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The Effects of Relative Humidity and Temperature on the Strength Properties of Corrugated Board

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"THE EFFECTS OF RELATIVE HUMIDITY AND TEMPERATURE ON THE STRENGTH PROPERTIES OF CORRUGATED BOARD"

by

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ABSTRACT

The objective of this thesis was the determination of the effect of temperature and relative humidity on the strength properties of corrugated board.

A testing laboratory was set up in a controlled humidity room. Both temperatures and humidities were varied to form testing levels. The temperatures ranged from 32°F to 92°F. The humidity varied from 25% to 75%. Extreme conditions in either direction were not used so as to avoid damage to the room and testing equipment. Three tests were performed on the exposed board. They were H & D flat crush test, G.E. puncture test, and the mullen test. All were performed in accordance with TAPPI and Astm Standards.

Results of the tests showed temperature and humidity to both have a definite effect on the strength properties of corrugated board. For example the mullen and G.E. puncture showed an increase in strength at a lower temperature with a 50% humidity. Yet at 75% humidity the strength is lost. The board at this point has reached or passed its saturation point causing the fibers to pull out of the lattice rather than stretch. The test results also proved temperature and relative humidity and also had an effect on strength due to what the board is made up of. A certain set of conditions could cause the liner board to add to the strength in a mullen test, while the corrugated medium of the board, under the same conditions, could completely destroy the crush strength.

The major controlling factor of all tests was the relative humidity. The amount of moisture absorbed by the board controlled the strength abilities. The results formed in this thesis are conclusive enough to show that relative humidity and temperature do effect strength properties and should be controlled within the plant when possible.

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HISTORICAL BACKGROUND AND DEVELOPMENT

The historical background on a topic of this nature is very limited. There have been very few articles published on this topic. Through talking to people in the industry there is evidence that this type of a study has been done on a limited basis, but not recorded. Many articles have been published pertaining to the effects of relative humidity on corrugated board in extreme conditions, but none have been centered around the effect of relative humidity on board under normal plant operating conditions.

Recent articles published in 1970 give insight to these studies. One article states in relation to corrugated board that, "Relative humidity is the critical factor, temperature changes alone do not have much effect " (1). This in itself leads to an assumption that the moisture in the corrugated board that can be gained from relative humidity while sitting in the plant can have a definite effect on the strength properties. "Material strength characteristics of corrugated board vary appreciably with moisture content; for example, under extremely hot and humid conditions (90-100 degrees, 85-90% relative humidity), boxes lose 40-50% of their compression strength and flat crush" (2). These statistics are from studies for conditioning of board but can be applied to plant storage conditions. It is quite possible that board sitting in a plant during the summer months could be exposed to conditions nearing these extremes. If so then, the results of the experimental should demonstrate a loss in the strength in the other properties being tested.

Another paper written in the past year was on the hygroexpansivity of corrugated board. Although this article does not relate to the strength properties of corrugated board, it does dwell upon the matter of expansion and contraction of corrugated board when exposed to different relative humidities. Some of the findings stated, "Dimensional changes were nonlinear with increases in relative humidity. There was approximately 1.1 per cent dimensional movement parallel to the flutes (cross-machine direction), and 0.5 per cent movement perpendicular to the flutes (machine direction), when the material was moved from a relative humidity of 30 per cent to one of 90 per cent (constant temperature 80 degrees F.)" (3).

Articles of this type show there is a definite relation between strength properties and relative humidity. To what extent remains to be seen. Hopefully the results of this experiment will demonstrate the extent of the effect, and possibly suggest a range of conditions under which corrugated board can be stored without appreciable loss of its strength properties.

EXPERIMENTAL SECTION

The samples of corrugated board being used are basically made up of 9 point Semi Chemical Hardwood Kraft Medium. Its caliper is .009, and has a basis weight of 26 pounds per 1000 square feet. The following Table (I) will indicate the basic information for each pound test of board used.

TABLE I

Test Flute	125 C	175 C	200 C	275 C	350 C	200 C	275 BC	350 BC	500 BC
Liners & Medium	26 / 26	42 / 33	42 / 42	69 / 69	90 / 90	33 / 26 / 33	42 / 26 / 42	42 / 42 / 42	90 / 42 / 90
Combined Facings	52	75	84	138	180	92	110	126	222
Combined Board Wt. #Wt/Mft.	97	120	129	183	225	179	197	313	309

All samples will be preconditioned at 72 degrees F. and 50% relative humidity. The samples used in testing will start in the form of a 6 inch square and will be cut down to fit appropriate testing qualifications. Minimum time for conditioning will be at least 24 hours of exposure to the simulated plant conditions, prior to testing.

The reference point for conditions of testing will be the same as the above standard conditions (72 degrees F. and 50% R.H.). This reference point shall be used in determination of the point of equilibrium for each of the different conditions. Equilibrium will be reached when the increase in moisture content of the sample has leveled off after exposure to the different atmospheric conditions.

The strength tests that will be run on the samples after reaching equilibrium under the different atmospheric conditions are as follows:

1. Determination of Moisture Content.
2. Flat Crush Test.
3. Mullen Test.
4. G.E. Puncture Test.

An outline of experimental procedures of each of these tests is included in this section.

The conditions to which the samples will be exposed will consist of temperatures held constant and the relative humidity being varied from high to low for that temperature. The temperatures will be 32 degrees F., 52 degrees F., 72 degrees F., and 92 degrees F.. For each of the five constant temperatures the relative humidity will vary within a range of 25% to 75%. Starting with 25% and increasing by 25% each time until 75% relative humidity is reached. Every time the relative humidity is changed, a new set of samples will be brought in from the standard conditions.

Measurement of Moisture Content

Moisture content will be measured by the weight increase or decrease

decrease of the sample from the weight of the same sample at standard conditions. The moisture content measurement of the sample will also serve as an indicator for when the samples have reached equilibrium under the conditions they are exposed to. When the weight of the sample has become constant then equilibrium has been reached and the tests will then be conducted.

Flat Crush

"The flat-crush test evaluates the resistance of the flutes in corrugated board to a crushing force applied perpendicular to the surface of the board" (4). The flat-crush test measures the rigidity of the corrugations themselves. High flat-crush indicates good corrugated medium and proper formation. At the same time low flat-crush indicates a poor quality corrugated medium and poor formation. the following procedure will be used in accordance with A.S.T.M. Standard D. 1225-54, using the H. and D. Flat Crusher:

1. 2 inch square samples will be used from undamaged and unprinted board.
2. Six tests will be made on one sample and an average computed.
3. In single wall board, the pressure will be recorded at collapse of the corrugated medium.
4. In double wall, the first complete failure of flute will be recorded.

Mullen Test

The mullen test measures bursting strength. "Bursting strength is defined for ths method of test as the hydrostatic pressure required to produce rupture of a circular area of the material under test 1.2 inches in diameter, when applied at a controlled, increasing rate, as described in Section 7. During the test, the specimen must be free to bulge under influence of the increasing pressure, but the periphery of the test area must be rigidly fixed so that it does not move while the pressure is being applied" (5). The following procedure will be followed:

1. Samples of 6 inch squares will be used with four pops being made on each side and being recorded as top and bottom. The recorded value will be the average.
2. Any pop not tearing in as "H" fashion or shape will be disregarded and another reading will be taken.
3. If any one pop is unusually low it will also be disregarded with another test being made.

Puncture Test

This test will be conducted with the use of the General Electric puncture tester. The machine itself will measure puncture resistance and stiffness of board, either in single sheets or in double wall form.

This type of a test simulates damage in use, similar to that occuring in shipping or in the plant. The tester actually "measures the energy required to puncture the container board with a point affixed to a pendulum arm (one scale unit equals 0.305 cm-kg or 0.265 in-lb). These energy units actually are made up of two major components: the energy to tear the material and the energy to bend it out of the way of the point" (6). The procedure for testing puncture will be done according to the procedure outlined in this section and in accordance with Tappi Standard T 803ts - 50. The testing will be done as follows:

1. Samples will be six inches square.
2. Five tests will be made on each type to get an average value.
3. Weights on the puncture arm will vary as to the poundage of the sample board being used.
4. The tested sample shall be clamped between plates with the corrugations running perpendicular to the angle swing of the puncture arm.

