

Progress Report on the Ink Drying Process of Rotogravure Presses

Eschenbach, Wolfram
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Progress report on the ink
drying process of rotogravure
presses

by Wolfram Eschenbach

Institut für Druckmaschinen und Druckverfahren der
Technischen Hochschule Darmstadt

PROGRESS REPORT ON THE INK DRYING PROCESS OF ROTOGRAVURE PRESSES

I. Introduction

The drying Problem has become especially meaningful because of the increasing use of high speed printing presses, in particular also those of multicolour rotogravure. Printing quality and hourly output depend strongly on the behaviour of the drying process which is especially so in the case of rotogravure with its specific inks. A wide variety of drying systems of relatively short drying distance testifies to efforts made for the creation of optimum drying conditions.

In the following we shall sketch some methods developed by the Darmstadt Institute which make possible measuring techniques for the continuous observation of drying behaviour in the rotogravure press under actual working conditions.

To begin with let us review a few points about rotogravure ink and its drying process:

Rotogravure ink, a relatively fluid liquid consists of pigments, binding agents, fillers and solvents. Pigments and fillers stay carefully distributed in suspension within the solvent; to them we must add also the binding rosins or cellulose binding agents which are to fix the ink particles to the printing surface after evaporation of the solvent. Once the solvents have, during the actual printing process, transferred the ink particles to the printing surface it is desired that the solvent evaporate as rapidly as possible. The characteristics of the printing material, special technical factors pertaining to printing and last but not least the demand for health protection being considered, it is practical to use solvents of good volatility of the aromatic series (toluene, xylene) and of aliphatic hydrocarbons (benzines). For special inks ester, glycole and simple alcohol may be used.

The study of the drying process in rotogravure raises questions of physical and chemical nature whereby different phases may be distinguished.

It may be assumed that the solvent in rotogravure inks (in other words the humidity which is to be removed subsequently) is bound by adsorption to the fixed ink components. As has been stated already, drying of rotogravure ink occurs through evaporation of the solvent, therefore through transfer of solvent molecules from the ink layer to the surrounding air. Evaporating speed, it is known, depends amongst other factors upon solvent vapour pressure and the "substance transfer factor". For example, the latter depends amongst other factors on the speed with which the drying air flows over the printing paper surface (slope of the concentration curve). The following equation can be established for evaporation intensity:

$$J = \frac{\alpha}{r} (t_2 - t_{fe})$$

$$\alpha = \text{Heat Transfer Coefficient Kcal/m}^2 \text{ h } ^\circ\text{C}$$

$$t_2 = \text{Air Temperature } ^\circ\text{C}$$

$$t_{fe} = \text{Surface Temperature of Evaporating Liquid } ^\circ\text{C}$$

$$r = \text{Latent Evaporating Heat of Solvent Kcal/kg.}$$

In operational practice the increase necessary in vapour pressure is attained through heat transfer by convection, radiation or contact drying methods. It is customary in a rotogravure press to heat either the drying air or the printing material from below by means of a drying drum or to simultaneously use both methods. In the example of an air heating system which we shall use in our discussion, the ink layer is drying from above and, as a rule, is forming a so called skin effect quite rapidly.

In the heat drum system the ink layer is being heated from below, a more advantageous solution; however, drying heat necessary must be conducted through the paper web. Paper is a bad heat conductor and loses humidity during the drying process; this can cause undesirable fluctuations in paper tension and register trouble.*) Let it be emphasized that, as a rule, completing of the drying process within the machine itself is not possible because certain solvent quantities will remain adsorbed within the paper capillaries and, some solvent residue will, as the skin forming process progresses remain within the ink body. The aimed at goal is primarily the achievement of a stick free surface drying process corresponding to the ink smear limit at given ink consistency.

Immediately after the contact moment of ink transfer to the paper in rotogravure the solvent and binding agents penetrate the depressions and capillaries of the paper followed by immediate inception of ink filtration. Pigments fix themselves at the paper surface and are in turn retained in their binding agent that is bonded in the solvent as well as in the main part of the highly fluid solvents. Here the skin formation already referred to occurs more or less rapidly, thus making the diffusion process more difficult. Penetration depends on thickness of ink layer, viscosity, printing pressure, contact time and naturally on paper porestructure.

Duration of evaporating process depends on characteristics and quantity of available printing ink (a function of etching depth and printing structure), on the printing material, on temperature, on speed and direction of heating air flow and on the substance transfer factor.

Already in 1954 ~~kaž~~ Beloserskiĵ***) attempted to express, in mathematical terms, the drying process during the evaporation of rotogravure solvents. He began with defining the evaporation process

*) W. Eschenbach, Archiv für Druck und Papier, 2/1960 S. 275

**) A.A. Tjurin: "Die Rotationsmaschine" Bd. IV S. 330/337, Moskau 1954 (Iskusstvo)

of pure solvents without assuming an auxiliary air flow. This author notices that benzole evaporates from saturated picture areas within about 40 - 50 seconds, a time consumption several dozen times greater than that of the paper web travelling through the drying system of the machine. If air, circulated at room temperature, is being used evaporation can be speeded up four to six times. Because the paper web remains in the drying system of the machine only fractions of seconds, it is necessary to apply additional heat to the air used in the drying process. For security reasons, at this increased drying temperature, the volume of benzole vapours in the waste air removed from the drying system may not exceed 20 - 25 g/m³ (explosion limit is 48,7 g/m³ at 20 °C).

Beloserskiĵ establishes the following basic equation for the evaporation process:

$$\frac{dB}{dt} = -j (B + a).$$

$\frac{dB}{dt}$ = Evaporating speed of the solvent at the moment.

B = Quantity of non-evaporated solvent at a given time.

a, j = Constants which consider all parameters influencing the drying process.

From this follows the equation for evaporation time:

$$T_0 = \frac{1}{j} \ln \left[\frac{B_A}{a} + 1 \right] \text{ seconds}$$

B_A = Original solvent volume.

Determination of constants j and a is naturally decisive for the practical usefulness of this formula. Evaporation speed of the solvent and together with it the characteristic values for "a" and "j" depend on many factors, to list:

1. Vapour pressure of the solvent.
2. Room temperature and heat supply to the ink layer.
3. Heat conductivity of the ink layer.
4. Specific heat of the solvent.

5. Vaporization entropy of the solvent.
6. Ink surface tension.
7. Molecular associations within ink.
8. Molecular weight of the solvent.
9. Resin and pigment concentrations within ink.
10. Air humidity.
11. Aerodynamic state above drying layer of ink.
12. Thickness of ink film.
13. Viscosity of ink film.
14. Chemical and physical properties of pigments and bonding agents.

The drying of rotogravure ink on the "printing material" is consequently established as a function of many factors. It is difficult therefore to make calculated predictions of drying time.

II. The task

I have initially stated that the performance of a rotogravure press depends essentially on the pattern assumed by the drying process. Practically this process is determined by type and design of drying system on one side and by evaporating capacity of the solvent on the other. Quantitative measurement of solvent evaporation following the printing process is, therefore, of considerable interest not only for the manufacturer of printing machines but also for the ink manufacturers and specifically for rotogravure plants. (We shall not deal within the framework of this paper with mathematical treatment of problems pertaining f.inst. to aerodynamic events, calculation of evaporation time, etc.).

In practice several methods, respectively apparatus have been developed for measuring evaporation speeds of different solvents. To mention but a few: the apparatus of MAN, those of Waldschmidt and of Warburg.

For the time being and by using new research methods, namely gas chromatographic methods, the Darmstadt Institute was successful in measuring the first phase of the drying process directly on

the paper web of the printing press; in such manner that over the standing but inked paper web an air-solvent mixture was blower-drawn from the ink layer surface and channelled into a system of alternating accumulators and hence to a Perkin-Elmer Gas Chromatograph.*) It was thus possible to establish a series of evaporation curves.

In the second phase of this research program we used an apparatus for measuring the presence of hydrocarbons, most of the commonly used inks belong to this group; this apparatus was the Hydrocarbon Detector 213 (Perkin-Elmer) which works on the principle of flame ionisation. With it we tested solvent concentration for compliance with MAK values in printing establishments. This will be discussed shortly in section A.

