THE USE OF MODELS FOR STUDYING THE CIRCULATION IN GLASS TANKS

By

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I. INTRODUCTION

The circulation of liquid glass in a tank furnace may be imitated qualitatively, by experimenting on a small model of the tank at such moderate temperatures as will admit of using some ordinary liquid to represent the molten glass. If all the circumstances of the model experiment could be suitable arranged and controlled, the imitation might be made quantitative, and observations on the behavior of the liquid in the model would then give definite and reliable in formation about what happens in full-scale operation. We propose to inquire into the conditions that would have to be satisfied in the model experiment in order to achieve this result.

The problem is altogether unmanageable unless we idealize it considerably by making simplifying assumptions, some of which are only rough approximations to reality. The greatest difficulties occur in connection with the choice of a model liquid, for the thermal and mechanical properties of this liquid must be related in certain definite ways to the corresponding properties of the molten glass, and it is doubtful whether any satisfactory liquid can be found or made up.

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But assuming that a suitable liquid can be obtained and accepting such other assumptions as seen unavoidable, we may attempt to fihd out how the model experiments ought to be conducted.

II. Similarity of Circulation

In the full-sized tank, let (O_o) be some fixed point on the free surface of the molten glass; (e.g.) the center of the refining end, and let (P_o) be a fixed point anywhere in the body of the liquid.

The surface speed (S.), can be found from observations on floats, but if the values of (V_o, δ_o) and (E_o) are be found it must be by inference from observations on the model, because the point (P_o) is inaccessible to measuring instruments or to visual observation.

S_o = Speed of flow at O_o.
V_o = Speed of flow at P_o.
δ_o = Angle between velocity at (P_o) and the vertical.
ϵ_o = Angle between this velocity and horizontal median line of tank .

In the model, let (O_1) and (P_1) be the points that correspond, geometrically, to (O_o) and (P_o) and let (S_1), (V_1) (δ_1) and (ϵ_1) have the same meanings, mutatis mutandis, as (So, V_o, δ_o) and (ϵ_o). Then, by saying that the circulation in the model is "Similar" to that in the large tank, we shall mean that.

$$\delta_1 = \delta_o , \quad \epsilon_1 = \epsilon_o , \text{ and } \frac{V_1}{S_1} = \frac{V_o}{S_o} \qquad (1)$$

for all positious of the point (P_o).

It the model experiment can be so arranged that this similarity subsists, observations of (δ_1) and (ϵ_1) at points in the model liquid will give the values of (δ_o) and (ϵ_o) at the geometrically correstponding points in the liquid glass, and observations of (S_1) and (V_1), together with observations of (S_o) in the large tank, will give the values of (V_o) so that we shall then know the speed and direction of motion of the glass at points below the surface where they can not be observed directly. If a model experiment is to serve this purpose, it must evidently be so devised that it is possible to determine the speed and direction of the flow at points in the body of the liquid. How this is to be done will not be discussed here, we Shall assume that it can be done and pass on.

III. Assumptions Relating to the Liquid

(a) The circulation of the molten glass, or the "velocity field" in the large tank, depends on certain mechanical and thermal properties of the glass, and the circulation in the model liquid. These properties vary with temperature, some more than others, and in any complete discussion of the relative behavior of two liquids in regions of nonuniform temperature it would be necessary to take account of the variations in question. We shall assume, however, that the properties of the glass that influence its circulation may be adequately specified by stating their values at some mean temperature, and we shall make the same assumption with regard to the model liquid. In the case of the glass, the assumption is equivalent to assuming that if a liquid could be found that had, throughout the range of temperature to which the glass is subject, the same properties as the glass has at a certain fixed, mean temperature and if the glass were replaced by this liquid, the substituted liquid would circulat in the same way as the molten glass actually circulates. Similarly with respect to the model liquid.

The assumptions may be only roughly true, especially for the glass, but they are indispensable simplifications.

(b) In the melting end of the tank, the glass is heated, partly by contact with hot gases and partly by radiation from the roof, and in the refining end, where the roof is cooler, the glass may be losing heat by radiation to the roof. In either case, the direct effect of radiation on the temperature of the glass is probably limited to a thin surface layer, for it seems probable that molten glass is very opaque to the kind of radiation involved.

We shall assume that the glass is so opaque that the temperatures at points in the body of the liquid below the surface are not appreciably affected by direct radiation but only by conduction and convection.

So far as this is true, the convection currents that accompany the space variations of temperature in the body of the liquid will not depend on the means by which a particular distribution of temperature is maintained in the surface layer but only on what that distributions.

(c) The viscosity of liquid glass is very high (of the order of 10000 times the viscosity of water at room temperature) and the speeds of circulation are low, hence the inertia forces are small in comparison with the viscous forces. We shall assume that the inertia forces are of negligible importance.

This assumption seems quite safe. It is advantageous in applying dimensional reasoning to model experiments, as we are about to do, for it authorizes us to ignore the existence of Newton's second law of motion and to use an arbitrary fundamental unit of force instead of a unit derived from the units of mass, length, and time.

(d) There would be a further advantage in ingoring the fact of the equivalence of work and heat and using an arbitrary fundamental unit of quantity of heat.

whore this is permissible depends on whether the amounts of heat produced by dissipation of the work done by gravity against visecous resistances are of any importance in comparison with the ammunts moved from place to place by conduction and convection. For if they are not, the distribution of temperature througout the body of the liquid, or the "temperature field". Will be sensibly the same as if the dissipated work were simply annihilated. In view of the high value of the mechanical equivalent of heat, it seems unlikely that the heat of dissipation is of appreciable importance, and if this surmise is correct, the fact that work can be dissipated into heat, with a fixed conversion ratio, has no bearing on the operation of a glass tank and may be disregarded. We shall assume that this is permissible, and we shall therefore use an independent fundamental unit of heat in experessing the dimensions of specific heat and thermal conductivity.

IV. Postulates Concerning Construction of the Model.

(a) The shape of the model tank, including the thickness of the walls and their internal roughness, is to be geometrically similar to that of the large tank, and the depth of the liquid is to be relatively the same in both.

The term "wals is to be understood as referring to the floor of the tank as well as the sides, but not to the roof or to parts of the sides above the level of the liquid surface.

(b) If the thermal conductivity of the walls of the large tank is the same everywhere, the model may be built of a single, uniform material. Otherwise, the material of the model is to be varied from point to point, in such a way that its conductivity at each point bears a fixed ratio to the conductivity at the corresponding point on the large tank. What this ratio must be need not be specified until later.

We may describe this requirement by saying that the distribution of thermal conductivity in the walls of the model is to be "similar" to that in the walls of the large tank, or that when we pass from the large tank to be the model the distribution of conductivity is to remain "similar to itself".

V. Heating and cooling of the Model

Part of the heat given to the glass in the melting end of the tank is used in heating and melting newly introduced, cold material, and part is carried to the walls by convection and escapes to the outside air by conduction through them.

Both parts depend on the fact that the glass is hotter than the air, and steady operation depends on the maintenance of this excess of temperature.

Hence, in arranging a model experiment to imitate the temperature field and the accompanying circulation in the large tank, it is necessary to provide for some sort of similarly as to differences of temperature: (a) between the free surface of the liquid and the outside air and (b) between the outer surface of the walls and the air in contact with them.

(a) The surface of the liquid in the melting and of the model tank is to be heated by contact with jets of hot air.

Heating by radiation from a heated roof, or from electric heaters placed over the surface of the liquid, would doubtless be more convenient. But to furnish enough heat would require a high radiator temperature and, unless the liquid were very opaque, this high-temperature radiation would penetrate to the deeper layers and heat them directly.

This would not be a satisfactory imitation of the manner in which we have assumed the heating to take place in the fullsized furnace.

The heating is to be so arranged that the distribution of temperature over the surface of the model liquid imitates, and is similar to, the distribution over the surface of the molten glass, and before this adjustment can be made, the temperature of the surface of the glass must have been measured at a considerable number of points so that we may known that we have to imitate. Such meas rements are not easy to make, but without discussing the obvious experimental difficulties, we shall suppose them to have been surmounted and shall procedd to consider how the terin a "similar" is to be understood in this connection.

In the case of the full-sized tank, let

t_o = Surface temperature of glass at any point ,(P_o).

m_o = mean temperature of whole surface.

a_o = mean temperature of outside air.

Δ_o = $m_o - a_o$

Then the distribution of temperature that is to be imiltated may be described by stating the constant values of (a_o) and (Δ_o) and by stating the values of $(m_o - t_o)/\Delta_o$ for all positions of the point, (P_o).

