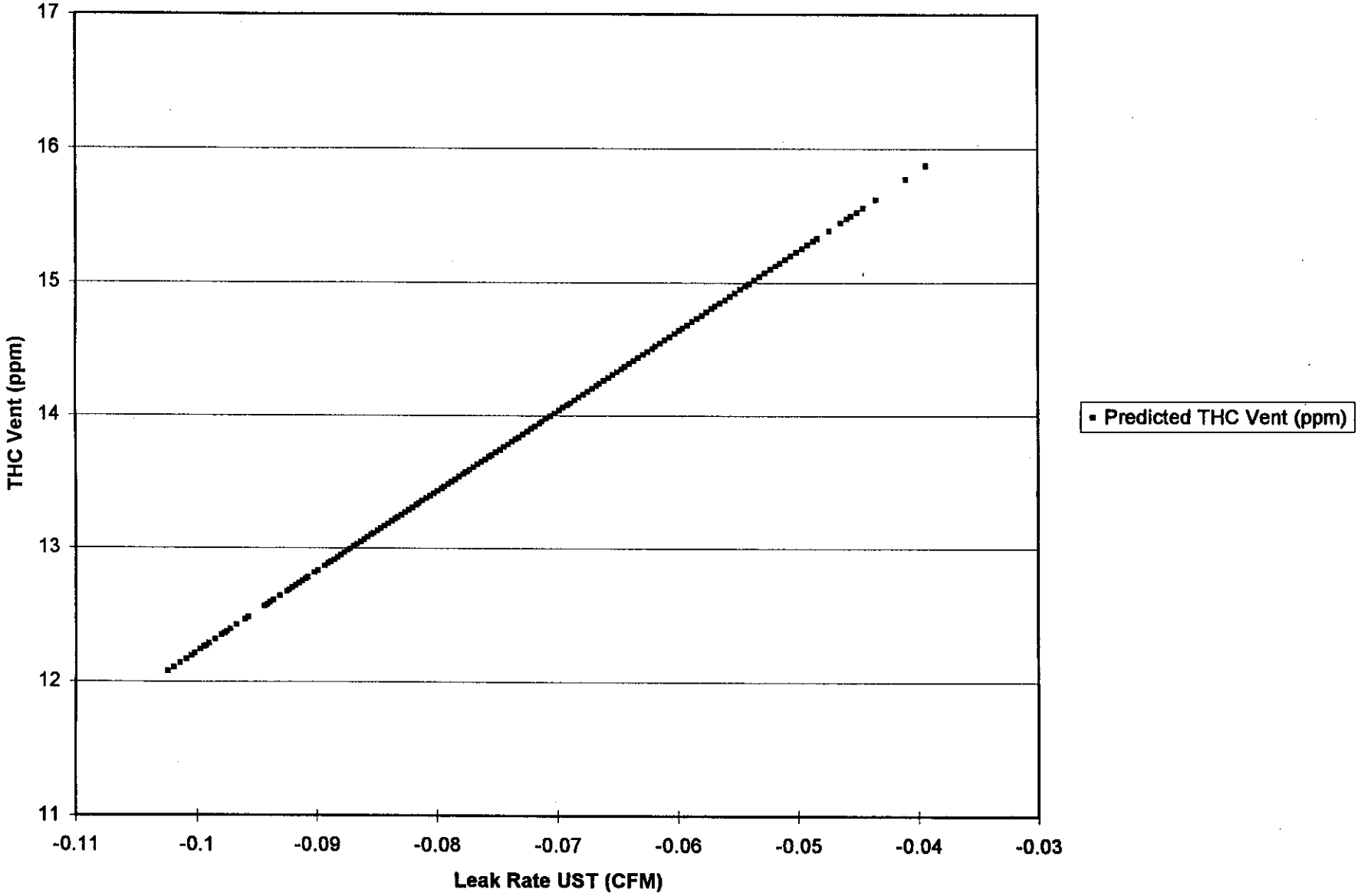


Figure 4-59 Balance System Vent Emissions as a Function of Leak Rate for Spring Conditions

