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Analysis of Temperature Effects on Gasoline Marketing Operations

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**ANALYSIS OF TEMPERATURE EFFECTS
ON
GASOLINE MARKETING OPERATIONS**

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R. V. Miller	Gulf Oil Company
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Additionally, the authors appreciate the information supplied by a number of individuals regarding hardware for use in gasoline temperature adjustment. These sources of information are listed in detail in Section 10 of this report.

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EXECUTIVE SUMMARY

Radian Corporation, under a previous contract to the American Petroleum Institute, compiled and analyzed data obtained as part of a calendar year 1975 gasoline temperature survey conducted by the EF-14 Task Force. Data were collected from fifty-six service stations across the United States during all seasons of the year. The data collected included such items as station throughput, physical characteristics of sites, meteorological data, and product temperatures from three primary locations: (1) the underground storage tank, (2) the service station dispenser, and (3) the vehicle fuel tank. The analysis provided insight into the complex subject of gasoline temperature variations, specifically as related to vapor shrinkage/growth during vehicle refueling.

The primary purpose of this report is to present additional results related to gasoline temperature adjustment in the petroleum marketing distribution system. Separate analyses involving the temperature data base were performed and the significant results included:

- When the ambient temperature is between 65°F and 85°F, vapor shrinkage will occur overall some 89% of the time.
- Mathematical regression models can predict average dispensed gasoline temperatures within an accuracy of ± 0.5 percent.
- The overall nationwide volume weighted average gasoline sales temperature is estimated as 61.6°F.

In addition to the temperature data base analyses, a comprehensive study was made of five different techniques for retail gasoline temperature adjustment and compared measurement precision with the corresponding cost to the nation. Temperature adjustment methods varied from a one-time meter adjustment based on estimated dispensed temperature to electronic compensators. The proportional volume uncertainty ranges from ± 0.0075 ($\pm 0.75\%$) for one-time meter adjustment to ± 0.0006 ($\pm 0.06\%$) for the electronic compensator. Additional cost for these methods ranges from \$11 million to \$1.2 billion. Although it was not included in this study, a comprehensive analysis should be considered in future work since the current no-temperature compensation practice provides the U.S. consumer as-a-whole with a yearly average gasoline temperature near 60°F.

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METRIC CONVERSIONS

to convert from	to	multiply by
Btu	joules	1.055×10^3
Btu/hr	joule/hr	1.055×10^3
Btu/lb	joule/kilogram	2.326×10^3
gal	cubic meters	3.785×10^{-3}
gal/hr	cubic meters/hr	3.785×10^{-3}
gal/yr	cubic meters/yr	3.785×10^{-3}
lb	kilogram	4.356×10^{-1}
mcf	cubic meters	2.832×10^1
mcf/yr	m ³ /yr	2.832×10^1
ton	metric ton	9.072×10^{-1}
ton/yr	metric ton/yr	9.072×10^{-1}
\$/Mgal	\$/m ³	2.642×10^{-1}
\$/Mlb	\$/metric ton	2.205×10^3
\$/MMBtu	\$/10 ⁶ joules	9.478×10^{-4}
\$/ton	\$/metric ton	1.102×10^1
°F	°C	Subtract 32 and multiply by 5.55×10^{-1}

DEFINITIONS

Accuracy -	freedom from error; degree of conformity of a measure to a standard
Ambient Temperature -	atmospheric temperature
Apportion -	to make a proportionate distribution
Correlate -	to establish a mutual relationship
Correlation Coefficient -	a measure of the degree of relationship between two variables; the closer the coefficient is to 1 or -1 the stronger the correlation
Contiguous -	have contact with; adjoining
Climatological -	science of climates and their phenomena, average course of the weather at a place over a period of time
Diverse -	unlike; differing from one another
Extrapolation -	to project, extend or expand known data into an area not known so as to arrive at conjectural knowledge of the unknown area
Finite -	having definite or definable limits; completely determinable in theory or in fact
Fluctuation -	shifting back and forth uncertainly
Interpolate -	to estimate values between two known values
Linear -	relating to or resembling a line; straight
Mean -	mathematical average of a set of values
Median -	the value that represents the point at which there are as many instances above as there are below
Meteorological -	dealing with the atmosphere and its phenomena, especially as related to weather
Parameters -	set of physical properties whose values determine the characteristics or behavior of a system

DEFINITIONS - Cont'd

Precision -	degree of refinement with which a measurement is stated
Qualitative -	relating to quality or to characteristic
Quantitative -	expressible in terms of quantity; involving actual measurement of amount
Regression -	a statistical method for developing an equation to predict a variable in terms of one or more other variables
Spatial -	relating to, occupying, or of the nature of space
Standard Deviation -	measure of dispersion (scattering of the values from an average) being the square root of the mean of the squares of all the individual deviations measured from the mean
Temporal -	pertaining to or limited by time
Tolerance -	permissible deviation from a standard
Variable -	a quantity that may assume any one of a set of values
Variations -	a measure of the change in a variable or function

Note: some of the definitions given above were derived from Webster's New Collegiate Dictionary, G. & C. Merriam Company, Springfield, Massachusetts, 1977.

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1.0 INTRODUCTION

Radian Corporation, under a previous contract with the American Petroleum Institute, performed data compilation and presentation tasks associated with the EF-14 Task Force survey. The survey was primarily concerned with the temperature of gasoline at retail outlets. The data base has been used in this program for studies in three areas: control of hydrocarbon vapors in the automobile refueling operations, determination of the need for temperature adjustment at the service station, and inventory control for gasoline distribution systems.

In the first year's study, Radian compiled the massive temperature data set collected by oil company marketers and created a computerized data base. The data base includes temperatures at four points: (1) the bulk delivery tank, (2) the underground storage tank, (3) the service station dispenser, and (4) the customer's fuel tank. Additionally, various related data were collected including the total daily volume dispensed, physical characteristics of the site, and meteorological data. The survey was conducted at fifty-six service stations located throughout the contiguous United States during calendar year 1975. The year 1975 was representative of average ambient temperature conditions in the United States. The western half was approximately 1°F cooler than the 30-year mean, and the eastern United States was approximately 1°F warmer. Although all stations did not report all requested data, the data base is extensive enough to support sound statistical studies.

The data are described in further detail in the reference, and initial studies involving the temperature data are discussed. The purpose of this report is to present additional

results which relate primarily to gasoline temperature adjustment and control of hydrocarbon vapors in automobile refueling.

