ELECTRICALLY HEATED GLASS ANNEALING LEHR[1]

By E. F. Collins

ABSTRACT

Time-temperature data relating to relaxation of stresses.—Existing time-temp. data covering the relaxation of stresses in annealing of glass has been assembled. Range, control, and distribution of temp. are important factors in annealing. The annealing time was reduced from 5 to 2.3 hours when temp. var. was reduced from 10° to 2.5° C, in the case of one glass whose annealing temp. was 476°.

Electric heat secures perfect anneal in shortened time.—Electric heat with its automatic control holds temp. within +0.6 per cent in ranges required for annealing, as shown by tests, even when the temp. changes 23° per hour and when the annealing treatment (as for optical glass) covers a month in time.

Vertical Lehr superior to horizontal type.—Electrically heated lehrs of horizontal and vertical types are discussed. The vertical lehr offers many apparent advantages and a higher thermal efficiency. A particular lehr of 500–600 lbs. ware capacity per hour, shows efficiencies in ratio of 6 to 10 in favor of electric lehr of vertical type. Tests made on an electrically heated vertical lehr annealing high grade ware showed a reduction in cost of manufactured part of 20 per cent, or more than 75 times total cost of electric power consumed.

In suggesting the use of electric heat for glass annealing lehrs, the writer of this paper is not unaware of the indefiniteness and scarcity of published data covering the conditions necessary for satisfactory and uniform anneal of a specific type of glass. Data presented in this paper is in nowise original; the writer has drawn freely from published reports.[2] He recognizes that this process is one of the most delicate in the manufacture of glass; and that the actual annealing procedure for one type of glass varies widely from that of another. On the other hand whether glasses differ in composition, and whether they be used for industrial and domestic purposes or optical and scientific work, the problems involved in the heat treatment or annealing procedure necessary to meet service requirements and specifica-

[1] Received February 21, 1921.

[2] Bureau of Standards' paper No. **358**, also Rosenhain, Williamson and Roberts, Tool and Valasek, and W. M. Clark.

