CORRELATION OF ROOM AIR AND WALL CAVITY FORMALDEHYDE LEVELS WITH ENVIRONMENTAL FACTORS, IN UFFI HOMES:
FROM THE STATISTICAL MASTER OF FEBRUARY 1, 1986.

(47 pages)

by

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January 26, 1987

Authorized for release:
S. Hall

Date: Feb 2/87
File Number: 10305-30

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Introduction

During the UFFI Assistance Program, room air and wall cavity formaldehyde levels, moisture levels, and environmental data were collected. Formaldehyde measurements were carried out at several stages in the Program, both before and after the implementation of corrective measures. Environmental data were derived from meteorological summaries from 53 weather stations across Canada, and for some homes, similar data were collected on-site during testing.

Passive room air formaldehyde measurements were made with the AQRI PF-1 formaldehyde monitor (dosimeter). This dosimeter provides a time-weighted average formaldehyde level over a period of a week. Since its limit of detection is 0.01 ppm, levels of formaldehyde at or below this level are excluded from statistical analyses.

The first testing stage where room air formaldehyde levels were determined was the Screening Test (SCR). Based on the levels obtained during this test, participants in the program were selected for Full Scale Testing (FST), or the Modified Remedial Information Procedure (MRIP).

During MRIP testing, two wall cavities as well as two room air measurements were made. The wall cavity tests were conducted with Dräger 0.5/a formaldehyde detection tubes, whose range is from 0.5 to 10.0 ppm.

A variety of data were collected during the FST. As well as dosimeter testing, up to 120 Dräger tests and up to thirty wood moisture measurements were made, the number of the tests depending on the size and construction of the home. General weather conditions were also determined.

Early in the Program, active Oakridge tests were carried out at FST in order to determine indoor and outdoor air formaldehyde levels. These tests were terminated at the end of 1982 for all provinces except Newfoundland where they were continued until November, 1983.

Since at zero degrees Celcius the Dräger tubes cease to function, at temperatures approaching zero, the results of Dräger Tests are questionable, especially when one considers that the walls were probably exposed to lower temperatures during the night. Therefore, FST's performed during the winters of 1983/84 and 1984/85 had "Bag Tests" as well as wall cavity tests. UFFI core samples, taken from the wall cavity locations where the usual Dräger tests were conducted, were placed in plastic bags and allowed to equilibrate to room temperature and relative humidity. Once equilibrated, the formaldehyde levels were measured with the Dräger tubes. A maximum of 60 wall cavity and 60 corresponding "Bag Tests" could be performed in one home.

The data from the "Bag Tests" override those of the corresponding wall cavity Dräger tests in the statistical data files. When there were no "Bag Tests", wall cavity Dräger results are excluded from the data files if the outside temperature during the test was less than five degrees Celcius. Thus, the Dräger data include wall cavity tests and "Bag Tests". In this report, they are referred to collectively as Dräger tests.

General weather conditions, that is, relative humidity, dry bulb temperature, windspeed and the percentage of cloud cover were also determined during the FST. For those homes where bag tests were performed, the indoor relative humidity and temperature were recorded and override the outside relative humidity and dry bulb temperature. The combined indoor and outdoor temperatures are referred to as temperature (FTR) in this report.

Wood moisture measurements, at FST, were made using two types of resistivity meter having limits of detection of 6% and 10%, respectively.

For statistical purposes, Dräger formaldehyde levels below the limit of detection had to be replaced by a numerical value. Thus, levels of formaldehyde of $<$0.5 ppm were converted to 0.25 ppm. Wood moisture levels below the limit of detection are excluded from calculations of means since the levels which are of concern are the elevated ones, and with two limits of detection, the choice of an appropriate level is problematic.

Post-corrective measures formaldehyde levels were determined at the Audit Inspection stage (AI), where two wall cavity and two room air measurements were made. Room air measurements were also made at the Modified Audit Inspection (MAI) or Homeowner Audit (HOA) stages. These three testing stages are collectively known as PCM (Post-Corrective Measures) testing.

At the beginning of the Program, the FST was the only testing stage where weather data were collected. It became clear early on that analyses of formaldehyde levels obtained during other tests with respect to the period of testing (month and year), rather than with individual weather data would be inadequate. There are too many weather and other factors in a home which can influence formaldehyde levels for a simple, global analysis to be meaningful. This can be seen in Graphs I and II which depict pre- and post-corrective measures room air formaldehyde levels, by period of testing. Although there are maxima and minima in the summers and winters respectively, there are also several secondary peaks which require more in-depth analysis.

The weather data collected from the weather stations included mean temperature, mean relative humidity, mean windspeed, and mean hours of bright sunshine insolation effective (hours of sun). From these data, mean absolute humidity was calculated.

For each day at each weather station, a seven day average was calculated for each of the above variables. For example, the seven day average temperature for a particular day would be the sum of the mean temperatures for that day plus the three preceding and three following days, divided by seven. These seven day averages were entered into a separate computer file named the Weather Analysis Subsystem (WASS). In this report, any data which came from this system are seven day averages and are identified by the acronym "WASS".

In comparing a weather variable such as mean temperature (WASS) with room air formaldehyde levels, which are also seven day averages, the mean temperature (WASS) for the fourth day is used. For Dräger formaldehyde levels which are short term tests, the same weather data as for the corresponding room air levels are used. Therefore, formaldehyde levels from the wall cavities from day 1 are compared to weather data (WASS) from days 1 to 7, inclusively.

An automated correlation between weather variables or other environmental factors and formaldehyde levels was attempted. Since computer time for the test run alone, which was made on a minute subset of the database, itself cost more than budgeted for all correlation calculations, it was decided that correlations on the entire database could not be made. Instead, the data were compiled in ranges and the mean values of the population of these ranges were used in the correlations rather than the raw data. Since this approximation could potentially result in significant error, these correlations should be interpreted only as indicating trends.

In some cases, the Graphs attached include both the mean and the maximum formaldehyde levels. Both were included where, depending on whether the mean or the maximum was used, there was a difference in the correlations.

Results

Correlations With Dräger Formaldehyde Levels

For both MRIP and FST, there was a strong correlation between the mean outside temperature (WASS) and the Dräger formaldehyde levels. Similarly, there was a strong correlation between the mean absolute humidity (WASS) and the Dräger formaldehyde levels. These relationships can be seen in Graphs VIII F and M, IX Fa and b, and IX M.

That Dräger formaldehyde levels are strongly correlated with seven day average temperatures and humidities indicates that UFFI responds better to general or long term environmental conditions than to short term conditions. Similar effects have been observed in other materials containing urea formaldehyde resins such as particleboard.[2] A short-term increase in absolute humidity after an extended period of low humidity results in decreased formaldehyde emissions, due to sorption effects. Long-term increases in humidity after extended periods of low humidity result in increased formaldehyde emissions, due to increased hydrolysis. Graphs VIII F and M show the effects of temperature (WASS) while Graphs IX F a and b and IX M show that of humidity (WASS).

With UFFI, formaldehyde emissions must be related to long-term conditions, as with particleboard, since there is a strong and direct relationship between Dräger formaldehyde levels and mean outside temperature and humidity (WASS).

Dräger formaldehyde levels are well correlated with the mean hours of sun (WASS). Although the heating effect of increased sunshine would not be uniform around the home, this effect appears to have been strong enough that the mean Dräger levels vary directly with the mean hours of sun (WASS). Since the mean hours of sun (WASS) are also seven day averages, long-term effects appear to be predominant. The effects of sun are seen in Graphs X Fa and b, and X M.

There was no correlation between relative humidity (WASS) and Dräger formaldehyde levels, as can be seen in Graph XII F. Although this was true for the seven day, outside relative humidity (WASS), there was a correlation for the relative humidity (FTR) on the day of the test as shown in Graph XII. The latter humidity was the outside measurement except for the "Bag Tests" where the relative humidity is that of the indoor air, and is much lower than in summer time when similarly warm temperatures are reached outside. The formaldehyde levels for the points which include the "Bag Tests" are correspondingly low. It should be noted that the "Bag Test" data cannot be isolated from the wall cavity data.

The Dräger formaldehyde levels are poorly correlated with the temperature (FTR) taken on the day of the test (see Graph XIII), a mixture of indoor and outdoor temperatures, because of the differences in humidity which have a greater effect on formaldehyde emissions than does temperature. The humidity effects are discussed in the section "Correlations With Indoor Air Formaldehyde Levels."

It was interesting to note that while there was no real correlation between the Dräger formaldehyde levels and the windspeed (FTR) measured at the time of the test, (Graph XIV), there was a good correlation between wall cavity levels and the seven day average windspeed (WASS) as seen in Graphs XI Fa and b, and XI M.

Both windspeed measurements are taken from the weather office, the difference being that the windspeed (WASS) represents long-term conditions whereas the windspeed (FTR) is a short-term measurement which could be misleading if the conditions at the time of the test were substantially different from the general conditions.

That the Dräger formaldehyde levels are not correlated with the windspeed (FTR) but are with the mean windspeed (WASS), indicates yet again that the overall environmental conditions are very important factors for UFFI.

The FST data collected did not include hours of sun, but did indicate whether the cloud cover was greater or less than 50 percent. There was a correlation between the percent of homes with cloud cover less than or equal to 50 percent and the wall cavity formaldehyde levels (Graph XV). This is similar to the effect of increased hours of sun.

As discussed in the Introduction, wood moisture levels below the limit of detection were not included in the calculations of mean wood moisture levels. Thus, correlations were made with the mean values of the detectable wood moisture levels (Graph XVI) and with the percentage of wood moisture levels below the limit of detection (Graph XVII). Dräger formaldehyde levels varied directly with detectable wood moisture levels, and inversely with the percent of non-detectable wood moisture levels; that is, the higher the moisture content of the cavity, the higher the formaldehyde level.

There was a direct relationship between the mean absolute humidity (WASS) of the outside air and the mean wood moisture level at FST (Graph XVIII). Other factors which would influence the wood moisture levels, such as sources of humidity inside the home, the condition of the air envelope and the temperature difference between the indoor air and the wall cavity, would account for the scatter seen in this graph. That the wood moisture levels varied directly with the absolute humidity (WASS), especially at higher wood moisture levels, is in contrast with the theory that the residual water from the wet UFFI at installation is responsible for wood moisture levels.

Graphs XIX and XX depict the relationship between the mean Oakridge formaldehyde levels and the Dräger formaldehyde levels or the room air dosimeter formaldehyde levels, respectively.

There was a direct relationship between the Dräger formaldehyde levels and the Oakridge formaldehyde levels (room air, active measurement). This was a good correlation, in spite of the low sample size for Oakridge tests. There were only 1,461 homes across Canada with Oakridge results, whereas there were 11,201 homes with dosimeter results.

It is interesting to note that in comparison to the Oakridge, the dosimeter levels were lower. This difference could have been due to difficulties with the Oakridge measurements, the low sample size for Oakridge tests, under-recovery with the dosimeters, or a reflection of higher levels during the day which the short duration Oakridge test would measure and the lower overall levels which the long-term dosimeter test would measure. It is not possible, however, to determine what factor(s) made the difference.

Correlations With Indoor Air Formaldehyde Levels

Room air formaldehyde levels vary directly with the wall cavity formaldehyde levels. As can be seen in Graphs VII F and M, the relationship is strong, especially at FST.

As discussed in the introduction, homeowners were selected for MRIP or FST depending on the formaldehyde levels at SCR. Throughout most of the Program, those having higher levels of formaldehyde ($>$0.05 ppm) were selected for FST, and those with lower levels ($\leq$0.05 ppm) were selected for MRIP. Although the selection criteria did change for a period of time, the majority of selections were based on these criteria. This can be seen by comparing SCR and MRIP or SCR and FST levels. Homes with both SCR and MRIP results had mean SCR levels of 0.042 $\pm$ 0.028493 ppm while those with both SCR and FST results had mean $\bar{\text{SCR}}$ levels of 0.075 $\pm$ 0.056109. These two means are significantly different at a confidence level of 95%.

Not only did homes selected for FST have higher room air formaldehyde, but also they had higher wall cavity formaldehyde levels, as can be seen in the table below.

Table I

Test Type	Mean Dräger Formaldehyde Level	Maximum Dräger Formaldehyde Level
FST	2.55 ppm	4.29 ppm
MRIP	1.63 ppm	1.99 ppm

That the relationship between room air and Dräger formaldehyde levels was stronger at FST than at MRIP could be attributable to UFFI being the major source of formaldehyde for FST homes, and to minimal offgassing from UFFI for MRIP homes.

Consistent with this correlation were the findings, discussed below, that the room air formaldehyde levels tended to respond to the various environmental variables measured, in the same way as did the Dräger readings. Understandably, however, for some variables such as windspeed and hours of sun exposure, the correlations with room air levels were considerably weaker than those with Dräger values.

A correlation was made between pre-corrective measures room air formaldehyde levels and the outside absolute humidity (WASS). It was found that as the absolute humidity increased, the room air formaldehyde levels also increased, as can be seen in Graphs IIIS, F, and M. The coefficients of determination indicate that the relationship observed is a definite trend, but that there is some scatter, which could be the result of other factors influencing the formaldehyde levels.

Studies made on urea-formaldehyde show that absolute humidity increases cause increased long-term hydrolysis. Increased temperature can also result in increased formaldehyde emissions, but to a lesser extent than increased humidity.[1]

An increase in formaldehyde levels in UFFI homes with increased outside temperature (WASS) was observed. Graphs IVS, F, and M show a direct relationship between room air formaldehyde levels and outside temperature (WASS). The correlations were made with the temperature in degrees Kelvin, but in order to increase the ease of interpretation of the graphs, the scale provides temperature in degrees Celcius.

That increased temperature has a lesser effect than increased humidity could not be seen in these graphs. Considering the uncertainty which may have been introduced by the approximation made in the method of statistical analysis, as discussed above, and the presence of other factors which could influence formaldehyde levels as well as other potential sources of formaldehyde, it is not surprising that the difference was not observed. Also, periods of the year with high temperature usually have high absolute humidity and in the winter, when the temperatures are much lower, the absolute humidity is also lower. Thus, separation of the two factors does not usually occur.

There was, however, an occasion where such a separation did occur. As discussed in the introduction, when there were "Bag Test" data, the temperature (FTR) and the relative humidity (FTR) used in the analysis were the data for the room air inside the house, not the outside temperature. Thus, during the winters when "Bag Tests" were conducted, the temperature (FTR) is high but the relative humidity (FTR) is low.

If the effects of temperature were greater than those of humidity, a correlation of temperature (FTR) (which includes indoor and outdoor temperatures) and Dräger levels (a mixture of indoor and "outdoor" measurements) should be better than one of mean outside temperature(WASS) and Dräger levels. The opposite would be true if the effects of humidity were greater than those of temperature. The formaldehyde levels would be better correlated to the outside temperature (WASS) which is high when the humidity to which UFFI is exposed is high, and low when the humidity to which UFFI is exposed is low. As can be seen in Graphs VIII F ($r = 0.76$) and XIII ($r = 0.35$), the Dräger Formaldehyde levels are better correlated to the mean outside temperature (WASS) than to the mixture of indoor and outdoor temperatures which comprise the temperature (FTR). Thus, the effects of humidity on formaldehyde emissions from UFFI are greater than those of temperature.

Windspeed (WASS) was only weakly correlated with room air formaldehyde levels, as can be seen in Graphs VS and M. For FST formaldehyde levels, the trend to decreased formaldehyde levels with increased windspeed was somewhat stronger, as can be seen in Graph V F.

Poor correlations should be expected since windspeed can, depending on the wind direction, the condition of the air envelope in the house, and the presence or absence of functioning combustion devices or exhaust fans, cause increased or decreased formaldehyde levels. The location of the test site within the home can also make a substantial difference. The same environmental conditions can lead to either positive or negative air pressure zones in the home, and can alter formaldehyde levels significantly.

A location with negative air pressure, for example, could have increased formaldehyde levels due to an increase in air passing from outside the home, through the wall cavities containing UFFI, carrying in formaldehyde gas. In this case, formaldehyde levels could be elevated.

Should higher windspeed cause an increase in infiltration of air through gaps in windows or door frames, or through open windows, the increased ventilation would result in dilution of the formaldehyde gas.

Room air formaldehyde levels were also poorly correlated with the hours of sun (see Graphs VIS, F, and M). In the Spring, Summer, and Fall, increased hours of sun correspond to increased temperatures in the wall cavities and hence, increased formaldehyde emissions. In the winter, however, the heating effect would be offset by the lower temperatures which usually accompany sunny periods. Also, if the dosimeters are placed, for example, in a room with a northern rather than southern exposure, the local heating effect would not be felt. Since increased hours of sun would not necessarily result in increased formaldehyde, poor correlations are probable.

Summary

Both room air and wall cavity formaldehyde levels were found to vary in a similar fashion with environmental conditions. In some cases, for example windspeed and hours of sun exposure, the room air correlations were weaker than those with the Dräger levels.

The formaldehyde levels varied directly with the outside air absolute humidity (WASS) and temperature (WASS), and the hours of sun (WASS). The Dräger formaldehyde levels also varied directly with the percentage of homes having cloud cover less than or equal to fifty percent and the wood moisture levels.

Wood moisture levels varied directly with the mean absolute humidity (WASS).

For both wall cavity and room air formaldehyde, increasing mean windspeed resulted in decreased formaldehyde levels, especially for the former. There was also an inverse relationship between wall cavity formaldehyde levels and the percentage of wood moisture measurements which were below the limit of detection.

Dosimeter room air measurements, Oakridge room air measurements and Dräger measurements were all well correlated.

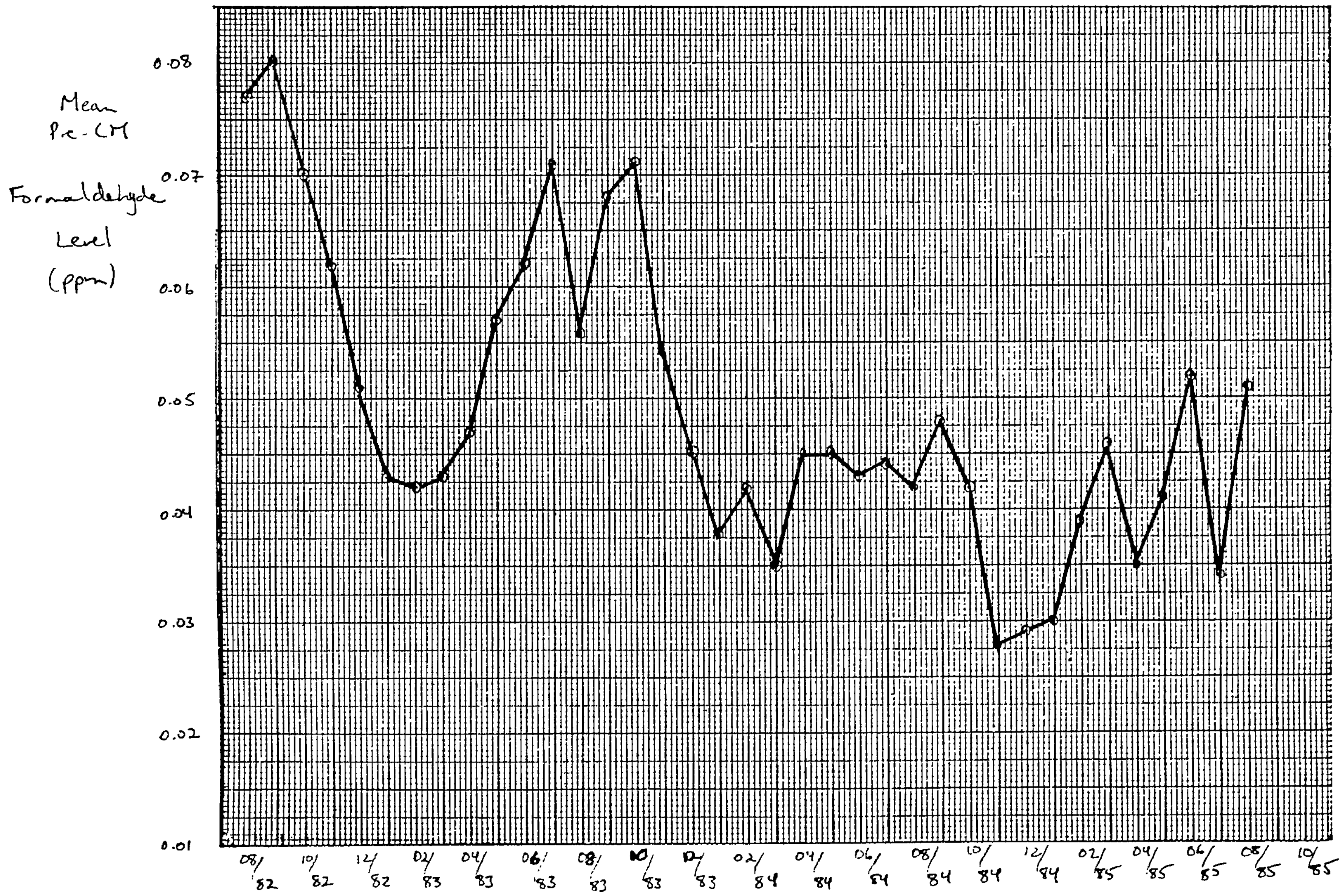
References

1) Meyer, Beat. Urea Formaldehyde Resins. London: Addison-Wesley, 1979.

