4-1978

The Effect of Carbon Black on TR Moisture Measurements and Beta Ray Basis Weight Measurements

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THE EFFECT OF CARBON BLACK ON IR MOISTURE MEASUREMENTS AND BETA RAY BASIS WEIGHT MEASUREMENTS

by

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A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University
Kalamazoo, Michigan
April, 1978

ABSTRACT

Computer control of paper industry processes is becoming a very significant segment of the industry. Of major importance is on-line measurement and control of moisture and basis weight in the web, these two parameters affect practically every other sheet characteristic. Accurate closed loop control is essential to keeping the product within customer-demanded specifications.

Board mills in particular utilize large quantities of waste paper, with the rate of usage expected to increase from 20.5 percent in 1970 to 26 percent by 1985. The concentration of contaminants will increase at a similar rate. One such contaminant, carbon black, will reduce the effectiveness of on-line IR (infrared) moisture sensors. Carbon black is the most important pigment in printing inks, since it colors virtually all black inks.

All materials will absorb or reflect light energy, the amount being a function of the material characteristics and the wavelength of the light beam. Carbon black being a black body is nearly an ideal absorber. When present in a web of paper the carbon black will absorb IR wavelengths used to detect water in the sheet, yielding erroneous moisture content measurements.

Experimental results showed that the relationship between carbon black level and the deviation from actual moisture is linear.

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INTRODUCTION

The increased use of recycled paper in the paperboard industry in particular poses a problem for on-line physical analyzers. Moisture measurements become inaccurate when carbon black, the main constituent in black pigmented printing inks, is present in the web. Carbon black and water both absorb wavelengths of radiation in a similar infrared band. Since this IR principle is used by many on-line moisture measurement systems there should be erroneous readings yielded when carbon black enters the process. This can create uneconomical situations when related to quality control in the industry.

By simulating carbon black concentrations in test samples and testing them on an IR gauge some type of relationship may be arrived at. Carbon black levels are characteristically less than one percent in paper mill situations. However, by controlling the addition of carbon black to levels of zero to eight percent more trends can be found.

Calibrating the on-line IR moisture gauge with the information arrived at will allow for more precise control of moisture in the web. Basis weight measurements would tend to be affected by a lesser degree by carbon black being present in the sheet.

THEORETICAL DISCUSSION

Computer control in board production

In order to analyze the research problem it is first necessary to understand the related topics that lead to the problem. The first such heading is the realization of the importance of on-line quality control in board mills through computer usage.

The early 1950's saw the introduction of some of the first gauges for on machine quality measurements in an attempt to overcome problems of testing paper after removal from the machine.[1] But the instruments were installed on fourdrinier machines producing lightweight papers, not on cylinder and linerboard machines.

Actually the first combination paperboard mill to install a computerized process control system did so in early 1974.[2] In June of 1971 there were only five U.S. linerboard machines under dedicated computer control.[3] Since there has always been some doubt about the applicability of computer control to cylinder machines, acceptance has been on a step-by-step, "let's see" basis.

Uniformity of moisture and basis weight are the two principle factors that determine sheet quality and also the profitability of a machine.[4] With board machines this makes accurate gauges exceedingly important as compared to lightweight paper products. Basis weight response times are limited to transport times from the stock pump to the sensor at the dry end (3 to 4 minutes depending on machine speed); the dead time for the moisture loop is about 100 seconds.[5] Obviously if the mill is producing a product in the range of 100 lb/1000 sq. ft., erroneous measurements are an expensive item to deal with.

Basis weight and moisture measurement information in some cases is achieved through the use of three scanners. The scanners are usually located as follows: (1) The first at the wet press before the dryers; (2) the second ahead of the size press; (3) the third at the reel. The installation of process control systems, with respect to moisture and basis weight uniformity produce the following benefits to fiberboard:

- Increased moisture level resulting in a better product and fewer dryer breaks
- Accurate on-line measurements of moisture and basis weight averages
- Basis weight control maintains the ideal target for the grade continuously
- Moisture control to a desired target
- Reduced basis weight and moisture spreads

The increase in the moisture content is achieved without the other quality properties being altered. Overall computer control results in better control of quality and in more efficient utilization of the machine to increase profits.

Use of wastepaper in board

The availability of vast forest resources as a force leading to declining rates of wastepaper recycling still generally prevails. However, external forces should provide incentives and create a demand for recycled products and increase the recycling rate to 26 percent by 1985, compared to 20.5 percent in 1970.[6]

Before 1965 linerboard furnished by wastepaper supplied a significant part of the market and diminished for the next few years. During the early

seventies some plants began using 5-25 percent wastepaper and presents one of the substantial opportunities to increase recycling, both with supplemental fiber or using 100 percent wastepaper.

Corrugating medium using recycled fiber can be produced on an equivalent basis to semi-chemical medium. The use of wastepaper in corrugating could increase to 5.1 million tons by 1985 compared to 1.4 million tons in 1970.

Combination paperboard is the most important user of post-consumer wastepaper grades, accounting for two-thirds consumption of all wastepaper for recycling. The wastepaper is going to be available in the future for recycling, but manufacturers realistically must consider technical factors such as runnability or aesthetics. Combination paperboard mills can be constructed using modern technology to be competitive with virgin fiber mills for commodity grades of paperboard, but at present unattractive economic return will prevent new investment by the industry.

Considerable benefits to both the industry and the community arise from the recycling of wastepaper. However, the optimum benefits to both can only be obtained by operating a rational program which takes into account the varying properties of each specific grade of wastepaper and the constraints on its use.[7]

Furthermore, board producers will adapt continously and rapidly to a changing market for board products, especially with a greater input of wastepaper than usual is expected.

The previous discussions dealt with computerized board control followed by use of wastepaper in board. The link between the two is carbon black, its presence in ink and its effects on infrared (IR) moisture gauges, and to a lesser extent effects on beta gauges for measuring basis weight.

An enormous drawback to the paper industry is the large capital outlay required for processing wastepaper. Facilities and equipment to undertake deinking fall under this category, and without this process carbon black enters the board mill through recycled wastepaper. Even if the mill does have deinking facilities, the efficiency is not 100 percent.

Carbon Black

Carbon black is one of the three main headings of pigments for printing inks, the other two being inorganic and organic pigments. Carbon black pigments consist largely of the element carbon, the basic constituent of all vegetable and animal materials. When these carbon containing substances are burnt in air a soot is formed. By controlling the air supply the soot can be deposited in extremely fine form which behaves as an effective black pigment. Many different types and grades of carbon black can be produced differing in chemical purity, surface properties, and particle size. Printing inks normally use grades of either furnace or channel blacks, made by burning oil or natural gas in a limited supply of oxygen.

Carbon black ranks as the most important pigment in printing inks, since it is used to color virtually all black inks. It is relatively cheap and possesses a remarkable range of properties including good color strength and excellent resistance to light, heat, moisture, and most chemicals. Carbon blacks have a very small particle size, ranging from 10 nm for channel blacks to 200 nm for furnace and lamp blacks. These tiny particles present a very large surface area to be wetted by a vehicle and accounts for high oil absorptions and difficulties in dispersing the pigment.[7]

The printing ink industry employs by far the major quantity of carbon black in new inks. High color blacks, the most expensive grades manufactured,

are utilized in high-grade letterpress and, particularly, in offset inks. Solid dispersions, or resin bonded blacks, are used for high quality web heatset inks. High viscosity pastes (base blacks) represent the largest volume used in the ink industry. In 1975, more than four million pounds were purchased by printing ink manufacturers. Base blacks are used to meet every requirement of the formulator in a wide variety of products.[8]

IR moisture gauge

Moisture gauges are available in a wide variety of forms; dielectric, DC resistance, AC conductivity, radio frequency, and infrared gauges. There are two types of IR gauges, one is reflectance and the other is the infrared transmission type.

Any material will reflect and/or absorb light energy. The degree of absorption is a function of both the characteristic of the material and the energy spectrum or wavelength of the light beam. Since it is desired to determine the moisture in the paper, a wavelength of light is required which is readily absorbed by water. Although the light may be readily absorbed by water, it is also absorbed to a degree by the other materials in paper like fiber, clay, TiO_2, and carbon black.

In order to determine what percent of the light absorption is due to water and what percent is due to the other materials, two wavelengths of light are selected. The first is absorbed by water, the second wavelength selected is essentially absorbed by the other paper materials to the same degree as the first but is not absorbed nearly as well by water. The difference in absorption of the two wavelengths of light is then due to the amount of water.