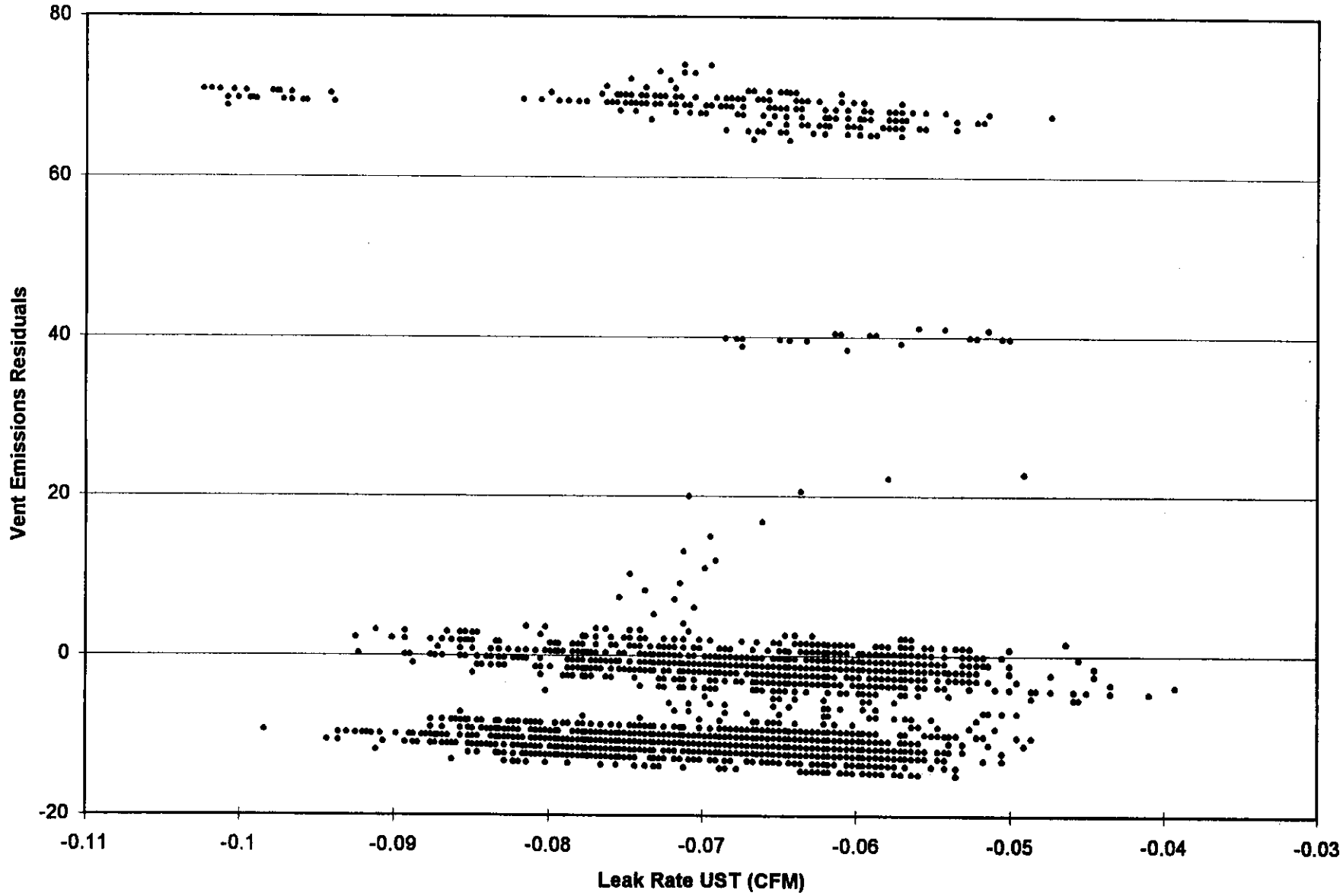


Figure 4-60 Balance System Vent Emission Residuals as a Function of Leak Rate for Spring Conditions