Turning to the model, let the corresponding quantities be denoted by (t_1, m_1, a_1, Δ_1 and t_1) referring to the point (P_1) which corresponds geometricaly to (P_o). The distribution of temperature over the surface of the model liquid may be described, as for the molten glass, by stating the values of (a_1), (Δ_1) and $(m_1-t_1)/\Delta_1$.

If the heating of the model is so arranged that the equation

$$\frac{m_1 - t_1}{\Delta_1} = \frac{m_o - t_o}{\Delta_o} \qquad (2)$$

is satisfied for all pairs of corresponding points (P_o) and (P_1) we shall say, as a matter of definition that the distribtions of temperature are similar, and we postulate, as one of the conditions to be observed in arranging a model experiment, that the surface of the model liquid shall be heated in such a way as to produce this temperature similarity between the model and the large tank.

(b) The temperature of the outside surface of the walls of the model must also be attended to and specified because it influences the rate of conduction through the walls.

Let (e_o) be the temperature at any point on the walls of the large tank and let (e_1) be the temperature at the corresponding point on the model. Then if the values of (e_1) are so adjusted that

$$\frac{e_1 - a_1}{\Delta_1} = \frac{e_o - a_o}{\Delta_o} \qquad (3)$$

for all pairs of corresponding points, we shall describe this adjustment by saying that the distribution of temperature on the outside surface of the model is similar to that on the outsdie of the large tank.

As a second temperature condition, we postulate that this similarity shall be maintoined. There should be no serious difficulty in satisfying this requirement for the values of (e_o) are readily accessible to measurement and those of (e_1) can be regulated by blowing air on the model.

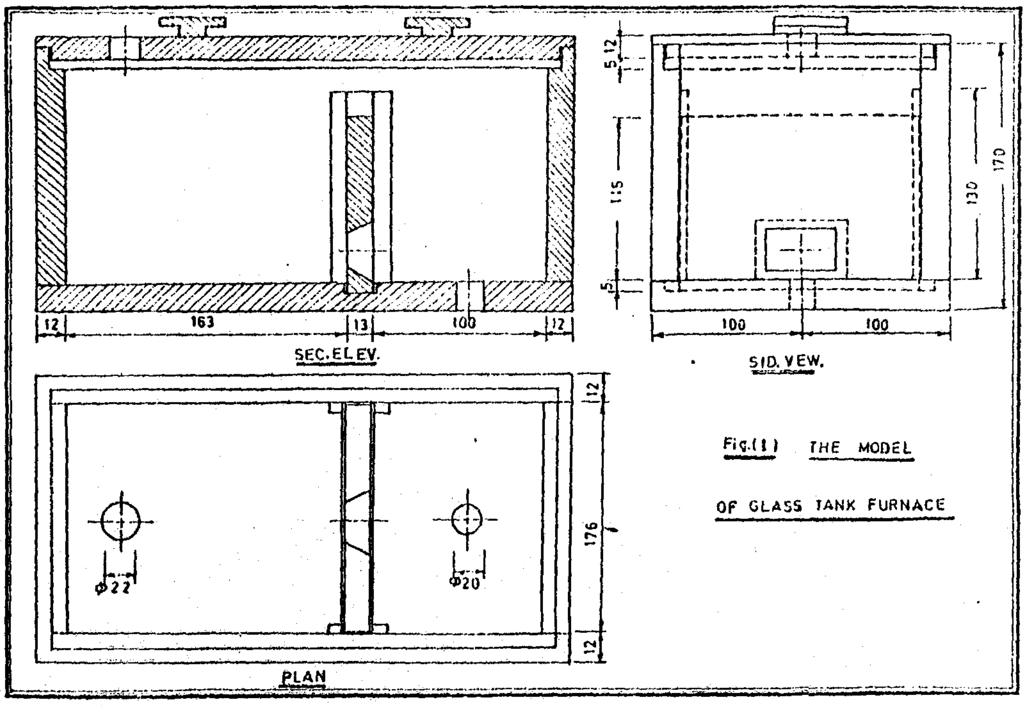
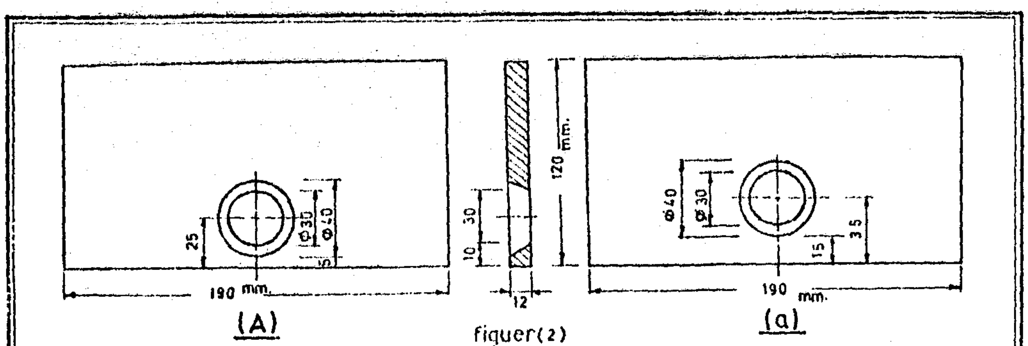


Fig.(1) THE MODEL OF GLASS TANK FURNACE



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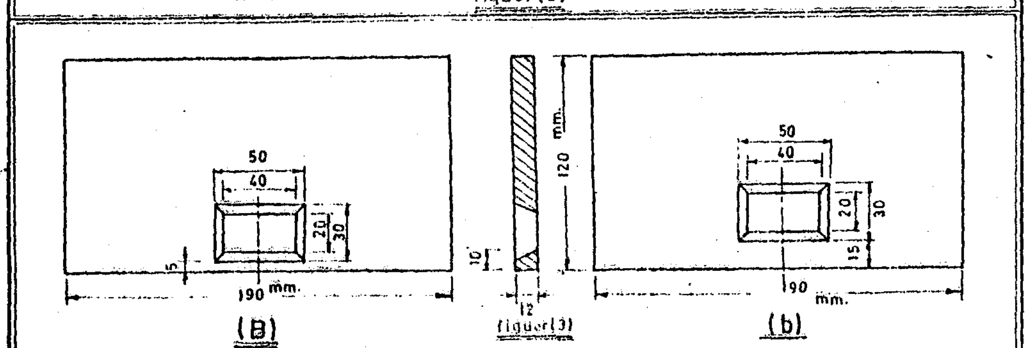

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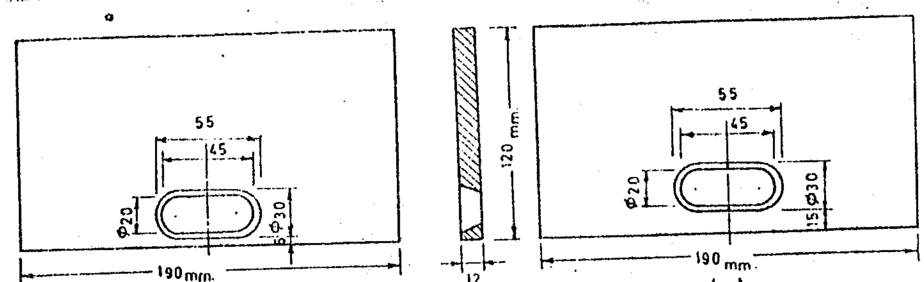
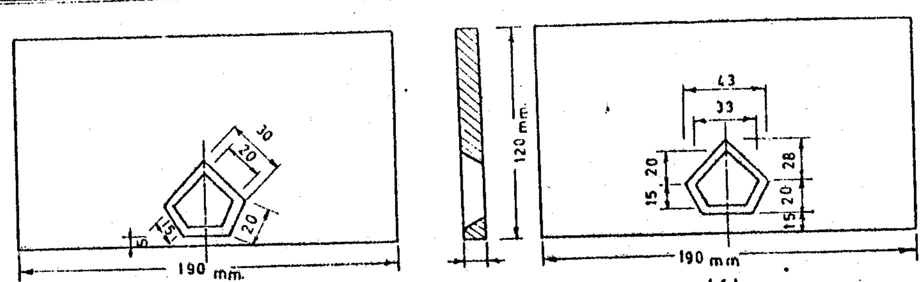
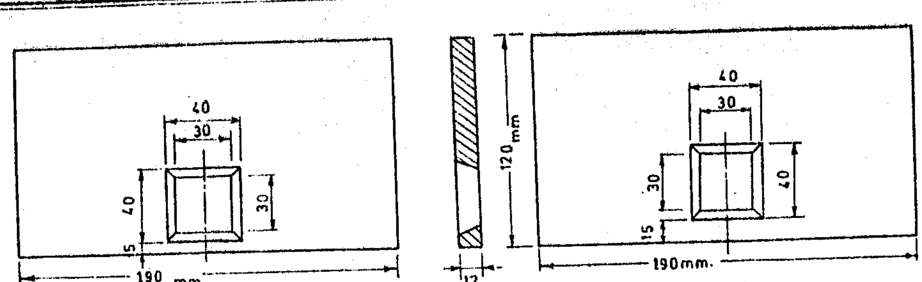