Determining the degree of light absorption is done by detecting the amount of light which is transmitted by the paper or reflected by it. The

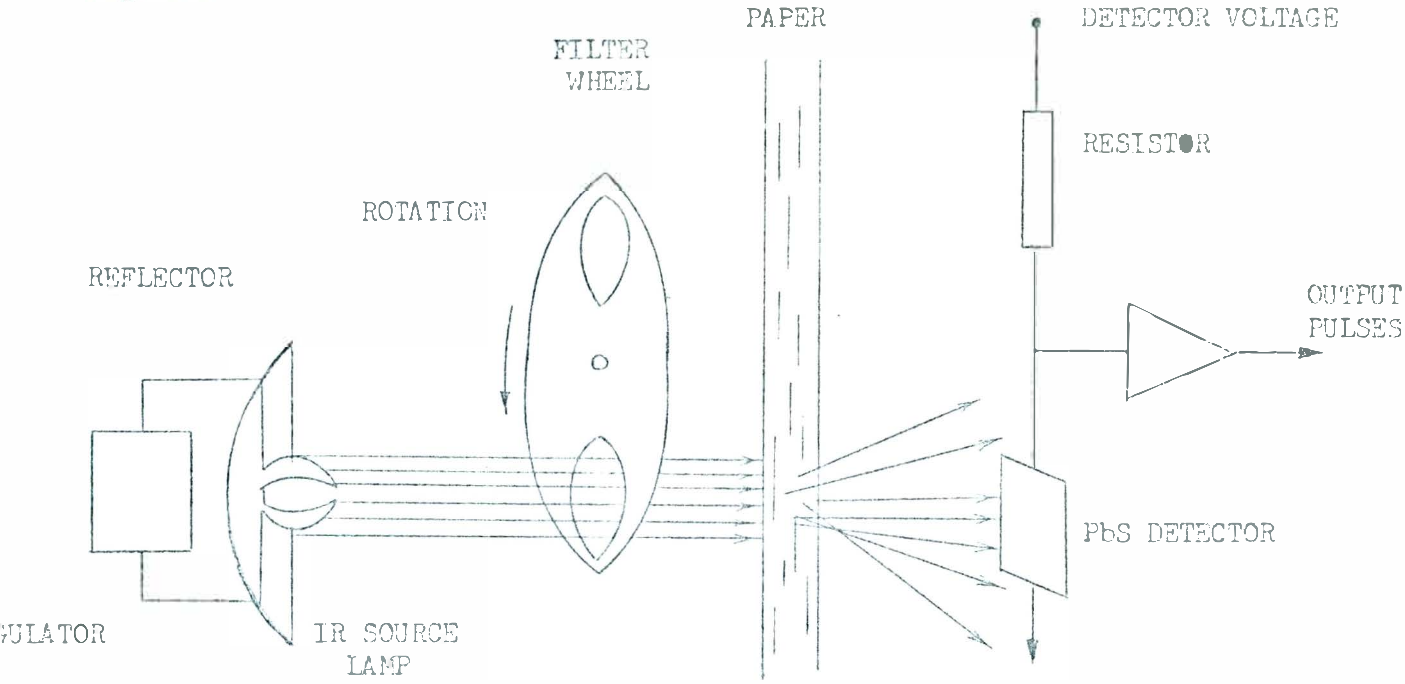
amount of light transmitted or reflected is measured by a detector which is sensitive to light intensity. The gauges are rated to measure a wide range of basis weights, but papers containing excessive amounts of carbon black cannot be measured (presumably this is true of all infrared gauges).[9]

Carbon in one form or other has been used to filter out short wavelengths since the beginning of far-infrared spectroscopy; sooted quartz was used for many years.[10] Carbon black, from inks in wastepaper, could scatter as well as absorb the transmitted light. The scattered radiation may reach the detector if the distance between the particles and detector is small.

The constructional materials for the detectors mentioned above must be blackened by applying an absorbing coating. One of the simplest means of blackening is to apply a thin layer of soot from a candle flame, such a film has an absorbtance of 0.99 in the visible.[11] Recall this is the same method used in producing carbon blacks for printing inks. The carbon black in the web of paper will offer a surface that absorbs any radiation falling on it, instead of reaching the detector.

The actual instrument has one light source and one detector but two light filters. The source and detector are sensitive to both wavelengths while the light filters are selected to pass only the desired wavelength and are opaque to the undesired. The paper transmittance is measured through one light filter; then the other filter is inserted and the second measurement made. This is accomplished by filters mounted on a spinning wheel shown in the accompanying illustration (Fig. 1-1).[12]

Fig. 1-1



The ratio of received energy through transmission is stated mathematically as:

$$R = \frac{I_R - I_A}{I_R}$$

Where R is the ratio
I_R is the intensity of energy received at the reference band
I_A is the intensity of energy received at the absorption band

In addition to the transmission type meters are the reflectance type, which also use IR radiation, but in these the source and detector are on the same side of the web. The internal components and theory are the same as the transmission type with respect to filter wheel, wavelength utilized, measurement, etc. The web is exposed to narrow-band radiation at the two wavelengths through the two filters. Reflected radiation, collected in an integrating sphere, activates a lead sulphide detector. The signals are amplified, and the ratio of these signals is read out directly as moisture content. This measurement technique essentially eliminates the effect of paper variables other than moisture content.[13]

Basis weight gauge

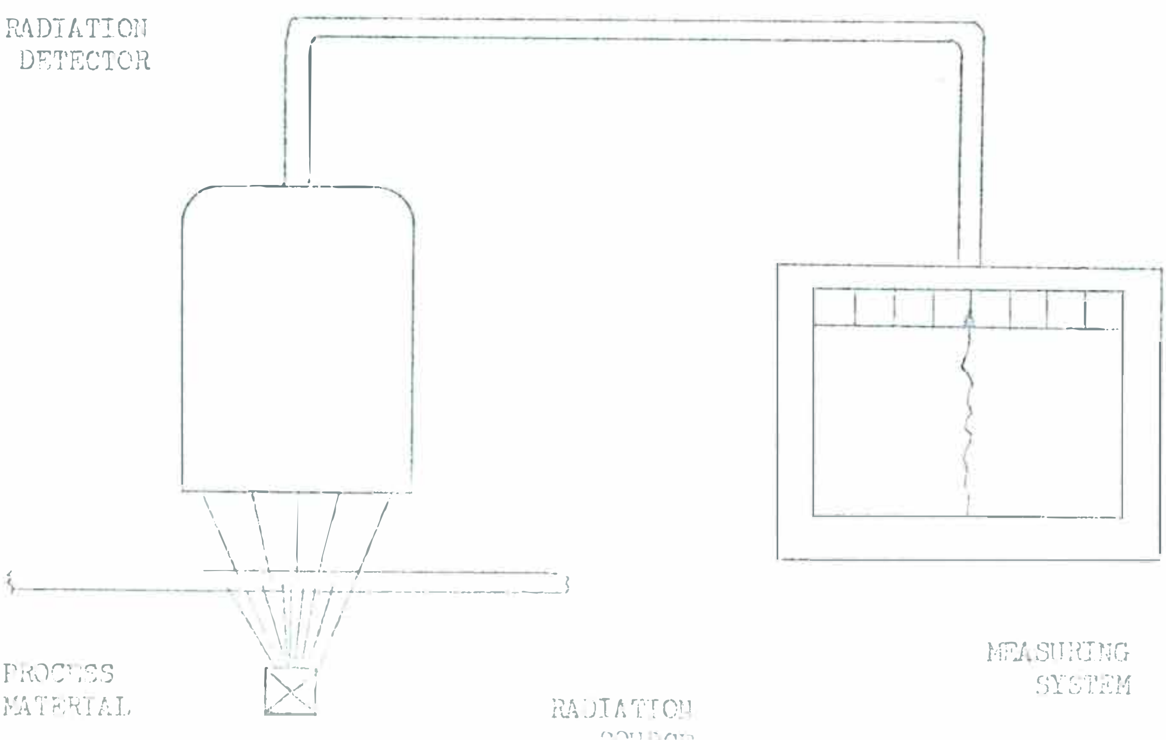
The beta gauge has evolved along fairly narrow lines with great similarities between manufacturers. On-machine basis weight instruments were developed first and widely accepted because basis weight variations effect almost every other paper characteristic.