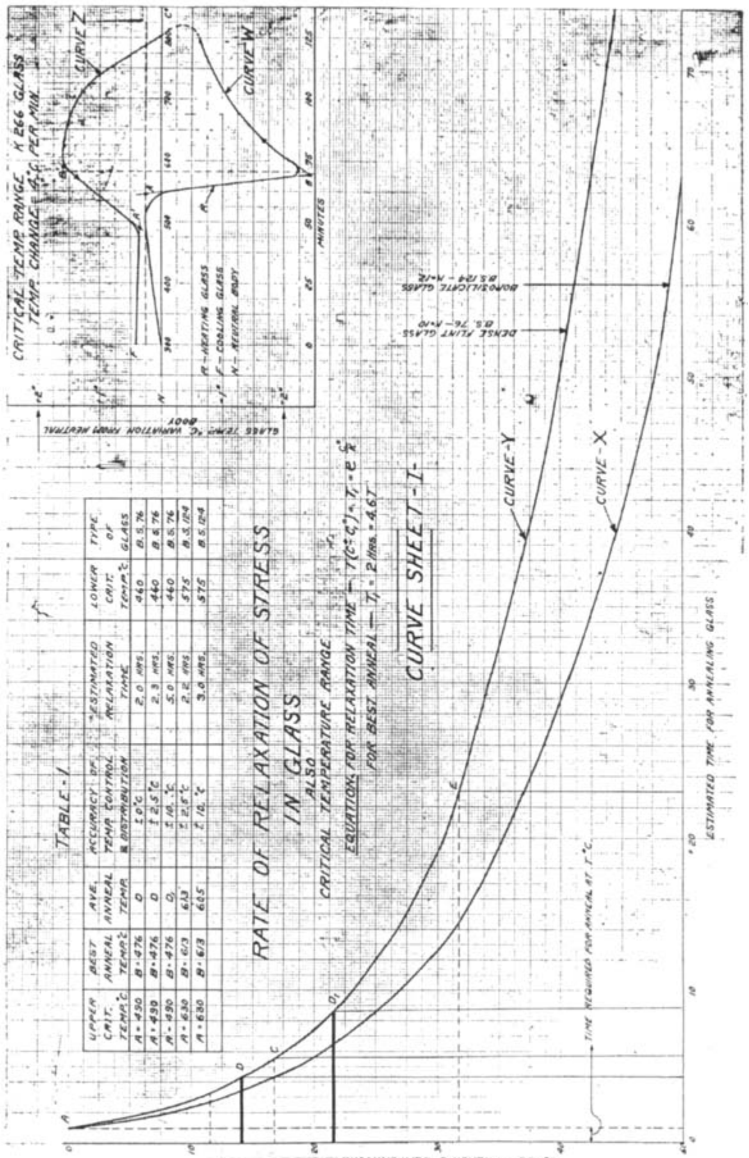

CRITICAL TEMP. RANGE K 266 GLASS
TEMP. CHANGE 6°C PER MIN.
CURVE Z
CURVE W
H—HEATING GLASS
F—COOLING GLASS
N—NEUTRAL BODY
MINUTES
GLASS TEMP. °C. VARIATION FROM NEUTRAL BODY
TABLE-1
RATE OF RELAXATION OF STRESS
IN GLASS
ALSO
CRITICAL TEMPERATURE RANGE
CURVE SHEET-I-
CURVE-Y
CURVE-X
DENSE FLINT GLASS
B.S. 76—K=10
BOROSILICATE GLASS
B.S.124—K=12
ESTIMATED TIME FOR ANNEALING GLASS
TIME REQUIRED FOR ANNEAL AT T °C
GLASS ANNEALING TEMPERATURE °C

FIG. 1.

tions are in general very much the same, whether the annealed product be judged by the sensitive polariscope, or "strain viewer," or by simple tests such as pouring hot water into fruit jars, "bump" and "drop" tests, or the testing of bottles by a sharp rap from a hickory stick in the hands of an inspector educated in its use.

Ordinary glass ware is considered to be sufficiently annealed when stresses as great as 5 per cent of the breaking stresses are present. However where double refraction must be eliminated, or where change of form due to slow relaxation of stresses is objectionable, as in optical instruments or thermometers, further

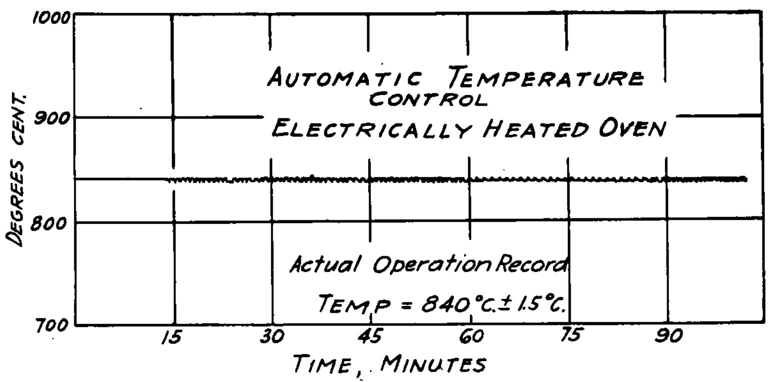
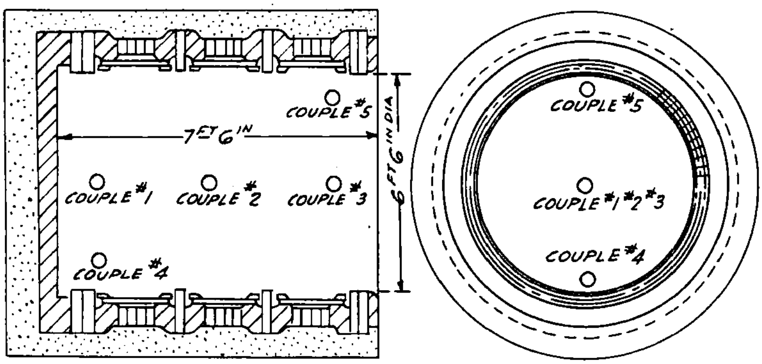


Fig. 2.

reduction of stresses are necessary. A piece of fine annealed glass, 8 inches in diameter suitable for a telescope lens, gave only one-third the retardation of a normally annealed plate.

In all glass annealing, it is of vital importance that the temperature of the glass mass should be uniform in the annealing range. Temperature gradients in the mass of homogeneous glass under treatment, are solely responsible for the setting up of strains. These gradients may result from too great speed of cooling, as well as from a non-uniform and unsymmetrical heat distribution. Hence the importance of heat control with respect to time and also proper heat distribution in the annealing lehr through which the ware is passing. Likewise where glass is treated in the box type oven, it is extremely important that the heat distribution of the oven be correct and that the heating equipment lend itself to the exact following of the time temperature cycle desired, what ever that may be, *i. e.*, annealing cycles covering a few hours and those covering a month should be equally accurately followed no matter what the temperatures and the rates of change required throughout; and preferably such temperature time control should be automatic and should correspond to a predetermined cycle.