DISCUSSION OF DATA

The data collected was limited due to the limited capabilities of the humidity room used for testing. Extreme conditions at either end of the spectrum were eliminated because of possible damage to the humidity room. The data collected under the various conditions does however indicate a definite effect on the strength properties of corrugated board.

The mullen test data shows an increase in board strength as the humidity increases. Here the increase in humidity tends to make the board more plyable and able to stretch. A moisture increase in the board from the increased relative humidity is accountable for this effect. The effect of temperature is exemplified in the 85% relative humidity data. Here the board at 32°F with a high humidity shows in almost all cases the greatest amount of strength. The increase in temperature in this R.H. range consistently, on all types of board, shows a definite decrease in mullen strength. As the temperature increases the moisture content also is increasing. By the time 92°F is obtained the corrugated board has reached a moisture content where the board has become so plyable that it begins to tear rather than stretch.

In comparing a certain temperature at various humidities the data does not indicate any definite pattern. Basically the mullen strength of the board does show a loss with increased humidity and increased temperature within a given % R.H. range. This is probably due to the amount of moisture content in the board. The moisture saturates the board both inside and out causing a breakdown in the fiber lattice of the liner board and a loss in strength. The medium used would also be highly susceptible to strength loss because of increased moisture content. The medium is the first area for the breakdown in strength by it's being a low density sheet of board with a more avid attraction for moisture.

The H & D flat-crush data indicates a decrease in strength with an increase in humidity and temperature. Unlike the mullen test results the H & D indicated either temperature of humidity could be held constant while the other was raised, and a decrease in strength would be recognized. If either the 72°F temperature or the 92°F is followed across any of the different type of boards the increase in % R.H. causes strength loss. At the same time all types of board at the 75% R.H. show a lower strength at 32°F with an increase to a maximum strength at either 52°F or 72°F, with a consistent drop in strength at 92°F.

The basis for strength in this type of test is how well the medium can withstand moisture. As the temperature and relative humidity increased, the moisture content of the board also increased. The flutes of the board, which are the basis for strength against crush, are the most succeptible to moisture absorption. The low grade of paper used for medium will readily absorb moisture, thus accounting for the loss in strength.

This effect can be most critical to a plant in the area of printing. To much impression from the ink rolls could cause severe crush and accordingly a poor quality box.

In the testing it was noticed that regardless of the temperature or humidity the C flute always gave out before the B flute. The greater strength of the B flute can be accounted for by the increased number of flutes per inch, than in C flute. "B" flute has 52 flutes/ inch, where-as C flute only has 42 flutes/inch. The C flute therefore has more exposed surface areas of flutes per inch than B flute, and would logically be capable of absorbing a greater amount of moisture causing a loss in strength.

The fluted mediums succeptability to moisture absorbtion and subsequently a strength loss is well indicated by the data collected in the H & D test results. Variation in flute size is one possible way to cut down the amount of strength lost. The strength of board in this area could definitely by helped by in plant controlled humidity.

The results of the G. E. Puncture test data showed many of the same effects as the mullen test data. An increase in humidity, holding the temperature constant, in most cases shows an increase in strength. This happens for much the same reasons as in the mullen test. The G.E. Puncture test also is dependent on the strength of the liner board. With a rise in humidity the liner board gains more flexibility or stretch with the increase in moisture content. The brittle effect of the board caused by a low temperature and humidity is eliminated. Again though, the temperature has a detering effect at a high temperature. At 75% relative humidity, as the temperature increases the board is becoming saturated with moisture. Consequently the board loses strength because the fiber lattice becomes so moist, there is a breakdown in the lattice rather than a stretch effect. The cooler temperatures (32°F & 52°F) keep the board brittle enough to offset the effect of the high percentage humidity.

The medium has much the same effect caused by humidity and temperature. The medium reaches it's saturation point much sooner than the liners. As a result, this can cause the liners to collapse against each other at the point of impact of the puncturing object. Here the effectiveness of the doublewall style of board can be helpful for retaining strength. The middle liner and the second fluted medium can offer additional resistence against a puncture or a mullen test.

TABLE II

MULLEN TEST RESULTS

Percent Relative Humidity

Temperature	25%	50%	75%	25%	50%	75%
°F		Single Wall 125 C			Double Wall 200 CB	
32	-	-	214	-	-	359
52	-	155	160	-	365	355
72	143	233	166	315	371	361
92	128	161	166	273	323	318
		Single Wall 175 C			Double Wall 275 CB	
32	-	-	268	-	-	455
52	-	215	243	-	362	385
72	235	281	270	341	388	397
92	205	238	225	313	343	378
		Single Wall 200 C			Double Wall 350 CB	
32	-	-	320	-	-	501
52	-	315	267	-	470	483
72	265	300	300	418	430	460
92	243	310	275	390	424	457
		Single Wall 275 C				
32	-	-	507			
52	-	453	427			
72	406	386	438			
92	423	425	355			
		Single Wall 350 C				
32	-	-	560			
52	-	481	500			
72	432	390	460			
92	518	447	480			

TABLE III

H & D FLAT CRUSH RESULTS

Percent Relative Humidity

Temperature	25%	50%	75%	25%	50%	75%
	Single Wall 125C			Double Wall 350C		
32	-	-	284	-	-	261
52	-	307	315	-	372	345
72	297	261	258	396	353	302
92	376	281	236	383	335	289
	Single Wall 175C			Double Wall 200 CB		
32	-	-	263	-	-	322
52	-	366	322	-	269	338
72	371	352	305	352	300	265
92	352	319	254	402	336	165
	Single Wall 200 C			Double Wall 275 CB		
32	-	-	268	-	-	208
52	-	338	293	-	355	295
72	344	317	252	401	369	333
92	354	330	213	432	332	267
	Single Wall 250 C			Double Wall 350 CB		
32	-	-	260	-	-	248
52	-	345	285	-	354	262
72	351	338	289	363	308	216
92	388	341	246	397	314	213