The specific tasks discussed in this report are as follows:

- Validation of the method used for obtaining average dispensed gasoline temperature from strip chart data,
- Study of the relationships among gasoline temperatures, ambient temperatures, and service station characteristics,
- Study of temperature conditions regarding vapor shrinkage and growth during vehicle refueling,
- Calculation of average ambient temperature and of the average temperature of stored and dispensed gasoline during operating hours of service stations,
- Calculation of national average dispensed gasoline temperature,
- Analysis of the effects of temperature adjustment of gasoline volume,
- Development of mathematical models to predict gasoline temperatures, and
- Study of design parameters and cost of temperature adjustment for service station dispensers.-.

Each of these tasks is discussed in a section of the report. Each section begins with a statement of objectives and a summary, after which the results are presented in further detail.

Throughout this report, results are presented on the basis of geographical region. The same six regions employed in

the first-year study have been used. These regions are shown in Figure 1.0-1. The locations of the test stations are given in Table 1.0-1.

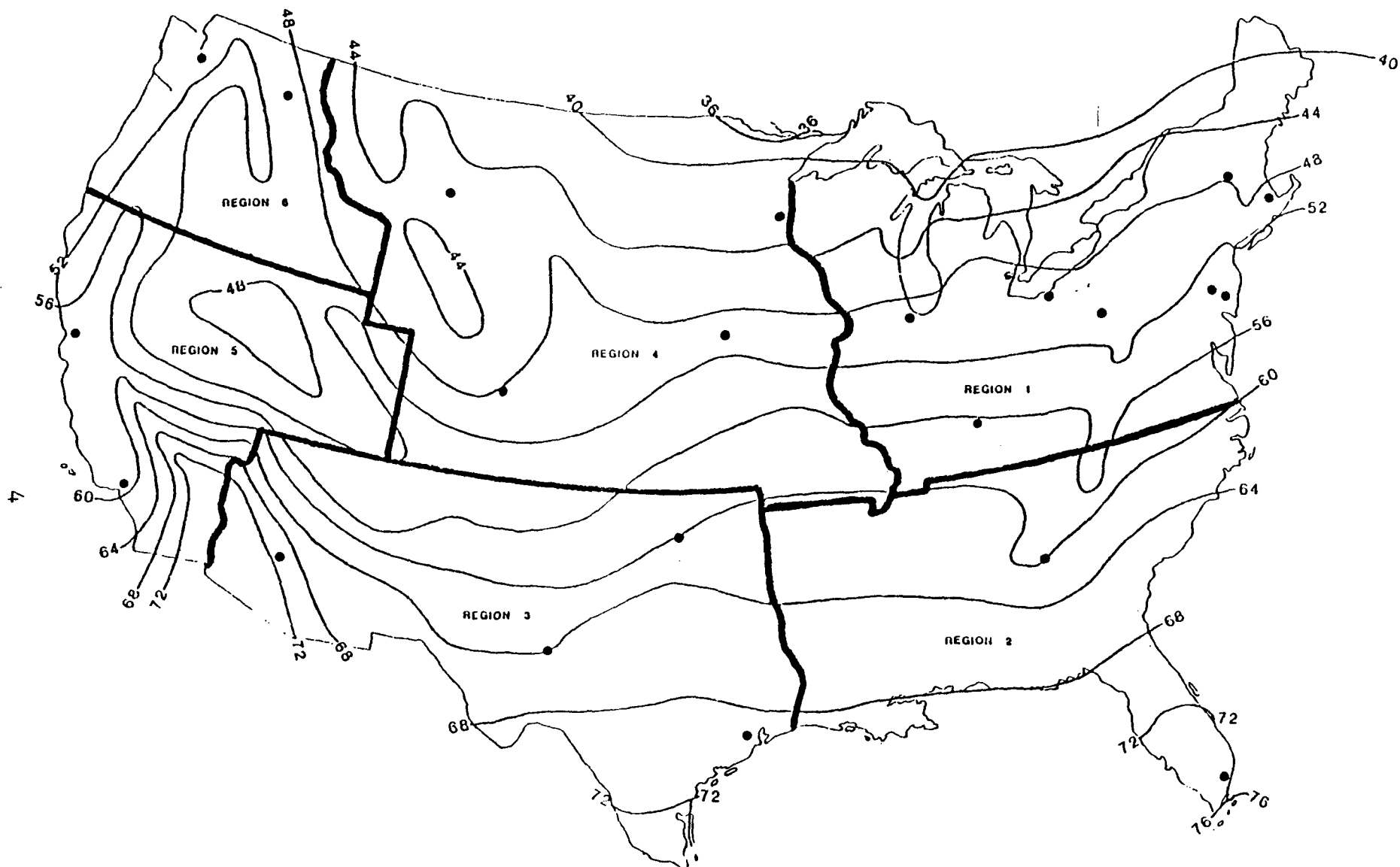


FIGURE 1.0-1
GEOGRAPHICAL REGIONS USED IN SUMMARY REPORTS
SHOWING ANNUAL AVERAGE AMBIENT ISOTHERMS (°F)

TABLE 1.0-1

STATIONS PARTICIPATING IN API-EF-14 GASOLINE TEMPERATURE SURVEY

<u>LOCATION</u>	<u>REGION</u>	<u>STATION CODES</u>
Southern New Jersey	1	1, 2, 3, 4, 5
Boston, Massachusetts	1	6, 7, 8, 9, 10, 36
Miami, Florida	2	11, 12, 13
Philadelphia, Pennsylvania	1	14
Los Angeles, California	5	15, 16, 17, 18
Pittsburgh, Pennsylvania	1	19, 20
Chicago, Illinois	1	21, 22, 39, 40
Lincoln Park, Illinois	1	23, 24
Seattle, Washington	6	25, 26
Phoenix, Arizona	3	27, 28
Cleveland, Ohio	1	29, 30, 56
Houston, Texas	3	31, 32
Louisville, Kentucky	1	33, 34
Burlington, Vermont	1	35
Omaha, Nebraska	4	37
Atlanta, Georgia	2	38
San Francisco, California	5	41, 42, 43, 44
Spokane, Washington	6	45, 46
Chamblee, Georgia	2	47
Concord, California	5	48
Del City, Oklahoma	3	49
Twin Cities, Minnesota	4	50
Denver, Colorado	4	51, 52
Billings, Montana	4	53, 54
Midland, Texas	3	55

2.0 SUMMARY AND CONCLUSIONS

In this report, a number of separate analyses regarding gasoline temperatures, temperature adjustment, and vapor recovery conditions are presented. The results are summarized briefly below. Each of these analyses is discussed in further detail in a subsequent section of the report. Additionally, each section begins with a statement of objectives and a more extensive summary of the results.