TIME	THERMOCOUPLES-TEMP °C.					AVER TEMP	PER CENT DEVIATION FROM AVERAGE		RATE OF CHANGE
	1	2	3	4	5		ABOVE	BELOW	DEG. PER. HR
11^{30}	25	25	25	25	25	25	0	0	
3^{30}	527	537	532	530	545	534	2.07	1.31	127°C
7^{30}	670	679	671	666	669	669	1.5	.45	34
11^{30}	777	783	776	766	780	776	1.0	1.3	27
3^{30}	858	864	857	849	864	860	.46	1.3	21
7^{30}	860	865	862	862	863	862	.35	.23	0
11^{30}	928	934	930	930	928	930	.43	.21	17
3^{30}	933	932	927	925	927	929	.64	.43	0
4^{30}	950	950	952	952	955	952	.31	.21	23

FIG. 3.—Test data of heat uniformity of electric furnace.

The importance of exact temperature control at least from the economic point of view, is illustrated by Curve Sheet I (Fig. 1), which in general shows the change in annealing time with the temperature of anneal. Suppose the point D, for a flint glass is the best temperature point to anneal in two hours time for ordinary purposes, say where stresses are reduced to $^1/_{10}$ the breaking value. Assume an automatic temperature control of 476° ± 2.50°C, then the actual time for anneal at the average temperature of 476°C is 2.3 hours as against 2 hours at 476°C with perfect control. Again assume a less close control, *e. g.*, one whose variation is ±10°C. Then the average anneal would occur at D_1 or about 468°C and a total relaxation time for safety corresponding to temperature E, or about 5 hours. Here due to the difference in sensitiveness of heat controls we have doubled the length of time for the anneal and undoubtedly for the greater part have an inferior glass product.

An automatic temperature control within ±2.5°C is available if electrically heated annealing lehrs of proper design are used. The variation of ±10°C is usually a fair measure of non-uniform or unsymmetrical temperature distribution and control met with in the fuel fired lehr operating at such temperatures as 475°C.

As an illustration of what may be accomplished in temperature control in electrically heated ovens, attention is called to the time temperature curve in figure 2. This is a curve record of an actual performance which holds temperature constant within 0.3 of one per cent.

An example of temperature distribution is given in figure 3 and its accompanying table. It will be noted that for a rising temperature of 125° per hour, only one point varies from the mean temperature by 2.07 per cent. With 35° change per hour, the variation from mean temperature is 1.5 per cent maximum while with the temperature changing at the rate of 17° per hour, the maximum deviation from mean is only 0.43 per cent, and at constant temperature, *viz.*, at 860° maximum variation is 0.35 per cent and at 930° the variation is 0.64 per cent in an oven 6 ft. 6 inches diameter and 7 ft. 6 inches deep. Such control and distribution of heat as the above, should, it would seem, meet the most exacting requirements of any and all types of glass annealing, including the fine annealing of large lenses for telescope work.

Curve Sheet III, figure 4, shows the time temperature cycle required in the "fine anneal" of a crown glass lens for telescopic purposes. Such a process is best carried on in the box type of lehr, figure 5 in which the lens is placed and subjected to a tem-