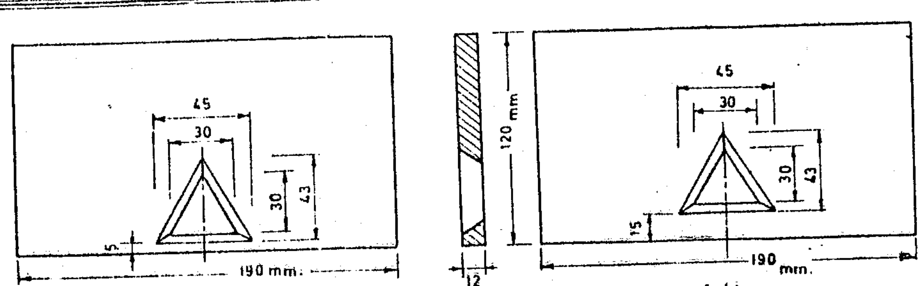
(E) figuer(4) (e)



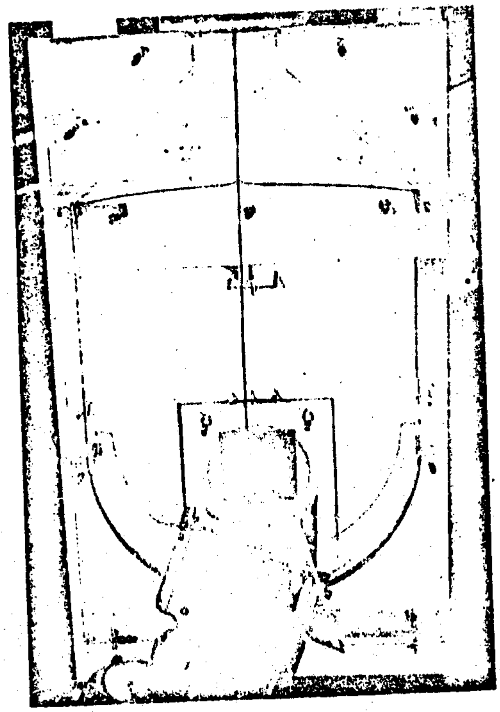
(F) figuer(5) (f)



(C) figuer(6) (c)



(D) figuer(7) (d)



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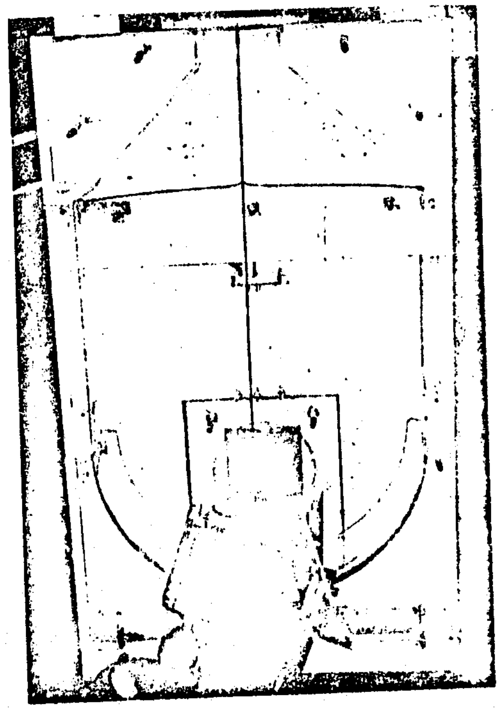

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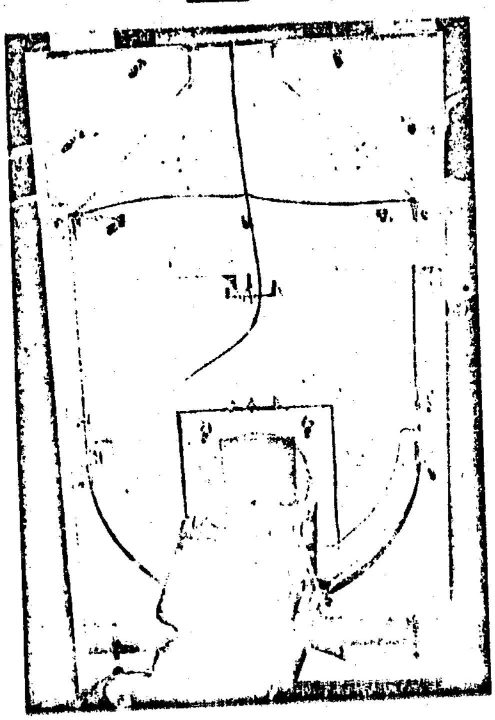

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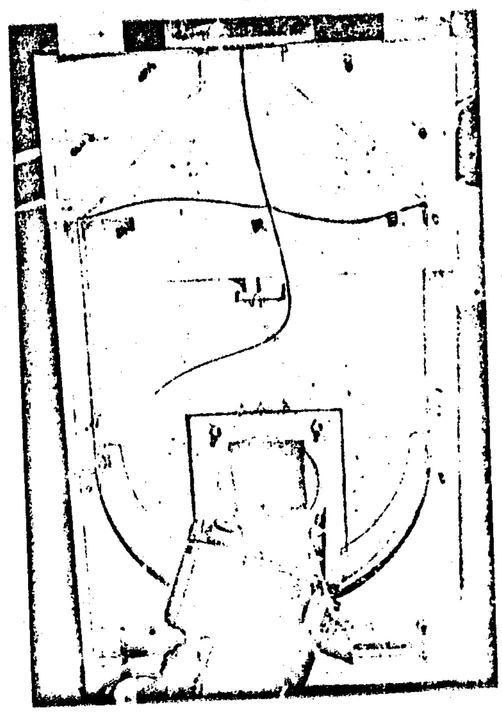

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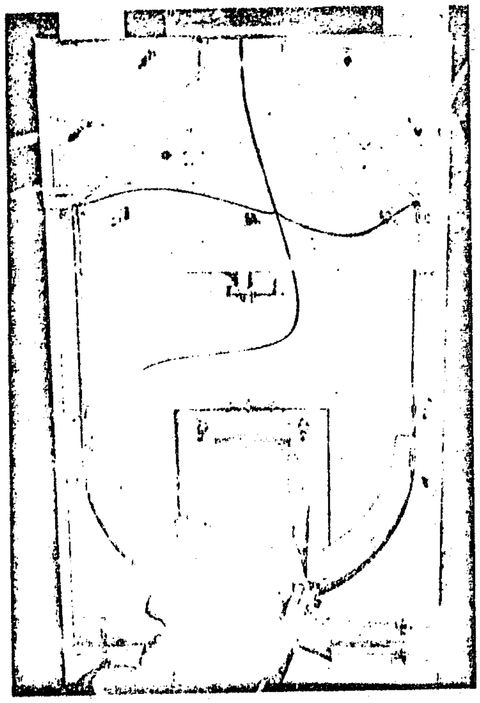

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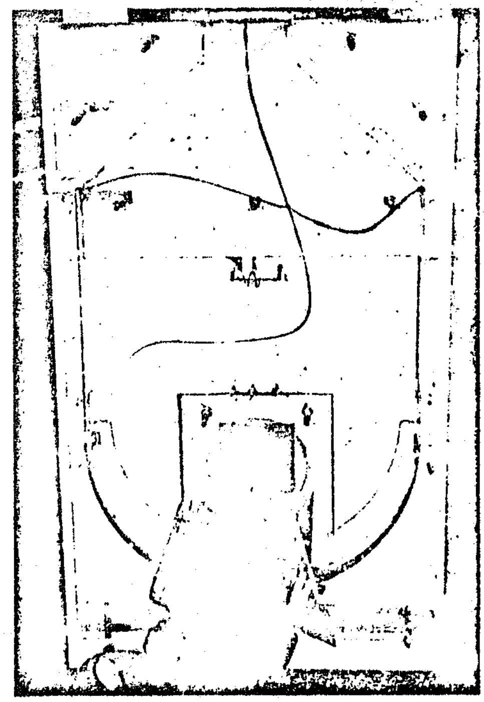