Measuring methods based on the realization that solvent content in drying chamber air is reciprocal to the solvent content of the printed paper ($K \rightarrow \frac{1}{L_m}$; K = concentration in the drying air; L_m = residual solvent), were developed in order to establish the solvent concentration in the drying chamber at a given instant under differing drying conditions on one hand and, on the other hand to evaluate the drying process by determining residual solvent quantity in the ink layer of the running paper web. Measurements of the first kind were made with the Hydrocarbon Detector; a report on this is found in section B. The investigations of the latter type were conducted by using a method for isolating solvents from printing ink layers through distillation of a cooking liquor containing the solvent. I shall refer back to this in section C.

According to the substance equation the following relationship applies for the solvent: Input = solvent content of the drying air + residual solvent content + solvent loss. The latter is caused mainly because of leakage from the drying chamber and losses during transportation of paper.

$$G_E = G_T + G_R + G_V .$$

*) There are many publications on the nature of gas chromatography such as those of E.Bayer, R.Kaiser, A.Keulemans, R.Pecsok und C.Phillips.

The drying chamber tests, it should be pointed out, are merely preliminary tests conducted for orientation purposes on the Rotogravure press of the Institute. (Drying air over heating rods; electrically heated drying drum; cylinder with full tone surface. Web width 670 mm, printing cylinder circumference 594 mm, maximum printing speed 12 000 rph).

III. Tests conducted

(Section A - Solvent concentration in room air)

In rotogravure printing the solvent evaporation process during physical drying begins already in the ink fountain because of the solvent's high vapour pressure and continues across the freshly printed paper web before the web reaches the drying chamber, and, is not finished completely even after passing through the chamber. Through this process which takes place in every single printing unit, the room atmosphere of a printing establishment is being more or less permeated by solvent vapours. This creates an explosion hazard; it is possible that apart from unpleasant odors health hazards for the workers may appear through toxic effects. To establish purposeful room ventilation and air evacuation, especially so at the vapour originating source, it is necessary to determine the degree of saturation for the room atmosphere and the areas of highest concentration in particular. According to the experiences of the Darmstadt Institute a measuring base is obtained by using the hydrocarbon detector 213; at the same time - as I shall outline in sections B and C - it can serve also for determining the solvent concentration of the "drying air" and for registering the residual solvent content of the printed paper.

The Hydrocarbon Detector 213 apparatus serves for the determination of hydrocarbons and organic matter found in the air in vapourized or gaseous condition.

The fundamental idea of flame ionization has been realized in this apparatus. If a gaseous atmosphere is heated, ionization of the gas takes place which can be shown, if constant voltage is

applied, by the flowing of an electric current. This phenomenon is utilized in the detector, better called ionization chamber. It consists of a cylindrical aluminium block with a jet flame nozzle, a wire type lighter and a thermoelement. An aluminium electrode insulated against the housing with Teflon is introduced through the axial bore of the ionization chamber (Table 1). The housing is connected directly by way of an amplifier with an amperemeter.

Ionization is caused by a hydrogen flame. If we now inject a sample into the hydrogen stream, the magnitude of the energy freed by the flame through burning of the introduced hydrocarbons changes and with it the ionization degree as well as the amperage. A one tube arrangement serves as amplifier for the electrometer.

At this point, the Fractometer 116 which has been used for the determination of residual solvent contents should be described briefly:

It is used for the separation of chemical mixtures which can be transformed into gaseous condition by heating up to 250°C. The sample is injected into a heated sample injection block, vapourized and flushed into the fractioning column by means of a carrier gas (in this case helium). The fractioning columns have the characteristic of adsorbing the components for different retention times. After a time span, characteristic for the individual phases, the components are freed and carried to the detector block. This is how the separation effect of the components occurs.

It should be emphasized that the latest tests have shown a high coincidence in the measuring results of the detector and those of the fractometer.

The problem of protection against explosions in printing plants may be glanced at but briefly. For instance, in Germany, on roto-gravure presses explosion-protected electrical installations ONLY may be used within a safety range of 1 meter. Lower, respectively upper explosion limits within the mixture with air of an inflammable material are expressed in volume percent and in grams per meter cube at 760 Torr and 20°C. The lower explosion limit for

pure toluene is 1 Vol.-% and the upper Explosion limit about 8 Vol.-%, corresponding to $38,2 \text{ g/m}^3$ and $305,6 \text{ g/m}^3$ at 20°C , respectively. I like to review briefly a question concerning the physiological effect of the solvent which, in industrial medicine, has evolved into the concept of "maximum concentration at working place", MAK, for short.

Let it be emphasized that poisonous benzole has been prohibited as a solvent in Germany because of its damaging effect on blood formation. Based on experience, the MAK figure indicates that there should be no ill effects for a daily working time of about eight hours even though exposure at this rate may go on for years. The MAK value for benzole has been fixed at 35 ppm (1 ppm = 1 part per million = 0,0001 %) and at 200 ppm for toluene and xylene; therefore, permissible maximum concentration for benzole is six times lower than for the latter. Benzine has a value of $500 \text{ cm}^3/\text{m}^3$ and spiritus one of $1000 \text{ cm}^3/\text{m}^3$. Because suitable measuring methods for determining allowable solvent concentrations have not been available until now, the detector 213 was used to this purpose for the first time by the Darmstadt Institute. During these measurements the following has to be considered:

- a) The printing machine (type of solvent, air exhaust system, aerodynamic conditions, machine speed, etc.).
- b) Air pressure, air humidity and temperature relative to the concentration ratios of the mixture.
- c) The climatological conditions (weather).
- d) The problem of reproducibility (this could not yet be solved).

In connection with protection against explosions it was of particular interest to learn more about concentration distribution between printing units and solvent vapours escaping sidewise. Measurements were carried out on a large production machine installed at a printing establishment (a suction tube was used). Concentration was strongest vertically above the ink fountain. Table 2 illustrates distribution of concentration between two printing units.

(Section B - Solvent concentration in the drying chamber)

Further uses of hydrocarbon detector may be reported on as follows: As stated already, it is possible to accelerate the drying process in rotogravure two ways, namely by choosing suitable printing inks and by erecting drying systems which allow for an optimum drying process. In Germany, rotogravure ink pigments and their synthetic resinous binding agents are frequently dissolved in volatile toluene (Evaporation coefficient 6) or in benzines of different fractions. (The printing quality of pure benzine inks does not always satisfy.)

To the machine designer goes the task of developing apparatus and methods for speeding up the drying process.

The drying process, it is known, can be accelerated by lowering pressure in the drying chamber and by suitable heat supply. It follows that the concentrations which appear in the drying apparatus are equal to the sum of the solvent contents because of partial pressure and temperature, minus reduced concentration caused by the thinning of drying air due to fresh air supply. In order to design an optimum drying system the designer must study the concentration course of the drying air under varying working and design conditions. The higher the solvent concentration in the drying unit of the running printing press, the lower the solvent content of the paper coming from the printing unit and, consequently the more intensive also the drying process. At constant machine speed the degree of drying is therefore inversely proportional to the solvent concentration. By now measuring the solvent concentration in the drying chamber, it should be established how this concentration behaves under differing drying conditions. We used as measuring instrument the hydrocarbon detector and as test machine the machine of the Institute (Rotogravure press). Table 3 shows the layout of the drying installation. The drying installation with electrical jet-air-heater, circulation and exhaust blower and heatable drying drum is capsule contained. Solvent concentrations, flow volumes through both blower systems, as well as drum

and circulating air temperatures were measured with the help of measuring shutter. One test series was conducted which revealed 1) the influence of the jet heater 2) the influence of drum heater and a third indicated the influence of machine speed on the drying process under constant drying conditions. Some results may be listed below: Table 4a shows the dependence of solvent concentration on the jet-air temperature under conditions of varying exhaust air volumes with unheated drying drum, Table 4b the dependence of solvent concentration as a function of drum temperature. Table 5 shows solvent concentration and surface temperature as a function of printing speed. Drying conditions were kept constant as far as practicable. Change in concentration is therefore proportional to change in speed (up to a critical point). Heating temperatures, it is known, are limited by the start of paper dehumidification and stickiness of the binding agent.

(Section C - Detection of residual solvent)

The process of extractive isolation of residual solvents from the ink layer having proved insufficient, it seemed purposeful to develop a method based on cooking and subsequent distillation of the solution (liquor) in order to isolate the solvent from the ink layer. This entire method was carried out in three individual processes:

- a) The printed paper was cooked for half an hour in order to transfer the residual solvent quantity from the ink layer into the cooking liquor.
- b) Thereafter followed a distillation of the cooking liquor containing the solvent.
- c) Finally, the separation of the residual solvent from the distillate (toluene from xylene) followed.