Variations in temperature affect the volume of gasoline being delivered, stored, or dispensed. These variations provide a motivation for the study of gasoline temperature effects and of possible methods for gasoline temperature adjustment.

Validation of Data Sampling Plan

Dispensed gasoline temperature data were used extensively in this study and in the preceding study, which is reported in the reference. Due to the enormous number of dispensed product data available, it was necessary to select a subset for reduction and analysis. A set of test cases representing varying geographical and climatic conditions were employed to validate the data sampling plan. For each day and service station examined, the error due to finite sampling was shown to be two degrees Fahrenheit or less. Thus, the sampling plan is considered to be very adequate for the purposes of the study.

Temperature Relationships

An analysis of the relationship between underground tank and dispensed gasoline temperatures and other variables was performed. It was shown that the average dispensed gasoline and underground tank temperatures relate very closely to average

ambient temperature. Some of the service station physical characteristics relate to the gasoline temperatures, but only to a limited degree.

Vapor Shrinkage or Growth

Another analysis was concerned with temperature effects regarding vapor shrinkage/growth during vehicle refueling. To supplement an earlier study for all ambient conditions, only refuelings when the ambient temperature was between 65°F and 85°F were considered in this study. In 89 percent of these cases, conditions favored vapor shrinkage. Such conditions were also shown to predominate in all geographical regions.

Ambient Temperature During Operating Hours of Service Stations

The data base used in this study includes the daily minimum, average, and maximum of the ambient temperature at each of the stations. The average temperature during station operating hours, as such, is not included.

An investigation was made of the differences between the average ambient temperature over 24 hours and over the station operating hours. This investigation involved developing a mathematical model to predict ambient temperature as a function of time of day. Then this model was used to compute the average ambient temperature during operating hours.

The results showed that using the 24-hour average ambient temperature in place of the average during operating hours had a small impact. The average temperature during operating hours is generally only a few degrees (0-4°F) higher than the 24-hour average.

National Average Dispensed Gasoline Temperatures

The nationwide dispensed gasoline temperature was computed. County-by-county dispensed product temperatures, weighted by county gasoline consumption, resulted in a nationwide dispensed temperature average of 61.6°F.

The calculation of the national average dispensed gasoline temperature involved the following two approximations:

- (1) The county gasoline consumption data were not directly available but were approximations. The gasoline consumption for a state was apportioned among its counties on the basis of the county population. This is equivalent to assuming that the county gasoline consumption data within a given state are proportional to population.
- (2) The average dispensed product temperature by county was also approximated. A regression model was developed which allowed dispensed product temperature to be estimated as a function of average ambient temperature. The equation has a high correlation coefficient of .92.

Neither of these approximations introduces a systematic error. It is reasonable to assume that the random errors averaged out to a very large extent when the data for over 3,000 counties were averaged.

Temperature Adjustment of Gasoline Volume

An investigation was made of (1) the consequences of no temperature adjustment and (2) the adequacy of regional or more detailed temperature adjustment. It was shown that volume changes of the dispensed product due to temperature can vary by more than 0.5 percent for a given month and state. The station owner's

inventory is also subject to variations due to temperature. The statistics which are presented quantify only station-to-station variations and not variations at an individual station.

Prediction of Dispensed Gasoline Temperatures

Mathematical models were developed which could be used for temperature adjustment in place of direct measurement of dispensed gasoline temperature. Predicted temperature errors would exceed 8°F in only some 5 percent of the refuelings. This temperature prediction error equates to a 0.5 percent volume change. Thus, the accuracy of the model is considered to be very good.

Design Parameters and Cost of Temperature Adjustment

A study of the following six methods of temperature adjustment was made to estimate the cost and temperature measurement precision for each:

- . no temperature adjustment,
- . one time meter adjustment,
- . quarterly meter adjustment,
- . Radian temperature prediction model compensation,
- . mechanical temperature compensation, and
- . electronic temperature compensation.

The results of this study showed that on a dispense-cycle to dispense-cycle basis, temperature compensated meters could more accurately dispense a 60°F gallon than meters with no temperature compensation.

If temperature adjustment is made, the resulting proportional gasoline volume uncertainty ranges from ± 0.0075 ($\pm 0.75\%$) for one-time meter adjustment to ± 0.0006 (0.06%) for the electronic compensator. The cost of the temperature adjustment methods ranged from \$6 per meter to \$700 per meter with the more accurate temperature adjustment methods having higher per meter costs. Although no-temperature-compensation had relatively the worst temperature measurement accuracy, it requires no cost and should be considered as the U.S. consumer as a whole currently receives dispensed gasoline at a yearly average temperature near 60°F (61.6°F in 1975).

3.0 VALIDATION OF METHOD FOR OBTAINING AVERAGE DISPENSED GASOLINE TEMPERATURES FROM STRIP CHART DATA

3.1 Objective

In this section, a validation of the method used to reduce the dispensed gasoline temperature data is presented. The strip chart data were analyzed by selecting four representative dispense cycles for each service station and for each day. The gasoline temperatures were then read at the beginning, middle, and end of each cycle and averaged. This sampling plan is also discussed in the reference (1).

3.2 Summary

To validate the sampling plan, six locations with complete data were chosen providing varying geographical and climatic conditions. At each of the six stations, the strip charts for two different days were read at closely spaced time intervals in order to compute very accurately the average dispensed gasoline temperatures for the selected days and stations. These averages, then, were compared to the corresponding averages of the sampled data points.

The differences between the two average temperatures were no greater than two degrees Fahrenheit in any case, and no seasonal or geographical bias was observed. It was concluded, therefore, that the data reduction method is very adequate for the purposes of this study.

3.3 Data Averages Used to Validate Sampling Method

Table 3.3-1 presents the data averages which were used to validate the sampling method. Both the average of the closely spaced data and of the sampled data are presented. For any given day and station, the difference between the two averages is at most two degrees Fahrenheit, and the average of the magnitudes of the differences is about one degree. This is within the accuracy with which the temperature strip charts can be read. Thus, very little information if any was lost by this sampling technique.

Table 3.3-1 also presents the number of points used to compute the average of the more detailed data sets. Since the strip charts for recording dispensed temperatures were activated only when the pump was activated, and since the station operating hours and the number of refueling cycles are variable, the number of data points available on any given day is also variable.