2) Pickrell, J.A.; Griffiths, L.C.; Mokler, B.V.; Kanapilly, G.M.; Hobbs, H. "Formaldehyde Release From Selected Consumer Products: Influence of Chamber Loading, Multiple Products, Relative Humidity, and Temperature". Environ. Sci. Technol. 1984: 662-688.

Graph I:

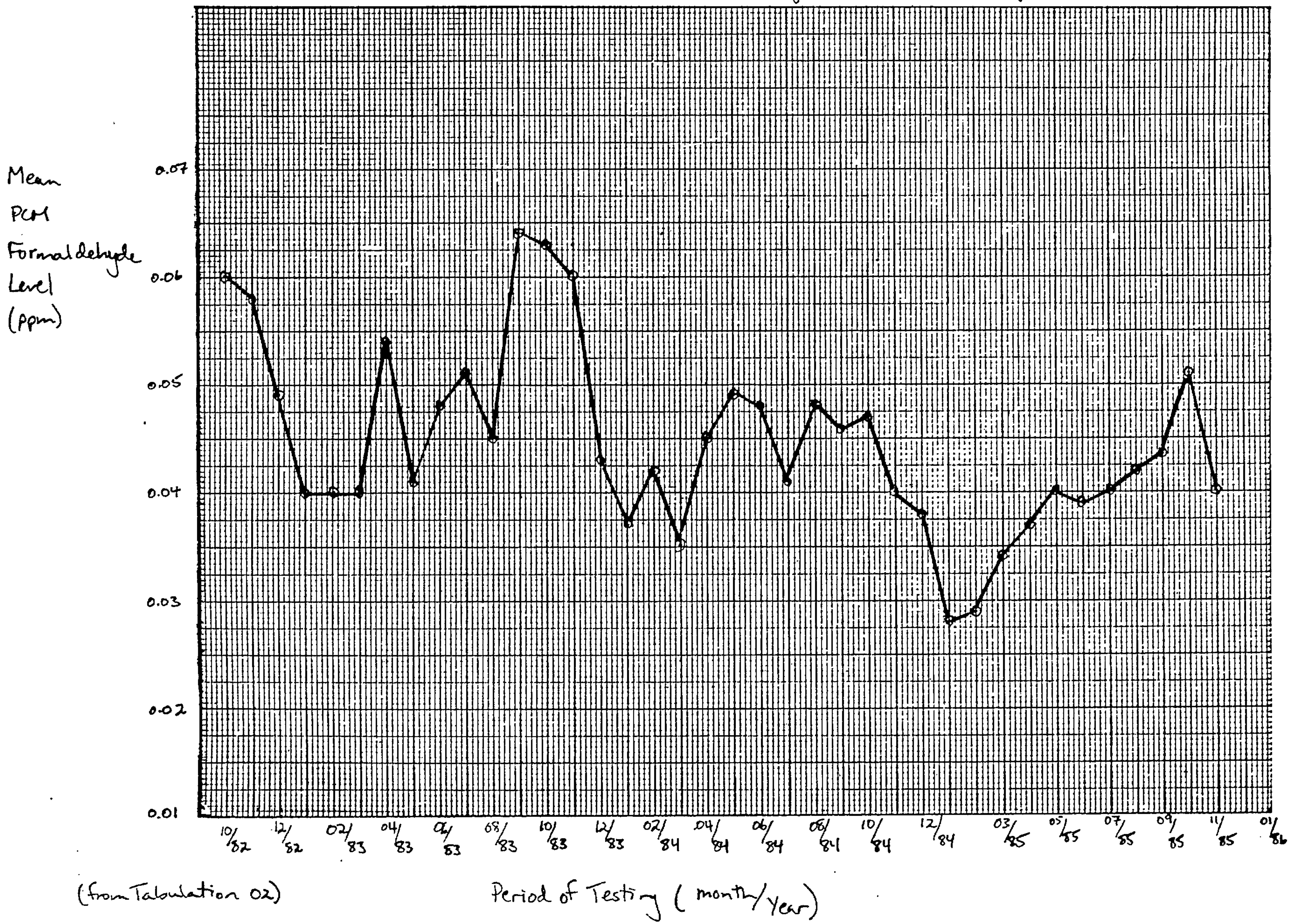
Mean Pre-Corrective Measures Room Air Formaldehyde Levels (Pre-CM), by Period of Testing.



(from Tabulation 02)

Graph II:

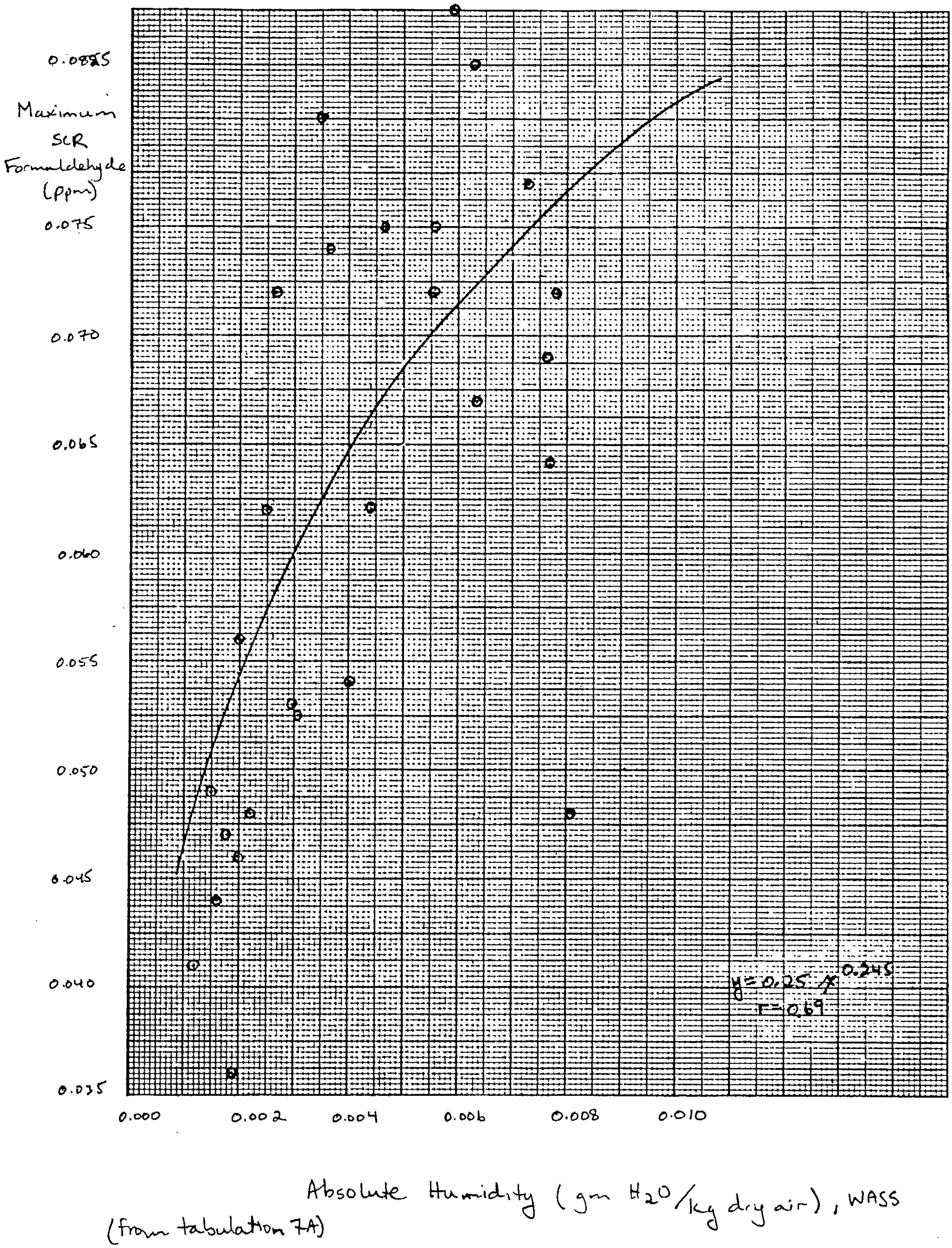
Mean Post-Corrective Measures (PCM) Room Air Formaldehyde Levels, by Period of Testing, for All Measures.



(from Tabulation 02)

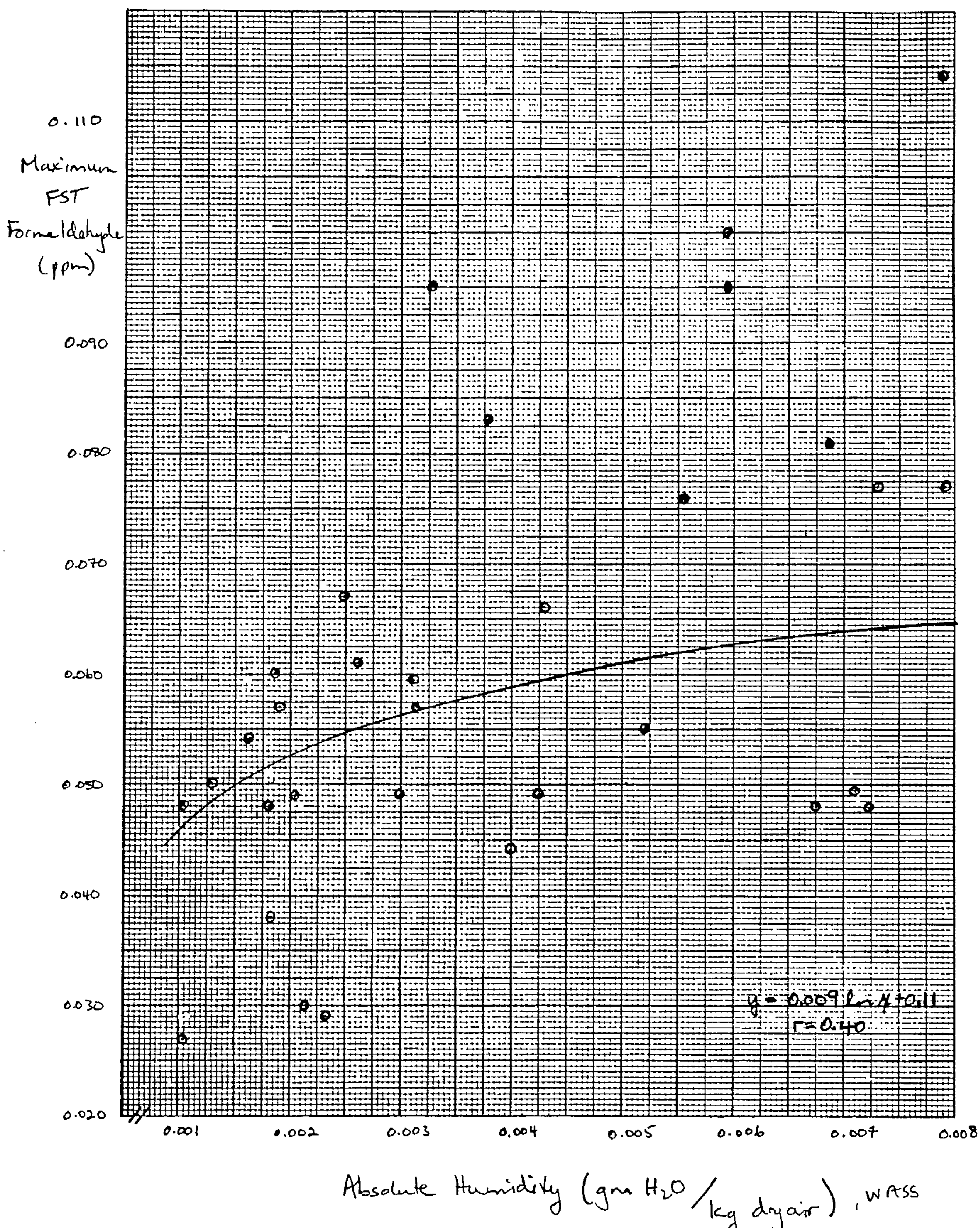
Graph IIIs

Absolute Humidity versus Maximum SCR Formaldehyde Levels



Graph IIIF

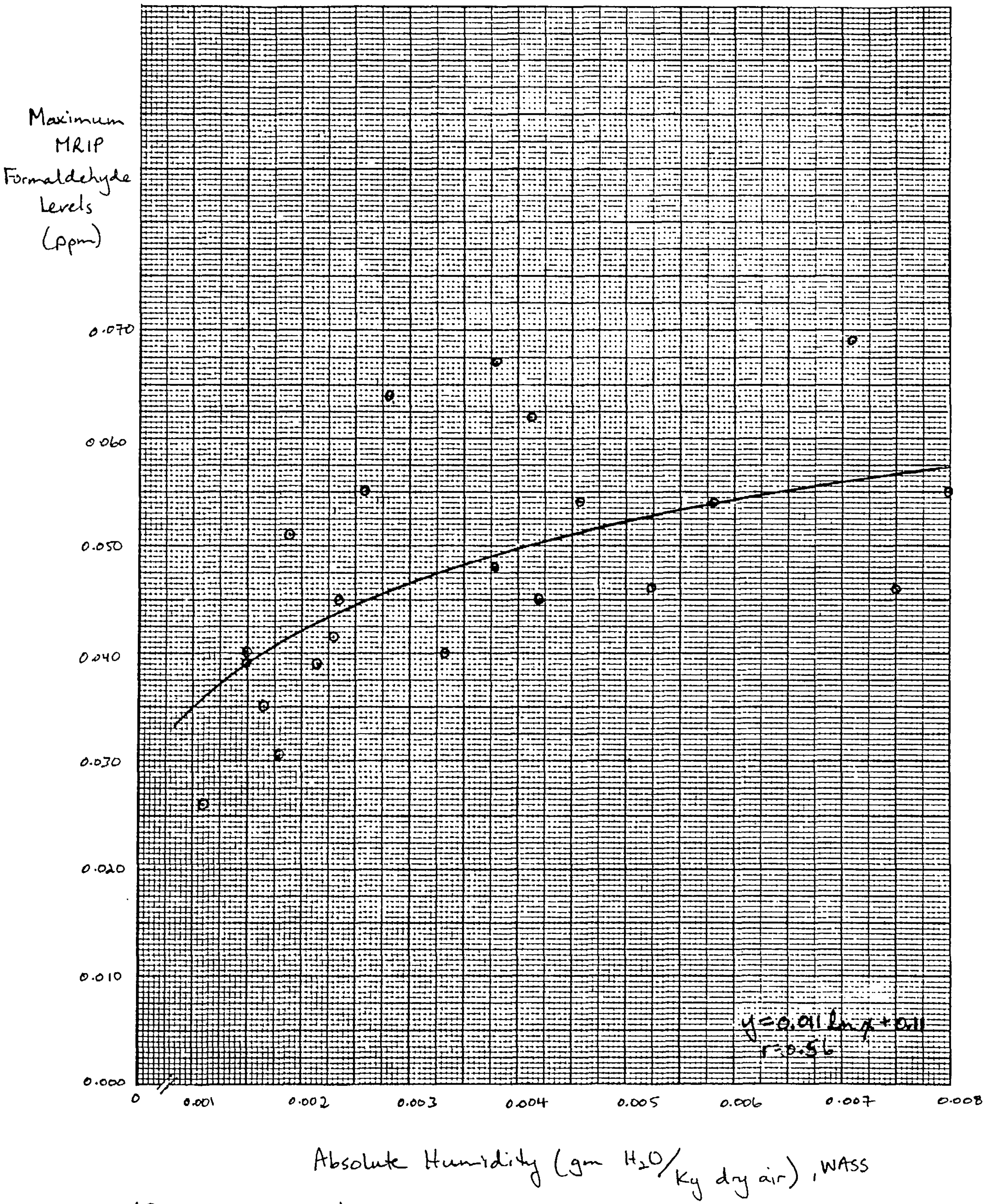
Absolute Humidity versus Maximum FST Formaldehyde Levels



(from tabulation 7B)

Graph III M

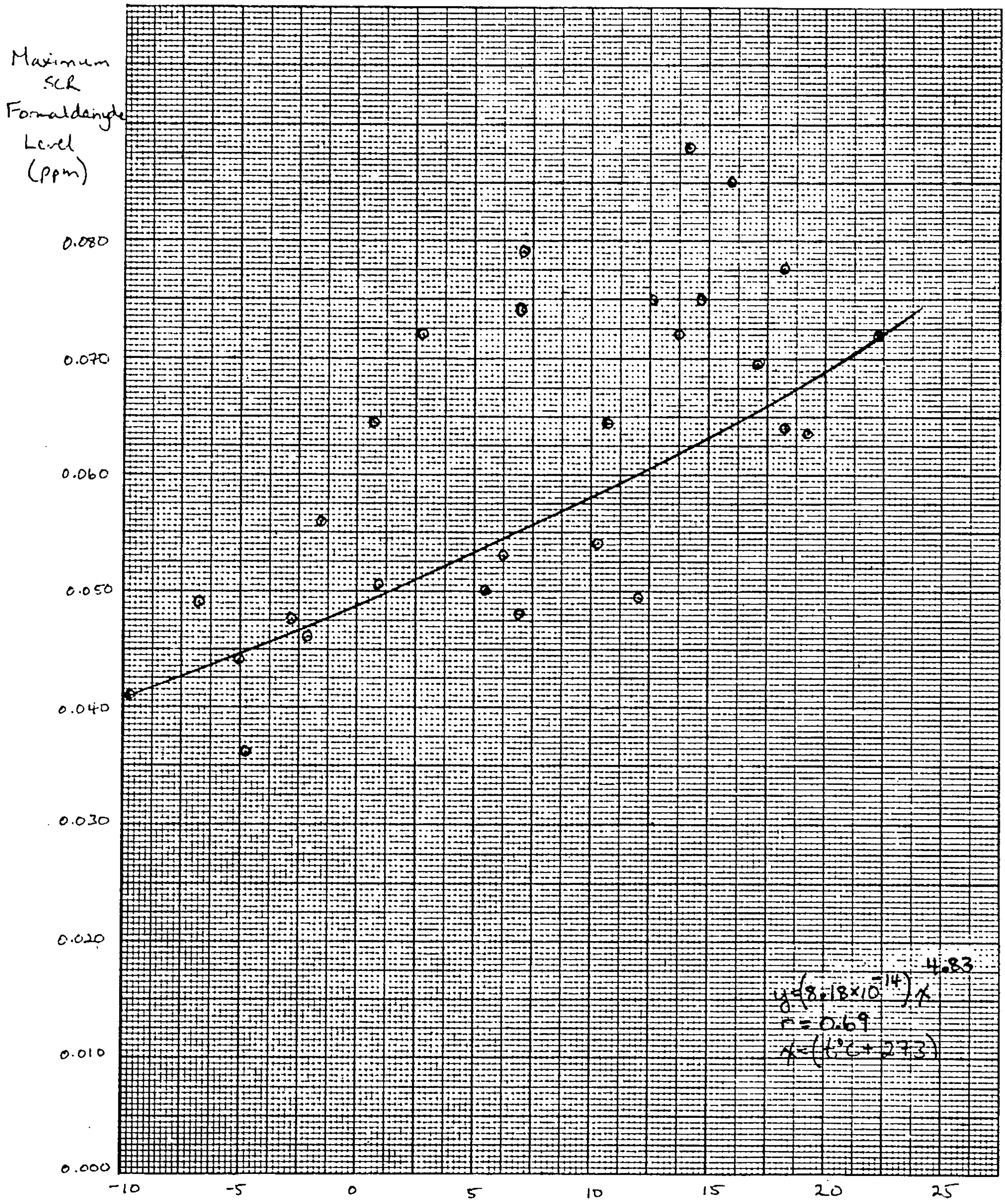
Absolute Humidity versus Maximum MRIP Formaldehyde Levels