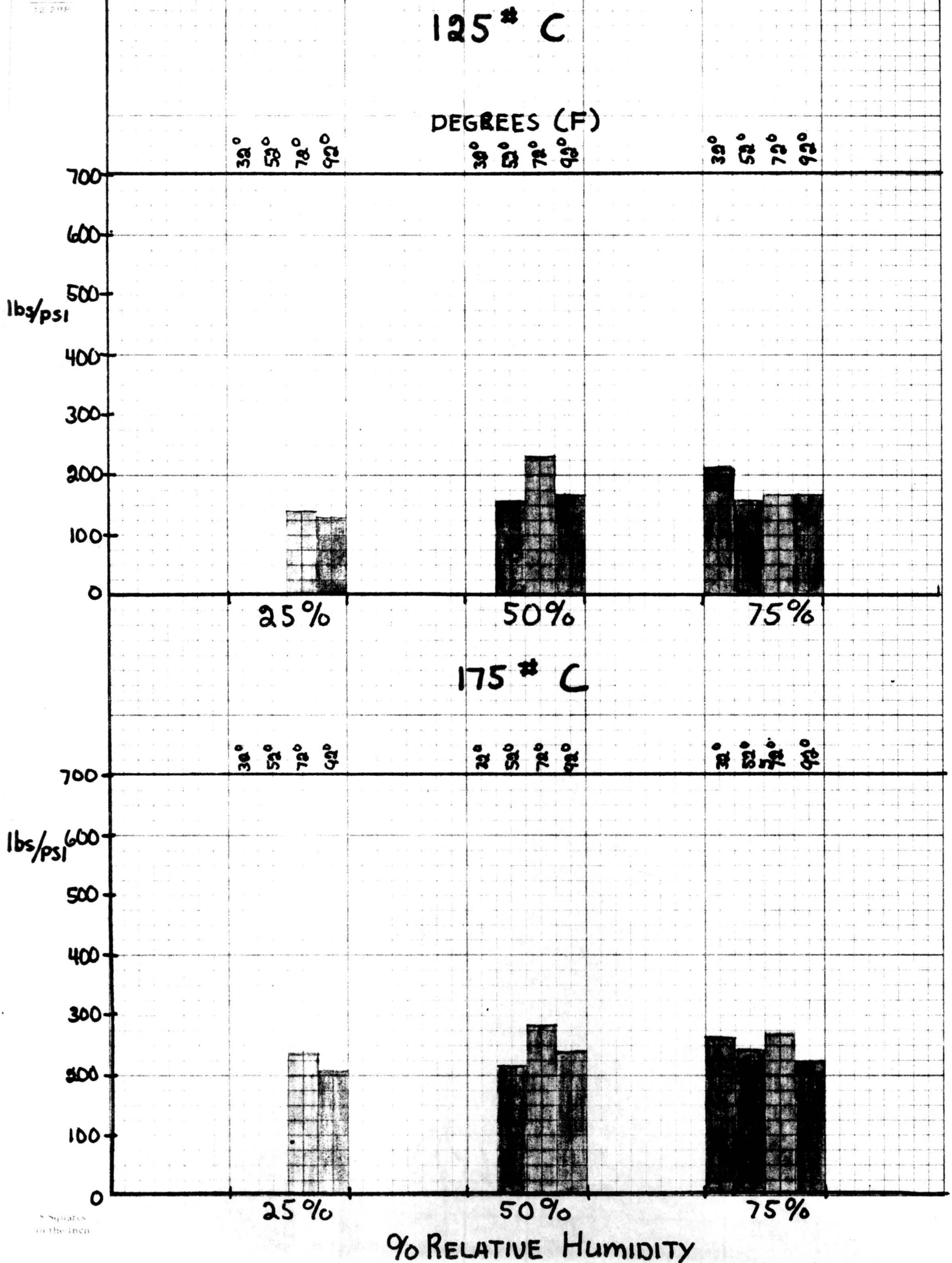
TABLE IV

G.E. PUNCTURE RESULTS

Percent Relative Humidity

Temperature	25%	50%	75%	25%	50%	75%
°F		Single Wall 125 C			Double Wall 350 C	
32	-	-	47	-	-	127
52	-	44	45	-	105	117
72	40	37	41	109	105	117
92	42	39	42	107	114	114
		Single Wall 175 C			Double Wall 200 CB	
32	-	-	59	-	-	109
52	-	56	57	-	100	107
72	56	53	54	88	99	102
92	52	51	54	90	103	106
		Single Wall 200 C			Double Wall 275 CB	
32	-	-	66	-	-	112
52	-	61	67	-	108	112
72	57	59	60	102	107	108
92	58	57	61	98	106	108
		Single Wall 275 C			Double Wall 350 CB	
32	-	-	101	-	-	126
52	-	88	91	-	125	131
72	80	76	84	131	145	152
92	85	87	88	105	127	126

Mullen Test Results



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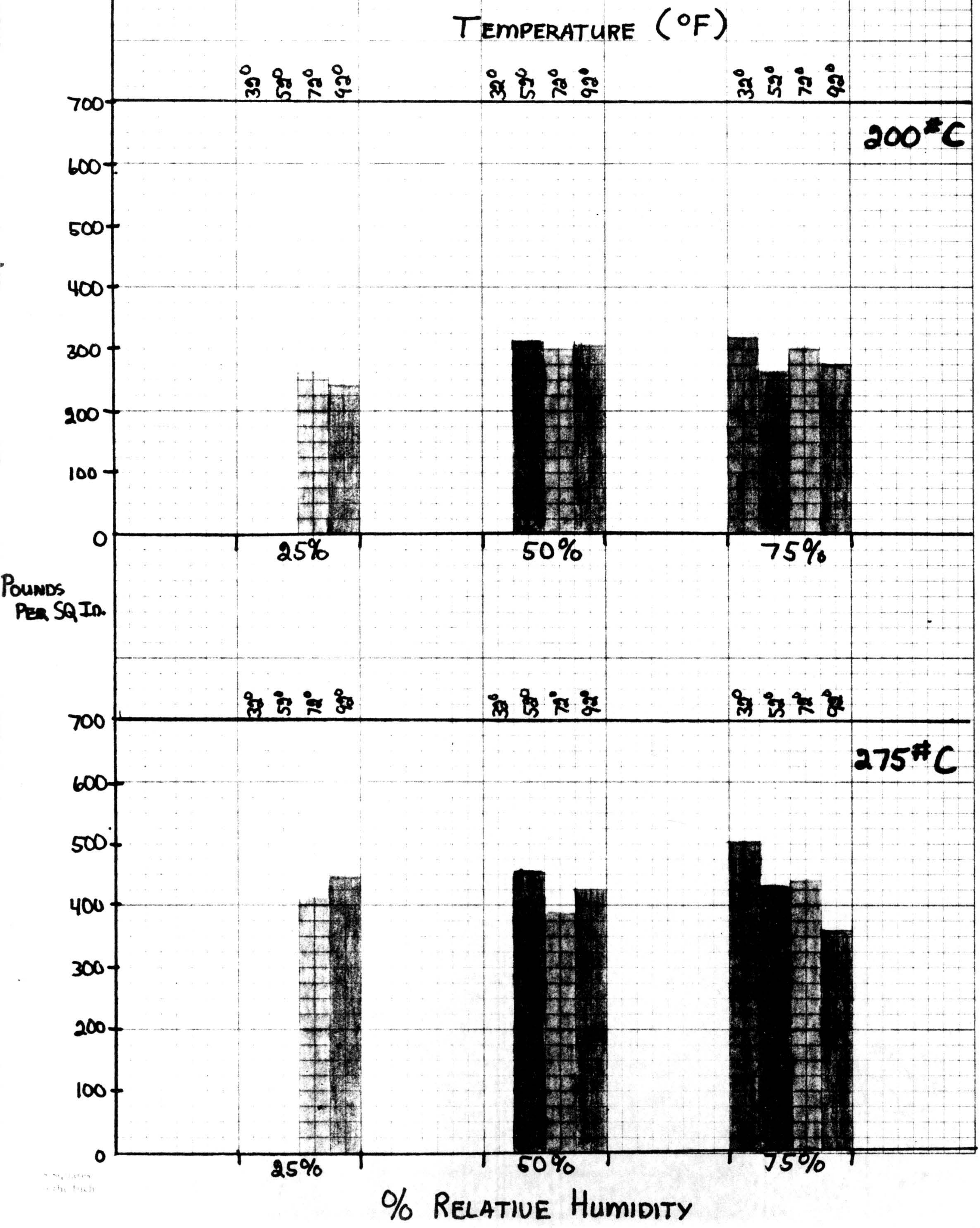