TABLE 3.3-1
DISPENSED GASOLINE TEMPERATURES
AT VARYING LOCATIONS AND SEASONS

STATION LOCATION	DATE	AVERAGE DISPENSED TEMPERATURE		
		TECHNIQUE 1*	NO. OF POINTS**	TECHNIQUE 2***
San Francisco	8/28/75	68	112	67
San Francisco	1/10/76	59	112	57
Spokane	9/10/75	71	112	71
Spokane	12/13/75	40	112	41
Del City, OK	5/16/75	71	112	72
Del City, OK	12/19/75	50	84	49
Denver	5/2/75	53	84	54
Denver	12/9/75	47	112	47
Midland	5/20/75	81	175	82
Midland	12/16/75	63	175	61
Cleveland	1/28/76	36	56	35
Cleveland	9/26/75	65	84	67

* Technique 1: In this method, all dispense cycles for the day were read with a very small step size. The total number of points for each day and each station is given above. In this method, due to the large number of temperature points used, the error due to sampling a continuous data record is small.

** Number of measured temperature values read from the strip chart for Technique 1.

*** Technique 2: Average of the sampled dispensed gasoline temperature data for the indicated day. Four cycles and three points per cycle were read per day per station.

4.0 STUDY OF THE RELATIONSHIPS AMONG GASOLINE TEMPERATURES, AMBIENT TEMPERATURE, AND SERVICE STATION CHARACTERISTICS

4.1 Objectives

Temperature fluctuations cause variations in the volume of gasoline stored and dispensed at gasoline stations. These volume changes affect station operators and consumers.

The objective of the work discussed in this section is to investigate the effect of various conditions on gasoline temperatures. These conditions include primarily service station physical and operational characteristics and ambient temperatures.

4.2 Summary

The results indicate that ambient temperature is closely related to the underground tank temperature and the dispensed product temperature. Measurable relationships exist between physical station characteristics and the gasoline temperatures, but these relationships are not strong.

The monthly average ambient temperature has a high correlation of .92 with average dispensed product temperature and of .81 with average underground tank temperature. No parameter describing station characteristics correlates more highly than .22 with dispensed product temperature or more highly than .35 with underground tank temperature.

An additional correlation study was performed using the variations of the gasoline temperatures about the ambient temperature. The purpose was to determine whether station

characteristics correlate highly with gasoline temperatures after the random fluctuations of the ambient temperature have been removed. Again, no parameter describing a station characteristic had a correlation higher than .35 with the gasoline temperatures.

A further analysis was performed to investigate whether seasonal effects could be obscuring the relationships between station characteristics and gasoline temperatures. The results indicate that this is not the case.

4.3 Data and Variables Used in the Correlation Study

Table 4.3-1 lists the variables used in the correlation study, and Table 4.3-2 lists the means and standard deviations of the variables. The mean value $\bar{X}$ of a set of values X_i , $i = 1, 2, \dots N$, is defined

$$\bar{X} = \frac{\sum_{i=1}^N X_i}{N}$$

The standard deviation s is defined

$$s = \sqrt{\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N - 1}}$$

The standard deviation of a variable X has the same units as X does and is a measure of the amount of scatter X has. A variable which has the well-known normal distribution falls within plus and minus one standard deviation of its mean 68 percent of the time.

TABLE 4.3-1
VARIABLES USED IN CORRELATION STUDY

- (1) Beginning time of operation (hr.)
- (2) Ending time of operation (hr.)
- (3) Elevation above mean sea level (ft.)
- Variables (4) - (7) refer to the direction the station faces:
- (4) North*
- (5) South*
- (6) East*
- (7) West*
- (8) No-lead product* (only other possibility is leaded product)
- (9) Product throughput, 1000's of gal.
- (10) Tank depth (ft.)
- (11) Tank capacity (1000's of gallons)
- (12) Piping distance (ft.)
- (13) Pipe diameter (in.)
- (14) Pipe depth (in.)
- Variables (15) - (20) refer to the type of material covering the pipe:
- (15) Cement*
- (16) Soil*
- (17) Gravel*
- (18) Sand*
- (19) Asphalt*
- (20) Slag*
- Variables (21) - (23) refer to the material the pipe is made of:
- (21) Fiberglass*
- (22) Plastic*
- (23) Steel*
- (24) Average underground tank temp ($^{\circ}\text{F}$)
- (25) - (36) Month of operation, January - December, in succession*
- (37) Temperature of dispensed product first of cycle ($^{\circ}\text{F}$)
- (38) Temperature of dispensed product middle of cycle ($^{\circ}\text{F}$)
- (39) Temperature of dispensed product end of cycle ($^{\circ}\text{F}$)
- (40) Average temperature of dispensed product ($^{\circ}\text{F}$)
- (41) Monthly average, daily high temperature ($^{\circ}\text{F}$)
- (42) Monthly average, daily low temperature ($^{\circ}\text{F}$)
- (43) Monthly average, daily average temperature ($^{\circ}\text{F}$)
- (44) Ending minus beginning time of operation (hr.)
- (45) Pipe diameter/piping distance (in./ft.)
- (46) Pipe depth/pipe distance (in./ft.)
- (47) Pipe diameter x pipe depth (in.²)
- (48) Tank depth x tank capacity (ft. x 1000's of gallons)
- (49) Average underground tank temperature minus average ambient temperature ($^{\circ}\text{F}$)
- (50) Average dispensed product temperature minus average ambient temperature ($^{\circ}\text{F}$)
- (51) Absolute value of variable (49) ($^{\circ}\text{F}$)
- (52) Absolute value of variable (50) ($^{\circ}\text{F}$)

*Dummy variable with the value 1 if the indicated condition is true and 0 otherwise.

For example, if the pipe is made of fiberglass, then variable (21) is 1. Otherwise, the variable is 0. If two conditions apply, e.g., if the pipe is covered with soil and slag, then both dummy variables have the value .5.

All averages were computed on a monthly basis.



