The Role of Gelatin in Paper Permanence, Part II, Phase One:
Gelatin as a Relative Humidity Buffer

submitted in fulfillment of the
requirements for the
Conservator Senior Project

by

Whitney Baker

December 15, 1997

1. INTRODUCTION

1.1 NATURE OF GELATIN

For over four decades, conservators and scientists have been interested in why papers produced in the 15fh and 16th centuries have remained in much better condition than many modern papers. One factor, overlooked until recently, is the presence of gelatin as size in many early Western papers. Size was applied to finished sheets of paper in order to render them impervious to water and inks.

Recent studies, such as the groundbreaking work by Barrett and Mosier, have determined that "a positive correlation may exist between the present, good condition of historical papers and the amount of gelatin size they contain." In their study, Barrett and Mosier examine gelatin in relation to calcium content, pH and lightness of paper color in order to determine which combination of factors affects permanence. While their research suggests that pH, calcium content and gelatin content may work together to improve paper permanence, Barrett and Mosier state that "gelatin is an important component in the chemical and physical systems of paper...that deserves additional research attention" (Barrett and Mosier 1995).

As evidenced by Barrett and Hosier's conclusion, gelatin's role in promoting paper longevity is not well understood. It is known that the amino acids of which gelatin is composed are able to buffer against the addition of both acidic and basic entities into paper. However, as Barrett and Mosier suggest, future work is needed on "temperature and humidity cycling to understand more fully the role of gelatin in paper stability" (Barrett and Mosier 1995).

1.2 RELATIVE HUMIDITY

In addition to its ability to buffer against acids and bases, gelatin may also partially buffer paper against changes in relative humidity (Barrett 1997). *Relative humidity <RH)* is defined as the amount

of water vapor in the air over the total amount of vapor the air can hold at a given temperature, expressed as a percent. Wild fluctuations in relative humidity, as well as consistently very high or low RH, catalyze degradation reactions that can lead to physical deterioration of a paper substrate. Tests have shown that "gelatin can hold at least twice as much moisture as paper at a given relative humidity," and that its presence may "stabilize fluctuations in moisture content [of paper]" (Barrett 1992). In an era of shrinking budgets, preservation emphasis has shifted from single-item treatments to care of whole collections. Maintaining stable RH and temperature in collection areas has become more important than ever.

A positive correlation between sizing and RH buffering might fuel debate in the book and paper conservation fields over the issue of resizing. Resizing refers to the application of a new layer of size to a paper artifact that has been washed and/or alkalinized as part of conservation treatment. In 1995, Schaeffer found that both Mg(HC03)2 and Ca(OH)2, the two most common alkalinizing agents, will remove some gelatin size (Schaeffer 1995). Despite these consequences, a survey of approximately 300 conservators determined that "resizing artifacts following aqueous treatment is an infrequently performed procedure about whose value or function there is little consensus" (Henry 1986). If a clear buffering effect of gelatin sizing toward RH changes were found, then conservators might have to reexamine the frequently overlooked and understudied issue of resizing practice.

1.3 PROJECT OBJECTIVES

This project was designed to build upon Barrett and Mosier's work to determine if gelatin is able to buffer not just against acids and bases, but against RH changes as well. The objectives of the project were : 1) to determine if different papers react differently to changes in RH, 2) to test papers at increasing concentrations of surface size, and 3) to test how the moisture content of papers is affected over time by conditioning at different relative humidities. In order to determine the moisture content of the paper samples, a test for the dry basis weight of paper, as developed by Hal Erickson, was used. Whatever the results of the experiment, the findings will be submitted as a scholarly article to the *Book and Paper Group Annual*.

2. PROCEDURES

2.1 METHODOLOGY

The project followed Erickson's test for "Dry Basis Weight of Paper," which requires that paper samples be cut, placed in tared weighing containers, weighed, placed for a predetermined time in a drying oven to drive out essentially all moisture, and reweighed. The change in weight is then used to determine the original moisture content of the paper sample.

2.2 SELECTION OF PAPER TYPES

The following papers were selected to be tested:

1) Whatman 1 chromatography paper (100% cotton alpha-cellulose)

2) University of Iowa Barrett B9 paper (flax, long fermented and cooked in 0.4% lime solution; unsized)

3) Cheney (865) paper (cotton muslin rag half stuff paper, cooked in sodium hydroxide, not bleached. Made at University of Iowa by author in fall of 1994.)

The three sample papers were comparable in thickness *(Please see Table 1)*.

In order to have sufficient weight of each paper type, one sheet of 2) and two sheets of 1) and 3) were used. All sheets were washed before sizing in order to remove residual processing chemicals that might interfere with experimentation. The same types of sheets were washed together in tepid (23.5°C) distilled water for 10 minutes in a large photographic tray. Samples were drained vertically for 20 seconds and then tipped to their left lower corner for 20 additional seconds until most free water had drained. All samples were air-dried horizontally overnight until completely dry.

TABLE 1: Papers Tested

Paper type	Thickness	Dimensions of sheets
Whatman	0.007-0.008"	58 x 68 cm.
Barrett	0.009-0.011"	53.5x73 cm.
Baker	0.008-0.012"	45x60.5 cm.

2.3 GELATIN SIZING

The second variable under scrutiny was the concentration of the gelatin size applied to each sample. Some samples were washed and air dried but not sized in order to serve as controls. Three different concentrations of gelatin size were prepared using purified, Fisher 100 Bloom Type B photographic gelatin. A scientifically pure "known" gelatin was chosen for the sake of controlling its composition, although a size that more closely approximated historical gelatins would have been useful to test as well.

Three gelatin suspensions were prepared at 0.5%, 1.5% and 2.5% (wt. / vol.) concentrations, respectively. These values were chosen to approximate the range of historical gelatin concentrations measured in Barrett and Mosier's earlier testing of historical papers (1995), and recommended by Spitzmueller as suitable resizing concentrations (Spitzmueller 1992).

The gelatin was swelled in room temperature distilled water for 30 minutes. The mixture was stirred for the first five minutes, allowed to dissolve for the next 20 minutes,and then stirred again for the last five. The suspensions were then heated in a Pyrex container placed over a hot plate kept to 45°C for a few minutes. After completely dissolved, the gelatin stocks were kept on low heat for the duration of the sizing process.

The pH of each gelatin suspension was taken before sizing began. All sizing baths were kept at pH 5.1-

5.2 in order to eliminate that variable from this experiment. The pH of each sizing suspension was also taken after the sized papers were removed from the bath. The Whatman and Baker baths did not greatly change in pH, but the Barrett paper, at 0.5% and 1.5% concentrations, displayed a raised pH of 5.8 and 6.0 respectively. This phenomenon may be due to the liberation of calcium deposited into the paper during the lime cook of the pulp.

For each paper type and gelatin concentration, 200 mL of gelatin was poured into a Pyrex tray resting on a hot plate at 40-45°C. Equipment limitations required that samples be cut in half and sized together. The paper halves were placed together in the size bath for 3 minutes, then removed individually and both transferred to a sheet of Mylar resting on a piece of Plexiglas after Schaeffer and Blyth-Hill's pressing method (1993). An additional piece of Mylar, followed by another piece of Plexiglas, was placed on top of the papers. A cylindrical weight was rolled rapidly across the Plexiglas, twice horizontally across and twice vertically with even pressure to approximate the pressing of a stack of sized papers. Samples were laid out horizontally to dry overnight at 23.5°C and approximately 50% RH.

2.4 PREPARATION OF SAMPLES PRIOR TO CONDITIONING

After sizing, the papers were cut into approximately 1 square cm pieces. Pieces of each type of paper at each size concentration were cut into clearly labeled containers and mixed thoroughly. This process was developed in order to reduce error associated with extracting individual samples from distinct parts of the paper, which are more likely to be sized to different degrees than a random sample. As noted by a renowned papermaker, sizing is an inexact science, so that "the edges may be soft sized. Small spots may be harder or softer sized. Bruising can cause higher absorption in some areas" (Green 1992). In the case of the Whatman and Baker samples, where two different sheets were used in order to have enough total weight of paper for the experiment both samples were cut and mixed thoroughly together.

After the papers were cut, approximately 1 g specimens were extracted for each sample and placed into clean, dry polystyrene petri dishes. Three samples for each specimen were prepared. Given the

accuracy of the available scale, the samples were weighed to approximately 1 g in weight, measured to the nearest ten-thousandth of a gram (0.0001 g). The upper lid of the petri dishes were labeled in indelible ink with the following information:

Type of paper was noted by "Chr" for Whatman chromatography paper, "W" for Baker's Cheney paper and "Ba" for Barrett's UICB flax paper.

Size concentration was noted by "R" for no size (reference specimen), "A" for 2.5%, "B" for 1.5%

and "*C*" for 0.5% gelatin size.

Trial number was listed as "i," "ii," and "iii," respectively.

Percent RH to which samples would be conditioned were listed as "27," "50," and "81," respectively.

There were 108 (36 per paper type x 3 trials each) samples in total.

2.5 RELATIVE HUMIDITY

Samples were conditioned at three different relative humidities: 27%, 50% and 81%. Because the testing room was kept at a very constant 50% RH, one-third of the samples were left in their petri dishes with the lids cocked in order to condition them to the ambient RH.

Salt conditioning was carried out by preparing saturated salt solutions that fit the RH requirements. Lithium chloride was chosen for the low RH and potassium bromide for the high RH. Both chambers were constructed in 20 liter aquariums with tightly-fitting Plexiglas lids sealed with vacuum grease. Care was taken to choose new aquariums that had been assembled more than a year before the beginning of the experiment in order to allow the silicon adhesives time to offgas any residual volatile species. Glass supports were placed in the bottom of the chambers, and a Plexiglas shelf was placed on these supports to act as a resting surface for the specimens. A quarter-inch sheet of glass was also placed on top the Plexiglas lids of the chambers in order ensure a tight seal. *(Please see Appendix A for a schematic drawing of the humidity chamber.)*

Before the samples were placed within the chambers, a motor-operated psychrometer was placed within each chamber to determine the RH. An ARTEN humidity gauge was then calibrated and placed within the chamber during the course of the experiment. Both humidity chambers provided stable set RH environments.

All samples were left within the chamber for at least 10 days before any testing began. Six stacks of petri dishes six deep were stacked in each of the two chambers. The lids were left off the dishes to facilitate diffusion of moisture between dishes and chambers. Because significant temperature variance of the drying oven was created each time the oven door was opened, no more than three samples could be run per day.

As a result of the disparity in length of time in the chamber among samples, a series of tests were conducted in order to determine how long was required for the samples to equilibrate to the chambers. Unsized and 2.5% sized Whatman paper samples were weighed immediately before and after residing in the chamber. The log of the differences in weight over the original weight percent were recorded and the results plotted versus the length of time in the chamber. Tests were run until values at each time were consistent.

2.6 EXPERIMENTAL PROTOCOL

Each testing day, before the weight of the samples were taken, it was necessary to determine the dry weight of each of the three Kimax weighing bottles. The bottles were placed into the oven with their lids nearby and dried for at least one hour at 105"C Each bottle was weighed by rapidly opening the oven door, placing the lid on the bottle, removing the bottle from the oven with tongs, and depositing it on the pan of the nearby balance. After dry weights were taken for the bottles, they were allowed to equilibrate to room temperature and then weighed again.

