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EXPERIMENTS IN MECHANICAL DRYING OF SALTED COD

by

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INTRODUCTION

In the spring of 1961 Memorial University of Newfoundland and the Industrial Development Service, Department of Fisheries of Canada agreed to co-operate in the obtaining of emperical data regarding the drying of salted cod products. The experimental phase of the project was carried out at the Fish Processing Experimental Plant in Valleyfield, Newfoundland, operated by the Industrial Development Service.

There were two main problems to be investigated when the work was started. One was the drying of "salt cod blocks", a new product aimed at a more efficient utilization of trap caught cod and of making salted cod a more attractive package, and the other was the production of light salted fish, a premium product which has not been easy to produce in Newfoundland.

The results of the first summer's work indicated the necessity of expanding the scope of the experiments. Work on drying continued to form part of summer projects which were carried out at Valleyfield until 1966.

EXPERIMENTAL MATERIAL

The fish required for the experiments were all caught by local fishermen using gill nets, traps and "long lines". Three types of products came under investigation: salt cod block, "heavy salted" cod and "light salted" cod. The fish were prepared for drying by the plant staff in the commercial manner. A brief description of the preparation of each product follows.

(1) The Salt Cod Block *

The product was prepared from fresh cod fillets. The fillets were skinned and placed in forming pans together with a layer of cheesecloth which was wrapped around the block to aid handling in the wet state. The forming pans were approximately 20"x10"x2". The blocks in the forming pans were placed under pressure (1 to 1.5 lbs/sq- in. approximately) for about 30 minutes and were then removed from the forming pan and put into the pickling tanks. They were evenly salted, using 30 lbs. of salt with 100 lbs. of fillets, and were left immersed in the pickling tanks for 18 to 21 days, after which time they were taken out, washed, drained and were then ready for drying. After the salting process the blocks contained approximately 61% water (Wet Basis) and 40% salt (Dry Basis).

* This product was originally proposed by Fishery Products, St. John's, Newfoundland. The co-operation of Fishery Products in the early stage of the work is gratefully acknowledged.

(2) Heavy Salted Fish

This product was prepared in the traditional way. Split fish were salted in bulks with excess salt (up to 50 lbs. per 100 lbs. of split fish). The brine was allowed to drain away. The curing period varied from 3 weeks to several months. The finished product (after washing and before drying) had a water content of about 57% (Wet Basis) and a salt content of about 46% (Dry Basis).

(3) Light Salted Fish

A good deal of the work covered in this report was done on this product. Split cod were salted using 9 to 14 lbs. of salt per 100 lbs. of fish and a pickling period of 3 to 6 days. The salt and water contents after washing and before drying varied considerably, depending on time in salt, etc. A typical figure was a water content of 67% (Wet Basis) and a salt content of about 26% (Dry Basis).

INFLUENCE OF AIR SPEED AND RELATIVE HUMIDITY

(1) Introduction.

Ambient conditions---i.e. air speed and relative humidity--- directly affect the drying rate during the period in which any portion of the fish surface remains wet. In commercial dryers, this can range from the first three hours to the first twelve or fifteen hours of the drying time.

The final condition of the product is dependant on its total history, and conditions early in the drying can have a profound effect on quality. For example, a low drying rate early in the drying period increases the chances of sliming with light salted cod and results in down grading.

The effect of ambient conditions on total drying time should probably be considered secondary to the effect on quality. Nevertheless, we shall see later in this chapter that in the case of light salted fish, the time saved due to higher air speed is significant.

(2) Apparatus.

The drying tunnel used in the experiments to investigate the influence of ambient conditions was constructed from an existing

"Bonavista Type" dryer. The maximum air speed was increased by diverting the total volume of air from the original fan (31,000 CFM rated) through a tunnel 4'2" wide by 4'10" high. The air speed could be varied by the adjustment of a door which allowed part of the air to bypass the tunnel.

The drying air temperature was controlled by a motorized valve in the steam supply line to the air heater. The control could be operated either manually or automatically.

No dehumidification equipment was used, so that the lower limit of obtainable relative humidity was governed by outside dew point temperature, since the dryer air temperature remained constant at 80°F. Relative humidity was increased by recirculating air and by admitting steam into the intake air. The general layout of the dryer and a control schematic are shown in Figures 1 and 2.

In order to establish weight loss and hence drying rates, an 800 lb. capacity floor-type scale was installed with the scale face outside the tunnel. The fish were placed on aluminum frame trays laced with nylon cord. The trays were supported by rack on the scale pan.

Temperatures were measured and recorded on an eight-point electronic strip-chart recorder. The unit used copper-constantan thermocouple sensing. A simple but effective wick arrangement was used to keep thermocouples wet to obtain wet bulb temperatures.

(3) Procedure.

The experimental procedure was essentially the same for all products. Some measurement of fish thickness was usually made. In the case of salt cod blocks this was not especially difficult, due to its regular shape. The thickness of ordinary split fish was measured in the thickest part of the fish. This measurement was solely for selection purposes, so that the range of thickness would not be too great, and more important, so that experiments should be as consistent as possible. After some preliminary measurements to establish the range of thicknesses, fish between 2.1 and 2.9 cm. were taken for all drying runs unless otherwise specified. Samples were taken for moisture and salt analysis at the beginning and end of the drying run.

The fish were placed on trays which were put into the dryer operating under specified conditions. The temperature and relative humidity of the air entering the drying tunnel were under the control of the operator, who also recorded the weight of fish at regular intervals.

(4) Effect of Relative Humidity on Light Salted Cod.

The effect of relative humidity on drying behaviour can be clearly seen in the curves of moisture content and drying rate with time. These curves are given in Figures 3, 4, 5 and 6.

The moisture content, M, is expressed as a fraction of the initial moisture content, M_0. Both M and M_0 have been calculated on a "dry basis" - i.e. as a fraction of dry material- hence $\frac{M}{M_0} = \frac{W}{W_0}$ where W is the weight of water present in the fish and W_0 is the initial weight of water present. The units of drying rate; $-\frac{dM}{dt}$, are per cent (dry basis) per hour, which is the same as loss in weight per 100 pounds of dry material per hour. The rate curves were obtained graphically from graphs of M with time.

It is immediately apparent from these curves that relative humidity has its most pronounced effect when the air speed is below 600 feet per minute. After this point, the curves for 35% and 50% are practically identical, although an RH as high as 65% slows drying considerably even if the air speed is as high as 1200 FPM.

(5) Effect of Air Speed on Light Salted Cod.

In the design of conventional dryers, one has more control over the air speed than the relative humidity. Consequently, the effect of air speed when the RH is held constant is of interest. To facilitate comparison of drying characteristics at various air speeds, Figures 7, 8 and 9 show the graphs of $\frac{M}{M_0}$ and drying rate with time for three constant relative humidities, 35%, 50% and 65%.

If the relative humidity of air passing over the fish is as low as 35%, Figure 7 shows that air speed does not have a great effect on the drying curves. There is a considerable difference between the rate curve at 300 FPM and that at 1200 FPM for the first four hours only, after which time the rate curves are practically identical. In fact, the rate curves have a tendency to "cross over", giving a slightly higher rate for low air speeds after the first few hours. This is due to the formation of a surface layer of material deposited by the evaporating water, combined with a hardening of the surface itself. The buildup of this barrier is most rapid when the drying rate is highest. This "cross over" of rate curves is usual in the drying of fish, and tends to offset the time advantage gained by rapid early drying.

Air speed becomes much more important when the relative humidity is increased. If the relative humidity is 50%, (Figure 8) the moisture content curve for 300 FPM lies considerably above the rest, as a result of the lower drying rate. The drying rate obtained at 300 FPM and 50% RH has been considered minimum (for the first 8 hours of drying) for the safe drying of light salted fish. [1]

If the relative humidity is 65%, (Figure 9) the effect of air speed is very considerable. The drying rate curves for the two highest air speeds lie well above the 300 FPM curve for about 10 hours of drying. If drying were to be carried out at 65% RH, the air speed would have to be at least 900 FPM to prevent "sliming" due to slow drying.

(6) The Effect of Air Speed on Drying Time.

The major reason for investing in equipment to permit higher dryer air speed would (and should) undoubtedly be the elimination of the quality problem (mainly "sliming") which is due to low air speed. However, it is also interesting to note the effect that increasing air speed would have on the drying time.

In order to make a comparison among air speeds, we will

[1] - Mechanical Drying of Light Salted Codfish, Project Report No. 8. Industrial Development Service, Department of Fisheries, May 1967.

estimate the additional drying time necessary to reduce $\frac{M}{M_0}$ at 24 hours to the value obtaining under fastest drying conditions observed, that of 1200 FPM.

If $w = \frac{M}{M_0}$, and r represents the drying rate (% dry basis per hour) during a time interval Δt, then it is easy to show that $\Delta w = \frac{r\Delta t}{M_0}$ and hence $t = \frac{M_0 \Delta w}{r}$ -----------(III-1)

Since the drying rate is not changing very rapidly, the value at 24 hours can reasonably be used to estimate Δt for a specified Δw. The value of M_0 will be taken to be 260% (Dry Basis) (72.2% Wet Basis). Tables 1 and 2 give values of M/M_0 and drying rates obtained under the various conditinns.

TABLE 1

M/M_0 - Light Salted Cod.

RH %	AIR SPEED FPM	DRYING TIME - HOURS				
		0	6	12	18	24
35	300	1.00	0.79	0.65	0.56	0.49
	600	1.00	0.73	0.60	0.52	0.46
	900	1.00	0.71	0.59	0.51	0.44
	1200	1.00	0.69	0.58	0.50	0.44
50	300	1.00	0.82	0.69	0.59	0.51
	600	1.00	0.74	0.61	0.52	0.46
	900	1.00	0.72	0.59	0.51	0.45
	1200	1.00	0.70	0.58	0.49	0.44
65	300	1.00	0.88	0.78	0.70	0.63
	600	1.00	0.82	0.70	0.62	0.55
	900	1.00	0.79	0.66	0.57	0.50
	1200	1.00	0.77	0.64	0.55	0.49

TABLE 2

Drying Rates - Light Salted Cod

RH %	AIR SPEED FPM	DRYING TIME - HOURS 6	12	18	24
35	300	7.3	4.8	3.4	2.7
	600	7.0	4.3	3.2	2.0
	900	7.0	4.3	3.2	2.4
	1200	6.8	3.6	2.7	2.0
50	300	6.7	5.3	4.0	2.6
	600	7.0	4.4	2.9	2.1
	900	7.5	4.0	2.7	1.9
	1200	7.6	4.8	2.8	2.0
65	300	5.0	4.2	3.4	2.7
	600	6.2	4.7	3.3	2.4
	900	7.0	4.5	2.9	2.2
	1200	7.5	4.4	3.2	2.4

The time lag due to lower air speeds is shown in Table 3. This time lag is the number of additional hours that light salted fish would have to remain in the dryer to bring $\frac{M}{M_0}$ down to that obtainable with 1200 FPM air speed under the same relative humidity.

TABLE 3

Time Lag at 24 Hours Due to Low Air Speed.

RH %	AIR SPEED 300 FPM	600 FPM	900 FPM
35	5	3	0
50	7	3	1
65	13	7	1

It follows immediately from Table 3 that air speeds higher than 900 FPM are unnecessary, since the lag behind 1200 FPM is insignificant. However, it can also be seen that air speeds as low as 300 FPM could easily make the first drying period one and one half times as high as it might be.

(7) Effect of RH and air speed on Heavy salted fish.

Heavy salted fish presents much less of a drying problem then does the light salted product. The high salt concentration and consequent low water content (about 57% (wet basis) before drying) makes the growth of slime-causing bacteria extremely unlikely.

The drying characteristics are shown in Figures 10, 11 and 12. The general results are similar to those observed above for light salted fish, but the drying rates are considerably lower. The variation in drying characteristics due to changes in ambient conditions are more difficult to measure for this product than for light salted fish and too much significance should not be attached to minor differences in the curves shown in Figures 10 to 12. In general terms, an air speed of 600 to 900 feet per minute will give most rapid drying when the relative humidy is in the region of 50%. The drying rate under all conditions is about 1% (dry basis) per hour at about 12 hours of drying time, and drops very slowly thereafter, reaching about 0.6% at 36 hours.

(8) Salt Cod blocks

The major obstacle in drying this specialized product is its thickness---about 2 inches before drying. Because of this, ambient conditions affect the drying characteristics only for a small proportion of the total drying time. However, it is essential that the water be removed as quickly as possible during the first few hours of drying to prevent spoilage. (The salt content of this product is intermediate between light and heavy salted fish).

Figure 13 shows the effect of air speed when the relative humidity is 50%. The effect of air speed is slightly more pronounced at lower relative humidity and less pronounced at higher relative humidity. The most rapid drying is obtained with an air speed of 600-900 feet per minute. Although 1200 FPM gives rapid early drying, the consequent hardening of the surface increases the overall drying time. On the other hand, 300 FPM leads to such slow drying early in the drying period that there is danger of spoilage.

(9) Conclusions

Relative humidity and air speed have considerable effect on drying in the case of light salted fish, but less in the case of heavy salted fish or salt cod blocks. In the case of blocks, however, the air speed must be at least 600 FPM early in the drying period in order to prevent spoilage. If a dryer is to be designed to take a variety of products, it should have installed fan capacity for air speeds up to at least 900 FPM. After the first 8 to 12 hours of drying, high air speed is no longer necessary for any product, and the product should be transferred to a low air speed zone, or another dryer. In practice, the low air speed zone or dryer should have a larger fish capacity than the high-speed zone, because the period in this low air speed dryer would be from two to three times as long as the period in the high speed zone. If a single dryer were to be used to provide both zones, a variable speed fan drive would allow the air speed to be lowered to an adequate but more economical level.

IV

DESIGN OF A DRYING SYSTEM

(1) Preliminary Considerations.

The experiments during 1962 and 1963 described in Chapter III verified a long-held belief that light salted fish could be successfully produced in Newfoundland if water could be rapidly removed during the initial drying stages - say the first eight to ten hours of drying. However, it is unnecessary to maintain a high drying potential throughout the entire drying period. In the first place it is expensive, and in the second place the drying rate is mainly controlled by diffusion and this is not greatly influenced by the drying conditions (i.e. air speed and relative humidity). The drying period should, therefore, be divided into two stages: a high drying potential but short first stage, and a lower drying potential but longer second stage.

During 1964, an agreement was reached between the Fishermen's Union Trading Company Ltd. of Port Union, Newfoundland, and the Industrial Development Service whereby a small, variable air speed dryer was built at Port Union to provide the first stage of a drying system to handle light salted fish. The air speed was made variable for the purposes of experimental work, and to give the unit flexiability. For example, if the amount of fish available was small, it might not be desirable to start up a large unit for the second stage, but the small unit could be run at low cost by lowering the air speed.

Facilities for the second drying stage were already available at Port Union, in the form of two "Glent" dryers. These are high capacity, semi-continuous dryers.

The next several sections will describe the design of the small unit for the first drying stage.

(2) Dryer Size and Choice of Fan.

The size of the dryer was limited by the space available and the desired air velocity. For reasons of economy and immediate availability, the motor size was restricted to 10 HP. A maximum open tunnel air velocity of about 900 feet per minute was chosen. A size 36 Vaneaxial Fan was chosen with a capacity of 26,000 cubic feet per minute at 1¾" static pressure, requiring 10.3 brake horse power. The theoretical open tunnel air speed is 867 FPM when the fan is driven at rated speed. The air speed can be varied from about 300 FPM to 900 FPM by means of a variable pitch pulley. The general layout is shown in Figure 14.

(3) Theoretical Performance.

The limiting design conditions were as follows:

1) Maximum outside dew point = 60°F

2) Temperature of air leaving heater = 80°F

3) Maximum relative humidity of air leaving fish = 60%

4) Minimum air temperature to heater = 50°F. (Note that when the outside temperature is lower than this, there will be considerable recirculation of already heated air.)

Conditions 1 to 3 inclusive determined the maximum drying load at any specified drying rate. The heat requirements were governed by conditions 2 and 4, together with the air flow rate.

Assuming an adiabatic dryer, the following equation relates the drying load to the "moisture pickup" by the drying air:

$$L = \frac{6Q(W_2 - W_1)}{7r} \qquad \text{.....................(IV - 1)}$$

where L is the dryer load (lbs. of dry material)

Q is the air flow rate (lbs. of dry air/min)

W_1 is the moisture content of air to fish (grains/lb)

W_2 is the moisture content of air from fish (grains/lb)

r is the drying rate of the fish (% dry basis/hr)

Equation (IV - 1) is useful for calculating the load which will give the maximum allowable relative humidity of the air leaving the fish, for any specified drying rate. This load is the "maximum load". Under condition (3) above, Figures 15A, 15B, 15C, give the variation of maximum load with air flow rate for several dew points and drying rates.

For the Port Union Dryer, the maximum air flow rate was 26,000 CFM, or approximately 1890 lbs. of dry air/minute. Figure 16 gives the variation of maximum dryer load with outside dew point for several drying rates. "Rated load" refers to the estimated quantity of light salted fish that the dryer can contain.

Note that the maximum load can be considerably increased if the temperature of the ingoing air is raised to 85°F instead of 80°F. This might be necessary during periods of very high dew point (over 55°F).

(4) Size of Heater.

The heater was required to heat roughly 1890 lbs. of dry air per minute from outside conditions of 50°F and 100% RH to 80°F. The resulting relative humidity would be about 35%. Since the relative humidity of air going to the fish was never required to be lower than this, the above condition represented the maximum heater load. A psychrometric chart will show that the heat demand was about 13,400 BTU/minute, or about 24 Boiler HP.

(5) Relative Humidity Control.

The method used to control relative humidity was the usual one of controlling the amount of recirculated air. The dampers were of the opposed blade type, having quite low leakage, according to the manufacturer's data. The relative humidity sensing device depended upon the changing resistance of a carbon film.

V

TESTING OF THE DRYING SYSTEM

(1) Preliminary.

The dryer was completed during the summer of 1964, and tests were carried out in 1965 to compare actual performance to theoretical prediction. Unfortunately, the summer of 1965 was a very poor one for the inshore fishery, and during the entire summer only 3000 lbs. (scarcely one load) of light salted fish was available. This was supplemented by several loads of heavy salted fish. Table 4 summarizes the experiments.

TABLE 4

SUMMARY OF PORT UNION EXPERIMENTS

Run No.	DESCRIPTION	APPROX. WT. IN LB.	APPROX. WT. OUT LB.	TIME IN DRYER HRS.
65 PU/1*	light salted	3460	2750	18
65 PU/2	partially dry light salted & 1 cart heavy salted			14
65 PU/3	2 carts light salted and 1 cart heavy salted	2508	1783	16
65 PU/4	heavy salted	2600	2150	29
65 PU/5	heavy salted	2810	2450	21
65 PU/6	heavy salted	3150	2670	40

* This run was carried out using temporary hot water heating system from Glent Dryer. Maximum air temperature that could be attained was about 63°F.

(2) Equipment Performance.

(a) Air Flow. The fan was driven by a variable pitch pulley so that fan speed and hence air volume and air speed could be controlled. Figure 17 shows the relationship between fan speed and mean air speed in the empty tunnel. The cross-sectional area of the dryer is 30 square feet, giving a flow of about 25,000 C.F.M. (cubic feet per minute) at 1100 r.p.m. (revolutions per minute). This was in line with expectations. It will be noted that there was very little change in air speed due to a change in the amount of recirculated air.

Figure 18 shows vertical and horizontal air velocity profiles near the tunnel centreline at about 20 feet from the fan. The length of the line indicates the range of air speeds encountered. Part of the range is due to changing from full to no recirculation. The horizontal profile shows that the air speed was a little low near one wall. This was probably due to the presence of structural pillars along this wall.

(b) Temperature Control. The temperature control is of the proportional type. Changes in temperature cause the control motor to adjust a motorized valve on the heater steam supply line.

Figure 19 shows the response of the control system to a sudden drop in temperature of the air being supplied to the heater. (The drop in temperature was brought about by cutting off recirculated air). The thermostat setting was 80°F. While there was some slight disagreement between the setting and the actual temperature, this was merely a matter of simple adjustment. In general, the temperature control was satisfactory.

(c) Relative Humidity Control. The sensing element in the RH control system is a carbon film, whose resistance changes with changes in RH. The signal from the controller drives a pair of electro-hydraulic motors which operate dampers which control the amount of recirculated air.

During the few runs that were carried out in the 1965 season, the dew point temperature was quite high, with the result that the RH control system consistently called for "no recirculation" in order to keep the RH in the dryer at the lowest possible level - which was usually in excess of the setting of 35 - 40%. Thus, the control system was never really called upon to "control" RH.*

* The system has apparently performed satisfactorily in subsequent commercial use.

(3) Psychrometric Measurements. A twelve point temperature recorder was set up to measure and record the following air temperatures: (See Figure 14 for the positions of these thermocouples)

Point A 1 - Dry bulb temperature, outside air
2 - Wet bulb temperature, outside air

Point B 3 - Dry bulb temperature, immediately before heater
4 - Wet bulb temperature, immediately before heater

Point C 5 - Dry bulb temperature, immediately before fish
6 - Wet bulb temperature, immediately before fish

Point D 7 - Dry bulb temperature, immediately after fish
8 - Wet bulb temperature, immediately after fish.

At each point, dew point temperature (DP) relative humidity (RH), absolute humidity (w) and specific enthalpy (h) were read from a psychrometric chart. Data sheets for Run No. 65/4 are shown in Tables 5 and 6. This run is significant only in that a full dryer load of fish was used. (About 2600 lbs.) It was heavy salted fish however, since at no time was a load of light salted fish available. The drying conditions were quite bad when the run began, as indicated by the high outside dew point temperature of 60°F. However, changing weather conditions led to considerable improvement soon afterward.

Figure 20 shows dryer air temperatures and relative humidities in the dryer during Run 65/4. Other observations can be made from the data in Table 6. The specific enthalpy (h, BTU/lb dry air) at points C and D was practically equal, as theory predicts for an adiabatic dryer. We may, therefore, conclude that heat losses are low. The rise in absolute humidity (w, grains of water per lb. of dry air) from point C to point D is a measure of the drying rate. The relationship is given in the following equation:

$$R = \frac{6M_a\ (w_D - w_C)}{700} \qquad \text{.......................(V - 1)}$$

where R is the absolute drying rate, lbs. of water per hour

$w_D - w_C$ is the rise in humidity, grains/lb dry air

M_a is the air flow rate, lbs. of dry air/minute

The drying rate "r" in per cent (dry basis) per hour is related to R by $r = \frac{R}{DM}$, where "DM" is the weight of dry material (lbs) in the dryer load. Drying rates calculated from the above equations agree reasonably well with those observed under good drying conditions in other dryers.*

* See, for example, Table 2, above.