TABLE 4.3-2
MEANS AND STANDARD DEVIATIONS OF THE VARIABLES

<u>VARIABLE*</u>	<u>MEAN</u>	<u>STANDARD DEVIATION</u>
BEG T 1	3.27619	3.36779
END T 2	22.95476	1.41729
ELEV 3	826.39998	1142.47075
NORTH 4	.30238	.41531
SOUTH 5	.35000	.42934
EAST 6	.19524	.34927
WEST 7	.15238	.28624
NOLEAD 8	.18095	.38590
THRU P 9	37.26095	15.22945
T DPTH 10	3.34286	.47580
T CAP 11	8.24738	1.69287
P DIST 12	72.49048	62.19986
P DIA 13	1.65714	.47580
P DPTH 14	19.70952	7.81891
CEM 15	.06429	.23844
SOIL 16	.27619	.43463
GRAVEL 17	.00476	.06901
SAND 18	.58571	.49378
ASPH 19	.05238	.22333
SLAGE 20	.01667	.08997
FGLASS 21	.06190	.24156
PLSTIC 22	.04762	.21347
STEEL 23	.89048	.31304
UGTEMP 24	65.04125	14.42849
JAN 25	.03810	.19188
FEB 26	.05714	.23267
MAR 27	.06667	.25004
APR 28	.07619	.26594
MAY 29	.08571	.28061
JUNE 30	.10952	.31304
JULY 31	.10476	.30698
AUG 32	.09524	.29424
SEPT 33	.09524	.29424
OCT 34	.10000	.30072
NOV 35	.09524	.29424
DEC 36	.07619	.26594
DISP1 37	65.43873	13.87457
DISP2 38	66.59541	13.63855
DISP3 39	66.88536	13.67972
DISPAV 40	66.23871	13.62048
T HI 41	68.82651	14.58519
T LO 42	50.07649	14.10613
T AV 43	59.69630	14.15013
E-BGIN 44	19.67857	4.57320
14/13 45	.03236	.01947
15/13 46	.39610	.31147
14*15 47	32.72857	16.58493
11*12 48	27.60857	7.00070
UG-TAV 49	5.34495	8.91897
DP-TAV 50	6.54242	5.53398
ABS 49 51	8.42354	6.07929
ABS 50 52	7.26949	4.53153

*The variable names listed below are acronyms.
Full descriptions of the variables are given in
Table 4.3-1.

A total of 210 data points were used in the study. A "data point" consists of the set of values for all of the variables for a particular service station for a particular month. The data set which was employed is described in Table 4.3-3.

The 210 data points actually represent a large amount of information. The data set used in the correlation analysis includes 210 values of each of the 52 variables listed; thus, over 10,000 numbers are involved. Some of these, such as the dispensed product temperature, moreover, are monthly averages; thus, up to 31 original values were required to produce each one of these numbers.

Only observations for which the values of all 52 variables are available were included. Thus, there is no danger that different correlation coefficients were computed from data representing vastly different circumstances. It is felt that the sample size, 210, and the diversity of cases included are adequate for the purposes of this study.

4.4 Meaning of the Correlation Coefficient

The correlation coefficient is a very useful measure of the extent to which two variables are related. For this reason, the correlation has been used in this study to quantify relationships between gasoline temperatures and other variables.

The correlation coefficient r is defined as follows:

TABLE 4.3-3
DATA DESCRIPTION 210 DATA POINTS

<u>STATION</u>	<u>LOCATION</u>	<u>MONTHS</u>
6	Dorchester, Massachusetts	6,7,8
11	Ft. Lauderdale, Florida	1-6,8-10,12
12	Ft. Lauderdale, Florida	2-4,12
14	Linwood, Pennsylvania	10
16	West Covina, California	5-11
17	Southgate, California	6-11
18	Glendale, California	5-11
19	Pittsburgh, Pennsylvania	6-12
20	Shaler Turnpike, Pennsylvania	6-12
21	Des Plaines, Illinois	3-11
22	Palatine, Illinois	6-11
23	Farmington, Michigan	4-7
24	Lincoln Park, Illinois	7
25	Seattle, Washington	3-6,11
26	Seattle, Washington	4,5
28	Phoenix, Arizona	11
29	Cleveland, Ohio	1-12
30	Cleveland, Ohio	2-7,9-12
31	Houston, Texas	1-10
33	Louisville, Kentucky	2-7,9-12
34	Louisville, Kentucky	2-12
35	Burlington, Vermont	3-9
38	Atlanta, Georgia	10
41	Woodside, California	11,12
42	San Francisco, California	1,11,12
43	San Francisco, California	6-11
44	Menlo Park, California	11,12
45	Spokane, Washington	8-12
47	Chamblee, Georgia	1-8,12
49	Del City, Oklahoma	1-12
51	Denver, Colorado	2-10
55	Midland, Texas	1-2,5-12
56	Cleveland, Ohio	1-10,12

$$r = \frac{\sum_{i=1}^N (X_i - \bar{X}) (Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^N (X_i - \bar{X})^2 \sum_{j=1}^N (Y_j - \bar{Y})^2}}$$

where

N = number of data points,
 $\bar{X}$ = average of the X values, and
 $\bar{Y}$ = average of the Y values.

The correlation is a number between -1 and +1, and r^2 can be interpreted as the proportion of the variation in Y that can be "explained" or "predicted" in terms of X.

