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IMPROVEMENT OF THE RESIDUAL MOISTURE CONTENT BY HYPERBAR VACUUM FILTRATION

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The combined pressure/vacuum filtration allows to combine the advantages of the rotating vacuum filters with the greater efficiency of the pressure filtration. In this way, it is possible to realize greater solids throughputs and lower moisture contents, so that in certain cases the thermal drying of the filter cake can be omitted. In this paper an overview is given about the process, the theoretical basis and some results.

INTRODUCTION

The continuous vacuum filtration is considered since long as a process-technical basic operation without technological difficulties. In view of the great number of possible applications of vacuum filtration due to the use of different apparatuses (drum filter, disk filter, belt filter) made of nearly all possible materials and owing to the wide range of efficient supplementary measures (filter cake removal, washing, pressing, cake composition, filter cloth exchange etc.) this solids-liquid separation practice is nowadays one of the most frequently used separation processes. The vacuum filtration method is adopted primarily in the beneficiation industry (iron ores, non-ferrous ores, coal, etc.) where large mass flows have to be treated under severe conditions.

However, the greatest disadvantage of the vacuum filtration is the maximum, adequate and technically possible pressure difference of $\Delta p = 0.8 - 0.9$ bar. Consequently, the mass throughput is not only limited but in many cases the required residual moisture content cannot be achieved. This phenomenon is even intensified by the fact that there is a world-wide trend to the processing of ever finer particles (1).

Therefore, it is advisable to combine the advantages of the conventional, continuous vacuum filtration with the higher efficiency of the pressure filtration, i.e. to carry out a combined vacuum/pressure filtration.

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THE PRINCIPLE OF HYPERBAR VACUUM FILTRATION

As can already be seen from the heading, this technique is a vacuum filtration operated in the overpressure range. For this purpose a usual rotary vacuum filter is completely installed in a pressurized room (figure 1). This means that the filter drive and the filter agitator drive, the filter cake removal and above all the control head of the filter are operated in the pressurized room and thus no rotating parts in the wall of the pressurized vessel are required.

The filtration vacuum can be produced with a waterring pump or more efficiently with a fan. In this way a vacuum filtration is possible. For the performance of the hyperbar vacuum filtration the pressure tank is closed and compressed air produced by a suitable compressor is introduced. A tank overpressure of $p_{abs} = 1.5$ bar then yields already a filtration differential pressure of $\Delta p = 1.3$ bar, i.e. a vacuum of $p_{abs} = 0.2$ bar is efficient below the filter medium in the filter cell whereas an overpressure of $p_{abs} = 1.5$ bar prevails above the filter medium. The overpressure presses upon the suspension surface so that the filter cake is formed and dewatered at a differential pressure of $\Delta p = 1.3$ bar. The system of the hyperbar vacuum filtration also allows, through the control head, the application of various differential pressures for cake formation and dewatering. In this way the cake thickness can be decreased by a lower vacuum and nevertheless be dewatered at maximum differential pressure.

The suspension is delivered by a suitable pump to the pressure tank. At a tank overpressure of 1 bar the suspension pump has to overcome a delivery head of $h > 10$ m.

After the solids-liquid separation of the suspension three components are obtained which have to be discharged from the pressurized room.

a) Filtrate and air stream

The filtrate is discharged through the filter cell, the control head and the filtrate tubes into the separators. The air passed through the filter cake for its dewatering simultaneously escapes. The two-phase mix is separated in the separator.

b) The humid filter cake

The previously suspended solids now consist of a cohesive and mostly abrasive bulk material. To ensure the material discharge at a minimum leakage air loss , the delivery is completely separated from the filtration. As a result either operation can be optimized independently.