TABLE 5

TEMPERATURES DURING RUN 65/4

TIME & DATE	HOURS OF DRYING	TEMPERATURES								FAN RPM	AIR SPEED FPM	RH SET
		1	2	3	4	5	6	7	8			
1100/16	0.00	73.0	64.8	73.5	64.8	83.0	67.0	70.4	63.8	1000	700	35
1115	0.25	74.8	65.4	74.3	65.3	79.0	66.6	73.6	66.2			
1130	0.50	74.3	65.4	74.8	65.6	79.8	67.0	73.9	66.4			
1145	0.75	74.0	65.2	74.2	65.5	79.6	67.0	74.2	66.9			
1200	1.00	74.0	65.4	74.2	65.7	79.8	67.3	74.7	67.0			
1215	1.25	73.0	64.9	72.9	65.0	78.3	66.3	74.2	66.7			
1230	1.50	72.3	64.6	72.8	65.0	80.0	67.0	74.8	66.8			
1245	1.75	72.0	64.6	72.2	64.8	78.6	66.8	74.6	66.7			
1300	2.00	66.4	60.2	67.0	61.0	78.3	64.4	73.7	65.0			
1315	2.25	65.4	57.8	66.0	58.3	78.6	62.7	72.3	63.0			
1330	2.50	64.4	57.0	64.9	57.7	78.0	62.3	72.2	62.3			
1345	2.75	64.4	56.3	65.1	57.0	78.0	61.9	72.3	61.8			
1400	3.00	63.9	55.3	64.6	56.1	78.2	61.0	72.3	61.0			
1430	3.50	65.0	56.0	65.3	56.3	78.9	61.9	74.2	61.3			
1500	4.00	62.1	55.2	63.0	56.0	78.2	61.6	74.6	61.3			
1530	4.50	62.0	54.6	63.0	55.2	76.8	60.4	74.4	60.8			

TABLE 5 (Cont'd)

TEMPERATURES DURING RUN 65/4

TIME & DATE	HOURS OF DRYING	TEMPERATURES								FAN RPM	AIR SPEED FPM	RH SET
		1	2	3	4	5	6	7	8			
1600/16	5.00	62.5	54.3	63.2	55.1	78.8	61.5	76.0	61.2	1000	700	35
1630	5.50	61.4	53.6	62.1	54.9	77.8	60.1	75.2	60.2			
1700	6.00	60.8	53.0	61.4	53.7	77.6	60.0	75.8	60.3			
1730	6.50	59.6	53.0	60.8	53.5	78.0	60.2	76.0	60.3			
1800	7.00	58.9	51.3	59.7	52.1	78.0	59.6	75.8	59.6			
1830	7.50	57.7	51.7	58.8	52.4	76.8	59.8	75.8	60.0			
1900	8.00	57.0	51.0	58.2	51.8	78.0	59.8	75.9	59.9			
2000	9.00	56.0	51.0	57.0	51.6	78.3	59.9	76.0	60.0			
2100	10.00	55.8	50.7	56.8	51.2	80.5	60.7	76.8	60.5	600	450	
2200	11.00	55.1	50.7	56.2	51.3	77.4	60.0	76.0	60.8			
2300	12.00	56.1	51.1	57.2	52.2	76.3	60.0	76.0	60.9			
0100/17	14.00	57.6	52.0	58.0	52.5	79.0	60.7	76.7	61.0			
0300	16.00	58.0	52.0	59.3	53.0	80.7	60.9	76.5	60.9			
0500	18.00		BOILER TROUBLE									
0700	20.00	55.2	52.4	51.0	53.3	76.8	61.8	76.8	62.1			
0915	22.25	56.4	53.3	57.3	53.9	78.4	62.2	72.9	60.8			

TABLE 6

PSYCHROMETRIC DATA, RUN 65/4

HOURS OF DRYING	Point A				Point B				Point C				Point D			
	DP	RH	w	h	DP	RH	w	h	DP	RH	w	h	DP	RH	w	h
0.00	60.5	65	79	29.8	60.0	63	78	29.9	59.0	44	74	31.5	60.0	70	78	29.2
0.25	60.5	61	79	30.4	61.0	63	80	30.4	60.0	53	78	31.2	62.5	68	85	31.0
0.50	61.0	63	80	30.4	61.0	62	80	30.4	60.0	52	78	31.5	62.5	68	85	31.0
0.75	60.5	63	79	30.2	61.0	63	80	30.4	61.0	53	80	31.5	63.5	69	87	31.4
1.00	61.0	63	80	30.4	61.5	64	81	30.4	61.0	53	80	31.8	63.5	68	87	31.5
1.25	60.5	65	79	29.8	61.0	66	80	30.0	60.0	54	77	31.0	63.5	68	87	31.4
1.50	60.5	67	79	29.7	61.0	66	80	30.0	60.0	51	78	31.5	63.0	67	86	31.5
1.75	60.5	68	79	29.7	61.0	68	80	30.0	61.0	55	80	31.5	63.0	67	86	31.4
2.00	56.5	70	68	27.0	52.0	72	70	27.2	56.5	47	68	29.5	60.0	63	78	29.8
2.25	53.0	64	59	25.0	53.0	63	60	25.4	52.5	41	59	28.4	57.5	60	71	28.6
2.50	52.0	65	58	24.5	53.0	66	60	25.0	52.5	41	59	28.2	56.5	58	68	28.0
2.75	51.0	62	55	24.2	51.0	61	56	24.5	52.0	40	57	27.7	56.0	56	66	27.8
3.00	49.0	60	52	23.5	50.0	60	54	24.0	50.0	38	53	27.2	54.0	53	62	27.1
3.50	49.0	57	52	23.9	52.0	62	57	24.7	51.0	38	55	27.6	53.0	48	60	27.4
4.00	50.0	65	54	23.4	51.0	65	56	23.9	51.0	38	55	27.6	55.0	50	64	28.0
4.50	49.0	62	51	23.0	50.0	62	52	23.5	49.0	38	52	26.7	51.5	45	57	27.0
5.00	48.0	60	50	22.8	51.0	66	56	24.0	50.0	38	55	27.6	52.0	43	57	27.4
5.50	47.0	60	48	22.4	50.0	63	54	23.3	48.0	36	50	26.7	50.0	42	54	26.6
6.00	46.5	60	47	22.0	47.5	60	49	22.5	48.0	36	50	26.5	50.0	41	54	26.7
6.50	48.0	65	50	22.0	48.0	63	50	22.5	48.0	36	50	26.5	50.0	41	54	26.7
7.00	45.5	61	45	21.3	46.0	61	46	21.5	46.5	33	47	26.4	48.0	38	50	26.3
7.50	47.0	67	47	21.3	47.0	66	48	21.7	48.0	37	50	26.5	49.0	39	52	26.5
8.00	46.0	67	46	20.9	47.0	66	47	21.5	47.0	33	48	26.4	49.0	39	52	26.5

TABLE 6 (Concluded)

PSYCHROMETRIC DATA, RUN 65/4

HOURS OF DRYING	Point A				Point B				Point C				Point D			
	DP	RH	w	h	DP	RH	w	h	DP	RH	w	h	DP	RH	w	h
9.00	47.0	72	48	20.9	47.0	70	48	21.3	47.0	34	48	26.5	49.0	39	52	26.5
10.00	46.5	71	47	20.7	46.5	68	47	21.0	47.0	31	48	27.0	49.5	38	52	26.7
11.00	47.0	75	48	20.9	47.5	73	49	21.1	48.0	37	50	26.5	51.0	42	56	27.1
12.00	47.0	72	48	20.9	48.0	73	50	21.5	49.5	38	52	26.5	51.0	42	56	27.1
14.00	48.0	69	49	21.9	48.0	70	50	21.8	48.0	34	50	26.7	50.5	40	55	27.1
16.00	47.0	68	48	21.4	48.0	67	50	22.0	47.0	31	48	27.0	51.0	41	53	27.0

SYMBOLS
DP: Dew Point temperature, °F
RH: Relative humidity, %
w: Absolute humidity - Grains per lb. of dry air
h: Enthalpy, BTU per lb. of dry air
7000 grains = 1 lb.

It is possible to define a "thermal efficiency" for the dryer by the ratio of heat used to evaporate water to that supplied by the heater.

$$e_T = \frac{(w_D - w_C)\ L \times 100}{7000\ (h_C - h_B)} \qquad \text{.................(V-2)}$$

where L is the heat of evaporation at wet bulb temperature = 1050 BTU/lb at 70 - 80°F,

$h_C - h_B$ is the enthalpy rise across the heater, BTU/lb.

e_T is the thermal efficiency, %.

Equation (V-2) shows that recirculating air will increase efficiency because less heat will be required from the heater. There is an upper limit to $w_D - w_C$ governed by the diffusion of water through the fish. Low dew point temperatures will raise efficiency by permitting more recirculation. A plot of thermal efficiency for Run 65/4 is shown in Figure 21. Up to about 8 hours, the curve is much like a drying rate curve. This is not surprising, since $w_D - w_C$ is proportional to drying rate, the amount of recirculation is small, hence $h_C - h_B$ is practically constant. After about 10 hours, however, the curve begins to rise due to increased recirculation.

A rough idea of the amount of recirculation can be gained from:

$$\% \text{ Recirculation} = \frac{w_B - w_A}{w_D - w_A} \times 100 \qquad \text{..........(V-3)}$$

The result is not usually very accurate because of the fact that w's are not greatly different and are read from a psychrometric chart. The equation is theoretically exact, however.

(4) Drying Rates.

With regard to this item, our assessment must be a rough one since only two carts (approximately 1800 lbs) of light salted fish were dried. This was in Run PU 65/3, which included also one cart (about 700 lbs.) of heavy salted fish.

The dryer was designed to operate with a relative humidity of less than 55% at the downstream end. If this condition is not met, a marked difference can be expected between the downstream cart and the upstream cart in drying rates.

Figure 22 shows the conditions in the dryer during Run PU 65/3, and Figure 23 shows the moisture loss curves for the upstream and downstream carts. There were four carts in the dryer.

It will be seen that the downstream RH was generally in excess of 55% (due to high outside dew point temperature) for the first four hours of drying. (The solution to the problem would have been to raise the air temperature to about 85°F. This could very well be done in practice).

If the moisture content of the fish had been 73% (Wet Basis) at the beginning of the run, after 9 hours the upstream cart would have a moisture content of 66% (Wet Basis) and the downstream cart 68.5%.

(5) Conclusions.

Although the tests were not extensive, due to lack of fish, they were sufficient to show that the equipment produced results in general agreement with the design. Some of the tests were carried out during periods of extremely high dew point temperatures, but there was no fish spoilage. The advantage of a variable air speed was confirmed in the use of the dryer for the complete drying of small amounts of fish.

Since 1965, the dryer has seen considerable satisfactory commercial use.

VI

PROGRAMMED AIR TEMPERATURE DRYING

(1) Background.

In the first part of this report we have described a drying system which used the advantage of higher air speed to obtain reasonably high drying rates. Throughout those experiments the air temperature was maintained at 80°F. In this section we examine the effect of raising the air temperature. The danger in this technique is of course the risk of heat damage to the product. It is not easy to establish the temperature at which heat damage will occur in salt fish, since the effects - such as separation of skin from the flesh - do not become apparent until some considerable time after the drying is complete. Nevertheless, experience has shown that salt fish will not be harmed if the flesh temperature reaches 80°F, but the upper limit is something of this order - although this upper limit is apparently somewhat dependant on water content. In what follows, 80°F will be considered a safe maximum for fish temperature.

The temperature of the fish during drying is lower than air temperature due to the cooling effect of evaporation. Consequently, the air temperature can be above 80°F, and the fish will not be damaged.

This idea was first used in a drying system by Legendre[2] of the Fisheries Research Board of Canada. In that system, the temperature of the air was controlled by sensing (using a thermocouple) the temperature of the fish flesh. The control system adjusted the heat input so as to keep the fish temperature at 80°F.

A control system whose sensing element would have to be inserted into the fish flesh presents some difficulties. In the first place, because the sensing element would be surrounded by low heat-conductivity flesh, the system would have a high time lag, which would allow the air temperature to rise quite high before it was sensed by the control system. During these peaks, heat damage would be likely to occur, especially near the surface of the product.

Secondly, there is the very practical difficulty of properly inserting the sensing element into the fish, and preventing damage to lead-in wires, etc. during usage.

These disadvantages led us to believe that in the practical salt-fish industry, a less troublesome method would have to be used. Accordingly, we tried to develop a safe air temperature program that would keep the fish temperature near (preferably not above) 80°F.

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(2) Journal of Fisheries Research Board of Canada, 15(4) p.543

(2) Theory. [3]

It might be useful if a little of the thermodynamics governing air and fish temperatures were presented.

A drying substance loses heat, H, at rate given by

$$- \frac{dH}{dt} = L \frac{dW}{dt} \qquad \text{.....................(VI-1)}$$

where L = heat of vaporization, and W is the weight of the substance and t is the time. This heat loss is balanced by a heat gain given by

$$\frac{dH}{dt} = k_h A \ (T_A - T_F) \qquad \text{.....................(VI-2)}$$

where K_h is the heat transfer coefficient, A is the exposed area, and $T_A - T_F$ is the temperature difference between the air and the substance. Combining these equatinns we have that

$$T_A - T_F = \frac{-L}{k_h A} \frac{dW}{dt} \qquad \text{.....................(VI-3)}$$

Now in the case of fish drying, the rate of loss of water $- \frac{dW}{dt}$ is usually expressed as the decrease in moisture content per unit time, normally per cent (dry basis) per hour. Thus $- \frac{dw}{dt}$ is proportional to r the drying rate in % DB/Hr.

Hence $T_A - T_F = Kr$ ....(VI-4)

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(3) See, for example, "A Study of Evaporation and Diffusion Processes in the Drying of Fish Muscle", by A.C. Jason, Torry Memoir No. 12, Torry Research Station, Aberdeen, Scotland.

where we may define K to be the "program constant". It is easy to show that $K = \frac{LxDM}{100k_h A}$ ....(VI-5)

where DM stands for the weight of dry material with exposed area A. L, the latent heat of vaporization, can be considered constant at about 1050 BTU/lb. The overall coefficient of heat transfer, k_h will be a function of air velocity, which is normally held constant. We may, therefore, expect K to be determined mainly by the ratio of dry material to exposed area for the fish under consideration.

(3) Procedure.

In a drying run to obtain data for programs, the fish temperature was kept as near as possible to a constant value by controlling the air temperature. The temperatures were measured by thermocouples and recorded on the chart of an eight-point electronic recorder. The operator controlled temperatures by remote control of a motorized valve on the steam line.

The weight of a quantity of fish was measured continuously on a scale installed in the dryer. The record of the weights with time enabled drying rates etc. to be calculated.

(4) Results.

Several experiments were carried out to obtain values of K in equation (VI-4). Figure 24 shows the graph of $T_A - T_F$ with drying rate for Run 65/4. The value of K is obtained from the slope of this line. In all experiments, the points lie reasonably well on a straight line, as predicted by theory. Table (7) summarizes experiments of this type.

There is no apparent correlation between salt content and the program constant in the range of salt contents from 0 to 25%. (This includes all light salted fish.) The mean value of K for light salted fish was found to be 1.28. This means, for example, that if the drying rate is 10% DB/Hr, the temperature difference between the air and the fish surface will be about 13°F. (Provided, of course, that the wet bulb depression is more than 13°F. When the fish temperature is in the vicinity of 80°F, this condition is easily met.)

One experiment using heavy salted (kenched) fish was carried out, yielding a value of K = 2.84. One possible reason for this high value is the long period in salt (6-7 months) which would have the effect of reducing the effective exposed area per pound of

TABLE 7

PROGRAM CONSTANTS

Run No.	Description	Salt Content % DB	K °F-Hr.
65/8	medium size, split fish, no salt	0	1.00
12	medium size, split fish	0	1.26
9	medium size, in salt 16 hours	20.2	1.20
10	medium size, in salt 16 hours	16.4	1.26
7	medium size, in salt 24 hours	20.3	1.28
3	medium size, in salt 26 hours	19.5	0.68
19	medium size, in salt 72 hours	25.2	1.23
4	medium size, in salt 92 hours	25.1	0.97
6	medium size, in salt 96 hours	24.1	1.75
17	thick fish, in salt 138 hours.	22.5	1.29
2	medium, heavy kenched	37.0	2.84
14	Fillets, in salt 17 hours	19.9	0.80
16	Fillets, in salt 21 hours	16.4	0.81
20	Fillets, in salt 90 hours	19.2	0.80
5	Round fish, no salt	0	0.91

fish. Another reason might be a decrease in k_h due to salt buildup on the surface during drying. In any case, there is no problem in drying heavy salted fish with traditional methods, so the experimental results are of academic interest only.

The three experiments on light salted fillets gave a consistent value of 0.80 for K. The fillets had skin on one side. The reason for the lower value of K compared to light salted fish probably lies in a higher ratio of drying area per pound of fish.

(5) A Temperature Program for Light Salted Fish.

To get a temperature program suitable for light salted fish, we merely have to use the many drying rate curves that have been obtained together with equation (VI-4) where $K = 1.28$.

Figure 25 shows the highest and lowest drying rate curve obtained in many experiments with light salted cod. Between the two curves shown will lie rate curves for air temperature at 80°F and RH at 50% as well as those for which the fish temperature is 80°F and the RH might be as low as 20%.

The safest program (with regard to heat damage) will be obtained when the temperature is lowest, i.e. we select the low limit for the rate curve and apply equation (VI-4). The resulting temperature program is shown in Figure 26. The dryer air temperature can be obtained by adding the temperature differences from the graph to any desired fish temperature. Four such programs are shown in Figure 27.

(6) Illustration.

For the sake of discussion, let us choose a theoretical fish temperature of 77°F. If the drying rate is exactly that shown as the lower limit curve in Figure 25, the actual fish temperature will be constant at 77°F during the program time. After 20 hours, the air temperature will be down to 80°F, and if drying is continued, it would be held constant at 80°F. However, the drying rate depends on many things, principally the diffusion coefficient for water in the fish and (early in the run) on the air conditions in the dryer, as shown in Chapter III. It is, therefore, unlikely that the fish temperature would be exactly 77°F. Since we have chosen the lowest observed rate curve, the actual rate would likely be higher and the fish temperature, therefore, less than 77°F.

Figure 28 shows how the RH before the fish would vary with time for dew point temperatures of 55°F, 60°F and 62°F. Even at a dew point temperature of 62°F (a rare occurrence in Newfoundland) the RH does not reach 50% until 10 hours have elapsed. By this time the moisture content would have decreased by at least 90% DB, and the fish should be beyond the stage where spoilage would occur.

(7) Effect of Program on Dryer Load.

The amount of fish that a dryer can safely handle is governed by the outside dew point temperature and the mass of dry air being passed through the fish per unit time.

Under any particular drying conditions, the limiting factor is ultimately the relative humidity at the downstream end of the load. We have previously set an upper limit of 55% on this RH. Hence the allowable moisture pickup, $W_2 - W_1$, (see equation (IV-1)) is dependent on the outside dew point since this controls W_1. When the dew point is high, $W_2 - W_1$ is quite low, and hence the load must be small.

The effect of using higher temperatures early in the run is to raise the value of W_2 which will give the limiting RH. This in turn allows the dryer load to be increased. The drying rate falls rapidly as drying progresses, so that in effect the allowable load increases as the fish dries. In practice of course, the load must be held constant at some value which is allowable at the beginning of the run.

Figure 29 shows graphs of $\frac{L}{Q}$ with time for an outside dew point temperature of 55°F. The drying rates "r", in equation (IV-1) were taken from the maximum rate curve shown in Figure 25. This will lead to an underestimate of $\frac{L}{Q}$ rather than an overestimate.

It can be seen from Figure 29 that the allowable load at a drying time of 2 hours for a constant air temperature dryer is 0.4Q while if the program is used it is about 1.0Q. This means that if a dryer were to be designed to adequately handle a load from 2 hours onward at air temperature = 80°F, the load could be 2.5 times as large if a temperature program were used. (The drying rate at 2 hours might be as high as 19% DB/Hr.) If the design were to be safe for 5 hours and onwards (rate at 5 hours is 10% DB/Hr), the ratio is 1.8.

The implication of all this discussion is that dryer loads could be approximately <u>doubled</u> for the same fan and motor if the air temperature program were used.

(8) Summary.

The following conclusions were drawn from the work on programmed air temperature drying of light salted fish:

(1) As predicted by theory, the difference in temperature between air and fish was directly proportional to drying rate, with the proportionality constant for light salted fish having a mean value of 1.28°F - Hr when the rate is measured in %DB/Hr.

(2) The range of program constants observed was from 0.68 to 1.75, but 5 of 8 values were between 1.20 and 1.29, and there was no apparent correlation between the constants and salt content.

(3) Drying rate curves for light salted fish lie within two reasonably close upper and lower limit curves.

(4) An air temperature program based on the lowest rate curve (therefore the "safest" program) was derived.

(5) Since the use of higher air temperatures early in the run will keep the relative humidity low at a time when the drying rate is high, a dryer can safely handle up to twice as much fish for a given air flow rate with a program as it can with a constant air temperature.

VII

TESTING OF PROGRAMMED AIR TEMPERATURE DRYING

(1) Procedure.

The aim of the testing program was to make the experiments conform as closely as possible to actual practice. To achieve this end, practically all of the handling and preparation of the fish was carried out by the regular plant staff.

The split fish were salted in tanks using approximately 9 lbs. of salt per 100 lbs. of split fish. After 4 days in the tanks the fish were washed by hand and usually were left to drain in the cool room overnight. The dryer trays were loaded by the plant workers, the only special instruction being that fish should not lie across the aluminum frame of the dray, since this could lead to heat damage.

After the fish was put into the dryer, the dryer air temperature was controlled according to a previously selected program. Four programs were used, in which the theoretical fish temperatures were 80°F, 77°F, 75°F and 73°F. These programs are shown in Figure 27. The dryer controls were operated by the research assistants on a 24 hour basis. During the drying period, temperature of air and fish, relative humidities, and weight of a scale load (about 22 trays) of fish were recorded. These data made possible the comparison of results with theoretical predictions. Salt and moisture contents were measured in the usual manner.

(2) Temperature Controls.

Special equipment was necessary in order to automatically control temperatures according to the programs of Figure 27. Of course, the program could be approximated by a series of constant temperature steps achieved by periodic resetting of an ordinary dryer thermostat. However, we were mainly interested in an automatic method of control, and our efforts were directed to this end. The main piece of new equipment used was an "Electronic Program Controller" manufactured by Thermovolt Instruments Limited, and a description of its operation follows.

The required program was cut (at Valleyfield) on a plastic disc cam. The cam follower positioned a photo cell and a light source on a temperature scale. The air temperature was sensed by a resistance thermometer and positioned a vane so as to cut off light to the photo cell when the air temperature equalled that required by the program.

When the air temperature was below the set point, the amplified photo cell output closed a relay which instructed the motorized valve on the steam line to open, and when the air temperature exceeded the set point, the motorized valve was instructed to close.

Three different methods of application of this equipment were investigated, and perhaps a brief comparison would be in order.

Method 1 - Motorized valve only - completely automatic. The operation here was that described above. There was a rather severe oscillation of dryer air temperature around the set point using this method.

Method 2. Shunt solenoid valve and motorized valve - completely automatic. In order to reduce the oscillation a 1" solenoid valve was installed in a shunt steam line around the 2" motorized valve. Both these valves were then driven by the automatic programmer, using a suitable electronic relay between the programmer and the valves.