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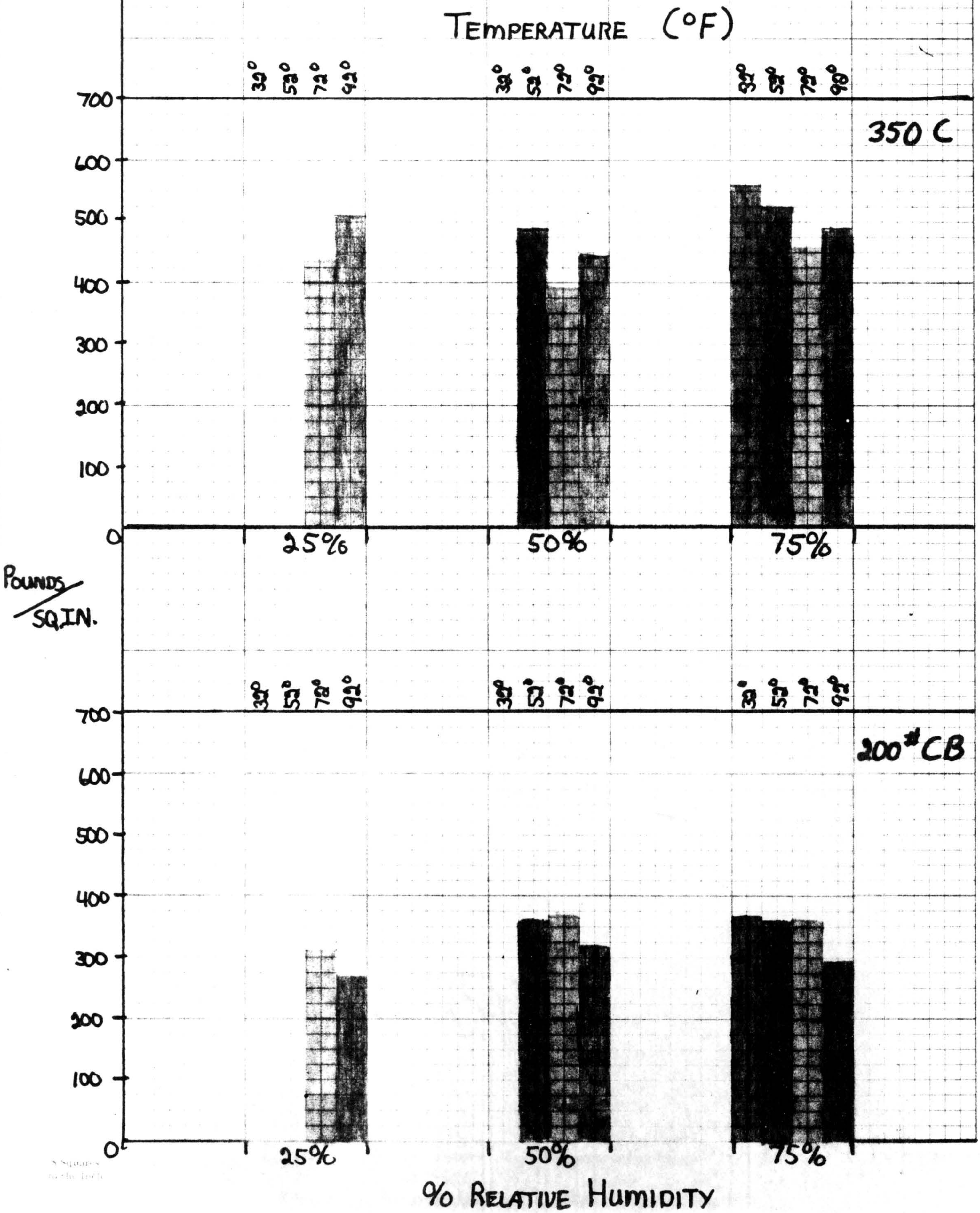

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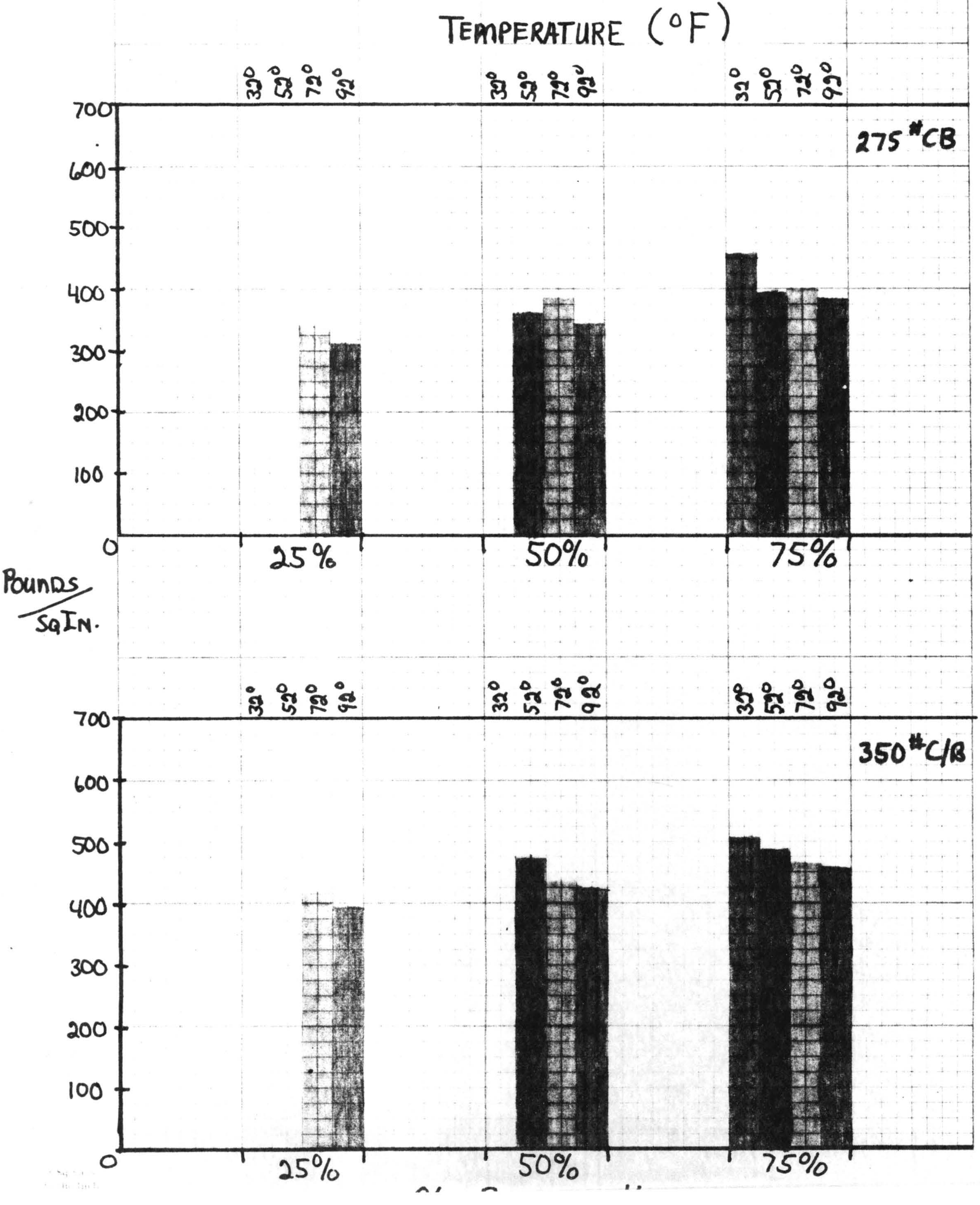