(from tabulation 7C)

Graph IV S

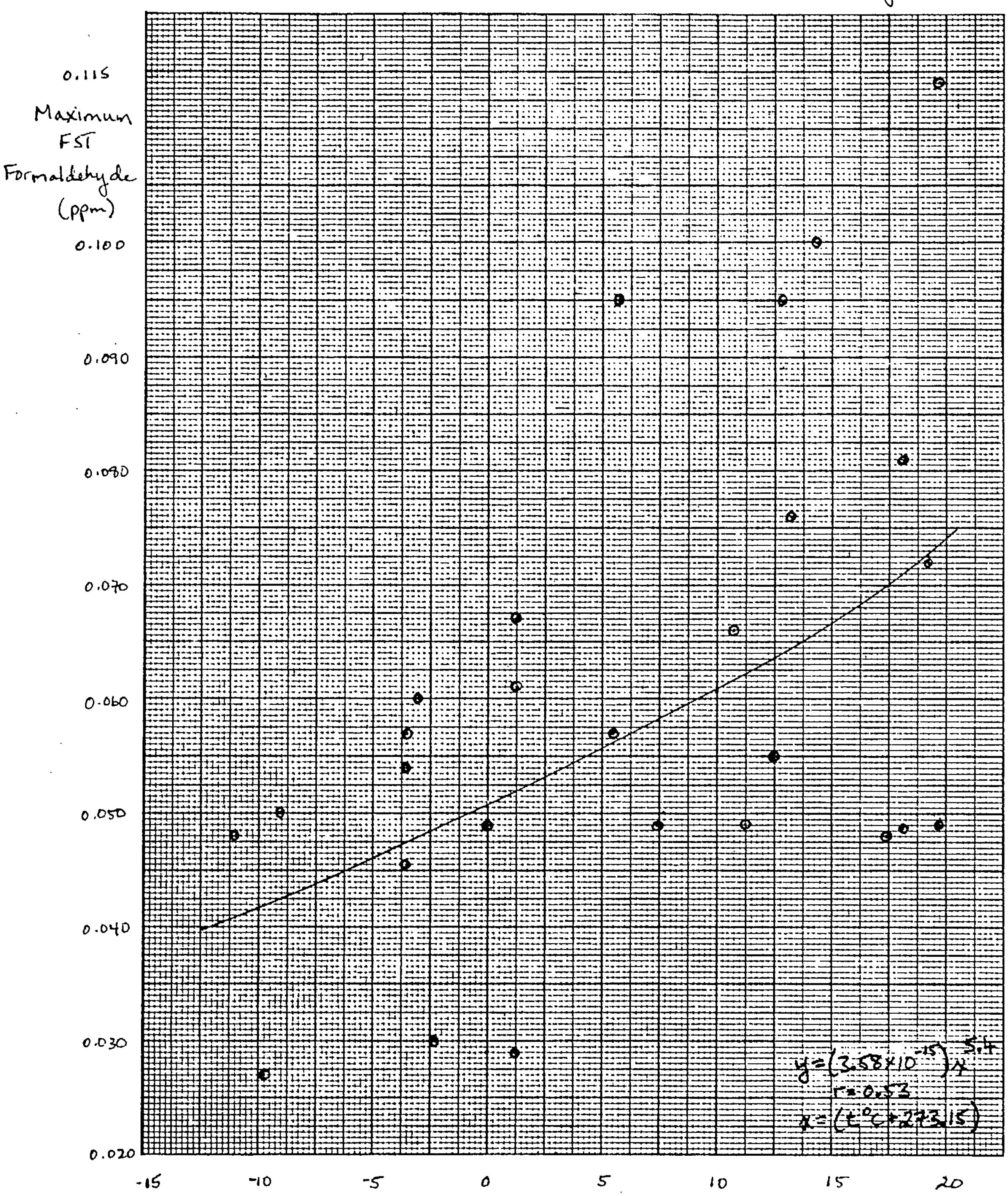
Outside Temperature versus Maximum SCR Formaldehyde Levels



(from tabulation 7A)

Graph IV F

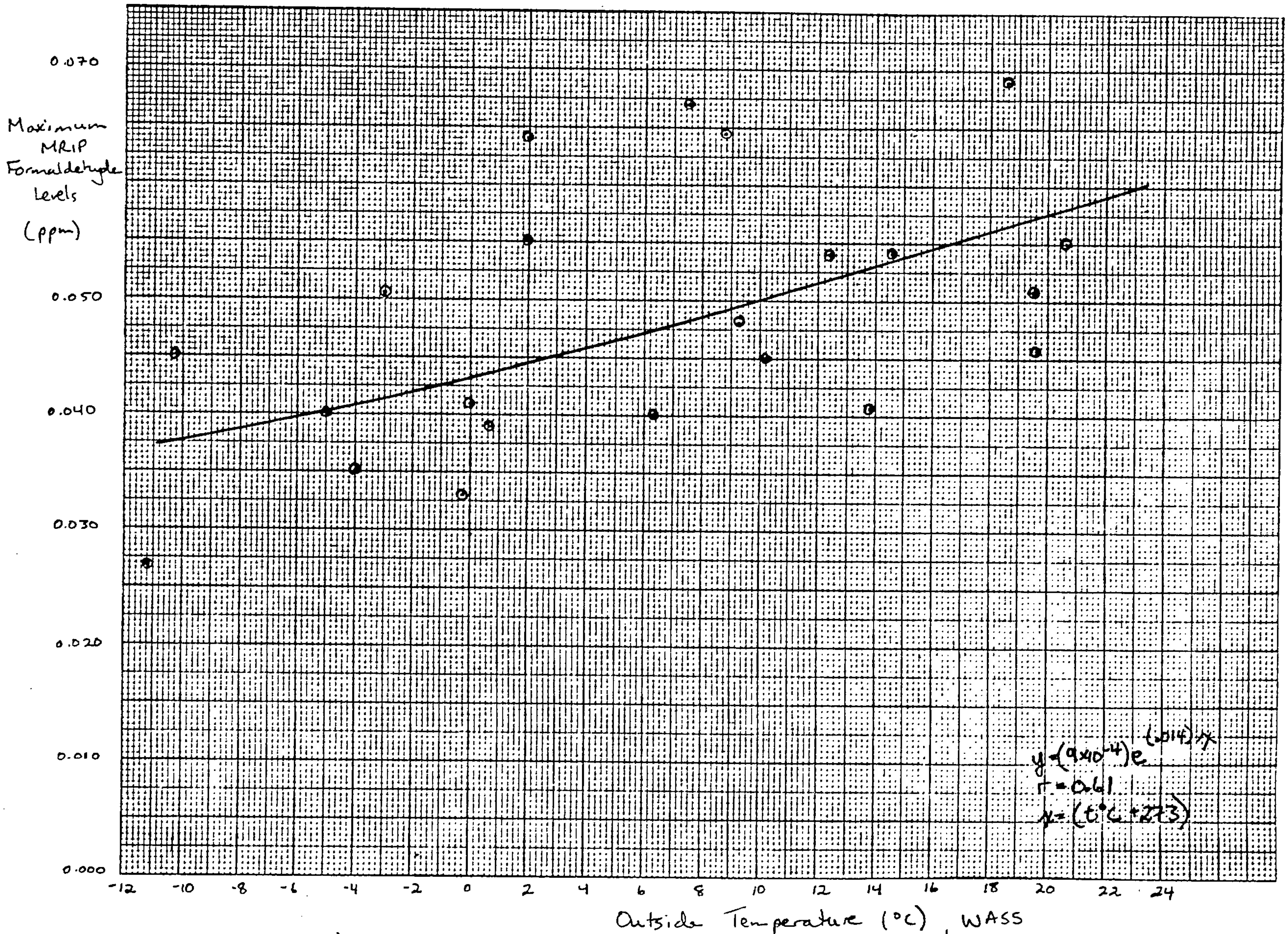
Outside Temperature Versus Maximum FST Formaldehyde Levels



(from tabulation 7B)

Graph IV M

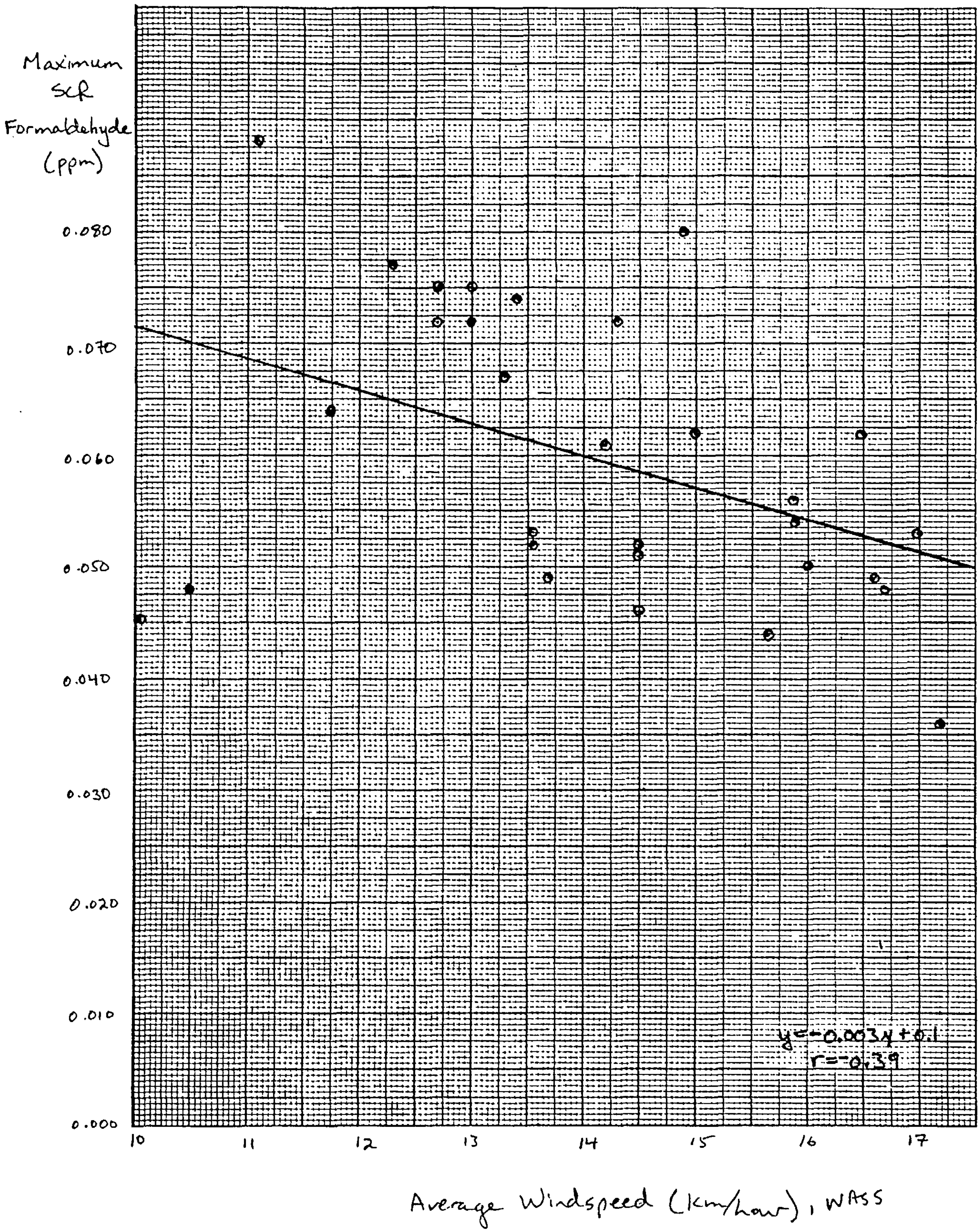
Outside Temperature Versus Maximum MRIP Formaldehyde Levels



(from tabulation 7C)

Graph V s

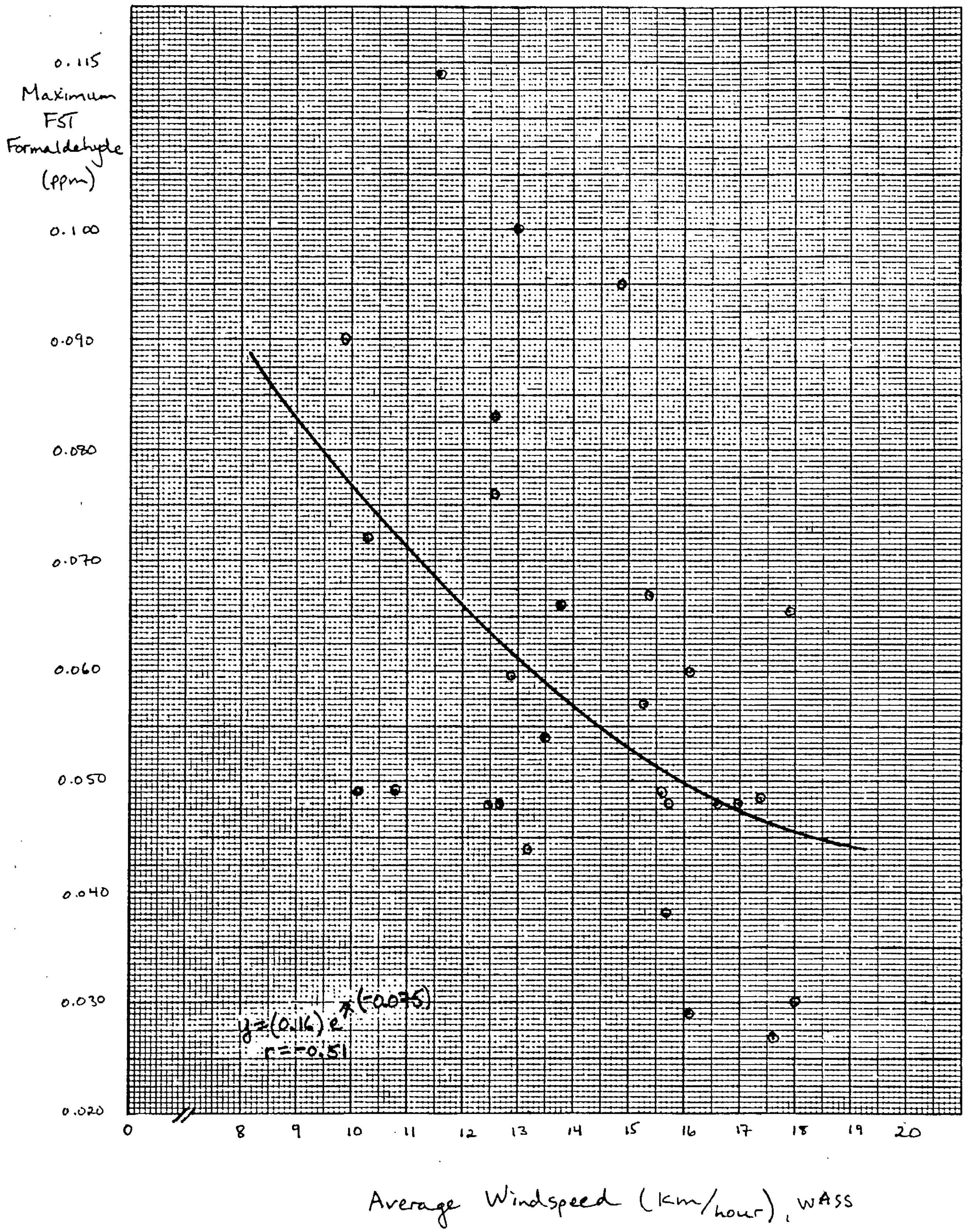
Windspeed Versus the Maximum SCR Formaldehyde Levels



(from tabulation 7A)

Graph V F

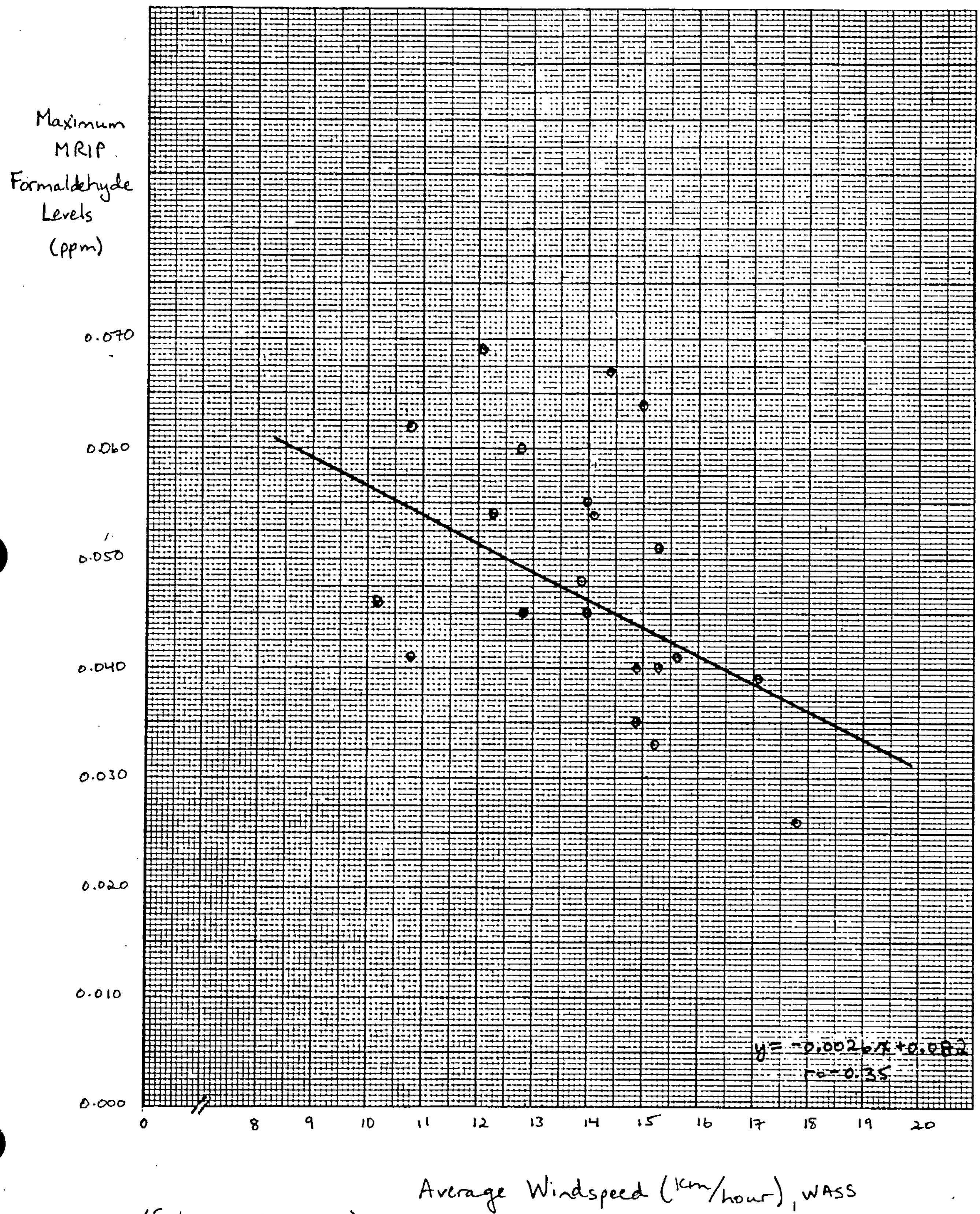
Windspeed Verses The Maximum FST Formaldehyde Levels



(from Tabulation 7B)