Method 3. Semi - Automatic. A further improvement could be obtained by controlling the motorized valve manually (by adjustment of a simple controller) and allowing the programmer to control only the solenoid shunt valve. Only occasional setting of the motorized valve was necessary, and after the first few hours it could be closed down completely and the solenoid valve used alone. The solenoid valve alone gave a much better response than the motorized valve alone. (See Figure 30.)

(3) Drying Results.

Table (8) shows a summary of the drying runs carried out.

(a) Fish Temperatures. The programs are supposed to keep fish temperatures near (but not above) the program temperature. An overall picture of the results can be seen in Figure 31. Fish temperatures were generally about those predicted and rarely exceeded 80°F. The runs in which temperatures were slightly higher than expected are those in which there was a higher proportion of very thick fish, leading to lower than anticipated drying rates. It might be mentioned at this stage that there was practically no heat-damaged fish produced.

(b) Drying Rates & Moisture Loss. A large quantity of information could be presented on drying rates, etc., but we feel that an overall picture can be obtained by looking at simply the

TABLE 8

SUMMARY OF DRYING RUNS

RUN NO.	DRYING HOURS	MOISTURE-% DB In	MOISTURE-% DB Out	SALT % DB	WEIGHT OF FISH In	WEIGHT OF FISH Out	PROGRAM TEMP.	CONTROL METHOD
1	30	267	102	34	2376	1340	77°F	Manual
2	41	266	95	26	2570	1364	77	Manual
3	43	307	112	32	2974	1435	77	Method 1*
4	27	297		25	2860	1782	77	Method 1
5	28	321	139	28	2587	1330	80	Manual
6	31		108	26	3153	1640	80	Method 3
7	28				2554	1153	80	Method 2
8	37		122	29	1730	1110	80	Method 2
9	29		146	26	1068	623	73	Method 2
10	27		111	22	1151	673	80	Manual
11	27		128	19	3004	1890	80	Method 3
12	30		122	20	2234	1700	75	Method 3
13	29		126	26	2326	1460	75	Method 3
14	29		145	24	3087	1957	73	Method 3
15	34	278	118	16	637	374	77	Method 3
16	34		135	21	2557	1483	77	Method 3
17	29		145	23		1873	73	Method 3
18	25			20	1017		75	Method 3

* See previous page.

mean moisture loss curves for the various programs. These are shown in Figure 32. The curves for 77°F and 80°F programs are nearly identical, as are the pair for the 73° and 75° programs. No explanation can be offered for this, and it is probably only coincidental, since there is considerable overlap in the range of curves from all four programs, although those of higher program temperature are usually (but not always) above those of a lower program temperature. Other factors (notably load size and fish thickness) have considerable influence on these curves.

(c) Quality. We now turn to what is possibly the most significant part of the project as far as application is concerned; that of product quality.

After the fish had received first drying using Programmed Air Temperature, it was usually stored in the cool room and repiled in the normal way of handling salt fish in the Valleyfield plant. After 7 - 10 days (ideally) the fish was put in for second drying in the large, low air speed "Bonavista Type" dryer. The second drying usually lasted about 36 hours. After complete drying, the fish was culled by the regular plant culler.

The results of the cull, by program temperature, are shown in Table 9. "Choice", "Prime", "Maderia" and "Thirds" are 1st, 2nd, 3rd and 4th grades, respectively.

TABLE 9

CULLING RESULTS (Small Fish - length 18" to 24")

PROGRAM TEMP.	Total Wt-lbs.	Choice %	Prime %	Maderia %	Thirds %
73°F	811	35	24	41	0
75°F	2365	16	25	56	3
77°F	2379	41	16	38	5
80°F	2665	18	14	67	2

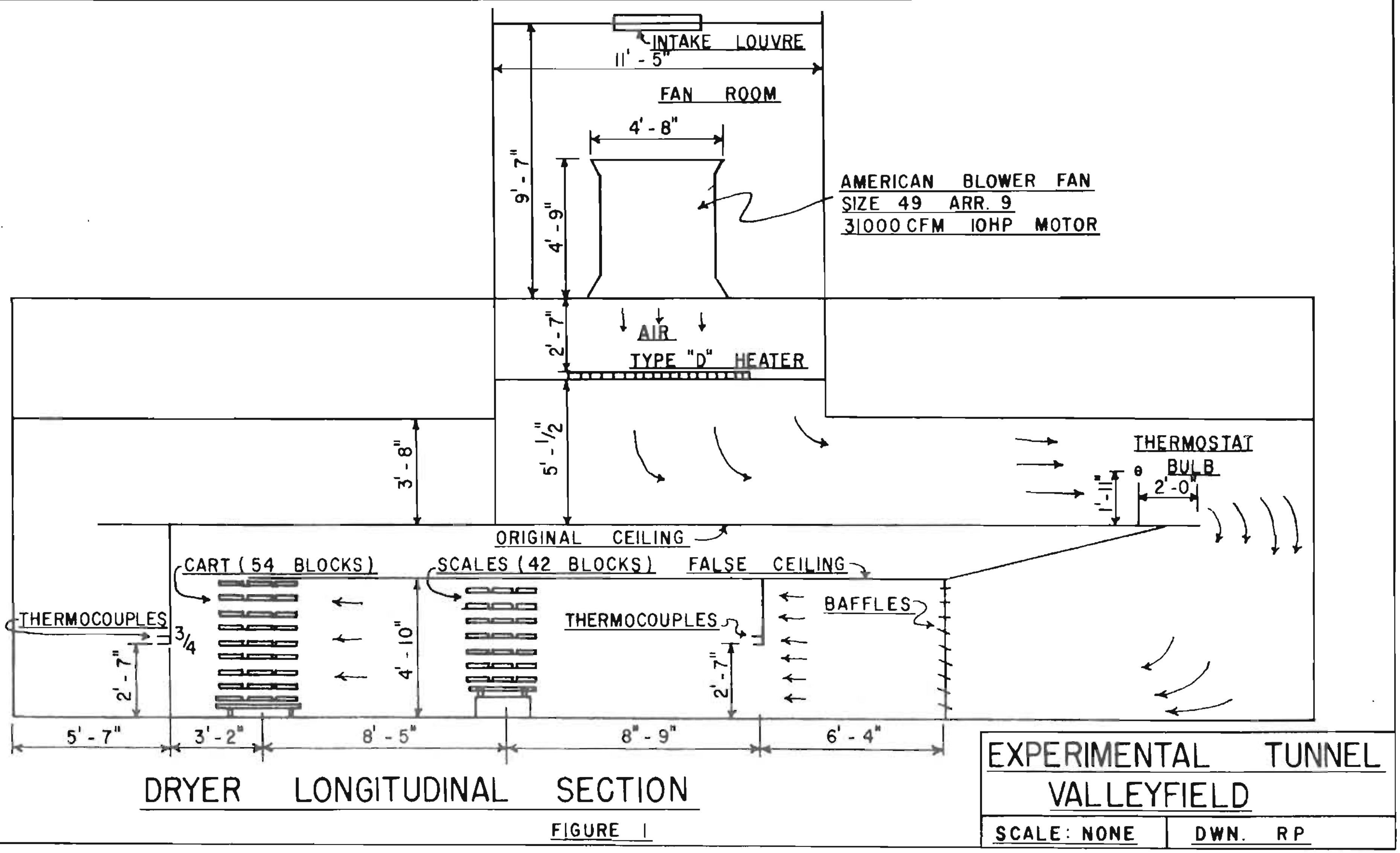
In addition to the "small" fish above, 1417 lbs. of "medium and large" (over 24") fish were also culled. These usually gave better grades because of fewer rejections due to thinness. The results here, taking all programs together were: Choice: 49%, Prime: 21%, Maderia: 30%. The overall results of the above culling for all program temperatures (including medium and large fish) are as follows: Choice: 30%, Prime: 18%, Maderia: 50%, Thirds: 2%.

Another significant fact is that not more than about 20 lbs. of fish in 10,000 was rejected because of heat damage.

(4) Conclusions.

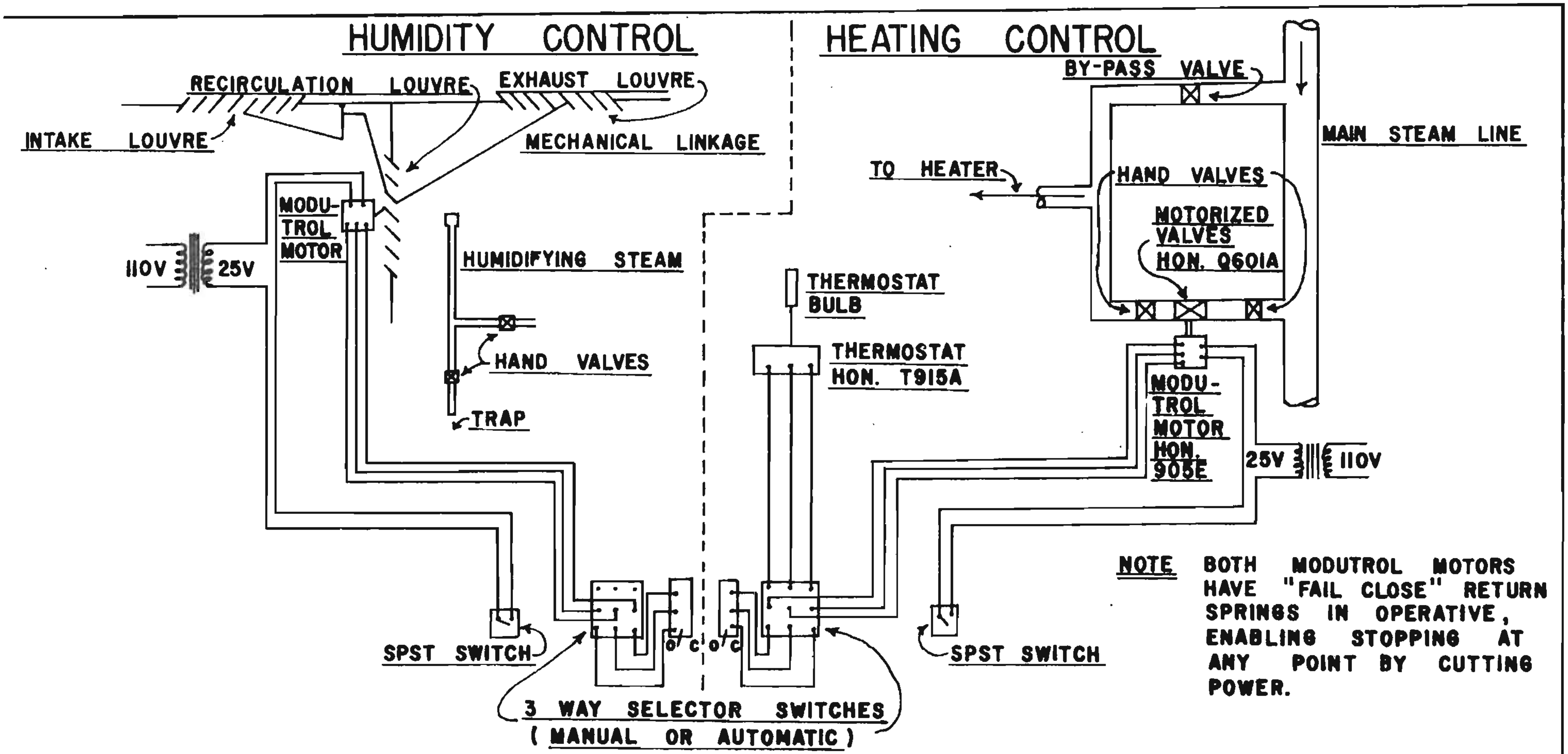
It has been demonstrated that it is possible to produce high quality light salted fish by using programmed air temperature drying.

Although time does not permit a detailed economic or design study, programmed air temperature drying seems sound from both an economic and engineering standpoint. Very little additional capital outlay is required beyond that of a constant temperature dryer - the additional expenditure being essentially that of the control system. Since (as was pointed out in Section VI (7)) the dryer will safely accommodate up to twice as much fish as a constant temperature dryer, a reduction in cost per unit output (of comparable quality) would probably be realized. The only factor leading to an increase in operating cost is the increased heat necessary to maintain the higher temperatures. A rough estimate, using an outside temperature of 60°F shows that the total heat demand over the first 20 hours of drying would be about 25% higher for the 77% program than for a constant air temperature of 80°F.



DRYER LONGITUDINAL SECTION

FIGURE 1



TEMPERATURE & HUMIDITY CONTROL SYSTEM

EXPERIMENTAL TUNNEL
VALLEYFIELD

SCALE: NONE | DWN. RP

FIGURE 2

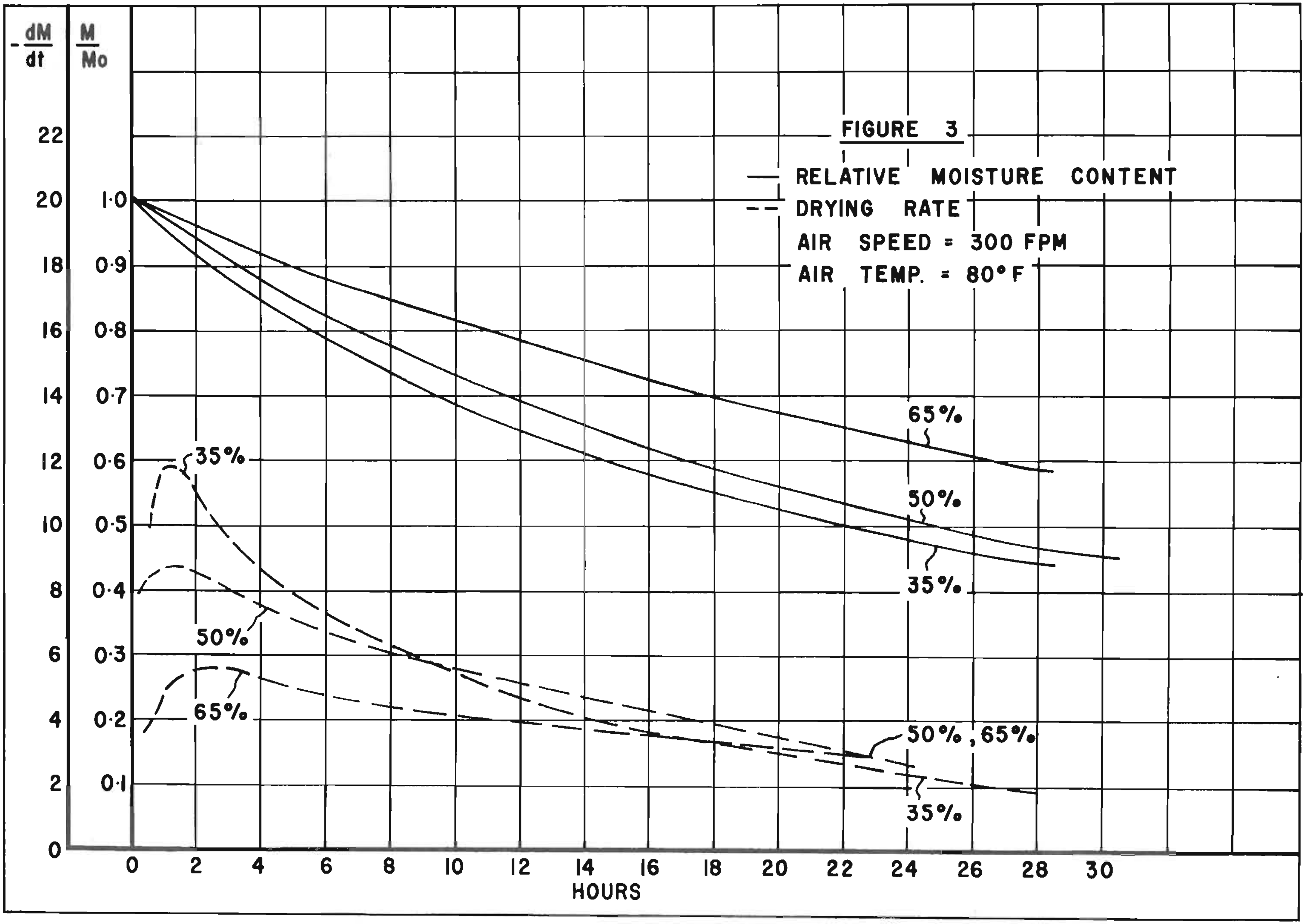


FIGURE 3
RELATIVE MOISTURE CONTENT
DRYING RATE
AIR SPEED = 300 FPM
AIR TEMP. = 80° F
$-\frac{dM}{dt}$
$\frac{M}{Mo}$
HOURS
65%
50%
35%
50%, 65%

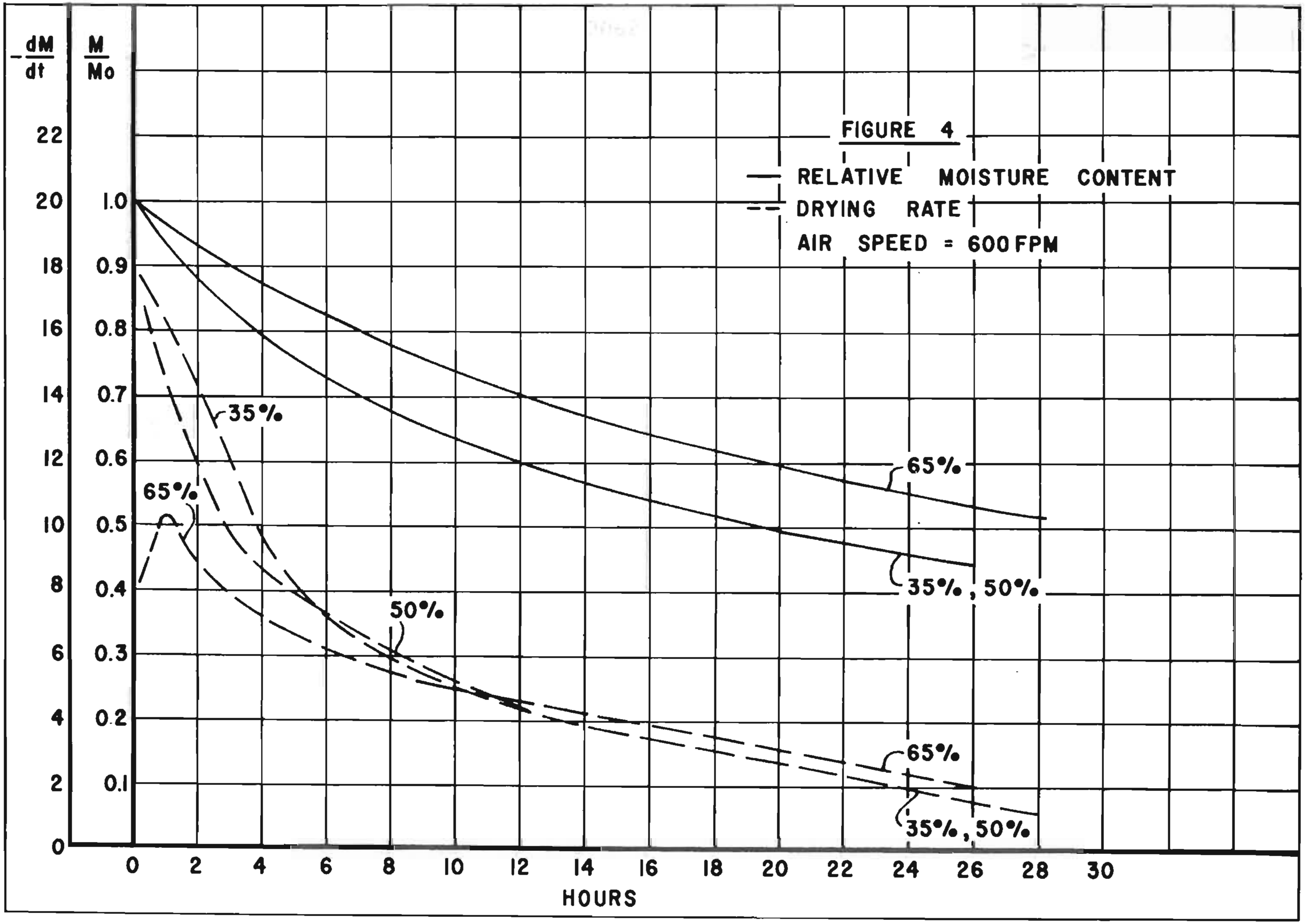


FIGURE 4
RELATIVE MOISTURE CONTENT
DRYING RATE
AIR SPEED = 600 FPM
-dM/dt
M/Mo
HOURS
35%
50%
65%
35%, 50%

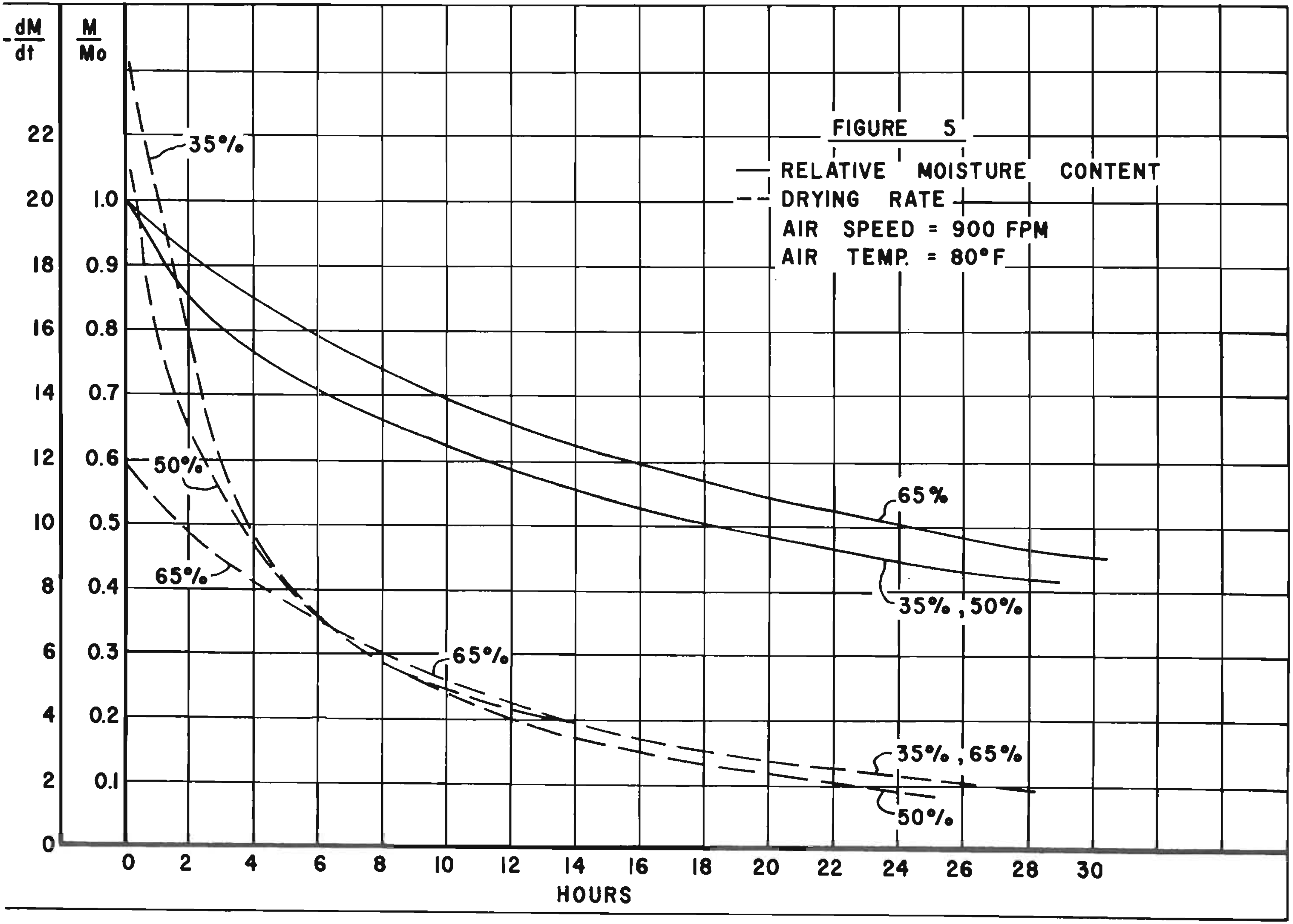


FIGURE 5
RELATIVE MOISTURE CONTENT
DRYING RATE
AIR SPEED = 900 FPM
AIR TEMP. = 80°F
$-\frac{dM}{dt}$
$\frac{M}{Mo}$
HOURS
35%
50%
65%
65%
35%, 50%
65%
35%, 65%
50%

