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The Effects of pH and Time on Fiber Surface Area

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THE EFFECTS OF pH AND TIME ON FIBER SURFACE AREA

BY

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ABSTRACT

In an effort to integrate some of the diverse approaches to pulp swelling evaluation, this study incorporated various test to reveal the possible swelling changes occurring in a fiber. The scope of this report is to study the effects of pH and time of soaking in water on secondary fiber swelling and surface area.

For each trial, fibers were soaked for different times ranging between 0 and 25 hours. The trials consisted of three different samples which had pH's of 7.2, 9.2 and 11.5. This study involved three tests to help analyze any changes in the fiber. They are the freeness test (drainage rate of fibers), water retention value test (affinity of pulp towards water) and the Pulmac Permeability Tester (surface area).

The results acquired revealed the following conclusions;
1) By increasing the pH of a wood fiber slurry, the overall fiber surface area will tend to increase accordingly.
2) Around ten hours of soaking is required to obtain a maximum in fiber surface area and WRV, and a minimum in freeness value.

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INTRODUCTION

In general, recycled fibers have poorer fiber-to-fiber bonding than virgin fibers. Conditions which cause recycled fiber swelling and increased surface area will result in better fiber bonding. The intent of this project was to determine the effects of pH and time of soaking in water on secondary fiber swelling and surface area. The secondary fibers used was double kraft lined, also known as container plant cuttings. The virgin fiber used was a 50% softwood, 50% hardwood bleached Kraft mixture.

Tests used to reveal the fiber changes included freeness (drainage rate of fibers), water retention value (affinity of pulp toward water) and the Pulmac Permeability Tester (surface area of fiber). The design was to correlate, via the three tests, how different pH's would affect the swelling rate and how much time is required to obtain noticeable changes in the swelling of the fiber.

THEORETICAL DISCUSSION

Freeness

The instrument and conditions for the freeness test were designed to yield results suited to the control of the manufacture of groundwood pulp. The freeness test (T227 om-85) is a wholly empirical procedure which gives an arbitrary measure of the rate at which a suspension of three grams of pulp in one liter of water can drain. The results depend mainly on the quantity of debris present, the degree of fibrillation of the fiber, and their fineness. It has also been suggested that freeness results are also dependent on the degree of fiber swelling. Besides these factors, the results are dependent on conditions under which the test is carried out, such as pressure head, stock concentration, temperature, character of the draining surfaces, and construction of the drainage orifices.

To a limited extent, the freeness of a pulp is a measure of its surface area[2]. It has been found in many studies that these two properties do correlate with each other to a certain extent. This extent being for freeness measurements of well-refined chemical pulps and mechanical pulps. These results are of limited value and in many instances can be very misleading. It has also been pointed out that water retention value characteristics are practically independent from freeness determinations[3].

Water Retention Value

The water retention value (WRV) is a centrifugal method for the characterizations of the wood fibers. This test has been

often used since its introduction by Jayme[3]. With this test, the affinity of a pulp towards water is determined by centrifuging a sample under standardized conditions. The apparatus used to determine WRV is a common laboratory centrifuge using a modified cup. The cup is equipped with a screen inside so that the water can drain from the pulp sample[4]. The apparatus can be seen in appendix II.

Various centrifugal forces ranging from 800 to 3000 times the force of gravity have been used since the beginning of this test. It has been determined that a higher centrifugal force will lower the WRV somewhat, but will attain a higher degree of reproducibility[3]. The force is determined by both the rotational speed and the rotational radius of the centrifuge[4]. The following equation is used:

$$Fc = 0.0000284\ RN^2$$

where Fc = centrifugal force (g's)
R = radius of rotation (in)
N = rotation speed (rpm)

Thode[4] states here that the centrifugal force that is used is critical, as too low a value will fail to overcome the forces of capillary pressure in the interfiber voids and results in a WRV that is greater than the intrafiber water responsible for swollen volume. On the other hand, too high a value of Fc may yield a fiber distortion and the loss of intrafiber water, resulting in an inaccurate low value for WRV. Thode and Ingmanson[5] state that the external specific surface of the pulp will increase with swelling.

Surface Area

The Pulmac Permeability Tester (PPT) was the first readily available instrument that can provide a quick and easy method for measuring the specific surface of a pulp. This property can be calculated from flow rate and pressure drop measurements on a thick mat of a pulp at a number of consistencies. The apparatus and calculations can be seen in appendices III and IV, respectively. The specific surface of a pulp is equal to the area (cm^2/g) of the fibers which provide bonding area in the final sheet.

The specific surface is somewhat different for each type of measurement and varies with the degree of swelling of the pulp. It has been shown that with the addition of sodium hydroxide, the fiber will swell faster than in water alone[6,7,8]. The difference in swelling behavior of pulps is interpreted in terms of the acidic group content and the cell wall flexibility. This can be understood from the fact that with increasing pH the degree of dissociation of the acidic groups in the cell wall increases[8]. Due to the increased electrostatic repulsion between these groups the cell wall swells. It is also generally agreed that the WRV of papermaking pulps increases when the pH is increased. Ideally, the WRV, drainage resistance and surface area may be thought of as experimental reflections of fiber swelling and of fiber flocculation[7].

EXPERIMENTAL PROCEDURE

MATERIAL

Two types of furnishes were used in this thesis project. The stock used for most of the trials was Double Kraft Line (DKL), donated by Greenbay Packaging. The other stock used was a virgin 50% softwood, 50% hardwood bleached Kraft furnish.

Common tap water was used for all trials.

EQUIPMENT

The Morden Slushmaker was used to disperse the fiber. For the virgin pulp, the laboratory Valley Beater was also used.

To determine the freeness of pulp, the TAPPI Freeness tester was utilized.

The apparatus used to obtain the water retention value was a common laboratory centrifuge with a modified cup. The cup is equipped with a removable screen inside so the water can be drained from the pulp sample[4]. The set-up can be seen in appendix II.

Analysis of the pulp surface area was completed with the Pulmac Permeability Tester.

PROCEDURE

The pulp was initially dispersed by the Morden Slushmaker for 30 minutes. The slurry was then divided evenly into three buckets and the pH adjusted to 7.2, 9.2 or 11.5. The pH was checked every one and a half hours. Occasionally, small amounts of caustic needed to be added to restore a minor decrease in pH.

Tests were initially performed on six percent consistency pulp at intervals 0,5,10 and 24 hours. The second trial used the same time increments, but the consistency was changed to three percent. This was done to ensure complete chemical dispersion and decrease possible sampling errors. The third trial maintained a three percent consistency, but with a change in the time intervals (0,10,15,20 and 25 hours). It was important to change to these time intervals in order to "observe" what was occurring between the tenth and 25th hours. For the fourth trial, the same time increments were kept, while a 1.5% consistency was used. Finally in the fifth trial, both the consistency and time intervals remained the same, as in the fourth trial, but a virgin furnish was used instead of DKL.

At each time interval, the freeness of pulp test was performed first. The test was completed twice according to TAPPI standard T 227 om-85.

The next test performed was the water retention value test (WRV). A common laboratory centrifuge with specially designed cups (seen in appendix II) was implemented to obtain the WRV. Pulp samples in a water suspension of 0.43% consistency were poured into the cups and allowed to gravity drain. Once the standing water had drained, samples were then centrifuged (two for each pH) for 30 minutes at a centrifugal force of 900 times the force of gravity. The fiber pads formed were then weighed, dried at 105 degrees C for 24 hours and reweighed. The following equation is used to determine WRV:

$$\text{WRV}(\%) = 100 * ((\text{wet weight} - \text{o.d. weight})/\text{o.d. weight})$$

The last test performed, was the Pulmac Permeability Tester. The apparatus can be seen in appendix III. Detailed instructions on how to use the Pulmac are included in appendix V. From this test, the flow rate and pressure drop through a pulp mat is obtained. Via the permeability calculations seen in appendix IV, a linear regression is performed to obtain the y intercept. With the y intercept and the graph found in appendix IV, the surface area can be calculated directly.

Results & discussion

a) The effects of time and pH on Canadian Standard Freeness

The first trial that was performed, had a DKL furnish of 6% consistency. Freeness was tested at the zero, fifth, tenth, and 24th hour. From figure 1, it appears as though the various pH's continued to decrease freeness until the tenth hour. After which, the pH's then increased freeness. This apparently revealed that the greatest amount of swelling was obtained around the tenth hour.

It is also apparent from figure 1 that as pH is increased, the freeness will tend to decrease. This drop in freeness is most likely due to the elimination of certain restrictions to swelling (by the alkaline medium) by the cleavage of ester bonds existing between xylans and xylan-lignin[6].

In an attempt to make sure that even chemical dispersion was maintained, the pulp consistency was lowered to 3.0%. Once again, freeness was tested a the zero, fifth tenth, and 24th hour. Different trends were discovered in comparison with the 6.0% consistency. Figure 2 shows essentially a constant decrease in freeness throughout the 24 hours with the exception of the 11.5 pH.

The change in consistency did effect the pH values. As in the 6% slurry, the 3% consistency slurry similarly showed an apparent greater swelling in fibers as the pH increases[6].

The next change within the tests tried to account for the differences found between the tenth and 24th hour tests. At a 3% consistency (fig. 3), a general decrease in freeness can be seen for all three pH's up to the time interval of 10-15 hours. Within this time period, a freeness minimum occurs, and afterwards an

increase is seen until the 20th hour. These apparently confusing trends can be explained due to the various layers found within a wood fiber[7,8]. Initially an external swelling may occur which would account for the decrease in freeness. It is known that the fiber is able to swell inward into the fiber lumen, and this could account for the increase in the freeness value later on. After the increase, a second decrease in freeness is seen which could be due to more swelling occurring as a result to the lack of restriction from the S1 layer and/or primary wall[9]. The greatest pH of 11.5 attained the lowest freeness values, as expected[10].

The pulp consistency was then decreased, this time to 1.5%. A similar result (compared to 3.0% consistency) was obtained when analyzing the decrease in freeness (fig. 4). Between the tenth and 15th hours a minimum freeness occurs, from there the freeness increases to around the 20th hour. A second decrease in freeness value is once again found.

With the 1.5% pulp consistency, the expected freeness trends occurred throughout the three pH's. That is, the higher the pH, the lower the freeness value.

Finally, a fifth trial was performed, this time to see if any noticeable changes would occur with a different furnish. The furnish being a 50% softwood, 50% hardwood bleached Kraft mixture. This "virgin" stock resulted in some slight changes in comparison with the DKL stock. In figure 5, it can be seen that all three pH's freeness values continued to decrease to and including the tenth hour. The pH's of 7.2 and 9.2 increased in freeness value after the tenth hour, while the 11.5 pH continued to decrease.

This could be due to the increased swelling which occurs at higher pH's. The 7.2 and 9.2 pH's revealed the consistent "second decrease" in freeness up to the 25th hour.

b) The effects of time and pH on Water Retention Value

The next test performed was the water retention value (WRV). The following discussion will parallel the aforementioned changes made as far as consistency and time is concerned. Initially, at a 6% consistency, an increase was observed in WRV through the fifth and tenth hours (fig. 6). This is as expected due to the fibers affinity towards water[2]. As in the freeness values, the WRV's showed a decrease after the tenth hour. This appears to be a result of the changes occurring in the cell wall dimensions[7].

At the various pH's, no particular trend could be deciphered from the data available. This might be a result of incomplete chemical dispersion or simply experimental error.

At a 3.0% consistency (fig. 7), the WRV seemed to attain a maximum around the fifth hour. This is probably incorrect due to the standard deviation of the data at the tenth hour. The data after the tenth hour generally appeared to increase. Whereas the 7.2 pH WRV appeared to be unusually high, the pH of 11.5 proved to have the largest WRV's as expected[11,12].

Again at 3.0% consistency, but with different time intervals, figure 8 reveals that the 11.5 pH WRV increased to the tenth hour. After which, a minimal decrease and then increase was seen with a somewhat large decrease after the 20th hour. At the higher pH, a WRV maximum could have already been reached and a collapsing lumen could mean a decreased WRV. The pH's of 7.2 and 9.2 essentially

remained constant or slightly decreased within the first ten hours. Both values continued to decrease until the 20th hour, and then increased. Due in part to a lower pH causing less swelling until a certain point where the fiber walls can absorb water more freely.

The WRV's for the various pH's were in accordance to many sources[6,10,12]. Here it was found that as the pH was increased, a greater WRV was obtained. These results can be understood from the fact that with an increasing pH, the degree of dissociation of the acidic groups in the cell wall increases[7]. The cell wall will then swell due to the increased electrostatic repulsions between these groups. On the other hand, if an electrolyte is added, the electrostatic repulsive forces are lowered since the charged groups in the cell wall are shielded, and thus the fiber shrinks.

When the pulp consistency of the DKL furnish was lowered to 1.5%, essentially the same trends took place (fig. 9) as that with a 3.0% consistency. The one difference between the two trials is that at a 1.5% consistency, all three of the pH's increased in WRV within the first ten hours of soaking. This trend is what was expected.

The pH of 11.5 (at hour 15) should be viewed as sampling error and eliminated from the discussion. As previously discussed, the greater the pH, the larger the WRV. This statement appears to hold true past the 10-15 hour mark. A curious trend occurs at the 20th hour for 7.2 and 9.2 pH. Both figures 8 and 9 show a lower WRV for 9.2 as compared with 7.2. It can only be speculated at this time, but a possible reason for this is due to a critical point between soaking time and pH and the strengths of the fiber layers to

withstand swelling and collapsing.

The last trial performed used the 50-50 virgin furnish at a 1.5% consistency. The first ten hours (fig. 10) reveal the expected trend of an increase in WRV for all three pH's. From there, the usual decrease in the pH's 9.2 and 11.5 occurs, with an increase for the pH of 7.2. This increase continues until the 20th hour where a decline in WRV is observed. The data point for 7.2 pH at the tenth hour has a large deviation. Because of this, I feel that a higher number for WRV should have been obtained. The WRV for the pH's of 9.2 and 11.5 decreased or stopped around the 20th hour, with a possibility of the WRV increasing after the 20th hour. As previously mentioned, this swelling could be due to an "overcoming" of the restriction of the S1 layer and/or the primary wall.

The pH trends follow that of the DKL furnish. That being, as the pH is increased, so will the WRV increase. Once again, at the 20th hour it is seen that the 9.2 pH obtains a lower WRV than does the 7.2 pH WRV.

c) The effects of time and pH on Surface area

The last test performed was that of surface area. Surface area was only determined on those trials with a 3.0% and 1.5% (DKL) consistency and also for the 1.5% consistency 50-50 virgin blend. From figure 11 it can be seen that at a 3.0% consistency, a surface area increase was generally attained through about the 15th hour. This increase in surface area is to be expected[1,4]. After the 15th hour, a decrease in the surface area value occurs up to the 20th hour where a second increase in surface area is found.

These changes are attributed to the ability of the different fiber layers to absorb water.

The trend that occurs from the three pH surface area values concurred with the data found in other literature. That being there was an increase of the specific surface of the fibers with increasing pH[10,13].

When the consistency is change to 1.5% (fig. 12), another increase in surface area is obtained for 9.2 and 11.5 pH up until around the 15th hour. It should be noted that at a pH of 7.2 (both in fig. 11 and 12), initially a "decrease" is observed and then the expected increase in surface area. Perhaps at the lower pH, the fiber walls do not respond as quickly to swelling as for the higher pH's. As was with the 3.0% consistency, a decrease in surface area is obtained until the 20th hour, where a second increase in surface area is achieved. The pH's followed the usual trend that at a higher pH the surface area will increase. The drastic decrease of the pH 9.2 surface area (at hour 20) is most likely due to experimental error.

d) Relationships between tests performed

Upon comparison of the three tests (freeness, WRV, surface area), it can be seen from figures 13, 14, and 15 that the three tests are often in agreement with each other. Ideally, WRV and surface area should always parallel each other, while freeness should be the opposite. (Note: In order to allow all data to be within a similar range, test values were divided by amount seen next to the test names on the graph) This can be seen to occur perfectly within the 0-10 hour range for the pH's of 9.2 and 11.5.

Afterwards, the three tests are then in agreement with each other only part of the time.

One reason being that perhaps the swelling will shift to one of an intracrystalline type[10]. Here the fiber wall thickness will increase and the size of the lumen will decrease. This results in a decrease in the compressibility and the surface area. Also, since the fluid in the lumen does not participate in the fluid flow, a continued swelling that changes the size of the lumen, would not affect the surface area greatly. Experimental error is certainly another reason for deviations. This is especially true when using the Pulmac Permeability Tester. As discussed in the Procedure, any entrained air in the pulp mat can cause inaccurate data.

The last surface area determination was performed on the 50-50 virgin furnish at a 1.5% consistency. Figure 16 shows an expected increase in surface area for all three pH's. The increase leveled off around the 10-15 hour mark. After the 15 hour mark, a continuous increase is seen once again for all three pH's. The common trend for a higher pH to result in a greater surface area was repeated. This time the 11.5 pH resulted in a substantial increase in surface area as compared with 7.2 and 9.2 pH.