Beta particles are high energy electrons emitted by a radioactive isotope through disintegration. By focusing this stream of radiation through a given material or absorber, the number of electrons reaching a "target" will be dependent on the weight per unit area and the composition of the absorber (Fig. 2-1).[14]

A high DC voltage connected across the detector causes a minute current to flow through the detector whenever radiation is present. The current is a function of the radiation and a developed voltage is measured.

Again carbon black in the path of the transmitted radiation may cause measurement errors in the unit.

Fig. 2-1



EXPERIMENTAL PROCEDURE

Equipment and materials list

Balance - a high resolution weighing device to measure carbon black addition and test sample weight.

Carbon black - the black used in these tests was a powder form of oil furnace black with a trade name of Regal 400. It has applications in letter-press, offset, flexographic, and packaging gravure.

Handsheet mold - to produce the test samples; includes wires, press, dryer, felts, and associated equipment required to make Noble and Wood handsheets.

IR gauge - moisture measuring device for sample testing (instrument used in this project was an Inframike II, model 11AW2)

Miscellaneous - freeness measuring instrument, pH meter, mason jars for stock storage, etc.

Moisture bag - to put samples in for use on IR gauge

Pulp - a controlled variable, all test sheets were made from the same commercial pulp - Espanola, a bleached softwood kraft.

Valley beater - to refine the pulp under the same conditions to approximately 325 CSf.

Procedure

The procedure utilized in the determination of the effect of carbon black on infrared moisture measurements was as follows.

The key variables to be controlled were the amount of carbon black in the sample and the amount of moisture in the sample. Samples were made using standard Noble and Wood procedure of basis weight 70 pounds/3300 square feet, as this is the practical limit for IR backscatter gauges. The same pulp was selected for sample preparation, a softwood bleached kraft variety. The pulp was beaten to approximately 325 Canadian Standard freeness in a 360 gram Valley beater; several beater runs were necessary to obtain 125 samples, of which seventy were selected for testing. Conditions were the same in each beater to minimize any effects other than carbon black concentrations in the samples (i.e. keeping the pH around 8.0 throughout).

The method of addition of carbon black to the sample was a difficult selection. This was due to the fact that any addition to the fiber while in suspension will run into retention problems. Since the percentage of carbon black present in the sample is the controlling factor of the experiment, knowledge of the amount present is of the utmost importance. Losses of carbon black in white water and to the drying felts had to be avoided.

The method selected achieved this by surface addition of the carbon black to the sample. A handsheet was formed in the sheet mold and removed. Prior to being pressed the carbon black was distributed on the surface of the sheet by applying the fine particles with a shaker. Then a second sheet was formed in the mold and placed directly on top of the first carbon-covered sheet. This sandwiched the carbon black between the sheets to prevent losses to the felts.

The sample was sent through the press, after which one of the wires was removed, and finally was dried by contact with a rotating steam-filled dryer can.

The shaker was weighed before and after application of the carbon black to obtain the weight of the carbon in the sample by difference. From this information and the bone dry weight of the sample, the percentage of carbon black was calculated. This required making twice as many handsheets (35#/3300 sq. ft.) as samples in this production stage.

From the 125 samples made, the best seventy were selected (42 were actually used) to be tested for data collection. The criteria used to determine quality was uniformity of distribution of carbon black, basis weight, and formation.

The samples were placed on the sensing head of the Inframike II to obtain a gauge reading of moisture. This figure was compared to the value of moisture determined by laboratory procedure in evaluating the effect of carbon black on IR moisture measurements.

Bone dry weight determinations had to be performed on all samples being tested in this manner. This was done three separate times on each of the forty two samples in order to obtain the correct and most reliable figure. This bone dry weight was used in the calculation of carbon black percentage for each sample. The following formula was used, the percentage is based on the bone dry weight of fiber in the sample.

$$\text{Percent Carbon Black} = \frac{CB}{BD - CB} \times 100$$

CB = weight of carbon black

BD = bone dry weight of sample

The samples were then coded, the code being a number that described the amount of carbon black in the sample.

A special plastic bag was required to put the samples in while taking readings on the gauge. The bag is not sensitive to infrared radiation, that is it does not hinder the transmission or reflection of IR. In this bag the samples are not in contact with the environment, thus removed from fluctuations in humidity. The moisture in the sample when being tested under the gauge is the same as the actual moisture determined by the following:

$$\text{Percent } H_2O = \frac{W - BD}{BD} \times 100$$

W = wet weight of sample

BD = bone dry weight of sample

Note: This is not the conventional method of representing percent moisture, although it is not incorrect.

The sample and bag were weighed immediately after the readings were taken from the gauge. The sample was removed from the bag, and the weight of the bag was obtained. From these two figures the wet weight of the sample was calculated.

The gauge reading that is used in all comparisons was obtained by averaging together five values taken from each sample. That is, a reading was taken at each of the four corners and the center of the sample when placed on the gauge. The mathematical mean of these five values is referred to as the gauge reading or Inframike reading. This helps eliminate some of the effect of nonuniform distribution of both carbon black and moisture in the sample.

The above procedure was used in obtaining data at three moisture levels in looking for trends on the effect of carbon black on IR moisture measurements. Samples were allowed to stand to the machine room environment which conditioned

them to a medium level moisture of approximately six percent. To obtain readings in the low moisture range, the samples were dried to nearly bone dry in an oven, then put in contact briefly with the atmosphere to pick up moisture in the one percent range. A steam line was used to treat the samples for high level moisture data; the samples absorbed enough water to have moisture levels of the order of ten percent.

DISCUSSION OF RESULTS

The raw data were arranged in table format for the three moisture levels. Each table had headings of Sample code (defining the forty-two samples), Percent carbon black, Gauge reading, and Gravimetric (actual) moisture reading. In order to plot this data and visually determine trends, a fifth column was added to the table. This column was denoted by ΔR, which is simply the mathematical difference obtained by subtracting the gravimetric value of percent moisture from the gauge (Inframike) reading. A ΔR of -3.72 means that the Inframike "sees" and displays a moisture reading of 3.72 percent less than the actual percent moisture present in the sample.

Plots were constructed using the parameters of ΔR, percent carbon black, and moisture level. The use of this information led to the development of seven plots; two for the low moisture level (Figures 1-a and 1-b), two for the medium moisture level (Figures 2-a and 2-b), and two representing the high moisture level (Figures 3-a and 3-b), and the last one (Figure 4) showing a family of lines plotting gravimetric moisture versus gauge reading of moisture at various carbon black levels. Figures 1-3 are similar in construction and plot ΔR on the ordinate as the dependent variable and percent carbon black on the abcissa as the independent variable. Keeping in mind that the ΔR variable is not an absolute value, it reads from positive to negative. More on this later. The plotted raw data available at this point was then further inspected for the purpose of analysis.

After a quick glance at the graphs or tables one might contend that this information is perhaps too random to have a defined trend. This is especially true when considering the plot of Table II referring to the medium level

moisture data. But it would take no imagination whatsoever to see that there is a very definite linear trend in the data points associated with the high moisture level (Fig. 3-a).

Any data that is obtained by making gravimetric determinations is inherently subject to error. The wet weight of the samples was found by first weighing the bag plus sample, weighing the bag, and subtracting. This bases the weight of the sample on two separate gravimetric determinations, twice the possibility of recording an inaccurate value.

The above discussion is born out when considering both the ΔR and gravimetric columns in the table pertaining to the medium level moisture. Inspecting the ΔR column a deviation of positive to negative values, especially for the mid-range levels of carbon black is seen. There appears to be no definite trends in the data without further thought. All of these samples had been under the same environmental conditions prior to testing. For all practical purposes the gravimetric reading should be all very nearly the same, but they are not. They range from a low of 1.50 percent to a high of 9.49 percent. This is due to the fact that the sample and bag were weighed to the nearest milligram, and their total weight was in the vicinity of twenty grams, and problems with the balance existed. This is where the poor correlation between ΔR and percent carbon black originated. Figure 4 eliminates those fluctuations by averaging together the high and low values and yields linear lines of gauge moisture levels plotted against gravimetric moisture at four carbon black concentrations.

It is not the intent of the experiment to use coy statistical tricks to make the data prove a preconceived supposition. It is the intent of the project to interpret the results of raw, untreated, laboratory data on the effect of

carbon black concentration on infrared moisture measurements.

Discussion, so far, has not touched upon the distribution of carbon black within the sample. Due to the crude method of application, the uniformity throughout the sample has to be questioned.