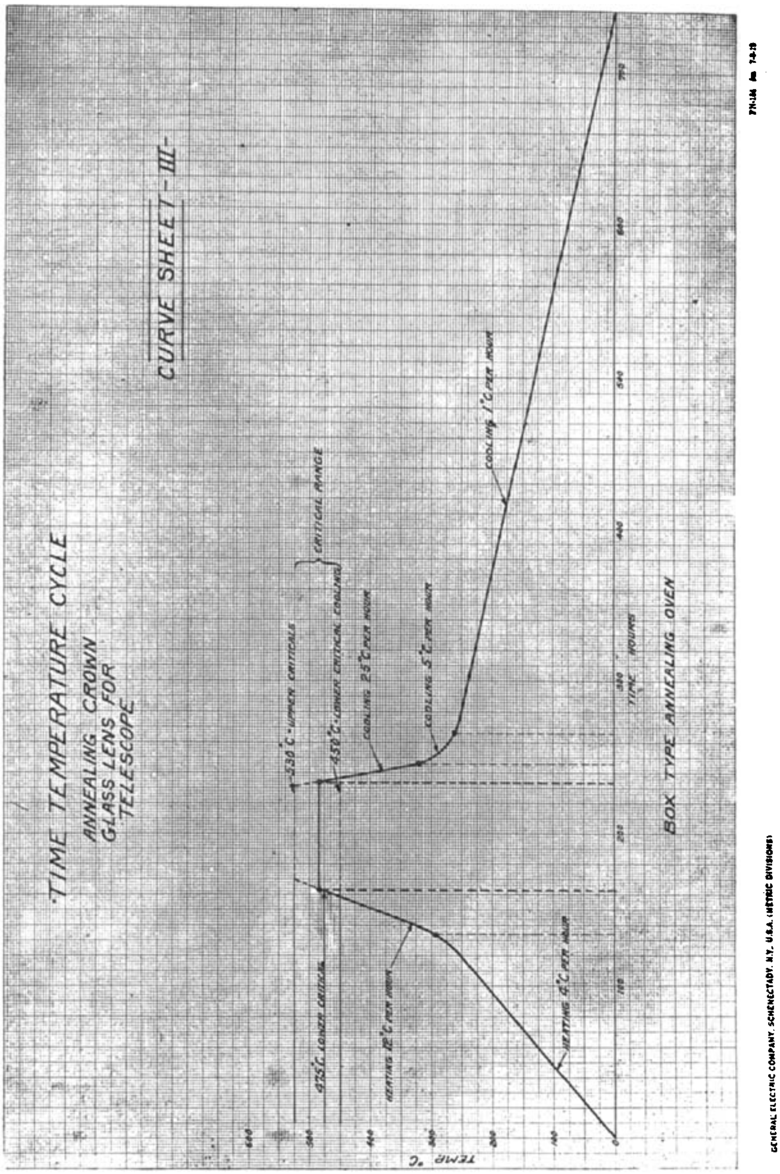

TIME TEMPERATURE CYCLE
ANNEALING CROWN GLASS LENS FOR TELESCOPE
CURVE SHEET - III -
530°C - UPPER CRITICALS
475°C LOWER CRITICAL
450°C - LOWER CRITICAL COOLING
CRITICAL RANGE
COOLING 25°C PER HOUR
COOLING 5°C PER HOUR
COOLING 1°C PER HOUR
HEATING 12°C PER HOUR
HEATING 4°C PER HOUR
TIME HOURS
TEMP °C
BOX TYPE ANNEALING OVEN
GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y. U.S.A. (METRIC DIVISIONS)

FIG. 4.

perature cycle as shown. Automatic control is available together with electric heat whereby this particular cycle or any similar one may be followed and repeated exactly whenever desired. The control instrument is operated by a time keeping motor supplemented by a simple cam arranged to give different rates of heating or cooling according to a predetermined characteristic such as shown on Curve Sheet III, figure 4. Certain tests for fine anneal with this type of apparatus have been made and our reports thus far seem to indicate that results may be obtained that have not been realized in any other method of annealing. Results are not the product of chance but may be duplicated repeatedly due to well nigh perfect distribution coupled with an absolutely positive and dependable automatic control of the temperature time cycle.[1]

Curve Sheet II, figure 6, shows the characteristics suited to the annealing of a large part of the glass ware in use for domestic and industrial purposes. These curves are built up from data on Curve Sheet I, which carries in general data regarding critical points and relaxation time which must be observed in arranging for successful anneal. Here it is assumed that the stresses are reduced to at least $^1/_{10}$ of those which will produce rupture of the glass ware. The two curves in figure 1 show how the relaxation[2] time varies with different glass compositions.

Returning now to Curve Sheet II, figure 6, the two heavy curves represent the annealing cycles which glass receives in a conveyor type lehr when the temperature control is ±5° (Curve X), and when the temperature control is ±15° (Curve Y), respectively, figure 7, shows the ordinary commercial lehr, with conveyor, and fitted with electric heat, and which when equipped with automatic control will readily give temperature cycle (Curve X), Curve Sheet II, required for a particular glass; this annealing period totals three hours and 20 minutes. This time includes heating up from 400°C to 590°C, the necessary relaxation time 5 minutes and safe cooling time three hours from 585°C to 375°C

[1] See the New York Tribune, Sept. 15, 1920, for news bulletin of the American Chemical Society in which successful operation of electric furnace to the annealing of telescope discs by Geo. W. Morey, is announced.

[2] For table showing critical range for several specific glasses, see Bureau of Standards, *Technical Paper* No. 358.