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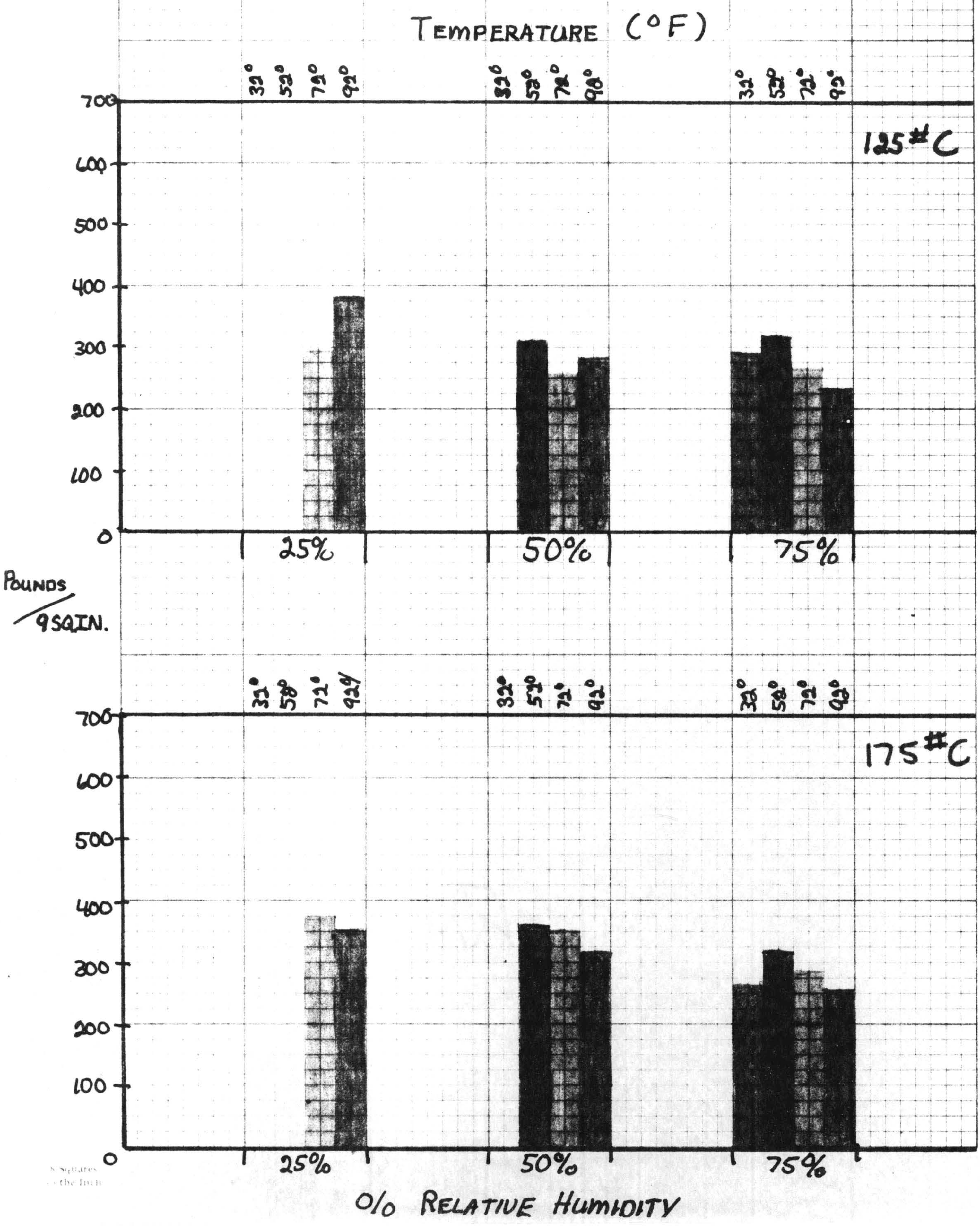

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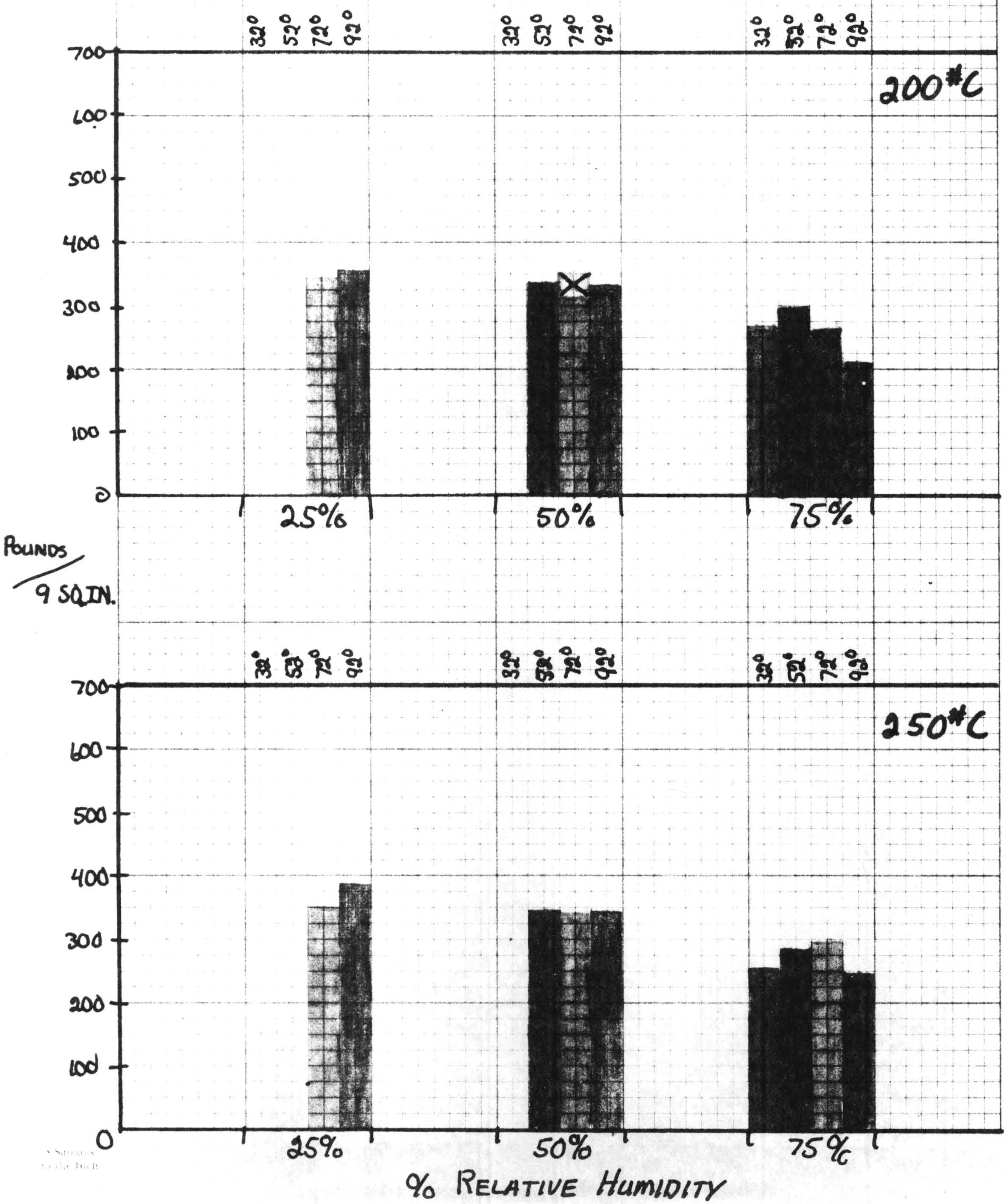