Previous mention was made as to the ΔR values being positive and negative. This could be eliminated by calibrating the Inframike to read out the percent moisture in the control (0 percent carbon black) to be the same as the gravimetric reading. Although the gauge was standardized prior to use on every occasion, it was not calibrated. This turns out to be inconsequential as the purpose of this experiment was to seek trends. This trend turned out to be the linear relationship between ΔR and the percent carbon black (discussed in the conclusions). Calibration would have yielded zero offset between the gauge and gravimetric values of moisture for the control samples. This would have eliminated positive ΔR's and fixed the y-intercept, but does not effect the slope, the main parameter of interest.

TABLE I - LOW MOISTURE (ALL DATA)

SAMPLE CODE	% CARBON BLACK	GAUGE	GRAVIMETRIC	ΔR*
01	0	1.40	1.41	-0.01
02	0	1.26	1.06	0.20
03	0	1.54	0.50	1.04
04	0	1.34	-	-
05	0	1.38	0.13	1.25
001	0.52	1.46	-	-
002	0.68	1.84	0.97	0.87
003	0.75	1.66	0.00	1.66
004	0.88	1.72	1.05	0.67
005	0.93	1.78	0.61	1.17
101	1.04	1.72	0.73	0.99
102	1.15	1.78	0.56	1.22
103	1.15	2.34	1.01	1.33
104	1.28	1.70	0.35	1.35
105	1.33	1.84	0.46	1.38
201	2.14	1.44	-	-
202	2.33	1.40	-	-
203	2.40	1.52	-	-
204	2.45	1.48	0.77	0.71
205	2.48	1.24	0.78	0.46
301	2.97	1.16	1.71	-0.55
302	3.02	1.24	0.93	0.26
303	3.11	1.44	1.46	-0.02
304	3.13	1.66	2.46	-0.80
305	3.25	1.34	0.67	0.67
401	3.98	1.28	1.84	-0.56
402	3.97	1.44	0.99	0.45
403	4.07	1.48	1.08	0.40
404	4.22	1.38	1.81	-0.43
405	4.34	1.42	1.38	0.04
501	5.16	1.12	1.08	0.04
502	5.21	1.30	1.67	-0.37
503	5.22	1.28	1.88	-0.60
504	5.48	1.26	1.72	-0.46
505	5.78	1.26	1.94	-0.68
601	6.11	1.32	1.51	-0.19
602	6.87	1.42	1.48	-0.06
603	6.87	1.12	1.46	-0.34
701	6.71	1.18	1.29	-0.11
702	6.96	1.22	1.44	-0.22
703	7.19	1.22	1.58	-0.36
801	8.01	1.18	2.01	-0.83

*ΔR = GAUGE - GRAVIMETRIC

FIGURE 1-a PLOT OF LOW MOISTURE LEVEL (ALL DATA)

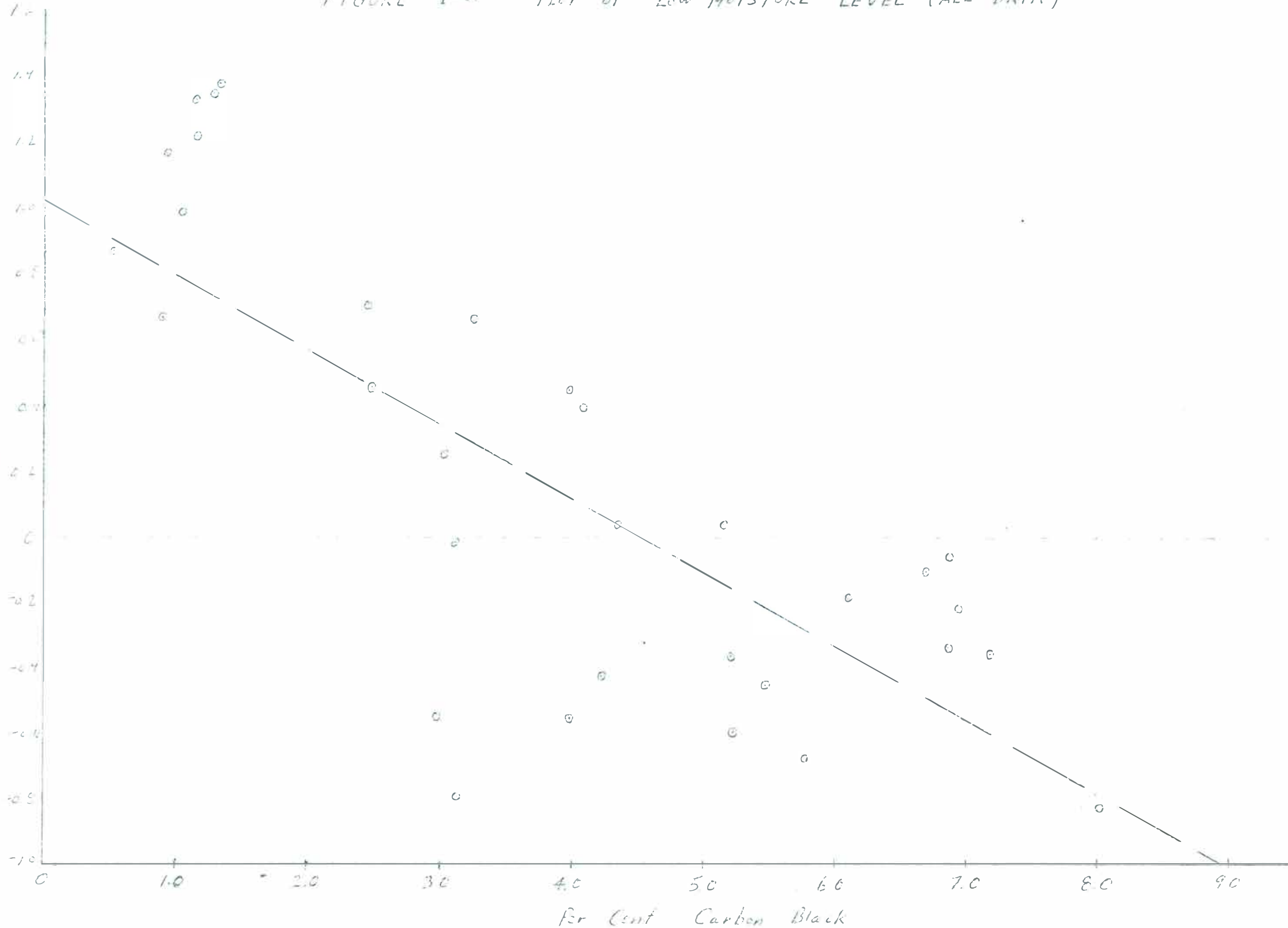


TABLE II - MEDIUM MOISTURE (ALL DATA)

SAMPLE CODE	% CARBON BLACK	GAUGE	GRAVIMETRIC	△ R*
01	0	6.24	6.25	-0.01
02	0	6.02	6.05	-0.03
03	0	6.28	5.93	0.35
04	0	6.48	6.03	0.45
05	0	6.56	6.71	-0.15
001	0.52	5.22	7.16	-1.94
002	0.68	5.46	8.03	-2.57
003	0.75	6.04	7.75	-1.71
004	0.83	5.78	7.11	-1.33
005	0.93	5.68	5.60	0.08
101	1.04	5.12	2.24	2.88
102	1.15	5.28	6.94	-1.66
103	1.15	6.06	9.15	-3.09
104	1.28	5.76	8.16	-2.40
105	1.33	5.20	6.72	-1.52
201	2.14	5.10	5.85	-0.75
202	2.33	5.42	7.14	-1.72
203	2.40	5.00	5.60	-0.60
204	2.45	5.00	6.10	-1.10
205	2.48	3.94	5.18	-1.24
301	2.97	4.16	4.11	0.05
302	3.02	4.22	5.28	-1.06
303	3.11	4.92	4.69	0.23
304	3.13	4.88	5.94	-1.06
305	3.25	4.91	4.91	0.00
401	3.98	4.62	5.97	-1.35
402	3.97	4.30	4.44	-0.14
403	4.07	4.64	9.49	-4.85
404	4.22	3.98	3.80	0.18
405	4.34	4.28	2.68	1.60
501	5.16	3.30	4.42	-1.12
502	5.21	3.48	1.50	1.98
503	5.22	3.70	3.08	0.62
504	5.48	3.82	8.42	-4.60
505	5.78	3.82	6.31	-2.49
601	6.11	3.54	7.42	-3.88
602	6.87	3.36	-	-
603	6.87	3.58	8.09	-4.51
701	6.71	3.60	7.82	-4.22
702	6.96	3.40	7.51	-4.11
703	7.19	3.32	7.86	-4.54
801	8.01	3.18	7.28	-4.10