THEORETICAL CONSEQUENCES OF THE INCREASED FILTRATION PRESSURE DIFFERENCE

The theoretical description of the filtration of suspensions with rotary vacuum filters is generally based on the law of Darcy:

$$\frac{dV_L}{dt_1} = \frac{A \cdot \Delta p}{\eta \cdot R} \tag{1}$$

By the insertion of the concentration parameter κ usually for filtration

$$\kappa = dh_c / \frac{dV_L}{A} \tag{2}$$

and under consideration of the fact that during the technical filtration the total flow resistance R consists of two components

$$R = R_c \cdot h_c + R_M; \; R_M = \text{const} \tag{3}$$

the differential form of the basic filtration equation is obtained:

$$dh_c = \frac{\Delta p \cdot \kappa \cdot dt_1}{\eta \cdot (R_c \cdot h_c + R_M)} \tag{4}$$

At a suitable choice of the filter cloth it is assumed that R_M is negligible against $R_c \cdot h_c$. After integration this results in the basic equation of the cake forming filtration ($t_1 = 0 : h_c = 0$):

$$h_c = \sqrt{\frac{2}{\eta \cdot R_c}} \cdot \sqrt{\kappa} \cdot \sqrt{\Delta p} \cdot \sqrt{t_1} \tag{5}$$

For the rotary filtration the cake forming time t_1 is determined by the cake forming angle α_1 and the filter speed n.

$$t_1 = \frac{\alpha_1}{360} \cdot \frac{1}{n} \tag{6}$$

From this results

$$h_c = \sqrt{\frac{2}{\eta \cdot R_c}} \cdot \sqrt{\kappa} \cdot \sqrt{\Delta p} \cdot \sqrt{\frac{\alpha_1}{360}} \cdot \sqrt{\frac{1}{n}} \tag{7}$$

As can be seen from equation (7), h_c is proportional to $\sqrt{\frac{1}{n}}$. This limits the arbitrary increase of the filter speed for raising the mass throughput because very soon filter cake thicknesses are reached which do no longer ensure any reliable removal of the filter cake from the filter cloth.

However, as it further applies that $h_c \sim \sqrt{\Delta p}$, this minimum cake thickness $h_{c,min}$ is only reached at higher speeds when higher differential pressures are applied so that the following equation is obtained:

$$h_{c,min} \sim \sqrt{\Delta p_1} \cdot \sqrt{\frac{1}{n_1}} = \sqrt{\Delta p_2} \cdot \sqrt{\frac{1}{n_2}} \tag{8}$$

$$n_2 = n_1 \cdot \frac{\Delta p_2}{\Delta p_1} \; ; \quad \Delta p_2 > \Delta p_1 \tag{9}$$

The importance of the filter speed increase becomes obvious when the balance equation of the mass throughput is used:

$$\dot{M}_S = h_K \cdot A_F \cdot (1-\varepsilon) \cdot \rho_s \cdot n \qquad (10)$$

or on the basis of equation (7) this gives:

$$\dot{M}_S = \sqrt{\frac{2}{\eta \cdot R_c}} \cdot \sqrt{\kappa} \cdot \sqrt{\Delta p} \cdot \sqrt{\frac{\alpha_1}{360}} \cdot \sqrt{n} \cdot A_F \cdot (1-\varepsilon) \cdot \rho_s \qquad (10a)$$

From equation (10) results for the mass throughput, referred to the filter area:

$$\dot{m}_s = \frac{\dot{M}_S}{A_F} \sim \sqrt{\Delta p} \cdot \sqrt{n} \qquad (11)$$

At an increase of the filtration pressure difference the mass throughput rises on one hand proportionally to the root of pressures and on the other due to the simultaneously possible filter speed increase.

Under these technological conditions the mass throughput rises linearly with the filtration pressure increase:

$$\frac{\dot{m}_{s,2}}{\dot{m}_{s,1}} = \sqrt{\frac{\Delta p_2 \cdot n_2}{\Delta p_1 \cdot n_1}} = \sqrt{\frac{\Delta p_2 \cdot n_1 \cdot \Delta p_2}{\Delta p_1 \cdot n_1 \cdot \Delta p_1}} = \frac{\Delta p_2}{\Delta p_1} \qquad (12)$$

If, on the other hand, a constant mass throughput is required, the following equation is obtained:

$$\text{const} = \dot{m}_s \sim \sqrt{\Delta p_1 \cdot A_{F1}} \cdot = \sqrt{\Delta p_2 \cdot A_{F2}} \qquad (13)$$

$$A_{F2}/A_{F1} = \sqrt{\frac{\Delta p_1}{\Delta p_2}} \qquad (14)$$

on the basis of equation (9) this gives:

$$\text{const} = \dot{m}_s \sim \sqrt{\Delta p_1 \cdot n_1 \cdot A_{F1}} = \sqrt{\Delta p_2 \cdot n_1 \cdot \frac{\Delta p_2}{\Delta p_1}} \cdot A_{F2} \qquad (15)$$

$$\frac{A_{F2}}{A_{F1}} = \frac{\Delta p_1}{\Delta p_2} \qquad (16)$$

This means that when the filtration pressure is raised and when $\dot{m}_s$ = const., the necessary filter area decreases proportionally to the root of pressures and under consideration of $h_{c,min}$ diminishes inversely proportionally to the increased pressure.