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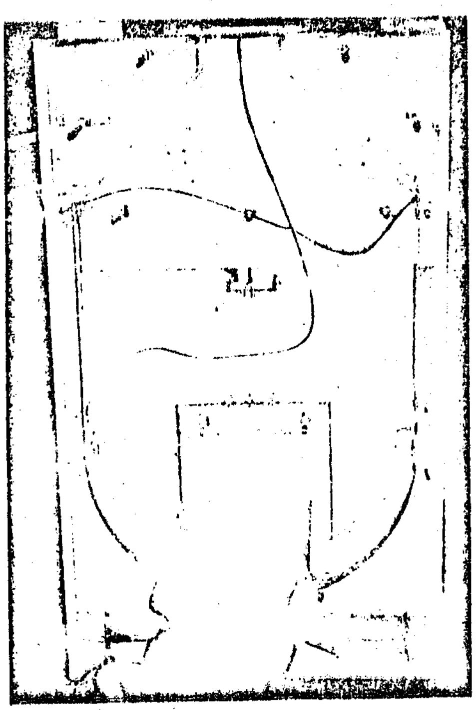

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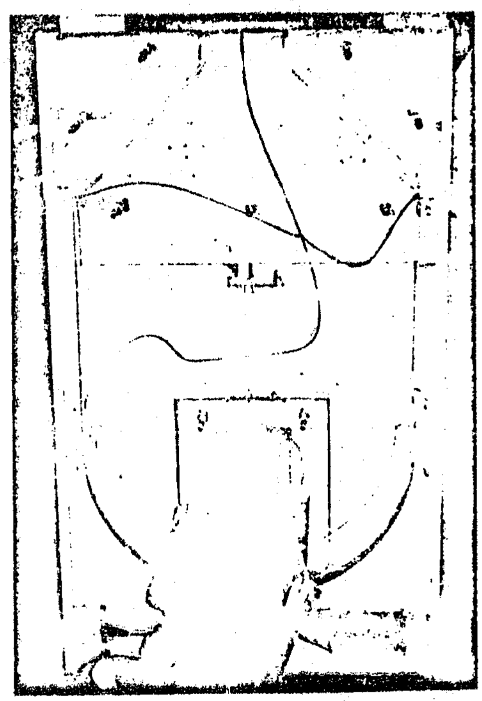

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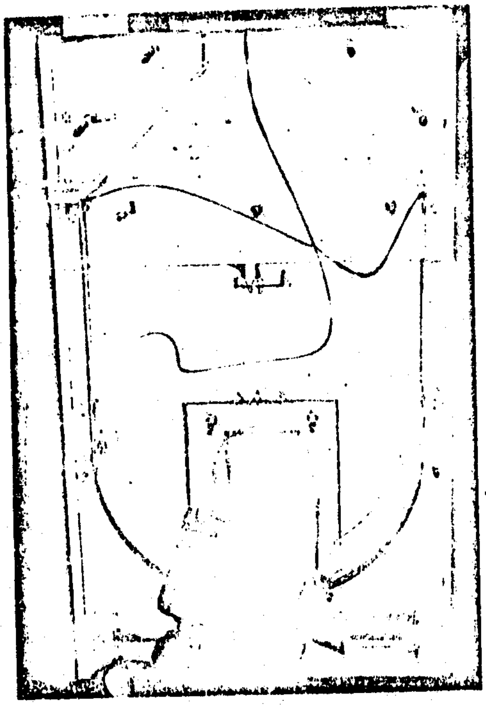

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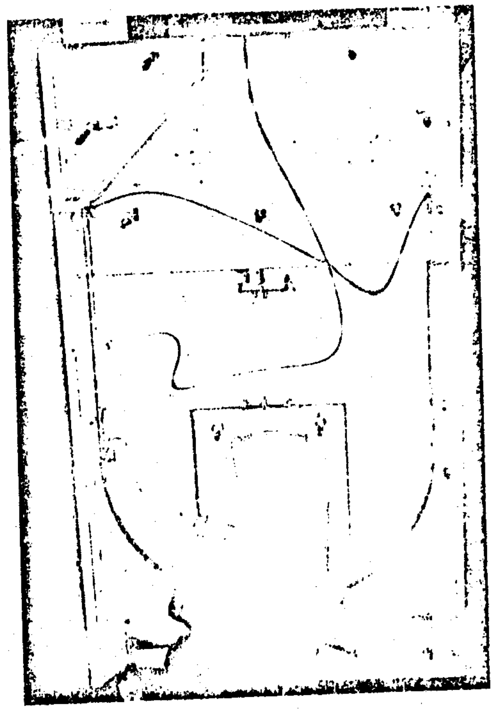

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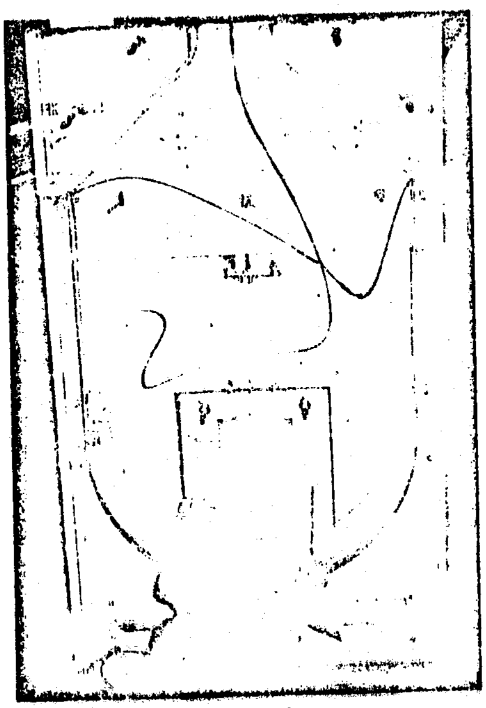

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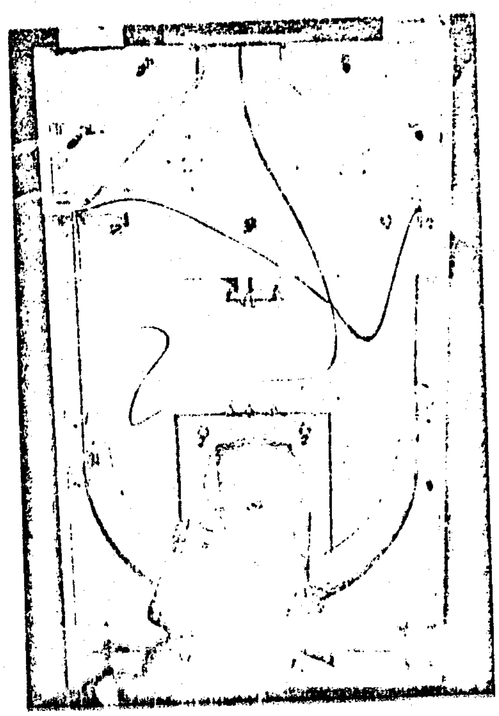

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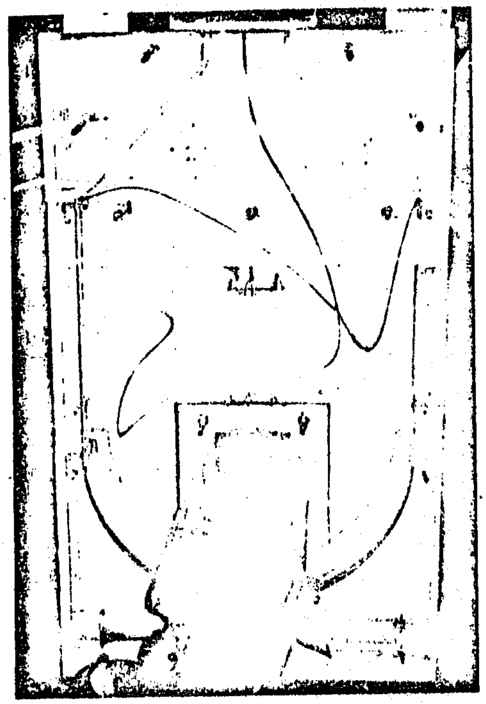