Graph V M

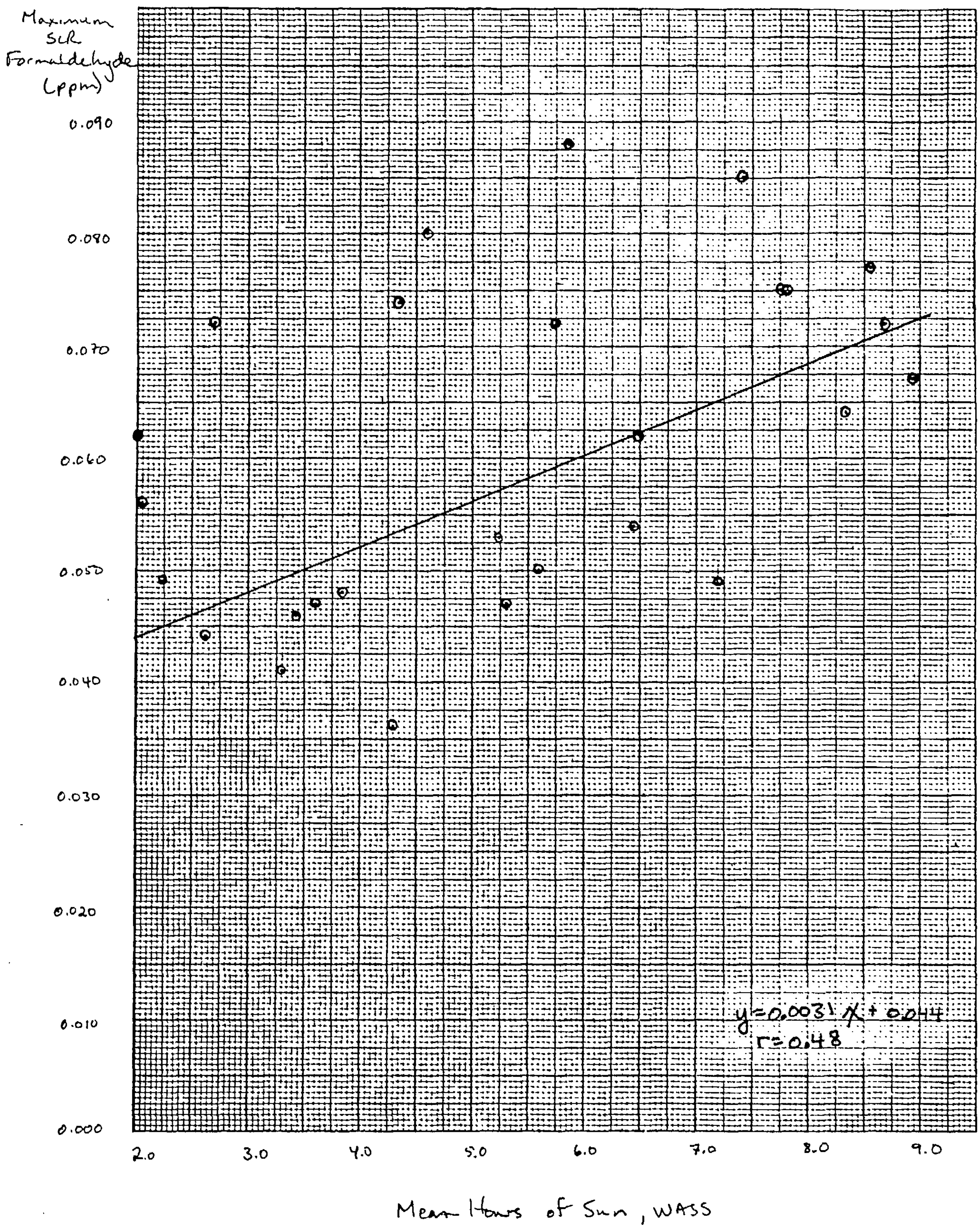
Windspeed Versus The Maximum MRIP Formaldehyde Levels



(from tabulation 7C)

Graph VI s.

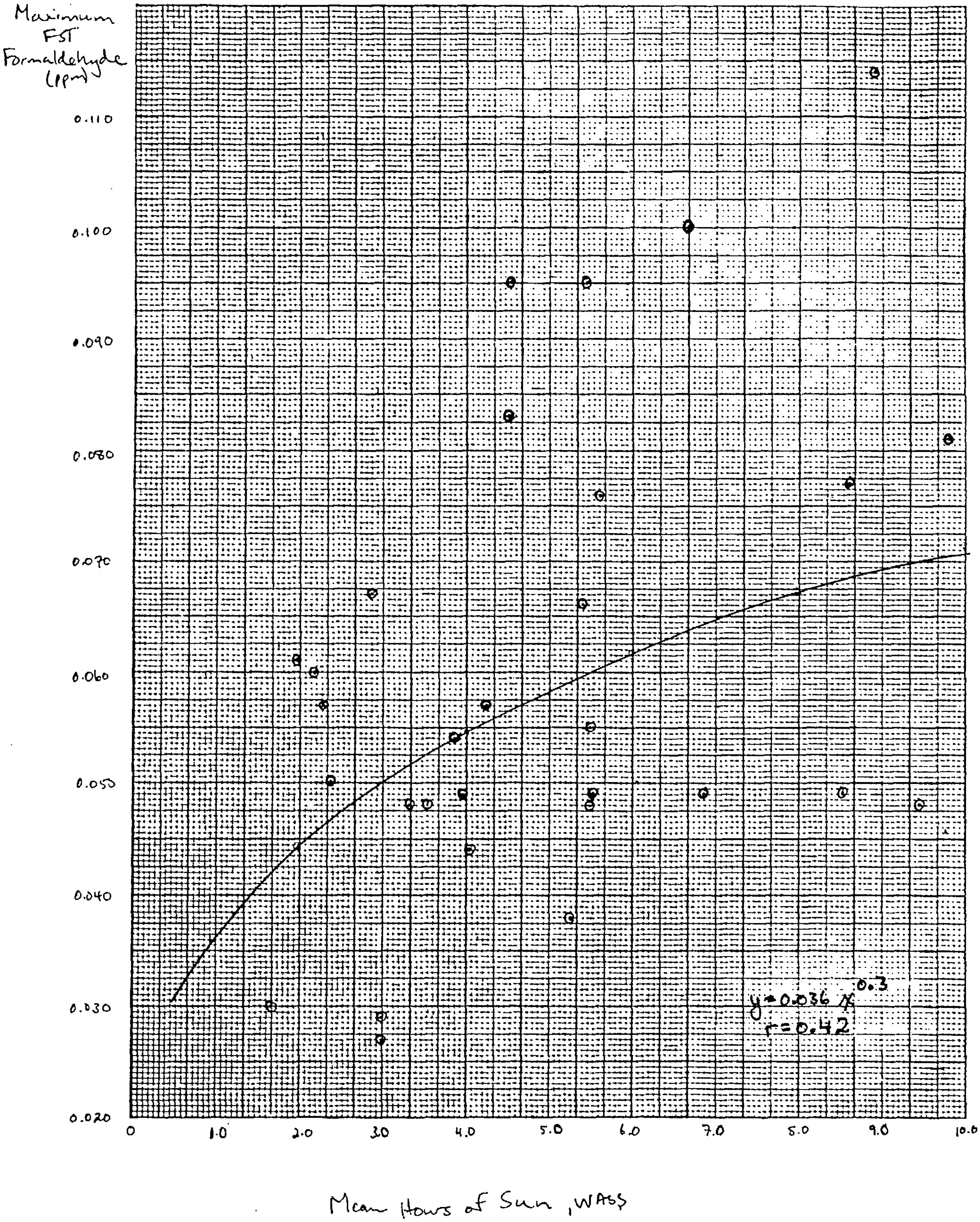
Maximum SCR Formaldehyde Levels versus Hours of Sun.



(from tabulation 7A)

Graph VI F

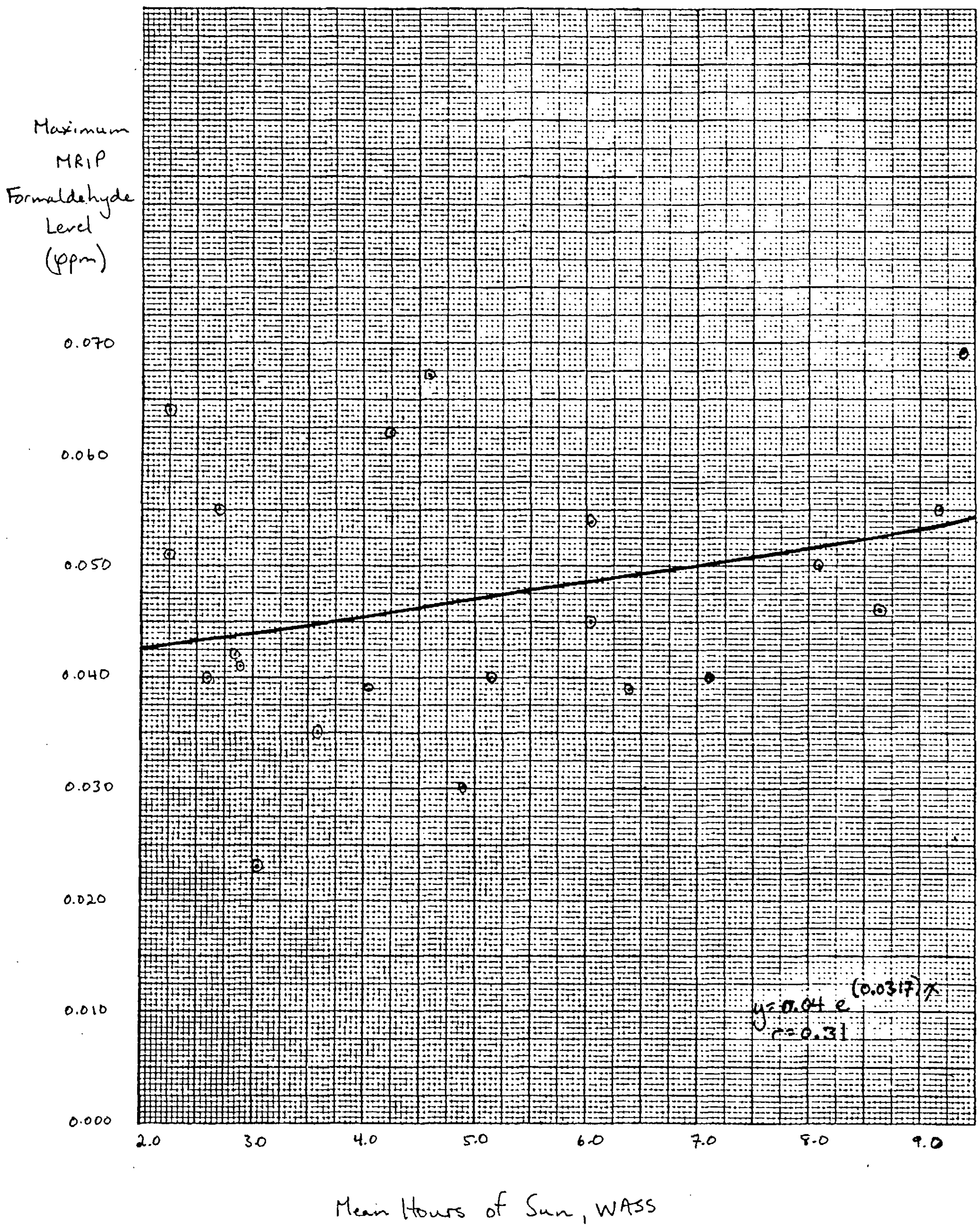
Hours of Sun Versus Maximum FST Formaldehyde Levels



(from tabulation 7B)

Graph VI M

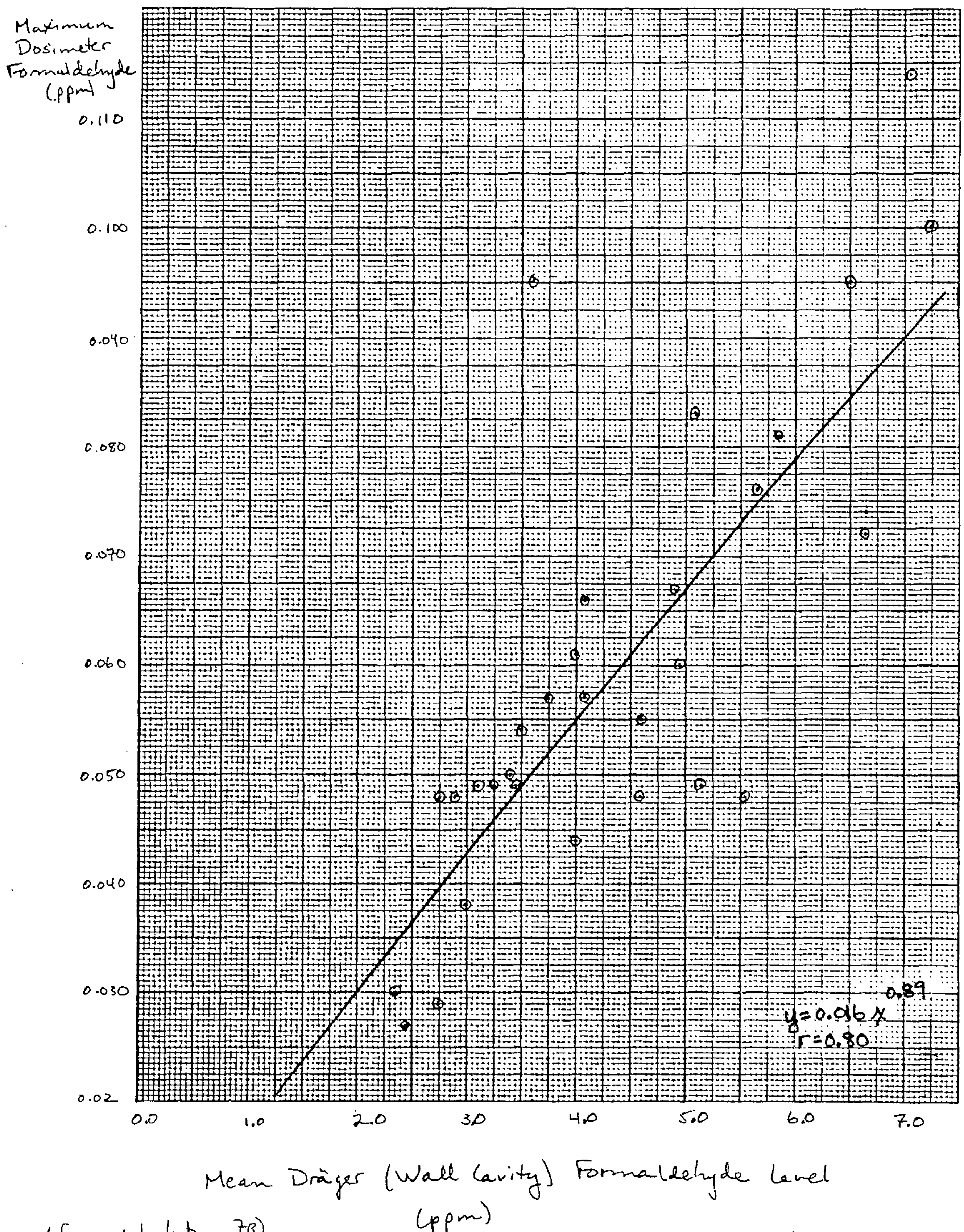
Hours of Sun versus Maximum MRIP Formaldehyde Levels



(from tabulation 7C)

Graph VII F

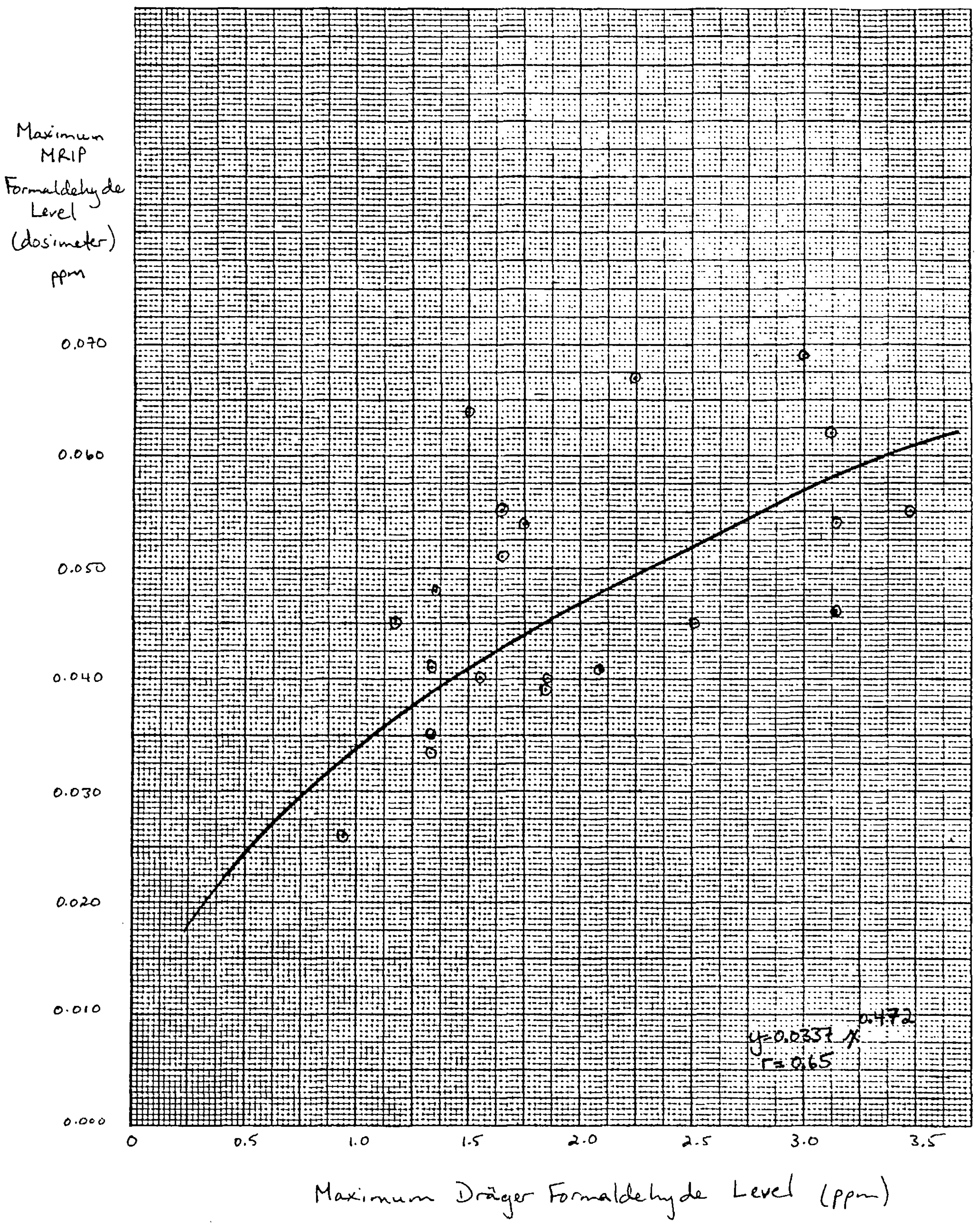
Maximum FST Dosimeter and Dräger Formaldehyde Levels



(from tabulation 7B)