Next, paper samples were placed into the three weighing bottles and the weights taken again with lids on. The weights of the paper samples were figured as the difference between the empty and filled

weighing bottles at equilibrium conditions. The bottles containing the paper samples and the bottle lids were dried separately in the oven at 105"C. Dry weights were taken as for the empty bottles at one, two and three hours. If the percent weight change between hours three and four was not less than 0.1%, the samples were returned to the oven for an additional hour. No sample required more than five hours of drying and testing. *(See Appendix B for a sample lab chart.)*

Ideally, the time required to remove the bottles from the oven and place them on the balance pan would be negligible. However, because the bottles and paper began to regain moisture immediately upon leaving the oven, it was necessary to extrapolate backwards in time from the recorded weights in order to determine the true weights of the samples at the moment when they emerged from the oven. Eight pretests were conducted in order to increase operator skill and to determine the rate at which the empty weighting bottles gained moisture. Bottles and lids were heated for two hours, and the weight recorded at 10 second intervals from the time the bottles were placed on the balance. The time required to remove the bottles from the oven and place them on the balance was also recorded, and averaged fifteen seconds. The results of the nine runs were plotted and the weight gain was extremely linear, averaging 0.00038729 g/ sec. Therefore, in fifteen seconds, the average sample would have gained 0.00580935 grams, or, to the accuracy of the balance, 0.0058 grains. This constant weight was added to the final report of all samples. *(Please see Appendix C far a graph of the weight gain trials.)*

3. RESULTS

The results of the tests to determine how long were required for the Whatman A (2.5%) and Whatman Reference papers acclimated to the 27% and 81% RH chambers show a linear relationship when the % weight difference was plotted versus the log of the time. After the first two hours, the weight loss or gain quickly leveled off for both sized and unsized papers, with the sized paper gaining slightly less moisture in high RH and losing slightly more moisture in low RH. *(Please see Appendix D for graphs of the weight loss and gain for the two Whatman papers and charts far the moisture loss and gain for all papers.)*

The results of the trials to determine moisture loss at varying RH and gelatin concentrations indicate that for most papers the sized papers lost more moisture than the reference samples. The trend, however, was not extremely pronounced and deviation among trials often varied greatly. Results for each paper at each RH were plotted as size concentration vs. the change in moisture loss from the reference for each trial. In this manner, the discrepancies associated with different paper types could be avoided. In addition, with all reference samples taken as zero, an easier final comparison was afforded across all papers.

In order to determine if a general trend existed across across all data between capacity to buffer against RH changes and amount of gelatin, least squares lines were generated for each paper type and relative humidity. *(See Table 2.)* Next a least squares line was generated for all least squares lines in order to determine the overall trend across papers. The number of samples equaled 36, providing enough data points to render the resultant least squares line significant. *(Please see Appendix E for charts of raw and extrapolated data. Please see Appendix F for least squares analysis for each paper type at each RH and the final least squares analysis across all samples.)*

TABLE 2: Least Squares Slopes and Their Standard Deviations

Paper type	**Best-fit slope and standard deviation**	**Is zero within experimental range?**
Whatman 27%	-0.0911 ± 0.0174	NO
Whatman 50%	0.2106 ± 0.1528	NO
Whatman 81%	0.1410 ± 0.1433	YES
Barrett 27%	0,0357 ± 0.0522	YES
Barrett 50%	0.1150 ± 0.0287	NO
Barrett 81%	0.1304 ± 0.1529	YES
Baker 27%	0.1968 ± 0.0209	NO
Baker 50%	0.0980 ± 0.0921	NO
Baker 81%	0.1072 ± 0.0195	NO
FINAL	0.1061 ± 0.0113	NO

4. ERROR ANALYSIS

Because this project necessarily involved more than one variable, there was the potential for multiple avenues of error propagation. The largest source of systematic error, or mechanical malfunctions that skew all measurements equally, was the result of not accurately zeroing the balance before each day of testing.

Random error, one-time inaccuracies that influence data points randomly, can be pinpointed in large part to the noise associated with the balance. Air currents in the room could fluctuate the balance readings by as much as ±0.0005 g, enough to affect the resulting moisture loss calculations. In addition, this experiment necessitated quick weighing of all samples; however, when the bottles were first placed on the balance pan, the weight often fluctuated substantially in the first few seconds. Hence the final weights could deviate from their actual values by somewhat arbitrary quantities.

Every precaution was taken to eliminate as many sources of error as possible, and to reduce those sources of error that could not be completely eradicated. To lessen systematic error, the drying oven, balances and conditioning chambers were rigorously calibrated before the project initiation and were checked periodically for variation. Random error was decreased by running multiple trials at every size concentration and RH, and conducting eight pretests to improve researcher skill before the real trials began.

5. DISCUSSION

From the graphs of time versus moisture content, it appears that the buffering capacity of the sized sample is recognizable at most over the span of a few hours. This amount of time is not significant in the life of a paper and cannot be said to constitute a significant capacity for RH buffering.

The results of the least squares data show that some of the standard deviations of the best-fit slopes include the zero value, which includes the possibility that there is no correlation between the two

variables (i.e., a zero slope). Most least squares slopes were weakly positive, and the overall least squares line across all data indicates a weak additional hygroscopicity associated with increased concentrations of gelatin size. However, the data cannot be said to support more than a weak positive correlation between size content and hygroscopicity. In light of these findings and the more statistically significant, previously-tested pH buffering capacities of gelatin size, it would seem that pH buffering is a more important factor in gelatin's role in paper permanence than any perceived RH buffering effects.

6. RECOMMENDATIONS FOR FUTURE TESTING

The publication of the study should serve as a vehicle for further research. The research methodology should be applied to other paper samples to determine its validity over a wider range of samples. In addition, other types of gelatin, perhaps not so purified, might be studied. Finally, the responses of historic and modern gelatins and historic and modern papers to relative humidity changes should be studied.

A weakness of this experiment was the absence of a method for determining how much gelatin was actually absorbed by the different papers during sizing. Macroscopically, it appeared that the Whatman samples took up the most gelatin while the Barrett paper took up the least. However, this study would benefit from hard data to support these intuitions. Clearly, there is still much work to be done to pinpoint the complicated role gelatin plays in paper permanence.

ACKNOWLEDGMENTS

University of Iowa Center for the Book: Timothy Barrett
Preservation and Conservation Studies: Hal Erickson, Karen Motylewski, Karen Pavelka, Anne Seago, my fellow students
Harry Ransom Humanities Research Center: Jim Stroud, Barbara Brown, Ken Grant

REFERENCES

Barrett, T. 1992. Evaluating the effect of gelatin sizing with regard to the permanence of paper. In *Conference Papers Manchester 1992,* ed. S. Fairbrass. Manchester: Institute of Paper Conservation. 228-233.

Barrett, T. 1997. Personal communication. University of Iowa, Center for the Book, Iowa City, Iowa 52240.

Barrett, T., and Mosier, C. 1995. The role of gelatin in paper permanence. *Journal of the American Institute far Conservation* 34:173-186.

Green, S. 1992. An outline history of sizing methods with special reference to practices at Hayle Mill. In *Conference Papers Manchester 1992,* ed. S. Fairbrass. Manchester: Institute of Paper Conservation. 197-200.

Henry, W. 1986. Resizing following aqueous treatment: Current American practice. *Book and Paper Group Annual* 5:108-119.

Leiner Davis Gelatin (International) 1997. World Wide Web pages at *www.gelatin.com*.

McCormick-Goodhart, M.M. 1996. The allowable temperature and relative humidity range for the safe use and storage of photographic materials. *Journal of the Society of Archivists* 17: 7-21.

Pouradier, J. 1987. History of Photographic Gelatin. In *Pioneers of photography: Their achievements in science and technology,* ed. E. Ostroff. Springfield, VA: SPSE: Society for Imaging Science and Technology. 25-29.

Schaeffer, T.T. 1995. A semiquantitative assay, based on the TAPPI method, for monitoring changes in

gelatin content of paper. *Journal of the American Institute for Conservation* 34:95-105.

Schaeffer, T.T., and Blyth-Hill, V. 1993. Preparation of reproducibly stained paper samples for conservation research. *Book and Paper Group Annual* 12:44-59.

Henry, W., et. al. 1988. Sizing and resizing. In *Paper Conservation Catalog* 17:1-33.

Spitzmueuer, P. 1992. Selecting a paper re-sizing agent and its concentration: a look at parchment size and photographic gelatin. In *Conference Papers Manchester 1992,* ed. S. Fairbrass. Manchester: Institute of Paper Conservation. 214-221.

Wexler, A., and Hasegawa, S. 1954. Relative humidity-temperature relationships of some saturated salt solutions in the temperature range 0 to 50 C. *Journal of Research of the National Bureau of Standards* 53:19-24.

SELECTED EQUIPMENT AND SUPPLIES INFORMATION

Balance: Mettler AC 100, top-loading

Drying Oven: Fisher Isotemp Series 200

Gelatin: Fisher Purified Grade, 100 Bloom (G7-500)

Humidity gauge: ARTEN Corporation

Papers:

Barrett: University of Iowa Center for the Book flax text weight (B9)

Whatman: Whatman #1 (3001 931) Psychrometer Industrial Instruments & Supplies Psychro-Dyne

Weighing bottles: Kimax 50 mL low form weighing bottles (Fisher 03-420-5B)

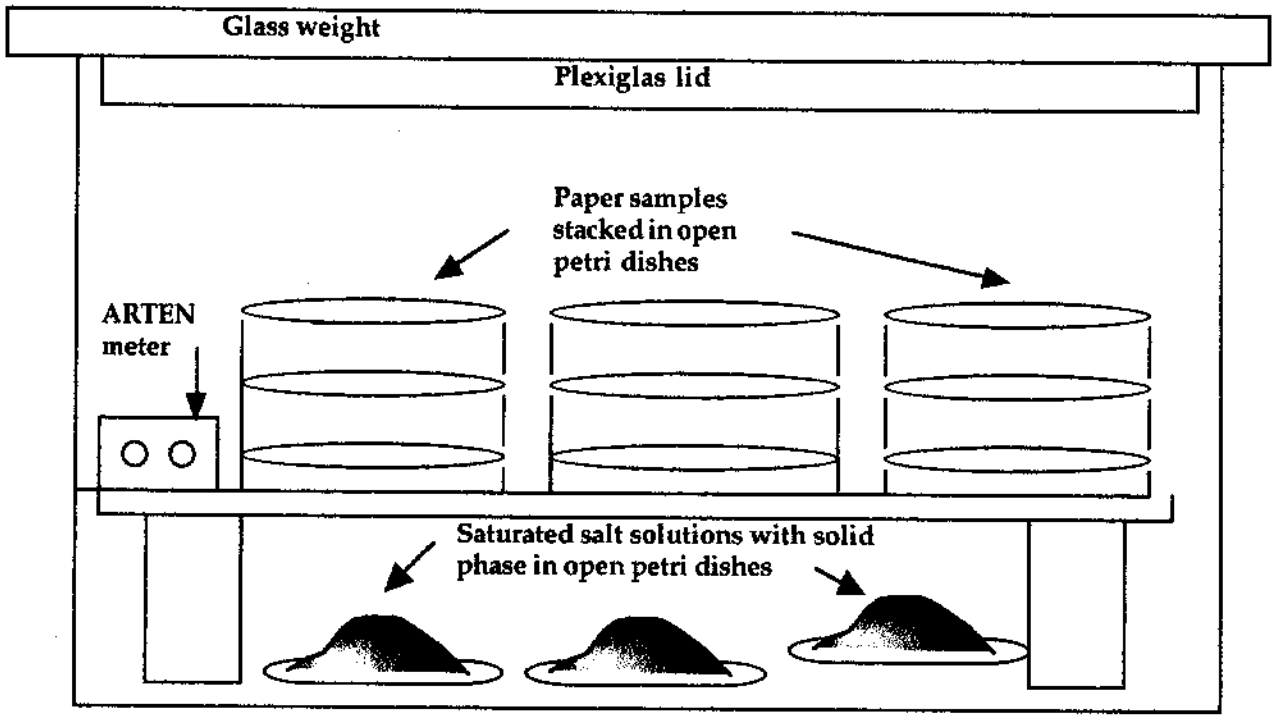
WHITNEY BAKER holds a B.A. in chemistry and Spanish from the University of Kansas and is finishing a M.L.S. and advanced certificate of library and archives conservation from Preservation andConservation Studies at the University of Texas at Austin. She will serve her third-year advanced internship at the Library of Congress.