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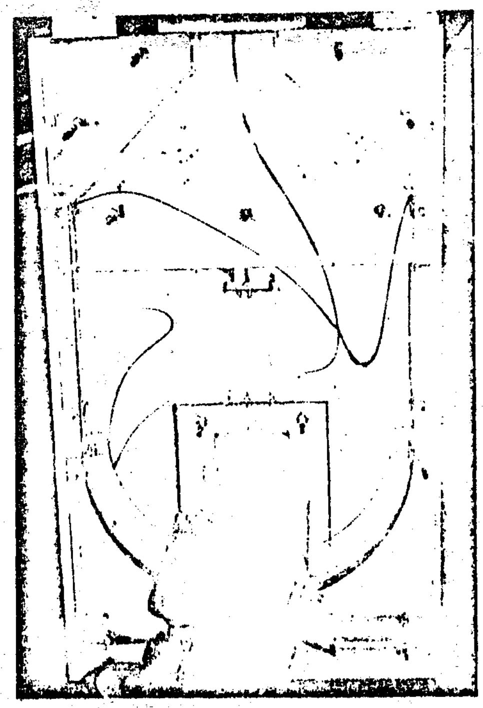

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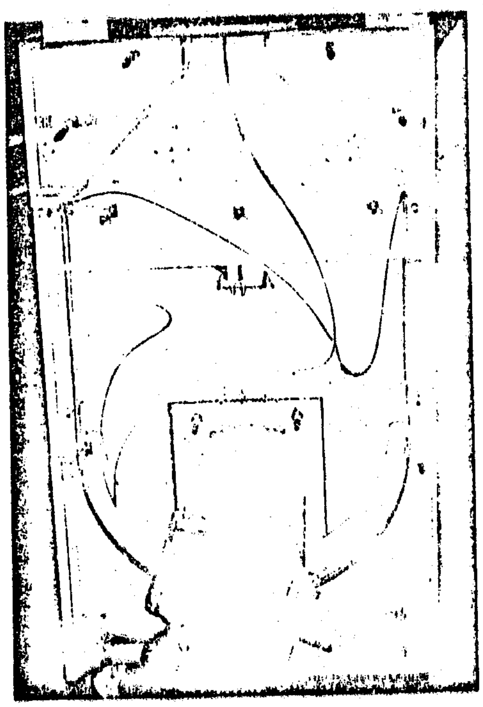

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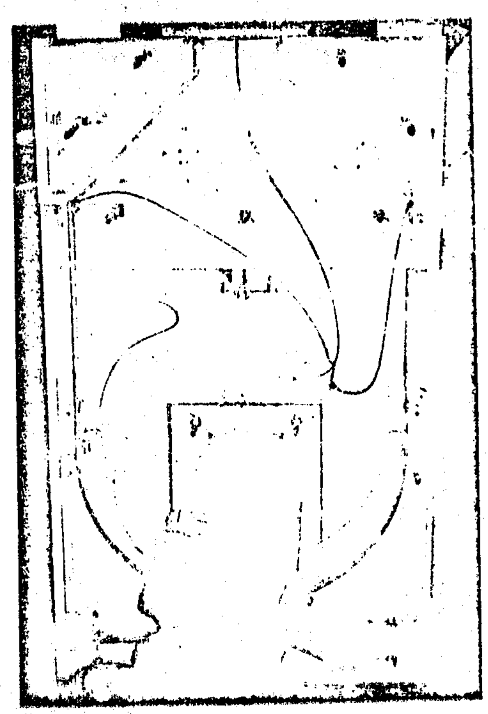

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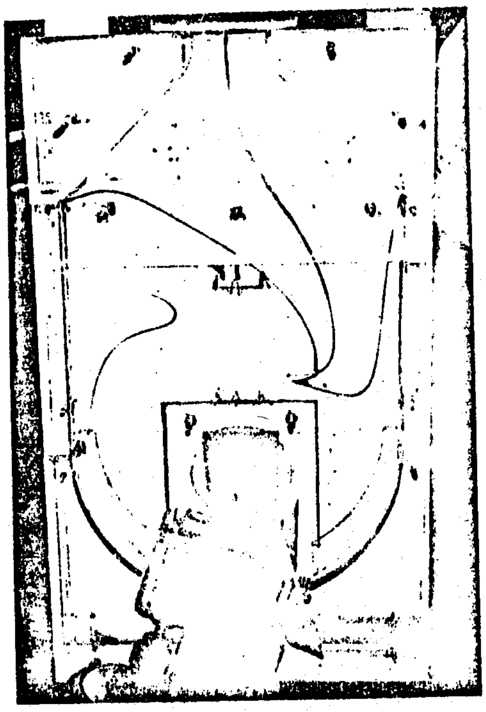

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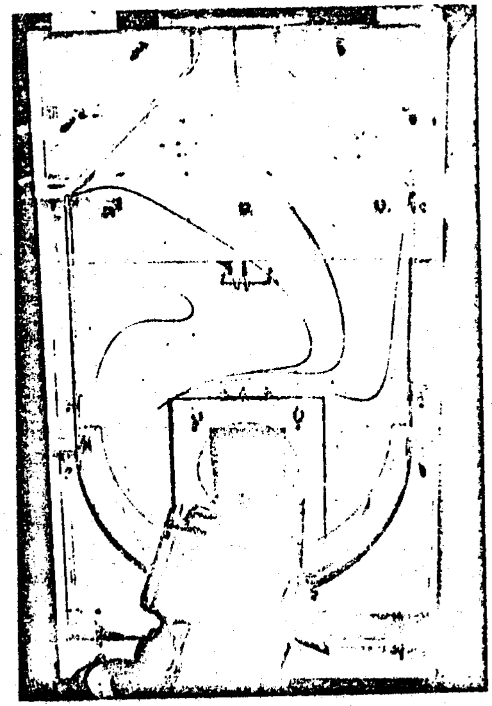

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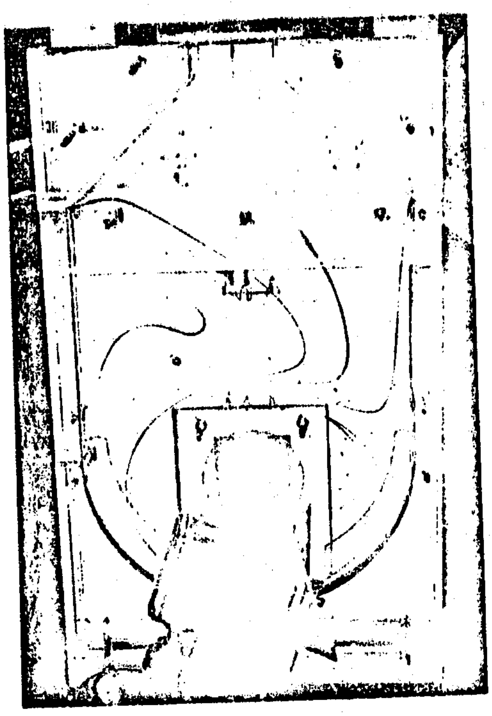

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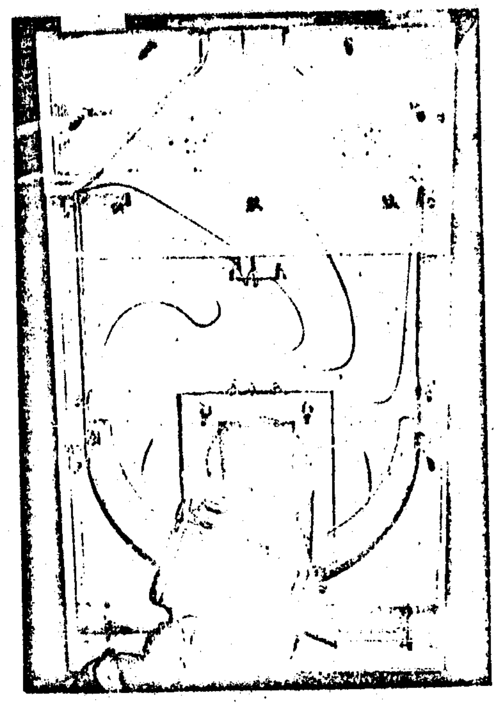