Graph VII M

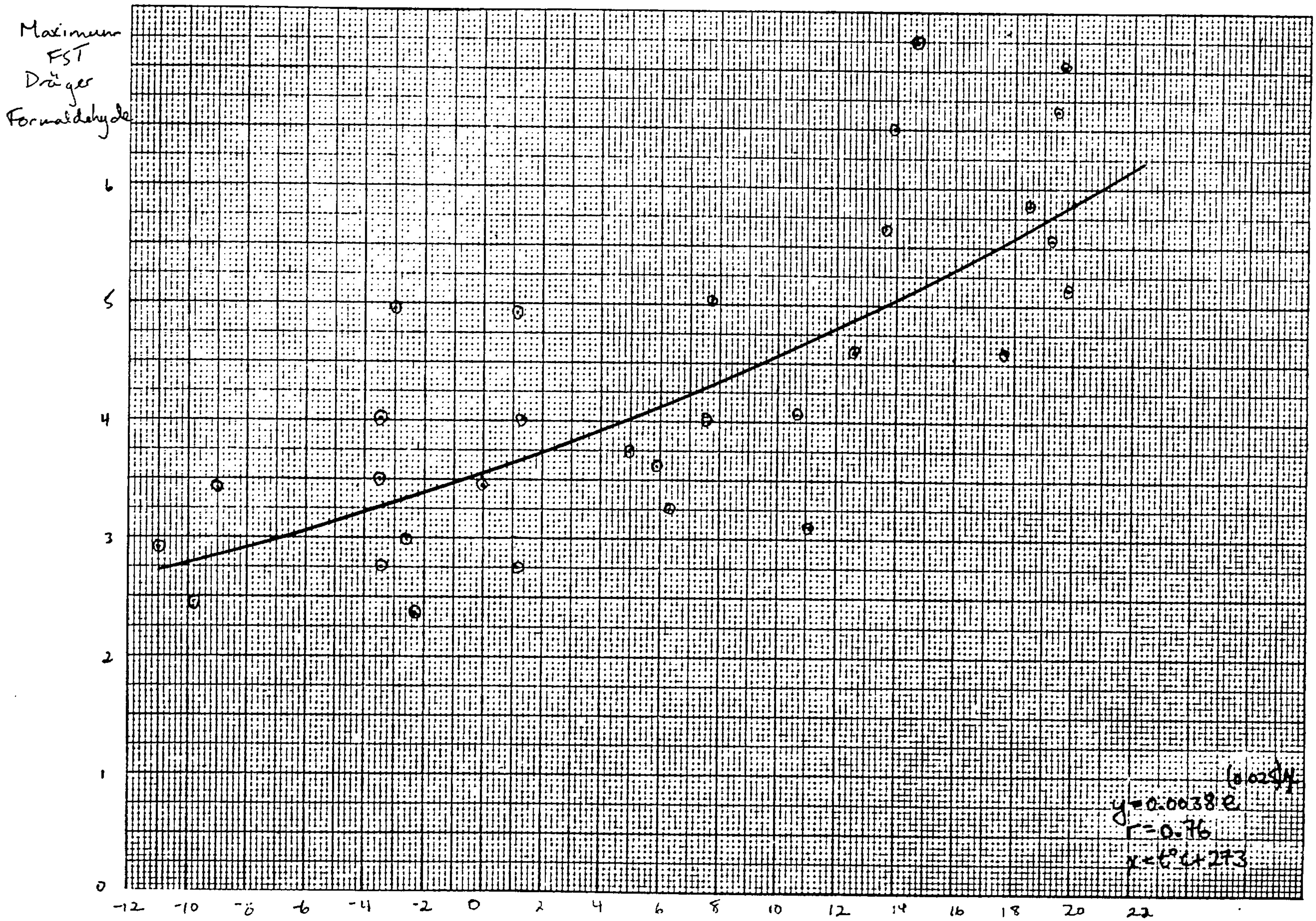
Maximum MRIP Dosimeter versus Dräger Formaldehyde Levels



(from tabulation 7C)

L VIII F

Outside Temperature versus Maximum FST Dräger Formaldehyde Level

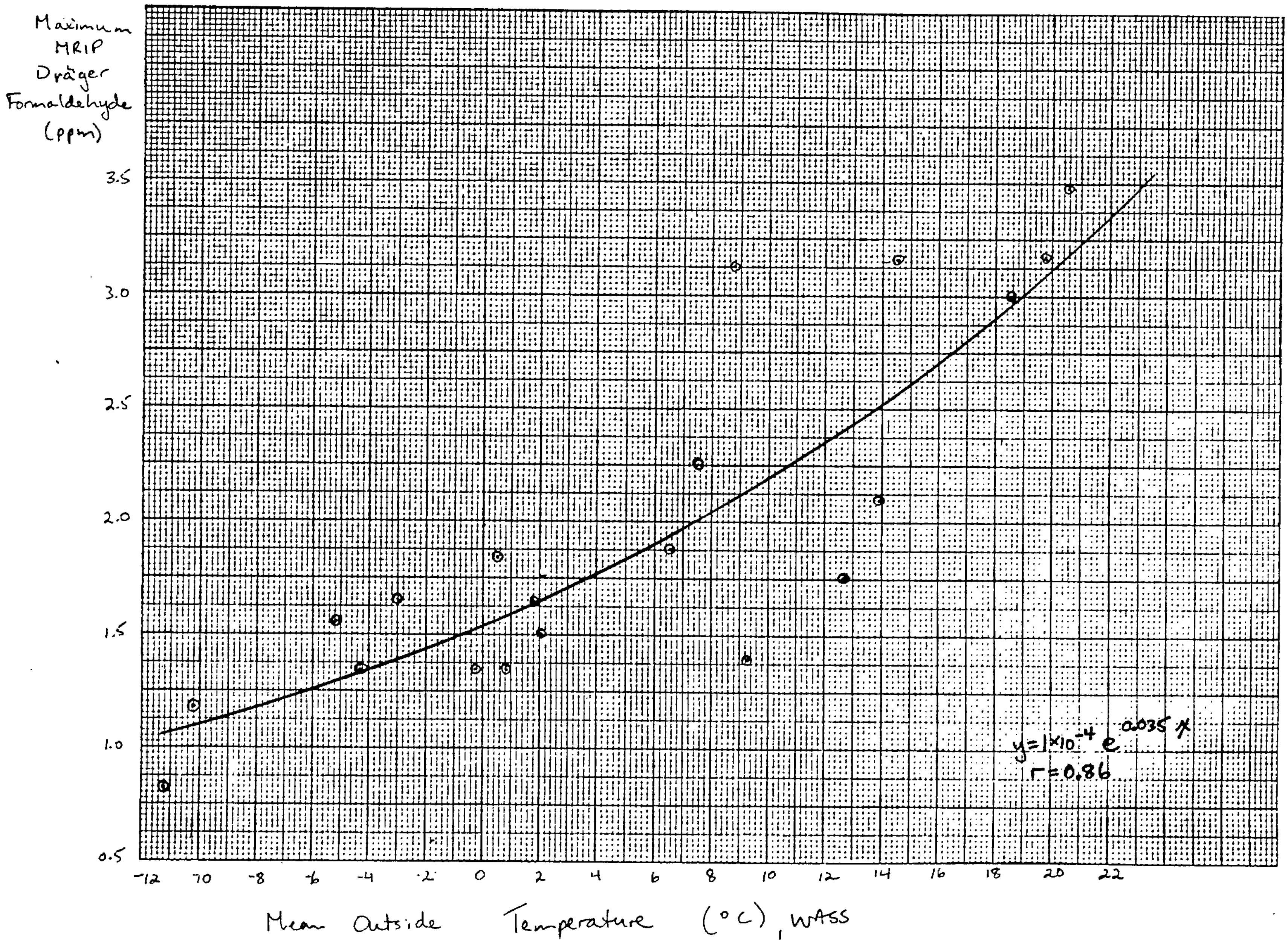


Mean Outside Temperature (°C), WASS

(from tabulation 7B)

Graph VIII M

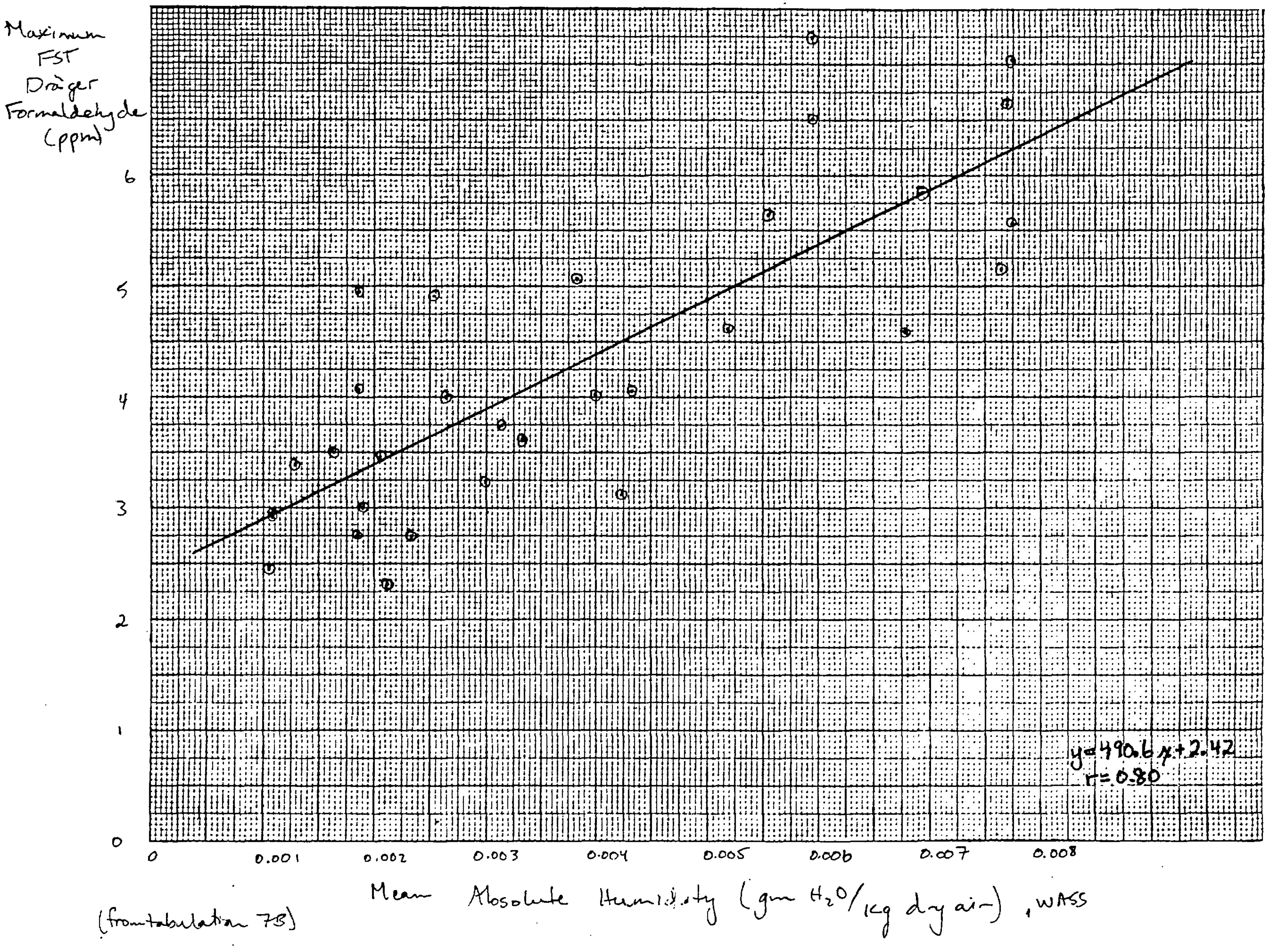
Mean Outside Temperature versus Maximum MRIP Dräger Formaldehyde Level



(from tabulation 7C)

Graph IX Fa

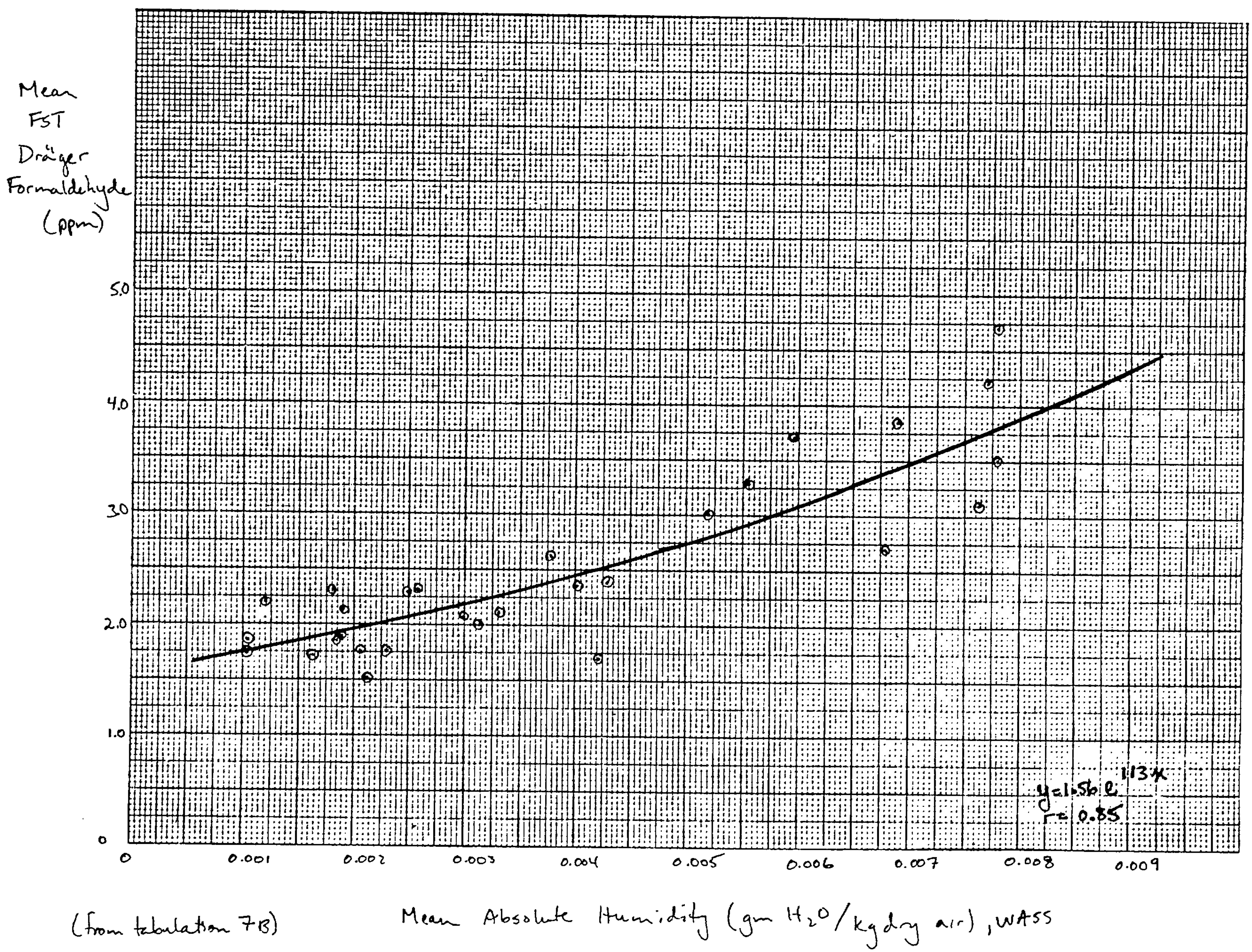
Absolute Humidity versus FST Dräger Formaldehyde Levels (Maxima)



(from tabulation 7B)

Graph IX F6

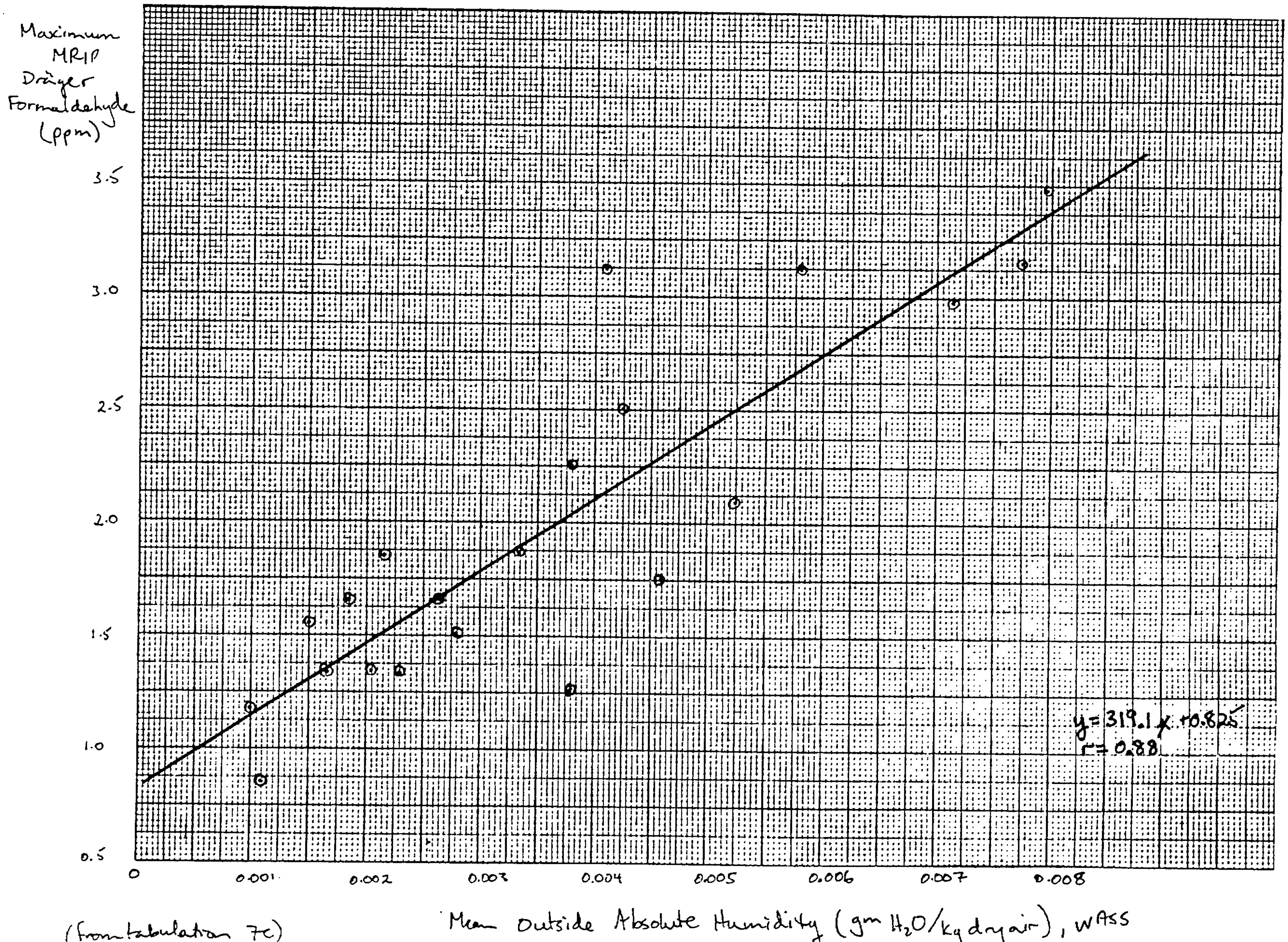
Absolute Humidity versus Mean Dräger Formaldehyde Levels



(from tabulation 7B)