APPENDICES

APPENDIX A:

Schematic of a Salt Conditioning Chamber

SCHEMATIC OF SALT CONDITIONING HUMIDITY CHAMBER



APPENDIX B:

Sample Dry Basis Weight Worksheet
(as developed by Hal Erickson)

DRY BASIS WEIGHT WORKSHEET

Date: 11-14

Weighing Bottle and Lid Number: 6 Sample: 15 Bar C 75i

Day 1	A.	Dry Weight: 73,1422
Day 2	B.	Equilibrium Weight (empty) with lid: 73,1591
	C.	Equilibrium Weight (with paper) and lid: 74.2180
	D.	Net Weight, Equilibrated Paper [C-B]: 1,0589
	E.	Dry Weight, after ONE HOUR: 74,0987
	F.	Net Weight, post 1 hour [E-A]: 0,9565
	G.	Dry Weight, after TWO HOURS: 74,0982
	H.	Net Weight, post 2 hours [G-A]: 0,9560
	I	Percent change in second hour [F-H/F] x 100%: 0.0523 %
	J.	Dry Weight, after THREE HOURS: 74,0984
	K.	Net Weight, post 3 hours [J-A]: 0.9562
	L.	Percent change in third hour [H-K/H] x 100%: 0.0209 %
	M.	Dry Weight, after FOUR and a HALF HOURS: _____
	N.	Net Weight, post 4.5 hours [M-A]: _____
	O.	Percent change in last 1.5 hour {K-N/K] x 100 %: _____

NOTE: If O is not less than 0.1%, then do not fill out report section. Instead, continue drying to 7 hours, 10.5 hours, etc. until percent change is less than 0.1%.

Report	P.	Moisture Loss [D-N]: 0.1027
	Q.	% Moisture Loss [P/D] x 100 %: 9,6987 %
	R.	Dry Basis % [100% -Q]: 90.3013 %

11-15

Weighing Bottle and Lid Number: 1 Sample: 28 - What C 75 iii

Day 1	A.	Dry Weight: 71,8850
Day 2	B.	Equilibrium Weight (empty) with lid: 71.9069
	C.	Equilibrium Weight (with paper) and lid: 73.0167
	D.	Net Weight, Equilibrated Paper [C-B]: 1,1098
	E.	Dry Weight, after ONE HOUR: 72.8847
	F.	Net Weight, post 1 hour [E-A]: 0,9997
	G.	Dry Weight, after TWO HOURS: 72.8840
	H.	Net Weight, post 2 hours [G-A]: 0.9990
	I	Percent change in second hour [F-H/F] x 100%: 0.0700 %
	J.	Dry Weight, after THREE HOURS: 72.8841
	K.	Net Weight, post 3 hours [J-A]: 0.9991
	L.	Percent change in third hour [H-K/H] x 100%: 0.0100 %
	M.	Dry Weight, after FOUR and a HALF HOURS: _____
	N.	Net Weight, post 4.5 hours [M-A]: _____
	O.	Percent change in last 1.5 hour {K-N/K] x 100 %: _____

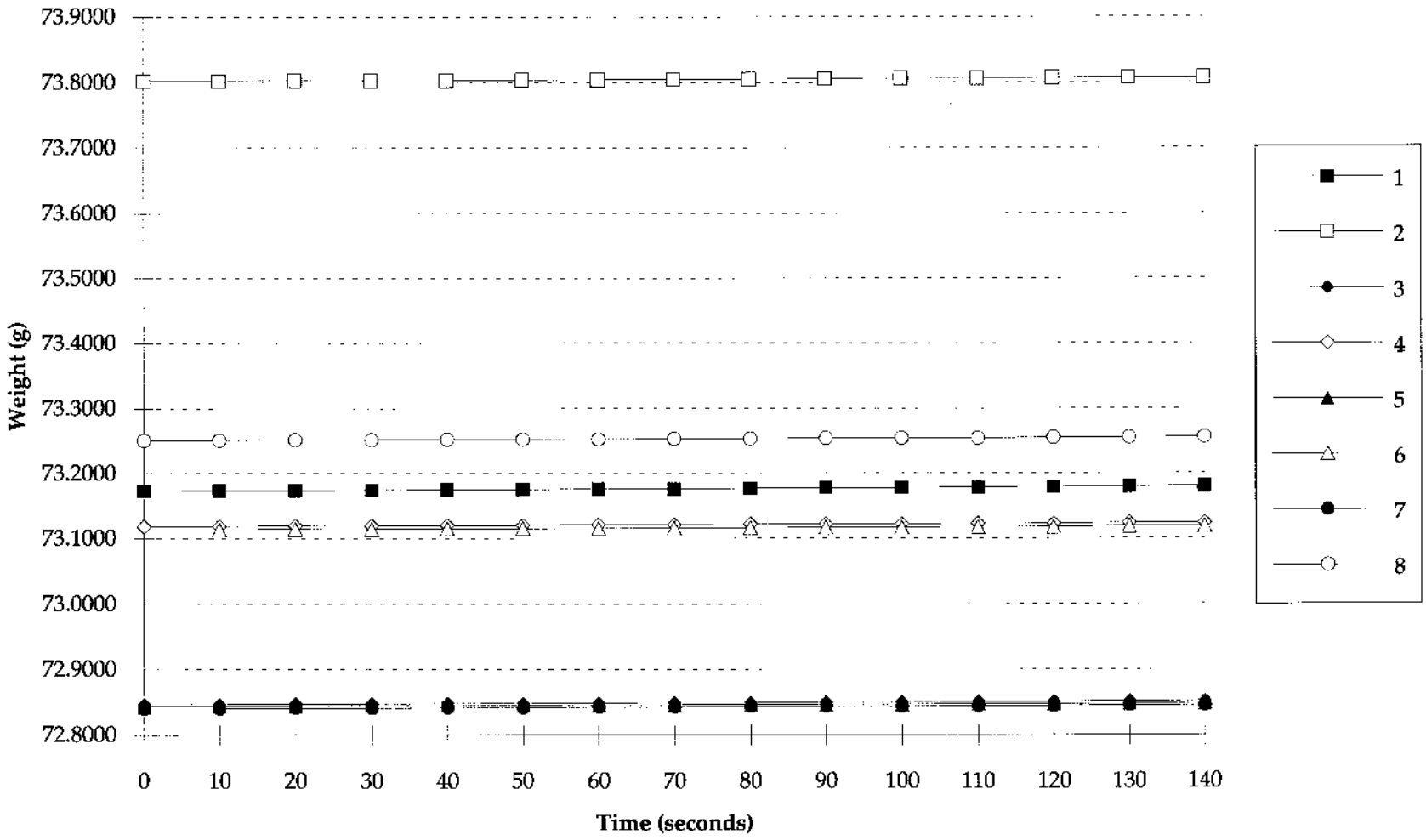
NOTE: If O is not less than 0.1%, then do not fill out report section. Instead, continue drying to 7 hours, 10.5 hours, etc. until percent change is less than 0.1%.

Report	P.	Moisture Loss [D-N]: 0.1167
	Q.	% Moisture Loss [P/D] x 100%: 9.9748
	R.	Dry Basis % [100% -Q]: 90.0252 %

APPENDIX C:

Graph of Weight Gain Trials
for
Empty Weighing Bottles

Weight Gain Trials



Slope = 0.00038729 g/sec.

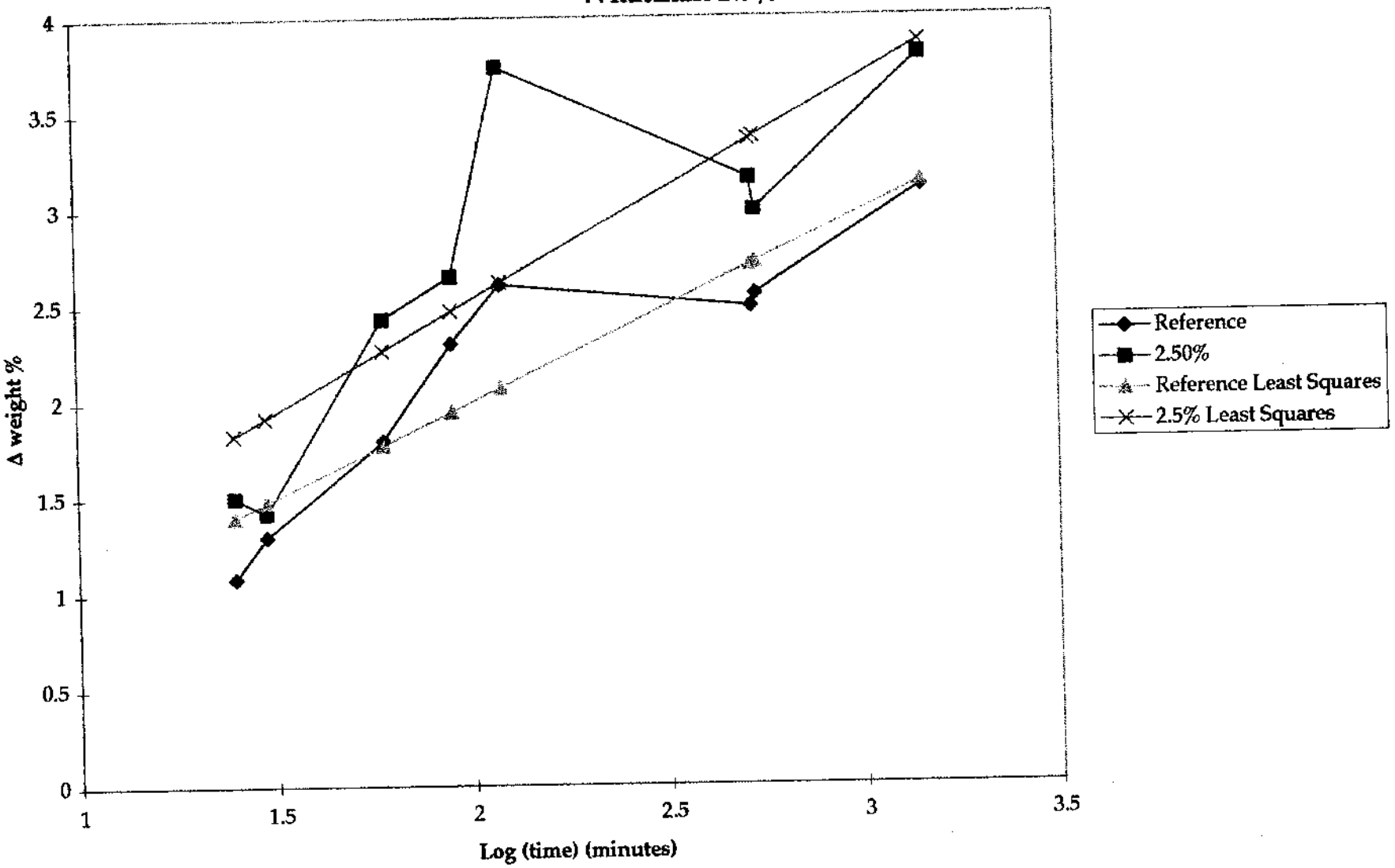
APPENDIX D:

Graph of Weight Loss and Gain Over Time
for
Whatman A and Reference Papers
at 27% and 81% RH

and

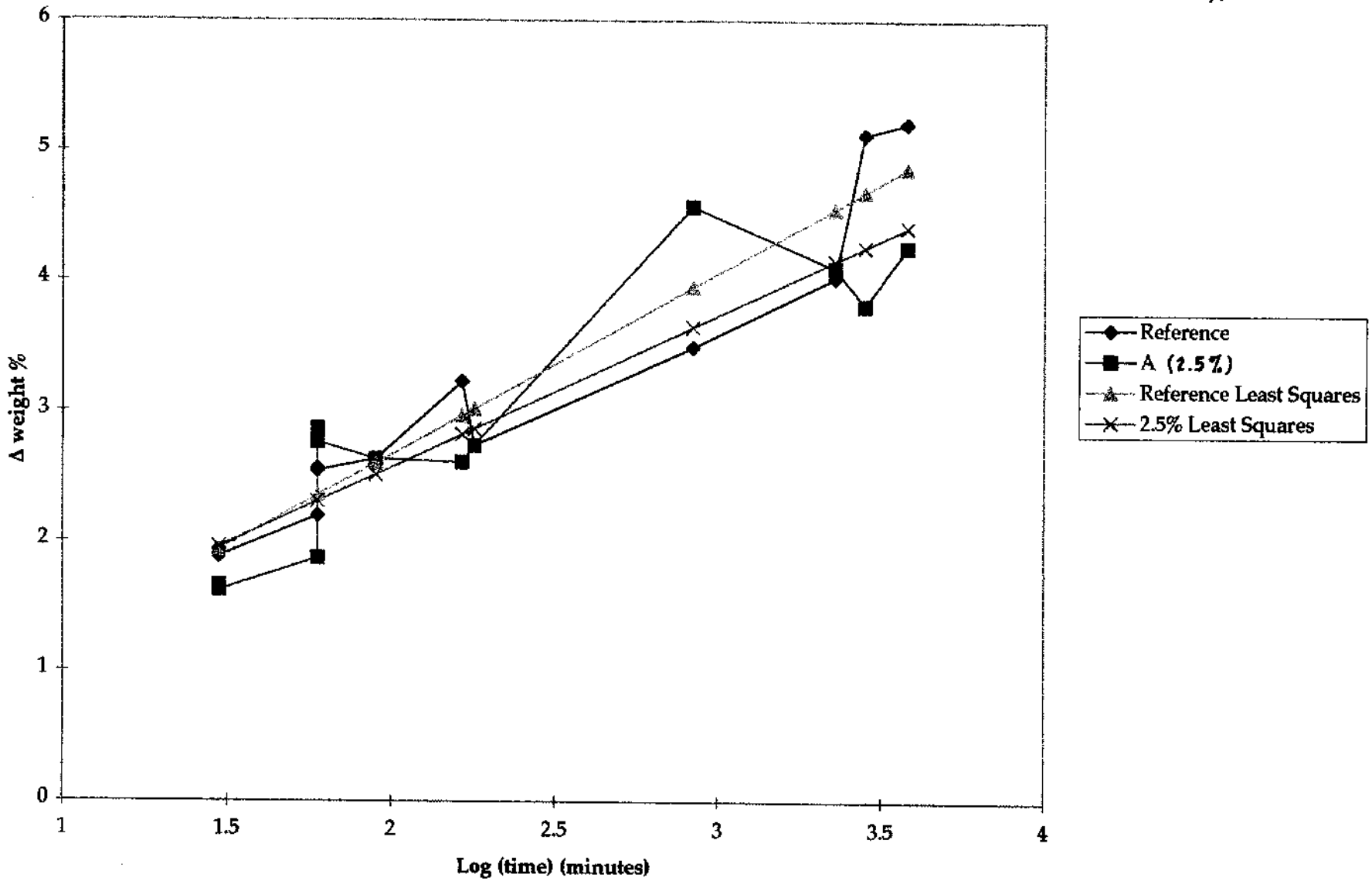
Moisture Loss and Gain Charts
for
All Paper Types in 27% and 81% RH
Humidity Chambers

27% RH Humidity Chamber Weight Loss over Time for Whatman Reference and Whatman 2.5%



Reference Least Squares: y=(0.9856+0.1893)x + (0.0193+0.4248)
2.5% Least Squares: y=(1.1587+0.3299)x + (0.2049+0.7403)

81% RH Humidity Chamber Weight Gain over Time for Whatman Reference and Whatman 2.5%



Reference Least Squares: $y=(1.3952\pm0.1256)x - (0.1337\pm0.3080)$
2.5% Least Squares: $y=(1.1691\pm0.1756)x + (0.2216\pm0.4309)$

27% RH Humidity Chamber Moisture Loss Data, All Paper Types and Trials

Sample	50% RH weight (g)	15% RH weight (g)	Δ weight (g)	Δweight/50% wt. x 100	Days in chamber beyond first sampling day
Baker R iii	1.0058	0.9735	0.0323	3.2110	4
Baker R ii	1.0543	1.0181	0.0362	3.4340	4
Baker R i	1.0002	0.9663	0.0339	3.3890	4
Baker C iii	1.0043	0.9692	0.0351	3.4950	5
Baker C ii	1.0061	0.9734	0.0327	3.2500	5
Baker C i	1.0036	0.9736	0.0300	2.9890	5
Baker B iii	1.0151	0.9801	0.0350	3.4479	19
Baker B ii	1.0184	0.9865	0.0319	3.1324	19
Baker B i	1.0114	0.9774	0.0340	3.3617	19
Baker A iii	1.0088	0.9753	0.0335	3.3320	6
Baker A ii	1.0133	0.9822	0.0311	3.0690	6
Baker A i	1.0124	0.9776	0.0348	3.4370	6
What R iii	1.0348	1.0063	0.0285	2.7540	0
What R ii	1.0740	1.0434	0.0306	2.8490	0
What R i	1.0277	0.9944	0.0333	3.2400	0
What C iii	1.0371	1.0024	0.0347	3.3459	15
What C ii	1.0424	1.0093	0.0331	3.1754	15
What C i	1.0390	1.0219	0.0171	1.6460	3
What B iii	1.0583	1.0280	0.0303	2.8630	17
What B ii	1.0305	0.9942	0.0363	3.6510	17
What B i	1.0201	0.9849	0.0352	3.4506	17
What A iii	0.9988	0.9665	0.0323	3.2340	10
WhatA ii	1.0056	0.9716	0.0340	3.3810	10
What A i	0.9952	0.9633	0.0319	3.2050	10
Barrett R iii	1.0076	0.9763	0.0313	3.1060	7
Barrett R ii	1.0143	0.9843	0.0300	2.9580	7
Barrett R i	1.0214	0.9878	0.0336	3.2900	7
Barrett C iii	1.0063	0.7471	n/a**	n/a	15
Barrett C ii	1.0063	0.9760	0.0303	3.0100	3
Barrett C i	1.0105	0.9770	0.0335	3.3120	3
Barrett B iii	1.0193	0.9860	0.0333	3.2670	16
Barrett B ii	1.0306	0.9987	0.0319	3.1470	16
Barrett B i	1.0157	0.9823	0.0334	3.2880	16
Barrett A iii	1.0141	0.9823	0.0318	3.1358	14
Barrett A ii	1.0120	0.9491	0.0311	3.0731	14
Barrett A i	1.0215	0.9933	0.0282	2.7606	14

***Note: Sample spilled as it was removed from chamber*

81% RH Humidity Chamber Moisture Gain Data, All Paper Types and Trials

Sample	50% RH weight (g)	81% RH weight (g)	Δ weight (g)	Δweight/50% wt. x 100	Days in chamber beyond first sampling day
Baker R iii	0.9965	1.0413	0.0448	4.496	4
Baker R ii	1.0255	1.0466	0.0211	2.508	4
Baker R i	1.0277	1.0733	0.0456	4.434	4
Baker C iii	1.0066	1.0498	0.0432	4.285	11
Baker C ii	1.0222	1.0660	0.0438	4.345	11
Baker C i	1.0081	1.0519	0.0438	4.344	11
Baker B iii	1.0032	**0.9769	n/a**	n/a	44
Baker B ii	1.0185	1.0637	0.0452	4.438	44
Baker B i	1.0054	1.0559	0.0505	5.023	44
Baker A iii	1.0090	1.0526	0.0436	4.142	20
Baker A ii	1.0110	1.0567	0.0457	4.325	20
Baker A i	1.0160	1.0659	0.0499	4.681	20
What R iii	1.0583	1.0804	0.0559	5.282	13
What R ii	1.0221	1.0686	0.0465	4.549	13
What R i	1.0115	1.0460	0.0345	3.411	13
What C iii	1.0601	1.1098	0.0497	4.688	20
What C ii	1.0357	1.0617	0.0491	4.741	20
What C i	1.0175	1.0848	0.0442	4.344	20
What B iii	1.0960	0.9974	n/a**	n/a	43
What B ii	1.0603	1.1221	0.0618	5.508	43
What B i	1.0669	1.1129	0.0460	4.133	43
What A iii	1.0234	1.0888	0.0482	4.710	6
What A ii	1.0060	1.0487	0.0427	4.245	6
What A i	1.0376	1.0716	0.0512	4.934	6
Barrett R iii	1.0158	1.0608	0.0450	4.430	0
Barrett R ii	1.0009	1.0502	0.0493	4.926	0
Barrett R i	1.0210	1.0656	0.0446	4.368	0
Barrett C iii	1.0268	1.0224	0.0044	0.428	19
Barrett C ii	1.0221	1.0673	0.0452	4.422	19
Barrett C i	1.0146	1.0589	0.0443	4.366	19
Barrett B iii	1.0088	1.0539	0.0451	4.471	43
Barrett B ii	1.0107	1.0538	0.0431	4.262	43
Barrett B i	1.0368	1.0810	0.0442	4.263	43
Barrett A iii	1.0086	1.0519	0.0423	4.194	7
Barrett A ii	1.0023	1.0427	0.0404	4.031	7
Barrett A i	1.0362	1.0854	0.0492	4.748	7

***Note: Sample spilled as it was removed from chamber*

APPENDIX E:

Raw and Extrapolated Moisture Loss and Dry Basis Weight Data for All Paper Types, Trials, and RH

27% RH Moisture Loss & Dry Basis Weight Data, All Paper Types and Trials

Sample	15% RH weight	Moisture Loss (g)	Moisture Loss Extrap. (g)	% Moisture Loss	%Moisture Loss Extrap.	Dry Basis Weight %	Extrap. DBW%
Baker R iii	0.9735	0.0289	0.0347	2.9687	3.5645	97.0313	96.4355
Baker R ii	1.0181	0.0282	0.0340	2.7699	3.3396	97.2301	96.6604
Baker R i	0.9663	0.0227	0.0285	2.3490	2.9494	97.6508	97.0506
Baker C iii	0.9692	0.0243	0.0301	2.5072	3.1057	97.4928	96.8943
Baker C ii	0.9734	0.0242	0.0300	2.4861	3.0820	97.5139	96.9180
Baker C i	0.9736	0.0279	0.0337	2.8657	3.4614	97.1343	96.5386
Baker B iii	0.9801	0.0281	0.0339	2.8671	3.4588	97.1329	96.5412
Baker B ii	0.9865	0.0301	0.0359	3.0512	3.6391	96.9488	96.3609
Baker B i	0.9774	0.0279	0.0337	2.8545	3.4479	97.1455	96.5521
Baker A iii	0.9753	0.0284	0.0342	2.9120	3.5066	97.0881	96.4934
Baker A ii	0.9822	0.0291	0.0349	2.9627	3.5532	97.0373	96.4468
Baker A i	0.9776	0.0315	0.0373	3.2220	3.8155	96.7778	96.1845
What R iii	1.0063	0.0321	0.0379	3.1900	3.7663	96.8101	96.2337
What R ii	1.0434	0.0272	0.0330	2.6069	3.1627	97.3931	96.8373
What R i	0.9944	0.0235	0.0293	2.3632	2.9465	97.6368	97.0535
What C iii	1.0024	0.0276	0.0334	2.7534	3.3320	97.2466	96.6680
What C ii	1.0093	0.0297	0.0355	2.9426	3.5173	97.0574	96.4827
What C i	1.0219	0.0299	0.0357	2.9259	3.4935	97.0741	96.5065
What B iii	1.0280	0.0261	0.0319	2.5389	3.1031	97.4611	96.8969
What B ii	0.9942	0.0252	0.0310	2.5347	3.1181	97.4653	96.8819
What B i	0.9849	0.0191	0.0249	1.9393	2.5282	98.0607	97.4718
What A iii	0.9665	0.0266	0.0324	2.7520	3.3523	97.2478	96.6477
WhatA ii	0.9716	0.0250	0.0308	2.5731	3.1700	97.4269	96.8300
What A i	0.9633	0.0273	0.0331	2.8340	3.4361	97.1660	96.5639
Barrett R iii	0.9763	0.0286	0.0344	2.9294	3.5235	97.0706	96.4765
Barrett R ii	0.9843	0.0291	0.0349	2.9564	3.5457	97.0436	96.4543
Barrett R i	0.9878	0.0274	0.0332	2.7738	3.3610	97.2262	96.6390
Barrett C iii	0.7471	0.0243	0.0301	3.2526	4.0289	96.7474	95.9711
Barrett C ii	0.9760	0.0263	0.0321	2.6947	3.2889	97.3053	96.7111
Barrett C i	0.9770	0.0251	0.0309	2.5691	3.1627	97.4309	96.8373
Barrett B iii	0.9860	0.0295	0.0353	2.9949	3.5801	97.0081	96.4199
Barrett B ii	0.9987	0.0262	0.0320	2.6234	3.2042	97.3766	96.7958
Barrett B i	0.9823	0.0266	0.0324	2.7079	3.2984	97.2921	96.7016
Barrett A iii	0.9823	0.0293	0.0351	2.9828	3.5732	97.0172	96.4268
Barrett A ii	0.9491	0.0313	0.0371	3.1909	3.9090	96.8091	96.0910
Barrett A i	0.9933	0.0278	0.0336	2.7988	3.3827	97.2012	96.6173