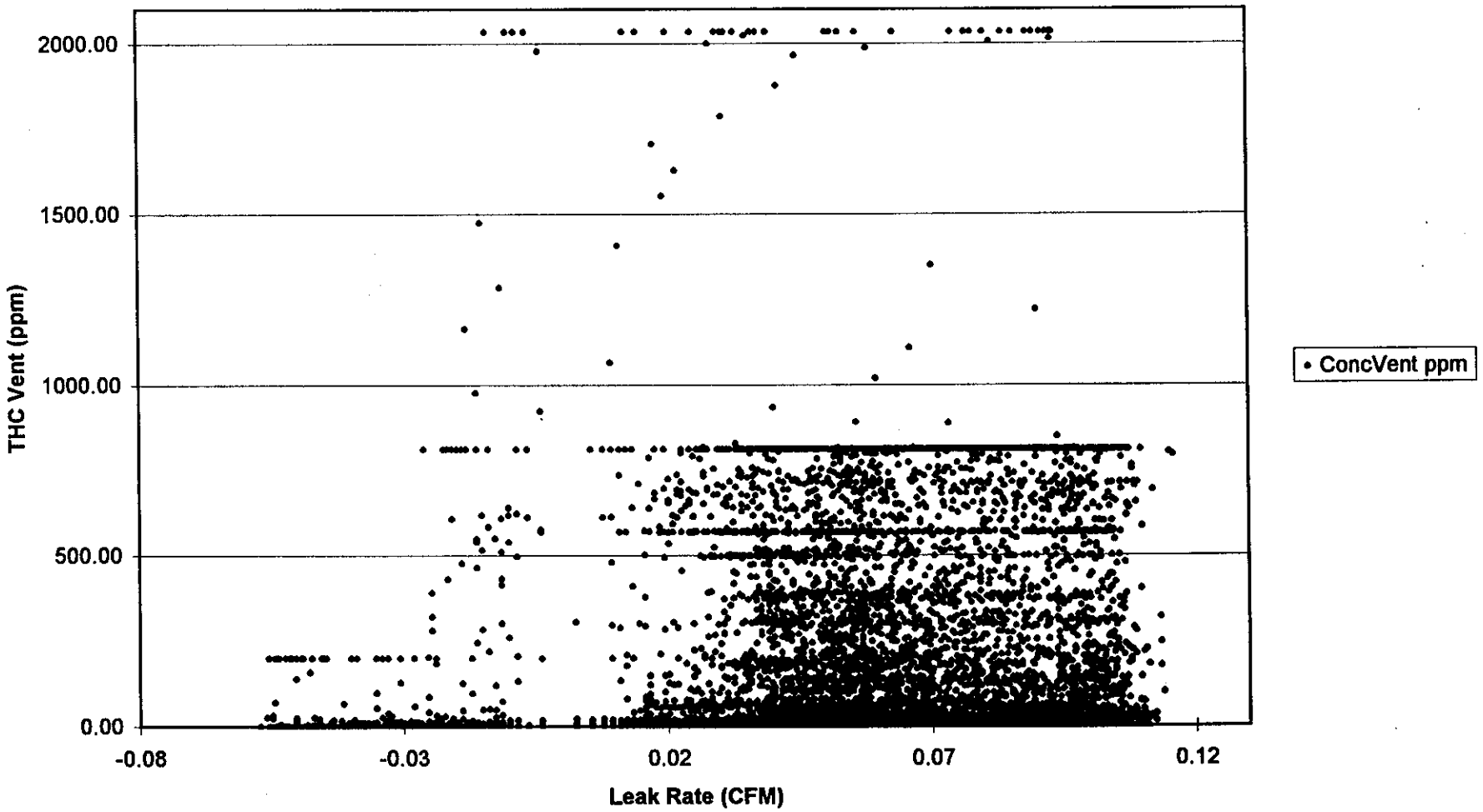


Figure 4-61 Vacuum Assist System Vent Emissions as a Function of Leak Rate for Winter Conditions