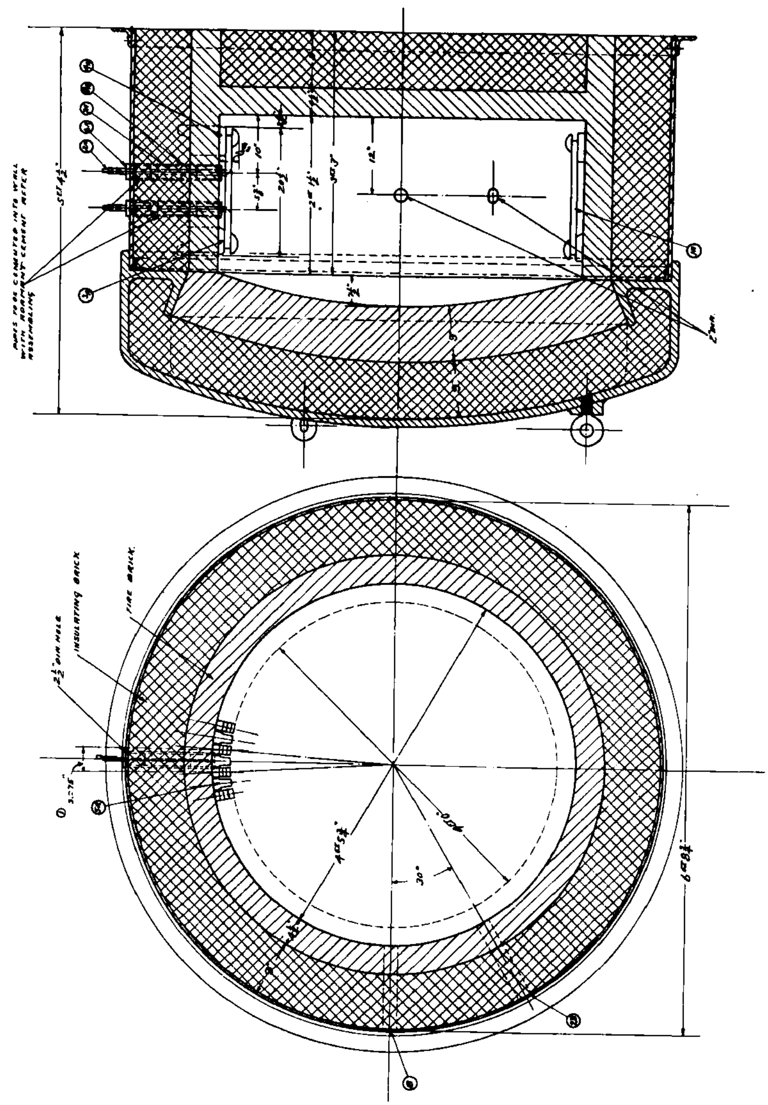


FIG. 5.

where it may be exposed to the air. Were the lehr, figure 7, of the usual fuel fired type, the glass would necessarily be subjected to a cycle comparable with Curve Y, due to non-uniformity of heat distribution and wider range of control. The output would be less uniform and dependable than glass subjected to the much shorter cycle, Curve X. In other words, the complete cycle length embracing the same temperature stages is 8 hours and 15 minutes for Curve Y, as against 3 hours 20 minutes for Curve X; a reduction of about 60 per cent in length of anneal in favor of the electrically heated lehr. In other words, the electric lehr should handle easily twice the ware of the fuel heated lehr when introducing and removing the ware from the lehr at the same temperatures, *viz.*, 400°C and 375°C.

While positive tests are not yet available to prove the correctness of the above reasoning, indications are that they will be realized in a lehr designed to take full value of the advantages inherent in the electric heat and its perfect control.

From the standpoint of the electric heating engineer, a glass lehr design, shown in figure 8 embodies many advantages for rapid, uniform and economic annealing of most commercial glass. Among its possible advantages are the following: (1) high thermal economy, (2) heat distribution easily secured, (3) small floor space required, (4) may be located near fabricator and receive ware at higher temperature, (5) reduction in labor, (6) no opportunity for ware to absorb products of combustion, (7) low temperature gradient, (8) heat control, —2.5°C may be secured automatically, (9) annealing time less than one-half that required by present day fuel fired lehr, (10) practical elimination of rejects, distortion, and breakage due to heat treatment, (11) no sulphuring of the ware occurs and the product has a bright polished surface requiring no subsequent cleansing or washing, (12) the ware is sterile and absolutely clean as all microbes are destroyed by heat so that for prescription ware, this feature has importance as medicinals can be filled in and sealed immediately after leaving the lehr.

Specific conditions would no doubt call for a modified design over that shown in figure 8, but it is presented here to call attention to some advantages which ought to be realized with this general type in commercial annealing.