* ΔR = GAUGE - GRAVIMETRIC

FIGURE 2-a PLOT OF MEDIUM MOISTURE LEVEL (ALL DATA)

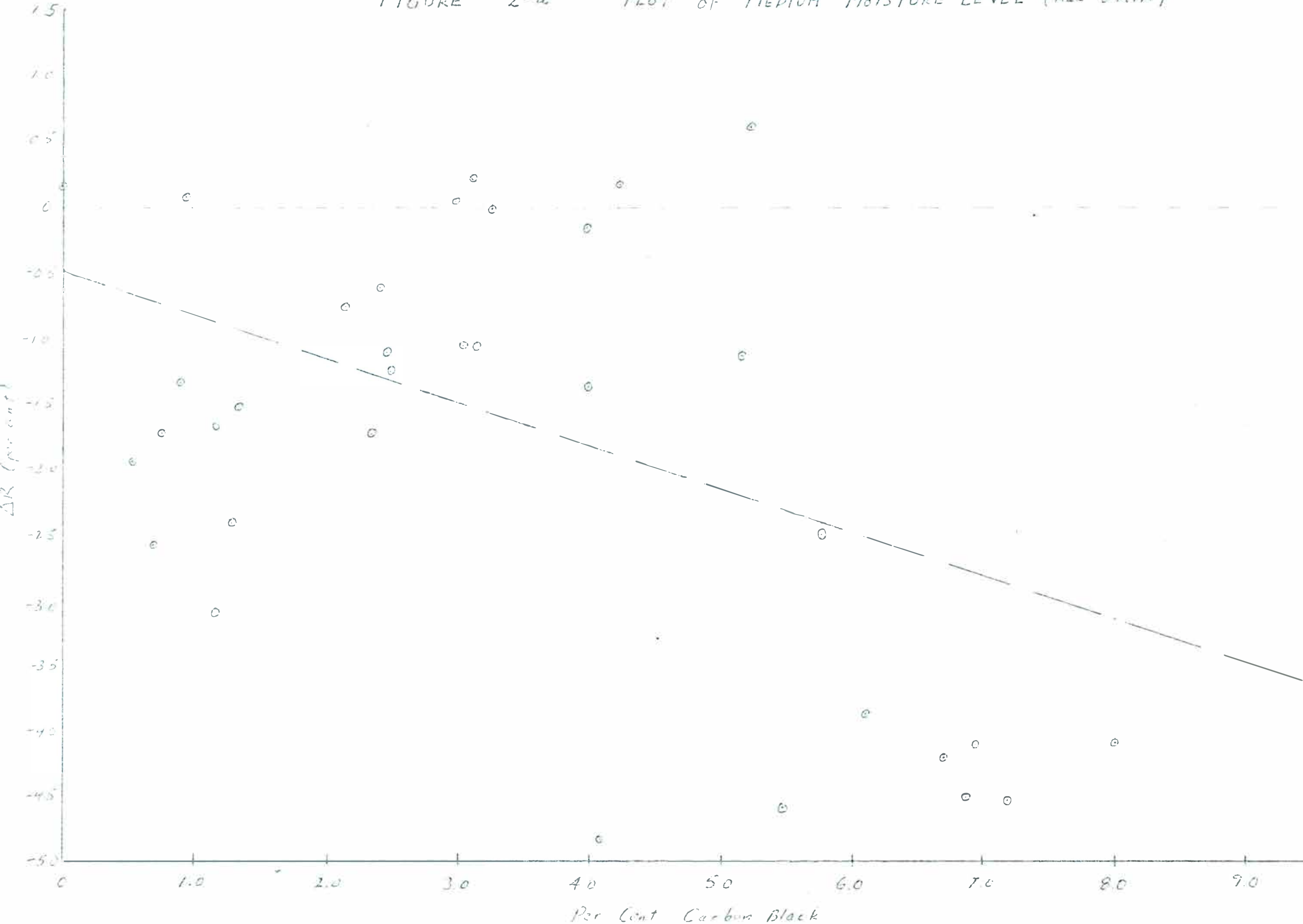


TABLE III - HIGH MOISTURE (ALL DATA)

SAMPLE CODE	% CARBON BLACK	GAUGE	GRAVIMETRIC	Δ R*
01	0	10.14	9.01	1.13
02	0	9.84	8.58	1.26
03	0	9.68	7.89	1.79
04	0	10.78	8.98	1.80
05	0	9.76	8.06	1.70
001	0.52	7.92	8.37	-0.45
002	0.68	7.66	7.38	0.28
003	0.75	9.56	9.35	0.21
004	0.88	11.16	11.14	0.02
005	0.93	8.60	8.46	0.14
101	1.04	8.70	9.38	-0.68
102	1.15	8.18	8.48	-0.30
103	1.15	9.80	10.40	-0.60
104	1.28	9.60	9.77	-0.17
105	1.33	8.10	8.41	-0.31
201	2.14	8.50	9.89	-1.39
202	2.33	8.58	7.85	0.73
203	2.40	9.88	10.27	-0.39
204	2.45	7.96	8.79	-0.83
205	2.48	6.80	8.74	-1.94
301	2.97	6.52	8.95	-2.43
302	3.02	7.48	9.97	-2.49
303	3.11	7.84	8.85	-1.01
304	3.13	8.82	10.98	-2.16
305	3.25	7.88	9.31	-1.43
401	3.98	6.14	8.36	-2.22
402	3.97	8.22	10.57	-2.35
403	4.07	8.20	10.68	-2.48
404	4.22	8.54	14.36	-5.82
405	4.34	7.86	10.74	-2.88
501	5.16	7.74	12.50	-4.76
502	5.21	6.40	10.40	-4.00
503	5.22	6.36	10.48	-4.12
504	5.48	6.94	10.14	-3.20
505	5.78	6.88	9.92	-3.04
601	6.11	8.42	12.67	-4.25
602	6.87	6.88	-	-
603	6.87	8.60	12.76	-4.16
701	6.71	7.10	11.34	-4.24
702	6.96	6.86	10.34	-3.48
703	7.19	8.34	13.75	-5.41
801	8.01	6.52	11.15	-4.63

* _R = GAUGE - GRAVIMETRIC

FIGURE 3-a PLOT OF HIGH MOISTURE LEVEL (ALL DATA)