It was observed that for the three test comparison (figs. 17, 18, and 19), a more consistent agreement was found between the tests for the 50-50 virgin furnish than that for the DKL furnish. The WRV and surface area paralleled each other well, while the freeness was opposite (as expected) only part of the time. One explanation could be that WRV characteristics are practically

independent from freeness determinations[2]. Another being that the 50-50 bleached Kraft furnish has probably had less contact with varying chemicals which might affect the fibers ability to swell.

CONCLUSIONS

It has been shown in this project that increasing the pH of a wood fiber slurry will increase the overall fiber surface area. Also, that an initial maximum in surface area and WRV, and a minimum in freeness is obtained around the tenth hour of soaking. This of course will vary slightly with different types of fiber used.

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APPENDIX I

WATER RETENTION VALUE

virgin	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	136	137	139	140	134
9.2	136	149	140	136	136
11.5	136	146	142	143	146

1.5%	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	188	206	180	173	193
9.2	188	210	178	138	151
11.5	188	201	126	207	195

3.0%	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	199	196	184	180	196
9.2	199	199	190	173	196
11.5	199	218	213	218	206

3.0%	HR 0	HR 5	HR 10	HR 24
7.2	178	194	181	173
9.2	178	174	170	184
11.5	178	194	182	212

6.0%	HR 0	HR 5	HR 10	HR 24
7.2	134	212	231	218
9.2	134	206	228	207
11.5	134	220	224	214

WATER RETENTION VALUE
STANDARD DEVIATION

virgin	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	5.8	24	8.5	0.7	7.8
9.2	5.8	2.8	0.7	1.4	3.5
11.5	5.8	0	5.7	1.4	8.5

1.5%	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	4.9	12.7	7.8	4.2	7.1
9.2	4.9	6.3	16.9	29.7	15.6
11.5	4.9	7.1	14.1	0	7.1

3.0%	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	1.4	2.1	5.7	3.5	2.1
9.2	1.4	1.4	2.1	1.4	4.9
11.5	1.4	7.8	12.7	6.4	0.7

3.0%	HR 0	HR 5	HR 10	HR 24
7.2	7.8	2.8	2.8	11.3
9.2	7.8	4.2	16.9	0.7
11.5	7.8	3.5	20.5	2.1

6.0%	HR 0	HR 5	HR 10	HR 24
7.2	23.3	11.3	5.7	7.8
9.2	23.3	8.5	10.6	12.7
11.5	23.3	0.7	12	4.9

FREENESS

virgin	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	593	590	602	599	593
9.2	593	588	596	592	598
11.5	593	583	580	584	590

1.5% pH	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	506	531	496	528	486
9.2	506	480	481	491	494
11.5	506	478	462	482	472

3.0% pH	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	508	511	504	512	502
9.2	508	497	522	526	502
11.5	508	481	478	498	456

3.0%	HR 0	HR 5	HR 10	HR 24
7.2	530	536	530	519
9.2	530	536	508	501
11.5	530	503	476	485

6.0%	HR 0	HR 5	HR 10	HR 24
7.2	505	490	486	496
9.2	505	475	474	516
11.5	505	477	466	480

FREENESS
STANDARD DEVIATION

virgin	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	7.4	0.7	0.7	1.4	5.7
9.2	7.4	0.7	0.7	7.1	7.8
11.5	7.4	1.4	0.7	7.1	2.1

1.5% pH	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	14.1	19.8	13.4	2.1	0.7
9.2	14.1	12	5.6	1.4	10.6
11.5	14.1	4.9	14.8	12	6.4

3.0% pH	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	18.6	15.6	0.7	12	17.7
9.2	18.6	16.9	4.2	12	2.1
11.5	18.6	5.7	3.5	30.4	0.7

3.0%	HR 0	HR 5	HR 10	HR 24
7.2	4.9	0.7	1.4	15.6
9.2	4.9	0.7	11.3	0
11.5	4.9	11.3	10.6	2.1

6.0%	HR 0	HR 5	HR 10	HR 24
7.2	8.1	6.4	19.1	3.5
9.2	8.1	33.9	28.3	10.6
11.5	8.1	15.6	2.1	5.7

'FACE AREA

3.0% DKL pH	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	12900	7600	18600	13600	16800
9.2	12900	14000	15600	15600	17700
11.5	12900	14200	18660	6280	31400

1.5% DKL	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	6150	5800	5980	7800	8100
9.2	6150	6370	7300	4550	5010
11.5	6150	7570	9010	8050	9000

1.5% VIR	HR 0	HR 10	HR 15	HR 20	HR 25
7.2	3380	3550	3750	3840	4700
9.2	3380	4030	4000	4100	4120
11.5	3380	7410	7290	8180	8220

FIGURE 1

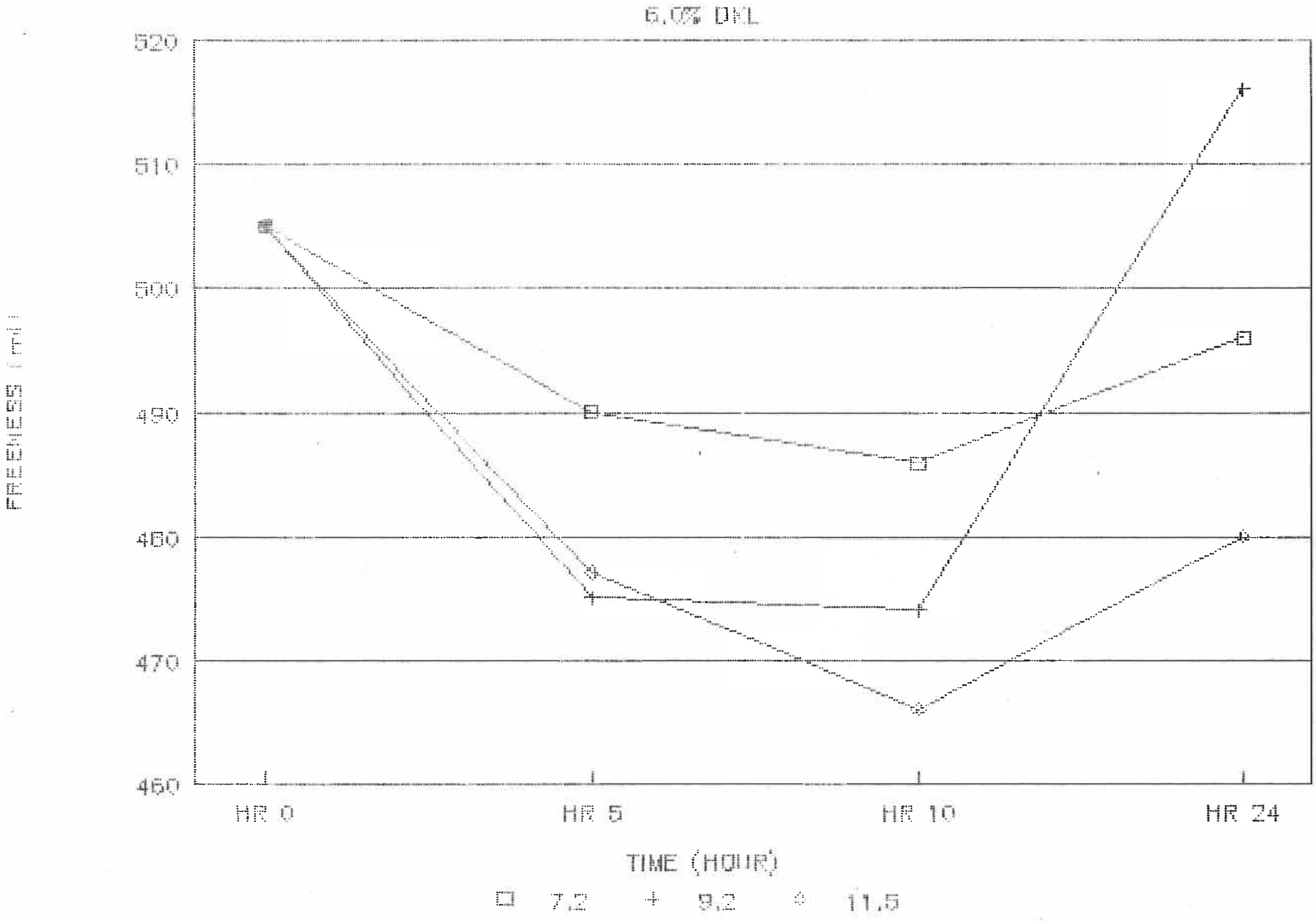

6.0% DKL
520
510
500
490
480
470
460
FREENESS (ml)
HR 0
HR 5
HR 10
HR 24
TIME (HOUR)
7.2
9.2
11.5

FIGURE 2

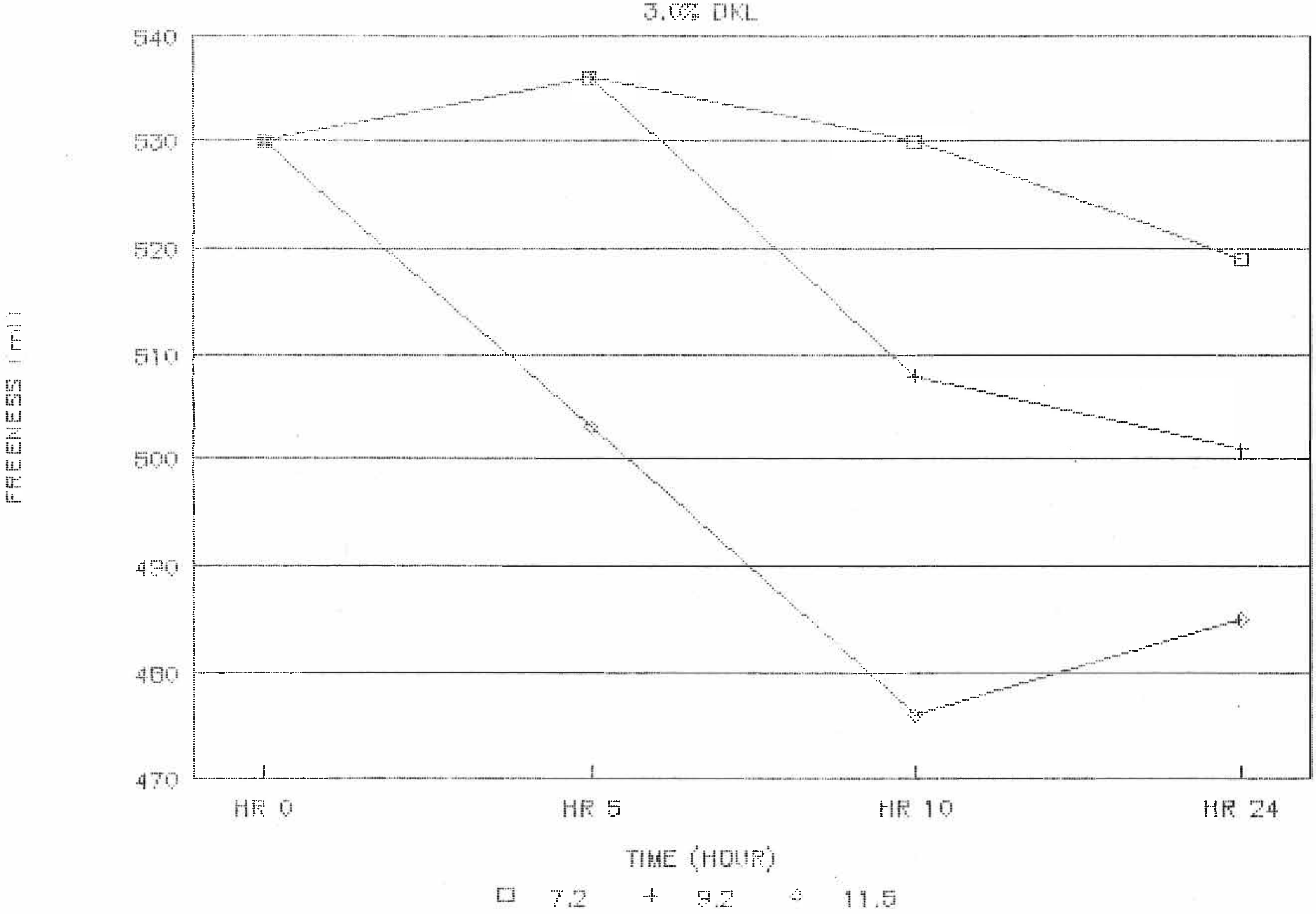

3.0% DKL
540
530
520
510
500
490
480
470
FREENESS (ml)
HR 0
HR 5
HR 10
HR 24
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 3