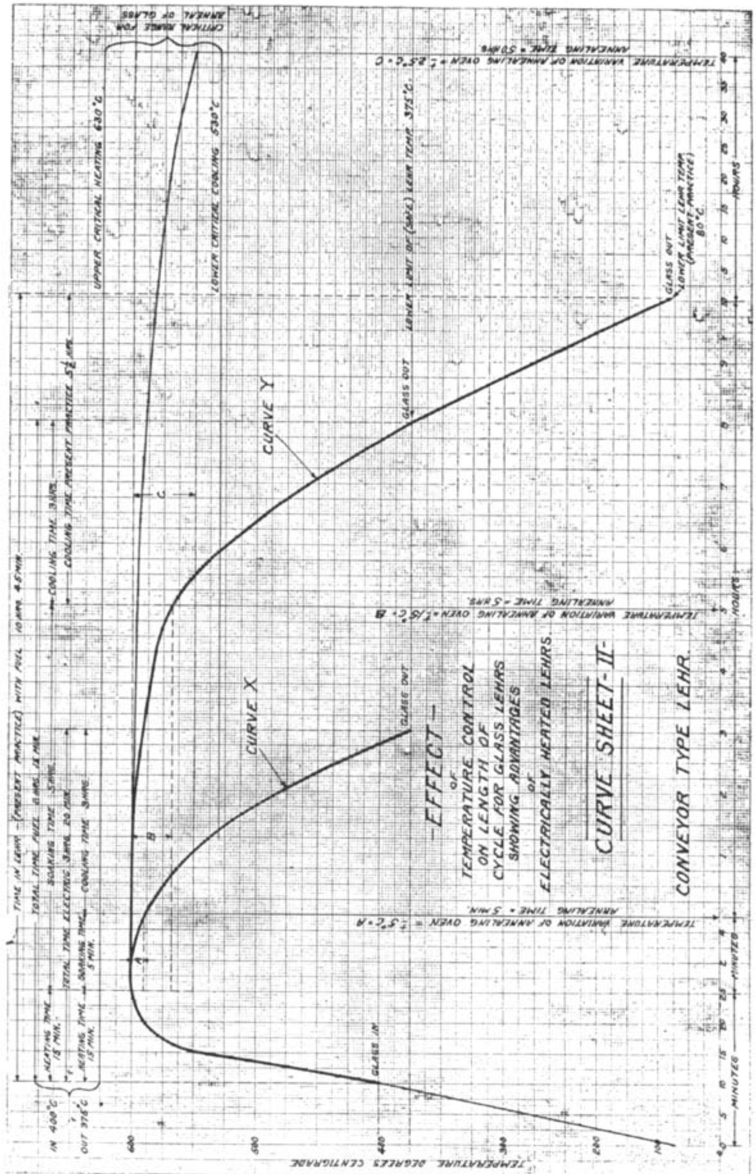

UPPER CRITICAL HEATING 630°C
LOWER CRITICAL COOLING 530°C
CURVE Y
CURVE X
GLASS IN
GLASS OUT
GLASS OUT
GLASS OUT
-EFFECT-
OF
TEMPERATURE CONTROL
ON LENGTH OF
CYCLE FOR GLASS LEHRS
SHOWING ADVANTAGES
OF
ELECTRICALLY HEATED LEHRS.
CURVE SHEET-II-
CONVEYOR TYPE LEHR.
TEMPERATURE DEGREES CENTIGRADE
MINUTES
HOURS

FIG. 6.

Exact operating costs for electrically heated lehrs are not yet available, but several estimates made for commercial work are being realized and in some installations, there are large savings in favor of electric heating, when overall costs, quality, increased production, and elimination of rejects are taken into account. The heavy conveyor type of lehr of present day usage, with its very great heat absorption or capacity and low thermal efficiency, which disqualifies it for best results of electrification, gives an efficiency when equipped with electric heating of six lbs. of glass ware per kw. hour. The estimate for the vertical type described above, electrically heated, is 10 lbs. of glass per kw. hour. These figures are based on ware entering lehr at about 900°F and being raised to temperature not above 1200°F. The horizontal lehr used for above calculations occupied a floor space of 70 ft. by 10 ft. and height of 10 ft. with a glass capacity of 600 lbs. per hour. The vertical lehr would occupy a floor space of 18 ft. by 21 ft. and its rated capacity would be 500 lbs. of ware per hour. The connected electric load of the vertical lehr would be 60 kw. as against 125 kw. for the horizontal type.