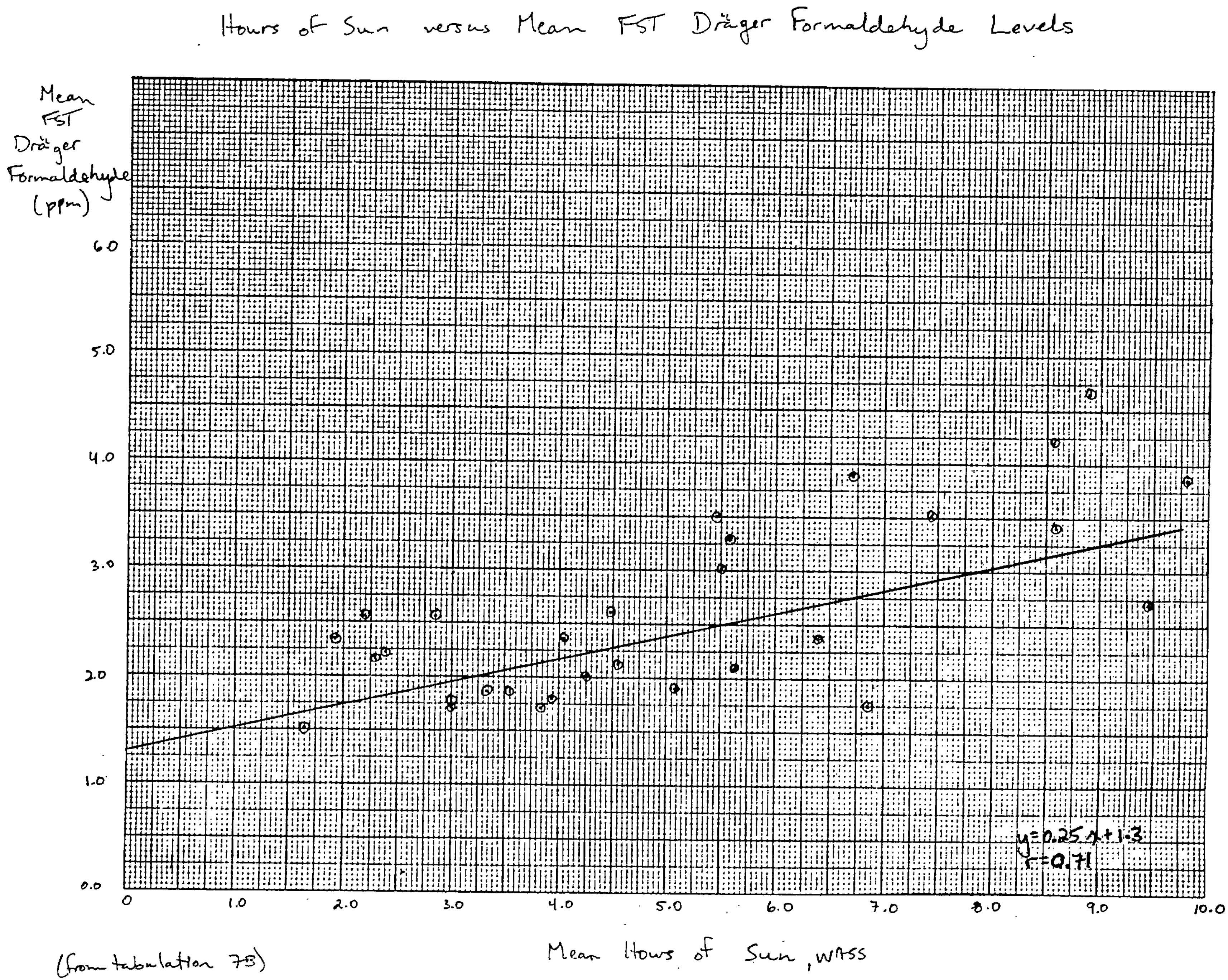
Graph IX M

Outside Absolute Humidity versus Maximum MRIP Dräger Formaldehyde Levels



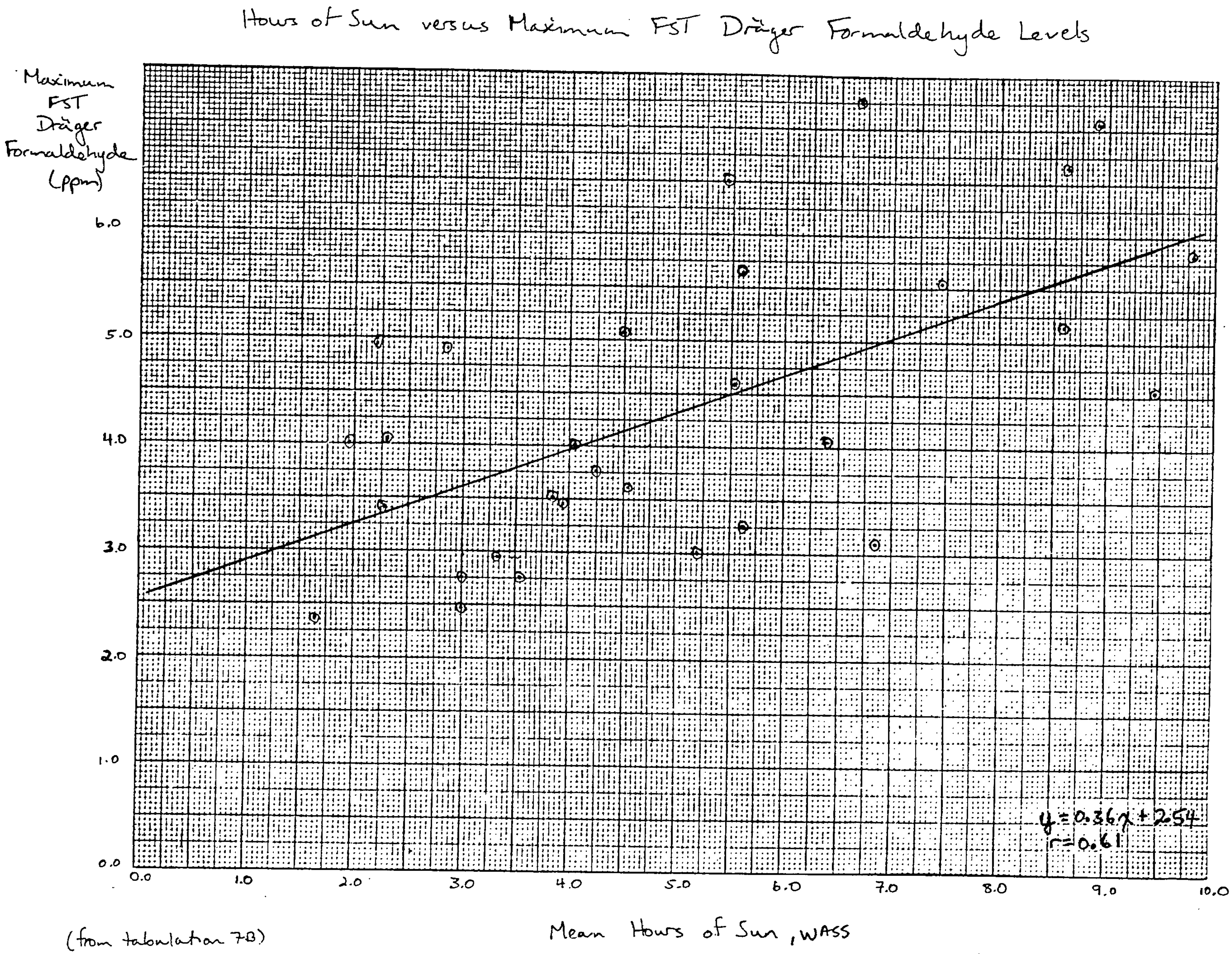
(from tabulation 7c)

Graph IX Fa



(from tabulation 73)

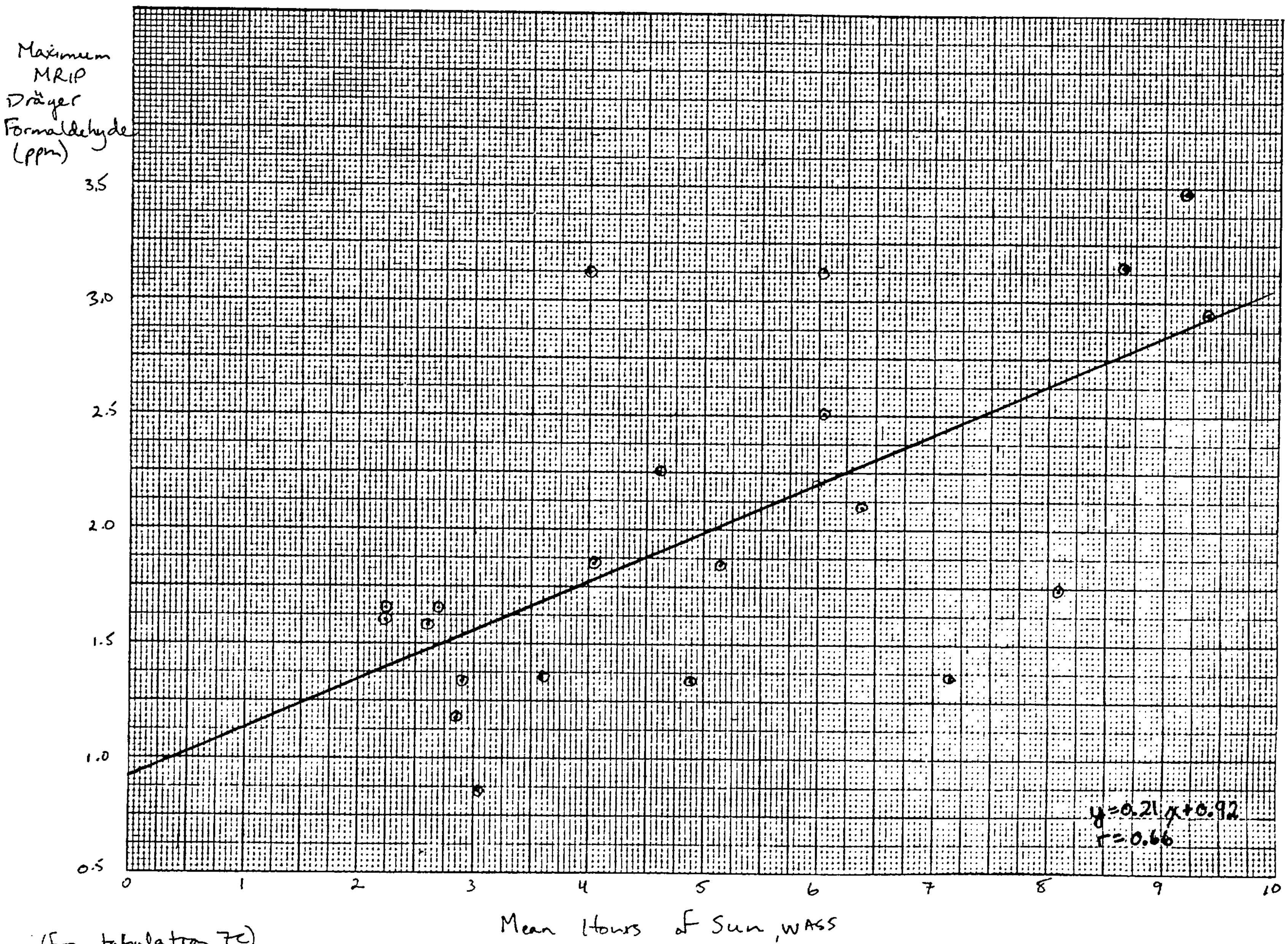
Graph 8F b



(from tabulation 7B)

Graph X M

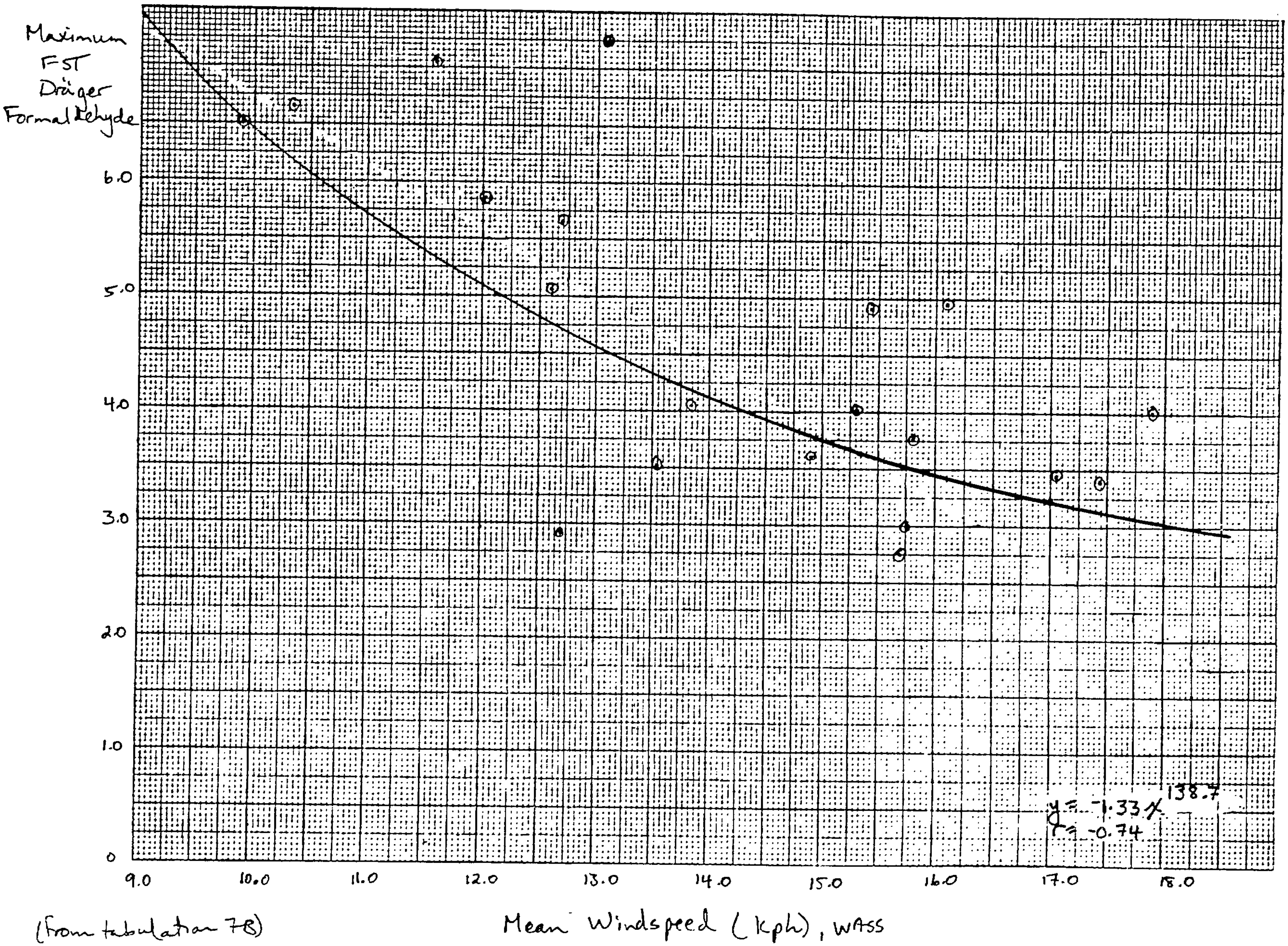
Hours of Sun versus the Maximum MRIP Dräger Formaldehyde Level



(From tabulation 7C)

Graph XI Fa

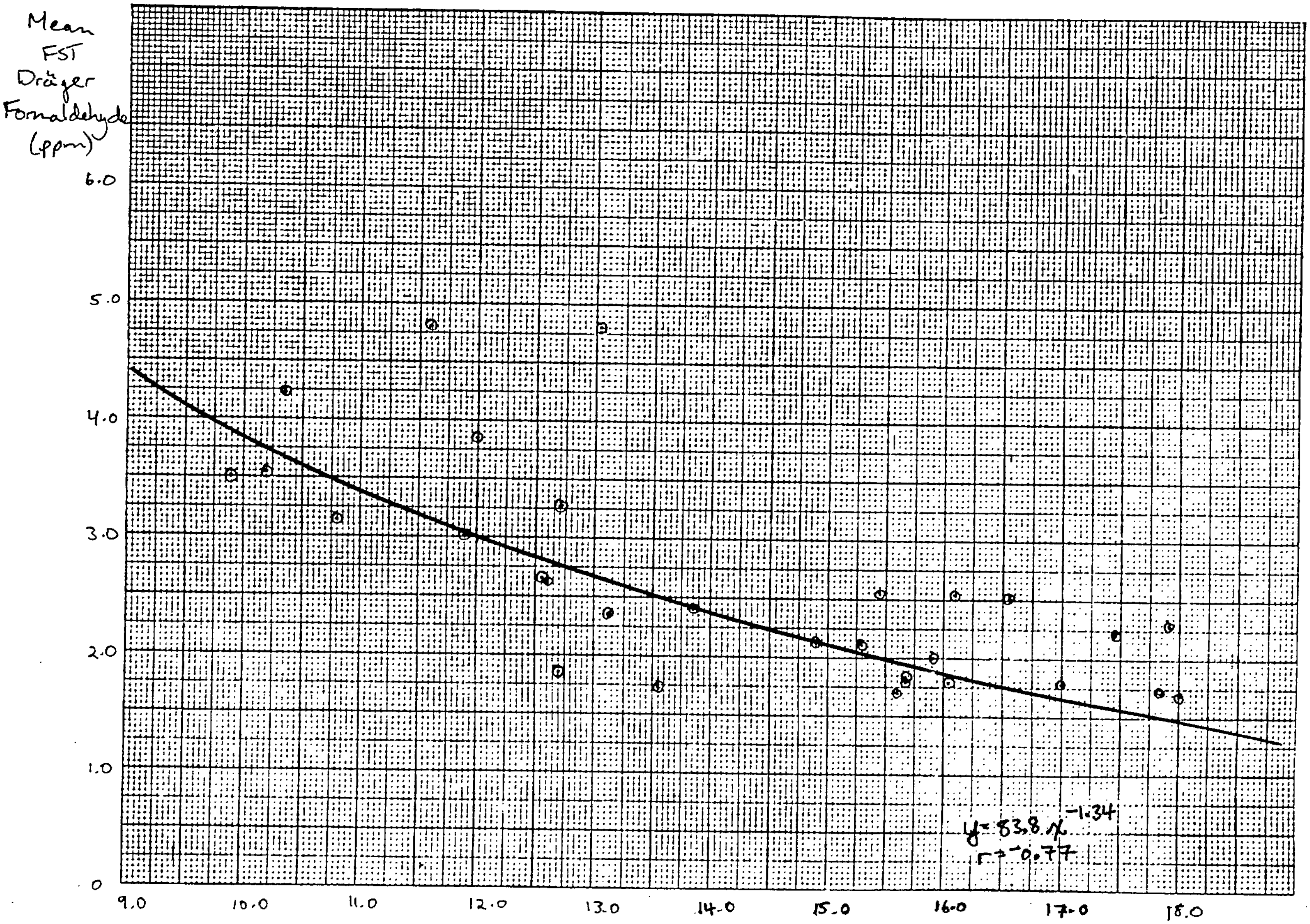
Maximum FST Dräger Formaldehyde Levels versus Mean Windspeed



(From tabulation 78)

Graph XI Fb

Mean Windspeed versus the Mean FST Dräger Formaldehyde Level.