3.0% DKL

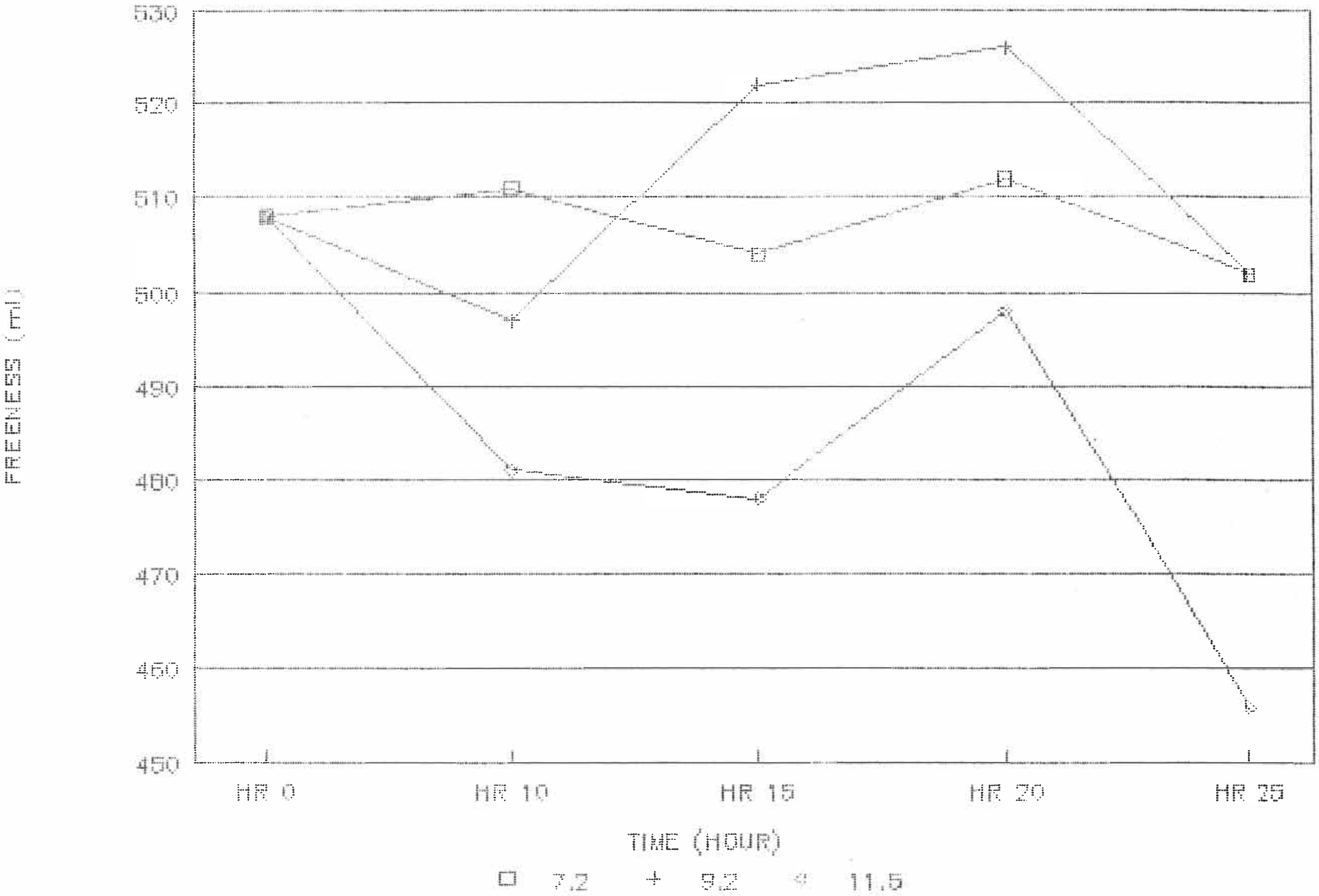
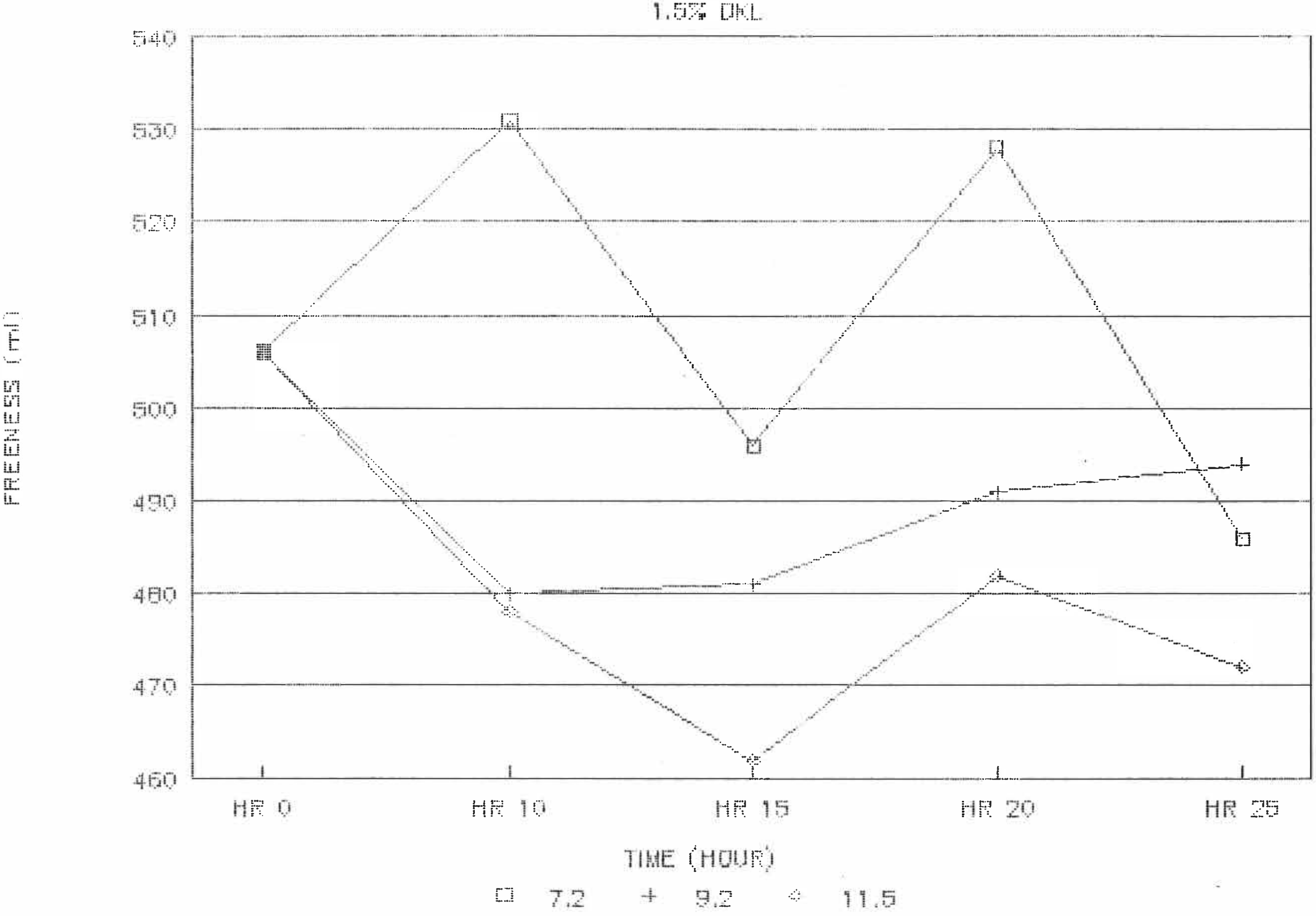
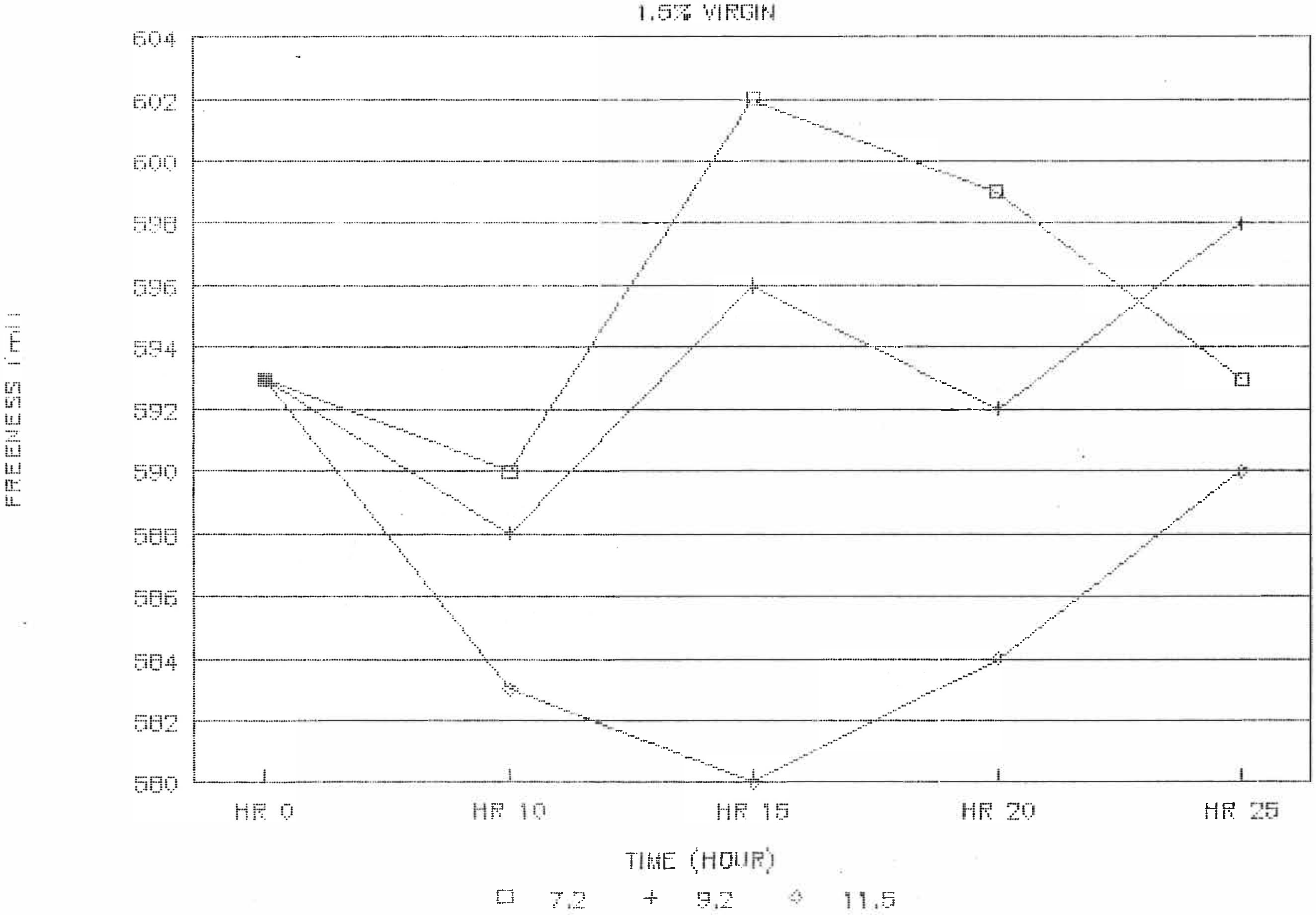


FIGURE 4



1.5% DKL
540
530
520
510
500
490
480
470
460
FREENESS (ml)
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 5



1.5% VIRGIN
604
602
600
598
596
594
592
590
588
586
584
582
580
FREENESS (ml)
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 6

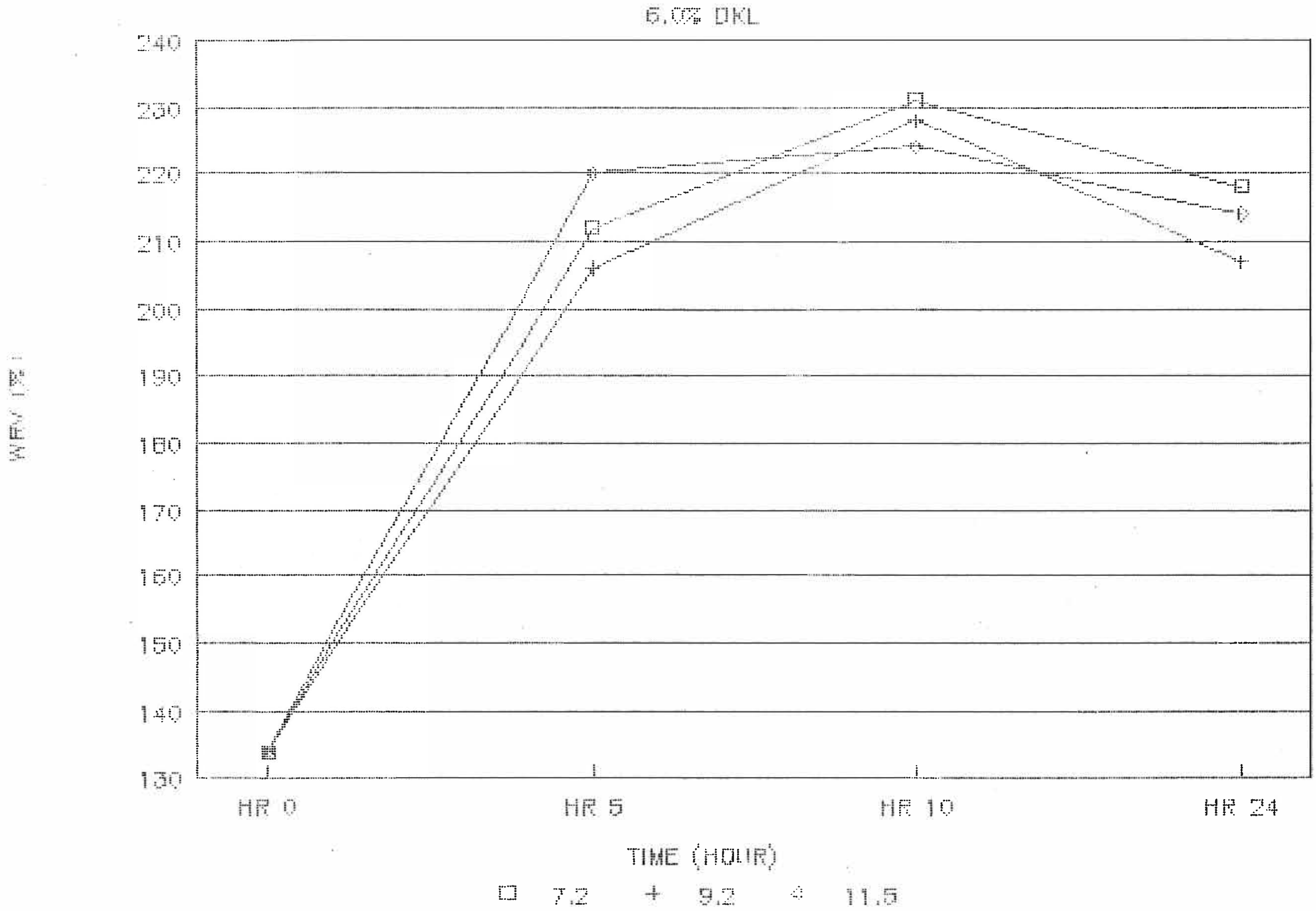

6.0% DKL
240
230
220
210
200
190
180
170
160
150
140
130
HR 0
HR 5
HR 10
HR 24
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 7

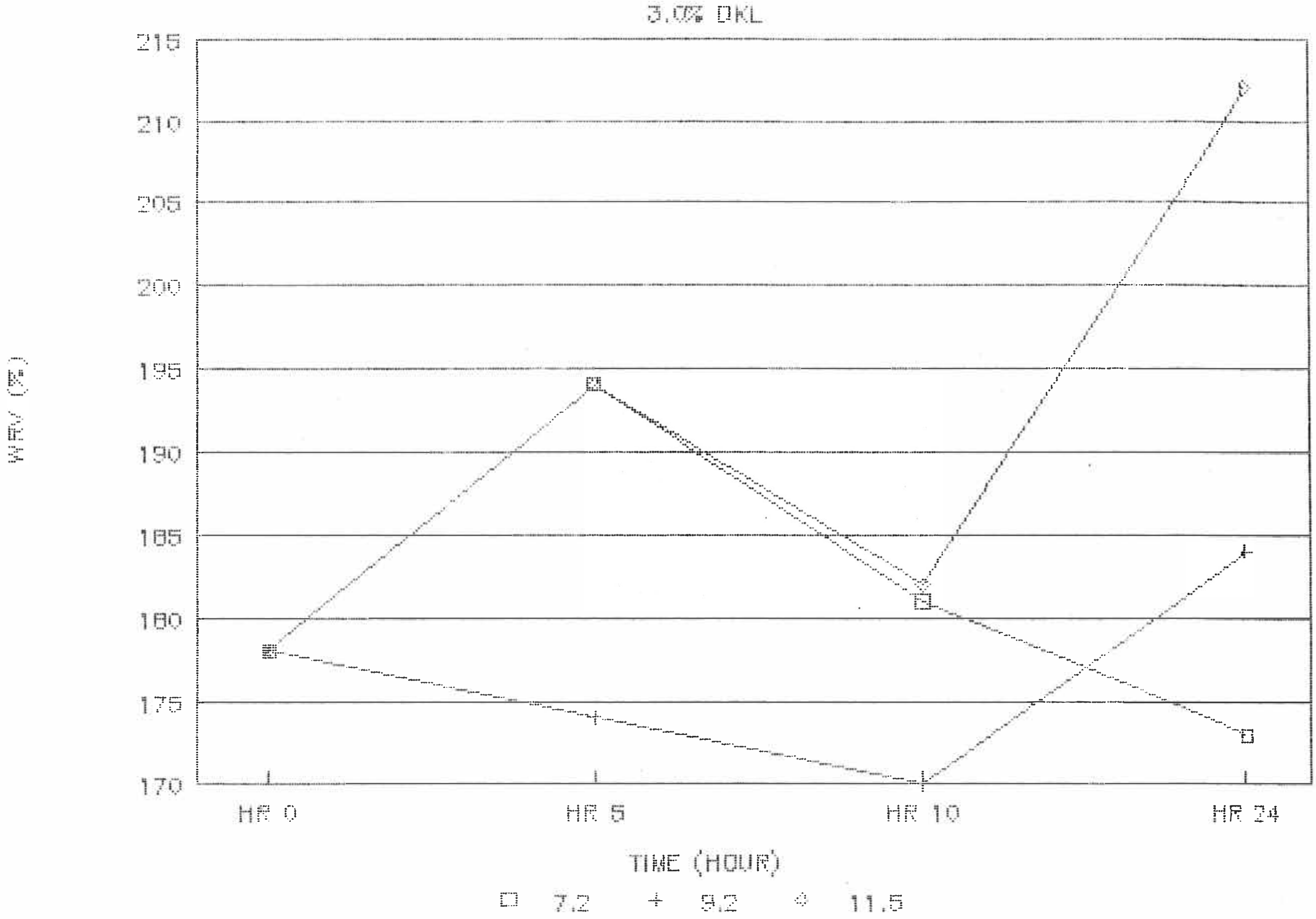

3.0% DKL
215
210
205
200
195
190
185
180
175
170
WRV (%)
HR 0
HR 5
HR 10
HR 24
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 8

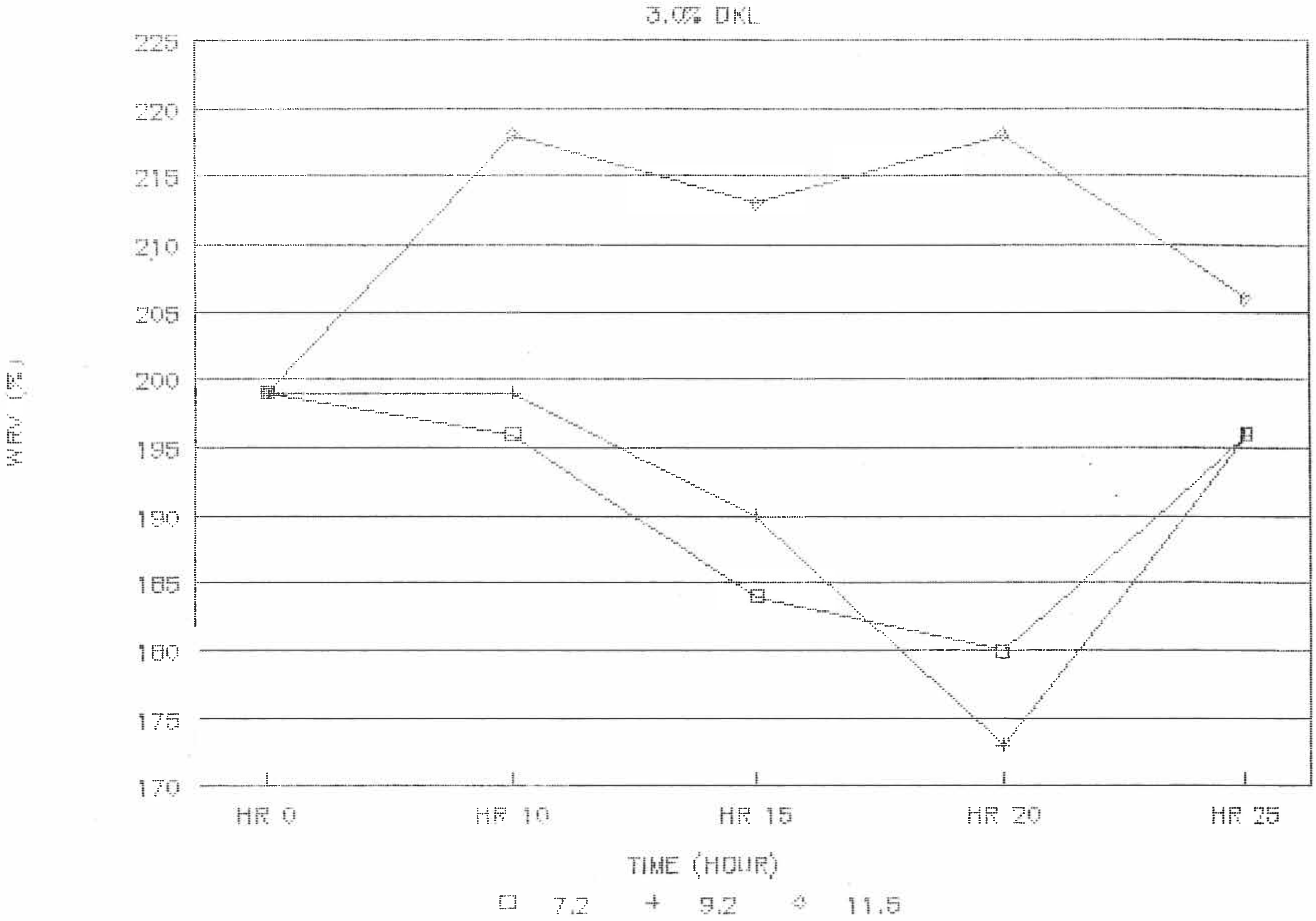

3.0% DKL
225
220
215
210
205
200
195
190
185
180
175
170
WRV (%)
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 9