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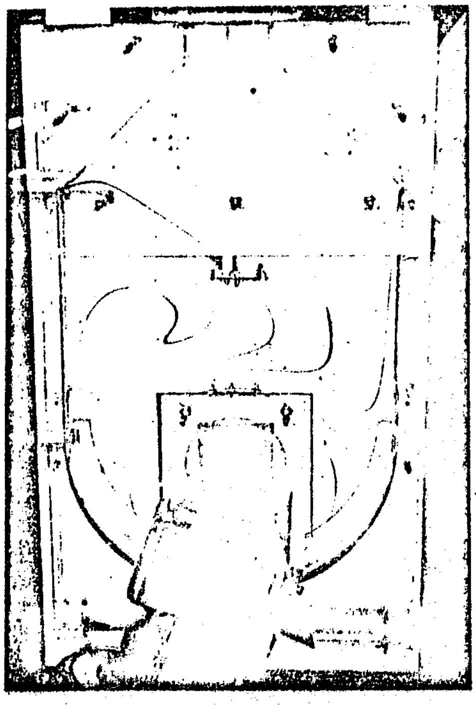

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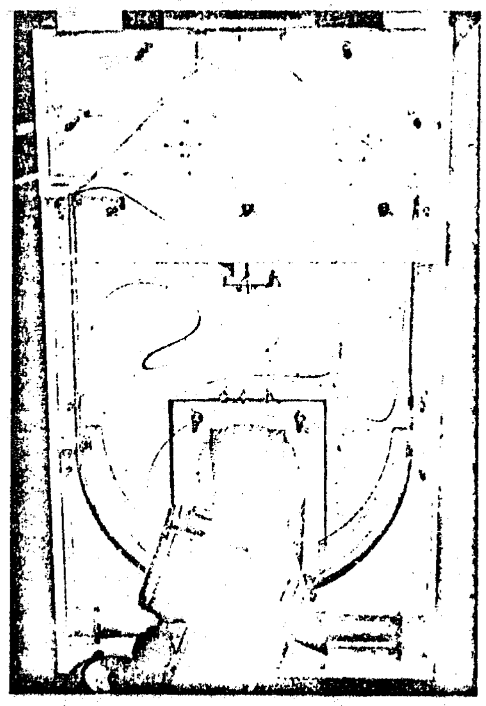

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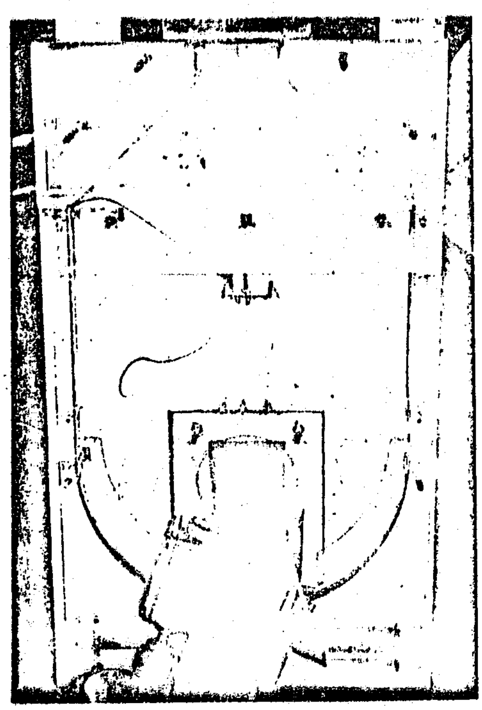

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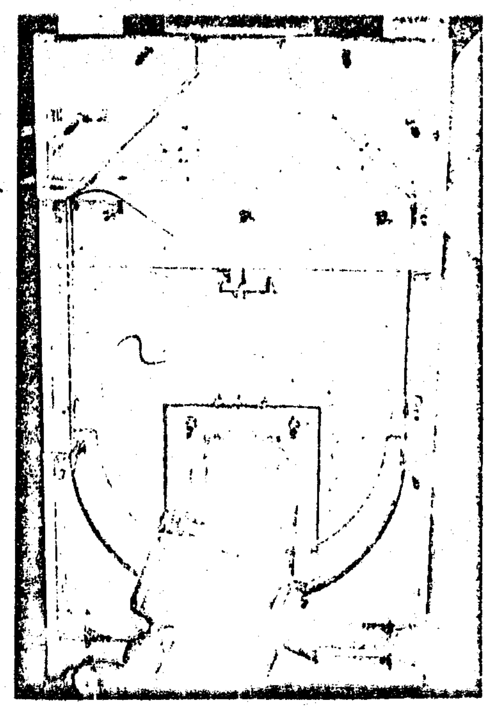

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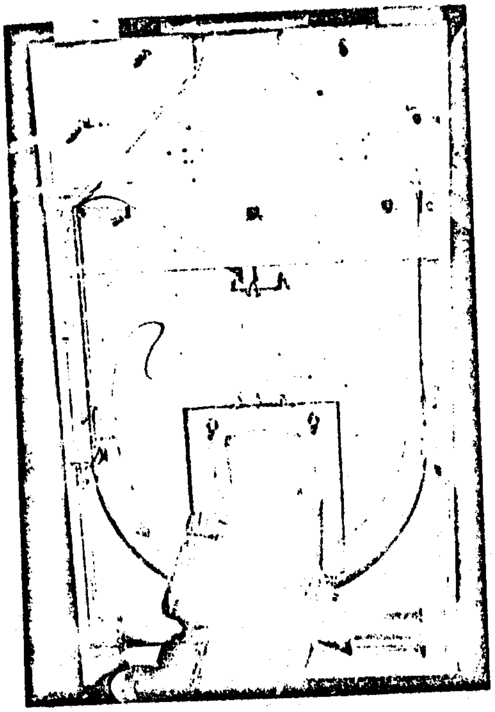

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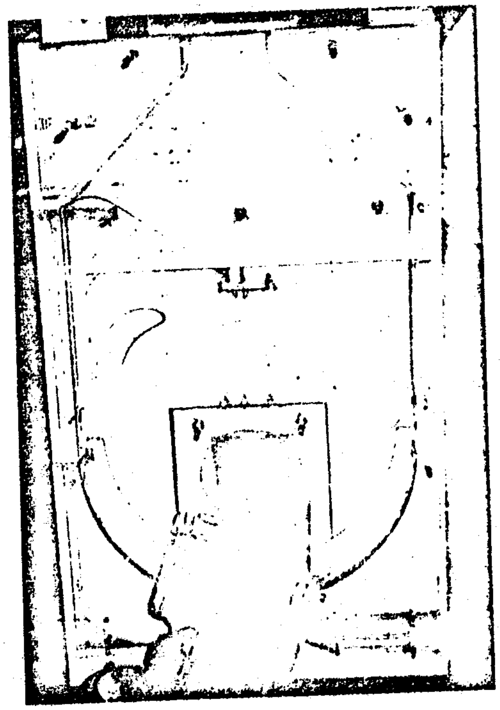

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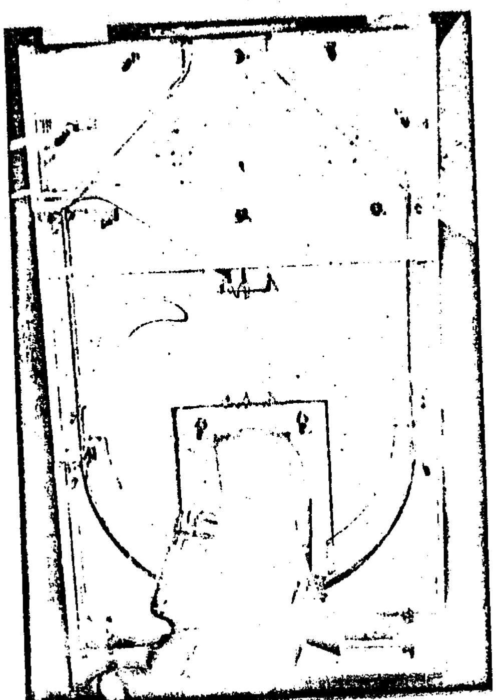

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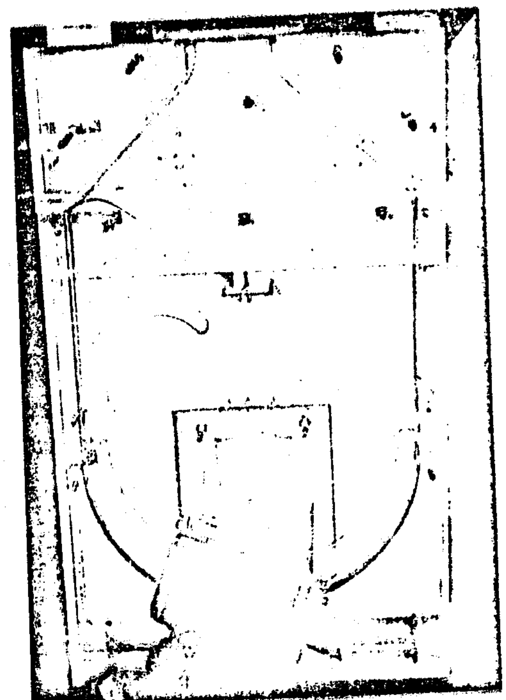