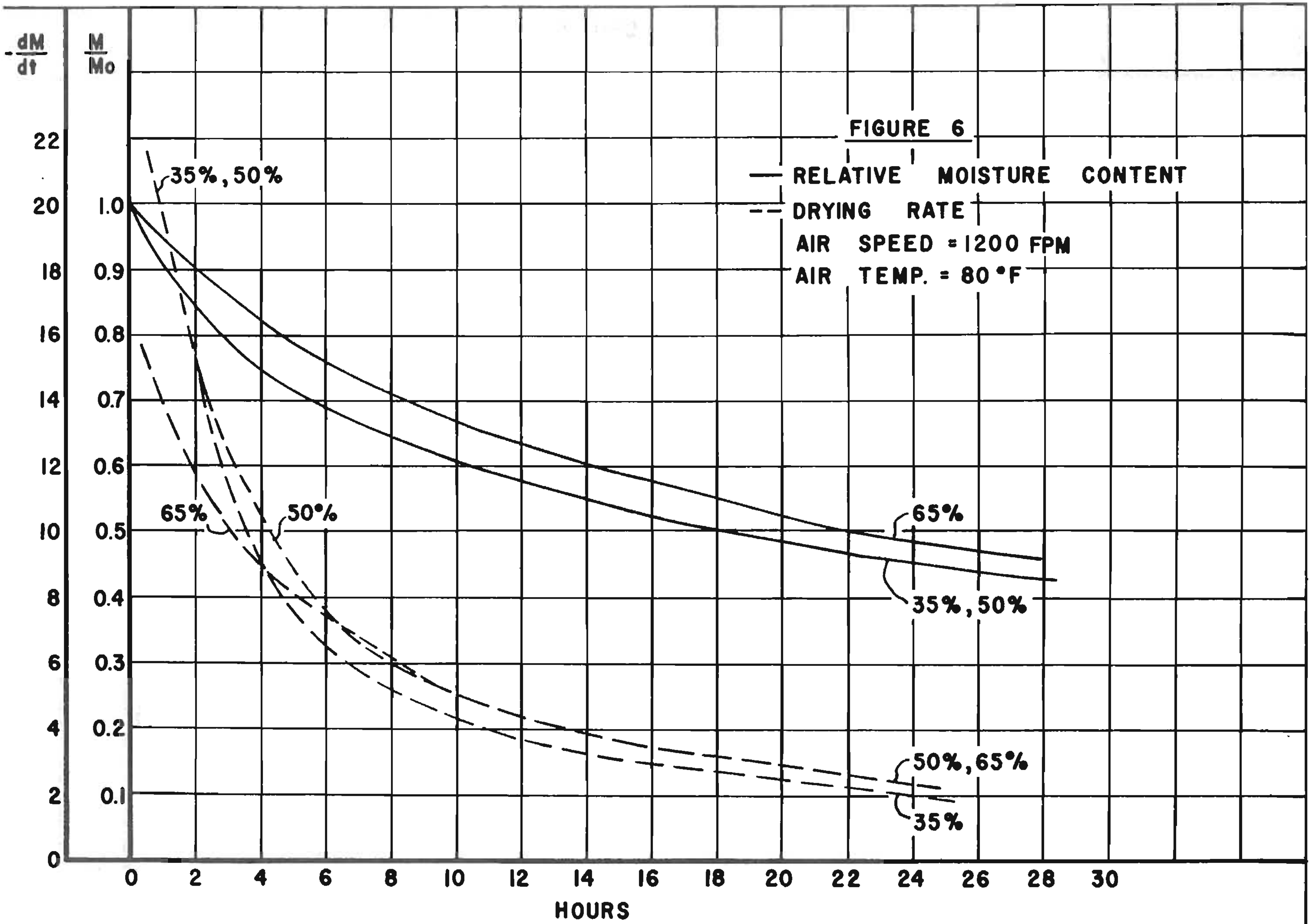


FIGURE 6
RELATIVE MOISTURE CONTENT
DRYING RATE
AIR SPEED = 1200 FPM
AIR TEMP. = 80 °F
- dM/dt
M/Mo
22
20
18
16
14
12
10
8
6
4
2
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
35%, 50%
65%
50%
65%
35%, 50%
50%, 65%
35%
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
HOURS

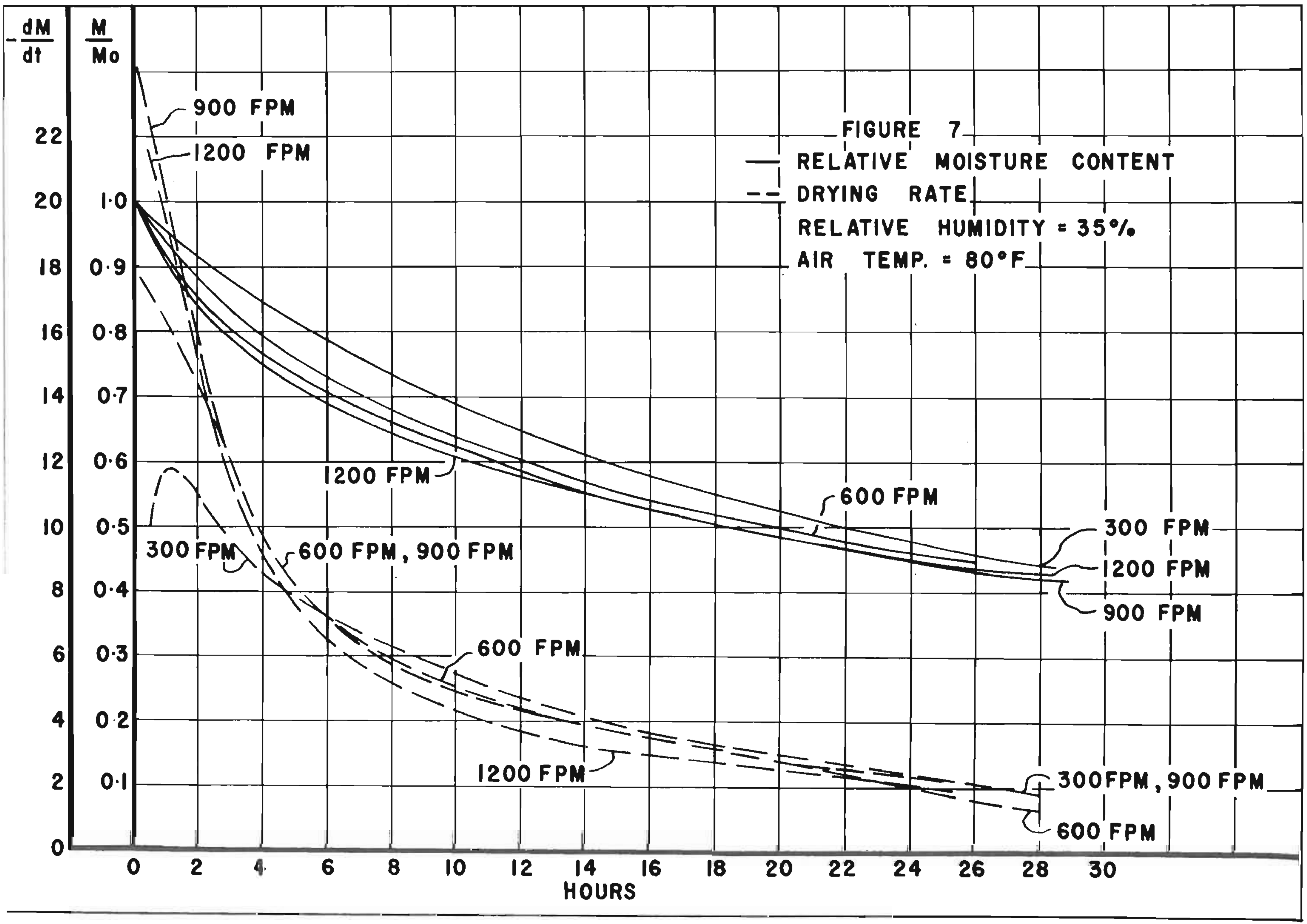


FIGURE 7
RELATIVE MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 35%
AIR TEMP. = 80°F
- dM/dt
M/Mo
900 FPM
1200 FPM
1200 FPM
600 FPM
300 FPM
1200 FPM
900 FPM
300 FPM
600 FPM, 900 FPM
600 FPM
1200 FPM
300 FPM, 900 FPM
600 FPM
HOURS

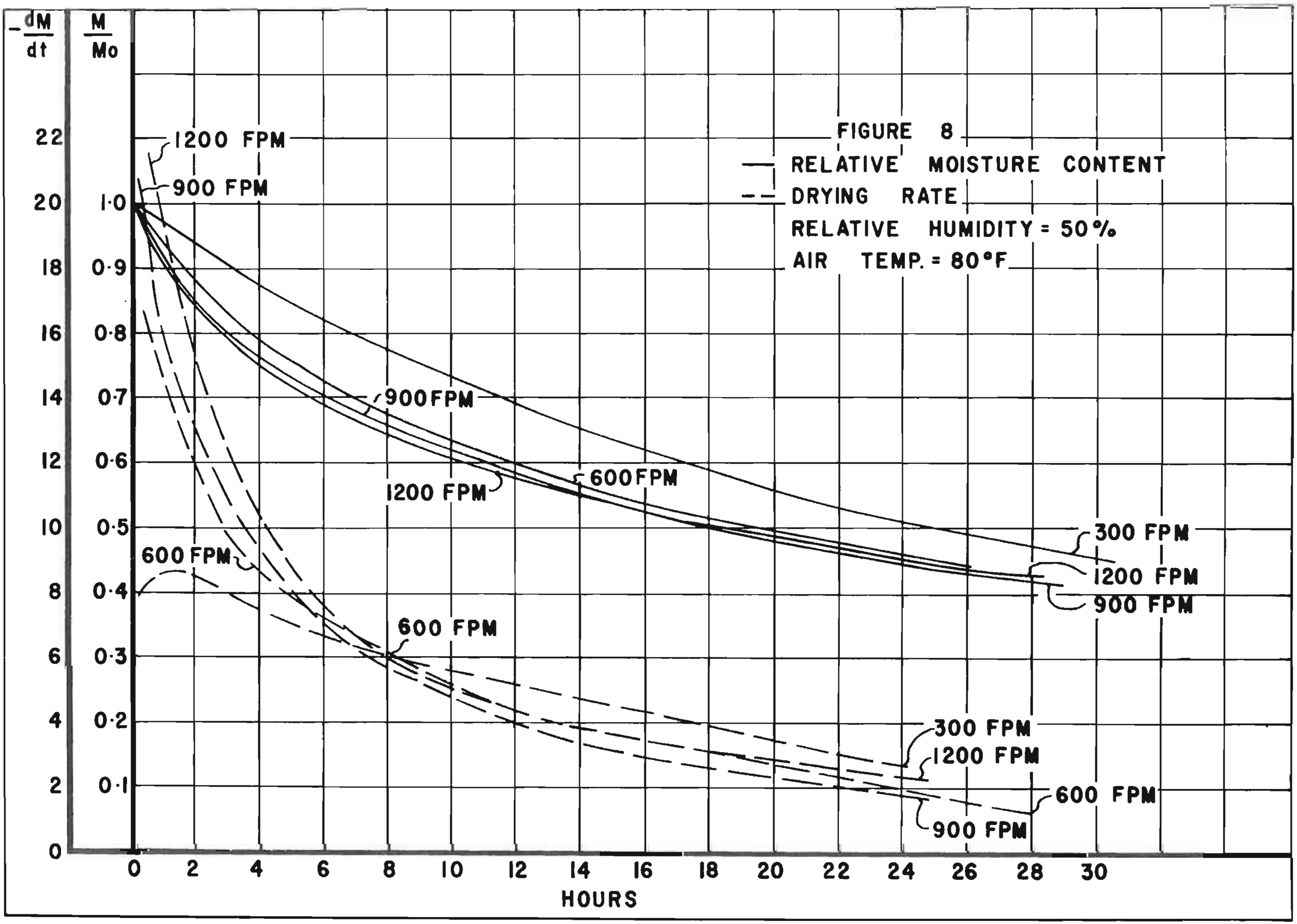


FIGURE 8
RELATIVE MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 50%
AIR TEMP. = 80°F
$-\frac{dM}{dt}$
$\frac{M}{M_o}$
1200 FPM
900 FPM
600 FPM
300 FPM
HOURS

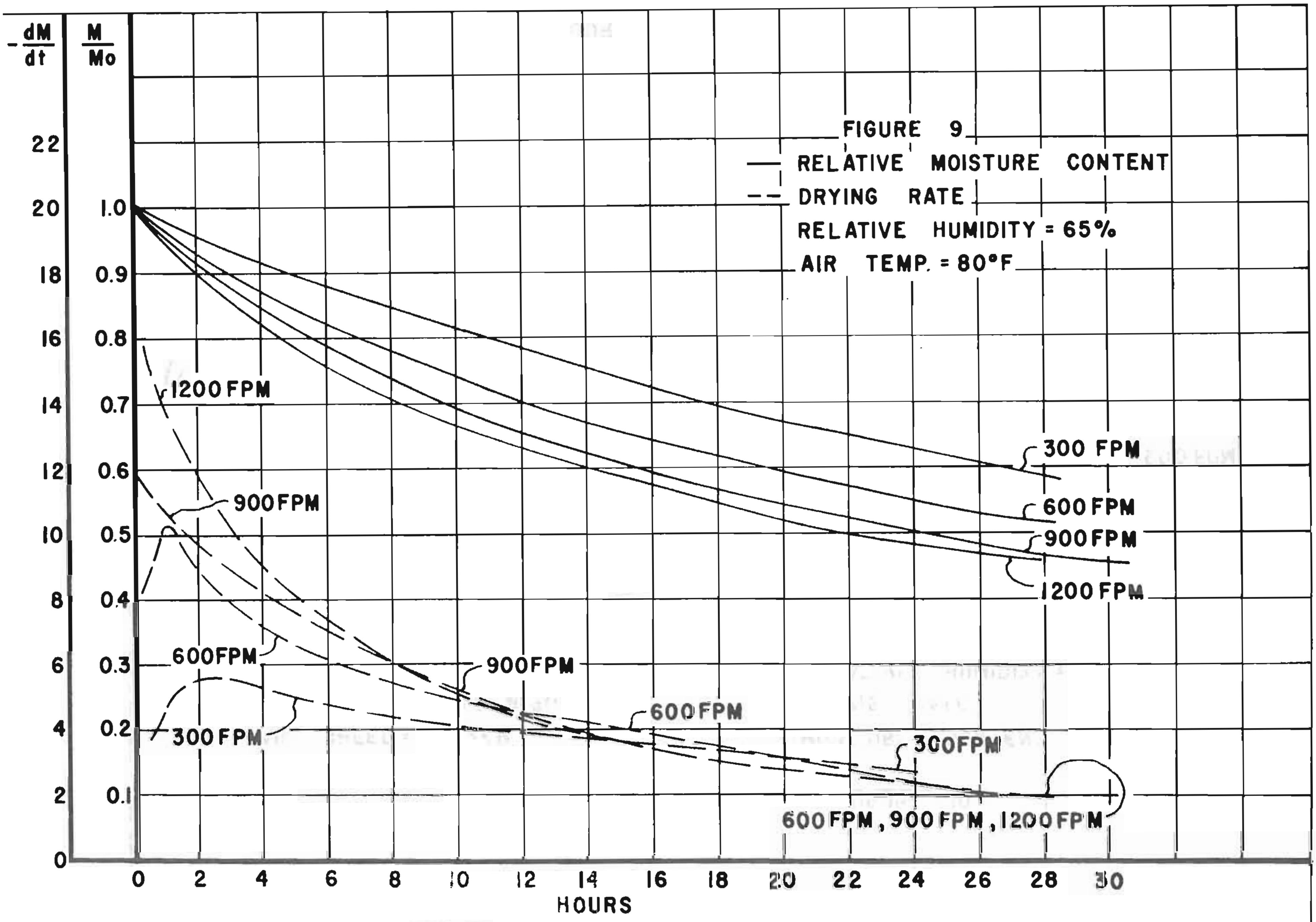


FIGURE 9
RELATIVE MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 65%
AIR TEMP. = 80°F
- dM/dt
M/Mo
0
2
4
6
8
10
12
14
16
18
20
22
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
HOURS
300 FPM
600 FPM
900 FPM
1200 FPM
1200 FPM
900 FPM
600 FPM
300 FPM
900 FPM
600 FPM
300 FPM
600 FPM, 900 FPM, 1200 FPM

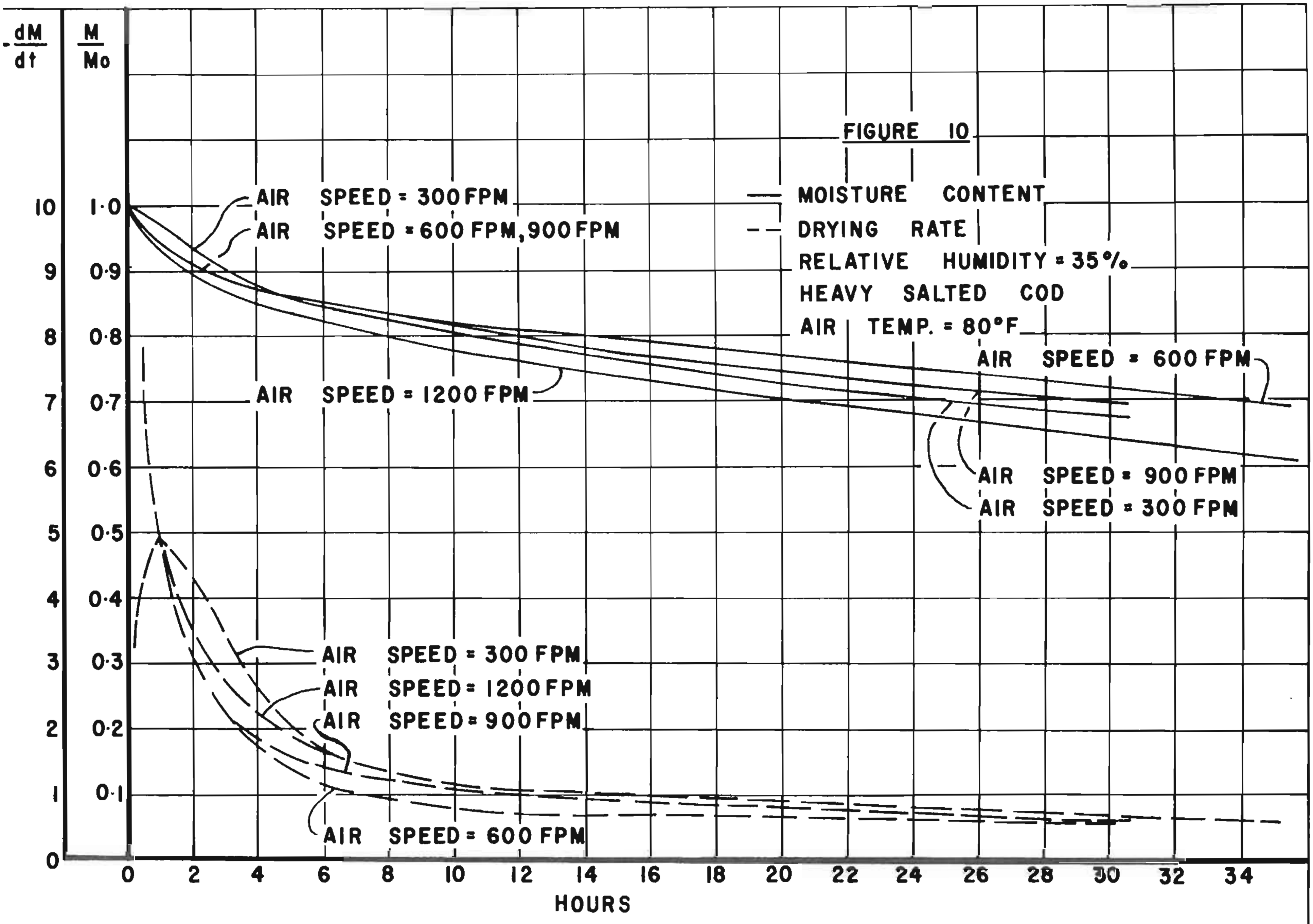


FIGURE 10
— MOISTURE CONTENT
- - DRYING RATE
RELATIVE HUMIDITY = 35%
HEAVY SALTED COD
AIR TEMP. = 80°F
AIR SPEED = 300 FPM
AIR SPEED = 600 FPM, 900 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 600 FPM
AIR SPEED = 900 FPM
AIR SPEED = 300 FPM
AIR SPEED = 300 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 900 FPM
AIR SPEED = 600 FPM
$-\frac{dM}{dt}$
$\frac{M}{M_o}$
10
9
8
7
6
5
4
3
2
1
0
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
HOURS