In order to avoid losses we developed an apparatus in which all the three processes immediately follow one another. This analytical method is characterized by the fact that the solvent contained in the ink layer is absorbed by a known quantity of "extraction-solvent" and that the concentration of the solvent in the "extraction liquor" is determined gas-chromatographically.

This method, in our opinion, should permit clarification of a series of relationships existing between drying speed and thickness of ink layer, dependence on ink viscosity, smear limits, etc.; it is further possible to investigate the inter-dependence of drying process and paper character by determination of residual solvents.

The method just outlined may offer alternate ways toward exact control of the drying process and therefore give the designer valuable aid in laying out a drying system of optimum drying performance.

Let us sketch briefly the method for determining residual solvents: Residual solvent content (mg/m^2) is defined as the quantity of solvent remaining in the ink layer on one squaremeter of paper after printing. Residual solvent content is to be determined in relation to the drying process of the printing machine. A sample of the printing product is removed under differing but well defined operating conditions; in the apparatus mentioned the ink is then removed from the paper through cooking (natron base as cooking liquor) and by adding a certain amount of carrier solvent (O-Xylole) the residual solvent is separated from the ink and absorbed. The mixture ratio is then determined in the gas chromatograph and from it the quantity of residual solvent is derived, which can be called "residual solvent content per meter square of paper".

Table 6 shows the machine drawing. A full tone surface is etched unto the form cylinder. Etching depth measured by means of the interference microscope amounted to 27μ with a screen of 70 lines per cm. Table 7 illustrates the distillation apparatus consisting of cooking and distillation components. The gas chromatograph which is comparable to an apparatus for fraction distillation is shown in table 8. Table 9 illustrates the hydrocarbon detector with accessories.

While carrying out these measuring methods, temperature and humidity of room air, paper quality ($70\text{ g}/\text{m}^2$), printing press and inking speeds were kept constant during a given test series (for example: 5000 rph). Variable influences measured continuously, were:

temperature of the drying air (2 thermometers with thermostat), the heating drum temperature at the surface (thermoelement), the flow rate of drying air (2 measuring shutters) and the saturation of drying air (solvent concentration in the drying air) as well as machine speed.

As soon as the drying conditions reached a constant state, test samples were taken from the paper web, either through paper punch sampling (about 20 circular disks are removed from the rewound roll by means of a punching device) or through removal of strips immediately after printing. In deference to the available distillation apparatus the sample weight was restricted to $0,15 \text{ m}^2$ of paper surface. Brown flasks of 10 ml volume were used to store distillation products. The distillation process with paper (after numerous painstaking tests) yielded residual solvent quantities which by their very nature were smaller than their theoretical values. Measurement values observed fluctuated up to 11 %. Sample injections into the fractometer were accomplished by means of injection dippers of maximum $10 \mu\text{l}$ content. Test mixtures of known concentrations were used for calibration. The calibration curves obtained were practically straight lines.

In this way a series of tests was run which aimed at determining the influence of the jet heater, the drum heating and of machine speed at different exhaust air conditions. Table 10 shows the effect of machine speed upon residual solvent content and upon solvent concentration in the air of the drying chamber.

Critical observation of these tentative measuring data revealed as yet sizeable scattering in the measured values, caused in particular by the sample removal method as well as a significant discrepancy between residual solvent content data and saturation data of the drying air.

It should be pointed out further:

The "fresh air supply" for the drying room during these tests was imperfect because air essentially enriched with solvents already could be sucked in through the inlet opening of the drying cabinet and through the sides thereof. This distorts the relationship bet-

ween the volume of exhaust air and the total volume of air flow. (It is self-evident that the humidity content of the printing paper influences the drying process.) These shortcomings will be corrected in later tests.

It is possible to calculate the printing ink consumption per squaremeter by weighing a printed sheet after one week f.inst. establishing thereby its dry content in %. (A dry ink content of 42 % ($3,8 \text{ g/m}^2$) thus corresponded to a solvent input of $4,8 \text{ g/m}^2$ into the printing process.) Drying time is expressed as the quotient of web length and web speed.

Table 11 shows approximately the curve of the drying process. By the way, this may be mentioned also: Concerning the speed of evaporation in general, the curve of Krischer* (Table 12) can be sensibly applied. (First section = evaporation phase, free surface; second section = drying phase, diffused, with surface skin existing; third section = phase of capillary effect. Simplified: Wet-humidand hygroscopic range.) The evaporation curve shifts with changing temperature.

In printing practice it is mandatory that the drying process takes place under conditions of constant inking and unchanged operating conditions and in all printing units for, changes in the rate of solvent evaporation lead to changes in ink viscosity and thereby to tonal shifts.

IV. SUMMARY

The tests conducted at the Darmstadt Institute with the help of gaschromatographic instruments, respectively of a hydrocarbon detector aimed first at determining the concentration of solvents in the air of printing plants under actual operating conditions and second at studying the drying process in running rotogravure presses under differing working conditions.

We realize in my Institute that the methods outlined for the determination of solvent concentration and especially those methods

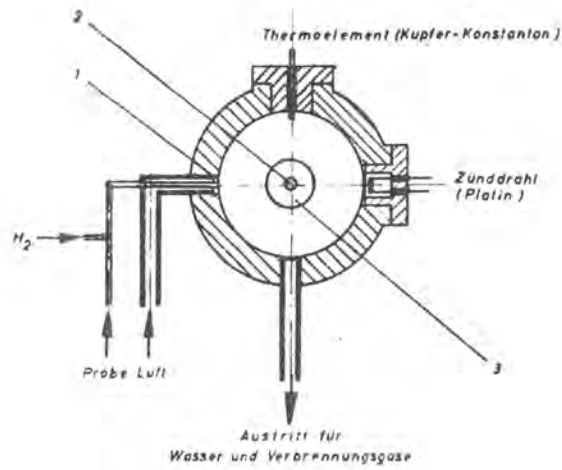
*) O.Krischer: Trocknungstechnik. (Drying technique.) Springer Edition, 1956 page 246

dealing with the experimental determination of solvent quantities in the room air of the drying installation and on the printed paper are still affected with certain shortcomings because of the relatively short testing time. An impressive series of investigations remains to be undertaken therefore. The new avenues chosen appear to promise success.

Our working team, including Messrs. Dr. Wagenbauer, Primavesi, Keppler, Antonoff, Fink, Tejidor and Richter, contributed primarily to these tests.

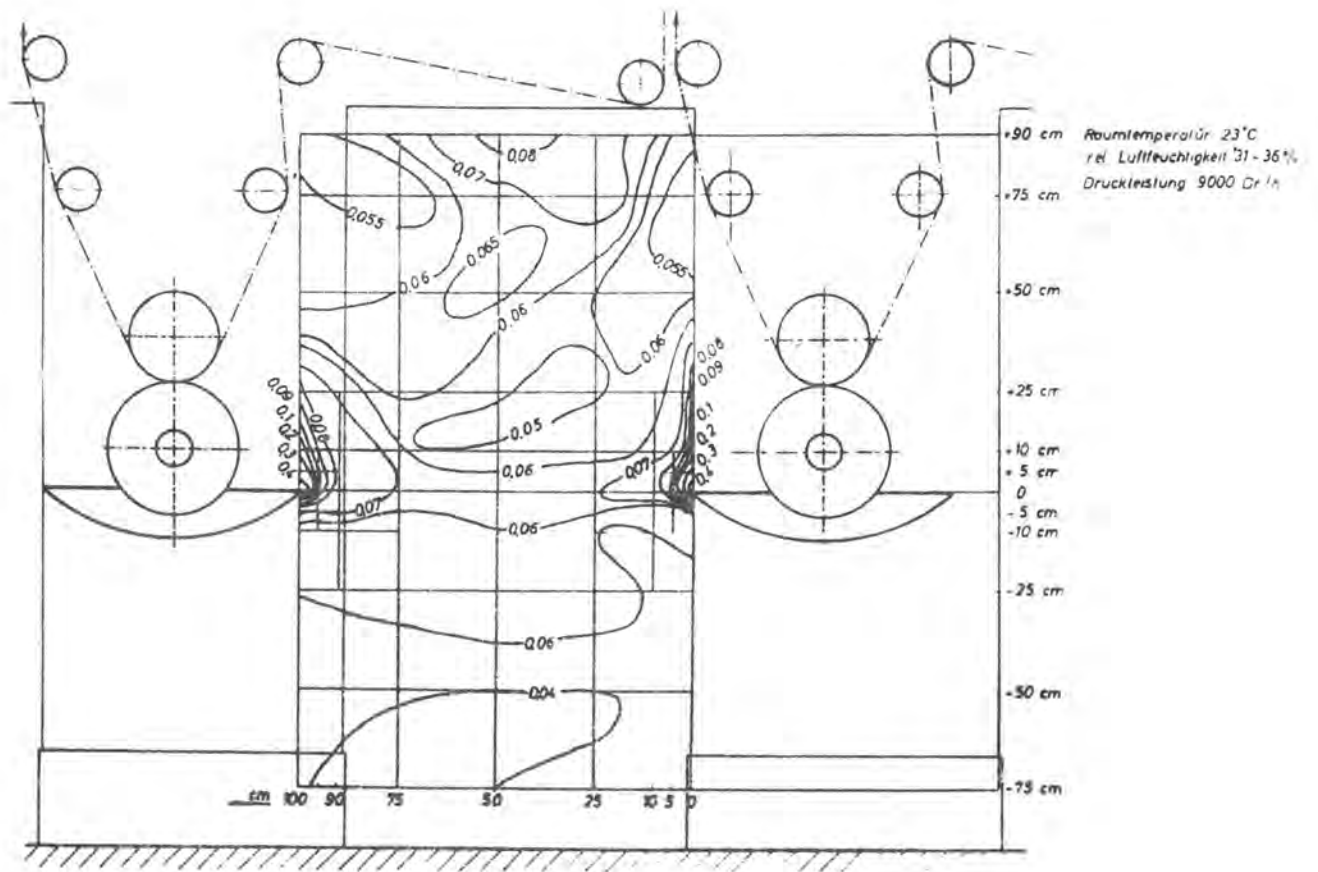
Darmstadt, 3. May 1961.