An electrically heated vertical lehr and which replaced a gas heated lehr has now been running for several months on a high grade glass ware and reliable overall factory costs have been made up for the annealed part. These factory costs show a decrease per unit annealed of 20 per cent or a cost of but 80 per cent of the former cost when annealed in gas-heated lehr. The saving was about 75 times the total cost of power for heating lehr.

In conclusion, while the writer appreciates that the logical development of annealing by electric heat, and certain assumptions in this paper may be at variance with, if not contradictory to, certain phases of established practice, he himself is thoroughly convinced that the soundness of the proposition has been fairly well demonstrated by the careful experiments reported by the Bureau of Standards, the Geophysical Laboratory, and the University of Sheffield, England, not to mention those conducted in our own laboratories, and supported by some satisfactory practical demonstrations with production lehrs. The writer urges that serious consideration be given the electric lehr by

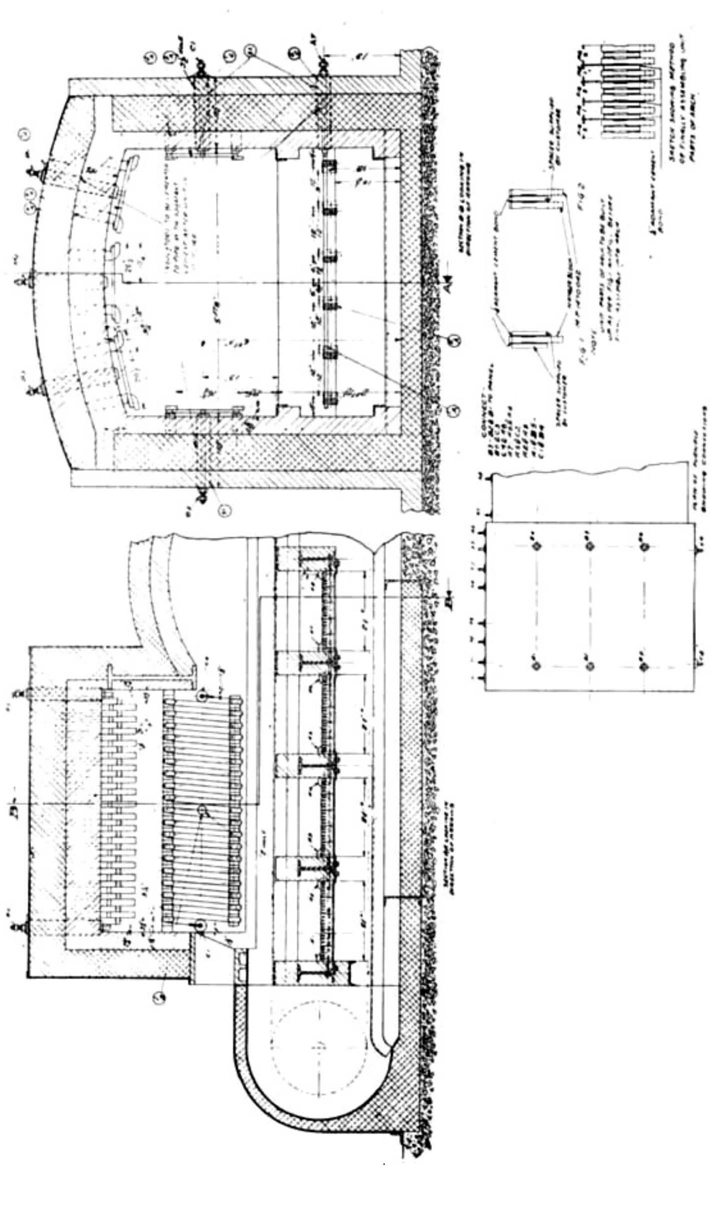


FIG. 7.—Assembly of ribbon resistor furnace.