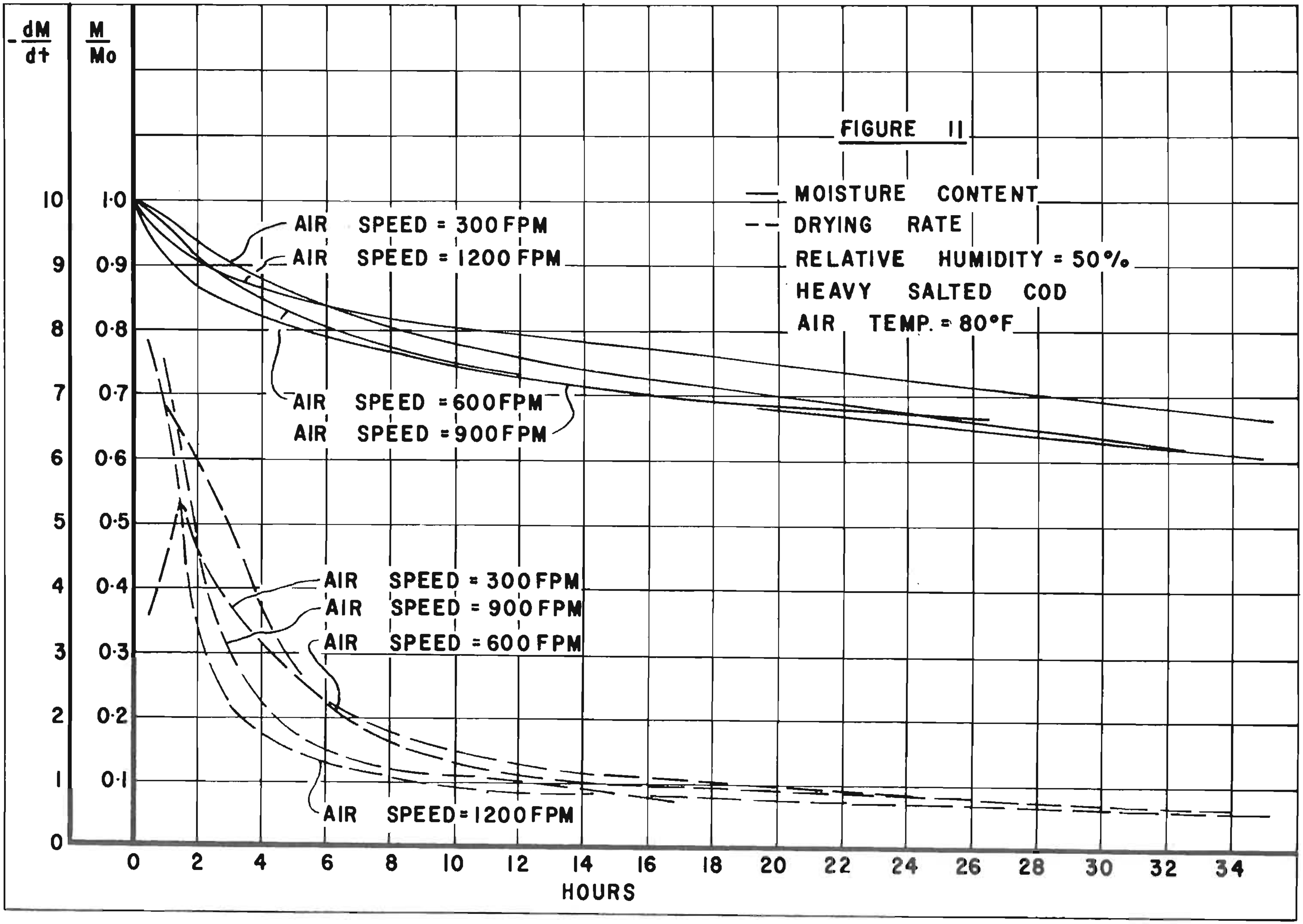


FIGURE 11
MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 50%
HEAVY SALTED COD
AIR TEMP. = 80°F
AIR SPEED = 300 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 600 FPM
AIR SPEED = 900 FPM
AIR SPEED = 300 FPM
AIR SPEED = 900 FPM
AIR SPEED = 600 FPM
AIR SPEED = 1200 FPM
$-\frac{dM}{dt}$
$\frac{M}{Mo}$
HOURS

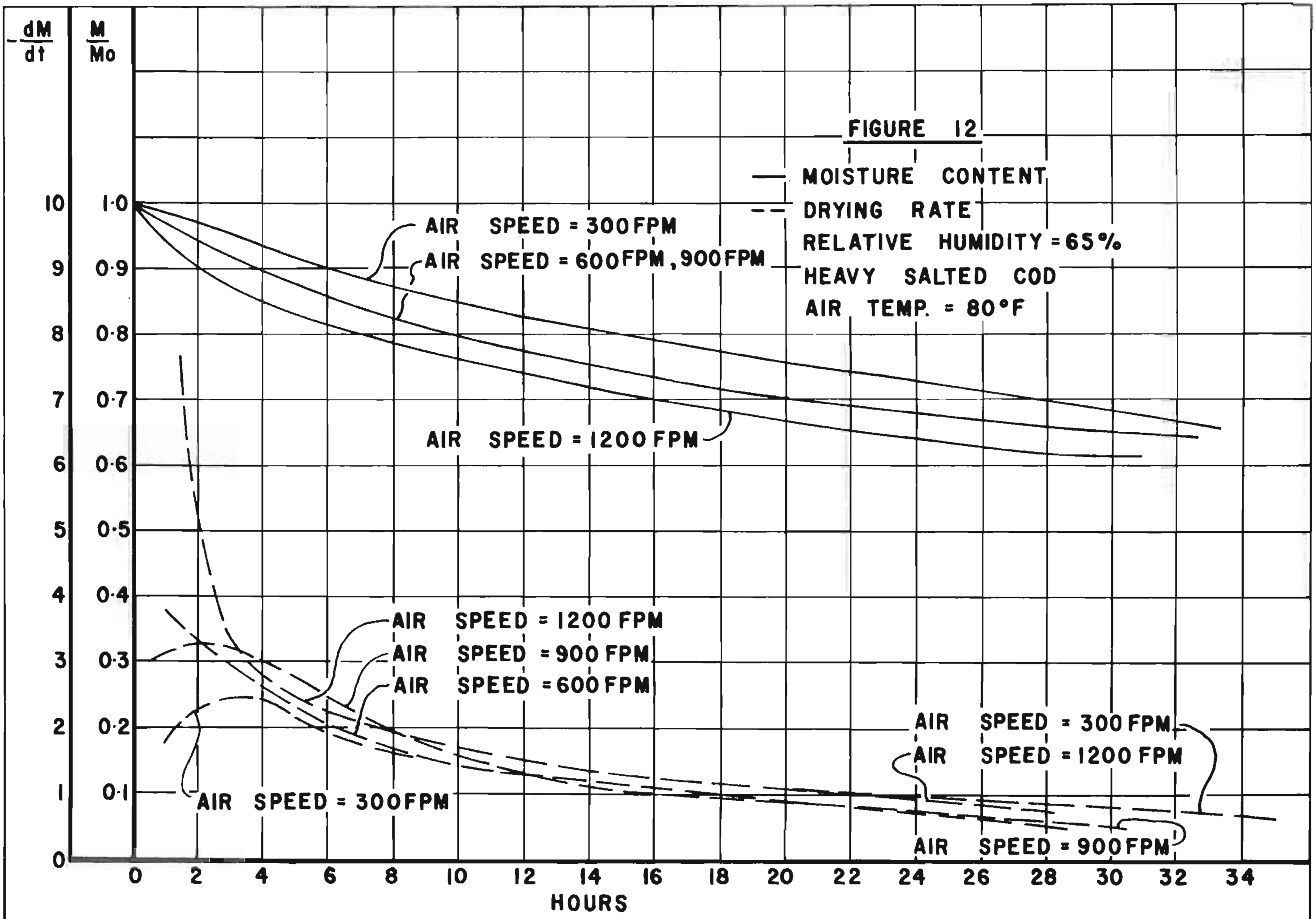


FIGURE 12
MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 65%
HEAVY SALTED COD
AIR TEMP. = 80°F
-dM/dt
M/Mo
10 9 8 7 6 5 4 3 2 1 0
1·0 0·9 0·8 0·7 0·6 0·5 0·4 0·3 0·2 0·1
AIR SPEED = 300 FPM
AIR SPEED = 600 FPM, 900 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 900 FPM
AIR SPEED = 600 FPM
AIR SPEED = 300 FPM
AIR SPEED = 300 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 900 FPM
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
HOURS

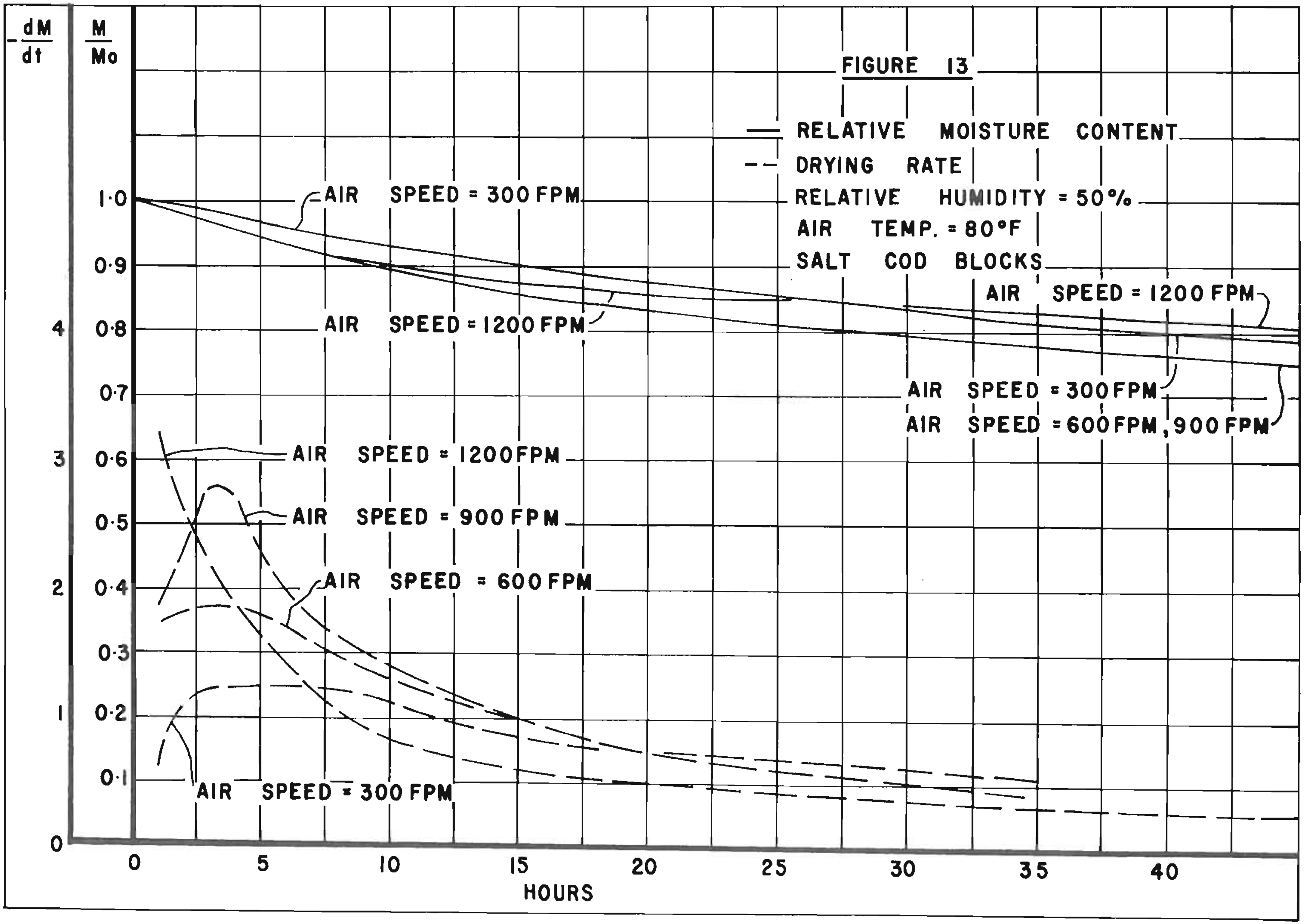

- dM/dt
M/Mo
RELATIVE MOISTURE CONTENT
DRYING RATE
RELATIVE HUMIDITY = 50%
AIR TEMP. = 80°F
SALT COD BLOCKS
AIR SPEED = 300 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 300 FPM
AIR SPEED = 600 FPM, 900 FPM
AIR SPEED = 1200 FPM
AIR SPEED = 900 FPM
AIR SPEED = 600 FPM
AIR SPEED = 300 FPM
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
1
2
3
4
0
5
10
15
20
25
30
35
40
HOURS

FIGURE 13

FIGURE 14

PORT UNION DRYER

SCALE : $\frac{1}{4}$" = 1'