- 1 Eintrittsdüse
- 2 Elektrode
- 3 Isolierung (Teflon)



Schematischer Aufbau der Ionisationskammer

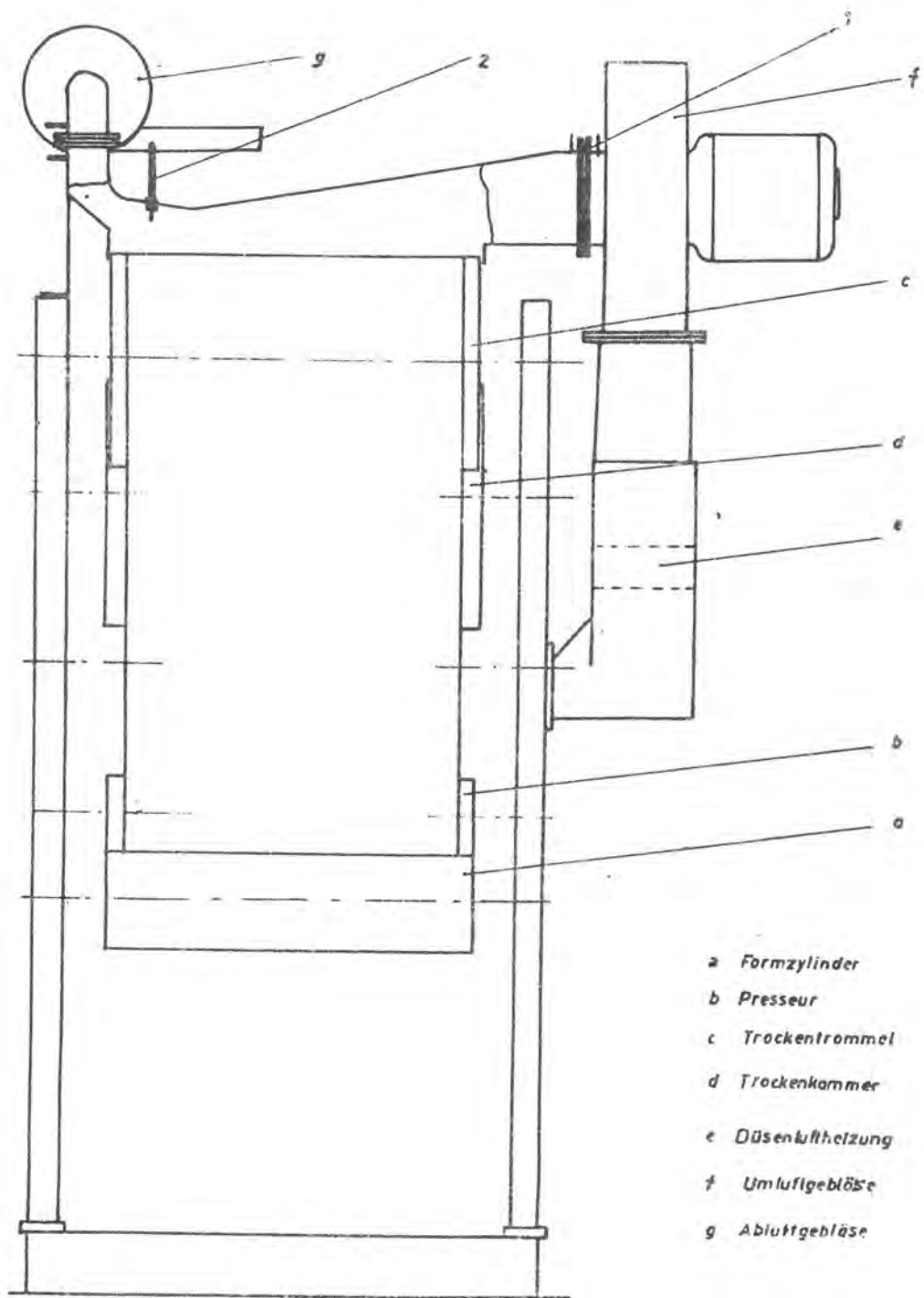
Fig. 1 Design of the ionisation chamber



Konzentrationslinien in Vol% bezogen auf Edukt
 1 Vol% = $10^6 \text{ cm}^3 \text{ Edukt} / \text{m}^3 \text{ Luft}$

Konzentrationsverteilung zwischen
 zwei Druckwerken

Fig. 2 Distribution of concentration
 between two printing units



Schematische Schnittzeichnung durch den Trockenraum der Versuchsmaschine mit einigen Meßstellen