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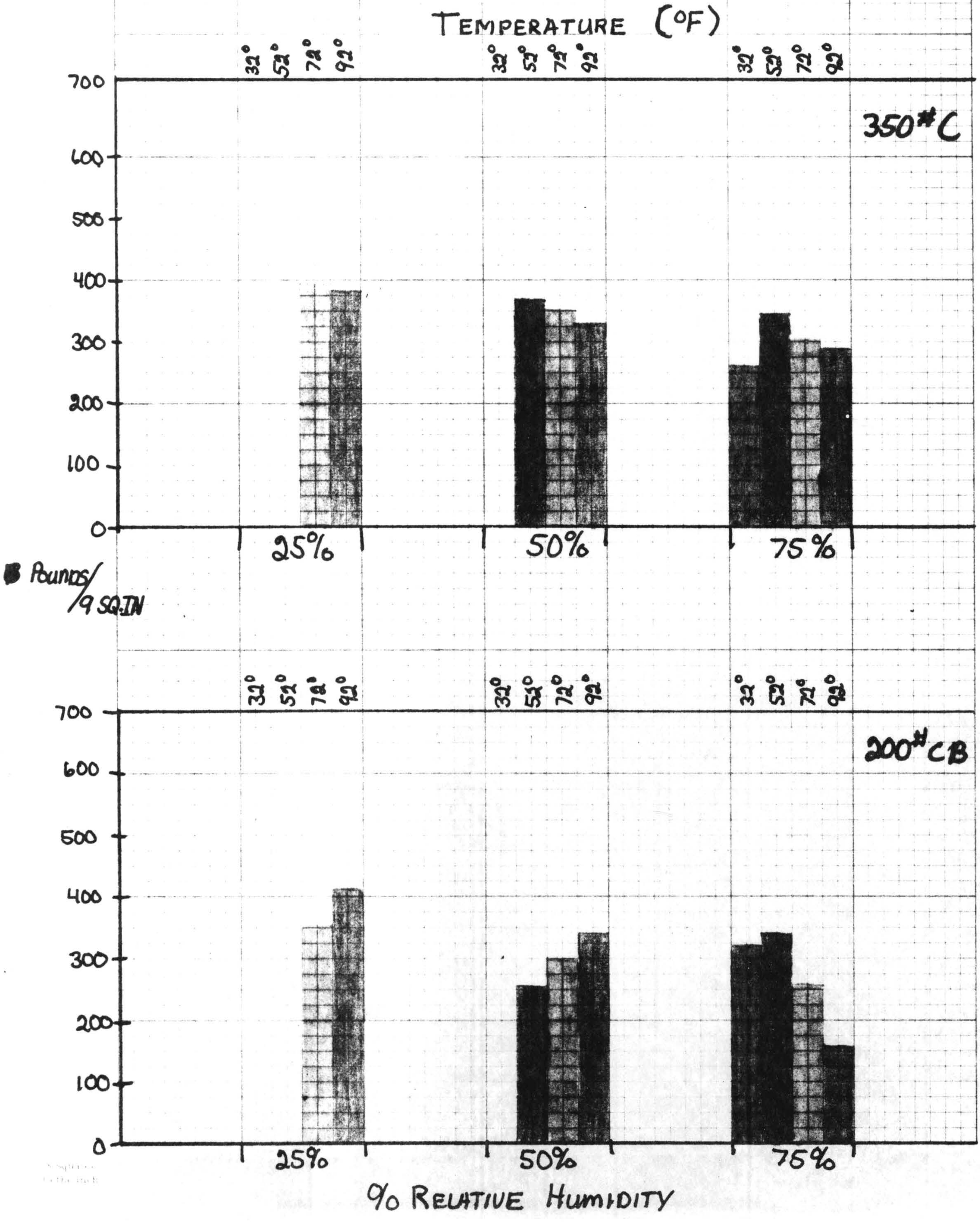

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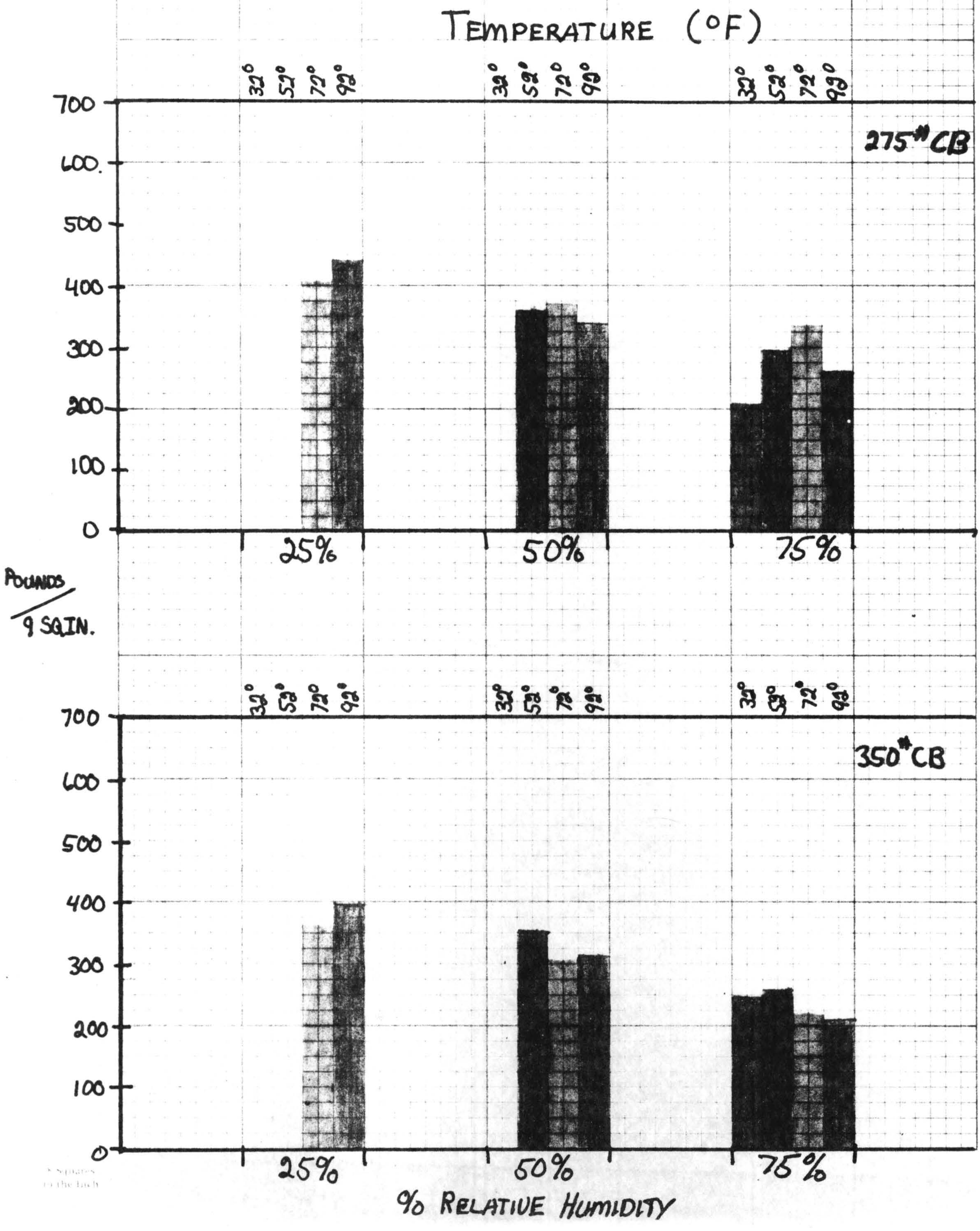