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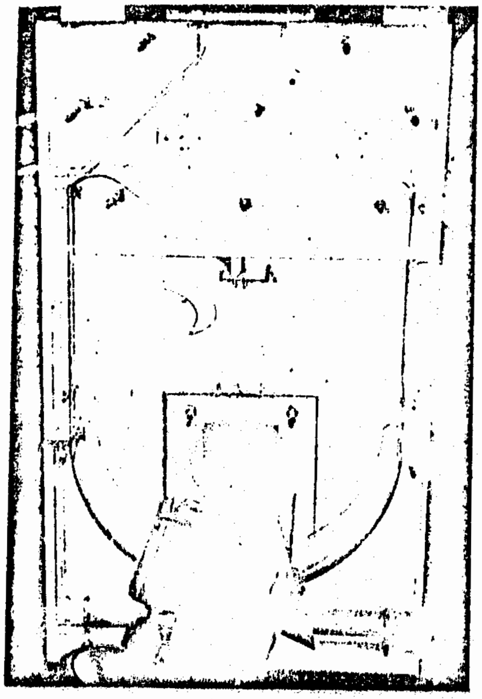

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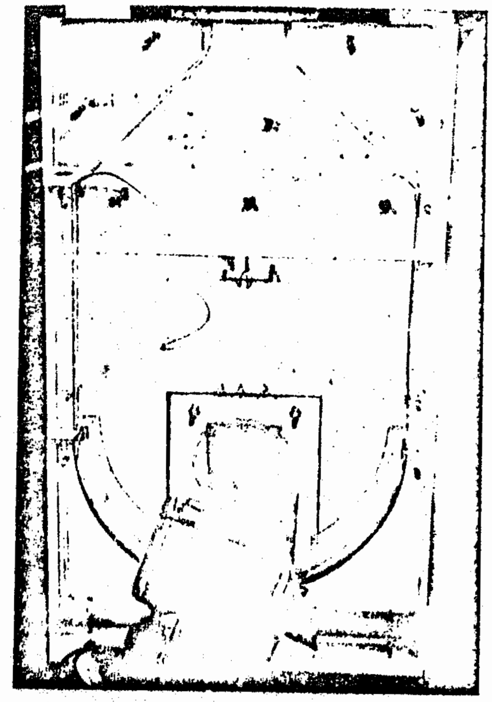

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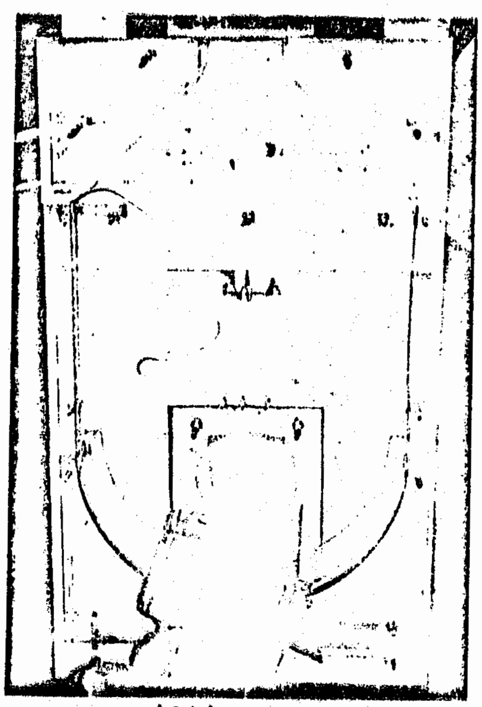

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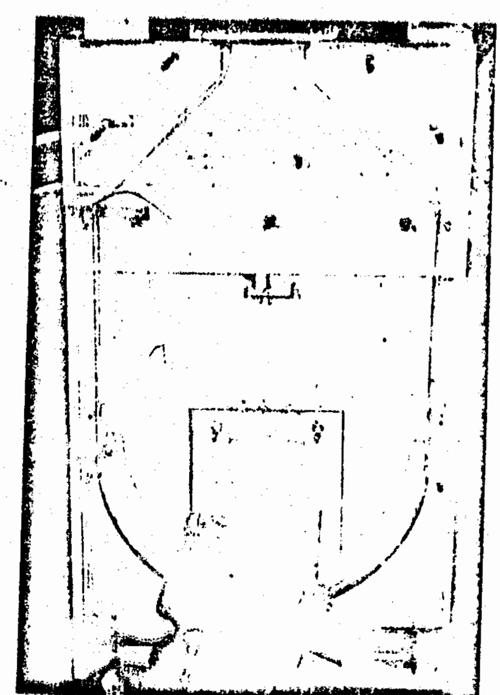

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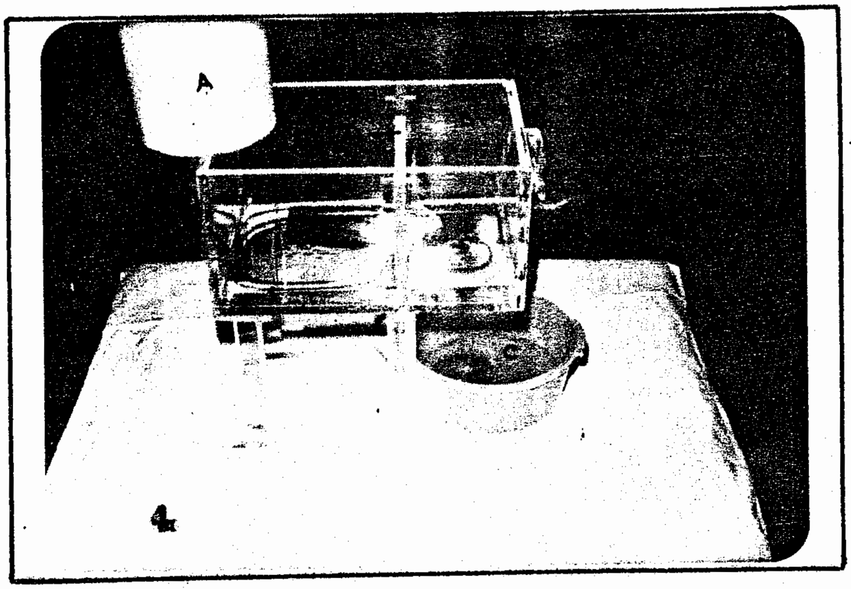


Figure (A): EXPERIMENT SET-UP

A- Supply Tank.
B. Scale-Furnace.
C- Drain Pot.
D. Throat.

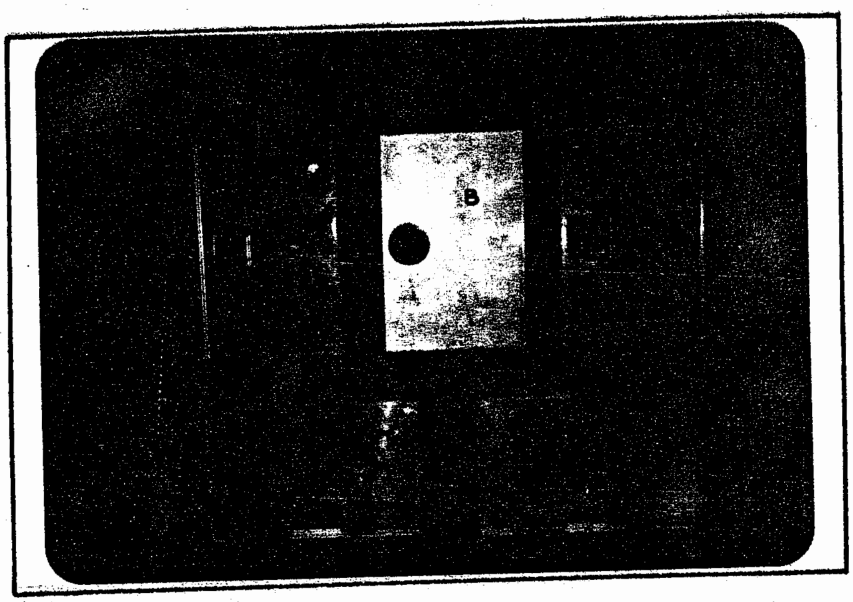
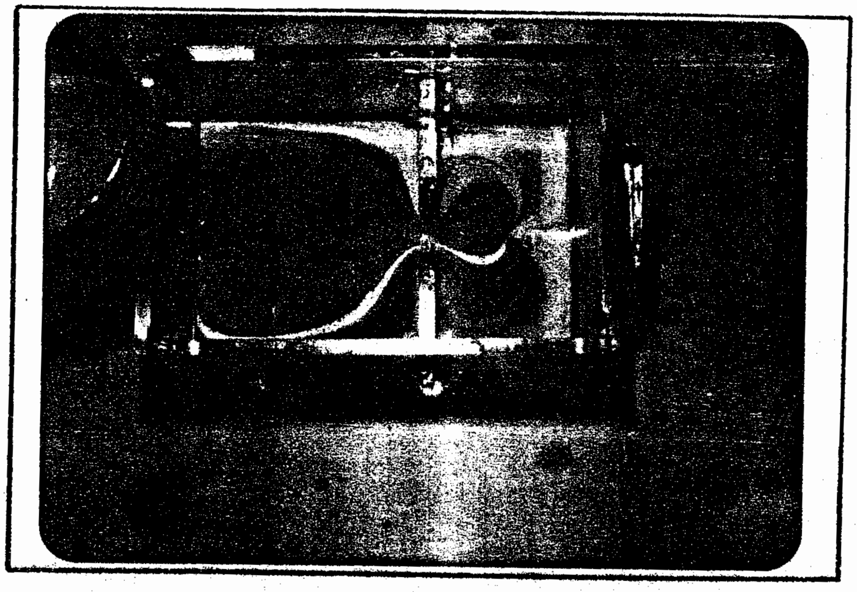