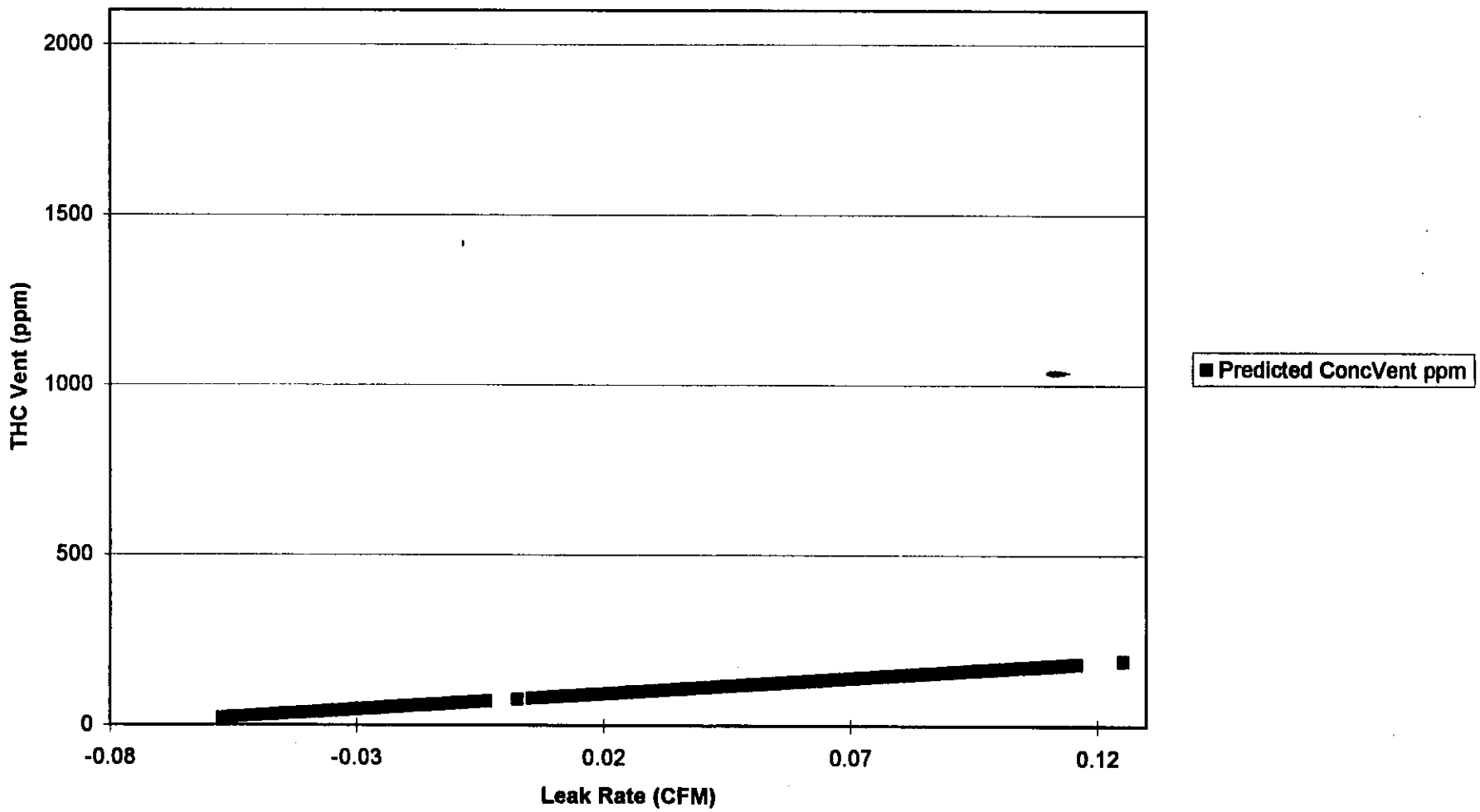


Figure 4-62 Vacuum Assist System Vent Emissions as a Function of Leak Rate for Winter Conditions