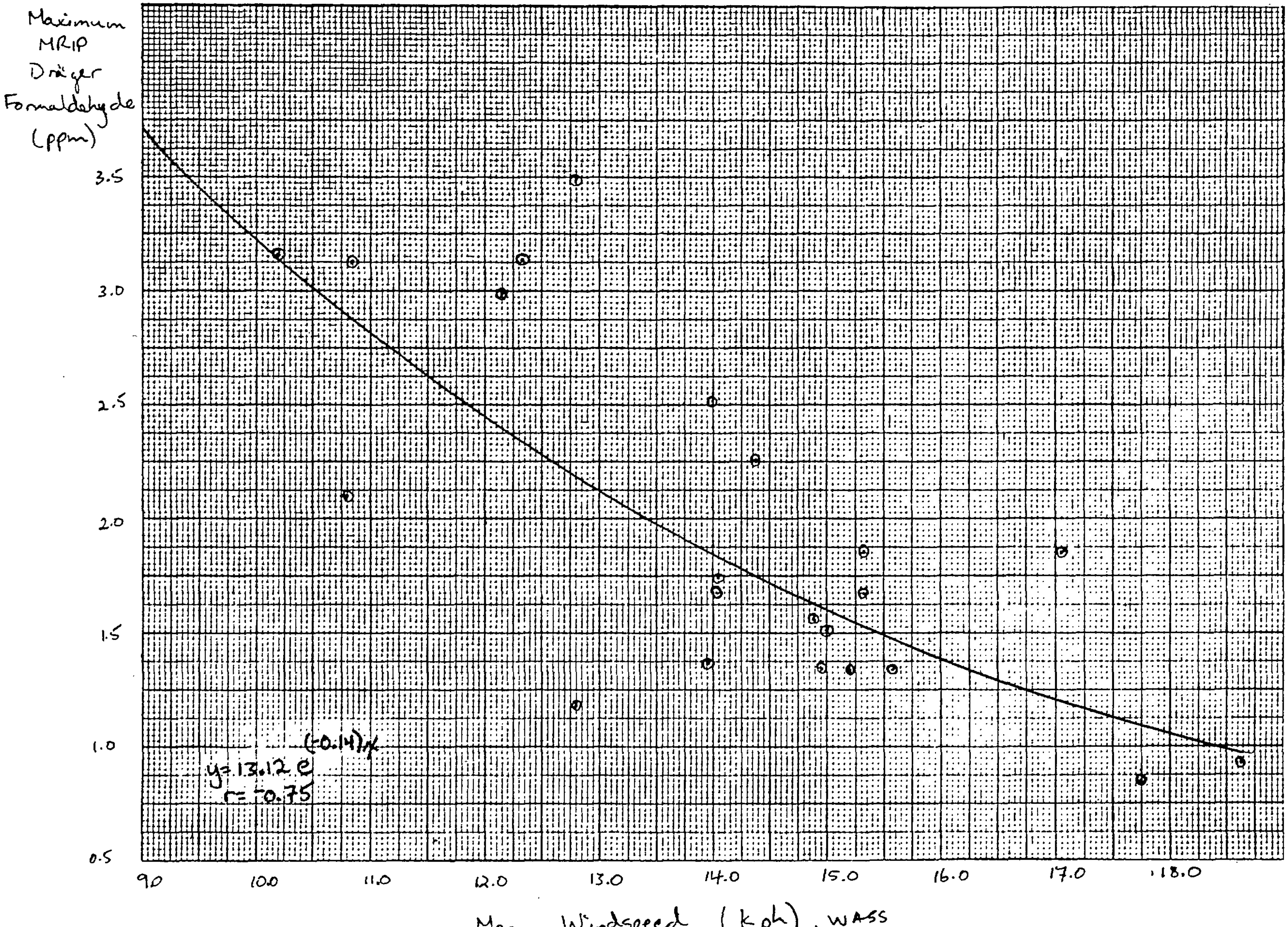


(from tabulation 7B)

Mean Windspeed (kph), WASS

Graph XI M

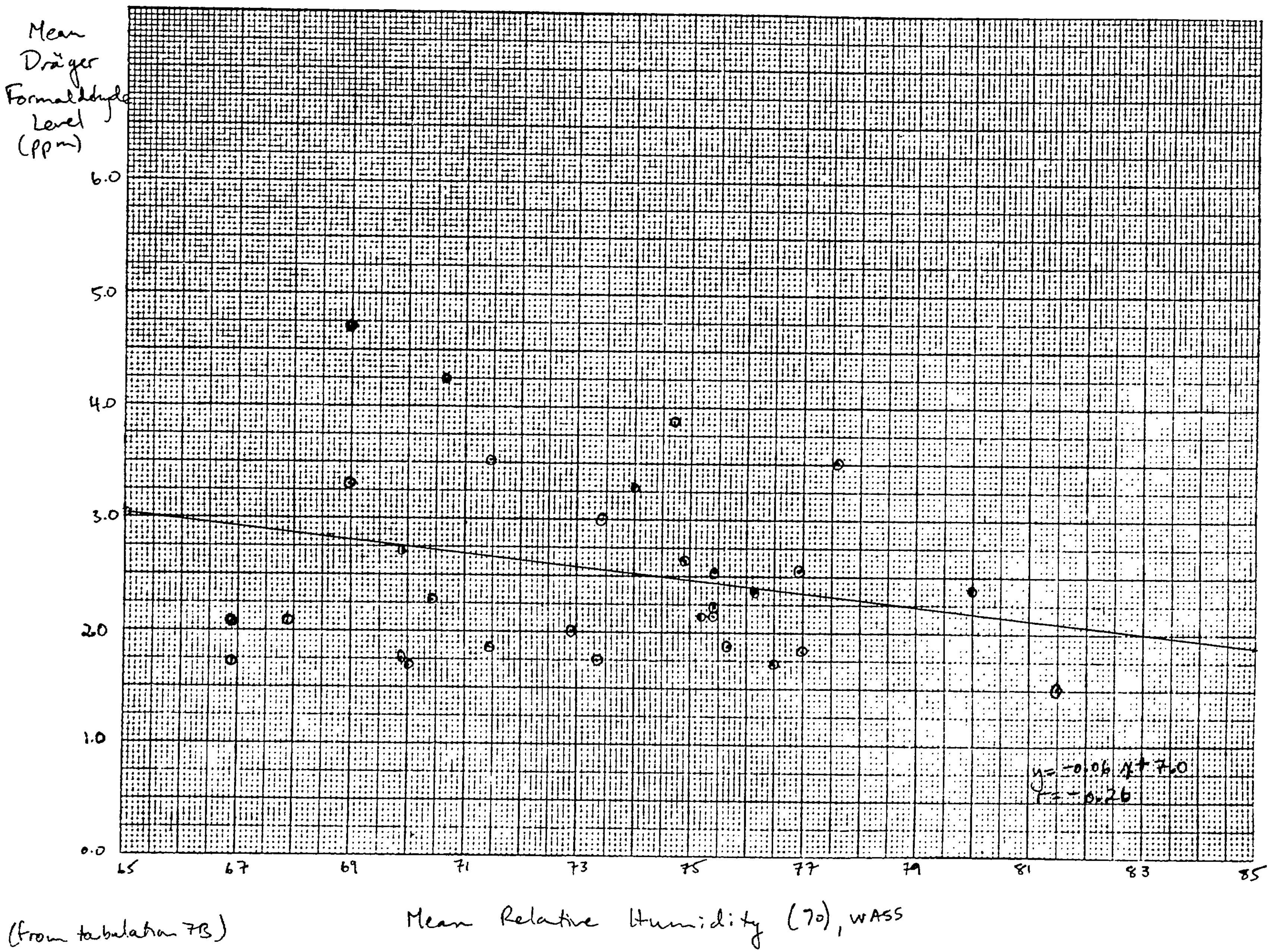
Windspeed versus the Maximum MRIP Dräger Formaldehyde Level



(From tabulation 7c)

Graph XII F.

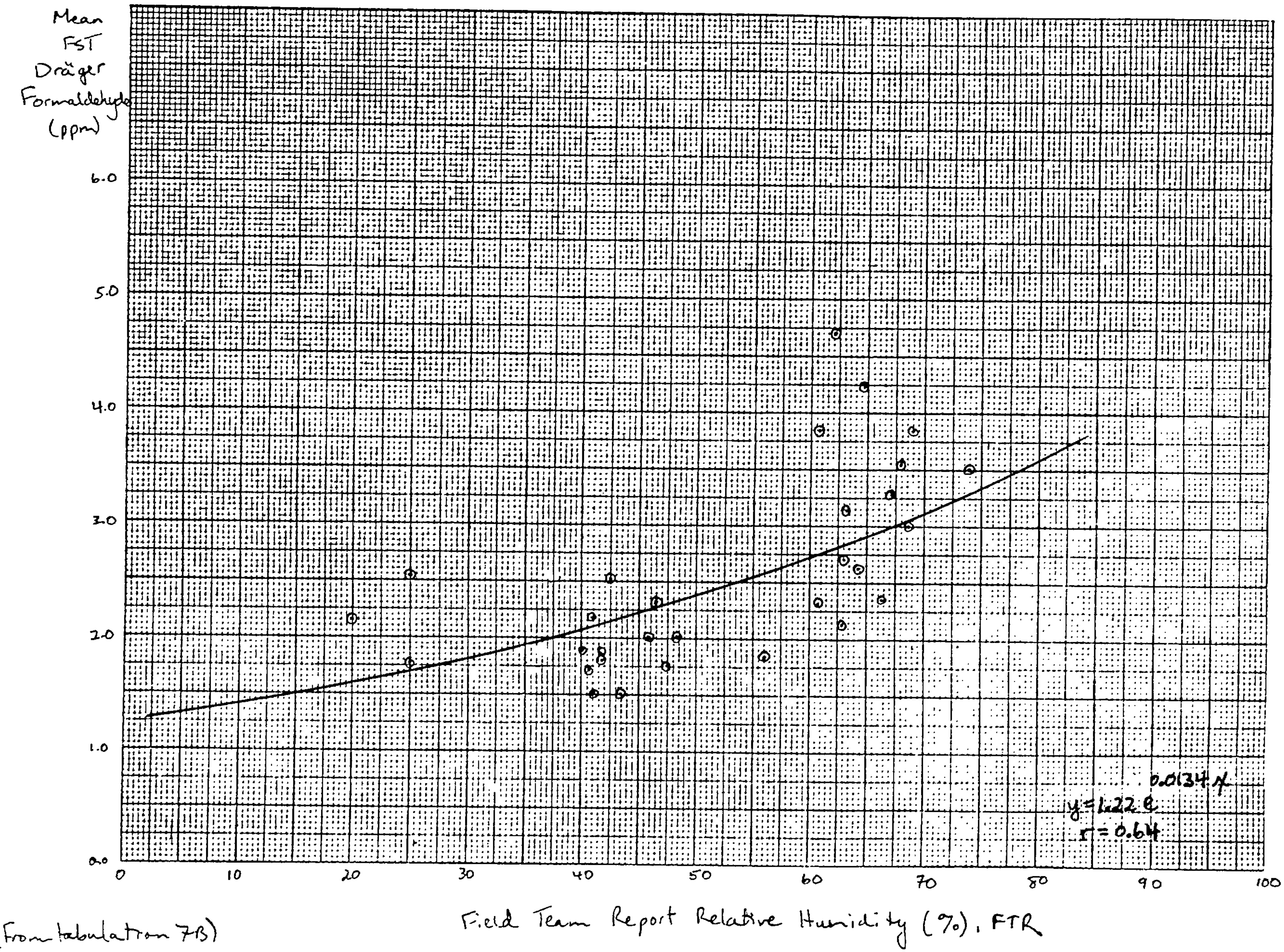
Relative Humidity versus Mean Dräger Formaldehyde Levels (FST)



(from tabulation 7B)

Graph XII

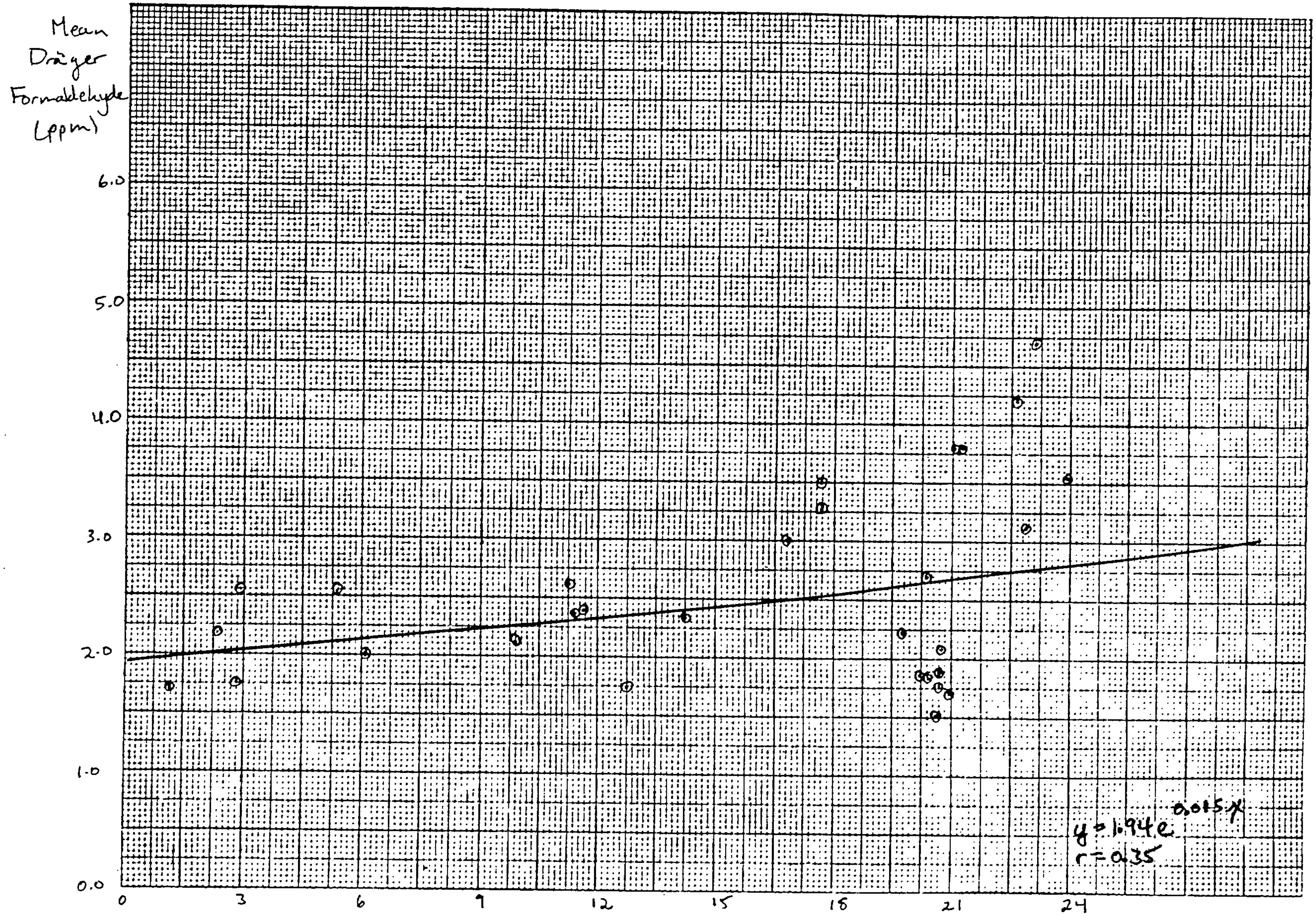
Field Team Report Relative Humidity versus Mean FST Dräger Formaldehyde Levels



(From tabulation 7B)

Graph XIII

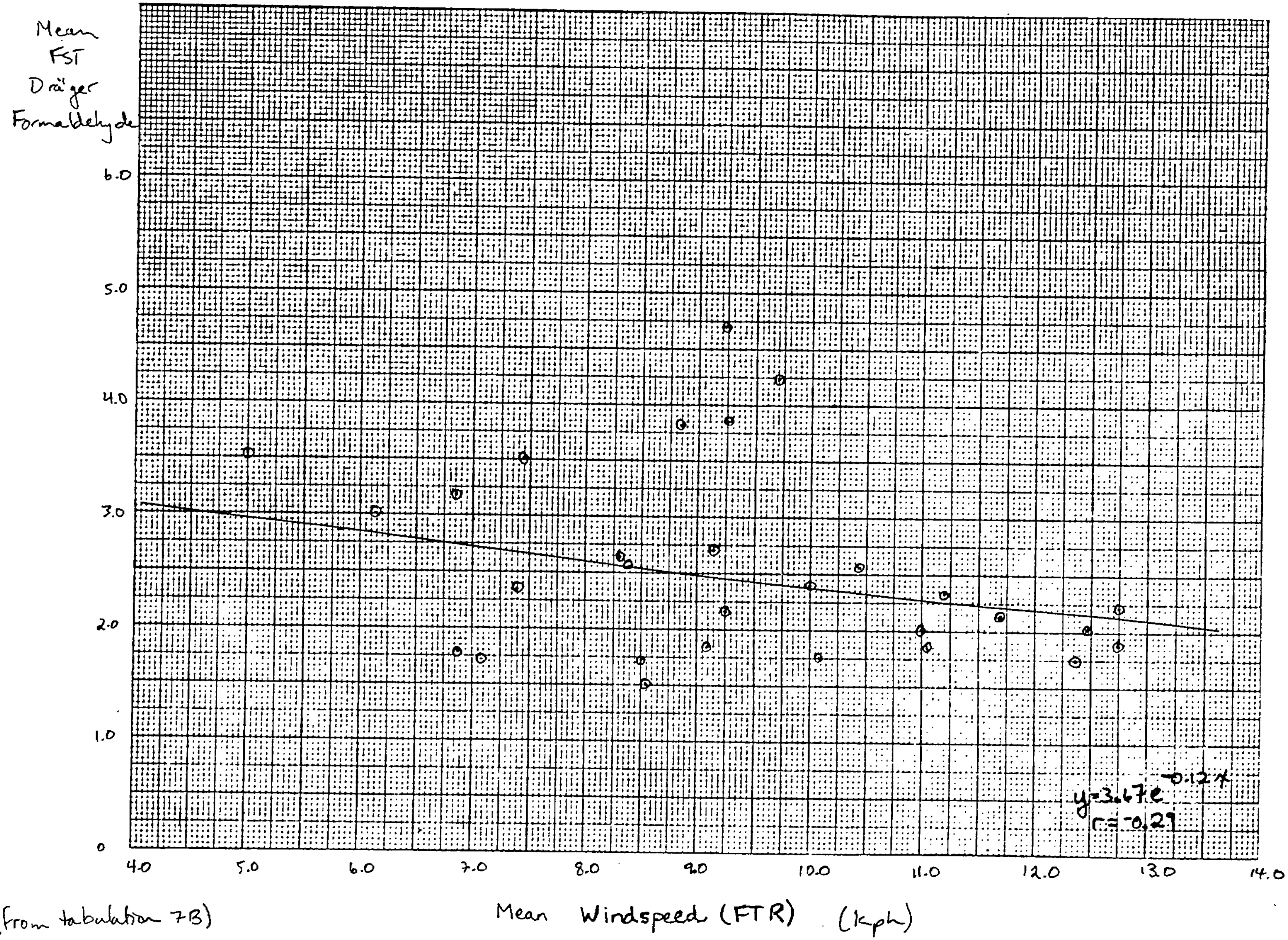
Mean Temperature (FTR) versus Mean Dräger Formaldehyde Level.



(from tabulation 7B) Mean Temperature (FTR) (inside and outside) °C

Graph XIV

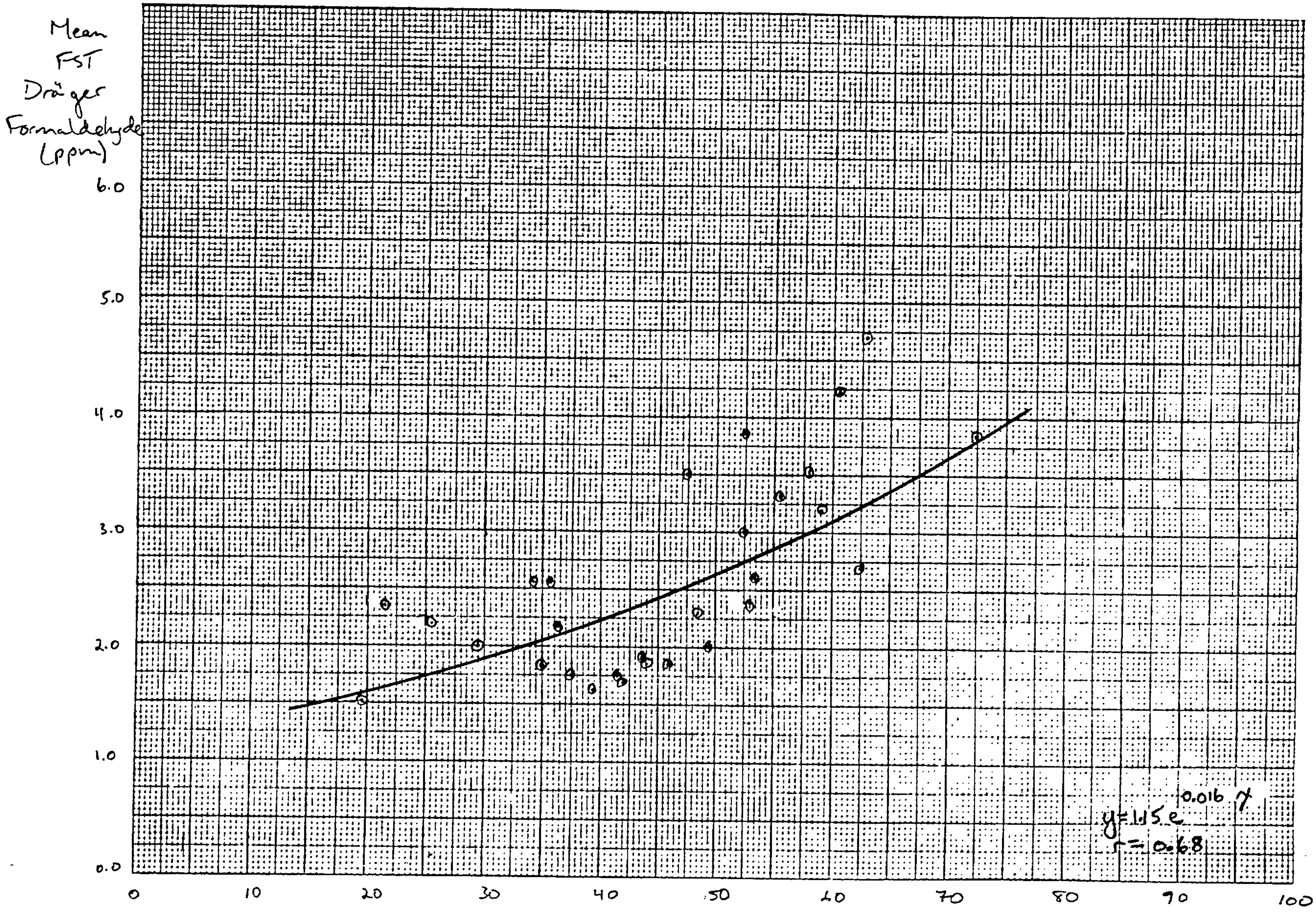
Mean Windspeed (FTR) versus Mean FST Dräger Formaldehyde Levels