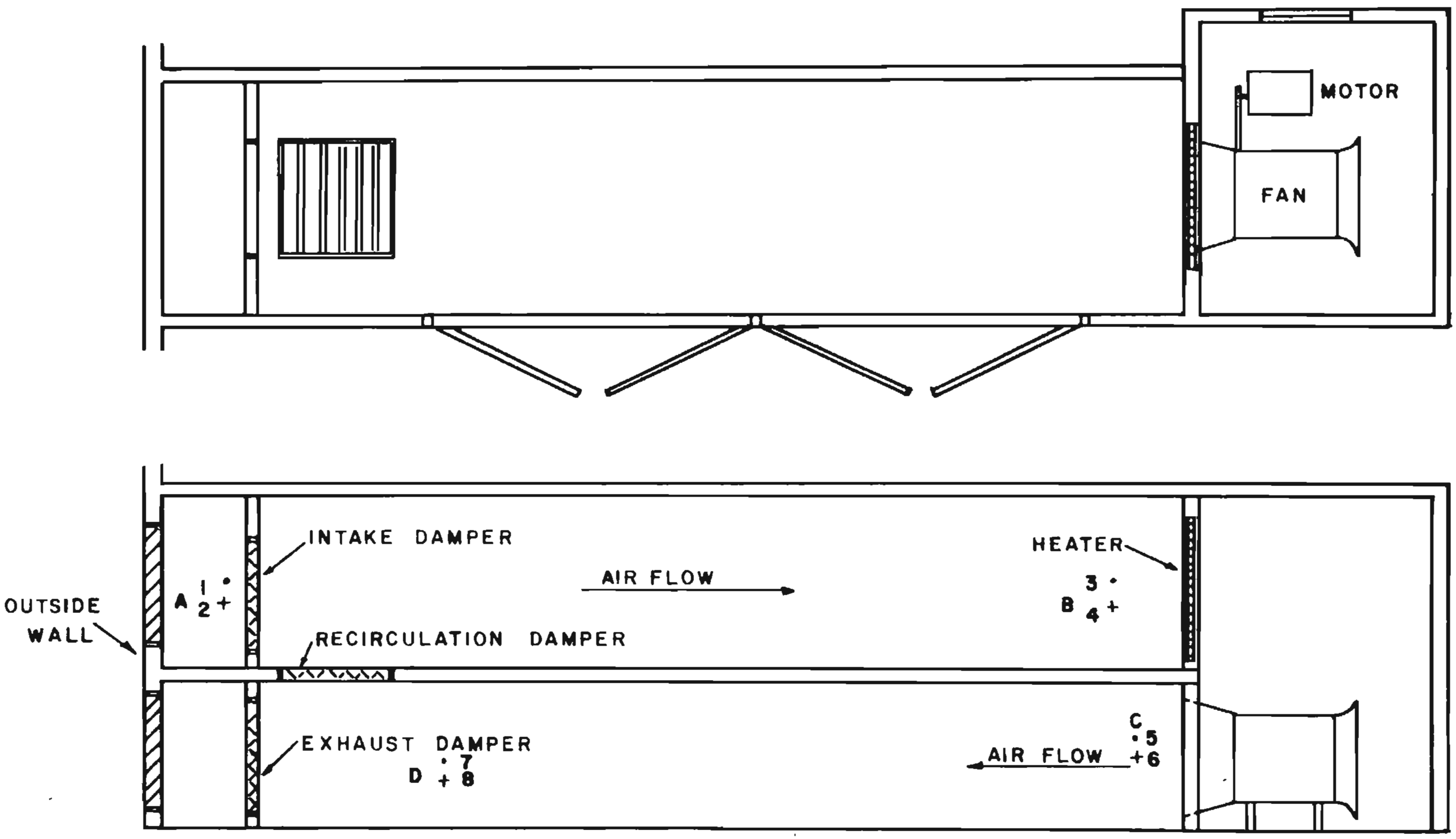


FIGURE 15A
LOAD WITH AIR FLOW RATE
VARIOUS DRYING RATES
DEW POINT = 50°F

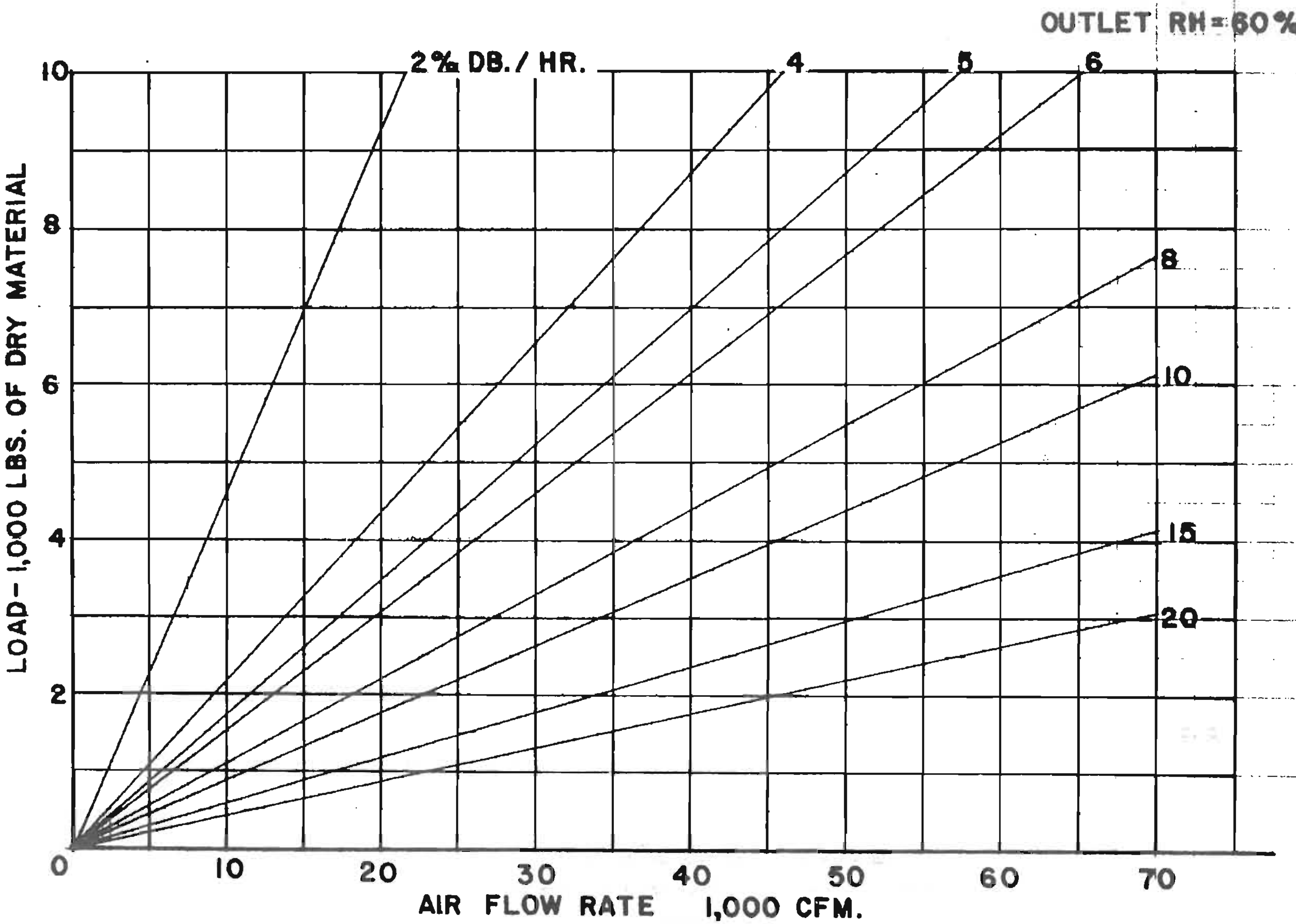


FIGURE 15B
LOAD WITH AIR FLOW RATES
VARIOUS DRYING RATES
DEW POINT = 55°F

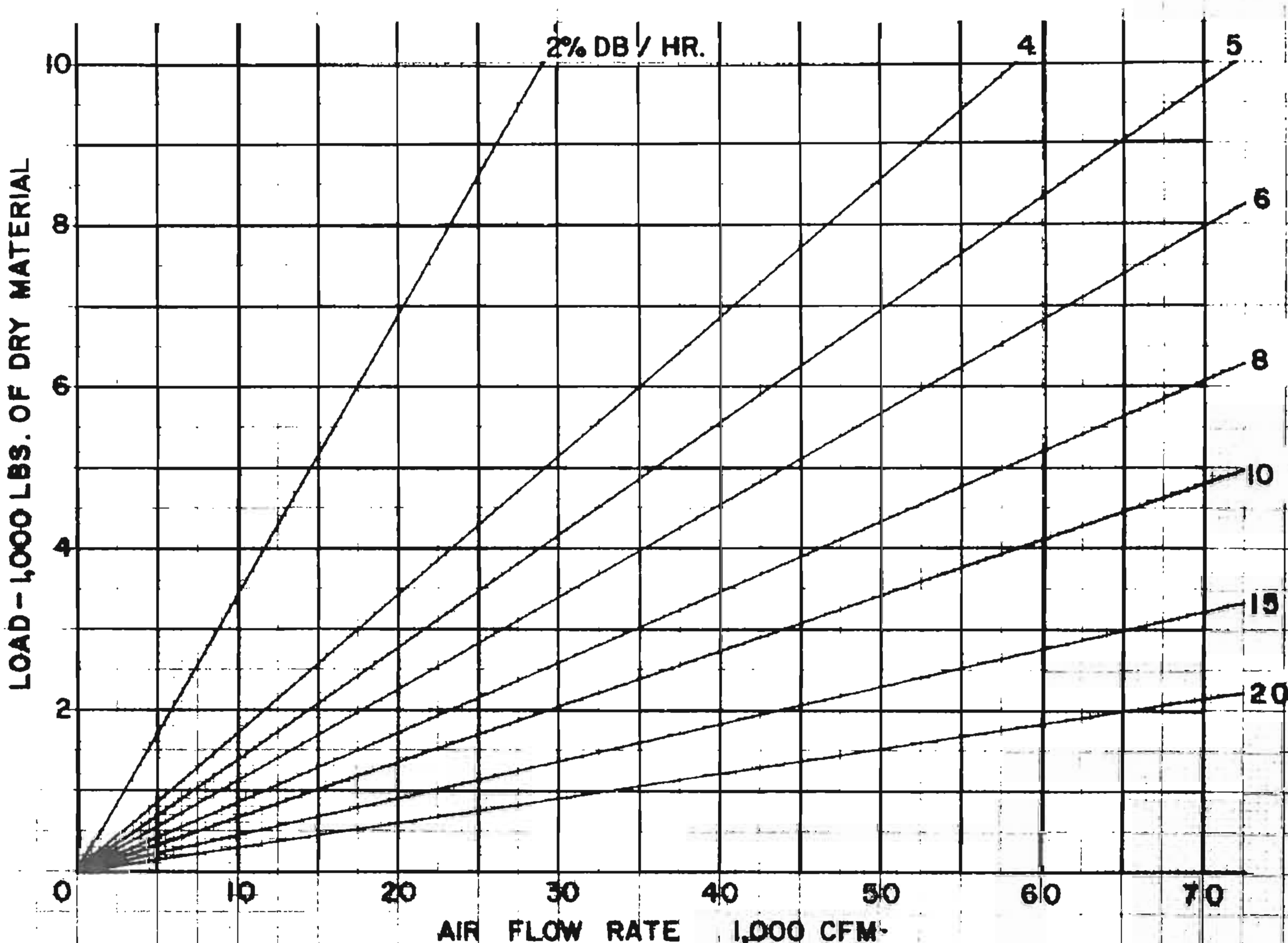


FIGURE 15C
LOAD WITH AIR FLOW RATES
VARIOUS DRYING RATES
DEW POINT = 60°F

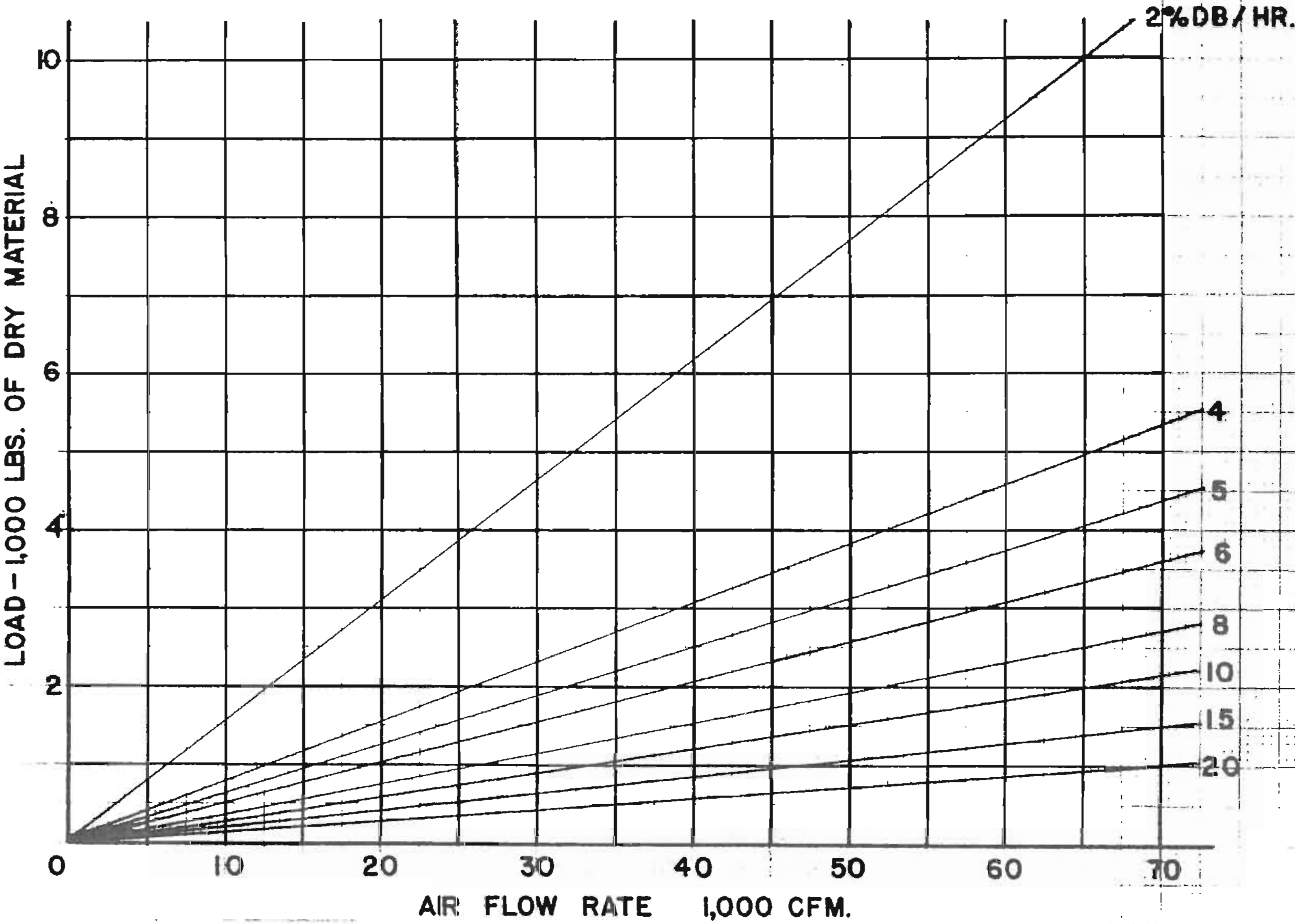
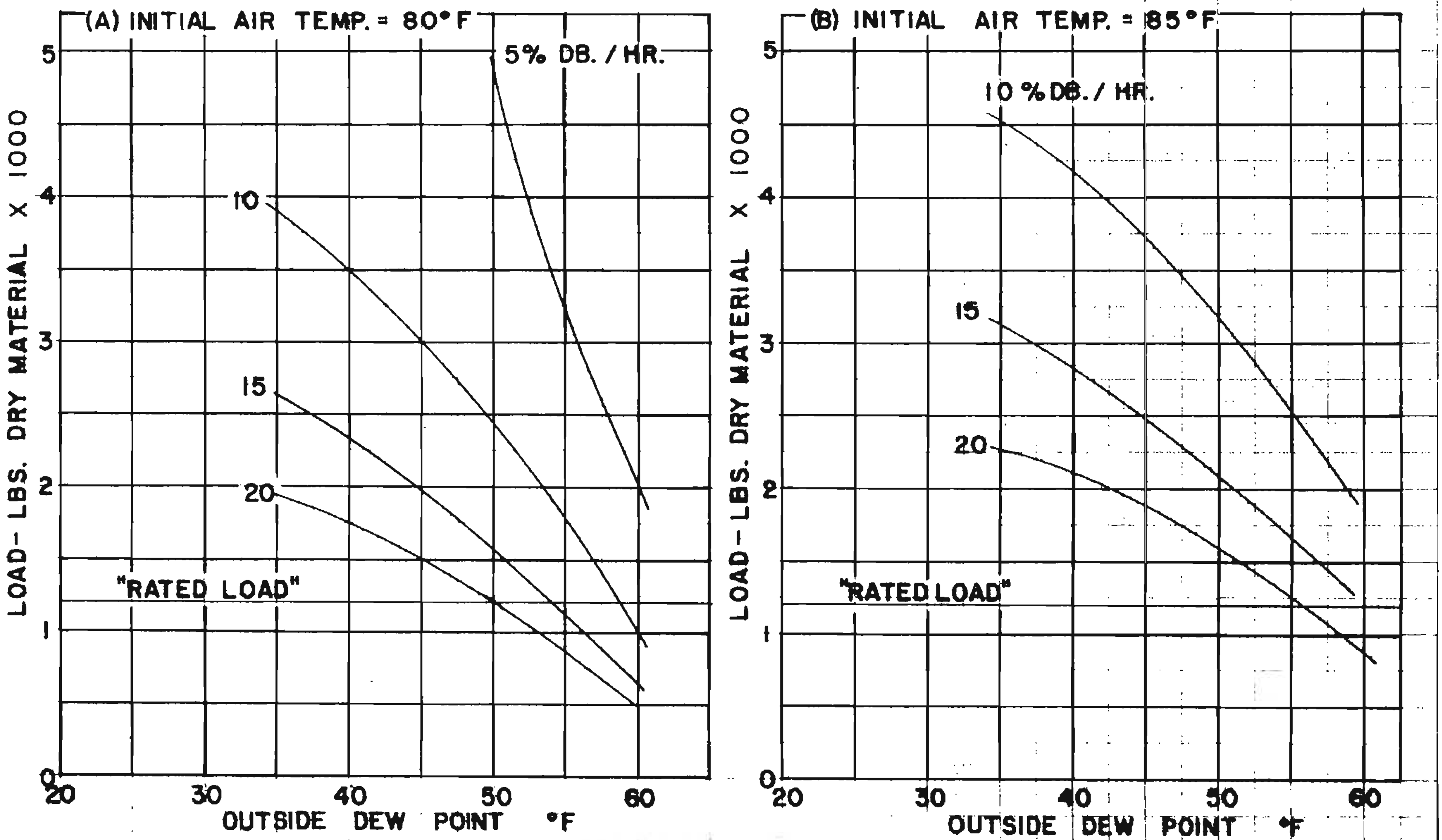


FIGURE 16
VARIATION OF MAX. DRYER LOAD WITH OUTSIDE DEW POINT
(FOR SEVERAL DRYING RATES)
Q = 26,000 CFM.



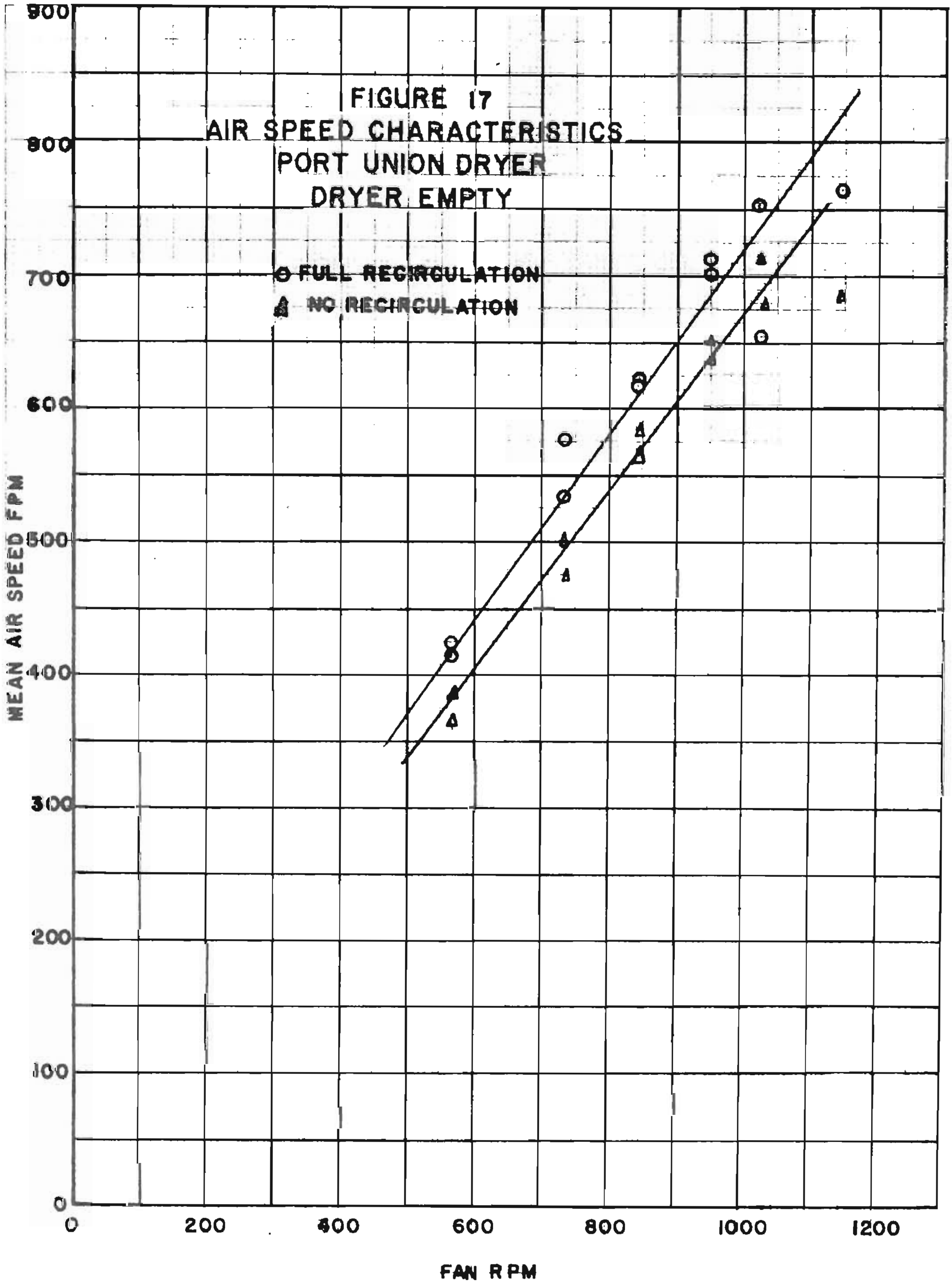
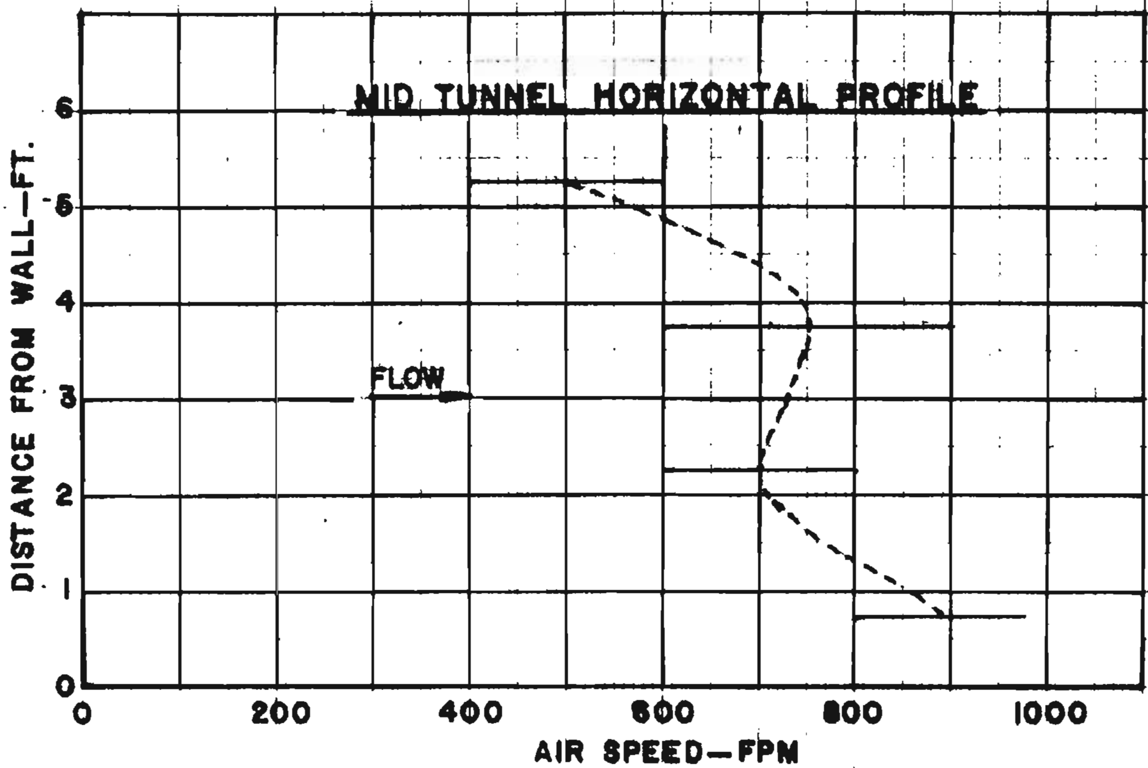
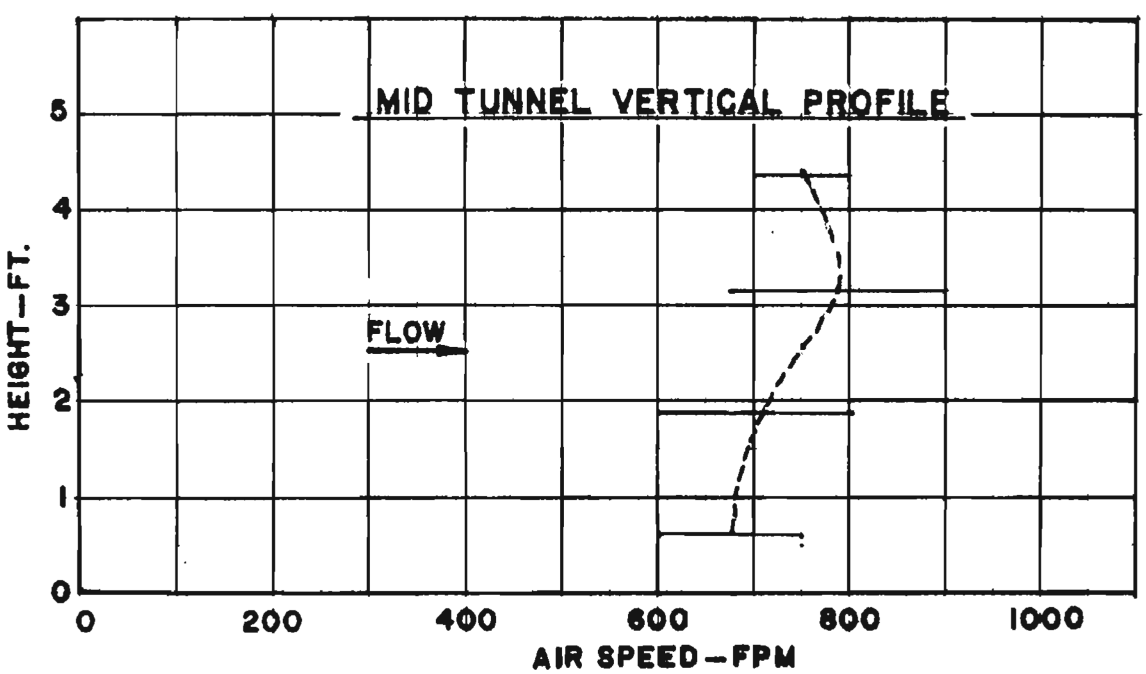


FIGURE 17
AIR SPEED CHARACTERISTICS
PORT UNION DRYER
DRYER EMPTY
FULL RECIRCULATION
NO RECIRCULATION
MEAN AIR SPEED FPM
FAN RPM
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200

FIGURE 18
AIR SPEED PROFILES





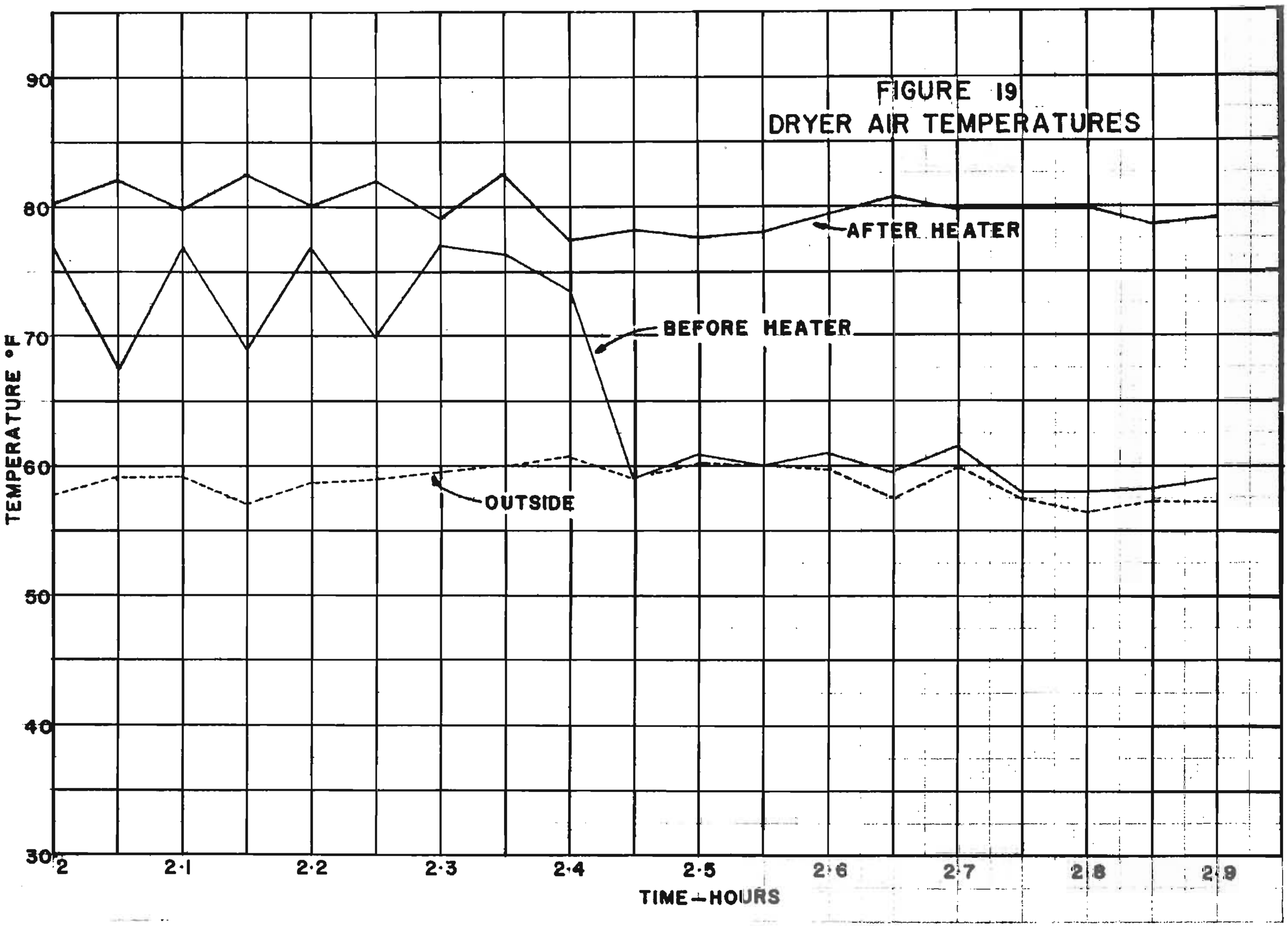


FIGURE 19
DRYER AIR TEMPERATURES
AFTER HEATER
BEFORE HEATER
OUTSIDE
TEMPERATURE °F
90
80
70
60
50
40
30
2
2·1
2·2
2·3
2·4
2·5
2·6
2·7
2·8
2·9
TIME—HOURS