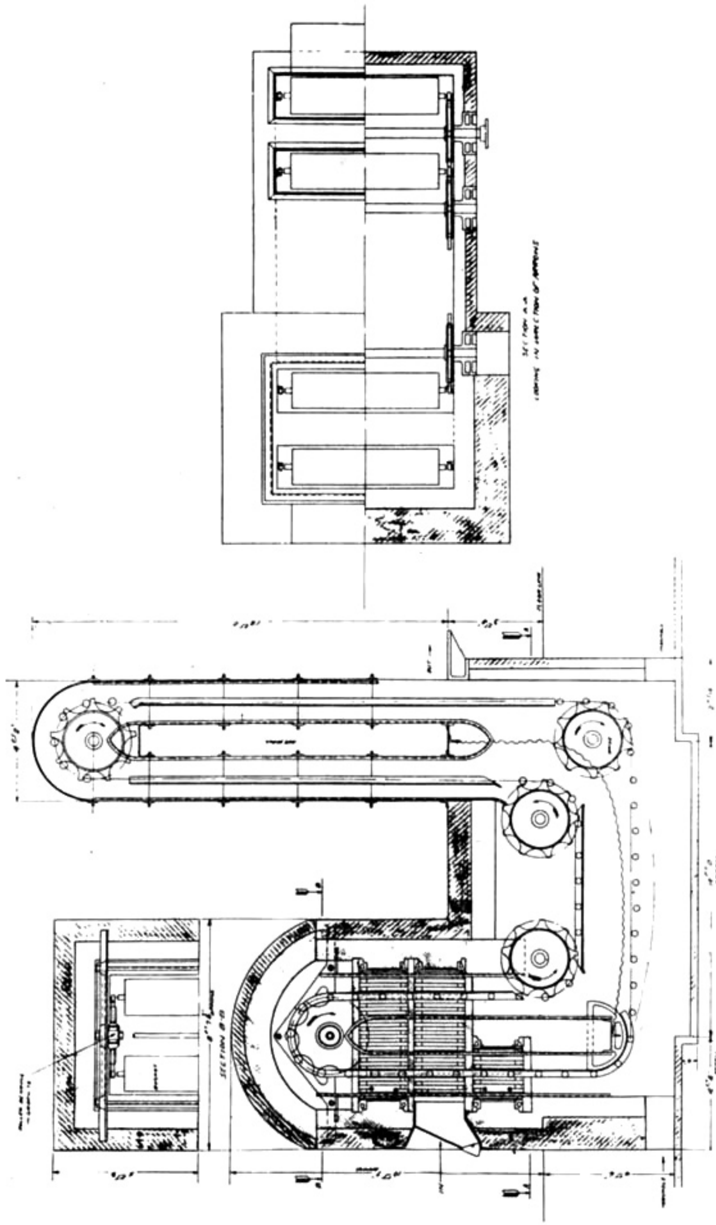


FIG. 8.

glass manufacturers, with the full confidence that its installation and use will demonstrate the claims of superiority and result in the standardization of such equipment for annealing glass.

INDUSTRIAL HEATING DEPARTMENT
GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y.

Discussion

L. H. ADAMS: To one who is interested in glass-annealing it is very gratifying to observe the progress made by Mr. Collins in developing electric annealing furnaces. The electric heated lehr is without doubt the ideal equipment for the purpose. A temperature constant within 2° or 3°C and uniform over the whole interior to within the same amount; the ease with which the temperature can be automatically controlled so as to follow any desirable time-temperature curve; low operating costs; uniform quality of annealing—all these indicate the superiority of the electric furnace as compared with the gas-fired equipment.

In working out actual annealing schedules, however, it would seem that Mr. Collins has not taken advantage of the most recent data on the annealing of glass. The most advantageous annealing schedule can not be determined solely from observations of the "critical ranges" for the various kinds of glass. It is necessary to have a complete set of data on the annealing-times for various temperatures. Furthermore, it can be shown that the best annealing schedule requires that the annealing-time be equal to the cooling time; that the glass be cooled at an increasing rate; that thick pieces be annealed at lower temperatures than thin pieces; and that the total time required is proportional to the square of the thickness. The time-temperatures given by Mr Collins show the glass to be cooled at a *decreasing* rate even at the higher temperatures.

The "best" annealing temperatures for "dense flint" glass (Bur. Stds. No. 76) is given as 476°. This is probably too high, since any kind of flint glass of reasonable thickness should not be annealed at a temperature higher than 430° (cf. *J. Franklin Inst.* 190, 852 (1920)). The schedule for a crown glass telescope lens as shown in "Curve Sheet III" indicates that a total of 700 hours would be required for the annealing process. Now the largest lens blank ever made in this country is six inches thick, and a piece of glass of this thickness should not require more than 300 hours for a very complete annealing. Similarly the schedule according to which commercial glass requires 3 hours is probably too long. The total time of the annealing process for thin glass ware could be reduced to little more than one hour.

Author's Closure.—I am gratified that Mr. Adams points out that the most recent data on the annealing of glass defines further, important conditions that work toward shortening the annealing cycle. This means that when the electric lehr is in the hands of the glass manufacturing expert, who can apply the most advantageous anneal schedule in every case, the limit of its accomplishment will be much in advance of the claims made in my paper.