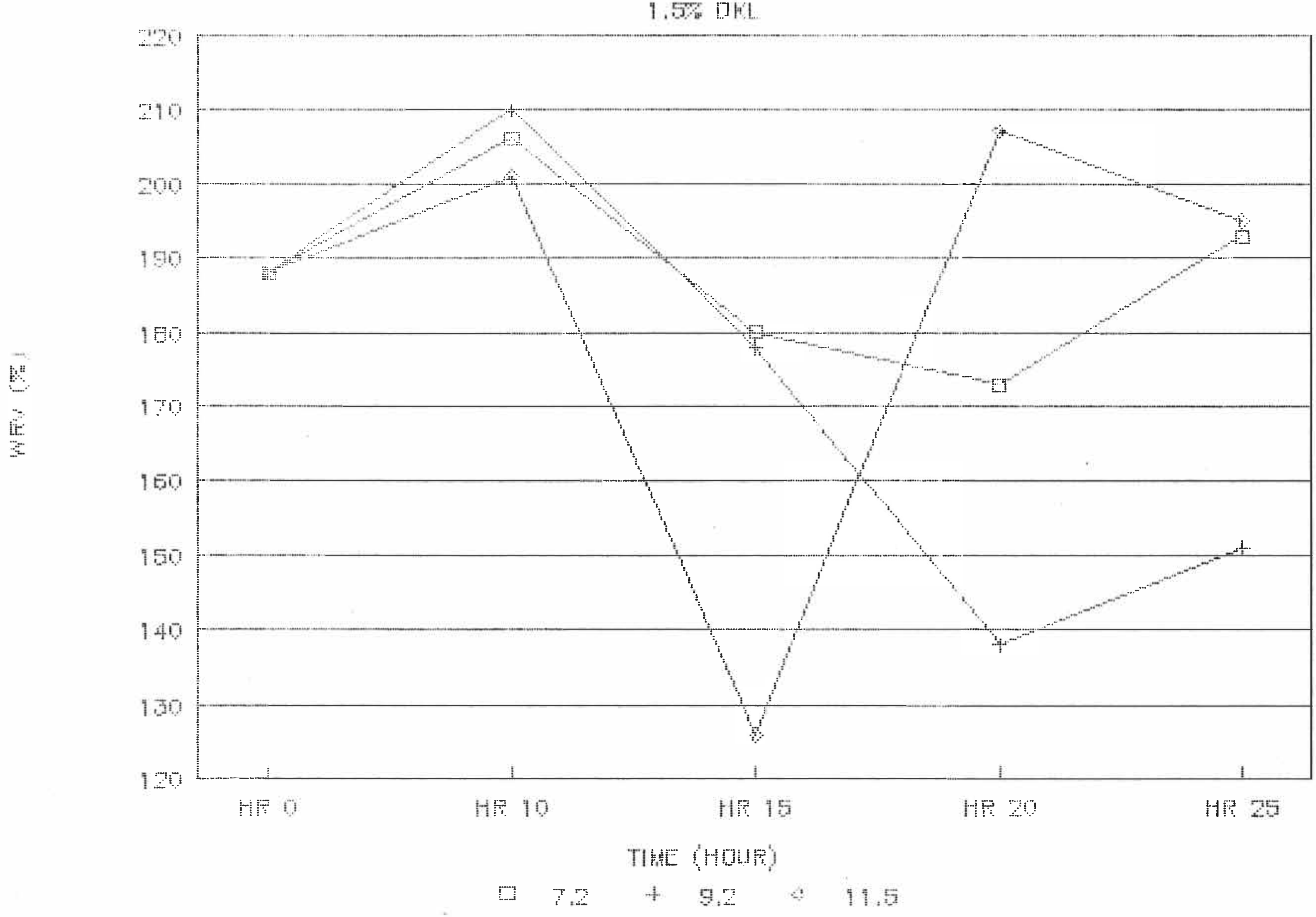
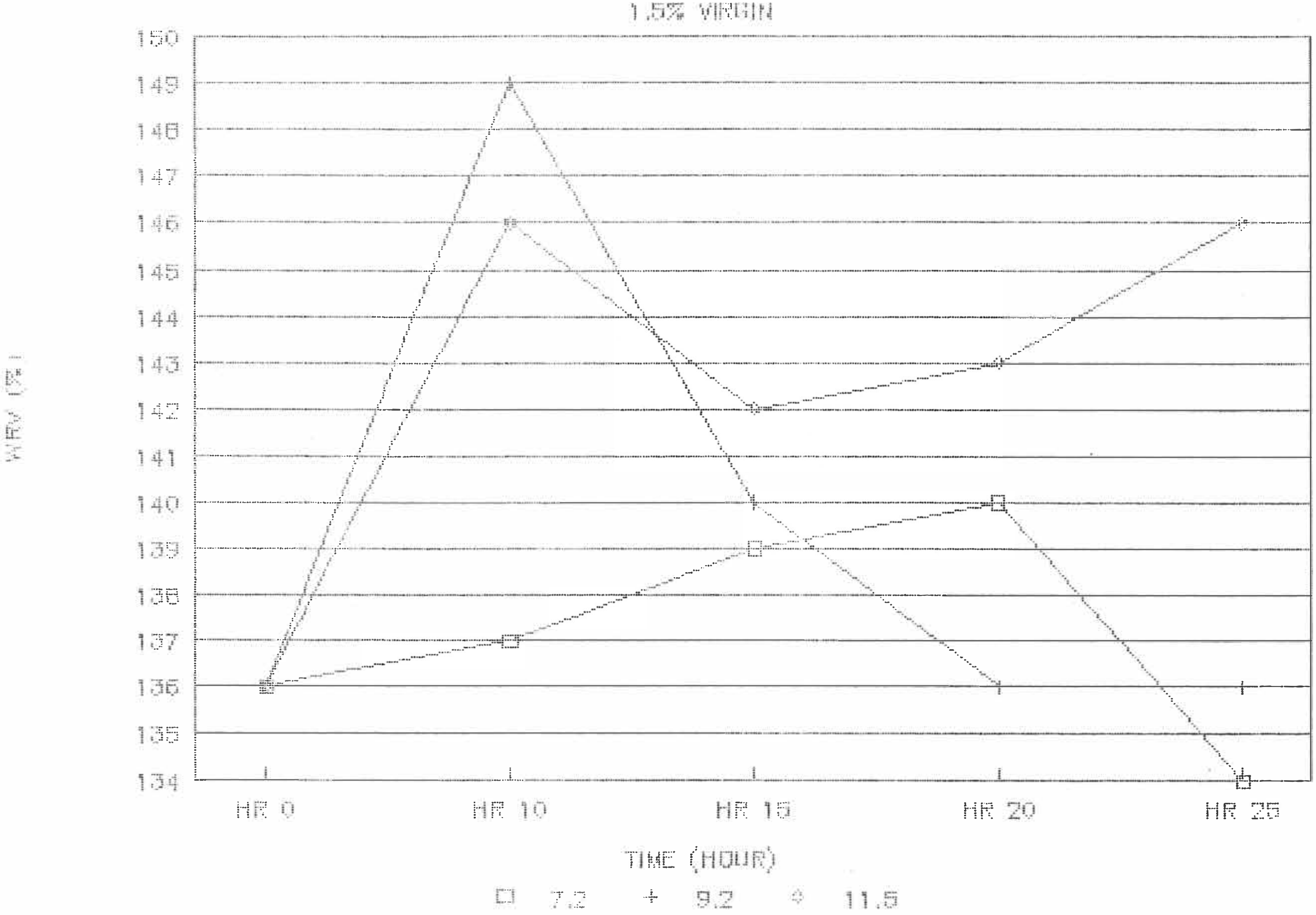

1.5% DKL
220
210
200
190
180
170
160
150
140
130
120
WRV (%)
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
7.2
9.2
11.5

FIGURE 10



1.5% VIRGIN
WRV (%)
150
149
148
147
146
145
144
143
142
141
140
139
138
137
136
135
134
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 11

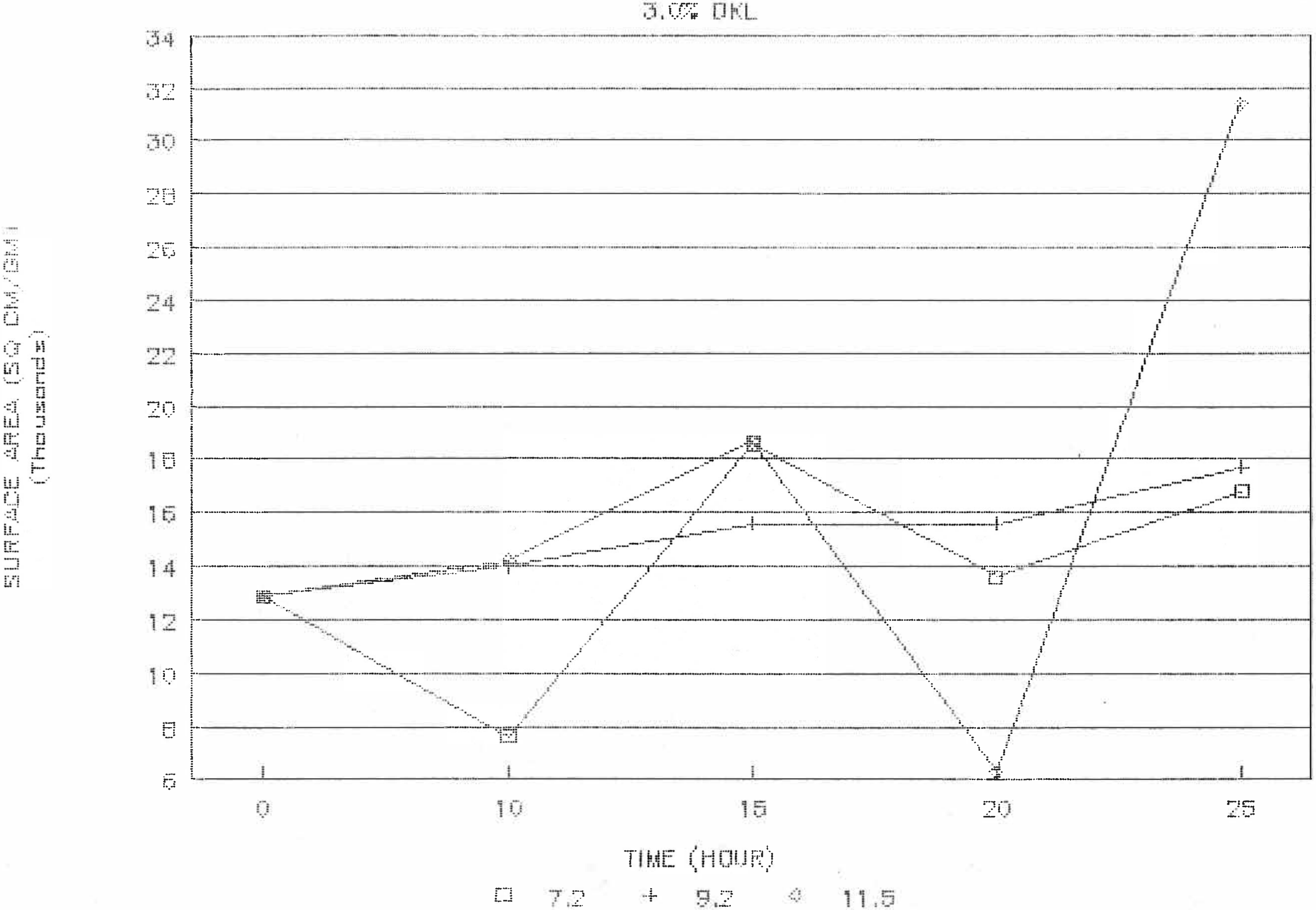

3.0% DKL
SURFACE AREA (SQ CM/GM)
(Thousands)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
10
15
20
25
TIME (HOUR)
7.2
9.2
11.5

FIGURE 12

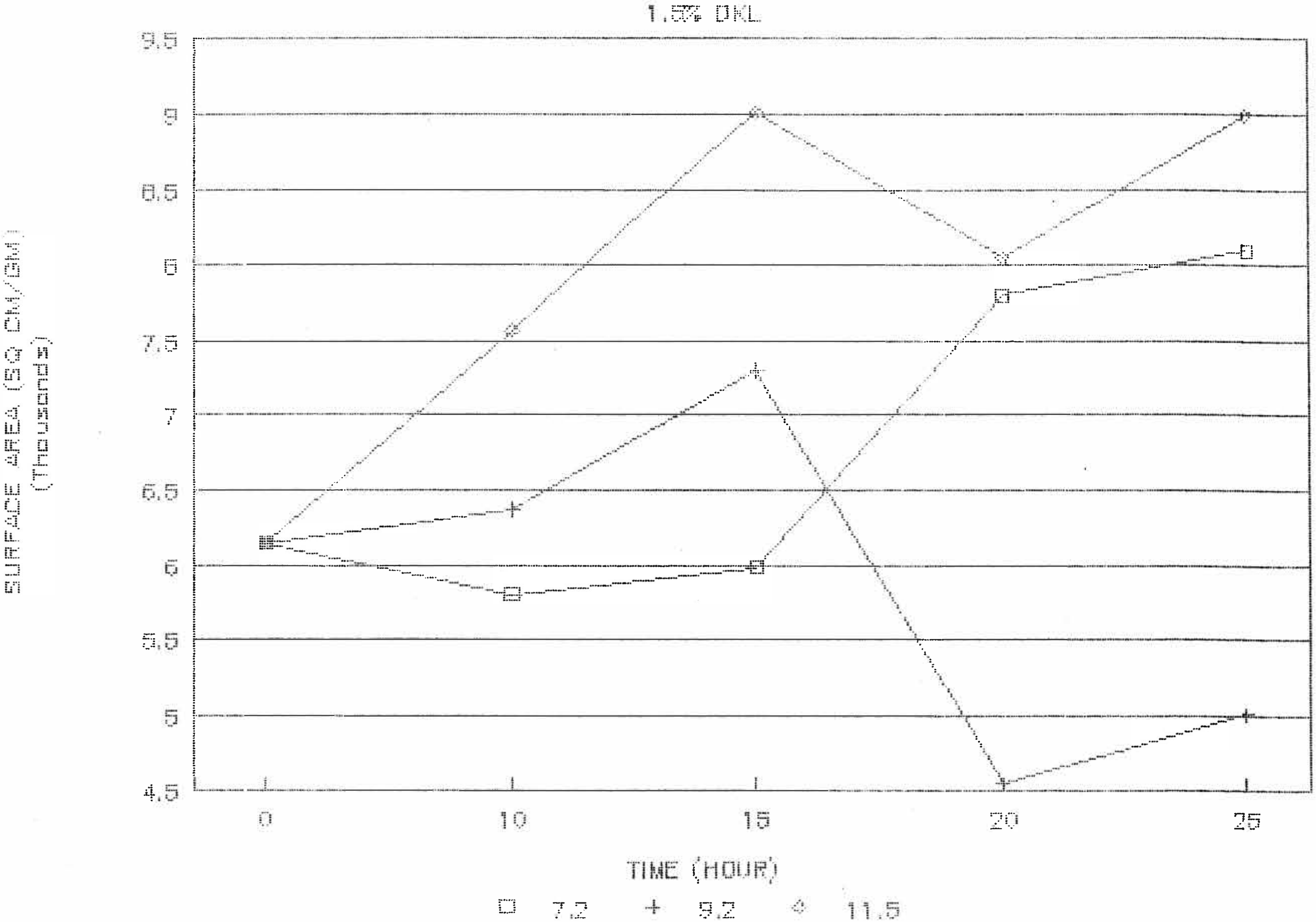

1.5% DKL
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
SURFACE AREA (SQ CM/GM)
(Thousands)
0
10
15
20
25
TIME (HOUR)
□ 7.2
+ 9.2
◇ 11.5