However, the rise of the solids throughput is first merely a consequence of the filtration pressure increase. The residual moisture content improvement of the filtered cake resulting from the pressure increase is of much greater importance.

This physical relationship is illustrated by a capillary pressure diagram. The curve $t_2 = \infty$ in figure 2 shows the typical development of the equilibrium capillary pressure for a beneficiation product as a function of the filter cake residual moisture content. The iron ore to be treated has an initial capillary pressure of $p_{ke} = 0.4$ bar. This indicates that only insufficient residual moisture content values can be achieved with the pressure difference $\Delta p = 0.8$ bar usual for vacuum filtration even in the case of an equilibrium. In this case the efficient dewatering pressure difference is $\Delta p = 0.8 - 0.4 = 0.4$ bar. In the case of the rotary filtration for which the dry suction periods are limited, this phenomenon is even intensified, see curve $t_2 = 20 - 80$ s. A superposition of the vacuum filtration pressure difference with a slight overpressure of $\Delta p = 0.5$ bar already yields significant residual moisture content improvements for such filtration products even within the scope of the technical filtration periods. In this case, the efficient pressure difference rises to $\Delta p = 1.3 - 0.4 = 0.9$ bar. This means that an increase of the total pressure difference by 38.5 % yields an improvement of the efficient filtration potential by 55.6 %.

In many cases an overpressure addition of $\Delta p = 1$ bar to the vacuum filtration pressure difference ($\Delta p_{total} = 1.8$ bar) is thus already sufficient to dewater the filter cake to the demanded residual moisture content.

When considering the increased solids throughput and the diminished residual moisture content it has also to be borne in mind that the gas throughput through the filter cake, which displaces the water from the pores of the pile, rises with the higher pressure difference and the lower residual moisture content.

Focal points of investigations

Apart from the investigation on the mechanical conversion of this filtration technique, the elaboration of design data for the various plant items and the solution of operational problems, a further focal point of our filtration studies is the economic research "profit$(mc,\dot{m}_s)$/cost $(\dot{V}_g)$".

For this purpose the gas throughput required for the dewatering is converted into the technical compression capacity and under consideration of the efficiency of machinery into pump capacity to be installed. On the other hand, the residual moisture content improvement ΔRF can be expressed as thermally required energy which is needed in driers with corresponding efficiencies to dry the filter cake to the same residual moisture content.

EXPERIMENTAL EQUIPMENT

For the investigation of the physical operations during the hyperbar vacuum filtration a laboratory-type pressure/suction filtration unit with a filter area of $A_F = 20$ cm^2 was started up. During the experiment the suspension is filled from top into a pressure resistant filter cell. After the simultaneous rise of overpressure and vacuum the filter cake is formed on a usual filter cloth (2).

This equipment allows the simple and reliable elaboration of the dewatering diagram of a filtration product with a small suspension quantity within a short time. Figure 3 shows by way of example the characteristic dewatering fields of an iron ore.

Section 1 shows the residual moisture content mc of this ore as a function of combined pressure difference Δp and filter cake thickness h_c. Section 2 represents the input diagram "gas volume $\dot{V}_g$ as a function of pressure difference Δp and filter cake thickness h_c". As was already demonstrated in a former paper (2), the efficiency of the hyperbar vacuum filtration decreases with rising pressure difference so that - as will be set forth later on - for different reasons an overpressure of p_{abs} = 2 bar, combined with a vacuum of p_{abs} = 0.2 bar, proved to be most economic in many applications.

To obtain suitable design data for this technologically uncomplicated but efficient filtration technique, which allow a reliable scale-up to the conditions of an industrial plant, a pilot plant was built with the assistance of LURGI, Frankfurt/Main. During the design of this plant, special care was taken that no unrealistic conditions were created and only realistic component parts were used.