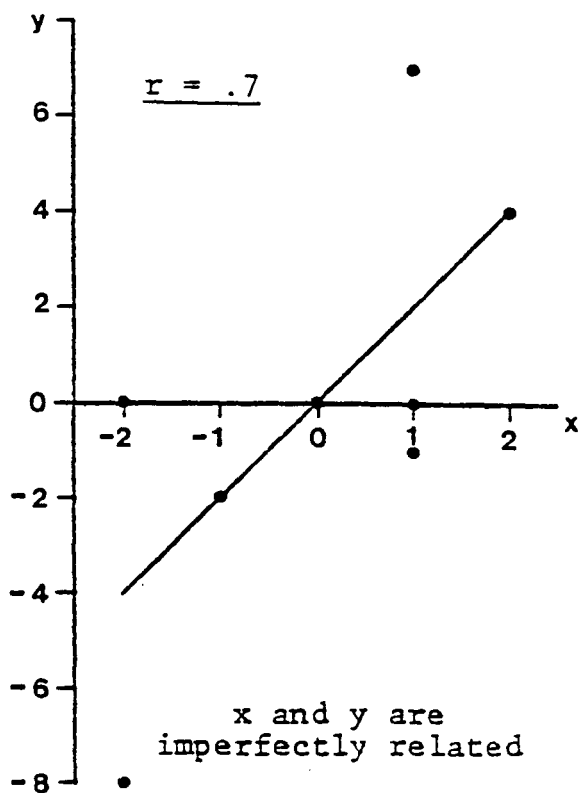
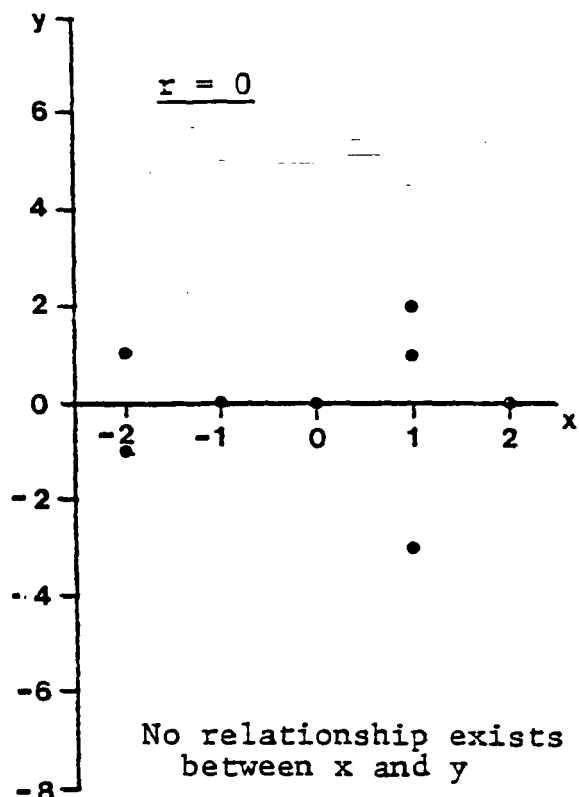
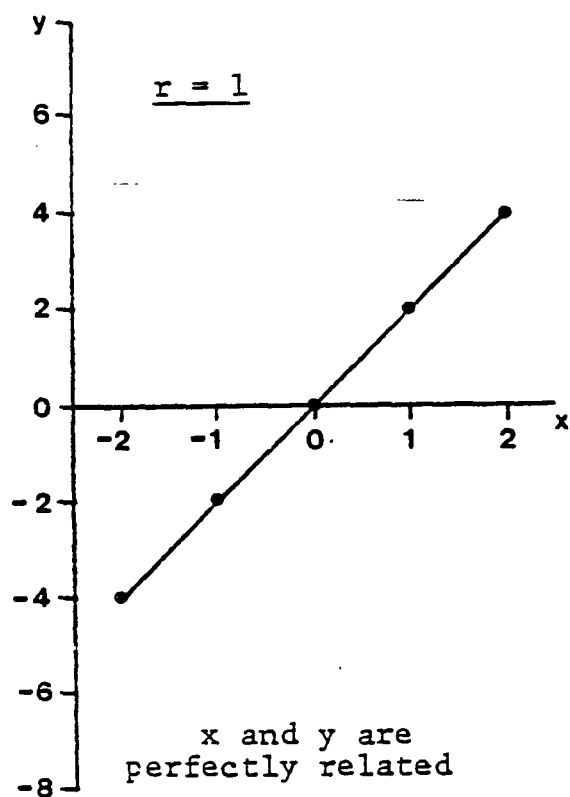
The correlation between the monthly average dispensed product temperature (Y) and average ambient temperature (X), for example, is .92. Since

$$(.92)^2 = .85$$

it follows that 85 percent of the total (station-to-station and month-to-month) variation in Y can be explained in terms of X.

Figure 4.4-1 illustrates the meaning of a non-negative correlation coefficient. A negative correlation between two variables occurs if one increases as the other decreases.

FIGURE 4.4-1 ILLUSTRATION OF THE MEANING OF CORRELATION, r



4.5 Criterion for Choosing Variables Which are Correlated

If two variables had no true relationship, their correlation computed from a finite data sample would still almost certainly be non-zero. The question, then, is how large should the correlation be to indicate a true or repeatable relationship between the two variables?

There is a small chance (one in twenty) that a correlation as large as .13 in magnitude would be obtained if the two variables being considered were unrelated. (The threshold correlation .13 was computed as a function of the sample size, 210.) Thus, if two variables have a correlation larger than .13 or less than -.13, there is a high probability that a true relationship exists between them. In this case, the correlation is said to be "statistically significant."

4.6 Correlations Between Gasoline Temperatures and Other Variables

The correlations between gasoline temperatures and the other variables are presented in this section. Only the correlations which are statistically significant, as is discussed in the preceding section, are listed.

The correlations of the other variables with monthly average dispensed product temperature and underground tank temperature are presented in Tables 4.6-1 and 4.6-2, respectively. The correlations of these two gasoline temperatures minus average ambient temperature are presented in Tables 4.6-3 and 4.6-4.

TABLE 4.6-1
VARIABLES THAT CORRELATE WITH AVERAGE
DISPENSED PRODUCT TEMPERATURE

<u>Variable</u>	<u>Correlation</u>	<u>Percent Explained*</u>
Station faces north?	-.16	3
Station faces east?	.19	4
Tank depth	-.16	3
Soil covering pipe?	.20	4
Sand covering pipe?	-.18	3
Fiberglass pipe?	.22	5
Steel pipe?	-.22	5
Underground tank temperature	.86	74
January?	-.18	3
February?	-.22	5
March?	-.30	9
April?	-.22	5
June?	.20	4
July?	.33	11
August?	.33	11
September?	.20	4
November?	-.14	2
December?	-.25	6
Dispensed product temperature, beginning of cycle	.988	98
Dispensed product temperature, middle of cycle	.996	99
Dispensed product temperature, end of cycle	.991	98
Average daily high ambient temperature	.89	79
Average daily low ambient temperature	.92	85
Average ambient temperature	.92	85
Tank depth times tank capacity	-.15	2

* This column gives the percent of the variance in dispensed product temperature that can be explained in terms of the variable at the left. The percent is $100r^2$. The sum of the percentages is greater than 100 because the variables listed are not independent.

TABLE 4.6-2
VARIABLES THAT CORRELATE WITH
UNDERGROUND TANK TEMPERATURE

<u>Variable</u>	<u>Correlation</u>	<u>Percent Explained</u>
Station faces north?	-.21	4
Station faces east?	.21	4
Tank depth	-.17	3
Pipe depth	.19	4
Pipe covered with soil?	.19	4
Pipe covered with sand?	-.25	6
Fiberglass pipe?	.32	10
Plastic pipe?	.14	2
Steel pipe?	-.35	12
January?	-.13	2
February?	-.20	4
March?	-.27	7
April?	-.22	5
July?	.21	4
August?	.29	8
September?	.23	5
October?	.14	2
December?	-.26	7
Dispensed product temperature, beginning of cycle	.84	71
Dispensed product temperature, middle of cycle	.86	74
Dispensed product temperature, end of cycle	.86	74
Dispensed product temperature, average	.86	74
Average daily high ambient temperature	.78	61
Average daily low ambient temperature	.81	66
Average ambient temperature	.81	66
Pipe diameter times pipe depth	.13	2