FIGURE 13

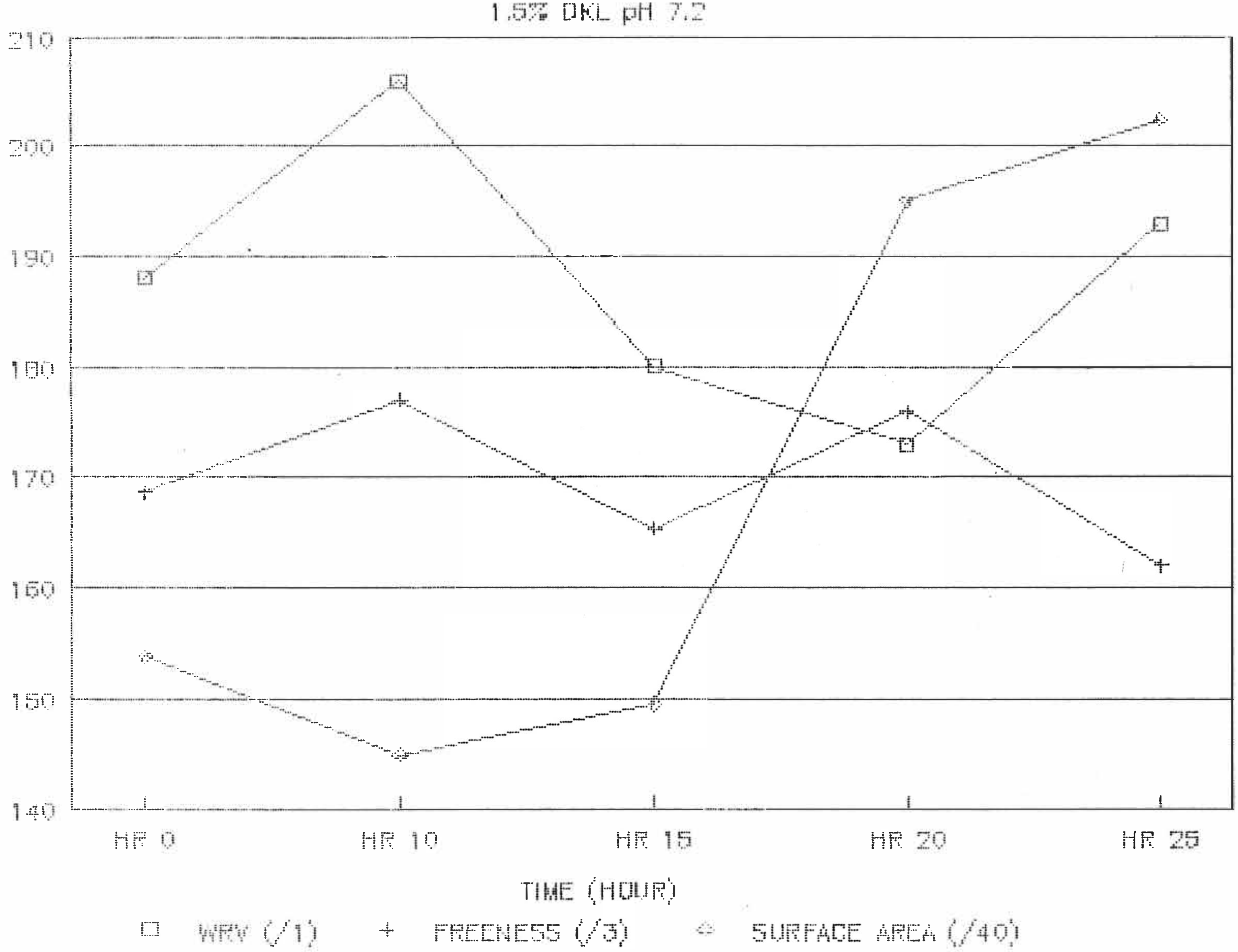

1.5% DKL pH 7.2
210
200
190
180
170
160
150
140
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
WRV (/1)
FREENESS (/3)
SURFACE AREA (/40)

FIGURE 14

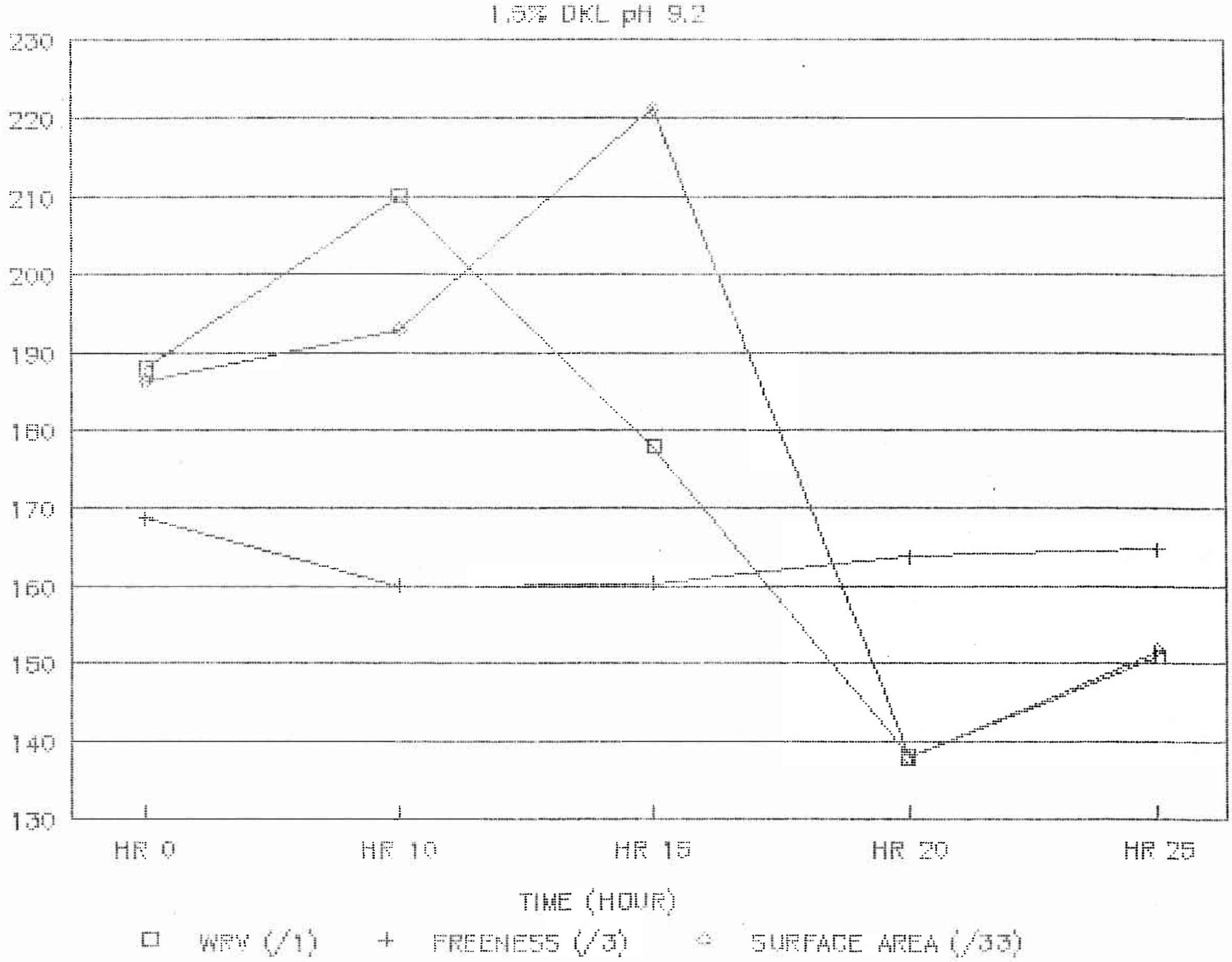
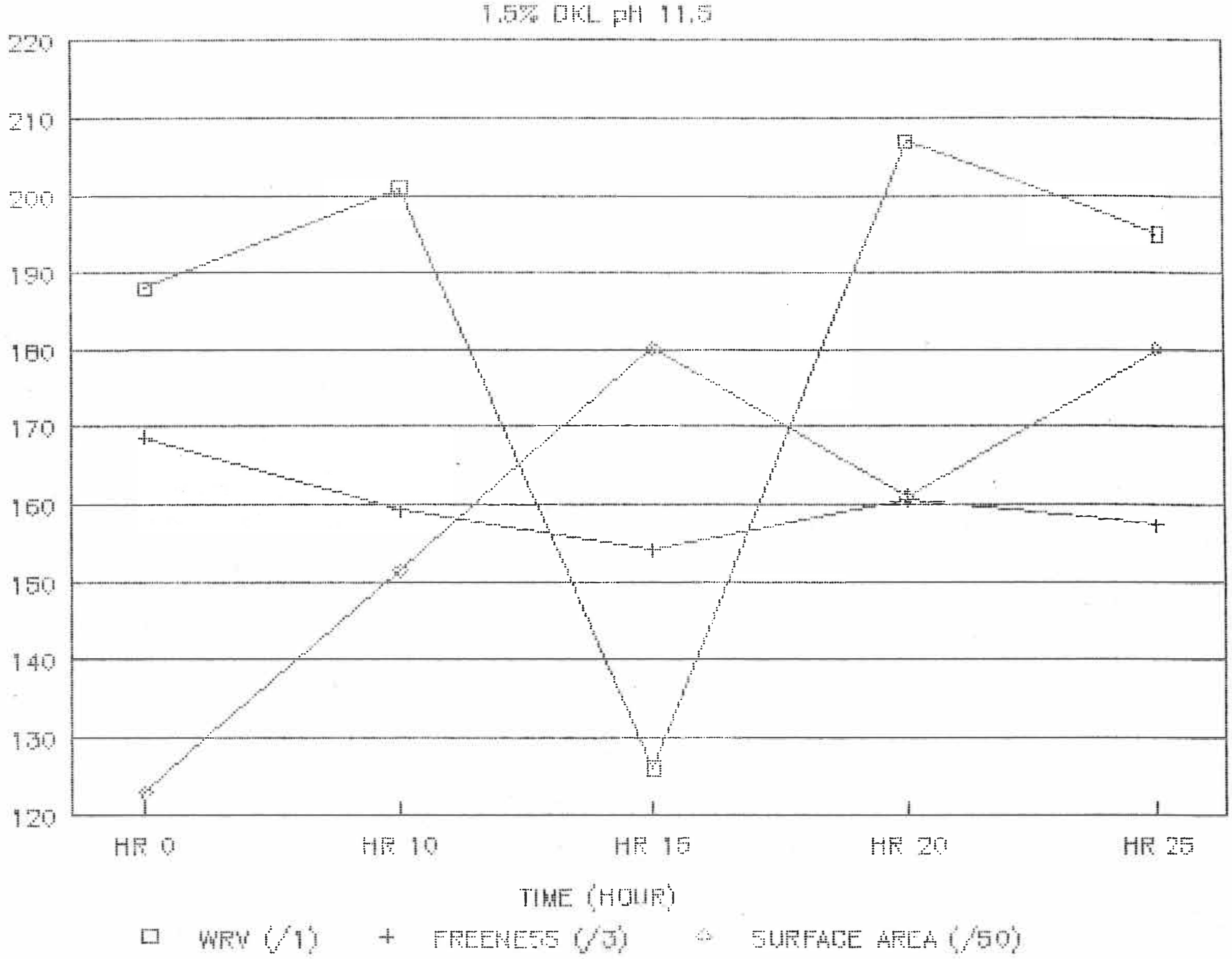

1.5% DKL pH 9.2
230
220
210
200
190
180
170
160
150
140
130
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
WRV (/1)
FREENESS (/3)
SURFACE AREA (/33)

FIGURE 15



1.5% DKL pH 11.5
220
210
200
190
180
170
160
150
140
130
120
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
WRV (/1)
FREENESS (/3)
SURFACE AREA (/50)

FIGURE 16

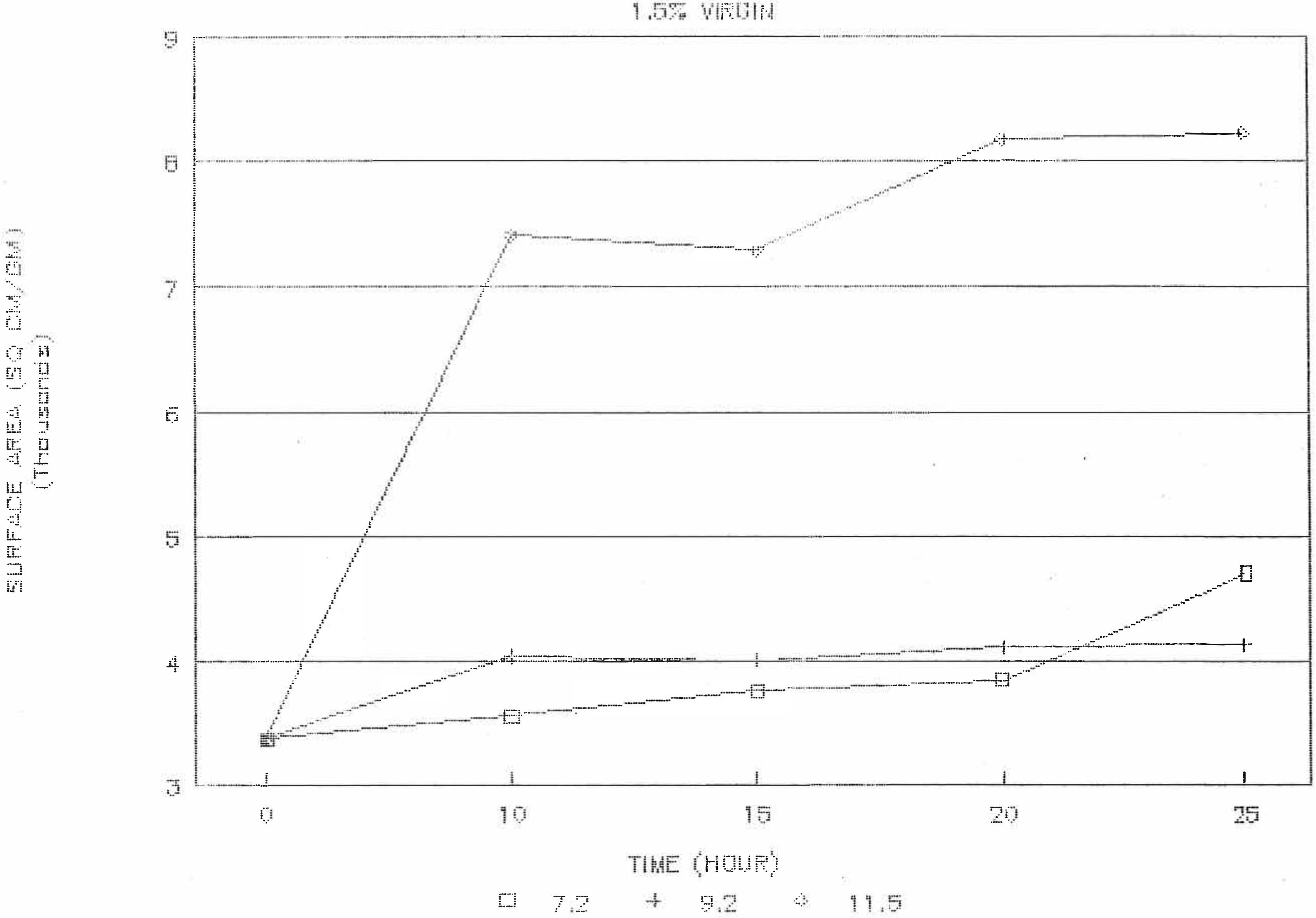

1.5% VIRGIN
SURFACE AREA (SQ CM/GM)
(Thousands)
9
8
7
6
5
4
3
0
10
15
20
25
TIME (HOUR)
□ 7.2 + 9.2 ◇ 11.5