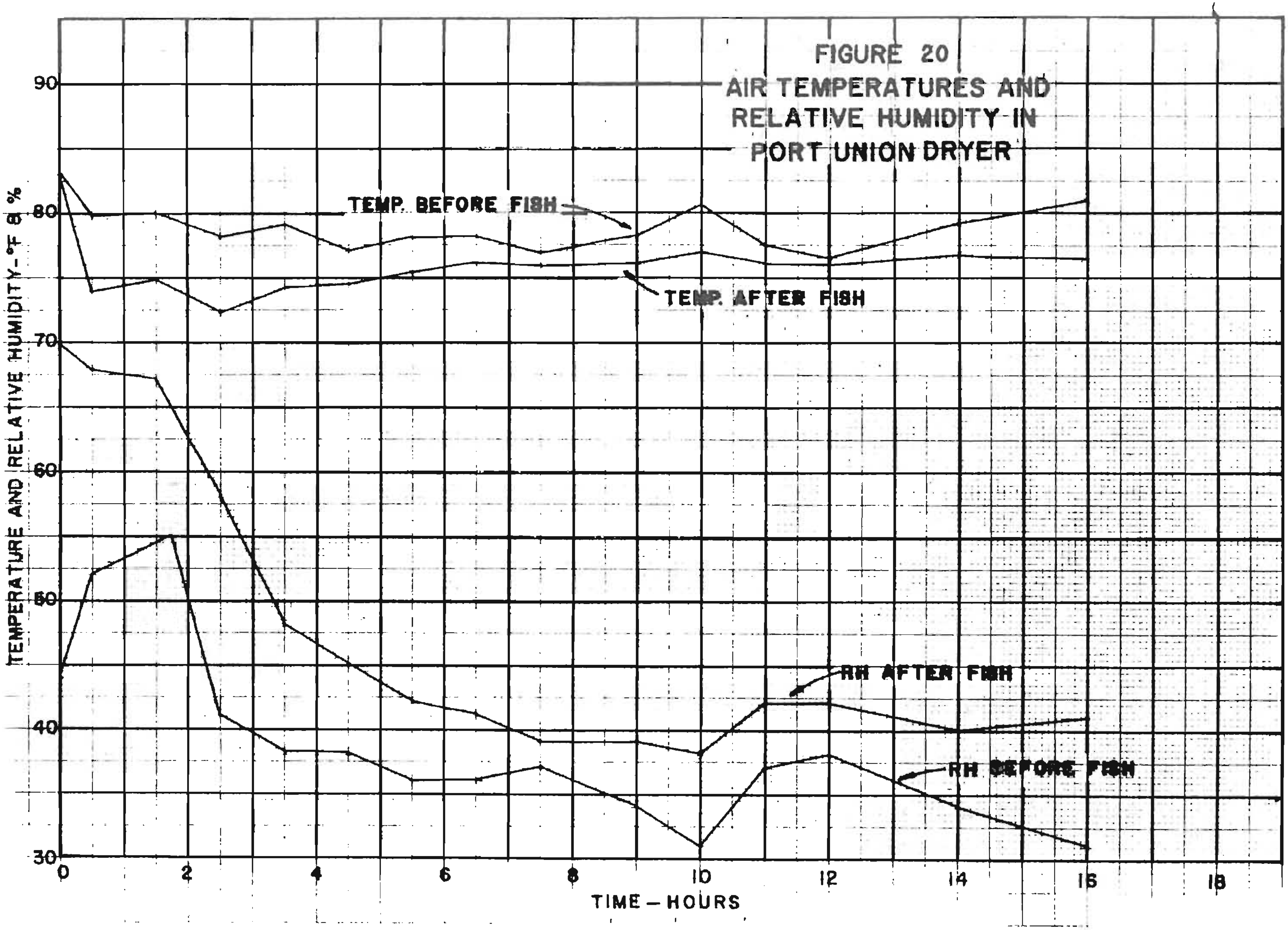


FIGURE 20
AIR TEMPERATURES AND RELATIVE HUMIDITY IN PORT UNION DRYER

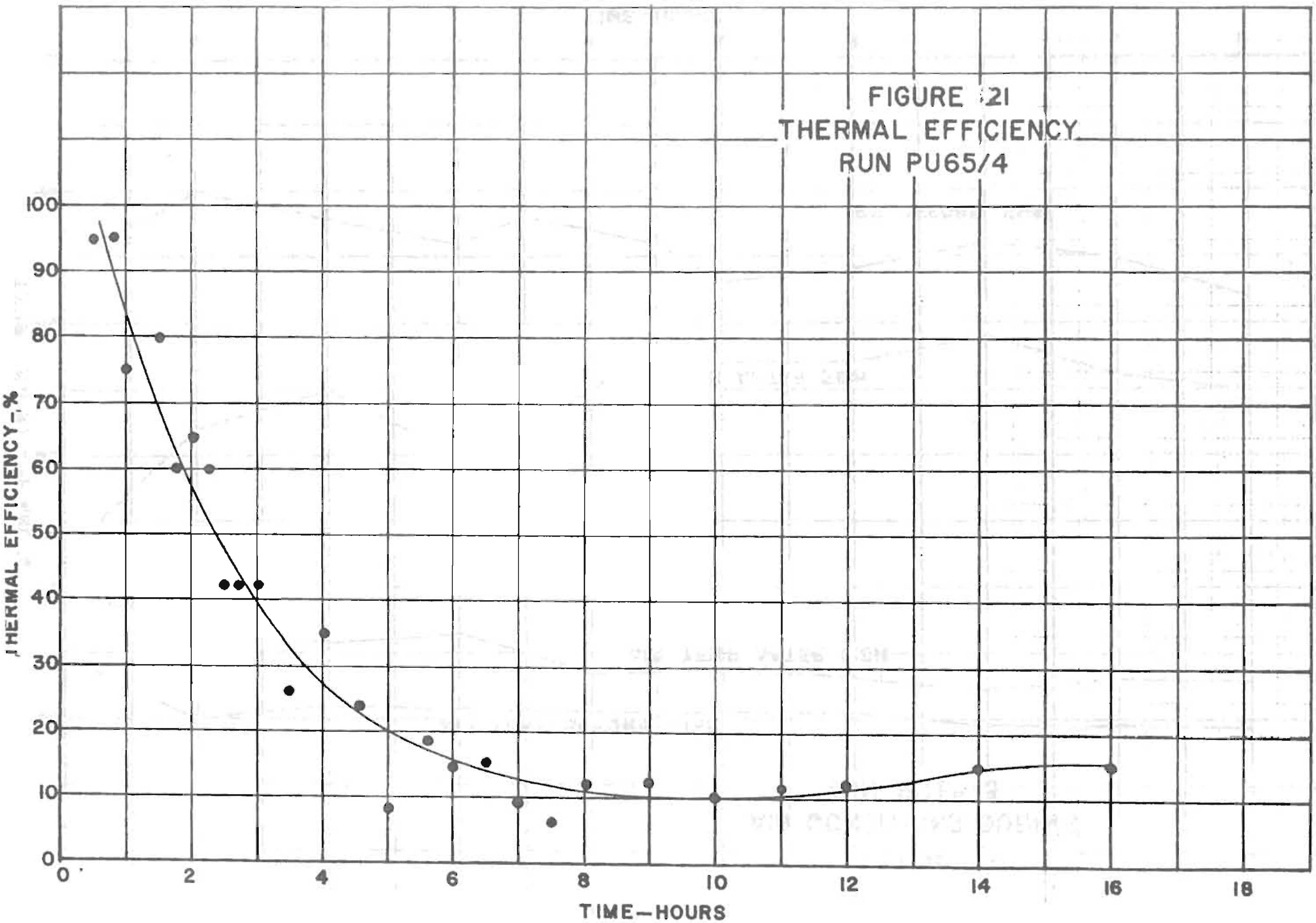


FIGURE 21
THERMAL EFFICIENCY
RUN PU65/4
THERMAL EFFICIENCY-%
TIME—HOURS
0
2
4
6
8
10
12
14
16
18
10
20
30
40
50
60
70
80
90
100

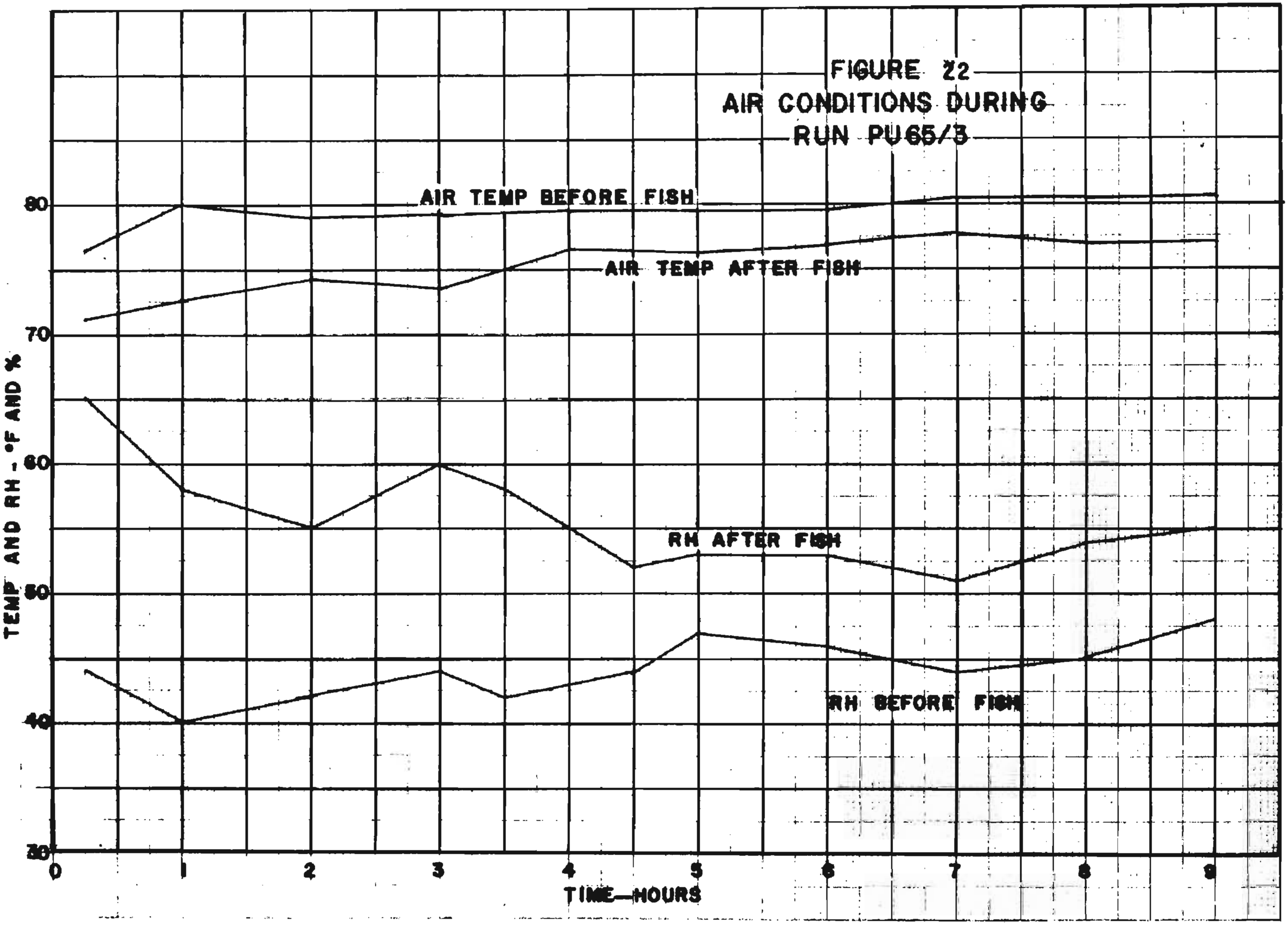


FIGURE 22
AIR CONDITIONS DURING
RUN PU65/3

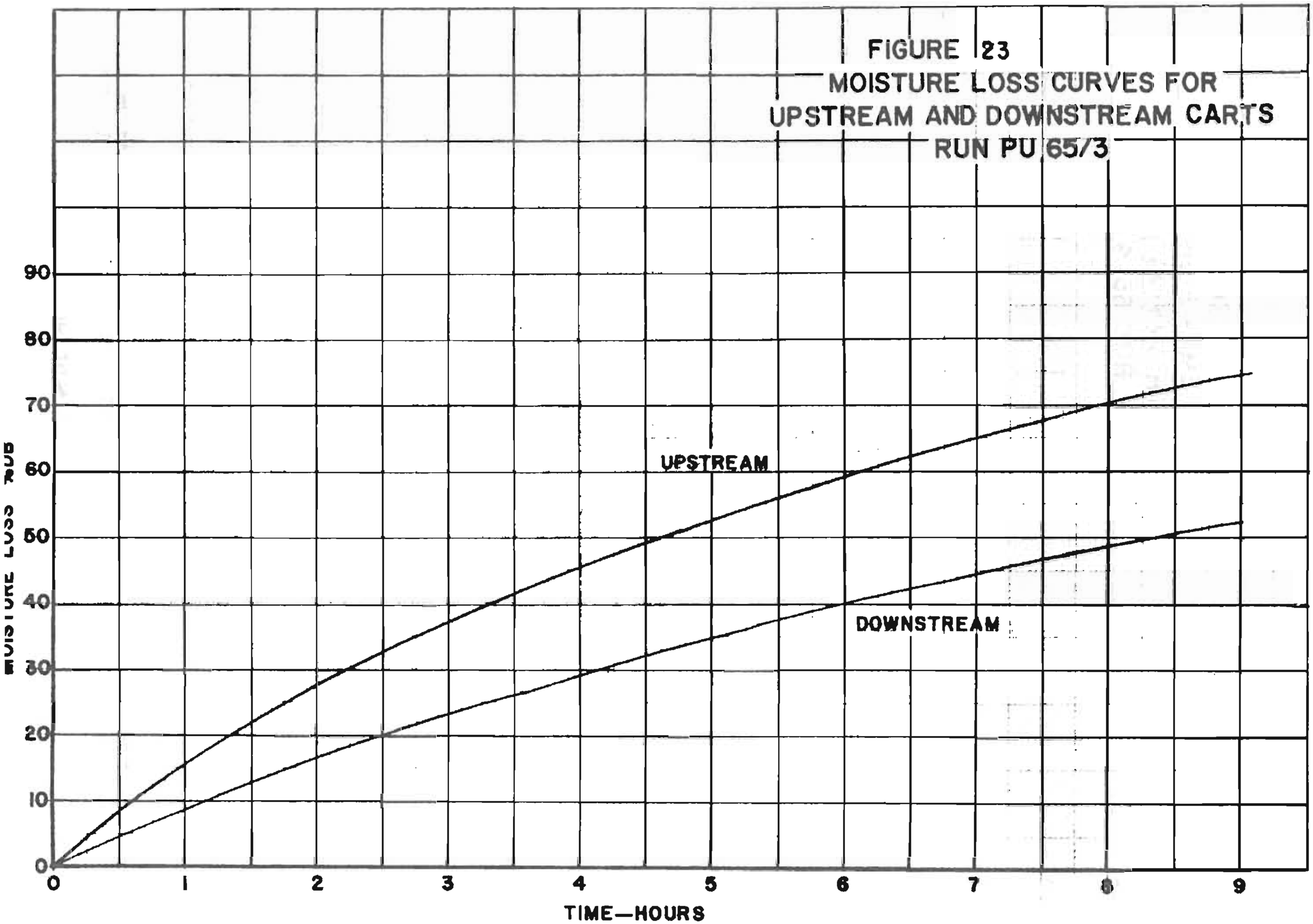


FIGURE 23
MOISTURE LOSS CURVES FOR
UPSTREAM AND DOWNSTREAM CARTS
RUN PU 65/3

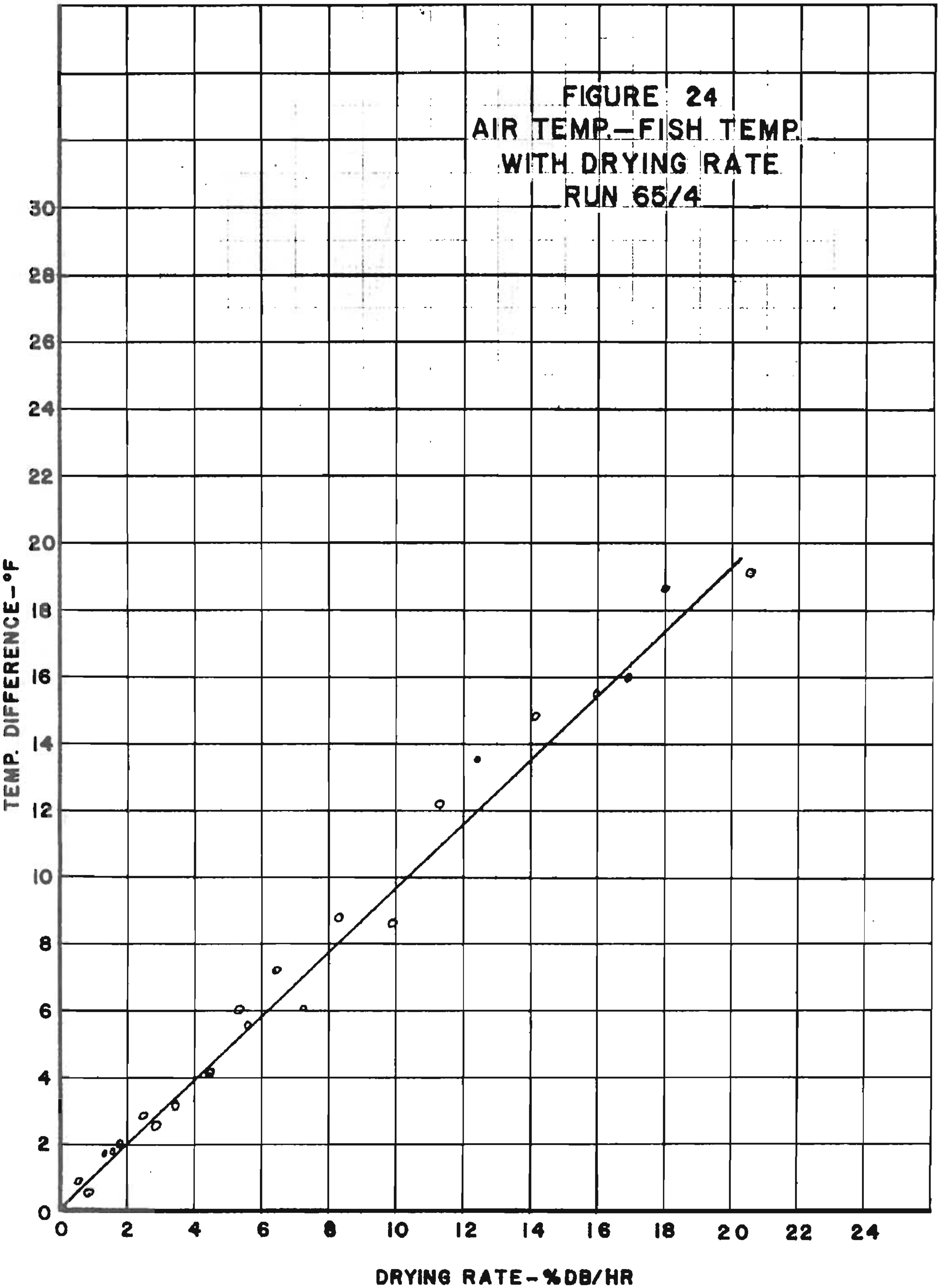


FIGURE 24
AIR TEMP.—FISH TEMP.
WITH DRYING RATE
RUN 65/4
TEMP. DIFFERENCE—°F
DRYING RATE—%DB/HR
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

FIGURE 25
DRYING RATES WITH TIME
LIGHT SALTED COD

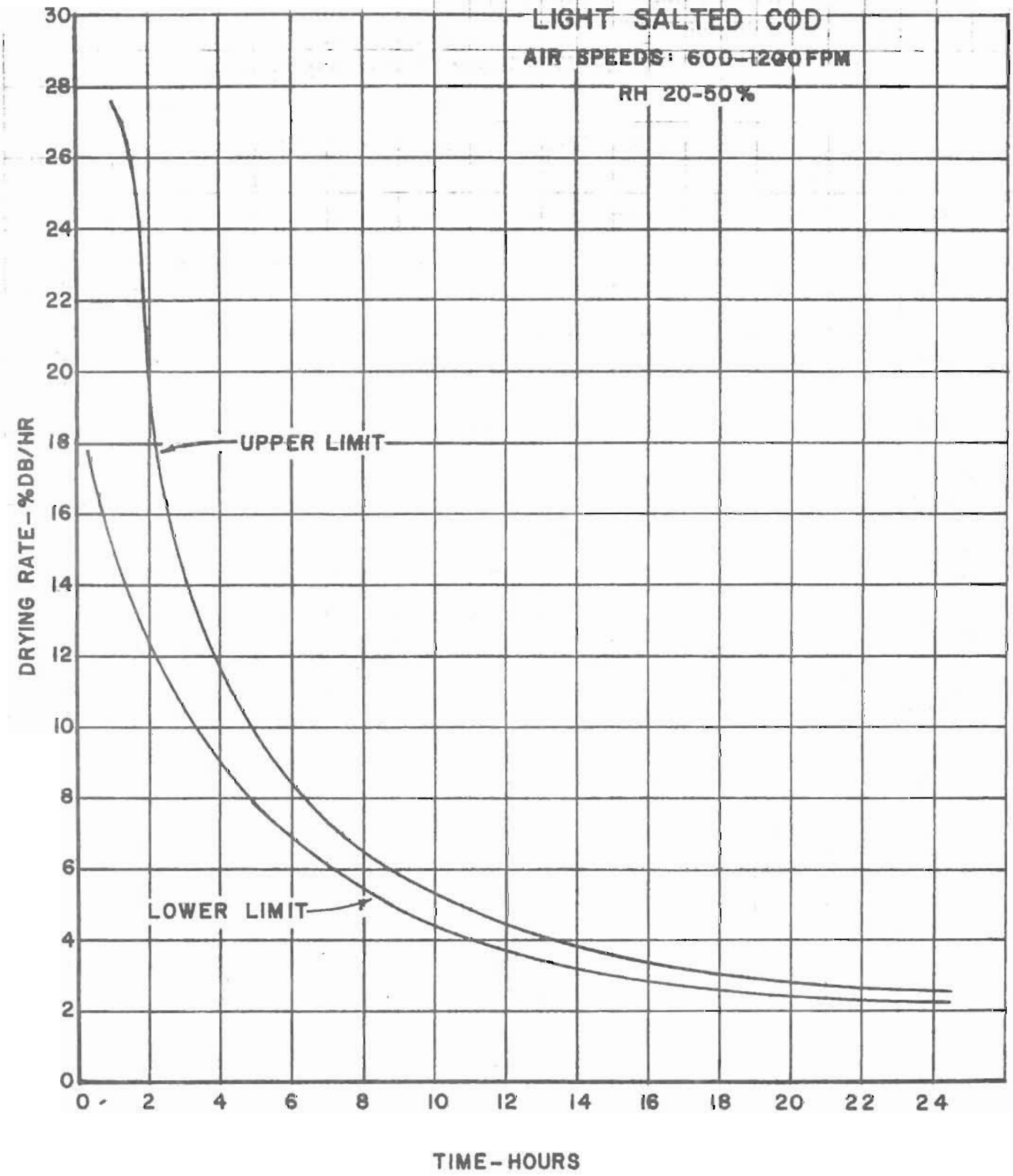
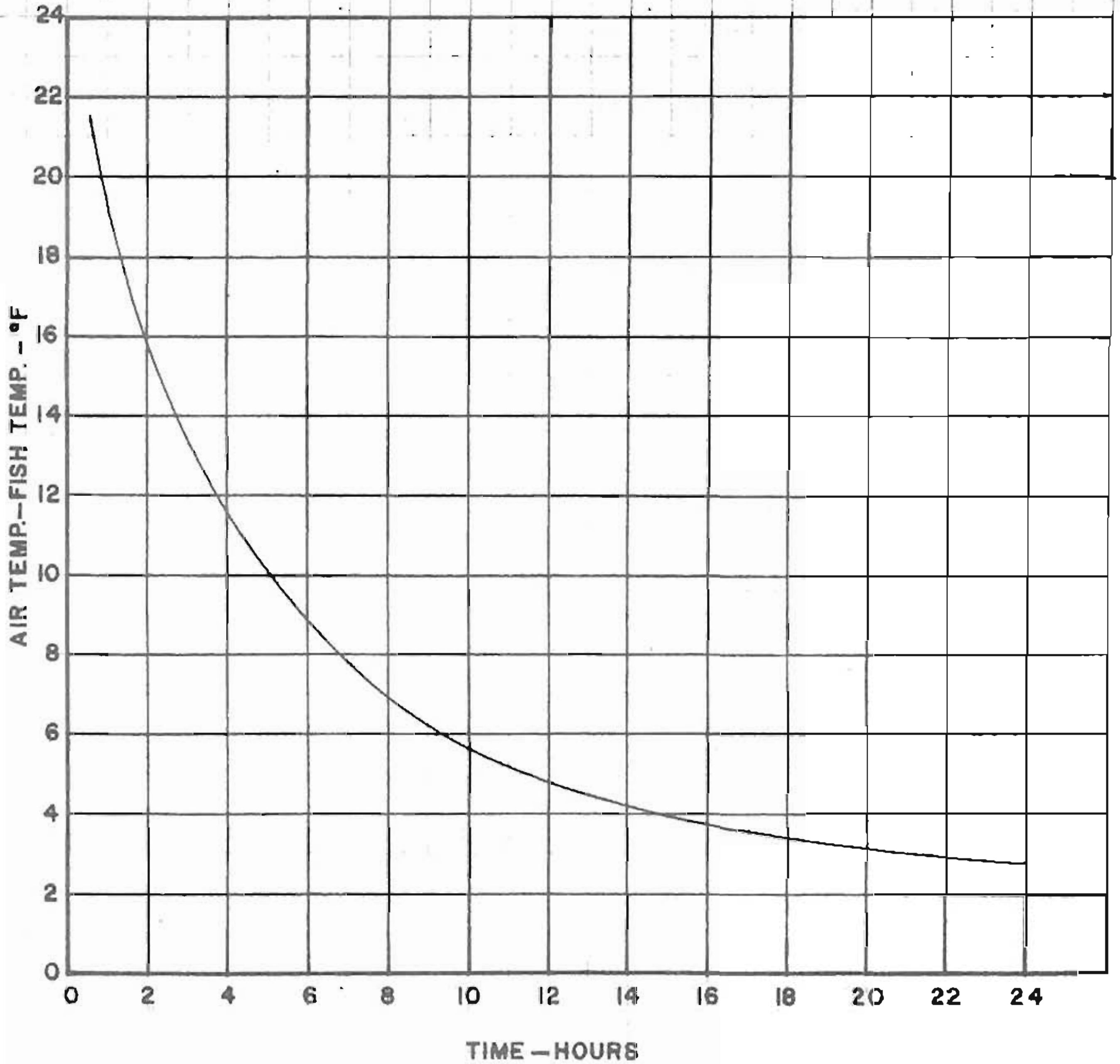