TABLE 4.6-3
VARIABLES THAT CORRELATE WITH THE QUANTITY:
UNDERGROUND TANK TEMPERATURE MINUS AVERAGE
AMBIENT TEMPERATURE

<u>Variable</u>	<u>Correlation</u>	<u>Percent Explained</u>
Station faces south?	.13	2
Station faces west?	-.20	4
Pipe depth	.26	7
Asphalt covering pipe?	.20	4
Fiberglass pipe?	.33	11
Steel pipe?	-.23	5
Underground tank temperature	.34	12
May?	-.26	7
June?	-.24	6
July?	-.19	4
September?	.19	4
October?	.21	4
November?	.26	7
Average daily high ambient temperature	-.30	9
Average daily low ambient temperature	-.26	7
Average ambient temperature	-.28	8
Pipe diameter times pipe depth	.14	2
Tank depth times tank capacity	.20	4
Dispensed product temperature minus average ambient temperature	.55	30

TABLE 4.6-4

VARIABLES THAT CORRELATE WITH THE QUANTITY:DISPENSED PRODUCT TEMPERATURE MINUS AVERAGEAMBIENT TEMPERATURE

<u>Variable</u>	<u>Correlation</u>	<u>Percent Explained</u>
Station faces west?	-.17	3
Pipe diameter	-.14	2
Cement covering pipe	-.27	7
Fiberglass pipe?	.24	6
Plastic pipe?	-.27	7
April?	-.16	3
May?	-.24	6
June?	-.18	3
September?	.17	3
November?	.16	3
December?	.23	5
Average daily high ambient temperature	-.32	10
Average daily low ambient temperature	-.25	6
Average ambient temperature	-.29	8
Underground tank temperature minus average ambient temperature	.55	30

4.7 Possible Seasonal Effects

The possibility that service station characteristics affect gasoline temperatures differently in different seasons was considered. A particular possibility is that certain characteristics might consistently affect the gasoline temperatures away from the ambient, but that the change might be a temperature increase in some months and a decrease in other months. The greater the depth of the underground tank, for example, the more the tank is insulated from the air, and thus, the greater the absolute value of the difference between the underground tank temperature and the ambient temperature is likely to be.

To investigate the possibility of this type of effect, the correlations were computed between the service station characteristics and the absolute values of

- (1) underground tank temperature minus average ambient temperature and
- (2) dispensed product temperature minus average ambient temperatures.

None of the correlations was greater than .36 in magnitude; thus, the effect in question does not have a large influence.

5.0 VAPOR RECOVERY: VAPOR SHRINKAGE AND GROWTH

5.1 Background and Objectives

In this section, a comparison of vehicle tank temperatures and dispensed product temperatures is presented. The motivation for this comparison involves vapor recovery systems which could be used in automobile refueling, as is discussed below. The study presented here, however, involved only the temperature data; no direct testing of vapor recovery hardware was performed.

One type of vapor recovery system returns the vapors displaced from the automobile's gasoline tank to the underground storage tank, rather than allowing them to escape into the atmosphere. If the vehicle tank temperature is higher than the temperature of the dispensed gasoline, then the vapors are cooled as they mix with the gasoline and exit from the tank. The cooled vapors, then, occupy less volume than did the gasoline which displaced them. Thus, the returned vapors can be contained in the underground tank; there will be no purging of excess vapors to the atmosphere.

The reverse situation, where the vehicle tank temperature is less than the dispensed gasoline temperature, is conducive to vapor expansion, which causes part of the vapor to escape the underground tank into the atmosphere.

In the reference, the distributions of the vehicle tank temperature minus the dispensed product temperature are presented by month and region. When this difference is positive, vapor shrinkage occurs.

In this section, the distributions are presented for cases when the ambient temperature is between 65 and 85°F. Thus, region-to-region and month-to-month climatic differences are minimized in the data sample, and extreme ambient temperatures are eliminated.

5.2 Summary

In 89% of all refuelings examined, when ambient temperature was between 65° and 85°F, conditions favored vapor shrinkage. There were very few cases in which conditions strongly favored vapor growth; the dispensed product temperature exceeded the vehicle tank temperature by more than 5°F in only 5% of the cases and by more than 10°F in only 1% of the cases.

Conditions also favored vapor shrinkage in every region. For each individual region, the vehicle tank temperature exceeded the dispensed product temperature at least 73% of the time. Excluding Region 5, the minimum percentage is 88%.

Thus, the results indicate that temperature conditions for vapor shrinkage would occur the clear majority of the time. It should be pointed out that temperature differential is but one of many variables that can cause shrinkage/expansion.

5.3 Distributions of Vehicle Tank Temperature Minus Dispensed Product Temperature

The distribution of vehicle tank temperature minus dispensed product temperature for all stations is displayed in Table 5.3-1 and in Figure 5.3-1. The distributions for the individual regions are presented in Appendix A.

TABLE 5.3-1
DISTRIBUTION OF TEMPERATURE DIFFERENCE
FOR ALL STATIONS: AMBIENT TEMPERATURE
BETWEEN 65°F AND 85°F

MONTH	NO. STATIONS	AVERAGE AMBIENT TEMP.	VEHICLE TANK TEMP. MINUS DISPENSED PRODUCT TEMP.																	
			-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55
			TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO
			-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
MAR	172	74.4	0.00	0.00	0.00	0.00	0.03	0.12	0.10	0.10	0.10	0.07	0.08	0.09	0.07	0.11	0.06	0.02	0.00	0.01
APR	130	74.7	0.00	0.00	0.00	0.02	0.04	0.03	0.08	0.15	0.12	0.16	0.09	0.14	0.05	0.06	0.02	0.00	0.00	0.00
MAY	352	74.1	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.21	0.20	0.18	0.18	0.06	0.03	0.02	0.00	0.00	0.00
JUN	482	76.7	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.19	0.23	0.19	0.09	0.06	0.05	0.02	0.01	0.01	0.01	0.00
JUL	352	78.1	0.00	0.00	0.00	0.02	0.02	0.05	0.11	0.16	0.20	0.16	0.13	0.06	0.05	0.02	0.00	0.00	0.00	0.00
AUG	550	77.1	0.00	0.00	0.00	0.00	0.04	0.07	0.15	0.22	0.17	0.10	0.09	0.05	0.03	0.00	0.00	0.00	0.00	0.00
SEP	384	75.8	0.00	0.00	0.01	0.03	0.05	0.05	0.21	0.14	0.16	0.14	0.12	0.06	0.00	0.01	0.01	0.00	0.00	0.00
OCT	427	74.9	0.00	0.00	0.00	0.00	0.00	0.02	0.21	0.42	0.15	0.08	0.06	0.04	0.00	0.01	0.00	0.00	0.00	0.00
NOV	156	69.2	0.00	0.00	0.00	0.04	0.09	0.13	0.06	0.19	0.18	0.14	0.09	0.04	0.03	0.00	0.00	0.00	0.00	0.00
DEC	217	69.2	0.00	0.00	0.00	0.07	0.20	0.18	0.14	0.05	0.15	0.05	0.08	0.03	0.01	0.00	0.00	0.00	0.00	0.00
ALL	3226	75.2	0.00	0.00	0.00	0.01	0.04	0.06	0.13	0.20	0.18	0.13	0.11	0.06	0.04	0.02	0.00	0.00	0.00	0.00