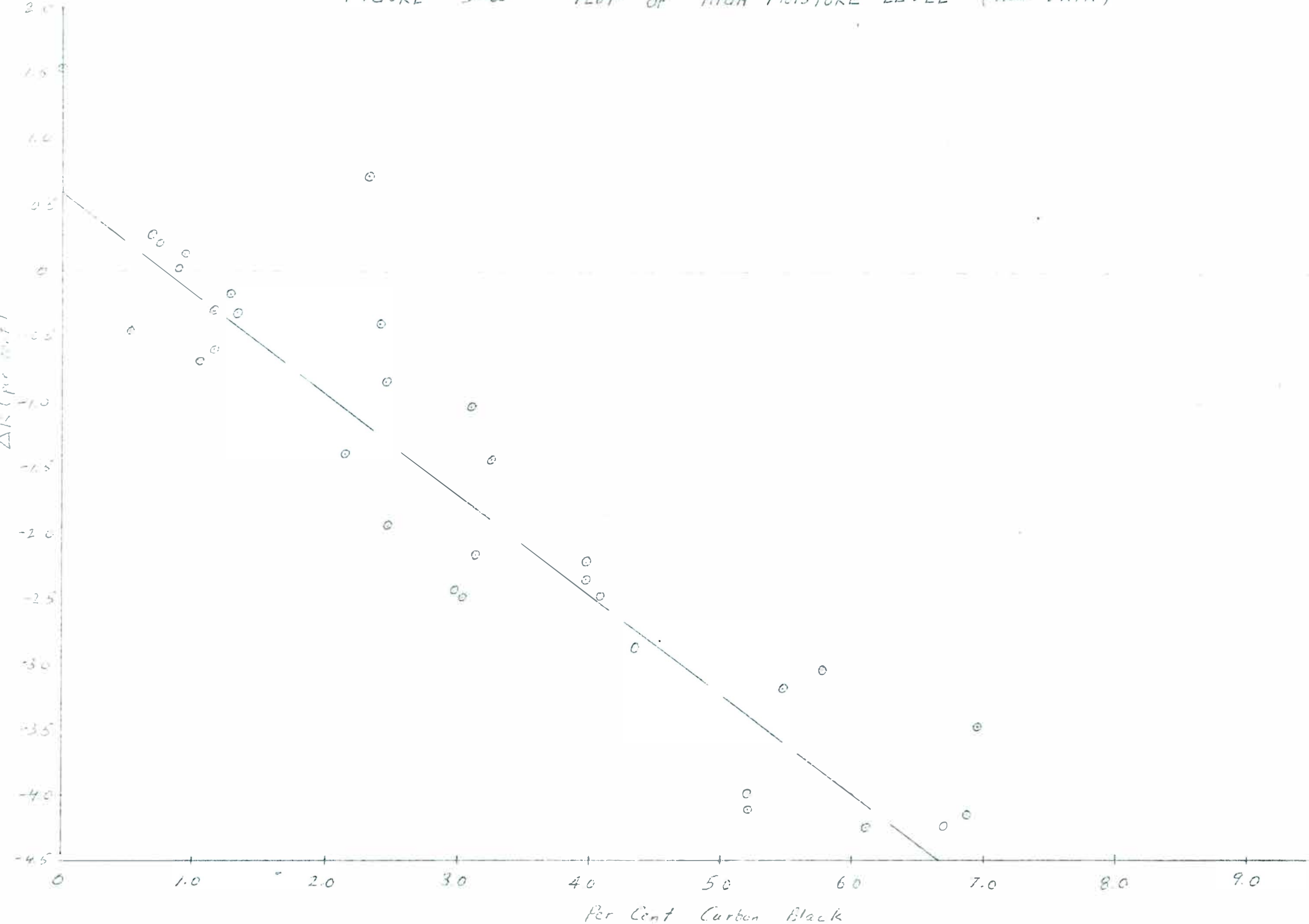


TABLE IV - GROUPED MOISTURE AVERAGES

PERCENT CARBON BLACK	ΔR *	ISTURE LEVEL
0	0.62	
0.81	1.09	
1.19	1.25	
2.46	0.58	LOW
3.10	-0.09	
4.12	-0.02	
5.37	-0.41	
6.96	-0.30	

PERCENT CARBON BLACK	ΔR *	MOISTURE LEVEL
0	0.12	
0.71	-0.49	
1.23	-2.17	
2.36	-1.03	MEDIUM
3.08	-1.06	
4.01	-2.11	
5.47	-2.74	
6.98	-4.23	

PERCENT CARBON BLACK	ΔR *	MOISTURE LEVEL
0	1.54	
0.75	0.04	
1.19	-0.41	
2.37	-1.14	HIGH
3.10	-1.90	
4.09	-2.48	
5.37	-3.82	
6.98	-4.36	

* ΔR = GAUGE READING - GRAVIMETRIC READING

FIGURE 1-6 PLOT OF LOW MOISTURE LEVEL (GROUPED AVERAGES)

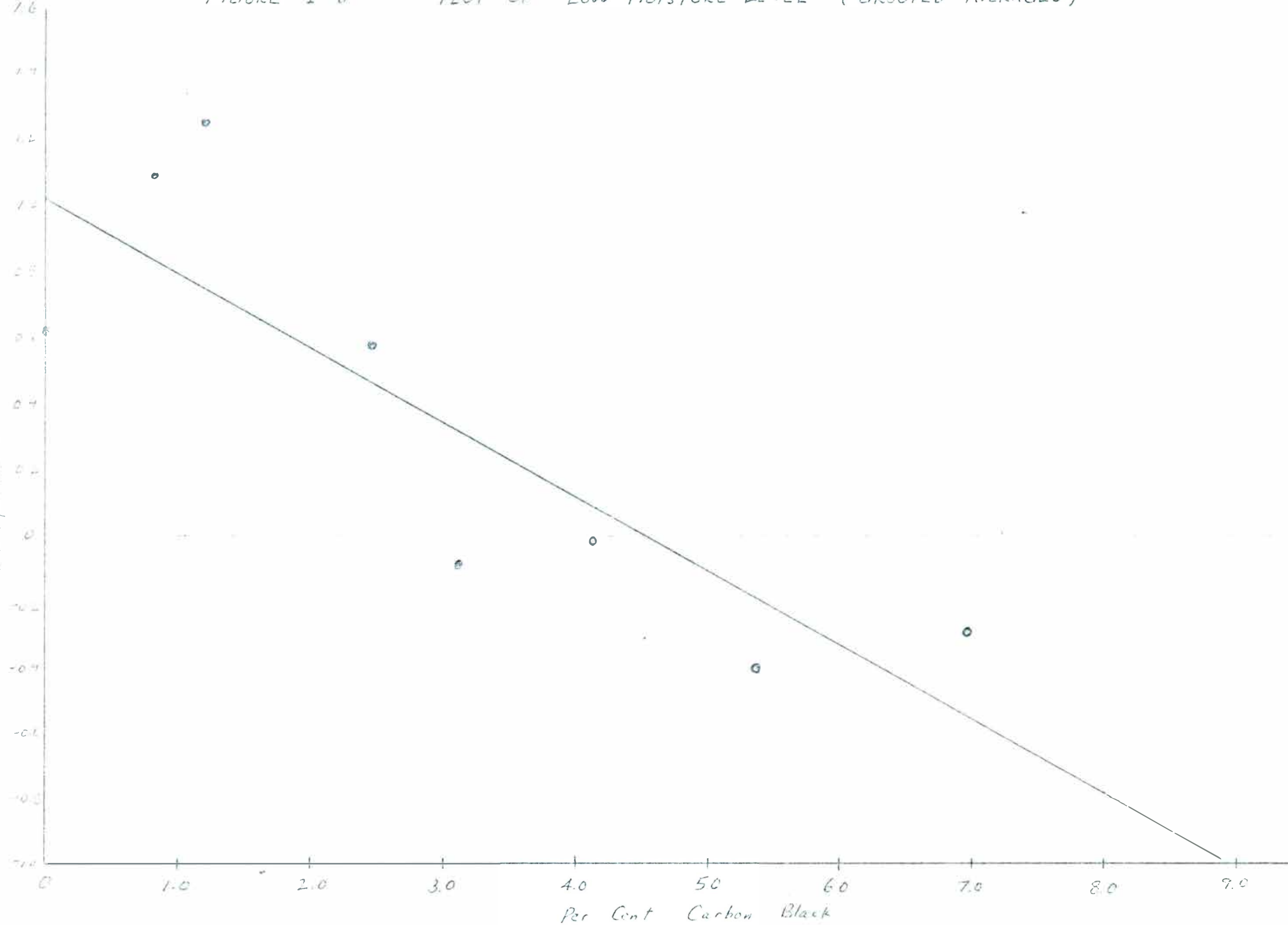


FIGURE 2-b PLOT OF MEDIUM MOISTURE LEVEL (GROUPED AVERAGES)