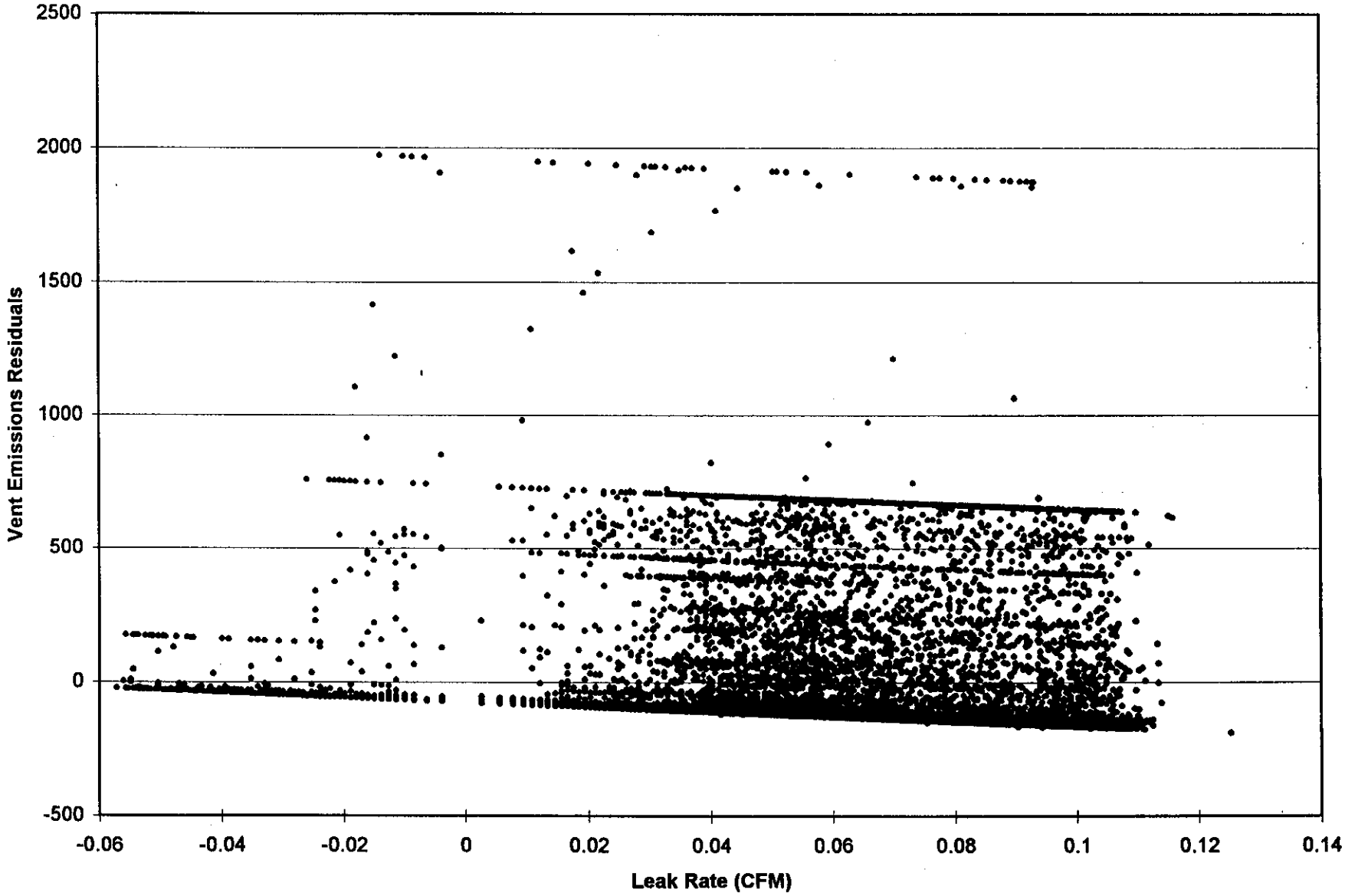


Figure 4-63 Vacuum Assist Vent Emissions Residuals as a Function of Leak Rate for Winter Conditions

Section 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

When evaluating a variety of independent variables that potentially influence emissions at gasoline dispensing facilities (GDF), a discernable, reproducible cause and effect relationship was not visible. However, several factors were noted that suggest possible interactions in governing vapor recovery system (VRS) emission characteristics. Vapor recovery system design specifications appear to be important determinants in predicting GDF emissions. VRS pressure, volume and temperature readings measured at the vehicle/nozzle interface, the return line and the vent line demonstrate specific patterns unique to both balance and vacuum assist VRS. Return line temperature, pressure and volume characteristics are singular in terms of their behavior relative to both the vent line and nozzle measurement test locations.