The flowsheet of the pilot plant, figure 1, shows the arrangement of the supplementary plant items around the rotary filter. A conventional rotary vacuum drum filter with a filter area of A = 0.7 m^2 serves as experimental equipment. This filter represents the smallest operational unit of a series of industrial units based on the same design. A filter cloth adapted to the filtration product is used as filter medium (Tamperen 71-2510).

The filter is installed in a pressure vessel which is designed for a maximum overpressure of 4 bar. The suspension to be filtered and originating from a beneficiation plant is pumped from an agitator tank arranged outside the pressurized room to the filter trough. On this occasion, the density and flow rate are measured. After cake removal, the filtered and dewatered cake is continuously extracted through a discharge device being fully separate from the filtration process. After the solids-liquid separation, the two-phase mixture consisting of air and filtrate is delivered through the filtrate lines into the separators and is there separated. The filtrate suction is carried out through barometric pipes so that the filtrate streams can be measured. The air required for the mechanical dewatering escapes at the top of the separators and is sucked off by the vacuum pump. At this point the air stream is measured and indicated in standard volumes. The overpressure needed for the combined pressure/vacuum filtration is produced by a compressor. According to the operating pressure to be kept constant, the compressed air flows through a control valve into the process chamber.

Figure 4 shows the opened pressure vessel of the pilot plant with a view of the drum-type filter.

DISCUSSION OF THE VARIOUS PLANT ITEMS

Rotary filter

As already mentioned above, all proved vacuum filter types such as drum type, disk type and belt filters are suitable for the hyperbar vacuum filtration. For the operation of the hyperbar vacuum filtration in a pressure vessel, no constructural changes are required. Only the closed cavities of the filter such as drums, gear box, bearings, etc. must be ventilated in order that during the pressure operation a pressure compensation can take place. As for the rest, the filters can be arbitrarily modified and adapted according to the experience gained in practical operation (see 3). Conforming to the operational requirements the ratio "filter area/Pressure vessel volume" must be optimally determined. In this connection, the disk-type filter is the most advantageous unit.

Pressure vessel

The process chamber must not only be pressure-resistant but also allows an easy installation of the filter, the laying of supply lines and pipelines without difficulties, the connection of the discharge unit to a suitable point and possibly the accessibility for maintenance personnel.

A simple and cheap construction would be a cylindrical steel vessel with dished ends, as it is used for the pilot plant. The statical calculation of this vessel by computer programmes with the necessary connections conform to to-day's technology. The utilization of standard parts allows a cheap manufacture.

A further possible construction would be reinforced concrete buildings which can be fabricated as gas-tight and pressure-resistant buildings without great expenses.

A new interesting variant consists of air-inflated structures which are already designed for a maximum overpressure of 1 bar.

When the hyperbar vacuum filtration process is used in beneficiation plants, it would be advantageous to install the filter station in a closed underground tunnel. According to the ore type involved, short transportation routes are obtained and one of the separation products may be directly deposited below ground.

All pressure vessel designs with the corresponding personnel sluices are the simpler and cheaper the lower the overpressure is. Despite the small overpressure, it is possible to operate an economically efficient overpressure filtration in combination with the vacuum filtration pressure difference which does not load the pressure vessel.

Solids discharge

The solution concerning the filter cake extraction from the pressurized room is at all times decisive for the industrial applicacation of the overpressure filtration. Besides some special apparatuses (5), suitable units are only used recently (6). The basic problem of the extraction is apart from the reliable discharge of the humid, frequently adhesive and abrasive bulk material, the minimization of the loss of compressed air stream connected with the extraction. In principle, it can be stated that all problems relating to the extraction diminish according as the differential pressure to be overcome can be kept at a low level.

Within the scope of the development of the hyperbar vacuum filtration a sensibility study (7) was carried out by the "Institut für Mechanische Verfahrenstechnik und Mechanik" for the solution of the discharge problem. The concept of the hyperbar vacuum filtration allows the use of any discharge system. After a star feeder was tested in the pilot plant over a long period, two new units resulting from the sensibility study are now used. These new units consist of a modified lift-lock with two JAUDT pivoted flaps of special design, which has already given excellent service, and a vertical discharge column in which the filter cake serves as a sealing element.