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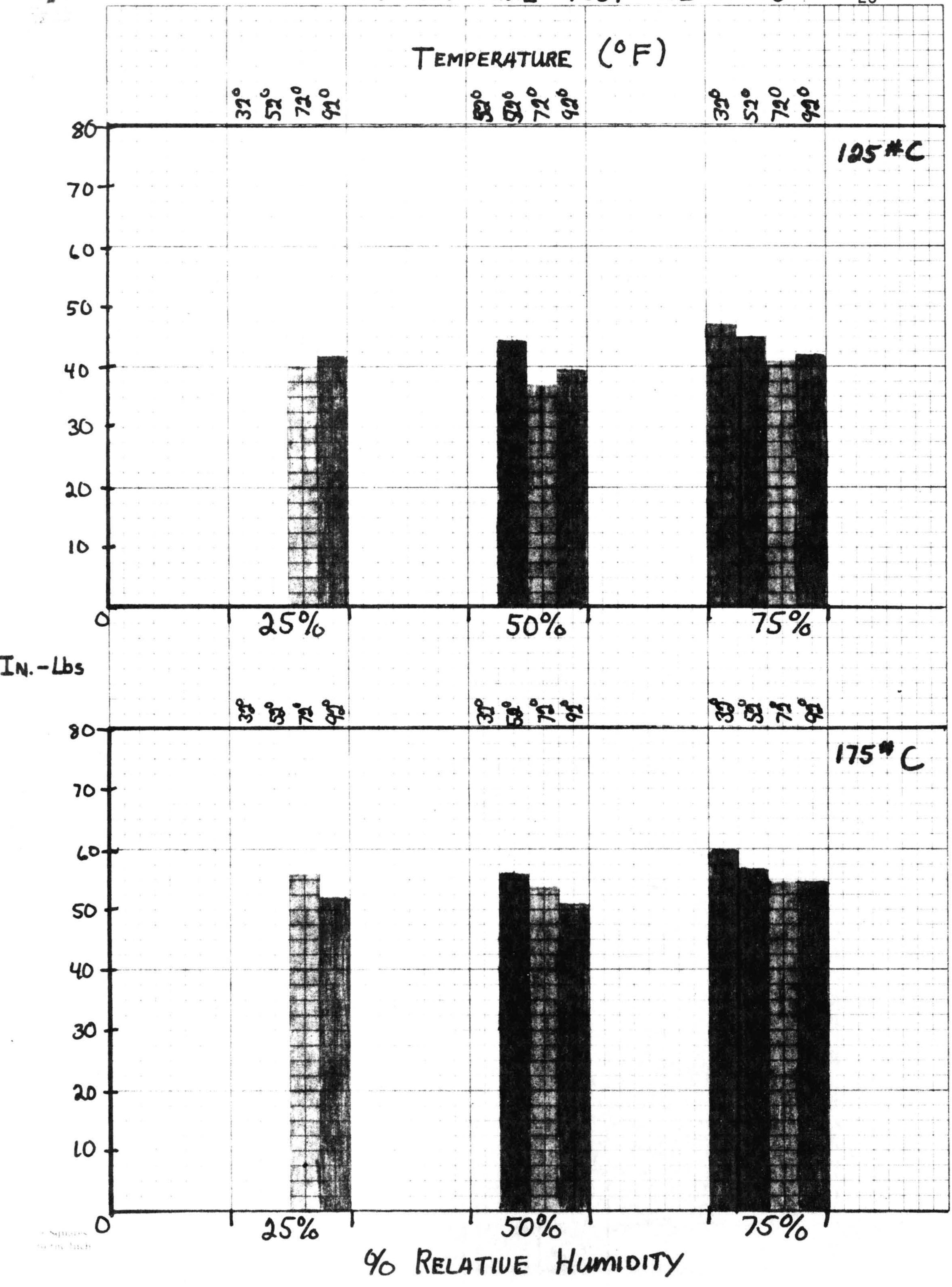

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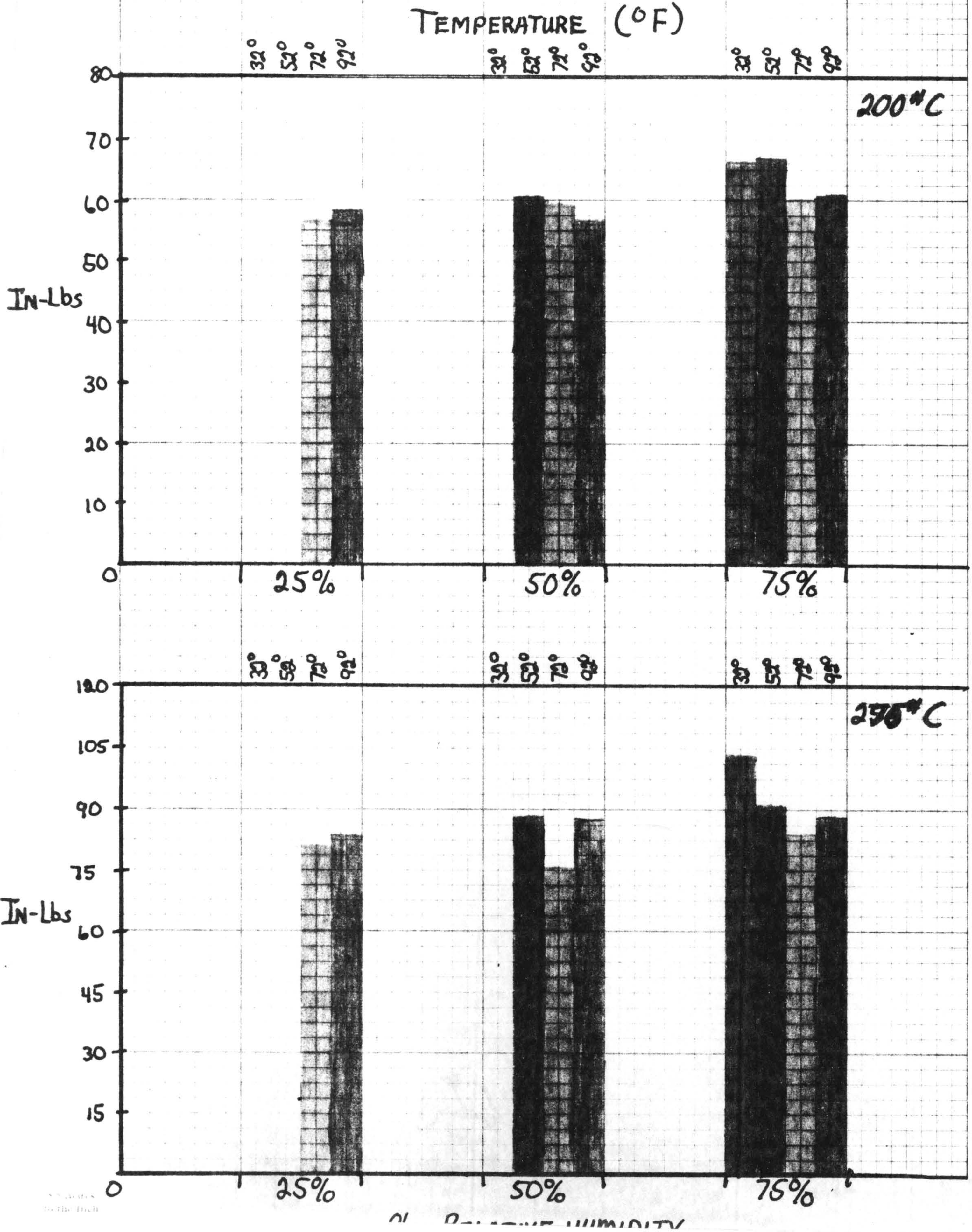

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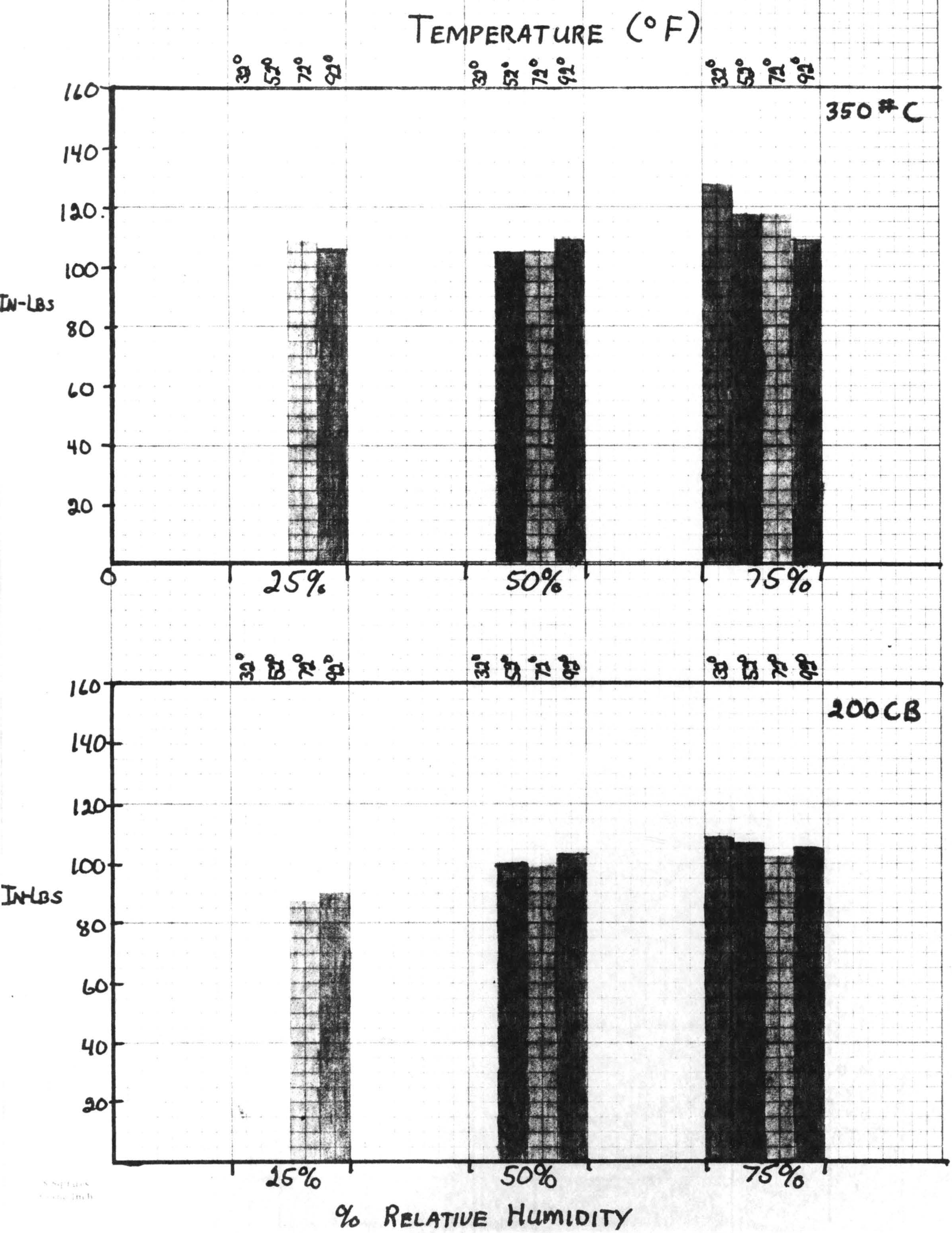