FIGURE 26
AIR TEMPERATURE PROGRAM
FOR
LIGHT SALTED FISH



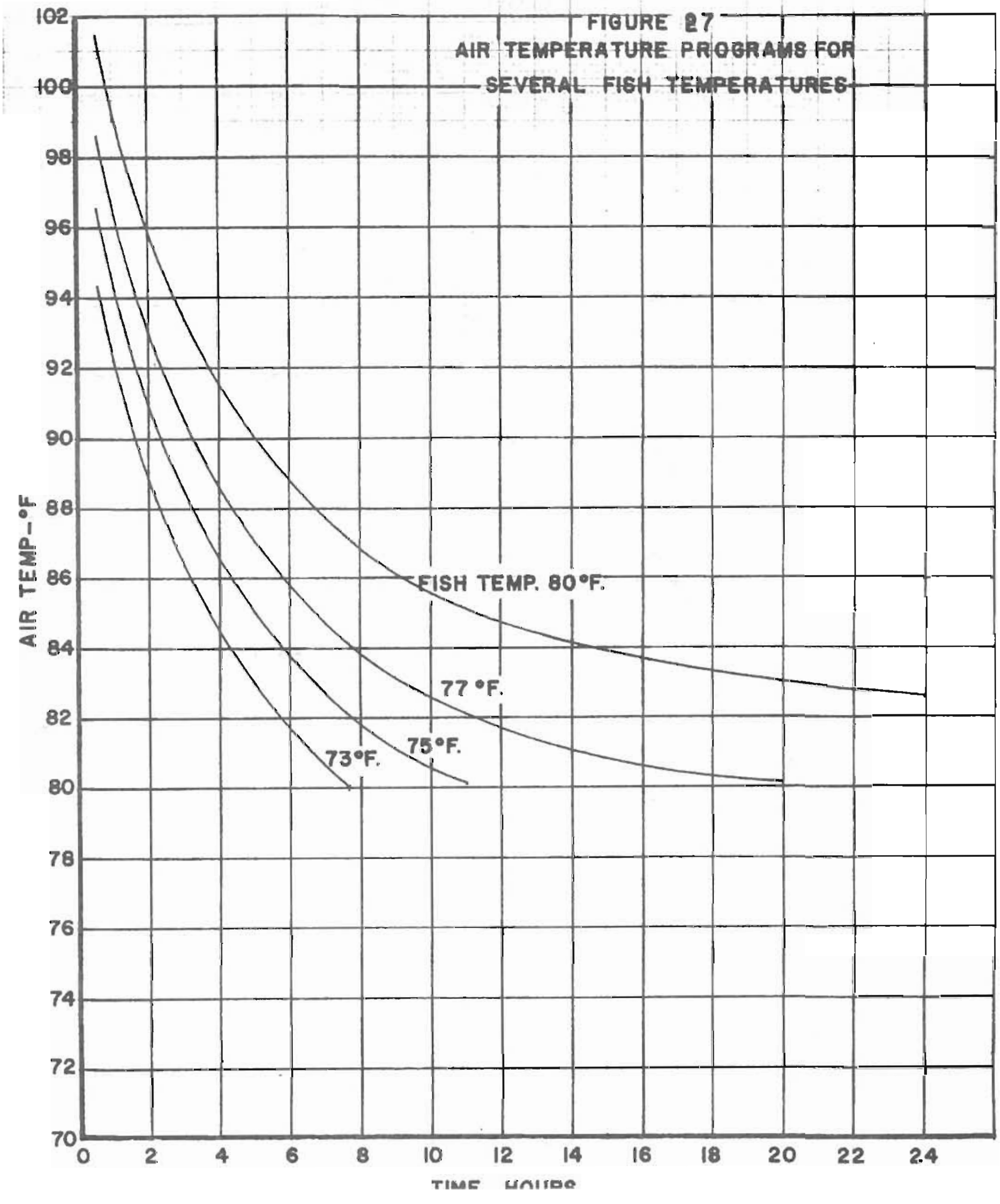


FIGURE 27
AIR TEMPERATURE PROGRAMS FOR
SEVERAL FISH TEMPERATURES
FISH TEMP. 80°F.
77 °F.
75°F.
73°F.
AIR TEMP.-°F
102
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
0
2
4
6
8
10
12
14
16
18
20
22
24

FIGURE 28
RH BEFORE FISH FOR
PROGRAM WITH FISH TEMP. 77°F.

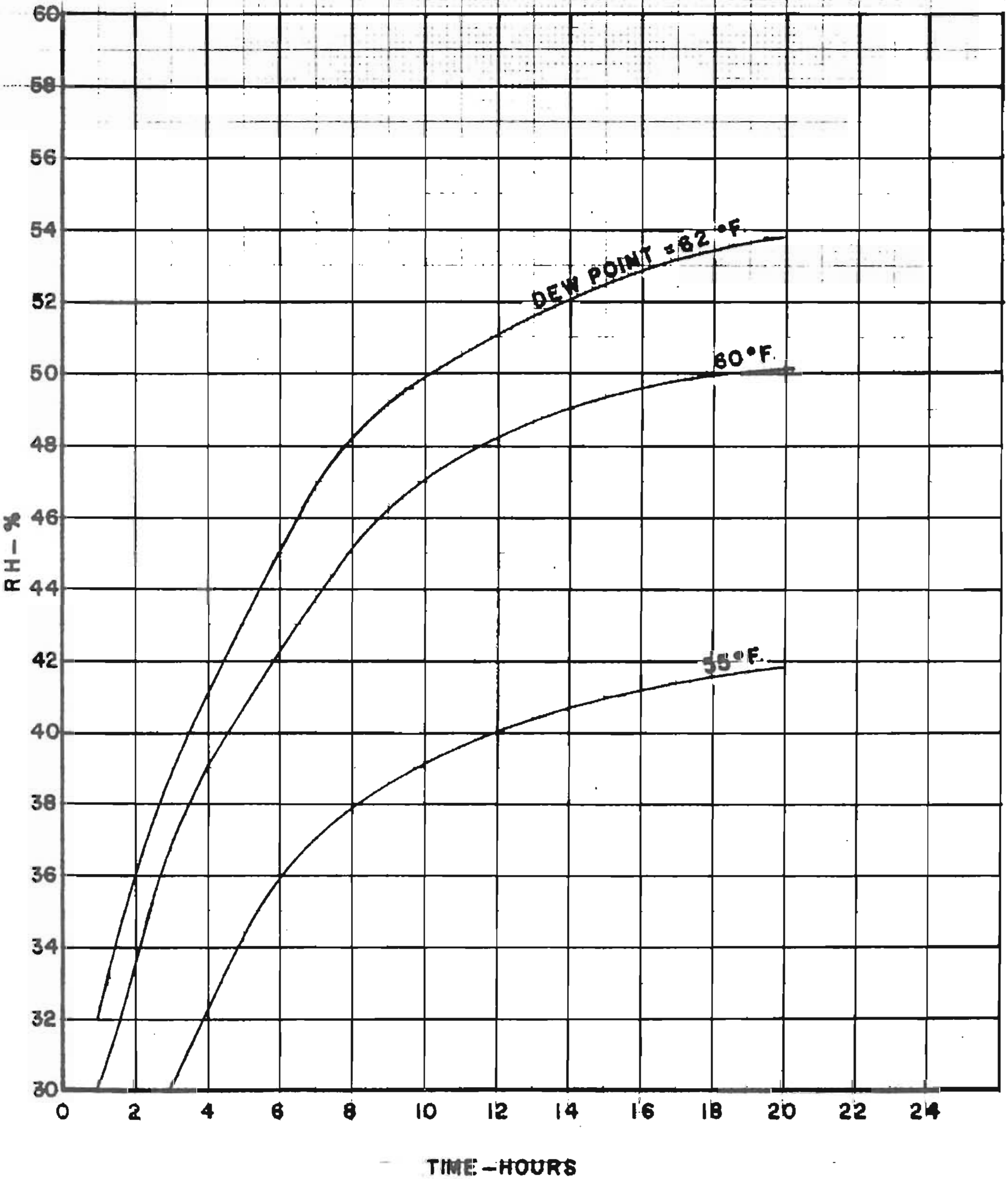


FIGURE 29

EFFECT OF PROGRAM ON DRYER LOAD

L/Q=WEIGHT OF DRY MATERIAL/LB DRY AIR/MIN

DEW POINT TEMP.=55°F

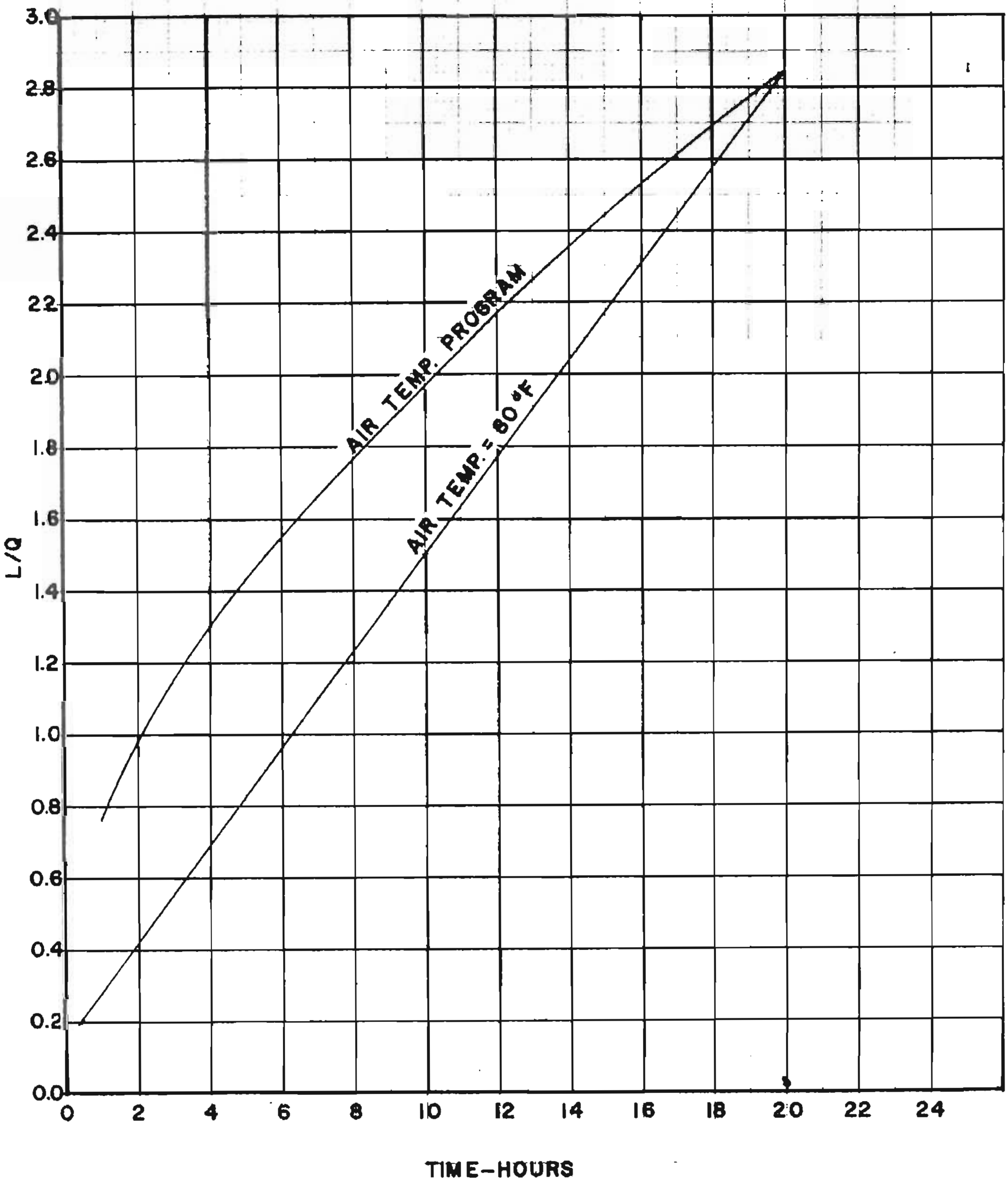


FIGURE 30

AIR TEMPERATURE FLUCUATION

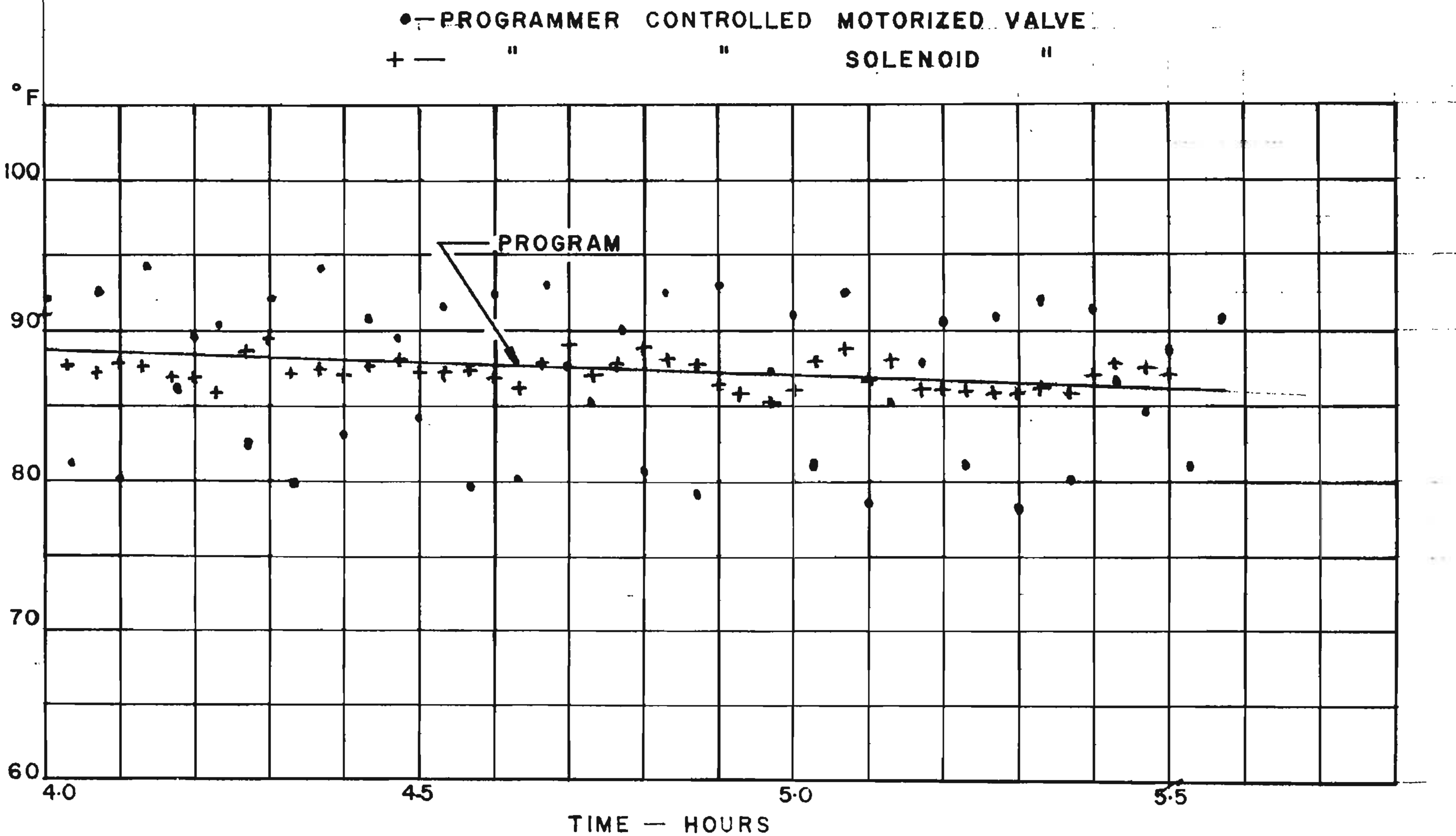


FIGURE 31
PROGRAMS AND OBSERVED FISH TEMPERATURES

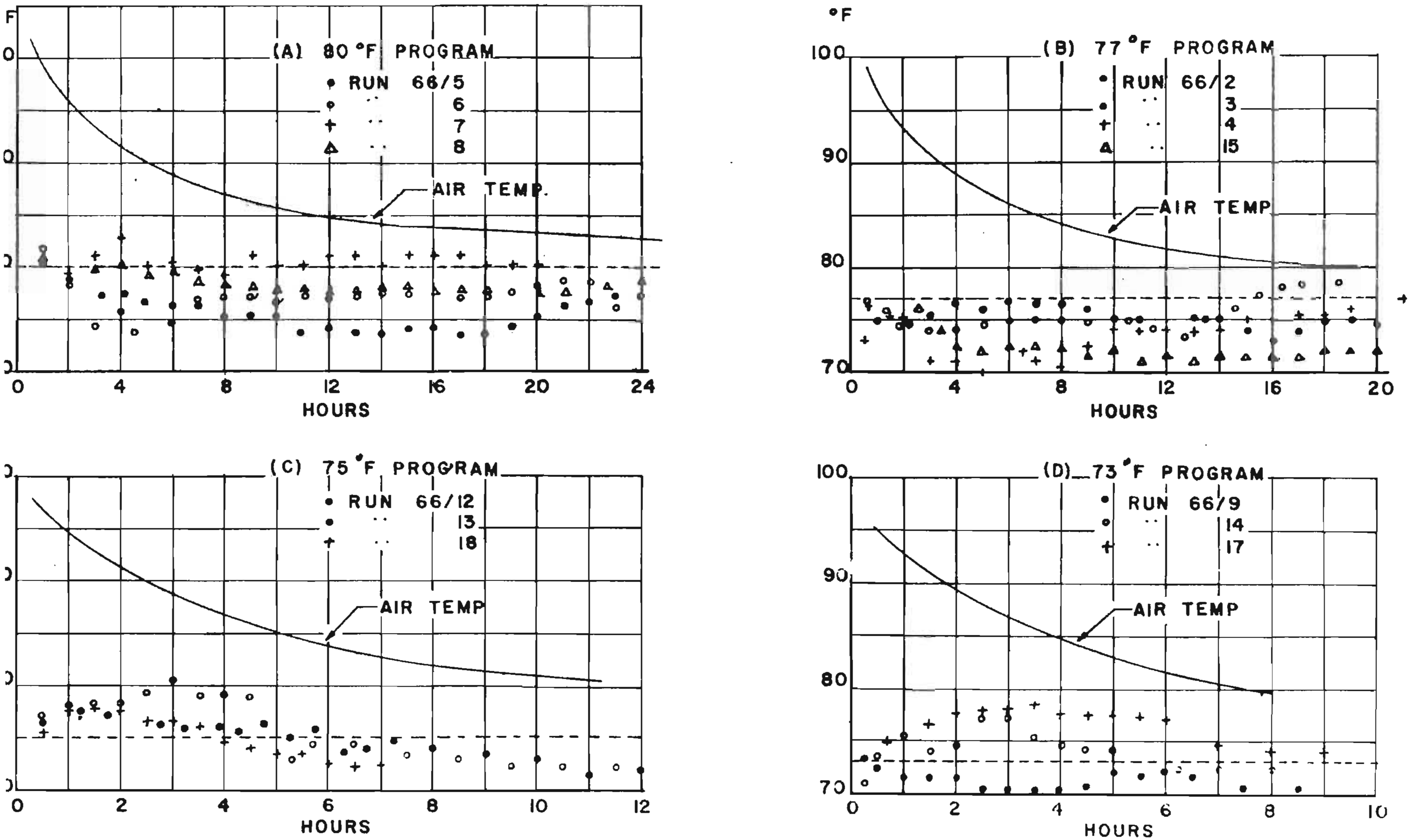


FIGURE 32

MEAN MOISTURE LOSS CURVES