50% RH Moisture Loss & Dry Basis Weight Data, All Paper Types and Trials

Sample	50% RH weight	Moisture Loss (g)	Moisture Loss Extrap. (g)	% Moisture Loss	% Moisture Loss Extrap.	Dry Basis Weight %	Extrap. DBW%
Baker R iii	1.0260	0.0680	0.0738	6.6277	7.1930	93.3723	92.8070
Baker R ii	1.0142	0.0664	0.0722	6.5470	7.1189	93.4530	92.8811
Baker R i	1.0434	0.0668	0.0726	6.4021	6.9580	93.5979	93.0420
Baker C iii	1.0233	0.0628	0.0686	6.1370	6.7038	93.8630	93.2962
Baker C ii	1.0068	0.0652	0.0710	6.4760	7.0520	93.5240	92.9480
Baker C i	1.0085	0.0672	0.0730	6.6634	7.2385	93.3366	92.7615
Baker B iii	1.0155	0.0625	0.0683	6.1546	6.7258	93.8454	93.2742
Baker B ii	1.0180	0.0837	0.0895	8.2220	8.7917	91.7780	91.2083
Baker B i	1.0125	0.0671	0.0729	6.6272	7.2000	93.3728	92.8000
Baker A iii	1.0069	0.0616	0.0674	6.1178	6.6938	93.8822	93.3062
Baker A ii	1.0124	0.0643	0.0701	6.3512	6.9241	93.6488	93.0759
Baker A i	1.0150	0.0624	0.0682	6.1478	6.7192	93.8522	93.2808
What R iii	0.9995	0.0575	0.0633	5.4527	6.3332	94.5473	93.6668
What R ii	1.0300	0.0586	0.0644	5.6893	6.2524	94.3107	93.7476
What R i	1.0343	0.0577	0.0635	5.7720	6.1394	94.2280	93.8606
What C iii	1.0155	0.0636	0.0694	6.1218	6.8341	93.7371	93.1659
What C ii	1.0094	0.0637	0.0695	6.3107	6.8853	93.6893	93.1147
What C i	1.0193	0.0654	0.0712	6.4162	6.9852	93.5838	93.0148
What B iii	1.0066	0.0626	0.0684	6.2190	6.7952	93.7810	93.2048
What B ii	1.0124	0.0635	0.0693	6.2722	6.8451	93.7278	93.1549
What B i	1.0087	0.0645	0.0703	6.3943	6.9694	93.6056	93.0306
What A iii	1.0040	0.0641	0.0699	6.3844	6.9622	93.6155	93.0378
WhatA ii	1.0036	0.0635	0.0693	6.3272	6.9051	93.6728	93.0949
What A i	1.0057	0.0637	0.0695	6.3213	6.9106	93.6786	93.0894
Barrett R iii	0.9943	0.0590	0.0648	5.9338	6.5171	94.0662	93.4829
Barrett R ii	1.0041	0.0590	0.0648	5.8760	6.4535	94.1241	93.5465
Barrett R i	1.0170	0.0581	0.0639	5.7129	6.2832	94.2871	93.7168
Barrett C iii	1.0279	0.0617	0.0675	6.0025	6.5668	93.9975	93.4332
Barrett C ii	1.0109	0.0591	0.0649	5.8463	6.4200	94.1537	93.5800
Barrett C i	1.0061	0.0610	0.0668	6.0630	6.6395	93.9370	93.3605
Barrett B iii	1.0082	0.0608	0.0666	6.0305	6.6058	93.9695	93.3942
Barrett B ii	1.0124	0.0607	0.0665	5.9957	6.5685	94.0043	93.4315
Barrett B i	1.0264	0.0591	0.0649	5.7580	6.3231	94.2420	93.6769
Barrett A iii	1.0166	0.0624	0.0682	6.1381	6.7086	93.8612	93.2914
Barrett A ii	1.0042	0.0606	0.0664	6.0035	6.6122	93.9653	93.3878
Barrett A i	1.0227	0.0639	0.0697	6.2482	6.8153	93.7518	93.1847

81% RH Moisture Loss & Dry Basis Weight Data, All Paper Types and Trials

Sample	81% RH weight	Moisture Loss (g)	Moisture Loss Extrap. (g)	% Moisture Loss	% Moisture Loss Extrap.	Dry Basis %	Extrap DBW%
Baker R iii	1.0413	0.1032	0.1090	9.9107	10.4677	90.0893	89.5323
Baker R ii	1.0466	0.1024	0.1082	9.7841	10.3382	90.2159	89.6618
Baker R i	1.0733	0.1042	0.1100	9.7084	10.2488	90.2916	89.7512
Baker C iii	1.0498	0.1018	0.1076	9.6971	10.2496	90.3029	89.7504
Baker C ii	1.0660	0.1053	0.1111	9.8780	10.4221	90.1220	89.5779
Baker C i	1.0519	0.1043	0.1101	9.9154	10.4668	90.0846	89.5332
Baker B iii	0.9769	0.0945	0.1003	9.6735	10.2672	90.3265	89.7328
Baker B ii	1.0637	0.1100	0.1158	10.3413	10.8865	89.6587	89.1135
Baker B i	1.0559	0.1067	0.1125	10.1051	10.6544	89.8948	89.3456
Baker A iii	1.0526	0.1074	0.1132	10.2033	10.7543	89.7967	89.2457
Baker A ii	1.0567	0.1108	0.1166	10.4855	11.0344	89.5146	88.9656
Baker A i	1.0659	0.1081	0.1139	10.1417	10.6858	89.8583	89.3142
What R iii	1.0804	0.1023	0.1081	9.4687	10.0056	90.5313	89.9944
What R ii	1.0686	0.1050	0.1108	9.8259	10.3687	90.1741	89.6313
What R i	1.0460	0.1049	0.1107	10.0287	10.5832	89.8757	89.4168
What C iii	1.1098	0.1107	0.1165	9.9748	10.4974	90.0252	89.5026
What C ii	1.0617	0.1076	0.1134	10.1347	10.6810	89.8653	89.3190
What C i	1.0848	0.1085	0.1143	10.0018	10.5365	89.9982	89.4635
What B iii	0.9974	0.1015	0.1073	10.1765	10.7580	89.8235	89.2420
What B ii	1.1221	0.1143	0.1201	10.1863	10.7031	89.8137	89.2969
What B i	1.1129	0.1126	0.1184	10.1177	10.6389	89.8823	89.3611
What A iii	1.0888	0.1083	0.1141	9.9945	10.4794	90.0533	89.5206
What A ii	1.0487	0.1031	0.1089	9.8312	10.3843	90.1688	89.6157
What A i	1.0716	0.1069	0.1127	9.9757	10.5170	90.0243	89.4830
Barrett R iii	1.0608	0.1010	0.1068	9.5211	10.0679	90.4789	89.9321
Barrett R ii	1.0502	0.1013	0.1071	9.6458	10.1981	90.3542	89.8019
Barrett R i	1.0656	0.1048	0.1106	9.8348	10.3791	90.1652	89.6209
Barrett C iii	1.0224	0.0537	0.0595	5.2523	5.8196	94.7577	94.1804
Barrett C ii	1.0673	0.1035	0.1093	9.6974	10.2408	90.3026	89.7592
Barrett C i	1.0589	0.1027	0.1085	9.6987	10.2465	90.3013	89.7535
Barrett B iii	1.0539	0.1006	0.1064	9.5455	10.0958	90.4545	89.9042
Barrett B ii	1.0538	0.1030	0.1088	9.7742	10.3245	90.2258	89.6755
Barrett B i	1.0810	0.1055	0.1113	9.7595	10.2960	90.2405	89.7040
Barrett A iii	1.0519	0.1031	0.1089	9.8013	10.3527	90.1987	89.6473
Barrett A ii	1.0427	0.1025	0.1083	9.8302	10.3865	90.1698	89.6135
Barrett A i	1.0854	0.1061	0.1119	9.7752	10.3096	90.2248	89.6904

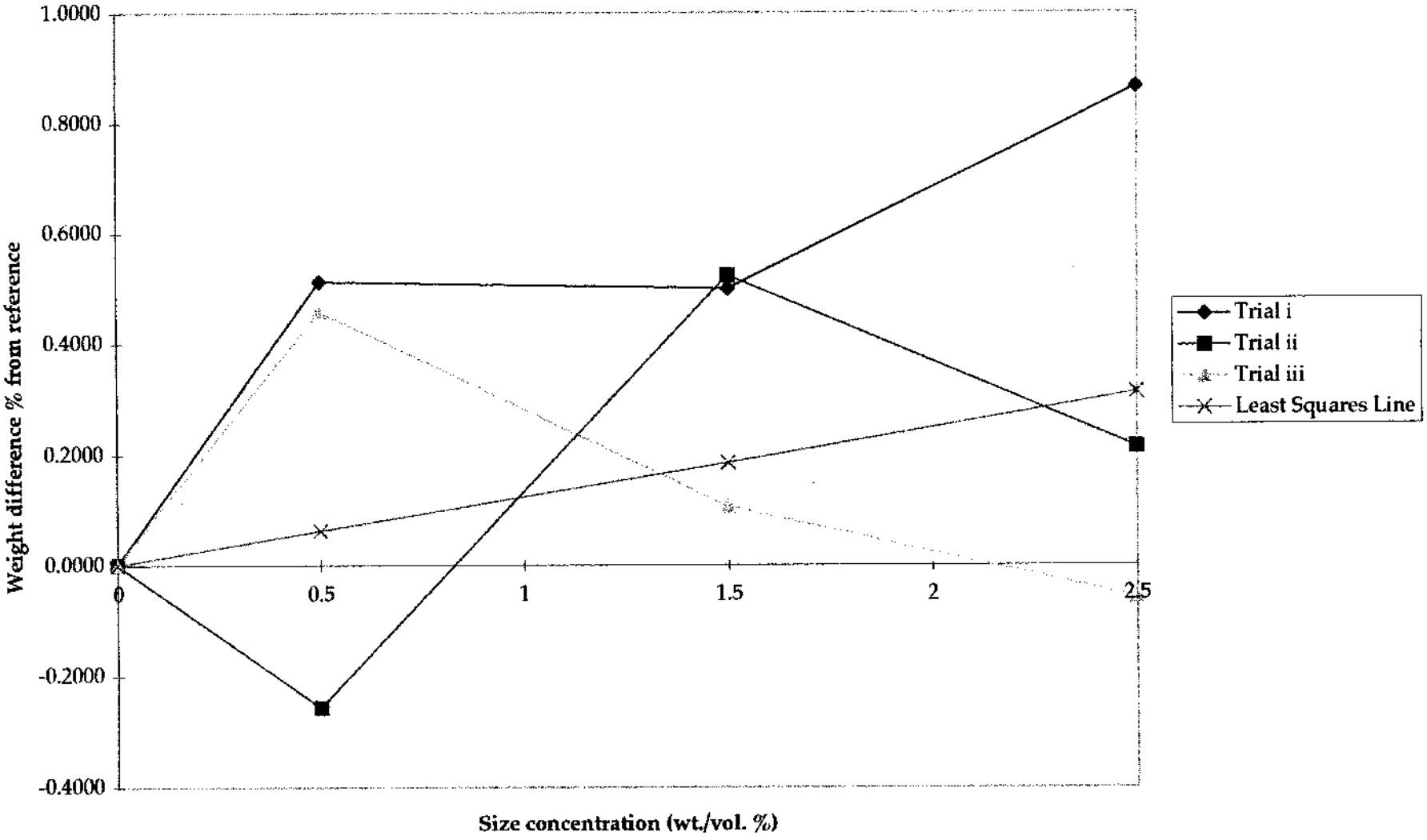
APPENDIX F:

Least Squares Graphs
for
All Paper Types, Trials, and RH's

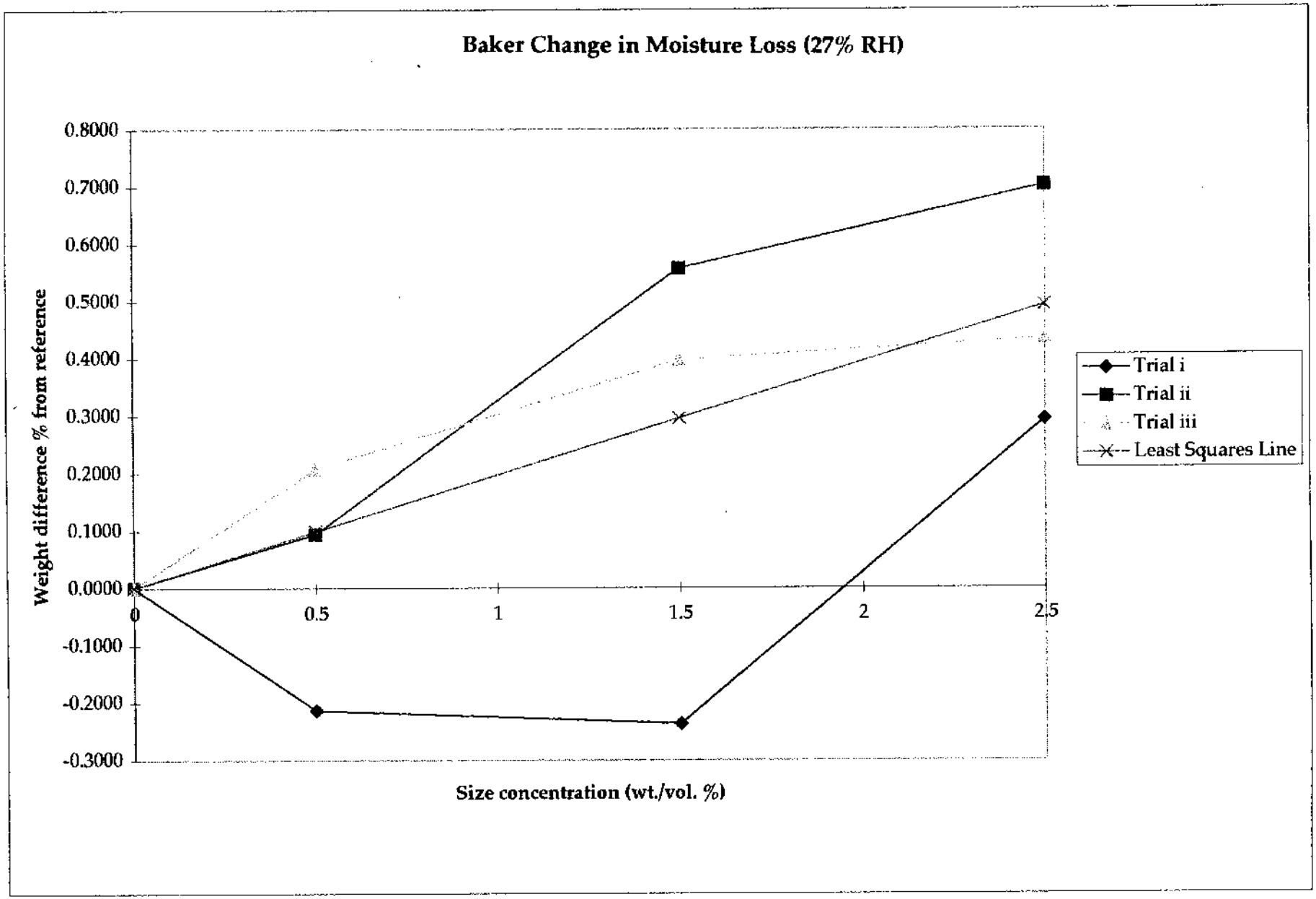
and

Final Least Squares Analysis

Baker Change in Moisture Loss (50% RH)

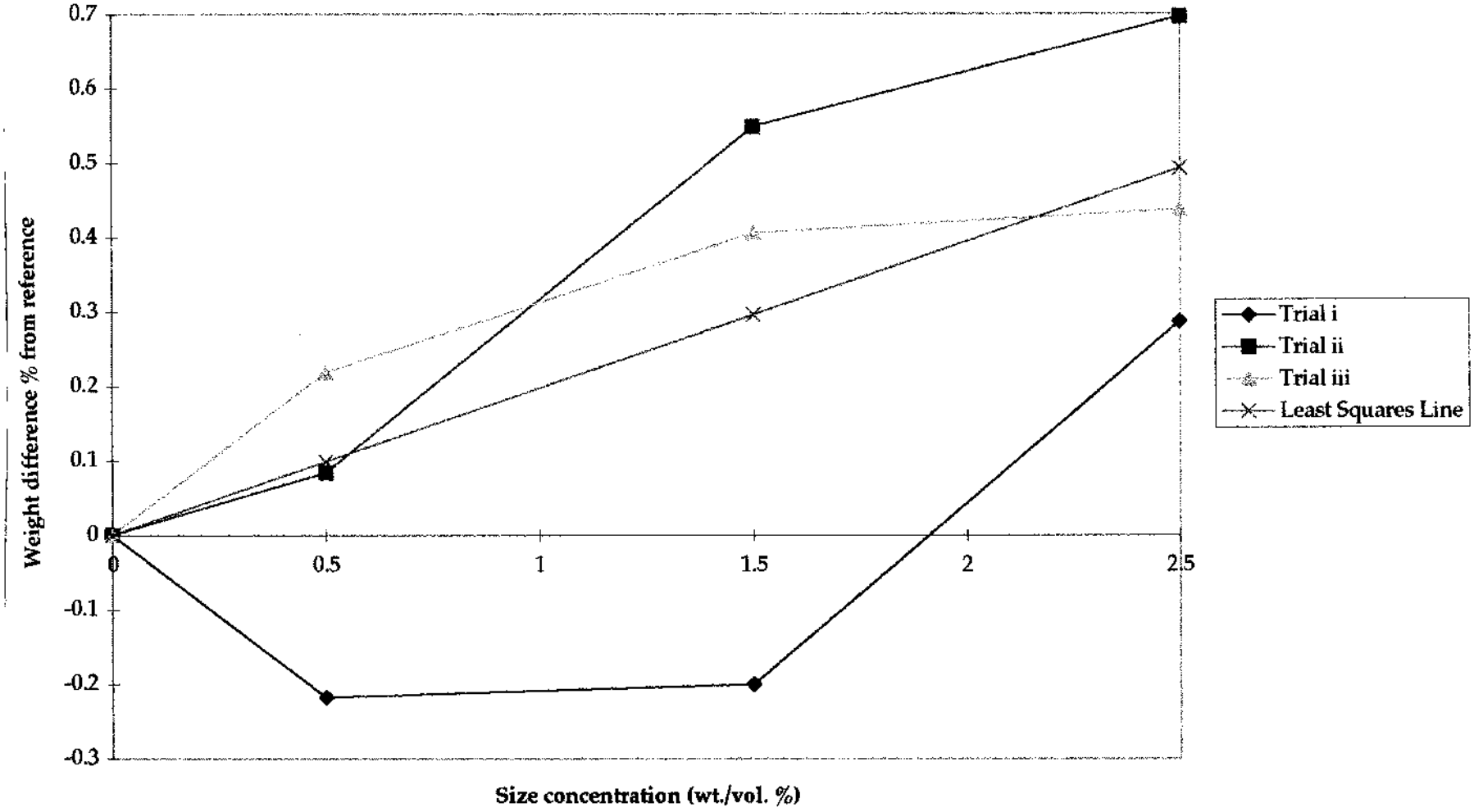


Least Squares Line: $y=(0.0980\pm0.0921)x + (0.0000\pm0.0622)$



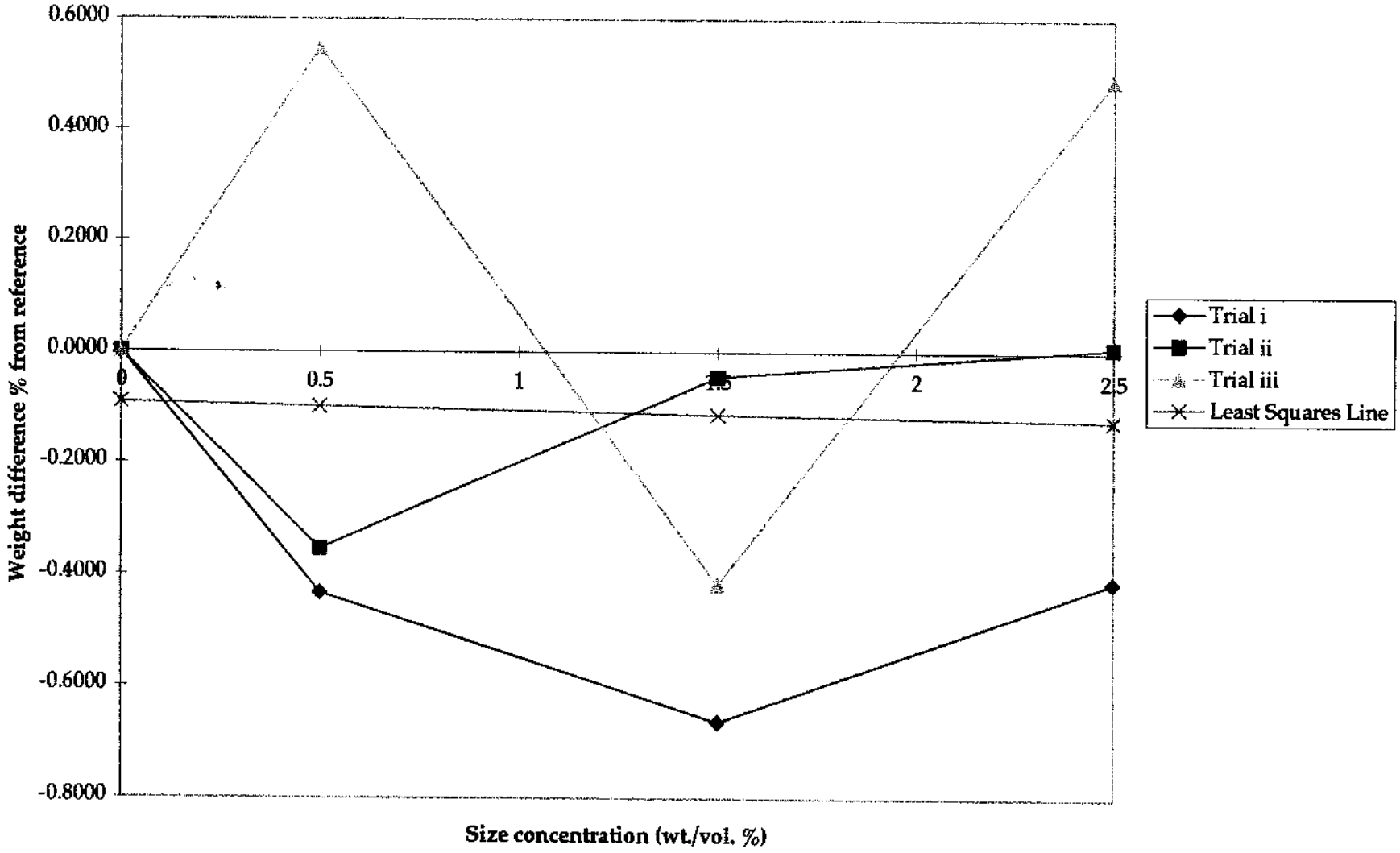
Least Squares Line: $y=(0.1968\pm0.0209)x + (0.0000\pm0.0308)$