Air compressor

According to the filtration principle, air must be available in vacuum and overpressure condition. For most of the existing vacuum filtration plants waterring pumps are used for air suction. However, this proved pump type has the disadvantage that it has a relatively low efficiency of η = 0.25 - 0.3. Recent investigations show that for this purpose machines with a higher efficiency such as screw-type compressors, Roots pumps etc. can be employed (8) which efficiency reaches η = 0.8.

For air compression oil-free operating compressors should be utilized which ensure the corresponding overpressure of the delivered volumetric flow. Machines with a high efficiency and low operating cost such as turbo and screw-type compressors are advantageous for this purpose.

However, it is also possible to produce the vacuum and overpressure by one single machine. Such machines are screw-type compressors with intermediate cooling which allow a maximum air pressure ratio of about 4.5. In this case the maximum vacuum is Δp = 0.5 bar which is absolutely required for the pure vacuum filtration. Since the absolute amount of the differential pressure is obviously decisive for the dewatering, the corresponding overpressure has to be produced on the other machine side.

Suspension supply

To ensure constant operating conditions it is imperative to keep constant the filling level of the suspension in the filter trough. In the case of the conventional vacuum filtration it is sufficient to arrange an overflow weir in combination with a slightly excessive suspension supply. As far as the hyperbar vacuum filtration is concerned, it is only allowed to pump such a suspension amount into the filter trough as can be momentarily processed in the filter. Any excessive quantities must be stored in the pressure vessel or be extracted at high expenses from the process chamber. For this purpose, a combination of filling level measurement and pump control is successfully applied in the pilot plant. Figure 1 detail 7, shows the flowsheet of this connection. The filling level in the filter trough is measured by an ultrasonic transmitter and receiver. This signal is electrically transmitted to the control station where the current signal is converted to a compressed air signal. The compressed air signal controls a pneumatic control valve installed in the compressed air supply line through which the suspension diaphragm pump is supplied with energy. When the filling level drops below the desired value, the control valve opens and the compressed air diaphragm pump delivers a greater suspension quantity. As soon as the desired value of the filling level is reached, the suspension stream is reduced.

DISCUSSION OF RESULTS

Corresponding to the theoretical explanations of the mass throughput increase as a function of the pressure difference has first to be considered. Assuming approximately incrompressible solids, it was possible to demonstrate the $\sqrt{\Delta p}$-proportional increase of $\dot{m}_s$ with a Brasilian iron ore ($100\% < 100 \mu m$, $x_{50} = 27 \mu m$, $\rho_s = 4.9\ g/cm^3$) as shown in figure 5. At a superposition of the vacuum filtration pressure difference $\Delta p = 0.8$ bar with an overpressure of $\Delta p = 0.5$ bar ($\Delta p = 1.3$ bar) $\dot{m}_s$ increases by 21% ($\sqrt{1.3/0.8} = 1.27$) and at an overpressure of $\Delta p = 1$ bar $\dot{m}_s$ increase by 51% ($\sqrt{1.8/0.8} = 1.50$).

If it is considered that in the case of the rotary filtration only a minimum cake thickness is admissible for a reliable filter cake removal and that at higher filtration differential pressures this cake thickness shifts towards a higher filter speed range, the relationship $\dot{m}_s \sim \Delta p$, is obtained, like it is shown in figure 6 (see equation 12). From this follows that according to equation 16 the superposition of the vacuum filtration with a moderate overpressure of $\Delta p = 0.8$ bar already brings about a bisection of the necessary filter area for producing a constant mass flow.

However, the more important effect of the hyperbar vacuum filtration is the improvement of the residual moisture content by a more intensive overcoming of the capillary pressure when higher pressure differences are applied. In this connection it is first assumed that for the dewatering of the filter cake only the overcoming of the capillary pressure in the pile pores is effective. Any influence of the passing air stream either by thermal effect or by shearing stress effect shall be excluded.

Figure 7 shows these details by the way of example of a Brasilian iron ore. Starting from a residual moisture content of mc = 10% for pure vacuum filtration, an improvement by 1.6% to mc = 8.4% is obtained at a pressure difference $\Delta p_{hyp} = \Delta p_{vac} + \Delta p_{Pr} = 0.8 + 0.5 = 1.3$ bar and the residual moisture content diminishes by 2.2% to mc = 7.8% at a pressure difference $\Delta p_{hyp} = 0.8 + 1.0 = 1.8$ bar. The residual moisture content which remains constant at a speed variation is a typical feature of the rotary filtration. On the basis of a theory developed by Schubert (9), this typical feature is described in a separate paper.