FIGURE 17

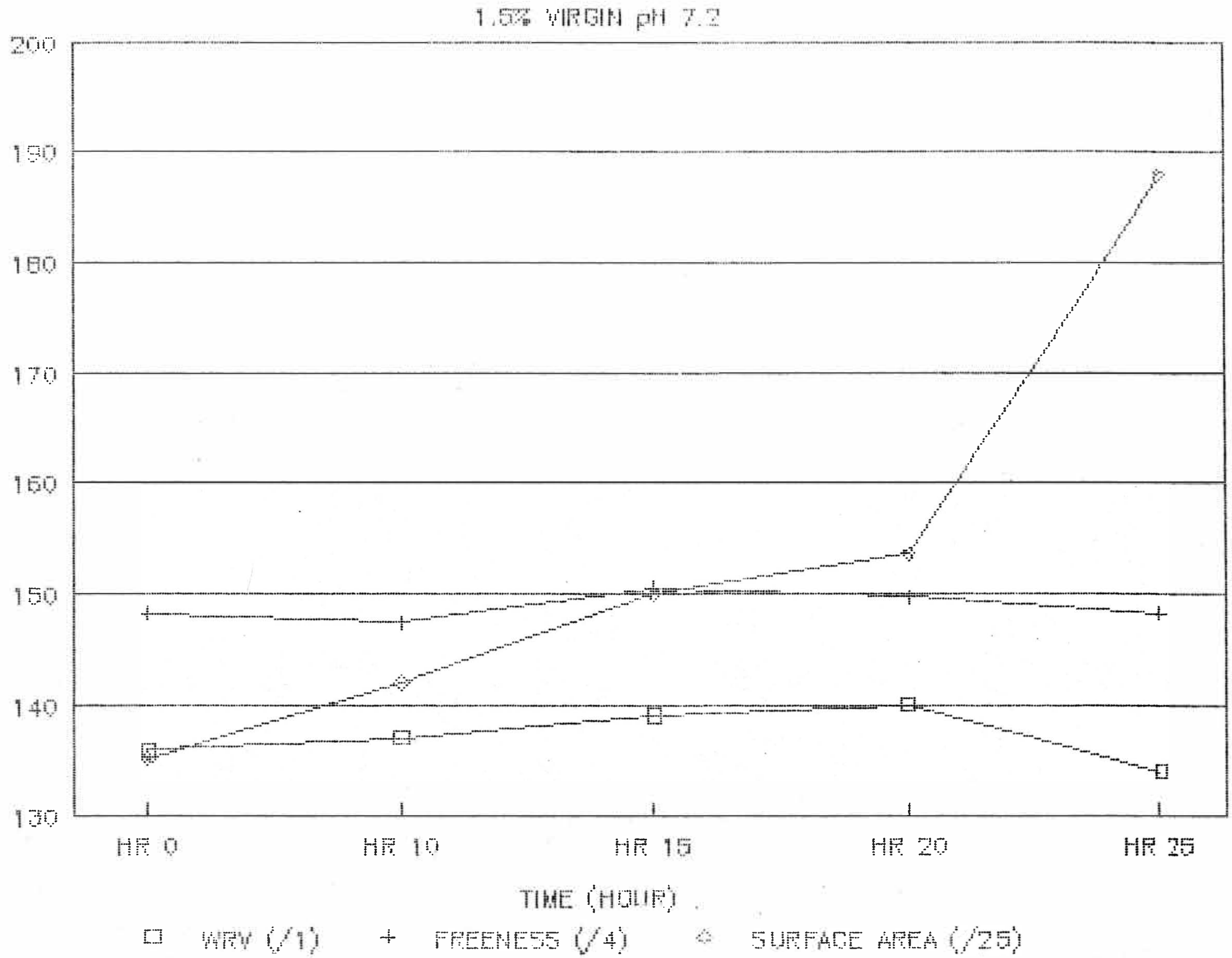

1.5% VIRGIN pH 7.2
200
190
180
170
160
150
140
130
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
WRV (/1)
FREENESS (/4)
SURFACE AREA (/25)

FIGURE 18

1.5% VIRGIN pH 9.2

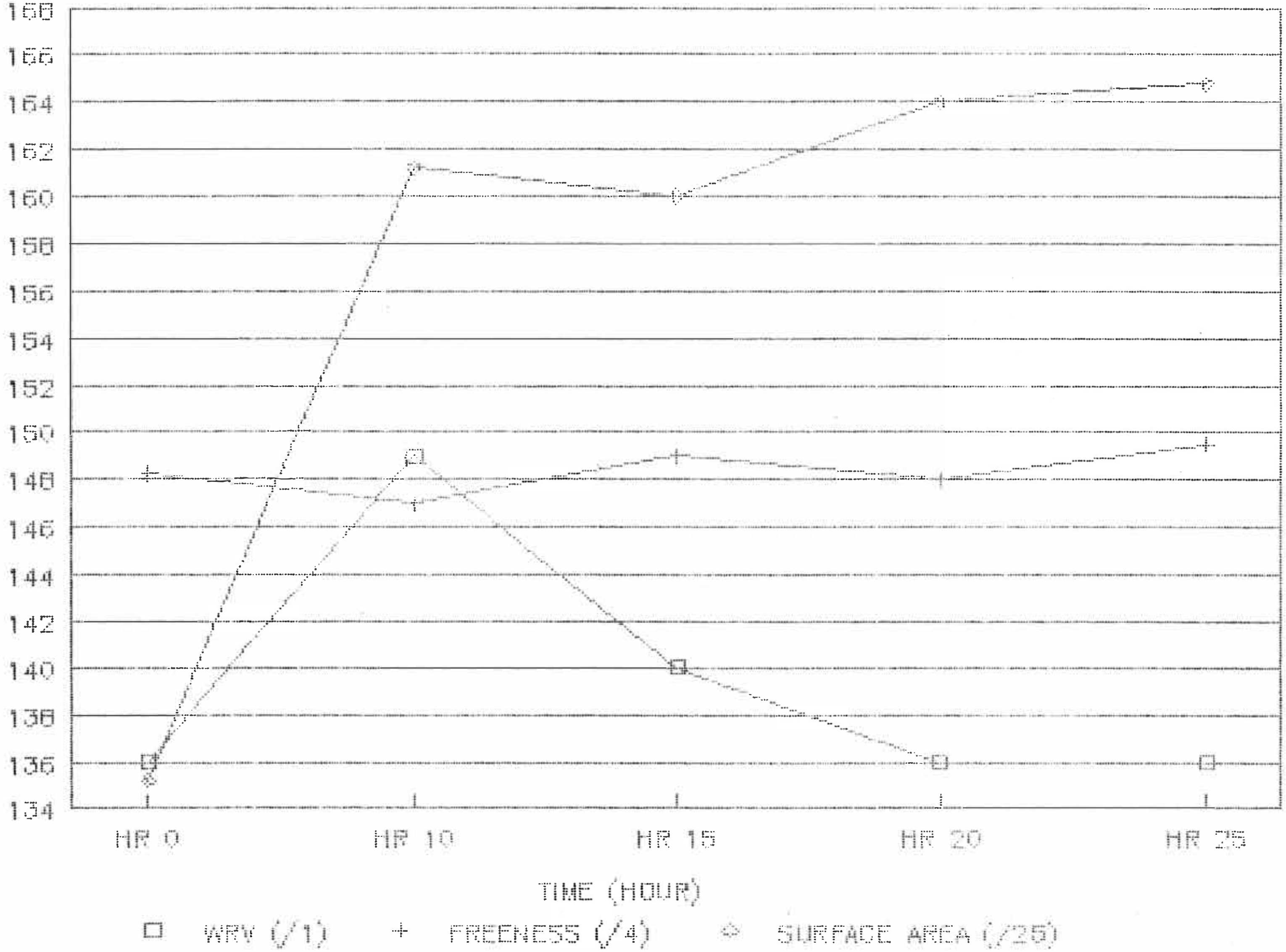
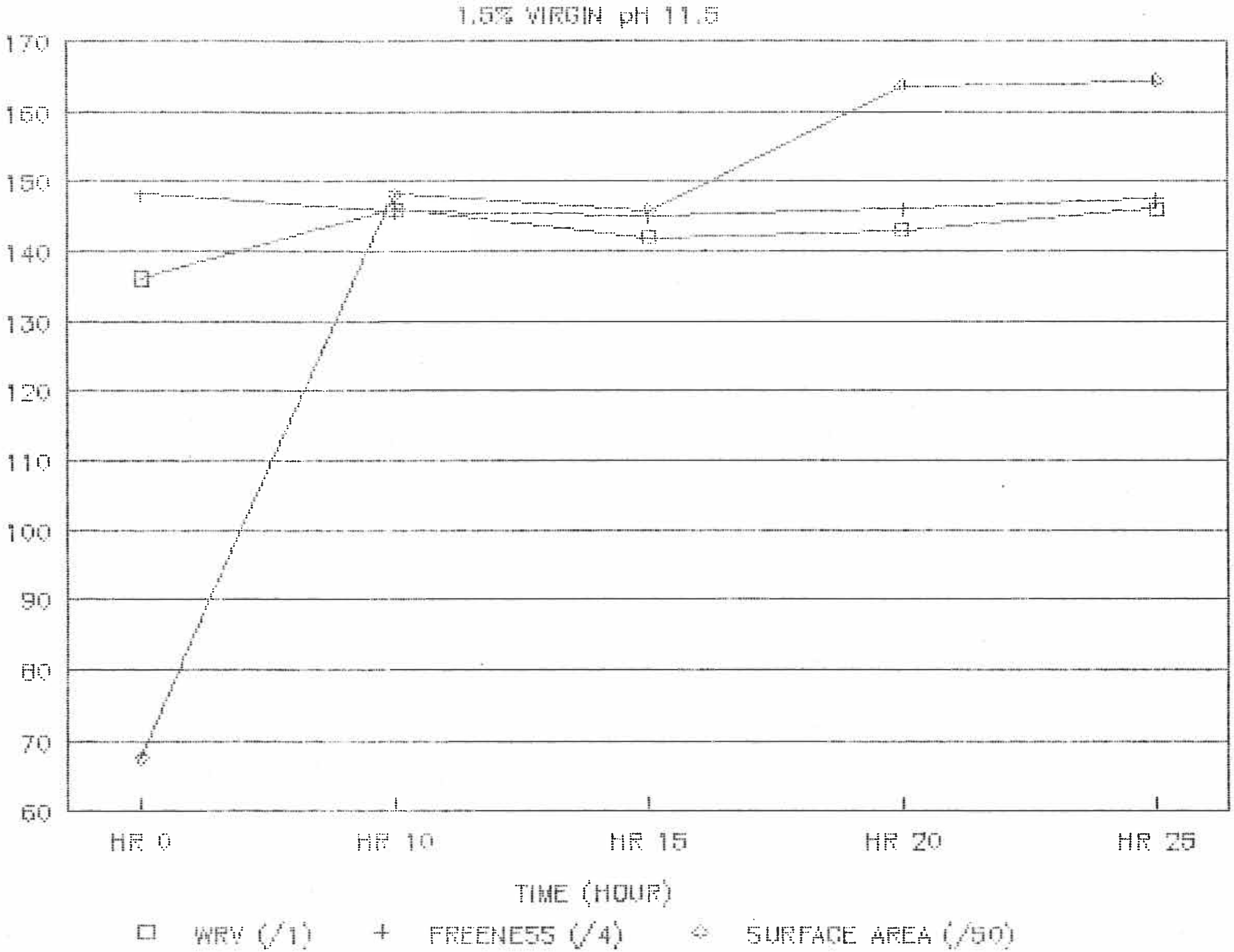
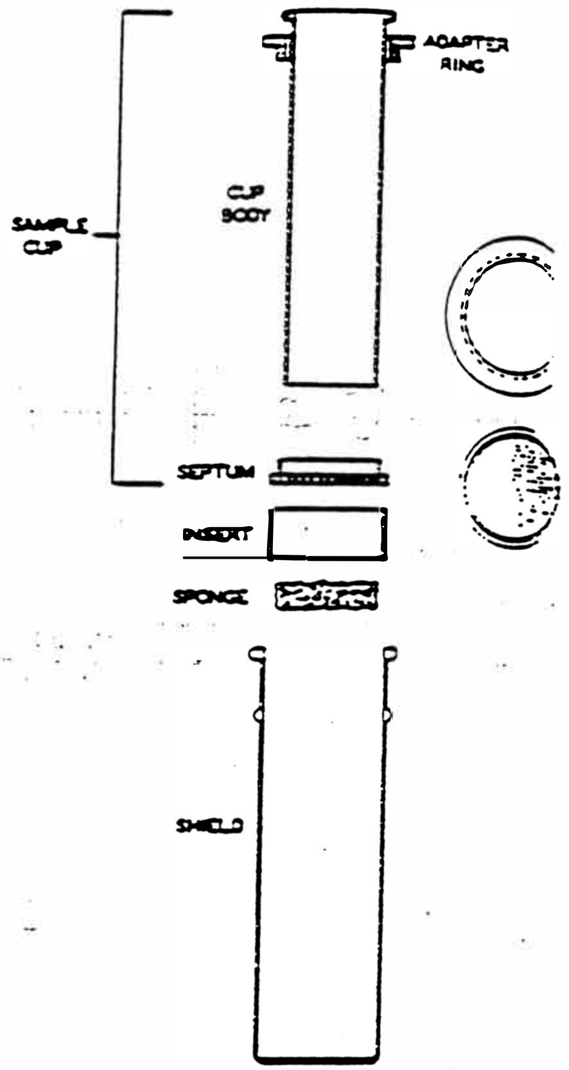


FIGURE 19


1.5% VIRGIN pH 11.5
170
160
150
140
130
120
110
100
90
80
70
60
HR 0
HR 10
HR 15
HR 20
HR 25
TIME (HOUR)
WRV (/1)
FREENESS (/4)
SURFACE AREA (/50)

APPENDIX II

Centrifugal Cup Apparatus for Water Retention Value



CENTRIFUGE CUP ASSEMBLY

Illustration from Thode[3]

APPENDIX III

Pulmac Apparatus

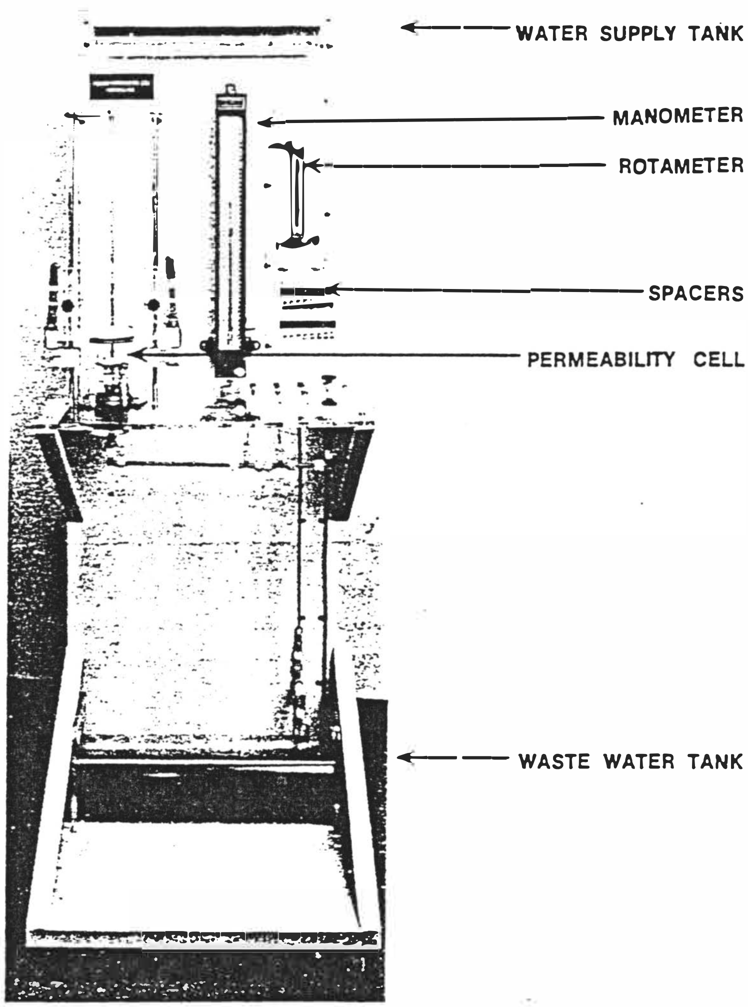


Illustration from Pulmac[1]

APPENDIX IV

SURFACE AREA hr 0

3.0% DKL

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.8**9 /9.52 =	Filtration Resis. Rp mult by Z	Bed Thickness cm	Y=9.52/ 31.67	Bed Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.2	5.1	0.431372	7.1E+08	3.1E+08	2.2	0.300599	0.136636	0.000000	0.000762
2	3.5	4.95	0.707070	7.1E+08	5.1E+08	2.1	0.300599	0.143142	0.000000	0.000656
3	3.5	4.75	0.736842	7.1E+08	5.3E+08	2	0.300599	0.150299	0.000000	0.000658
4	3	4.5	0.666666	7.1E+08	4.8E+08	1.9	0.300599	0.158210	0.000000	0.000692
5	3.6	4.3	0.837209	7.1E+08	6.0E+08	1.8	0.300599	0.166999	0.000000	0.000653