Fig. 3 Drying apparatus of test machine with some measuring points

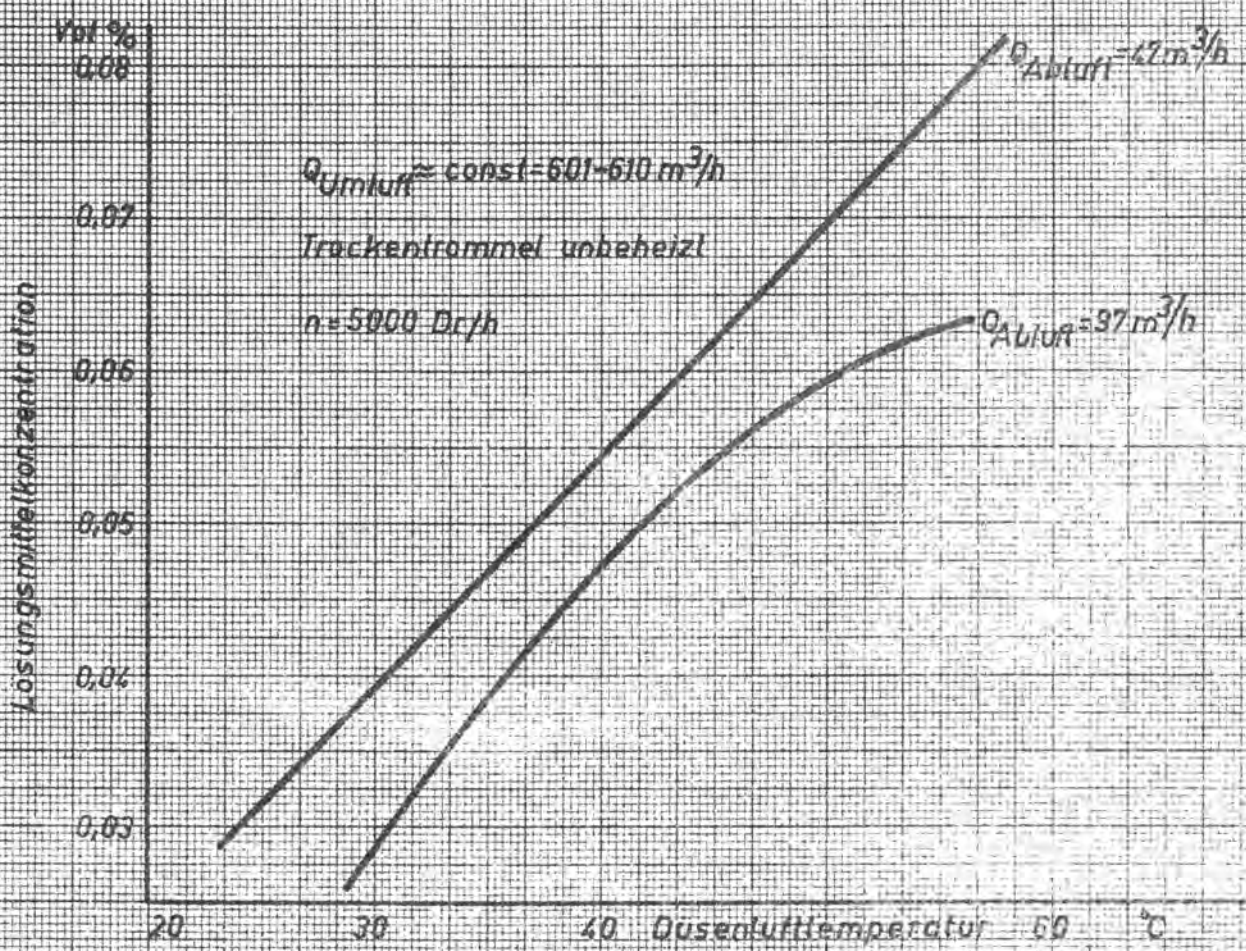


Fig. 4a Konzentration als Funktion der Düsenlufttemperatur
 Concentration as a function of jet air temperature

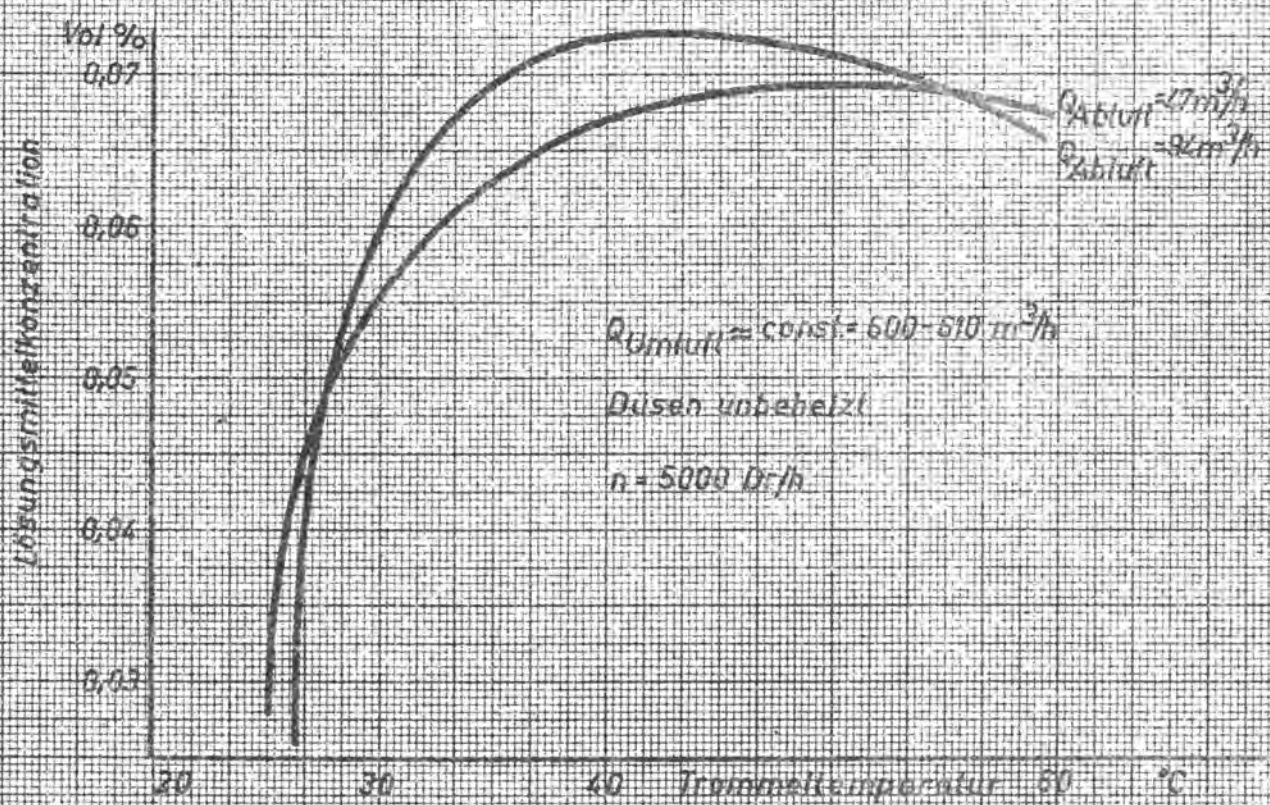


Fig. 4b Konzentration als Funktion der Trommeltemperatur
 Concentration as a function of drum temperature

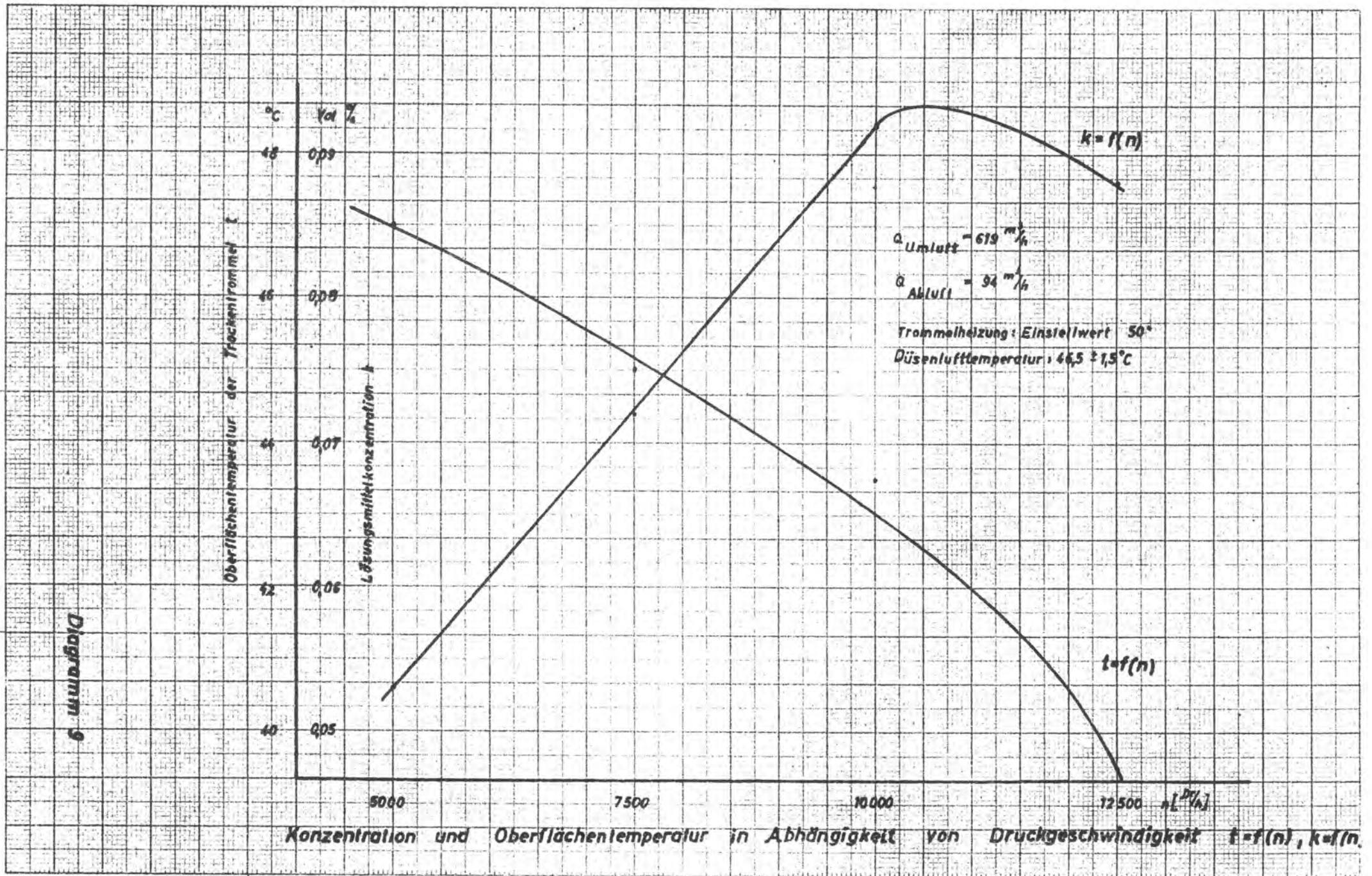


Fig. 5 Concentration of solvents and surface temperature as a function of printing speed