Baker Change in Moisture Loss (81% RH)



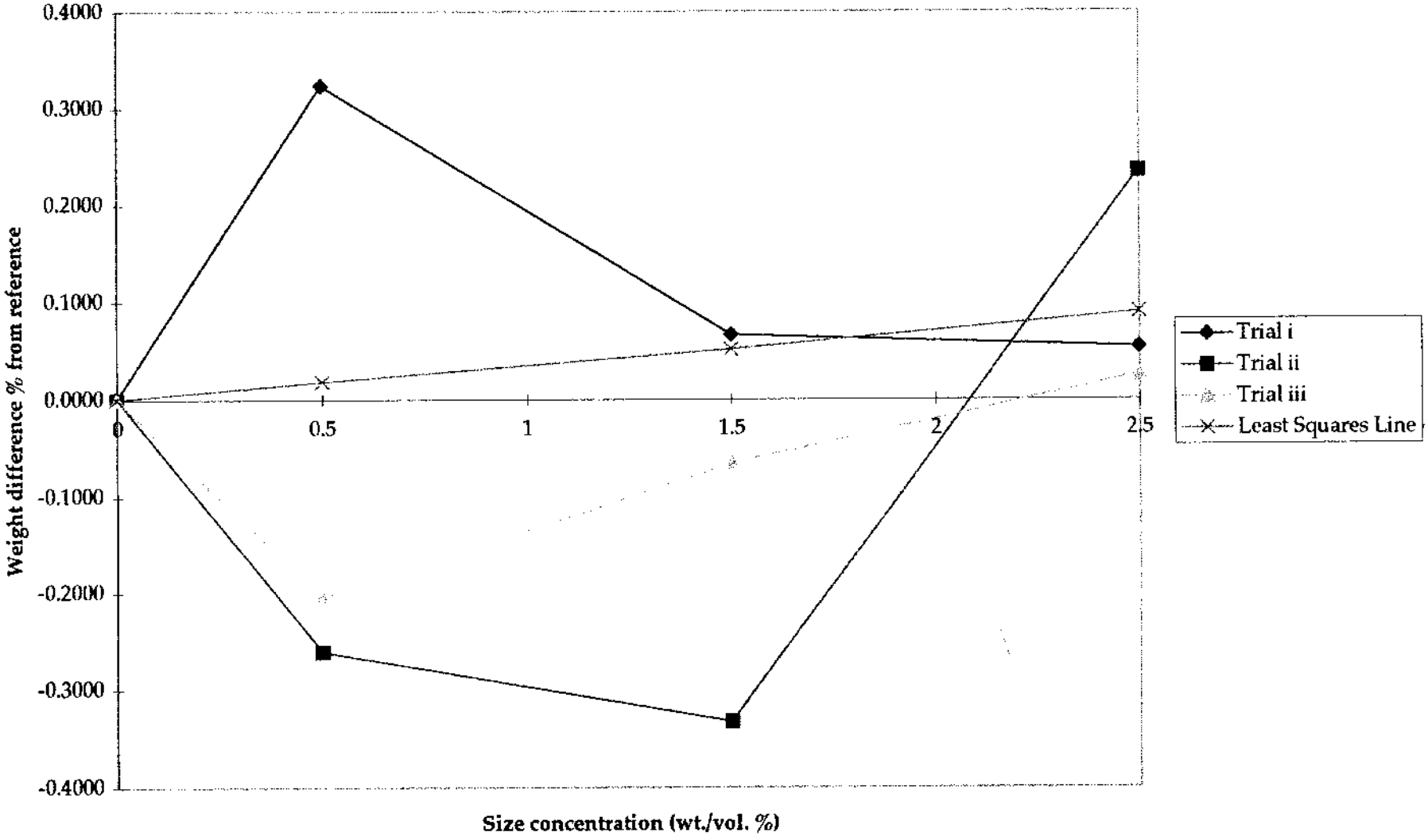
Least Squares Line: y=(0.1972±0.0195)x - (0.0339±0.0289)

Whatman Change in Moisture Loss (27% RH)



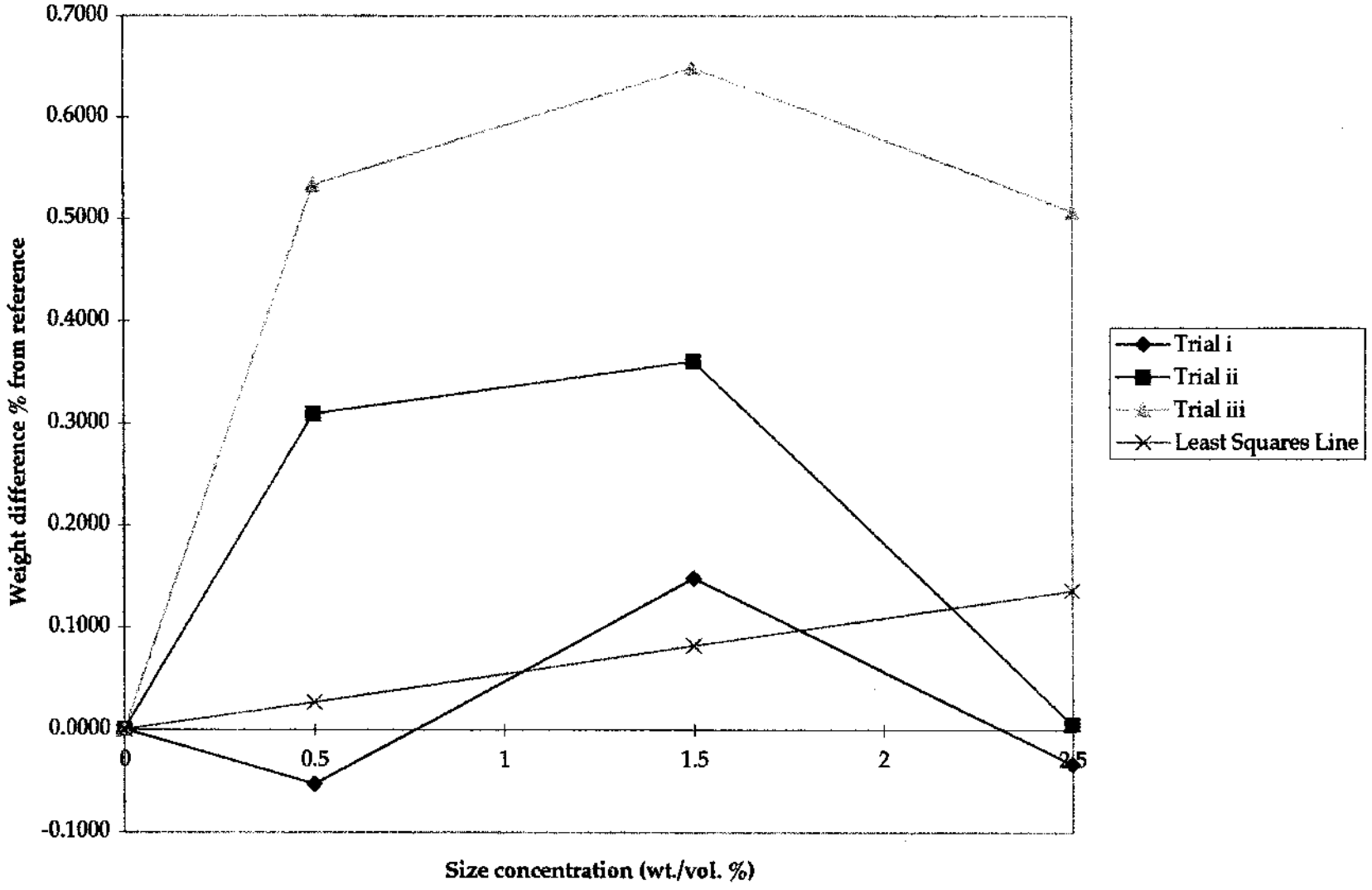
Least Squares Line: y=(-0.0911±0.0174) - (0.0142±0.1173)

Barrett Change in Moisture Loss (27% RH)



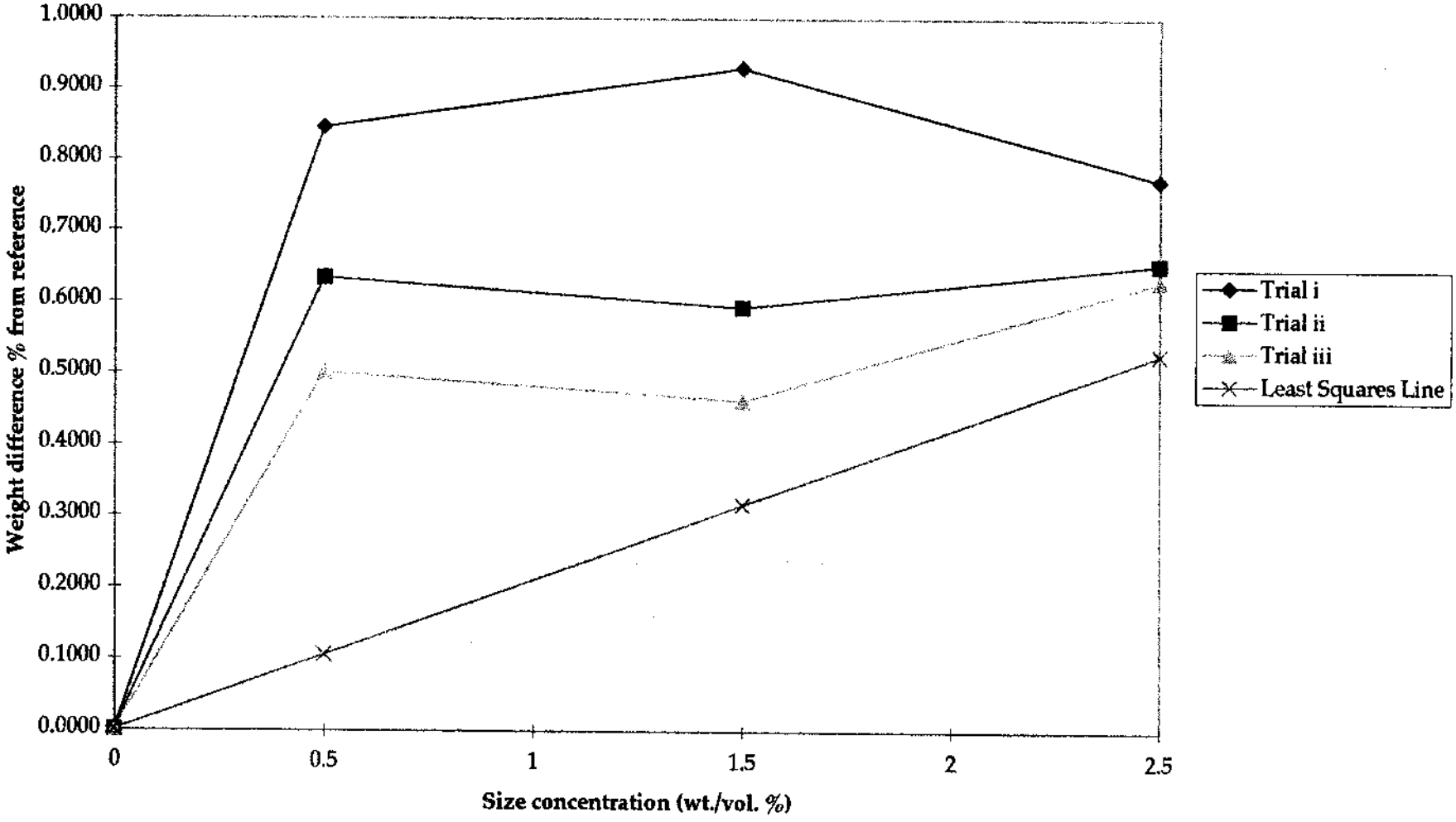
Least Squares Line: $y=(0.0357\pm0.0522)x + (0.0000\pm0.0722)$

Whatman Change in Moisture Loss (81% RH)