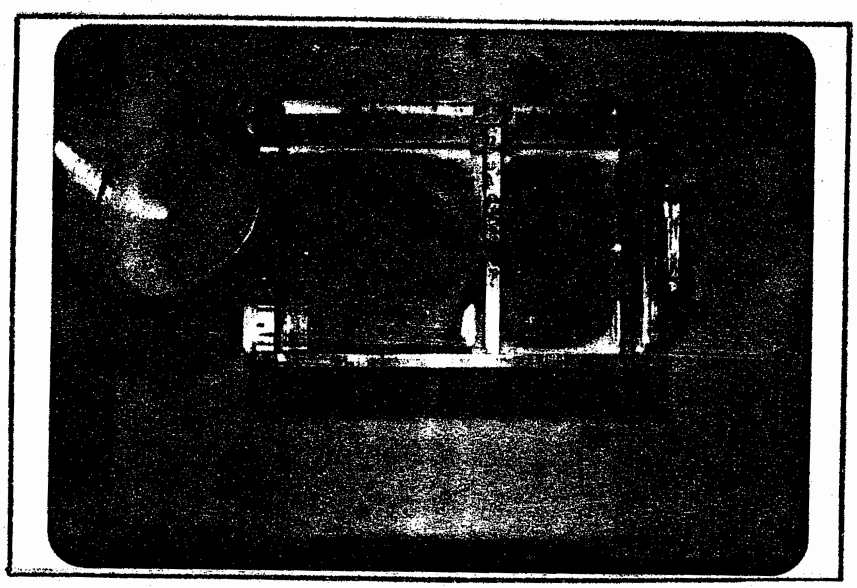
Figure (B): THROAT CONFIGURATIONS

A. BEVELLED
B. CIRCULAR
C. SQUARE
D. RECTANGULAR
E. TRINGULAR.

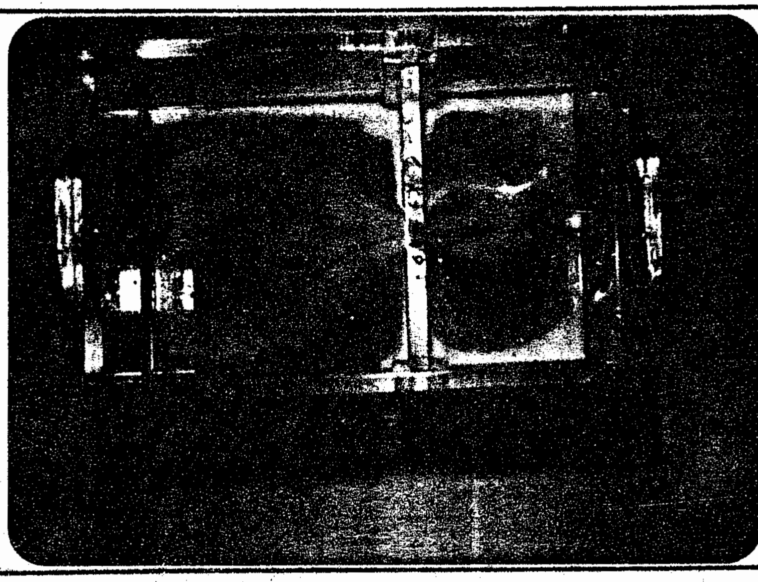
Figure (C): RECTANGULAR THROAT



1. Flow lines directed to throat.



2. Two distinct flow lines.



3. Stable similar flow.

Figure (C): RECTANGULAR THROAT

The pictures indicate flow pattern of liquid glass in furnace tank and throat:

1. Flow lines directed to throat.
2. Two distinct flow lines.
3. Stable similar flow.

I- RESULTS:

The Figs.(1-32) show the experimental result which clearly indicates:

(1) It is possible to predict the behavior of glass furnace by using scale models.

(2) The best results are with circular throat, however the rectangular throat have less but very similar results, we thers recommend rectangular throat as circular throat practically are expansive and difficult to produce and maintian during the operation of furnace.

II. RECOMMENDATION:

We recommend the following:

After design a glass furnace a scale model is recommended to predict the different parameters of the furnace such as:

(1) Threat shope.

(2) Throat dimensions.

(3) Length to width ratio.

(4) Glass depth.

If glass movement is satisfactory no further investigatios are required if not some changes in the model is made untill satisfactory results achieved.

This modification are then done on the experimental furnace to validate its application.

References:-

(1) EDGAR BUCKING "The use of models for studying the ceiculation in glass tanks"

report sesearch lab. Asahi glass No. (3), Vol. (26)-1976.

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استخدام النماذج المصغرة لدراسة سلوك الزجاج في أفران الصهر

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استعرضت البحوث المنشورة في هذا المجال والتي تقترح بناء نماذج مصغرة لأفران صهر الزجاج تتخذ لزوجة السائل المستخدم بها طبقا للزوجة الزجاج المنصهر والنسبة بين النموذج المصغر وفرن الصهر. واستنادا الى ذلك فقد تم عمل نموذج مصغر بنسبة (١ : ٥) يحاكي الفرن الأصلي وتغيير أبعاد وشكل فتحة الزور " مجرى مرور الزجاج بين منطقة الصهر ومنطقة التشغيل " وقد تم تصوير سريان السائل الذي استخدم "جلسرين + سولار " بعد تلوينه مع كل مقطع متغير لأبعاد الزور ــ وقد أسفرت النتائج التي تم التوصل اليها لما يلي :ــ

أولا : تتأثر حركة الزجاج كثيرا بتغيير شكل الزور ويفضل الشكل الدائري ونوصي باستخدام الشكل المستطيل للأغراض الصناعية .

ثانيا : تيارات الزجاج الأمامية والعكسية بالنسبة لأبعاد الفرن الأصلي والذي يحاكيه النموذج المصغر المستخدم مناسبة ولا تشكل أي صعوبات متوقعة في التشغيل أثناء سريان الزجاج .

ثالثا : أسفرت التجارب عن نجاح فكرة النماذج المصغرة والمصورة معمليا امكانية استخدامها للتنبؤ بحركة الزجاج في أفران الصهر.

التوصيات:

ان استخدام النماذج المصغرة مصاحبة لأفران صهر الزجاج ضرورة لاغنى عنها وذلك لدراسة مايلي :

١ ــ تأثير شكل وأبعاد مقطع الزور وموقعه .
٢ ــ النسبة بين طول وعرض الفرن .
٣ ــ عمق الفرن اللازم لصهر الزجاج .
٤ ــ لزوجة الزجاج المنصهر ودرجة حرارة الصهر.

هذه المتغيرات والبارامترات سالفة الذكر يصعب للغاية تغيرها أو الاستدلال عليها بنماذج رياضية قابلة للحل الأمر الذي يؤكد ضرورة استخدام النماذج المصغرة لأفران صهر الزجاج في دراسة تصميم أفران صهر الزجاج .