(from tabulation 7B)

Graph XV

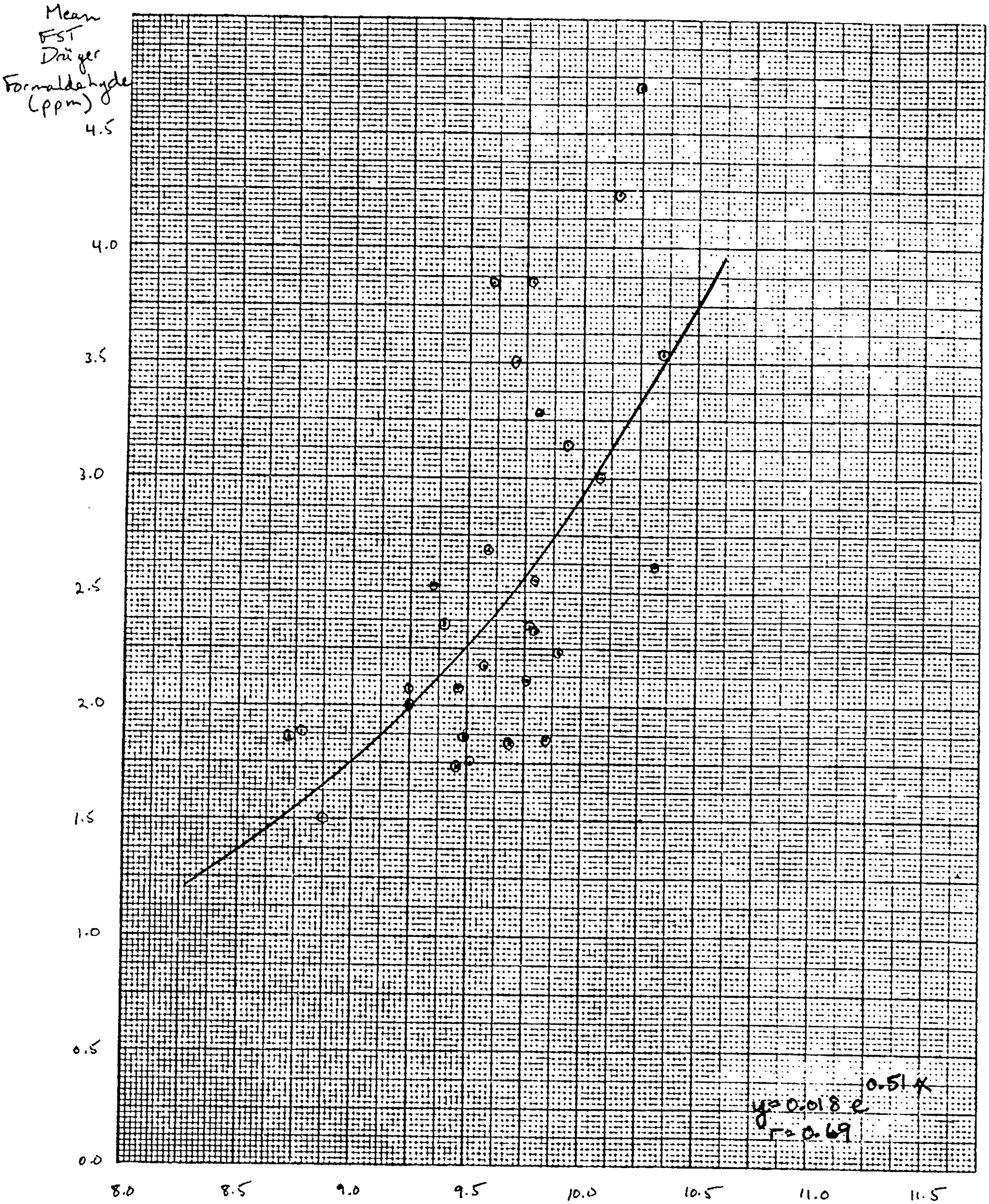
Percent of Homes with Cloud Cover ≤ 50% versus Mean FST Dräger Formaldehyde



(from tabulation 7B)

Graph XVI

Mean Wood Moisture versus Mean FST Dräger Formaldehyde Level



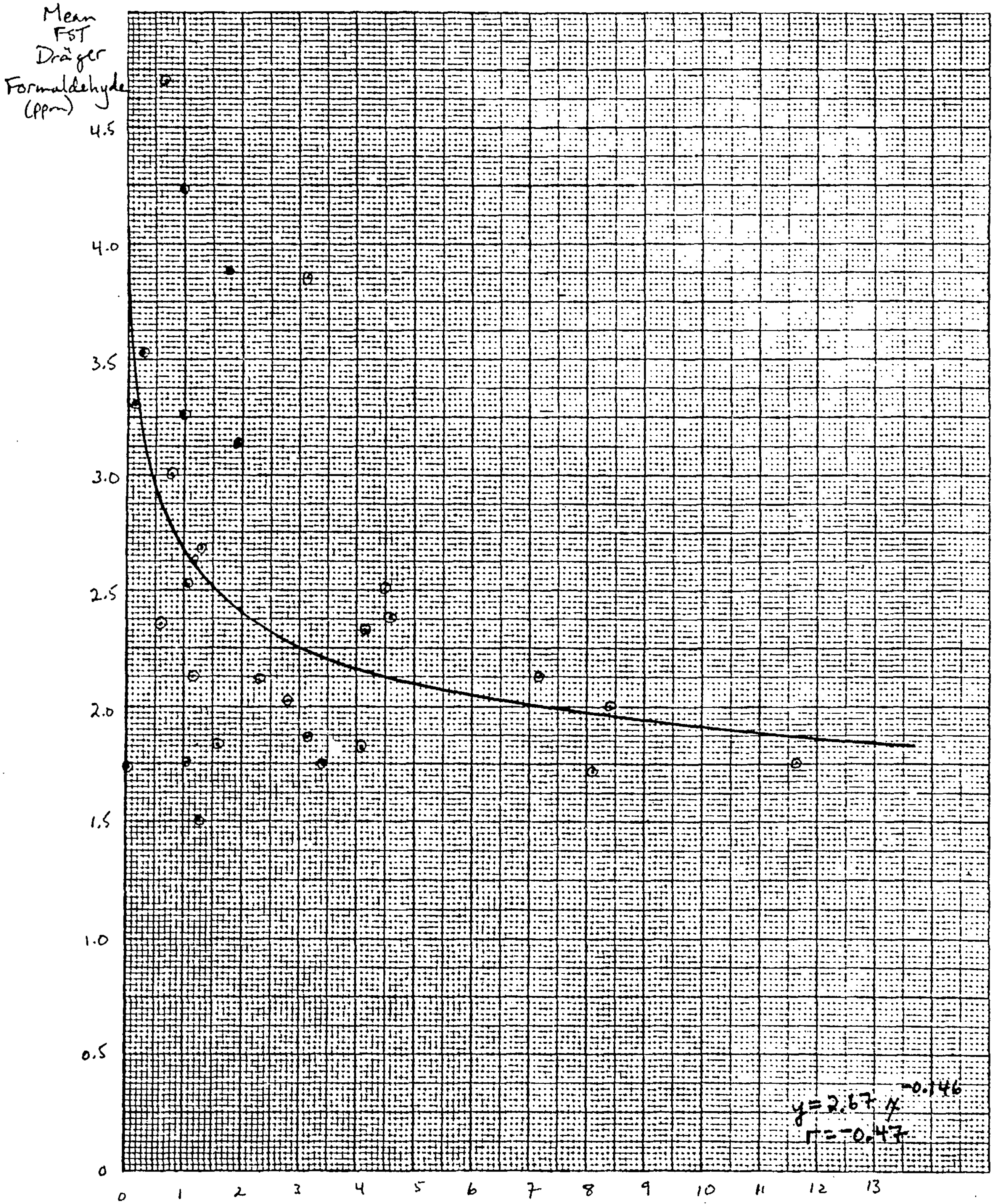
*Mean Wood Moisture (%)

(excluding readings <6.0% or <9%)

(from tabulation 7B)

Graph XVII

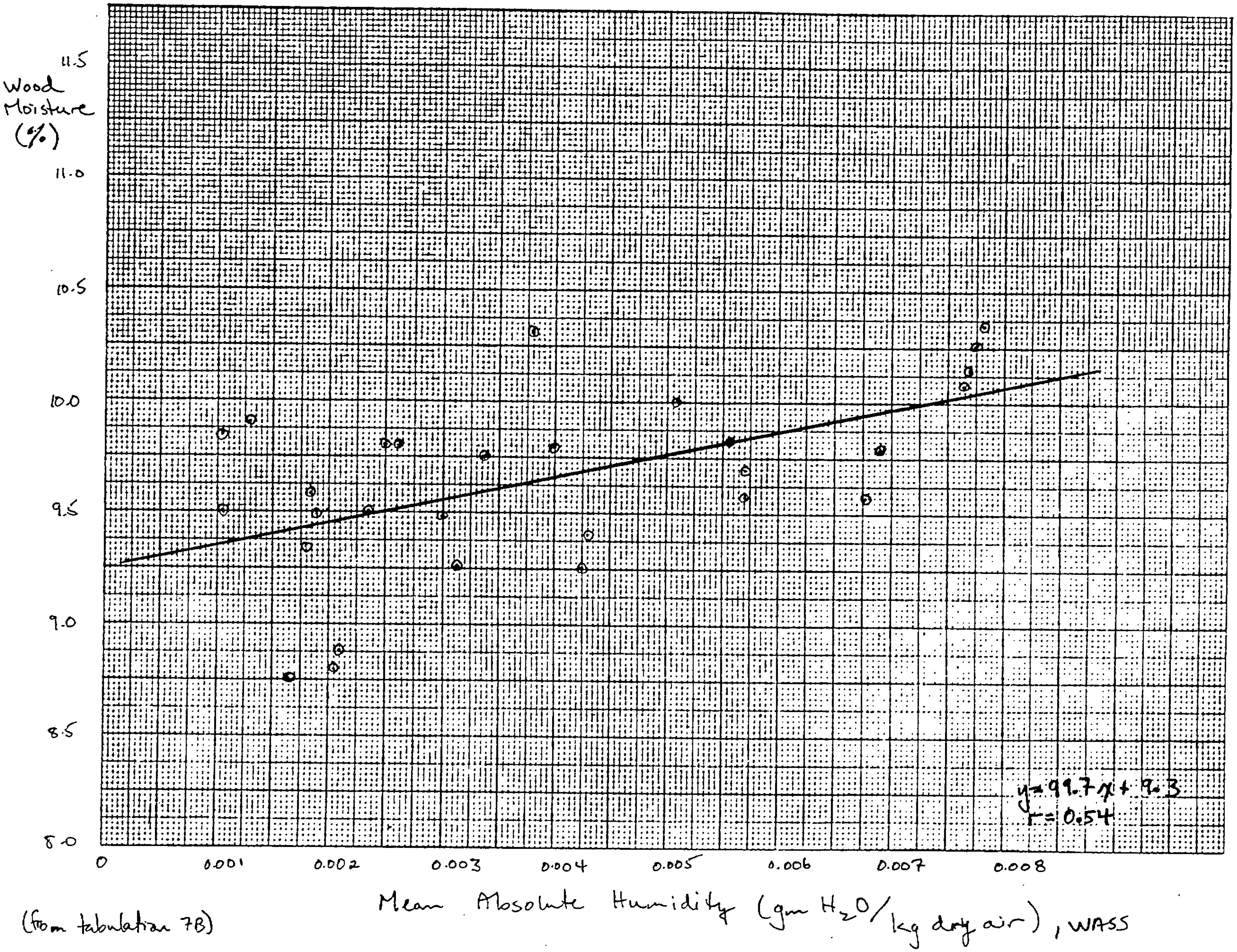
Percent of Wood Moistures <6 or <9.9 %, versus Mean FST Dräger Formaldehyde



(from tabulation 7B)

Graph XVIII

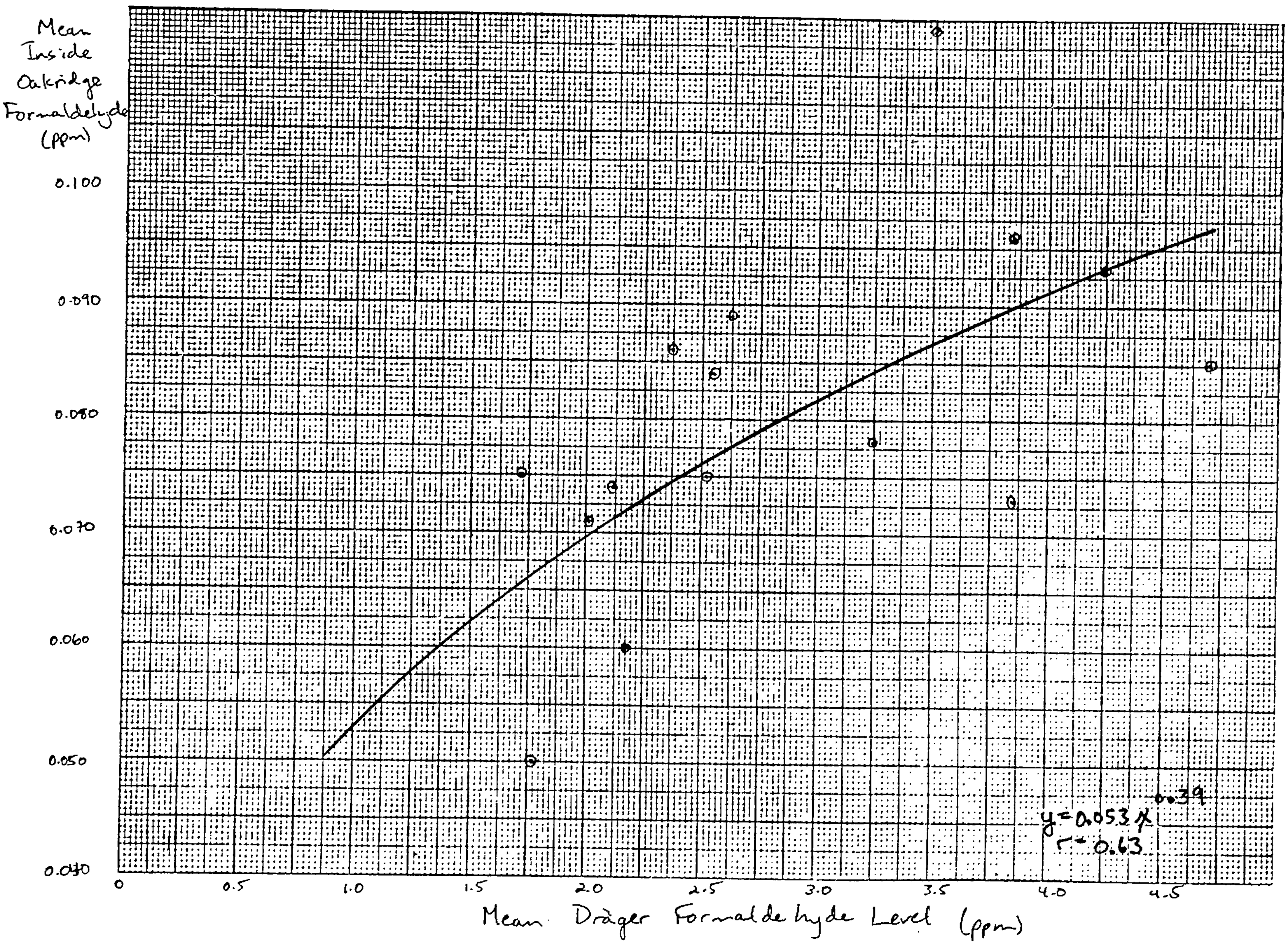
Mean Absolute Humidity versus Mean Wood Moisture at FST



(from tabulation 7B)

Graph XIX

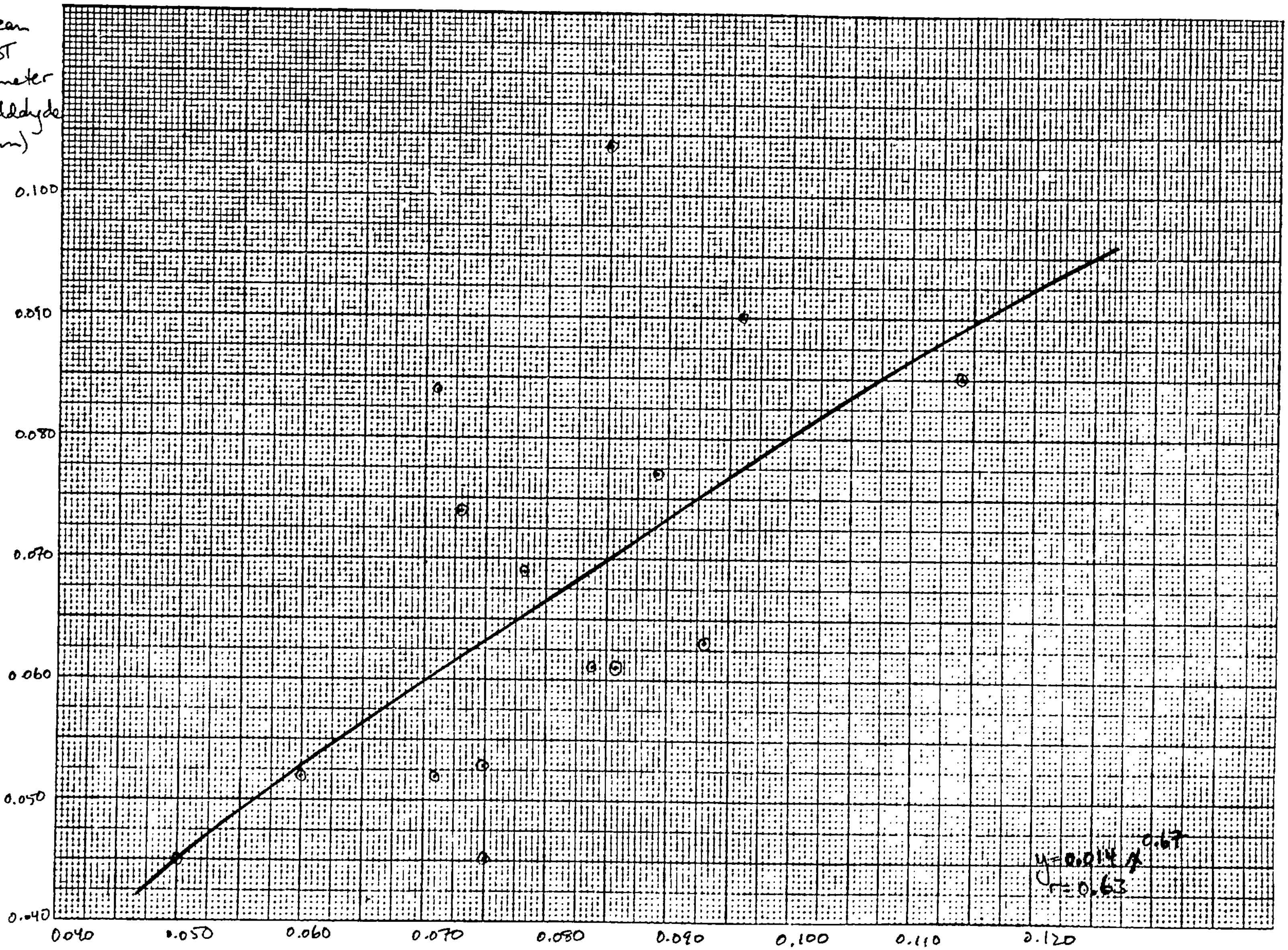
Mean Oakridge versus Mean Dräger Formaldehyde Levels, at FST.



Graph XX

Mean Oakridge versus Mean FST Dosimeter Formaldehyde Levels

Mean FST Dosimeter Formaldehyde (ppm)



Mean Oakridge Formaldehyde Level (ppm)

(from tabulation 7B)