Hydrocarbon concentrations and mass values exhibit variability for each the field test locations and VRS measurement ports. Nozzle and vent line values are consistently lower than the return line concentrations or mass readings. UST pressure is a key determinant of VRS emissions consistently accounting for the leak rate variance in both VRS types. However, neither UST pressure or leak rate appears to be related to vent line emissions for a variety of experimental conditions. What appears to be an important question is what are the primary determinants of UST pressure. A hypothesized independent variable potentially affecting UST pressure, return line vapor volume, does not appear to be a strong predictor of UST pressure behavior.

Ambient temperature and pressure effects do not predict any significant variance in VRS performance or emission characteristics apart from VRS temperature distributions. However, ambient temperature is a strong predictor of vehicle fuel tank vapor temperature. This observation underscores the importance of ambient conditions in governing vehicle evaporative emissions.

Both VRS type and seasonal effects were noteworthy in their influence of possible VRS emissions. Based on the study dataset, VRS type is the key determinant of UST pressure. Vacuum assist systems consistently demonstrated a propensity for positive UST pressure values which in turn lead to proportional leak rate releases of system fugitive emissions. In contrast, balance system UST pressure characteristics are reproducibly negative. This creates an environment of nonexistent fugitive releases.

Product deliveries can influence UST pressure conditions. However these impacts do not by default increase VRS emissions. What are critical are the existing pressure conditions in the UST at the time of product delivery. A UST at sufficient negative

pressure may be able to absorb the temporary burst in vapor volume thereby mitigating potential releases of fugitive emissions.

5.2 CONCLUSION

Based on testing at three different GDFs representing two VRS types and two meteorological conditions, VRS emissions are strongly influenced by UST pressure. The determinants of UST pressure appear to be VRS system type. Postulated VRS design elements that have been demonstrated to effect UST pressure in previous studies (e.g., volume of air returned to the UST during refueling events) were not consistently strong predictors of UST pressure for this study. Other observed differences in VRS performance, including pressure and temperature, may be factors that influence UST pressure and the associated leak rates. Postulated seasonal (e.g., ambient pressure and temperature) and fuel characteristics (e.g., RVP) did not influence GDF emissions as hypothesized at the onset of this study.

Section 6

RECOMMENDATIONS

6.1 RECOMMENDATIONS

Based on an evaluation of the empirical dataset collected for this project, future studies investigating the causal influences on GDF emissions should address the following issues:

- The data collection time should be significantly longer than the time periods allocated for this project. A minimum of 7 days for each experimental condition (i.e., VRS type, meteorological conditions) should be considered, assuming resources are available to support the field measurement program.

- The challenges of maintaining vapor recovery system integrity (e.g., system tightness) need to be aggressively addressed in any future study. There are several areas that include difficult to control for phenomena (i.e., the impact of customers on gasoline dispensing equipment, the influences of delivery truck personnel on Phase I integrity) that have dramatic impacts on system tightness. A systematic effort needs to be exerted to either control for these factors or to estimate, within an acceptable range of error, the systematic error term that is introduced into the emission factor calculations due to compromises in system integrity.

- The impact of system leak rate (Q) and pressure in determining the magnitude of fugitive emission releases suggests the importance of an emission control strategy that targets the maintenance of neutral system pressure.

- The potential impact of product deliveries on vent line and fugitive emission releases suggests the need to vigilantly monitor the correct application of Stage I vapor recovery methodologies. Deviance from standard practices can result in significant increases in system pressure and concomitant emission releases.

Section 7

REFERENCES

Shearer. D. F. and D. F. Gilson (1994). Underground Storage Tank Vent Line Emissions from Retail Gasoline Outlets. AeroVironment Final Report prepared for Western States Petroleum Association, AV-FR-92-01-204R2