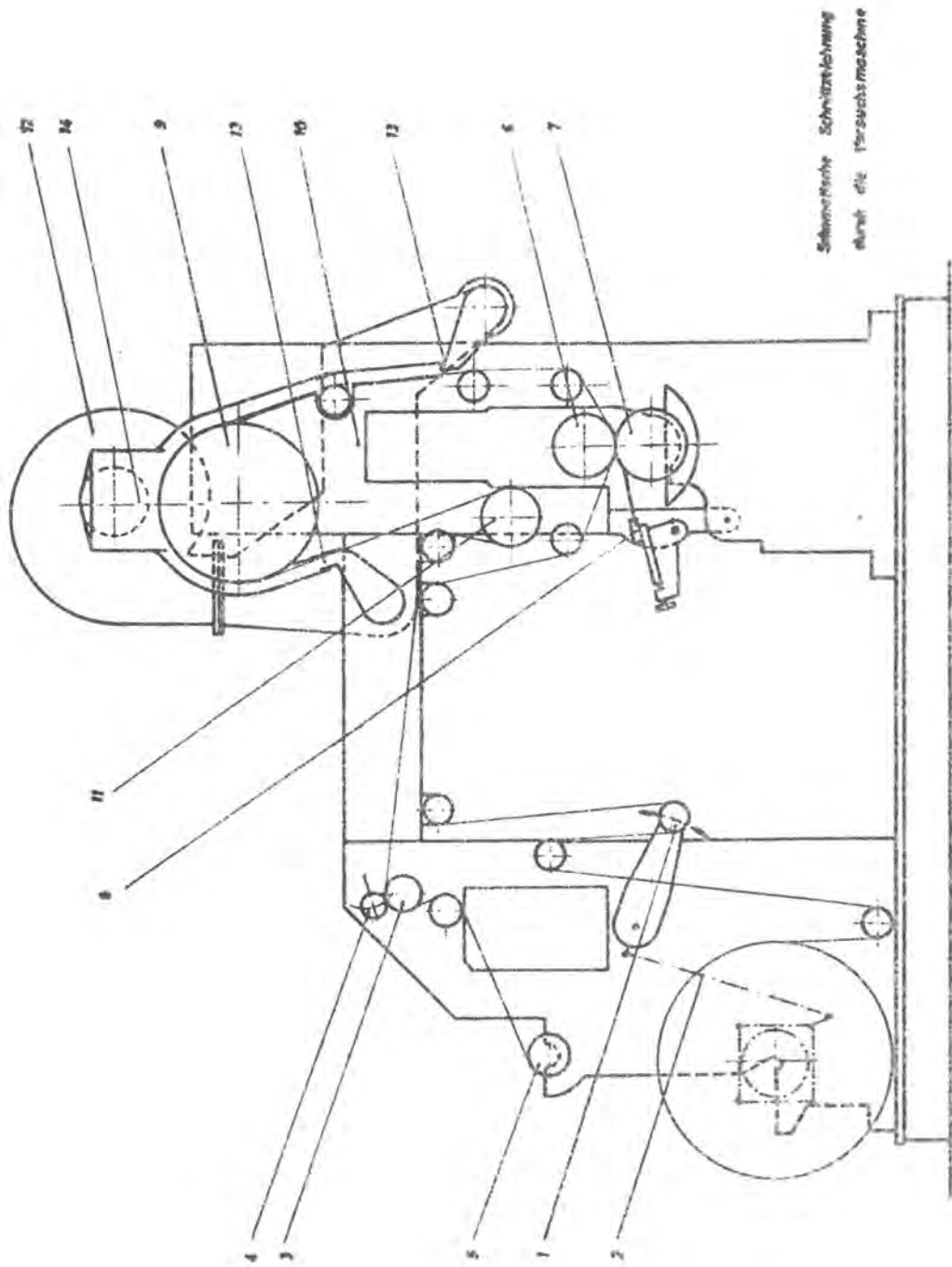


Fig. 6 Test machine — schematical drawing

- 1 STATIV
- 2 EISBAD
- 3 SCHLIFFKOLBEN 300ml
- 4 GLASHAHN
- 5 STAHLFEDERN
- 6 SCHLANGENKÜHLER
- 7 STAHLFEDERN
- 8 LIEBIG-KÜHLER
- 9 MONTAGE-BRETT
- 10 KÜHLER-HALTERUNG
- 11 APPARATUR-HALTE-STANGE
- 12 SCHAUMSTOFF-UNTERLAGE
- 13 KÜHLER-HALTERUNG
- 14 KOMBINIERTER SCHLANGEN-LIEBIGKÜHLER
- 15 STAHLFEDERN
- 16 SCHLIFFKOLBEN 1000 ml
- 17 HEIZKORB