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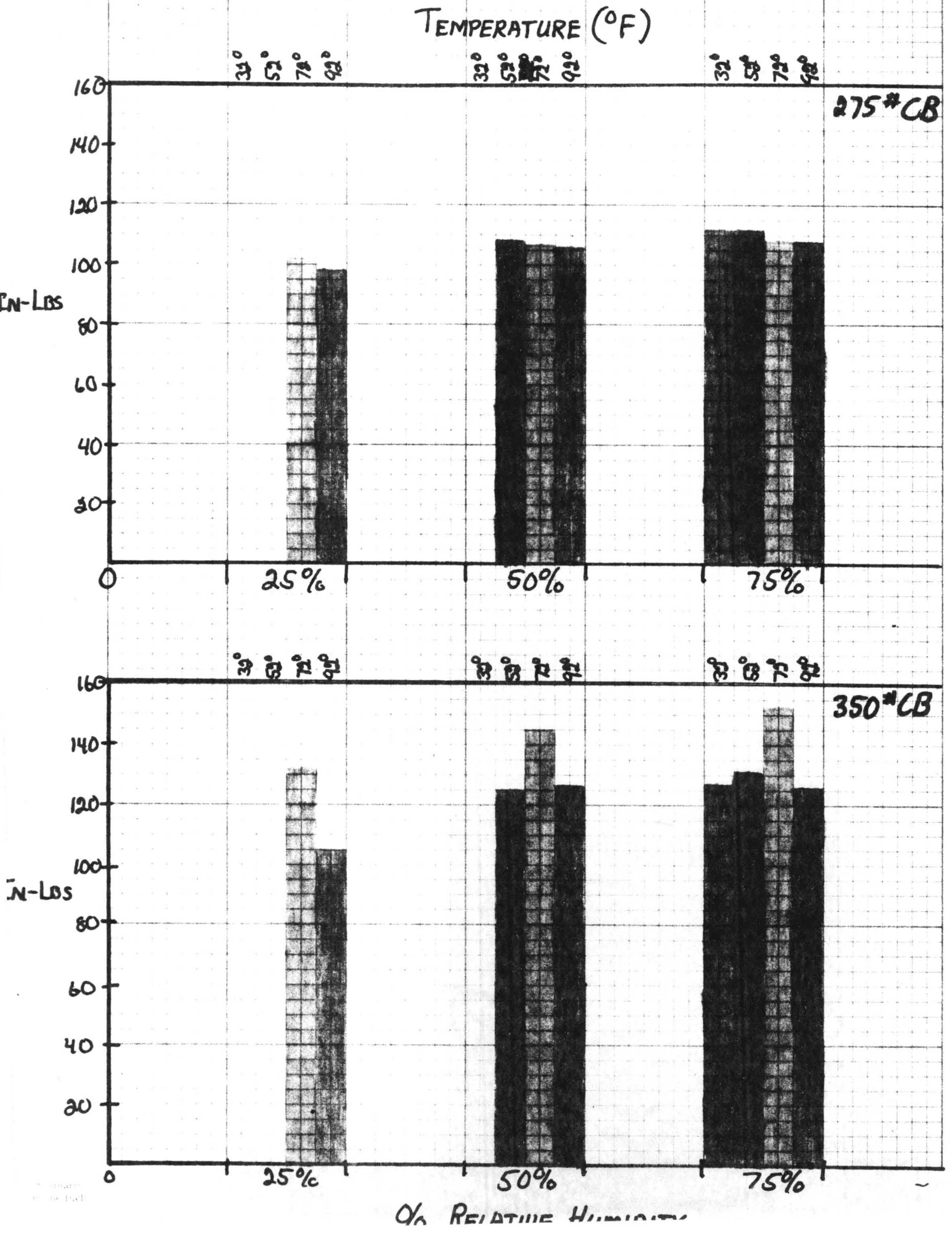

CONCLUSIONS

The data collected for this thesis, although limited, is indicitative of the fact that humidity and temperature do have a definite effect on the strength properties of corrugated board. The conditions used for testing could easily be found in any corrugated plant anywhere in the world.

In two of the three tests, Mullen and G.E. Puncture, it was found that an increase in percent humidity at a lower constant temperature can effectively increase the strength of the board. This increase in humidity creates moisture in the liner board that eliminates brittleness of the fibers and gives them the ability to stretch when subjected to force. But at the same time the fibers can only stand so much moisture absorption. When the temperature is increased at a higher constant humidity (ex. 75%), the fibers become increasingly saturated with moisture and begin to lose strength. Here the fiber lattice of the liner board has reached the point where an exerted force on them causes pull-out and separation rather than strength. As exemplified above the liner board is the critical point of strength in the two types of tests. The medium in this case deters the resistence of the board. It is easily saturated and can collapse, causing the resistance of force to be put on the liners. The effect of the medium is shown in the results of the H & D flat-crush test. Here the medium is the critical factor for strength. As the medium gained moisture from increased humidity it weakened. The medium which is a much lower grade of paper, more readily absorbs the moisture. Although this gives a certain flexibility, it also causes the flutes formed by the medium to collapse when pressure is exerted. Consequently the strength for the medium is best at lower temperatures and humidities where the fibers are somewhat brittle.

In all three types of tests, % Relative Humidity, is the key factor. The humidity puts the moisture in the air that the board can absorb. If the humidity is low the temperature can be high or low and cause little change. Yet if the humidity is high the temperature can be cool and help the board retain its stiffness thus adding to the strength. But if the temperature is high the warm air can increase the moisture of the air and correspondingly cause the boards moisture content to reach it's saturation point, yielding a loss in strength.

The effects of humidity and temperature illustrated by this thesis indicated a need for controlled conditions in the plant situation. To determine the amount and type of control would take many more years of research and testing of all types of board. Much research has been done on paper and its products in relation to plant conditions under which they are produced. Unlike this corrugated board has had most of it's studies done on sub-zero and tropical conditions. With the industry growing as it is today, much more research as done in this thesis will be conducted. Hopefully it will find the overall effect of temperature and humidity on all the strength properties of corrugated board produced in the plant

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