SURFACE AREA HR 10

pH 7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /8.77 =	Filtration Resis. Rp mult by Z	Bed Thickness cm	Y=8.77/ 31.67	Bed Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.9	9.8	0.193877	8.0E+08	1.6E+08	2.4	0.276918	0.115382	0.000000	0.000905
2	1.9	9.5	0.2	8.0E+08	1.6E+08	2.3	0.276918	0.120399	0.000000	0.000909
3	1.9	9.1	0.208791	8.0E+08	1.7E+08	2.2	0.276918	0.125871	0.000000	0.000909
4	2.4	8.6	0.279069	8.0E+08	2.2E+08	2.1	0.276918	0.131865	0.000000	0.000838
5	2.6	8	0.325	8.0E+08	2.6E+08	2	0.276918	0.138459	0.000000	0.000810

pH 9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /9.54 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.54/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	4	7.9	0.506329	7.4E+08	3.7E+08	2.6	0.301231	0.115858	0.000000	0.000677
2	2.1	7.2	0.291666	7.4E+08	2.1E+08	2.4	0.301231	0.125512	0.000000	0.000835
3	2.2	6.8	0.323529	7.4E+08	2.4E+08	2.3	0.301231	0.13097	0.000000	0.000819
4	2.1	6.4	0.328125	7.4E+08	2.4E+08	2.2	0.301231	0.136923	0.000000	0.000827
5	2.1	6	0.35	7.4E+08	2.6E+08	2.1	0.301231	0.143443	0.000000	0.000822

pH 11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /9.09 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.09/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.9	9.7	0.195876	7.7E+08	1.5E+08	2.6	0.287022	0.110393	0.000000	0.000899
2	2.3	8.6	0.267441	7.7E+08	2.1E+08	2.4	0.287022	0.119592	0.000000	0.000833
3	2.4	8	0.3	7.7E+08	2.3E+08	2.3	0.287022	0.124792	0.000000	0.000813
4	1.9	7.4	0.256756	7.7E+08	2.0E+08	2.2	0.287022	0.130464	0.000000	0.000869
5	1.9	6.9	0.275362	7.7E+08	2.1E+08	2.1	0.287022	0.136677	0.000000	0.000862

hr 15

pH 7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /8.01 = Rp	Resis. mult by Z	Bed Thickness cm	Y=8.01/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	3.1	6.6	0.469696	8.8E+08	4.1E+08	2	0.25292	0.12646	0.000000	0.000674
2	3.1	6.3	0.492063	8.8E+08	4.3E+08	1.9	0.25292	0.133115	0.000000	0.000675
3	3.2	6	0.533333	8.8E+08	4.7E+08	1.8	0.25292	0.140511	0.000000	0.000669
4	3.4	5.6	0.607142	8.8E+08	5.3E+08	1.7	0.25292	0.148776	0.000000	0.000653
5	3.5	5.25	0.666666	8.8E+08	5.9E+08	1.6	0.25292	0.158075	0.000000	0.000646

pH 9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /9.42 = Rp	Resis. mult by Z	Bed Thickness cm	Y=9.42/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.2	6.5	0.338461	7.5E+08	2.5E+08	2.4	0.297442	0.123934	0.000000	0.000788
2	2.6	6.3	0.412698	7.5E+08	3.1E+08	2.3	0.297442	0.129322	0.000000	0.000748
3	2.3	6	0.383333	7.5E+08	2.9E+08	2.2	0.297442	0.135200	0.000000	0.000778
4	2.8	5.7	0.491228	7.5E+08	3.7E+08	2.1	0.297442	0.141639	0.000000	0.000728
5	2.4	5.4	0.444444	7.5E+08	3.3E+08	2	0.297442	0.148721	0.000000	0.000765

pH 11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=7.03**9 /10.35 =Rp	Resis. mult by Z	Bed Thickness cm	Y=10.35/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2	3.9	0.512820	6.8E+08	3.5E+08	2.2	0.326808	0.148549	0.000000	0.000752
2	2.2	3.7	0.594594	6.8E+08	4.0E+08	2.1	0.326808	0.155622	0.000000	0.000727
3	2.4	3.5	0.685714	6.8E+08	4.7E+08	2	0.326808	0.163404	0.000000	0.000705
4	2.5	3.3	0.757575	6.8E+08	5.2E+08	1.9	0.326808	0.172004	0.000000	0.000693
5	2	3.1	0.645161	6.8E+08	4.4E+08	1.8	0.326808	0.18156	0.000000	0.000745

Hr 20

. 7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /8.08	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.08/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.7	10.1	0.267326	8.5E+08	2.3E+08	2.6	0.255131	0.098127	0.000000	0.000755
2	1.1	9.6	0.114583	8.5E+08	97565989	2.4	0.255131	0.106304	0.000000	0.001029
3	2.7	9.3	0.290322	8.5E+08	2.5E+08	2.3	0.255131	0.110926	0.000000	0.000765
4	2.1	8.8	0.238636	8.5E+08	2.0E+08	2.2	0.255131	0.115968	0.000000	0.000829
5	2.5	8.45	0.295857	8.5E+08	2.5E+08	2.1	0.255131	0.121490	0.000000	0.000784

pH 9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /7.28	Resis. = Rp mult by Z	Bed Thickness cm	Y=7.28/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.4	10	0.14	9.5E+08	1.3E+08	2.6	0.22987	0.088411	0.000000	0.000874
2	1.1	9.8	0.112244	9.5E+08	1.1E+08	2.4	0.22987	0.095779	0.000000	0.000966
3	1.5	9.65	0.155440	9.5E+08	1.5E+08	2.3	0.22987	0.099943	0.000000	0.000879
4	1.3	9.4	0.138297	9.5E+08	1.3E+08	2.2	0.22987	0.104486	0.000000	0.000928
5	1.6	9.2	0.173913	9.5E+08	1.6E+08	2.1	0.22987	0.109461	0.000000	0.000873

pH 11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /7.07	Resis. = Rp mult by Z	Bed Thickness cm	Y=7.07/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	9.1	0.142857	9.7E+08	1.4E+08	2.4	0.223239	0.093016	0.000000	0.000874
2	1.2	9	0.133333	9.7E+08	1.3E+08	2.3	0.223239	0.097060	0.000000	0.000907
3	1.1	8.8	0.125	9.7E+08	1.2E+08	2.2	0.223239	0.101472	0.000000	0.000941
4	1.8	8.65	0.208092	9.7E+08	2.0E+08	2.1	0.223239	0.106304	0.000000	0.000806
5	2.3	8.4	0.273809	9.7E+08	2.7E+08	2	0.223239	0.111619	0.000000	0.000748

Hr 25

7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /8.71	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.71/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.5	8.3	0.301204	7.6E+08	2.3E+08	2.4	0.270129	0.112553	0.000000	0.000790
2	1.9	8	0.2375	7.6E+08	1.8E+08	2.3	0.270129	0.117447	0.000000	0.000868
3	1.8	7.75	0.232258	7.6E+08	1.8E+08	2.2	0.270129	0.122785	0.000000	0.000887
4	2.3	7.4	0.310810	7.6E+08	2.3E+08	2.1	0.270129	0.128632	0.000000	0.000818
5	2.3	7	0.328571	7.6E+08	2.5E+08	2	0.270129	0.135064	0.000000	0.000816

pH 9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /8.55	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.55/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.9	9.4	0.308510	7.7E+08	2.4E+08	2.6	0.269972	0.103835	0.000000	0.000759
2	1.9	8.8	0.215909	7.7E+08	1.7E+08	2.4	0.269972	0.112488	0.000000	0.000878
3	1.6	8.5	0.188235	7.7E+08	1.4E+08	2.3	0.269972	0.117379	0.000000	0.000932
4	1.9	8.05	0.236024	7.7E+08	1.8E+08	2.2	0.269972	0.122714	0.000000	0.000877
5	3.1	7.6	0.407894	7.7E+08	3.1E+08	2.1	0.269972	0.128558	0.000000	0.000742

pH 11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /8.01	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.01/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	2.9	9.35	0.310160	8.2E+08	2.5E+08	2.6	0.252921	0.097277	0.000000	0.000725
2	1.8	8.7	0.206896	8.2E+08	1.7E+08	2.4	0.252921	0.105383	0.000000	0.000852
3	2.3	8.35	0.275449	8.2E+08	2.3E+08	2.3	0.252921	0.109965	0.000000	0.000786
4	2.1	7.9	0.265822	8.2E+08	2.2E+08	2.2	0.252921	0.114964	0.000000	0.000807
5	2.2	7.5	0.293333	8.2E+08	2.4E+08	2.1	0.252921	0.120438	0.000000	0.000793

RUN NUMBER 2 **

.5% DKL

. 0

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.2**9 /8.68 =	Resis. Rp mult by Z	Bed Thickness cm	Y=8.68/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.5	9.8	0.153061	7.1E+08	1.1E+08	2.4	0.274076	0.114198	0.000000	0.001014
2	1.8	9.4	0.191489	7.1E+08	1.4E+08	2.3	0.274076	0.119163	0.000000	0.000955
3	1.5	9.1	0.164835	7.1E+08	1.2E+08	2.2	0.274076	0.12458	0.000000	0.001019
4	2.6	8.9	0.292134	7.1E+08	2.1E+08	2.1	0.274076	0.130512	0.000000	0.000855
5	1.9	8.4	0.226190	7.1E+08	1.6E+08	2	0.274076	0.137038	0.000000	0.000946
6	3	7.9	0.379746	7.1E+08	2.7E+08	1.9	0.274076	0.144250	0.000000	0.000810

HR 10

7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /7.97 =	Resis. Rp mult by Z	Bed Thickness cm	Y=7.97/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1	7.2	0.138888	8.3E+08	1.1E+08	2.4	0.251658	0.104857	0.000000	0.000970
2	1.4	7.1	0.197183	8.3E+08	1.6E+08	2.3	0.251658	0.109416	0.000000	0.000876
3	1.6	6.95	0.230215	8.3E+08	1.9E+08	2.2	0.251658	0.11439	0.000000	0.000844
4	2	6.85	0.291970	8.3E+08	2.4E+08	2.1	0.251658	0.119837	0.000000	0.000792
5	2.3	6.6	0.348484	8.3E+08	2.9E+08	2	0.251658	0.125829	0.000000	0.000759
6	2.5	6.4	0.390625	8.3E+08	3.2E+08	1.9	0.251658	0.132451	0.000000	0.000743

HR 10

9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /7.05 =	Resis. Rp mult by Z	Bed Thickness cm	Y=7.05/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.8	10.15	0.177339	9.3E+08	1.7E+08	2.4	0.222608	0.092753	0.000000	0.000824
2	1.1	10.1	0.108910	9.3E+08	1.0E+08	2.3	0.222608	0.096786	0.000000	0.000983
3	0.7	9.6	0.072916	9.3E+08	68055531	2.2	0.222608	0.101185	0.000000	0.001141
4	1.3	9.3	0.139784	9.3E+08	1.3E+08	2.1	0.222608	0.106003	0.000000	0.000933
5	2.4	8.9	0.269662	9.3E+08	2.5E+08	2	0.222608	0.111304	0.000000	0.000761
6	2.3	8.55	0.269005	9.3E+08	2.5E+08	1.9	0.222608	0.117162	0.000000	0.000775

HR 10

11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /9.37 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.37/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.1	5.8	0.189655	7.0E+08	1.3E+08	2.4	0.295864	0.123276	0.000000	0.000974
2	2	5.6	0.357142	7.0E+08	2.5E+08	2.3	0.295864	0.128636	0.000000	0.000800
3	1.4	5.35	0.261682	7.0E+08	1.8E+08	2.2	0.295864	0.134483	0.000000	0.000901
4	1.9	5.15	0.368932	7.0E+08	2.6E+08	2.1	0.295864	0.140887	0.000000	0.000816
5	2	4.85	0.412371	7.0E+08	2.9E+08	2	0.295864	0.147932	0.000000	0.000799
6	2.1	4.55	0.461538	7.0E+08	3.2E+08	1.9	0.295864	0.155717	0.000000	0.000783

HR 15

7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.29**9Resis. /6.93 = Rp	mult by Z	Bed Thickness cm	Y=6.93/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	9.55	0.136125	9.1E+08	1.2E+08	2.4	0.218819	0.091174	0.000000	0.000903
2	1.1	9.5	0.115789	9.1E+08	1.1E+08	2.3	0.218819	0.095138	0.000000	0.000967
3	1.4	9.3	0.150537	9.1E+08	1.4E+08	2.2	0.218819	0.099463	0.000000	0.000899
4	2.2	9.2	0.239130	9.1E+08	2.2E+08	2.1	0.218819	0.104199	0.000000	0.000783
5	2.3	9	0.255555	9.1E+08	2.3E+08	2	0.218819	0.109409	0.000000	0.000778
6	2.6	8.7	0.298850	9.1E+08	2.7E+08	1.9	0.218819	0.115167	0.000000	0.000751

HR 15

9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.44**9Resis. /7.69 = Rp	mult by Z	Bed Thickness cm	Y=7.69/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	8.3	0.156626	8.4E+08	1.3E+08	2.2	0.242817	0.110371	0.000000	0.000944
2	1.9	8	0.2375	8.4E+08	2.0E+08	2.1	0.242817	0.115627	0.000000	0.000834
3	2.2	7.6	0.289473	8.4E+08	2.4E+08	2	0.242817	0.121408	0.000000	0.000794
4	2.2	7.3	0.301369	8.4E+08	2.5E+08	1.9	0.242817	0.127798	0.000000	0.000797
5	2.6	6.95	0.374100	8.4E+08	3.1E+08	1.8	0.242817	0.134898	0.000000	0.000755
6	2.8	6.5	0.430769	8.4E+08	3.6E+08	1.7	0.242817	0.142833	0.000000	0.000734

HR 15

11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.44**9Resis. /8.77 = Rp	mult by Z	Bed Thickness cm	Y=8.77/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.1	6.15	0.178861	7.3E+08	1.3E+08	2.4	0.276918	0.115382	0.000000	0.000957
2	2.1	6.05	0.347107	7.3E+08	2.5E+08	2.3	0.276918	0.120399	0.000000	0.000778
3	1.6	5.8	0.275862	7.3E+08	2.0E+08	2.2	0.276918	0.125871	0.000000	0.000853
4	2	5.5	0.363636	7.3E+08	2.7E+08	2.1	0.276918	0.131865	0.000000	0.000790
5	2.1	5.25	0.4	7.3E+08	2.9E+08	2	0.276918	0.138459	0.000000	0.000778
6	1.9	4.95	0.383838	7.3E+08	2.8E+08	1.9	0.276918	0.145746	0.000000	0.000802

HR 20
7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /8.8 =	Resis. Rp mult by Z	Bed Thickness cm	Y=8.8/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.2	7.75	0.154838	7.5E+08	1.2E+08	2.4	0.277865	0.115777	0.000000	0.001000
2	1	7.6	0.131578	7.5E+08	98385131	2.3	0.277865	0.120810	0.000000	0.001070
3	2.2	7.25	0.303448	7.5E+08	2.3E+08	2.2	0.277865	0.126302	0.000000	0.000822
4	2.2	6.95	0.316546	7.5E+08	2.4E+08	2.1	0.277865	0.132316	0.000000	0.000823
5	0.8	6.65	0.120300	7.5E+08	89952120	2	0.277865	0.138932	0.000000	0.001156
6	2.5	6.15	0.406504	7.5E+08	3.0E+08	1.9	0.277865	0.146244	0.000000	0.000783

HR 20
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /7.75 =	Resis. Rp mult by Z	Bed Thickness cm	Y=7.75/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	9.8	0.081632	8.5E+08	69306734	2.4	0.244711	0.101962	0.000000	0.001137
2	1.5	9.6	0.15625	8.5E+08	1.3E+08	2.3	0.244711	0.106396	0.000000	0.000929
3	1.2	9.3	0.129032	8.5E+08	1.1E+08	2.2	0.244711	0.111232	0.000000	0.001005
4	2.1	9.1	0.230769	8.5E+08	2.0E+08	2.1	0.244711	0.116529	0.000000	0.000841
5	2	8.7	0.229885	8.5E+08	2.0E+08	2	0.244711	0.122355	0.000000	0.000855
6	2.2	8.3	0.265060	8.5E+08	2.3E+08	1.9	0.244711	0.128795	0.000000	0.000830

HR 20
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /9.26 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.26/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1	5.8	0.172413	7.1E+08	1.2E+08	2.4	0.29239	0.121829	0.000000	0.000998
2	1.4	5.7	0.245614	7.1E+08	1.7E+08	2.3	0.29239	0.127126	0.000000	0.000899
3	1.3	5.4	0.240740	7.1E+08	1.7E+08	2.2	0.29239	0.132904	0.000000	0.000919
4	1.5	5.15	0.291262	7.1E+08	2.1E+08	2.1	0.29239	0.139233	0.000000	0.000876
5	1.7	4.85	0.350515	7.1E+08	2.5E+08	2	0.29239	0.146195	0.000000	0.000837
6	1.5	4.55	0.329670	7.1E+08	2.3E+08	1.9	0.29239	0.153889	0.000000	0.000869

HR 25
7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.36**9 /8.92	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.92/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	7	0.185714	7.1E+08	1.3E+08	2.4	0.281654	0.117355	0.000000	0.000960
2	1.2	6.9	0.173913	7.1E+08	1.2E+08	2.3	0.281654	0.122458	0.000000	0.000995
3	1.1	6.7	0.164179	7.1E+08	1.2E+08	2.2	0.281654	0.128024	0.000000	0.001030
4	1.6	6.4	0.25	7.1E+08	1.8E+08	2.1	0.281654	0.134120	0.000000	0.000909
5	1.8	6.1	0.295081	7.1E+08	2.1E+08	2	0.281654	0.140827	0.000000	0.000874
6	1.6	5.8	0.275862	7.1E+08	2.0E+08	1.9	0.281654	0.148236	0.000000	0.000910

HR 25
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.36**9 /8.11	Resis. = Rp mult by Z	Bed Thickness cm	Y=8.11/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.9	9	0.1	7.8E+08	78421700	2.4	0.256078	0.106699	0.000000	0.001108
2	1.3	8.8	0.147727	7.8E+08	1.2E+08	2.3	0.256078	0.111338	0.000000	0.000986
3	1.1	8.45	0.130177	7.8E+08	1.0E+08	2.2	0.256078	0.116399	0.000000	0.001044
4	1.6	8.2	0.195121	7.8E+08	1.5E+08	2.1	0.256078	0.121941	0.000000	0.000927
5	2	7.75	0.258064	7.8E+08	2.0E+08	2	0.256078	0.128039	0.000000	0.000858
6	1.8	7.3	0.246575	7.8E+08	1.9E+08	1.9	0.256078	0.134777	0.000000	0.000886