APPARATUR ZUR
LÖSUNGSMITTEL-
ISOLIERUNG AUS
TIEFDRUCKFARBSCHICHTEN

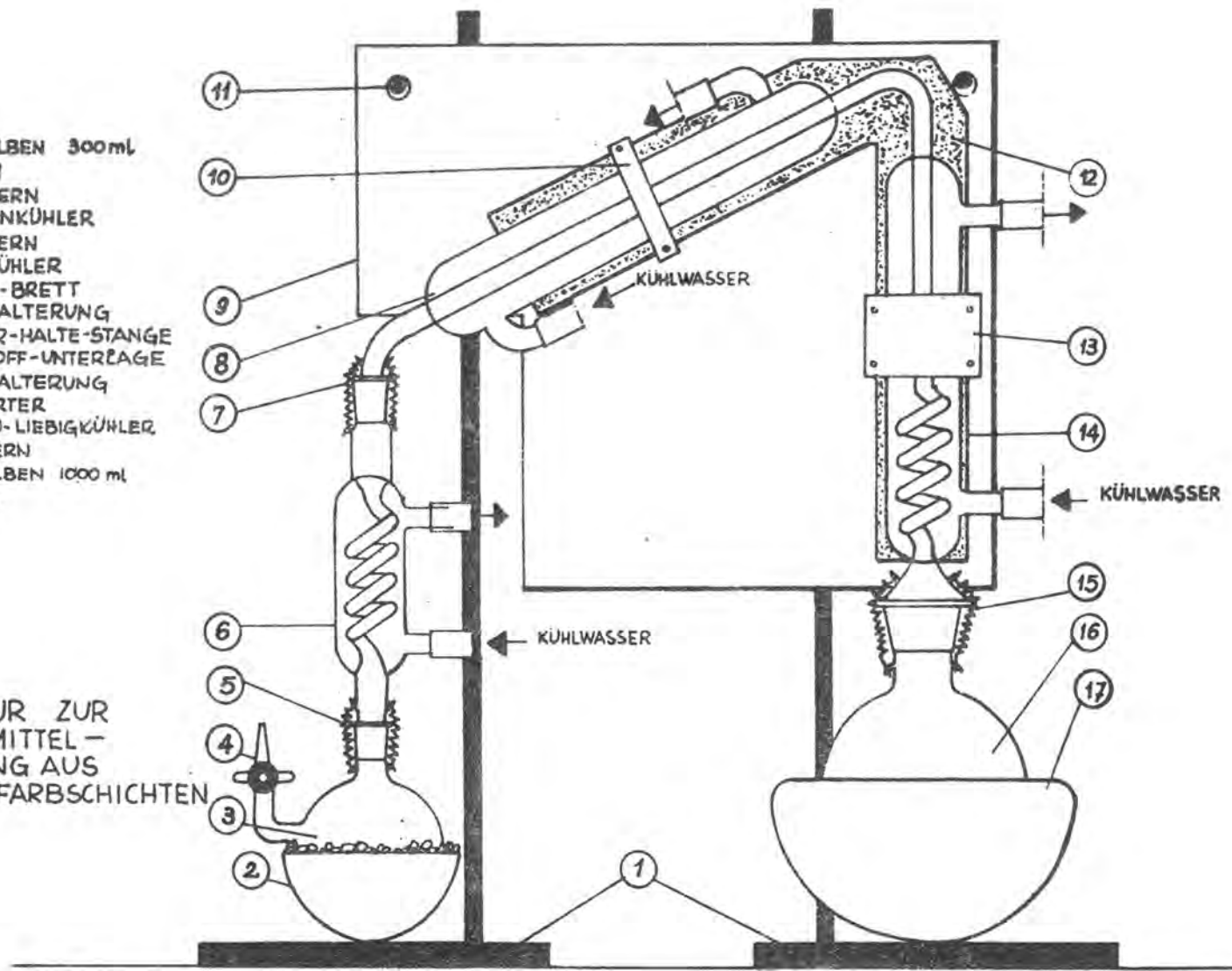


Fig. 7 Apparatus for isolating of solvents from rotogravure ink layers

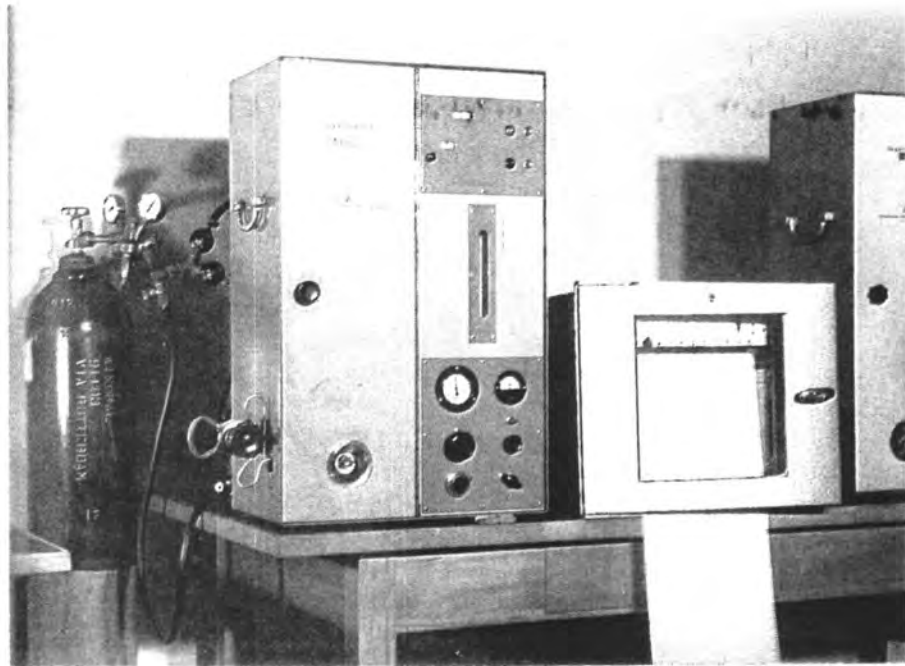


Fig. 8 Illustration of Vapor Fractometer Perkin Elmer

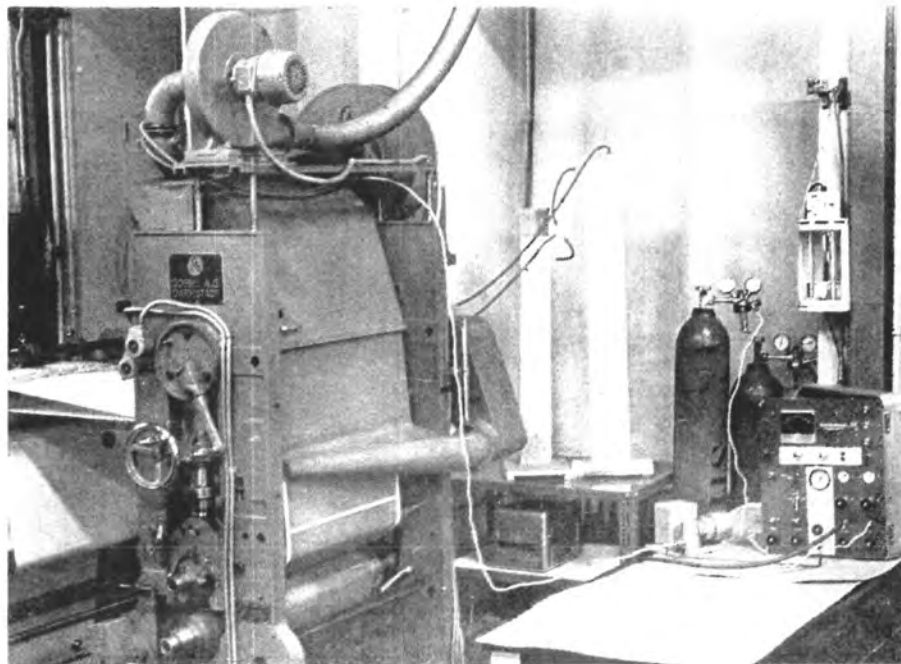


Fig. 9 Illustration of Hydrocarbon Detector 213