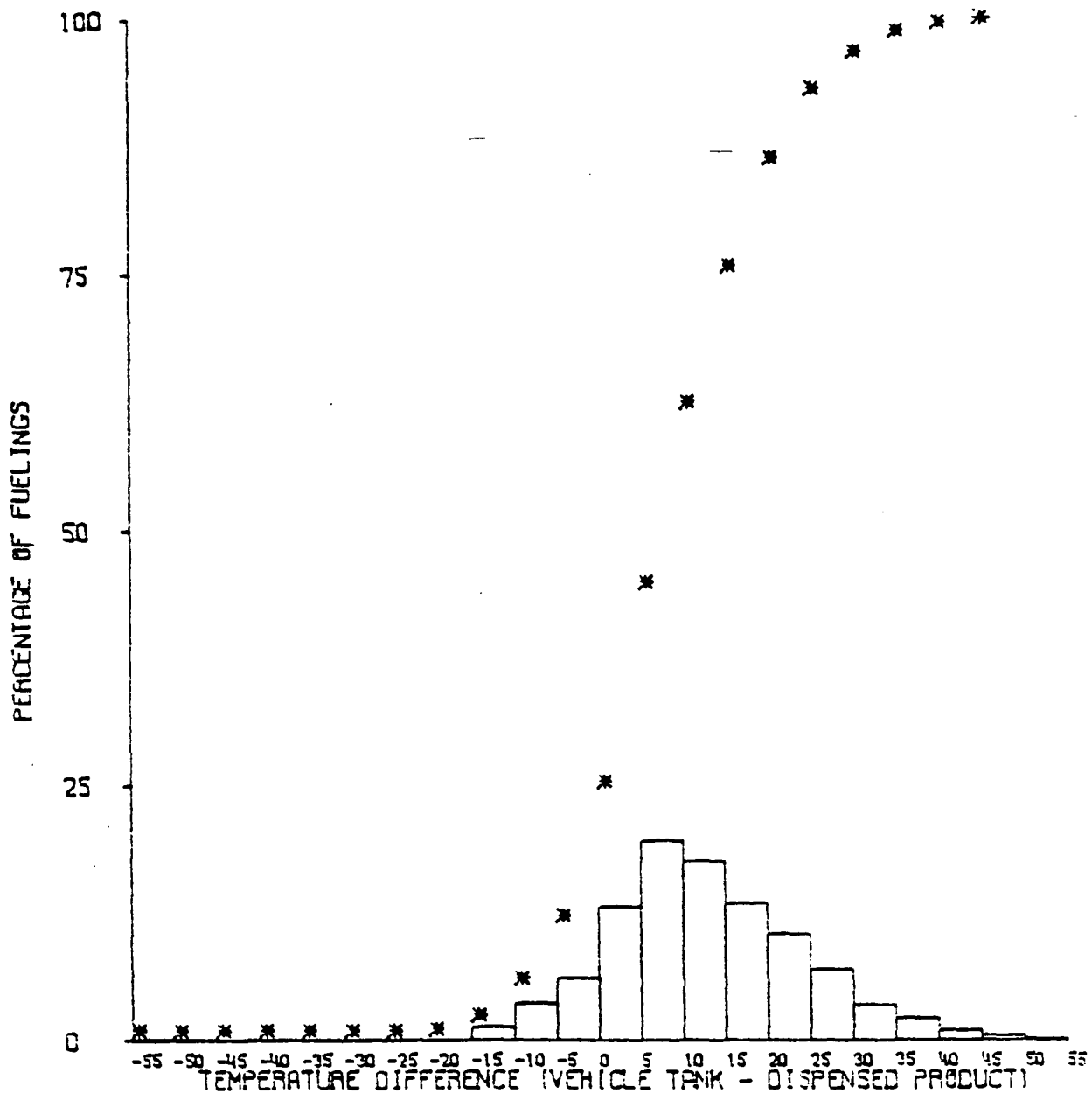


FIGURE 5.3-1
DISTRIBUTION OF VEHICLE TANK TEMPERATURE
MINUS DISPENSED PRODUCT TEMPERATURE FOR
ALL STATIONS: AMBIENT TEMPERATURE
BETWEEN 65°F AND 85°F

6.0 AMBIENT TEMPERATURE DURING OPERATING HOURS OF SERVICE STATIONS

6.1 Objectives

The data base used in the study reported herein and in the preceding study includes the daily maximum, minimum, and average ambient temperatures. The average temperature during service station operating hours, as such, is not included in the data base. The primary objective of this section is to investigate the differences between the 24-hour average ambient temperature and the average temperature during operating hours.

It was first necessary to develop a model to predict ambient temperature as a function of time of day. Then this model was used to compute the average ambient temperature during operating hours.

6.2 Summary

The 24-hour-average ambient temperature and average ambient temperature during hours of service station operation are presented by month and region. Another set of results, in which the operating hours were arbitrarily set to 6 a.m. until 9 p.m., are also presented.

The primary conclusion of this section is that the use of the 24-hour-average ambient temperature in place of the average during station operating hours has a small impact. The average temperature during operating hours is generally only a few degrees (0-4°F) higher than the 24-hour average.

6.3 Temperature Data

The temperature data for all stations are presented in Table 6.3-1. The temperature data for each region and the average operating hours are presented in Appendix B.

6.4 Development of a Mathematical Model for Ambient Temperature as a Function of Time of Day

As is stated in the summary of this section, the data base includes only the 24-hour minimum, maximum, and average ambient temperatures for each day. It was necessary, therefore, to develop a model to predict hour-by-hour temperatures, so that the average temperatures during station operating hours could be computed.

The model developed has the following form:

$$T = T_{\min} + 1.96802 - .17325t + (T_{\max} - T_{\min}) \left[.17547 - .09858t + .02032t^2 - .00071t^3 \right]$$

where

t = time of day (hour)

T = ambient temperature ($^{\circ}\text{F}$) at time t ,

$T_{\max}$ = daily maximum temperature, and

$T_{\min}$ = daily minimum temperature.

The agreement between the equation and the data from which it was developed is indicated by the correlation coefficient of .88 and the standard error of 3.79°F . The "standard error" can be thought of as the standard deviation of the differences between the values predicted by the equation and the measured temperature data points.