HR 25
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.36**9 /8.6 =	Resis. Rp mult by Z	Bed Thickness cm	Y=8.6/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1	6.8	0.147058	7.4E+08	1.1E+08	2.4	0.27155	0.113145	0.000000	0.001013
2	1.6	6.65	0.240601	7.4E+08	1.8E+08	2.3	0.27155	0.118065	0.000000	0.000872
3	1.2	6.2	0.193548	7.4E+08	1.4E+08	2.2	0.27155	0.123431	0.000000	0.000951
4	1.5	6	0.25	7.4E+08	1.8E+08	2.1	0.27155	0.129309	0.000000	0.000887
5	1.5	5.8	0.258620	7.4E+08	1.9E+08	2	0.27155	0.135775	0.000000	0.000892
6	1.5	5.3	0.283018	7.4E+08	2.1E+08	1.9	0.27155	0.142921	0.000000	0.000880

RUN NUMBER 3 WITH VIRGIN *************************************

0

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /9.75 = Rp	Resis. mult by Z	Bed Thickness cm	Y=9.75/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1	10.25	0.097560	6.7E+08	65841073	2.4	0.307862	0.128275	0.000000	0.001249
2	0.8	10.15	0.078817	6.7E+08	53191802	2.3	0.307862	0.133853	0.000000	0.001360
3	1.2	9.95	0.120603	6.7E+08	81391477	2.2	0.307862	0.139937	0.000000	0.001198
4	1.2	9.6	0.125	6.7E+08	84358875	2.1	0.307862	0.146600	0.000000	0.001202
5	1.6	9.5	0.168421	6.7E+08	1.1E+08	2	0.307862	0.153931	0.000000	0.001106
6	2.3	9.3	0.247311	6.7E+08	1.7E+08	1.9	0.307862	0.162032	0.000000	0.000990

HR 0

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /10.21 =Rp	Resis. mult by Z	Bed Thickness cm	Y=10.21/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	9.6	0.083333	6.4E+08	53705500	2.4	0.322387	0.134327	0.000000	0.001357
2	0.9	9.5	0.094736	6.4E+08	61054673	2.3	0.322387	0.140168	0.000000	0.001319
3	0.9	9.3	0.096774	6.4E+08	62367677	2.2	0.322387	0.146539	0.000000	0.001329
4	1.6	9.1	0.175824	6.4E+08	1.1E+08	2.1	0.322387	0.153517	0.000000	0.001106
5	1.7	9	0.188888	6.4E+08	1.2E+08	2	0.322387	0.161193	0.000000	0.001098
6	1.8	8.8	0.204545	6.4E+08	1.3E+08	1.9	0.322387	0.169677	0.000000	0.001087

HR 10
7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /9.3 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.3/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	10.5	0.076190	7.1E+08	53906742	2.4	0.293653	0.122355	0.000000	0.001314
2	0.8	10.3	0.077669	7.1E+08	54953475	2.3	0.293653	0.127675	0.000000	0.001324
3	1.1	10.2	0.107843	7.1E+08	76301823	2.2	0.293653	0.133478	0.000000	0.001205
4	1.2	10.1	0.118811	7.1E+08	84062495	2.1	0.293653	0.139834	0.000000	0.001184
5	1.8	9.9	0.181818	7.1E+08	1.3E+08	2	0.293653	0.146826	0.000000	0.001045
6	1.7	9.6	0.177083	7.1E+08	1.3E+08	1.9	0.293653	0.154554	0.000000	0.001072

HR 10
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /8.7 =	Resis. Rp mult by Z	Bed Thickness cm	Y=8.7/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.6	10.5	0.057142	7.6E+08	43218342	2.4	0.274708	0.114461	0.000000	0.001383
2	1.5	10.45	0.143540	7.6E+08	1.1E+08	2.3	0.274708	0.119438	0.000000	0.001032
3	1.4	10.35	0.135265	7.6E+08	1.0E+08	2.2	0.274708	0.124867	0.000000	0.001068
4	1.6	10.2	0.156862	7.6E+08	1.2E+08	2.1	0.274708	0.130813	0.000000	0.001033
5	1.8	10	0.18	7.6E+08	1.4E+08	2	0.274708	0.137354	0.000000	0.001003
6	1.8	9.7	0.185567	7.6E+08	1.4E+08	1.9	0.274708	0.144583	0.000000	0.001010

HR 10
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9 /9.25 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.25/ 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	11.3	0.070796	7.1E+08	50361132	2.4	0.292074	0.121697	0.000000	0.001342
2	0.9	11.1	0.081081	7.1E+08	57677108	2.3	0.292074	0.126988	0.000000	0.001301
3	0.9	10.95	0.082191	7.1E+08	58467205	2.2	0.292074	0.132760	0.000000	0.001314
4	1.3	10.8	0.120370	7.1E+08	85625583	2.1	0.292074	0.139082	0.000000	0.001175
5	0.5	10.6	0.047169	7.1E+08	33554292	2	0.292074	0.146037	0.000000	0.001632
6	1.6	10.4	0.153846	7.1E+08	1.1E+08	1.9	0.292074	0.153723	0.000000	0.001120

HR 15
7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.44**9 /9.87 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.87 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	10.6	0.075471	6.5E+08	49243924	2.4	0.311651	0.129854	0.000000	0.001381
2	1.2	10.5	0.114285	6.5E+08	74569371	2.3	0.311651	0.135500	0.000000	0.001220
3	1.3	10.3	0.126213	6.5E+08	82352097	2.2	0.311651	0.141659	0.000000	0.001198
4	1.6	10.1	0.158415	6.5E+08	1.0E+08	2.1	0.311651	0.148405	0.000000	0.001128
5	2	9.85	0.203045	6.5E+08	1.3E+08	2	0.311651	0.155825	0.000000	0.001055
6	1.8	9.6	0.1875	6.5E+08	1.2E+08	1.9	0.311651	0.164026	0.000000	0.001102

HR 15
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.44**9 /8.35 =	Resis. Rp mult by Z	Bed Thickness cm	Y=8.35 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	10.3	0.077669	7.7E+08	59903456	2.4	0.263656	0.109856	0.000000	0.001224
2	0.6	10	0.06	7.7E+08	46275420	2.3	0.263656	0.114633	0.000000	0.001353
3	0.7	9.85	0.071065	7.7E+08	54810142	2.2	0.263656	0.119843	0.000000	0.001298
4	1	9.75	0.102564	7.7E+08	79103282	2.1	0.263656	0.125550	0.000000	0.001166
5	1.2	9.55	0.125654	7.7E+08	96911874	2	0.263656	0.131828	0.000000	0.001108
6	1.4	9.3	0.150537	7.7E+08	1.2E+08	1.9	0.263656	0.138766	0.000000	0.001061

HR 15
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.44**9 /9.17 =	Resis. Rp mult by Z	Bed Thickness cm	Y=9.17 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1	10.65	0.093896	7.0E+08	65942723	2.4	0.289548	0.120645	0.000000	0.001223
2	1	10.5	0.095238	7.0E+08	66884761	2.3	0.289548	0.125890	0.000000	0.001234
3	0.8	10.4	0.076923	7.0E+08	54022307	2.2	0.289548	0.131612	0.000000	0.001345
4	1.1	10.3	0.106796	7.0E+08	75001844	2.1	0.289548	0.13788	0.000000	0.001225
5	1.2	10.15	0.118226	7.0E+08	83029359	2	0.289548	0.144774	0.000000	0.001203
6	1.3	10	0.13	7.0E+08	91297700	1.9	0.289548	0.152393	0.000000	0.001186

HR 20
7.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9/10.14	Resis. =Rp mult by Z	Bed Thickness cm	Y=10.14 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.9	10.6	0.084905	6.5E+08	55096556	2.4	0.320177	0.133407	0.000000	0.001342
2	0.9	10.5	0.085714	6.5E+08	55621285	2.3	0.320177	0.139207	0.000000	0.001357
3	0.9	10.4	0.086538	6.5E+08	56156105	2.2	0.320177	0.145535	0.000000	0.001373
4	1.4	10.25	0.136585	6.5E+08	88632292	2.1	0.320177	0.152465	0.000000	0.001198
5	1.4	10.1	0.138613	6.5E+08	89948613	2	0.320177	0.160088	0.000000	0.001211
6	1.8	10	0.18	6.5E+08	1.2E+08	1.9	0.320177	0.168514	0.000000	0.001130

HR 20
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9/9.08	Resis. = Rp mult by Z	Bed Thickness cm	Y=9.08 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.7	11	0.063636	7.2E+08	46115300	2.3	0.286701	0.124652	0.000000	0.001393
2	0.8	10.9	0.073394	7.2E+08	53186715	2.2	0.286701	0.130318	0.000000	0.001348
3	1.1	10.7	0.102803	7.2E+08	74498682	2.1	0.286701	0.136524	0.000000	0.001223
4	1.3	10.4	0.125	7.2E+08	90583625	2	0.286701	0.143350	0.000000	0.001165
5	1.2	10.1	0.118811	7.2E+08	86099287	1.9	0.286701	0.150895	0.000000	0.001205
6	1.4	9.6	0.145833	7.2E+08	1.1E+08	1.8	0.286701	0.159278	0.000000	0.001146

HR 20
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.58**9/9.37	Resis. = Rp mult by Z	Bed Thickness cm	Y=9.37 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	10.2	0.127450	7.0E+08	89501303	2.4	0.295864	0.123276	0.000000	0.001112
2	1.1	9.9	0.111111	7.0E+08	78026777	2.3	0.295864	0.128636	0.000000	0.001181
3	1.3	9.8	0.132653	7.0E+08	93154418	2.2	0.295864	0.134483	0.000000	0.001130
4	1.3	9.5	0.136842	7.0E+08	96096136	2.1	0.295864	0.140887	0.000000	0.001136
5	1.5	9.3	0.161290	7.0E+08	1.1E+08	2	0.295864	0.147932	0.000000	0.001093
6	1.6	9.05	0.176795	7.0E+08	1.2E+08	1.9	0.295864	0.155717	0.000000	0.001078

HR 25
7.2

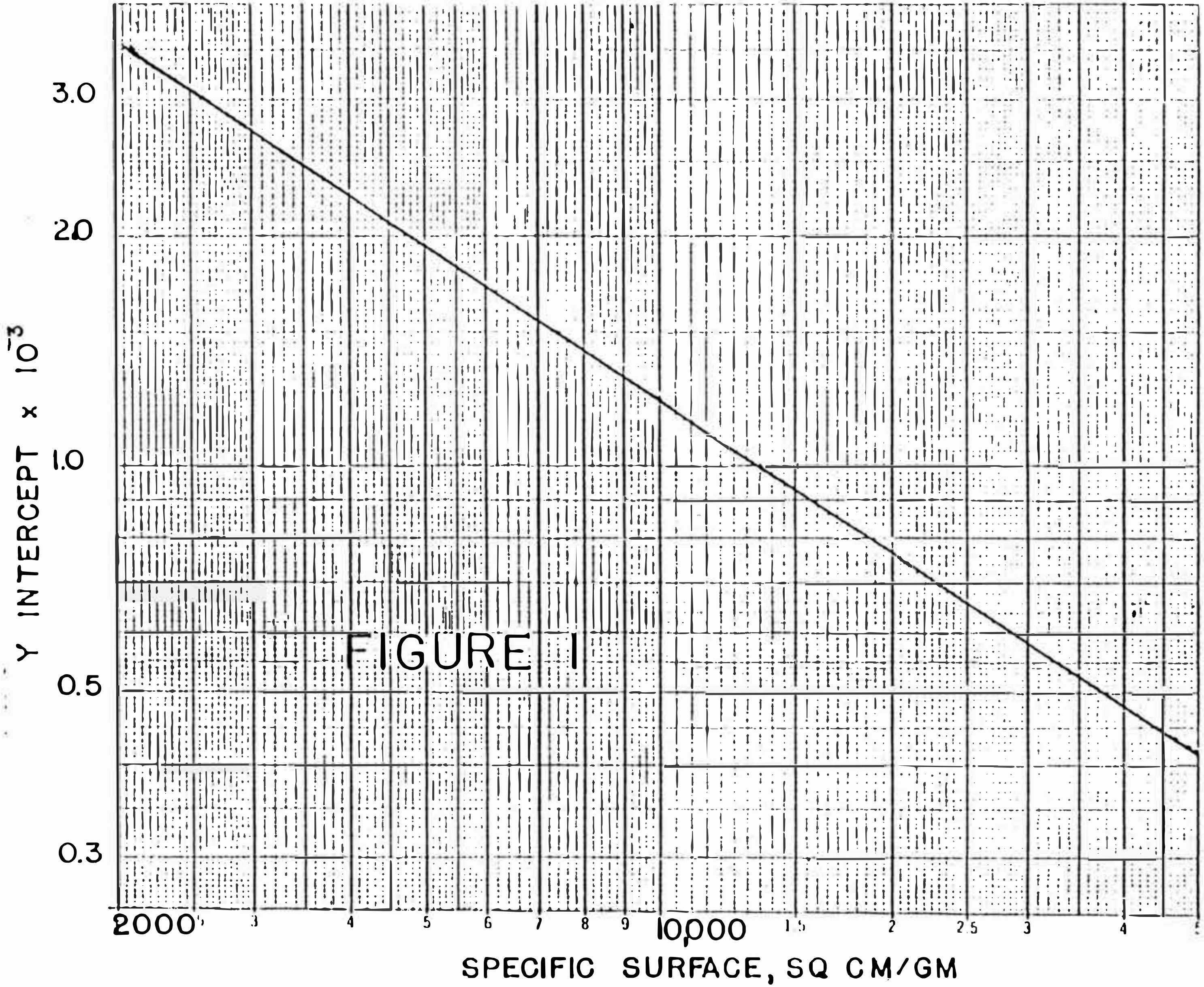
Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /9.85 = Rp	Resis. Rp mult by Z	Bed Thickness cm	Y=9.85 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.8	9.9	0.080808	7.0E+08	56442585	2.4	0.31102	0.129591	0.000000	0.001319
2	0.6	9.7	0.061855	7.0E+08	43204762	2.3	0.31102	0.135226	0.000000	0.001462
3	0.8	9.4	0.085106	7.0E+08	59444851	2.2	0.31102	0.141372	0.000000	0.001334
4	0.7	9.1	0.076923	7.0E+08	53729000	2.1	0.31102	0.148104	0.000000	0.001402
5	0.8	8.5	0.094117	7.0E+08	65739011	2	0.31102	0.15551	0.000000	0.001332
6	1.2	8.3	0.144578	7.0E+08	1.0E+08	1.9	0.31102	0.163694	0.000000	0.001174

HR 25
9.2

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /8.47 = Rp	Resis. Rp mult by Z	Bed Thickness cm	Y=8.47 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	0.7	9.85	0.071065	8.1E+08	57725340	2.3	0.267446	0.116280	0.000000	0.001263
2	0.6	9.6	0.0625	8.1E+08	50767375	2.2	0.267446	0.121566	0.000000	0.001337
3	0.9	9.4	0.095744	8.1E+08	77771297	2.1	0.267446	0.127355	0.000000	0.001178
4	0.9	9.15	0.098360	8.1E+08	79896196	2	0.267446	0.133723	0.000000	0.001187
5	1.1	8.9	0.123595	8.1E+08	1.0E+08	1.9	0.267446	0.140761	0.000000	0.001119
6	1.4	8.7	0.160919	8.1E+08	1.3E+08	1.8	0.267446	0.148581	0.000000	0.001043

HR 25
11.5

Trial No.	Pressure Drop g/cm2	Flow cm3/min	P/q	Z=6.88**9 /9.64 = Rp	Resis. Rp mult by Z	Bed Thickness cm	Y=9.64 31.67	Density g/cm3 div Y by bed (C)	C/Rp	C/Rp^.3
1	1.3	10	0.13	7.1E+08	92779960	2.4	0.304389	0.126828	0.000000	0.001109
2	0.7	9.75	0.071794	7.1E+08	51239425	2.3	0.304389	0.132343	0.000000	0.001372
3	0.7	9.45	0.074074	7.1E+08	52866074	2.2	0.304389	0.138358	0.000000	0.001378
4	1	9.15	0.109289	7.1E+08	77999125	2.1	0.304389	0.144947	0.000000	0.001229
5	1.2	8.85	0.135593	7.1E+08	96771796	2	0.304389	0.152194	0.000000	0.001162
6	1	8.45	0.118343	7.1E+08	84460591	1.9	0.304389	0.160204	0.000000	0.001237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SPECIFIC SURFACE, SQ CM/GM

FIGURE 1

APPENDIX V

<u>Pulmac Permability Tester Instructions</u>

1) Place removable screen in permeability cell
2) Close drain
3) Fill permeability cell and upper container with water
4) Add approximately 8-10g o.d. fiber carefully, as to avoid aerating the sample
5) It is extremely important to remove any entrained air
6) Open drain
7) With slurry in permeability cell, lower piston until it rests on pulp mat
8) Open overflow valve
9) Close drain
10) Add spacer and compress to respective height
11) Open manometer and rotameter valves to reverse the flow
12) Record flow rate and pressure
13) Repeat with smaller spacer for a total of seven readings
14) Remove pulp mat and obtain o.d. weight
15) Follow examples in Pulmac folder to determine surface area (folder in Mr. Klines office)