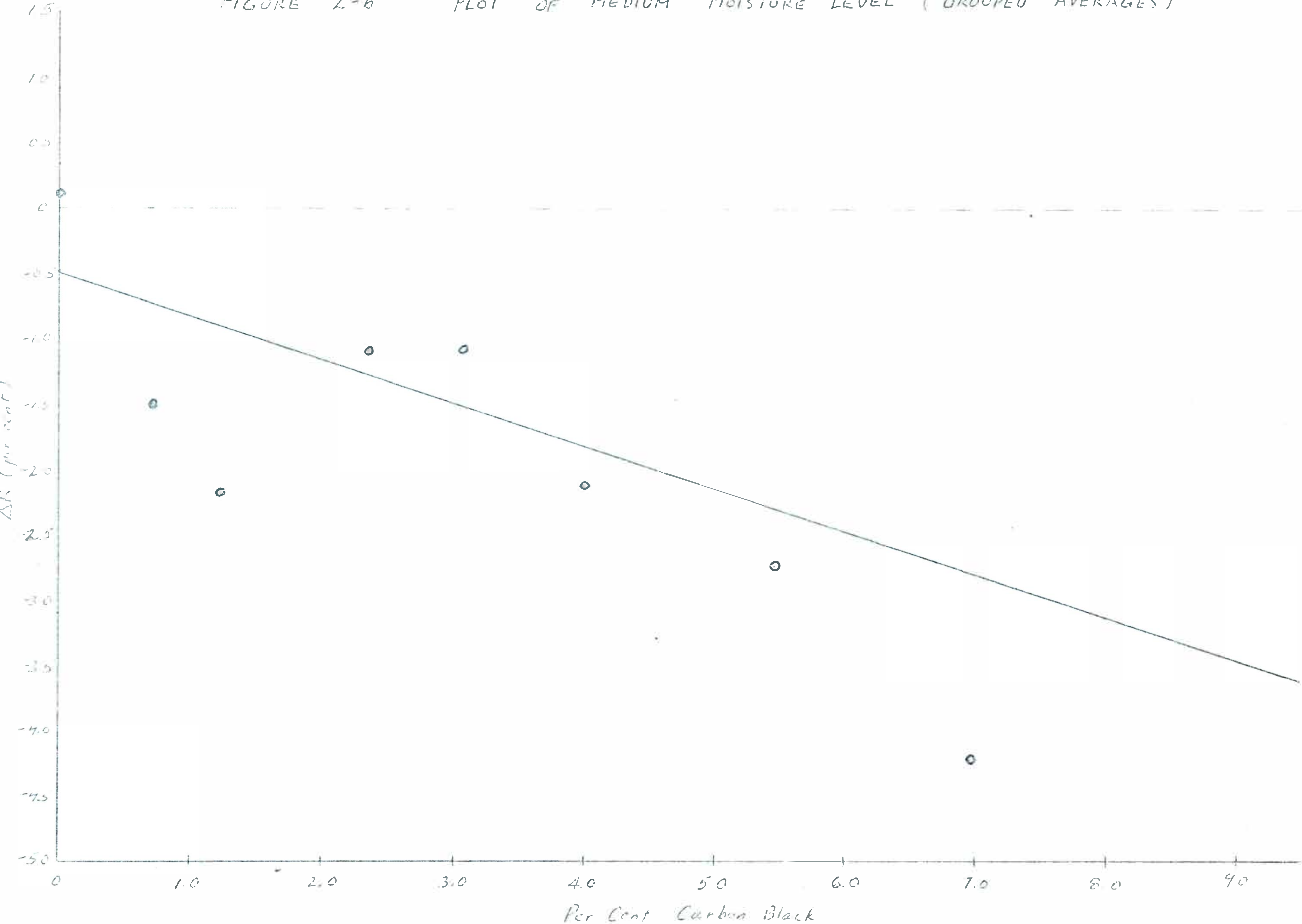


FIGURE 3-6 PLOT OF HIGH MOISTURE LEVEL (GROUPED AVERAGES)

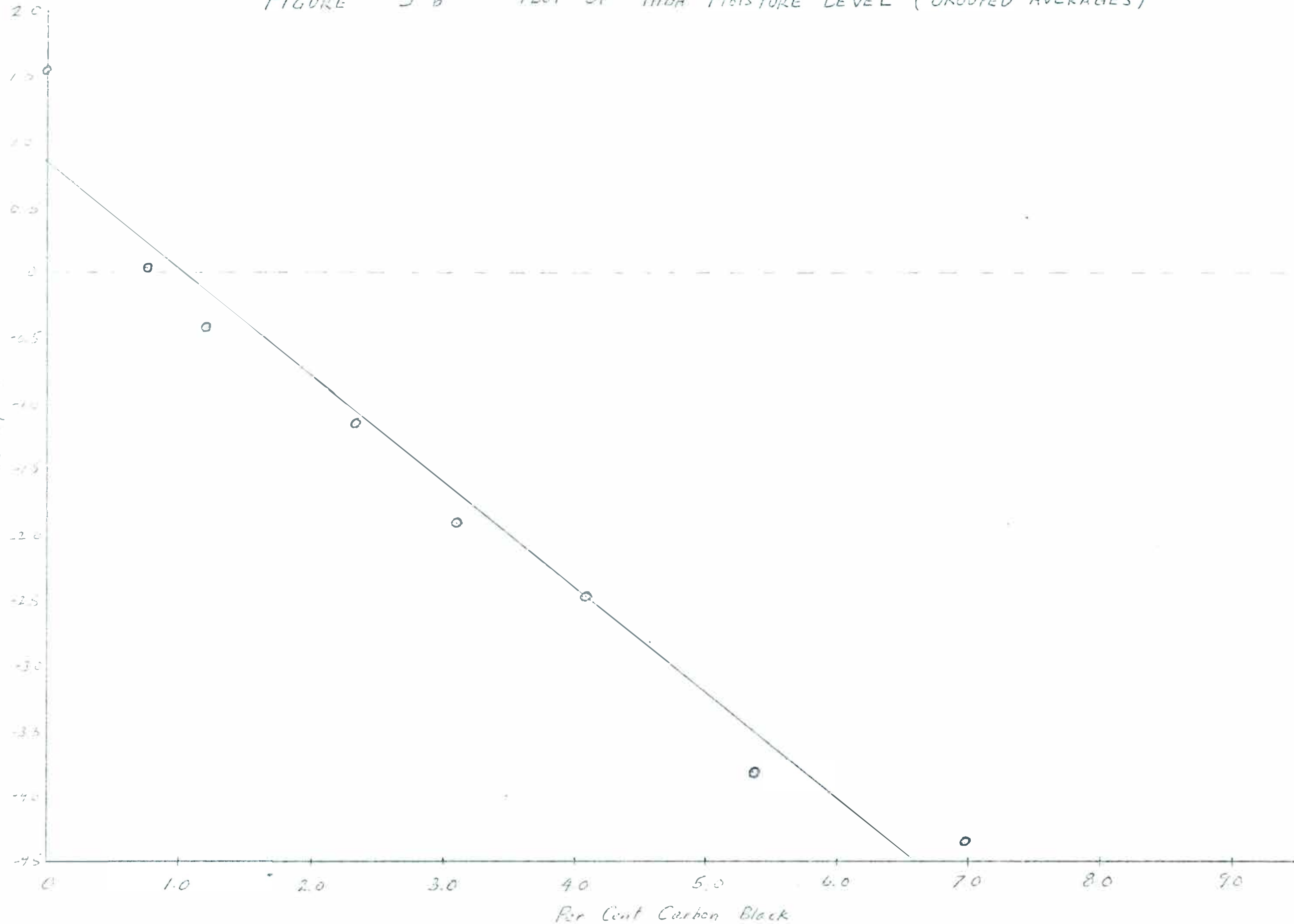


TABLE V - Comparison of Readings at Various Carbon Black Levels

	0% Carbon Black	1.20% Carbon Black	4.10% Carbon Black	6.98% Carbon Black
LOW:				
Gravimetric	0.62	0.62	1.42	1.54
Gauge	1.40	1.88	1.40	1.24
MEDIUM:				
Gravimetric	6.19	6.64	5.28	7.66
Gauge	6.32	5.48	4.36	3.44
HIGH:				
Gravimetric	8.50	9.28	10.94	12.00
Gauge	10.04	8.87	7.79	7.64