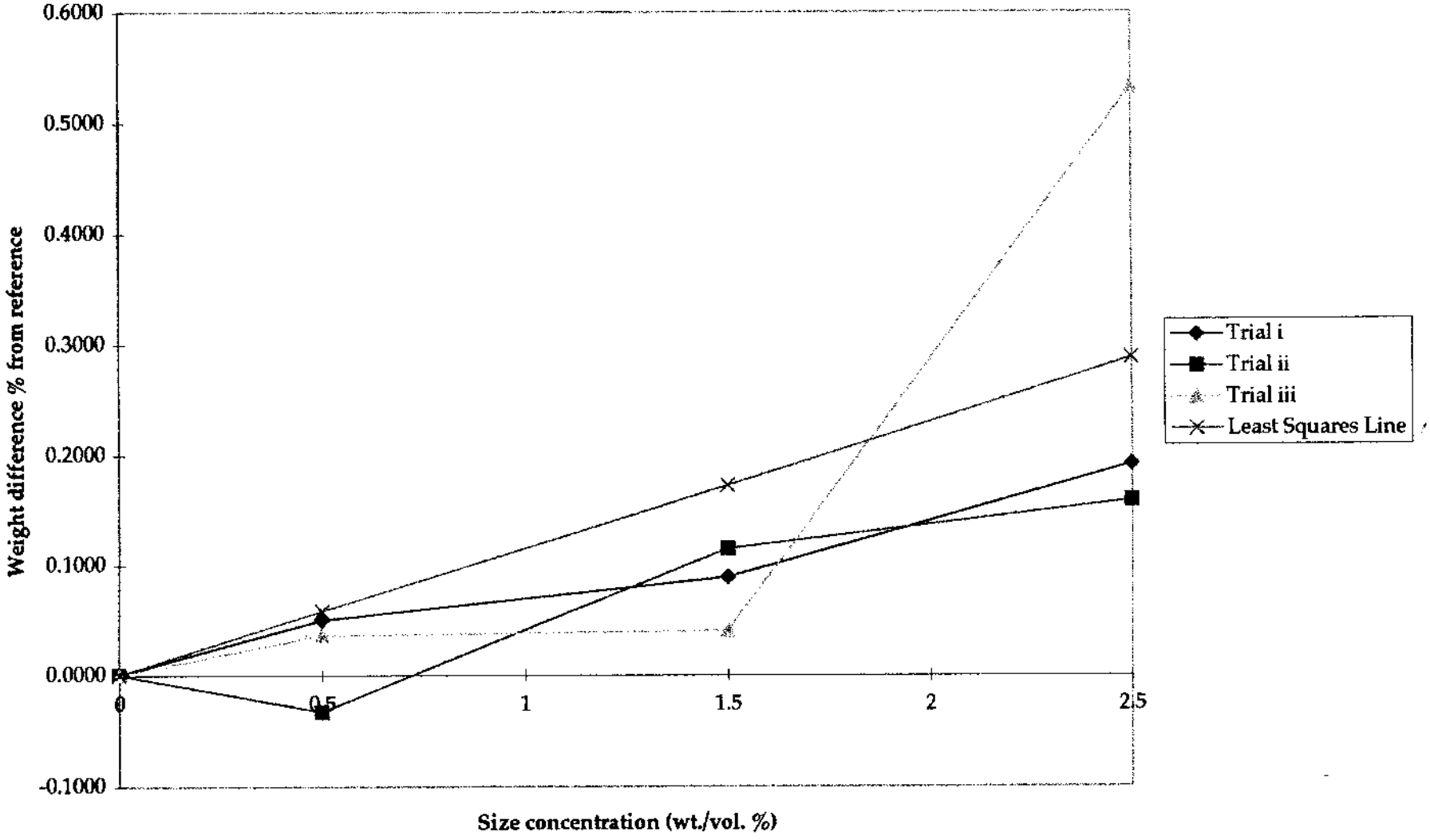
Least Squares Line: $y=(0.1410\pm0.1433)x + (0.0000\pm0.09686)$

Whatman Change in Moisture Loss (50% RH)



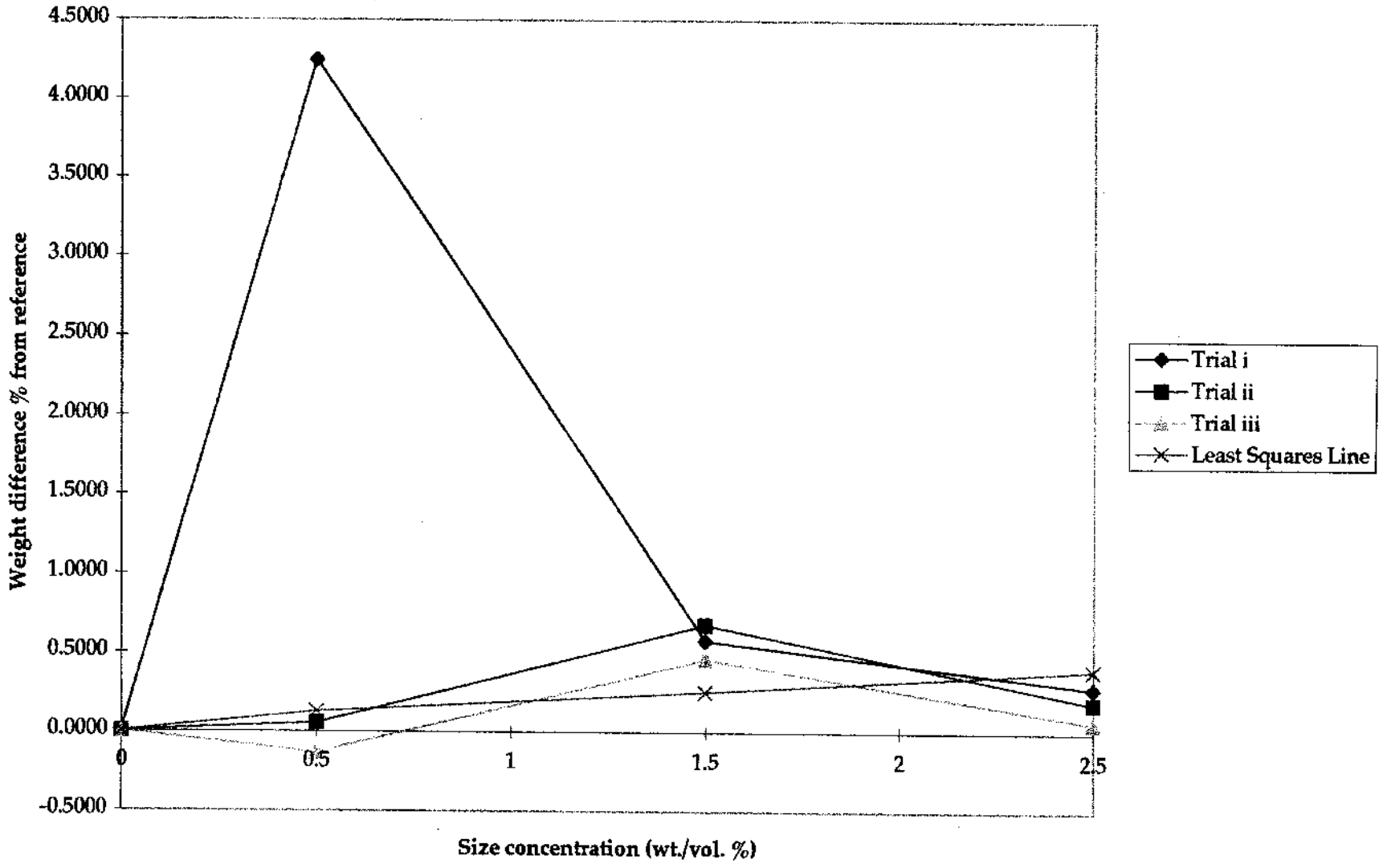
Least Squares Line: $y=(0.2106\pm0.1528)x + (0.0000\pm0.2259)$

Barrett Change in Moisture Loss (50% RH)



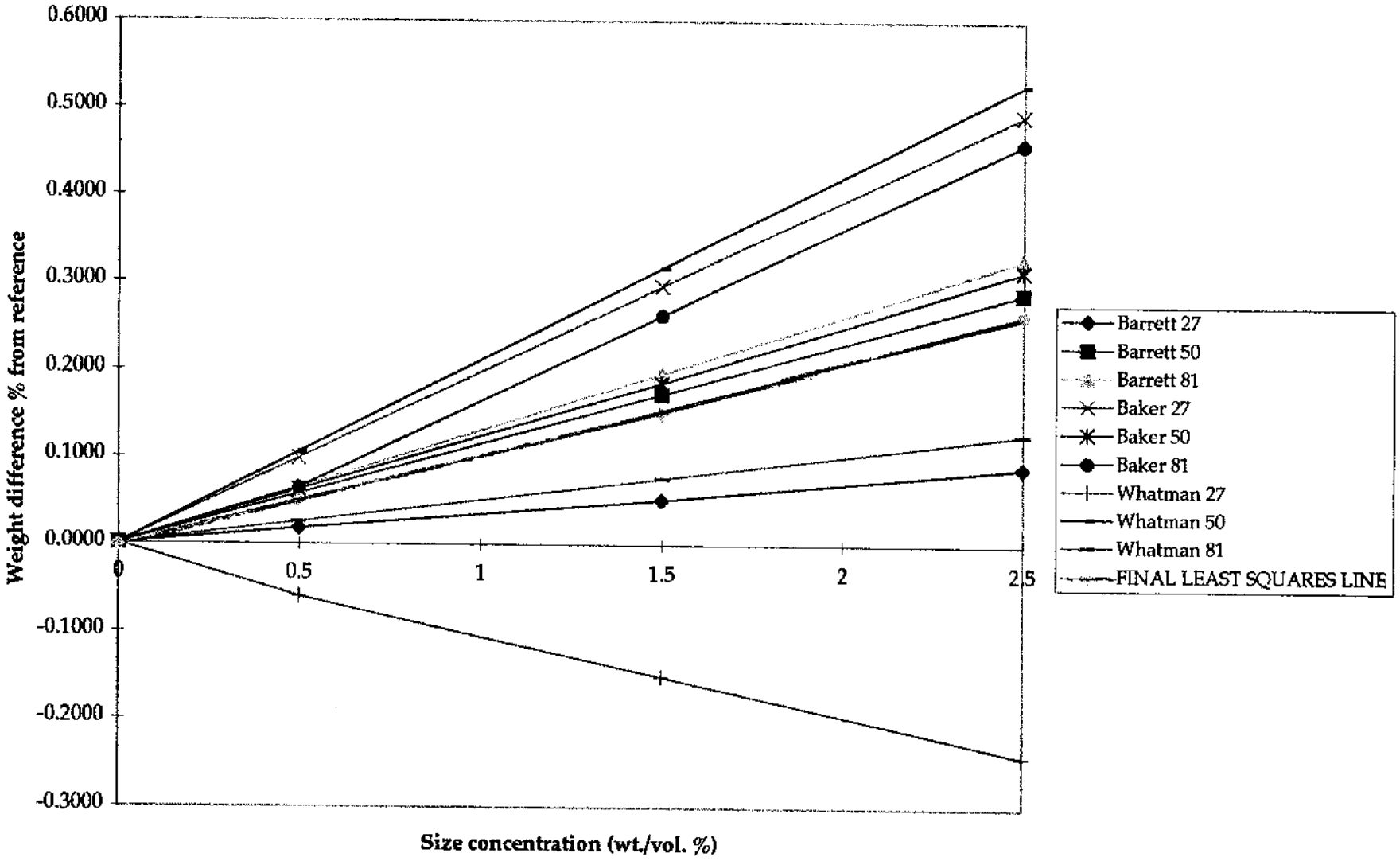
Least Squares Line: $y=(0.1150\pm0.0287)x + (0.0000\pm0.0432)$

Barrett Change in Moisture Loss (81% RH)



Least Squares Line: $y=(0.1304\pm0.1529)x + (0.0000\pm0.2261)$

Least Square Lines vs. Concentration for All Paper Types and RH



Final Least Squares Line: $y=(0.1061\pm0.0113)x + (-0.0022\pm0.0019)$