Einfluß der Maschinengeschwindigkeit

Fig. 10 Influence of machine speed

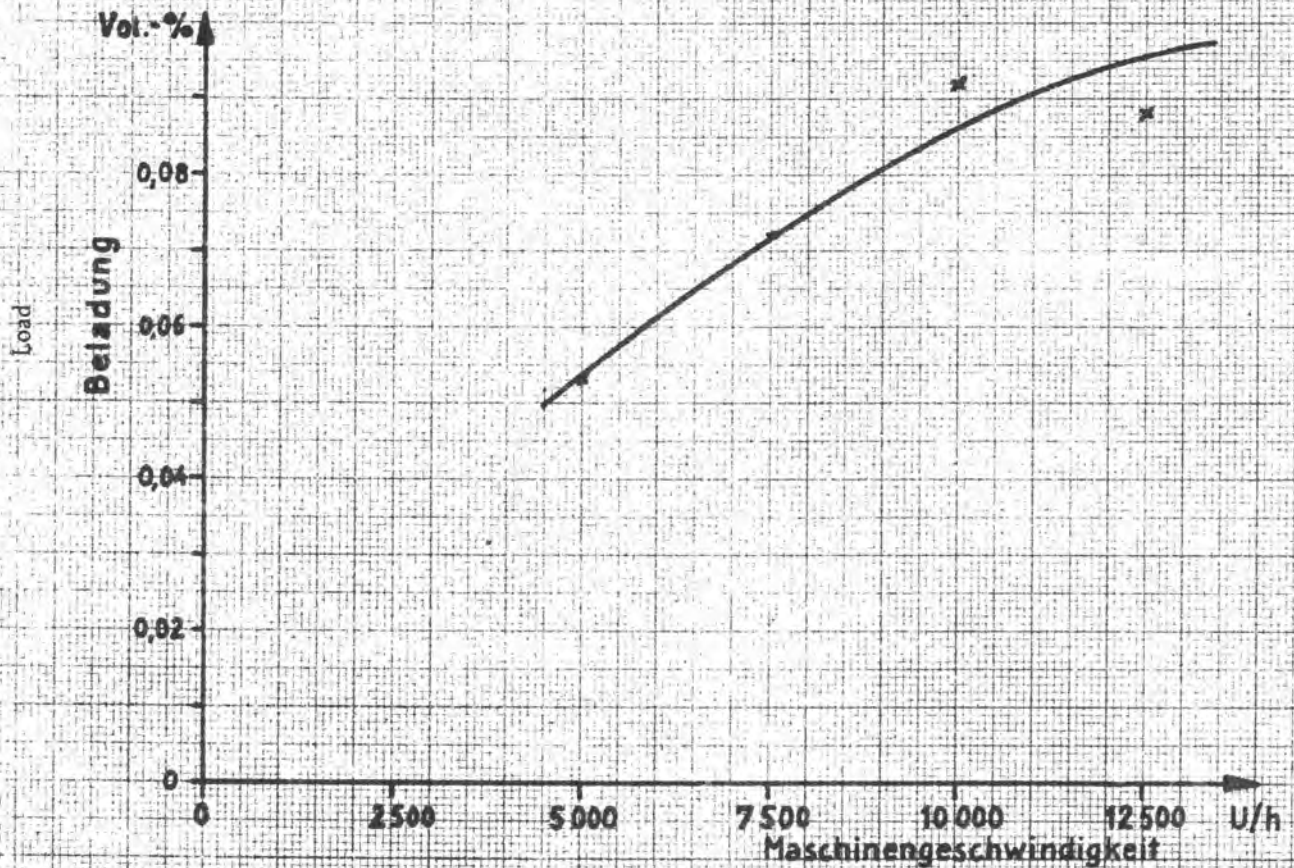
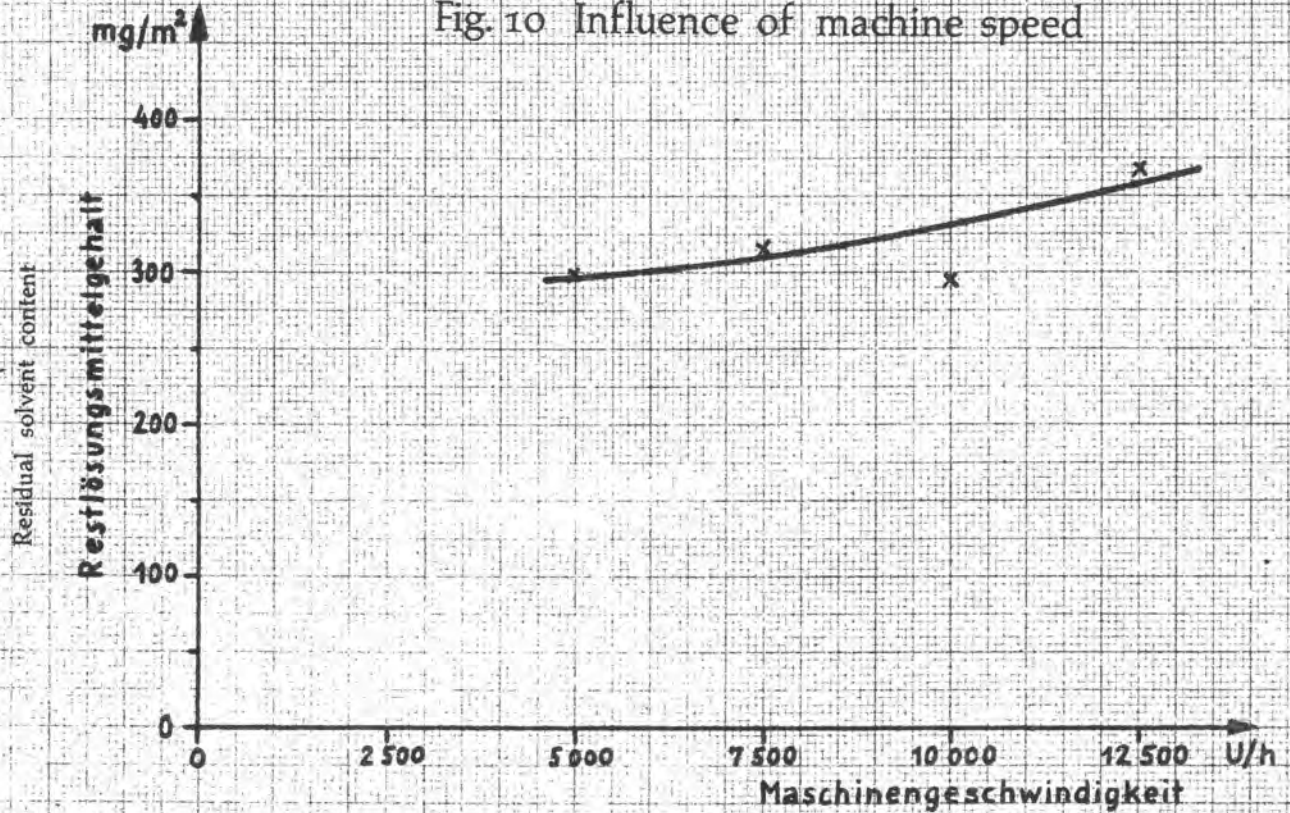
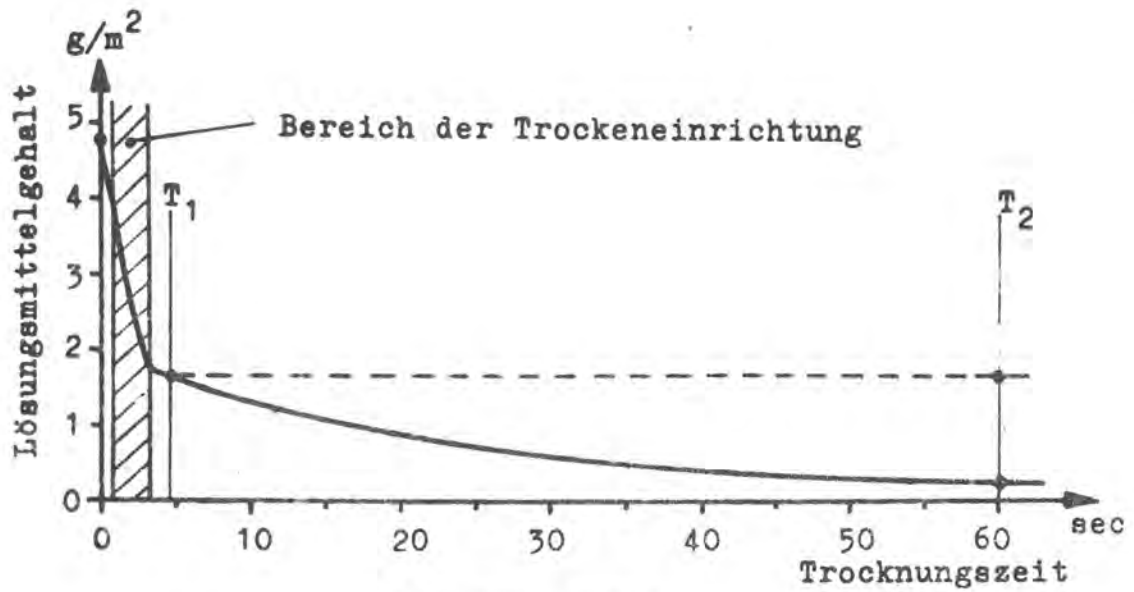


Diagramm 8



Trocknungskurve
(Lösungsmittelgehalt im Papier)

Fig. 11 Drying curve (solvent content in paper)

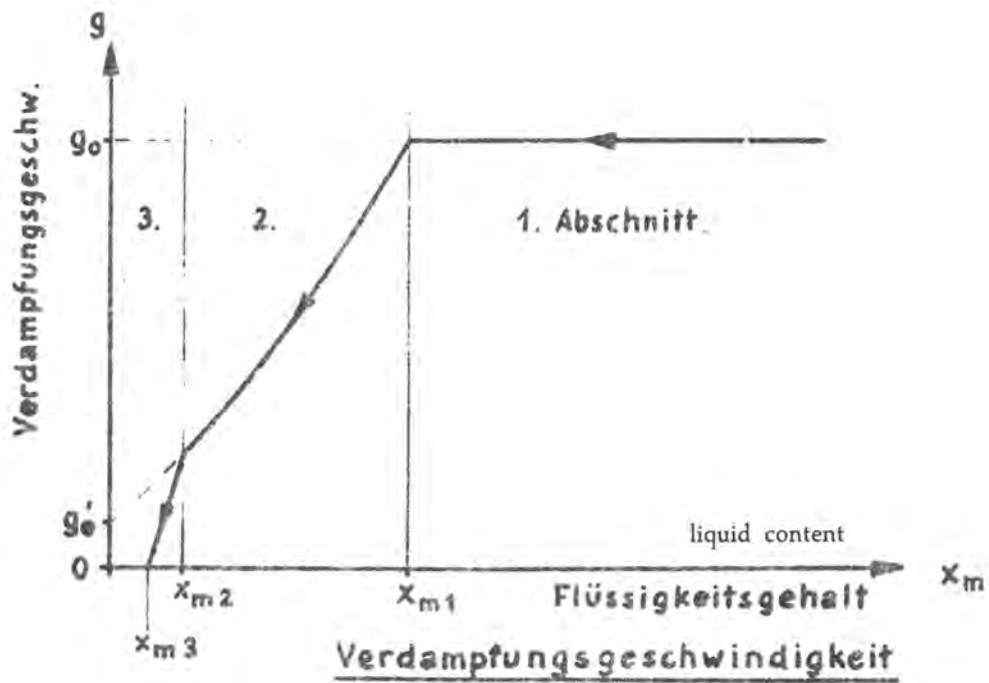


Fig. 12 Vaporisation speed