FIGURE 4 - RELATIONSHIP OF GAUGE AND GRAVIMETRIC READINGS AT VARIOUS CARBON BLACK LEVELS

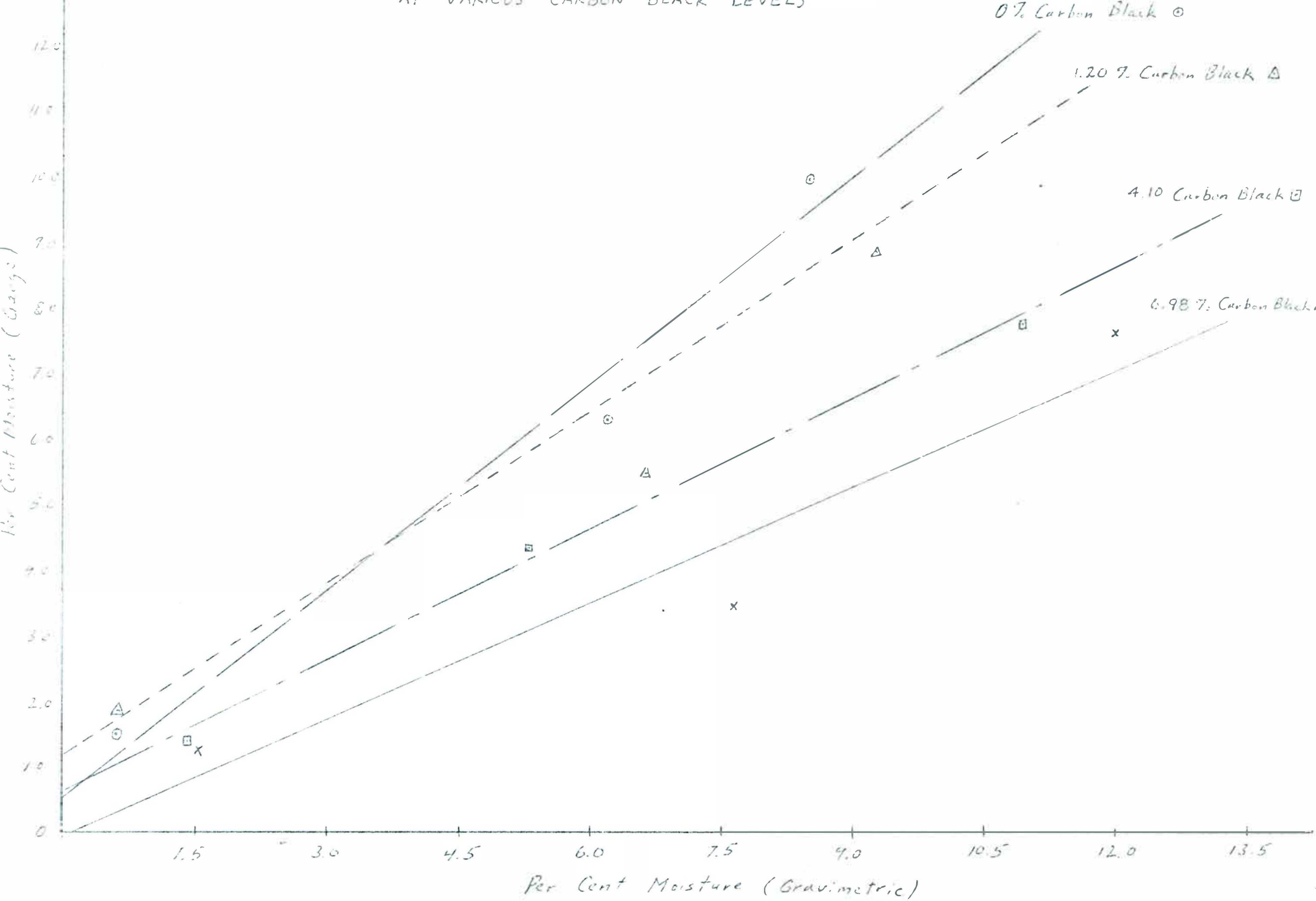


TABLE VI - REGRESSION ANALYSIS

	Line Equation	Correlation Coefficient
Figure 1-a and 1-b	y = -0.23x + 1.02	0.85
Figure 2-a and 2-b	y = -0.46x - 0.49	0.84
Figure 3-a	y = -0.76x + 0.59	0.92
Figure 3-b	y = -0.81x + 0.85	0.98
Figure 4:		
0% Carbon black	y = 1.06x + 0.52	0.99
1.20% Carbon black	y = 0.77x + 1.16	0.98
4.10% Carbon black	y = 0.67x + 0.60	1.00
6.98% Carbon black	y = 0.60x - 0.10	0.96

CONCLUSIONS

Mention was made earlier in the report (in 'IR moisture gauge') that carbon black absorbed infrared radiation, particularly the IR emitted by moisture gauges. Therefore, it is not possible for a properly calibrated IR moisture measuring device to display a percent moisture value greater than the actual moisture present in the sample.

Construction of a table (Table IV) that eliminates such data points that do not belong to their respective populations due to the above consideration was then made. These points are plotted in Figures 1-b, 2-b, and 3-b. A linear regression analysis performed on these three sets of plots resulted in the following:

Figure 1-b   Equation of line - $y = -0.23x + 1.02$ (1)

Correlation coefficient = 0.85

Figure 2-b   Equation of line - $y = -0.46x - 0.49$ (2)

Correlation coefficient = 0.84

Figure 3-b   Equation of line - $y = -0.81 + 0.85$ (3)

Correlation coefficient = 0.98

The line described by Equation (1) is the line plotted in Figures 1-a and 1-b. Equation (2) is likewise the line shown in Figures 2-a and 2-b. Figures 1-a, 2-a, 3-a show the plots of all data points and represent the scatter that did result. By comparison, Figures 1-b, 2-b, and 3-b show the more well defined linear line that results from the data plotted from Table IV. Tables I-III list all data points that were obtained during the experiment.

The line drawn in Fig. 3-a is described by :

$$y = -0.76x + 0.59 \qquad (4)$$

which differs slightly from Equation (3). The data plotted in Fig. 3-a (1)

is raw and untreated and (2) contains the drawback of non-ideal distribution of carbon black. With these two facts in mind the conclusion now made is that:

> There is a linear relationship between ΔR and the percentage of carbon black in the sample.

The correlation coefficients arrived at support this conclusion.

Although the slopes (ΔR/percent carbon black) become more negative as moisture levels increase, this probably cannot be attributed to the carbon black. This trend is due to the sheer magnitude of the numbers involved, at higher moisture levels the ΔR will increase while the percent carbon black remains constant.

The carbon black does definitely play a role in measurements at equal moisture levels as suggested by the linear relationship. This is due to the increased surface area exposed by a large concentration of infrared-absorbing carbon particles. This information could be used to calibrate IR moisture sensing devices to provide accurate readout if the carbon black level is known. The end-all answer to this dilemma is the development of a carbon black insensitive moisture sensor.

RECOMMENDATIONS

This experimental discussion is conspicuous in its absence of the effect of carbon black on beta ray basis weight measurements. And it is concerning this phenomena that I begin my recommendations. It should be followed up on because what has been discovered in this paper. A detailed study of the effect of carbon black on IR moisture measurements has contained enough material to produce a paper in itself. Perhaps carbon black does not affect beta ray basis weight measurements, but this report can do nothing but suggest there is a possibility. Along the same lines, a very interesting project would be to determine the effect of carbon black on IR transmission type gauges relating to moisture measurements. This could then be compared to the conclusions drawn in this paper, which dealt only with the reflection gauge.

FOOTNOTES

[1]Eric Hazlewood, "Continuous Measurement of Quality on the Paper Machine," Paper Trade Journal, 152 (Nov. 25, 1968), p. 48.

[2]Dudley E. King, Jr., "Computer Control of a Combination Paperboard Machine," TAPPI, 59 (Aug. 1976), p. 52.

[3]E. E. Locke, "Computer Control on MacMillan Bloedel's Pine Hill Fourdrinier," Southern Pulp and Paper Manufacture, 37 (April 1974), p. 20.

[4]Maury Castagne, "Weyerhauser's Valiant Paperboard Mill- A Show-case Project," American Paper Industry, 54 (Aug. 1972), p. 31.

[5]Lars Henrikson and Nils Grano, "Asea computer handles PML and quality control at Lovholmen linerboard mill," Pulp and Paper International, 16 (Aug. 1974), p. 39.

[6]William E. Franklin, Paper Recycling: The Art of the Possible 1970-1985, (New York, American Paper Institute, 1973).

[7]L. C. Young, Materials in Printing Processes, (New York, Hastings House, 1973), p. 156-7.

[8]Phillip T. Pope, "Dispersed Carbon for Printing Inks," American Ink Maker, 54 (Sept. 1976), p. 30-32.

[9]Eric Hazlewood, "On-machine measurements of paper properties and characteristics," Paper Trade Journal, 152 (Nov. 25, 1968), p. 55.

[10]M. F. Kimmitt, Far-Infrared Techniques, (Oxford, Clarendon Press, 1973), p. 30.

[11]Richard D. Hudson, Infrared System Engineering, (New York, Wiley-Interscience, 1969), p. 43.

[12]Industrial Nucleonics Corporation, Machine Operators Manual-Accuray Basis Weight and Moisture Measurement and Control System, (Columbus, Ohio: Industrial Nucleonics Corporation), p. 1-2.

[13]Arthur J. Beutler, "An Infrared Backscatter Moisture Gauge," TAPPI, 48 (Sept, 1965).

[14]Machine Operators Manual-Accuray Basis Weight and Moisture Measurement and Control System, p. 2-3.

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