Figure 8 shows the two profit components $\dot{m}_s$ and mc in dependence on the filtration pressure difference. As can be seen from this figure, the moderate increase of the pressure difference brings about the highest residual moisture content improvement rates at a simultaneously rising coefficient m_s.

In this connection it has to be considered that due to the dewatering mechanism the improvement of the residual moisture content brings about a remarkable rise of the gas volumetric flow Vg. Figure 9 shows, according to figure 8, the factor Vg in dependence on the coefficient $\dot{m}_s$ and Δp. The factor Vg represents the exclusive gas throughput passing through the filter cake for its dewatering. The dead volumes of the pilot drum-type filter cells are eliminated to obtain data which are independent of the filter types used. As can be seen, the factor $\dot{V}g$ rises with increasing coefficients Δp and $\dot{m}_s$ with linear approaches of the curves occurring in the upper limit range. In this range the pile is already dewatered to such a degree that a further pressure rise does no longer yield any substantial residual moisture content improvement. In this range the gas throughput only rises proportionally to Δp. Figure 10 represents the specific gas throughput indicated for many filters and important for the evaluation of the profitability as a function of the pressure difference Δp. The compensation curve shows that in a first approximation this process-characteristic coefficient rises linearly with the pressure difference in the technically relevant range. In the examined pressure range ($\Delta p = 1.3 - 1.8$ bar), these values are $\dot{V}g/\dot{m}_s = 20 - 30$ Nm^3/t which corresponds to a theoretical energy consumption of $W_t = 0.93 - 1.54$ kWh/t.

FINAL REMARKS

The hyperbar vacuum filtration offers the possibility of combining the advantages of the pressure filtration (smaller mc, greater $\dot{m}_s$) with the mechanical advantages of the conventional vacuum filtration. In this connection the necessary overpressure can be considerably reduced by the utilization of the vacuum filtration pressure difference. The moderate overpressure simplifies, as was demonstrated, all the vital plant items of a hyperbar filtration plant such as pressure vessel, pumps and discharge device. The lower the overpressure can be kept, the lower will be the wear of the machines and the longer will be their life-time.

For the practical operation the hyperbar vacuum filtration presents the advantage of a high plant fexibility since in the same plant both a pure vacuum filtration and a combined pressure/vacuum filtration can be carried out. Apart from the cheap adaptation of the filtration method to the product to be treated, this fact is of great importance primarily for the start-up and shut-down of a pressure filtration plant.

Existing vacuum filtration plants can be adapted to hyperbar-operating conditions with plant items of the conventional vacuum filtration. Especially in plants operating at high altitudes (decrease of the vacuum filtration pressure difference), the superposition of the vacuum filtration with overpressure allows a very significant residual moisture content improvement. In new plants almost closed gas circuits can be established by means of this filtration technique so that the treatment of problematic products is possible, see also (4).

However, the most important factor is the substantially improved residual moisture content. Within the scope of a cost/profit analysis, the advantages resulting therefrom such as omission of the thermal drying, lower transportation cost, fewer problems during the further process stages clearly show the profitability of the hyperbar vacuum filtration. At an increase of the differential pressure to Δp = 1.8 bar the water content of the treated iron ore already dropped about 24 kg/t solids. In the case of thermal drying, this means apart from the transportation costs decrease a reduction of the energy consumption by about 40 kWh/t solids.

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Formulae

A	surface m^2
h	height m
$\dot{M}$	mass throughput kg/h
$\dot{m}$	area specific mass throughput kg/m^2h
n	speed min^{-1}
p	pressure bar
R	resistance m^{-1}
mc	residual moisture content weight-%
t	time s
V	volume m^3
$\dot{V}$	volume throughput m^3/s
W	energy kWh
x	particle diameter m

α	process angle ^{o}
Δ	difference
ε	porosity
η	toughness Pa s
κ	concentration parameter
ρ	density kg/m^3

Indices

abs	absolute
c	cake
Pr	pressure
g	gas
hyp	hyperbar
L	liquid
M	medium, filter cloth
min	minimum
s	solid
vac	vacuum
1	1. filtration phase, cake formation
2	2. filtration phase, dewatering
F	filter

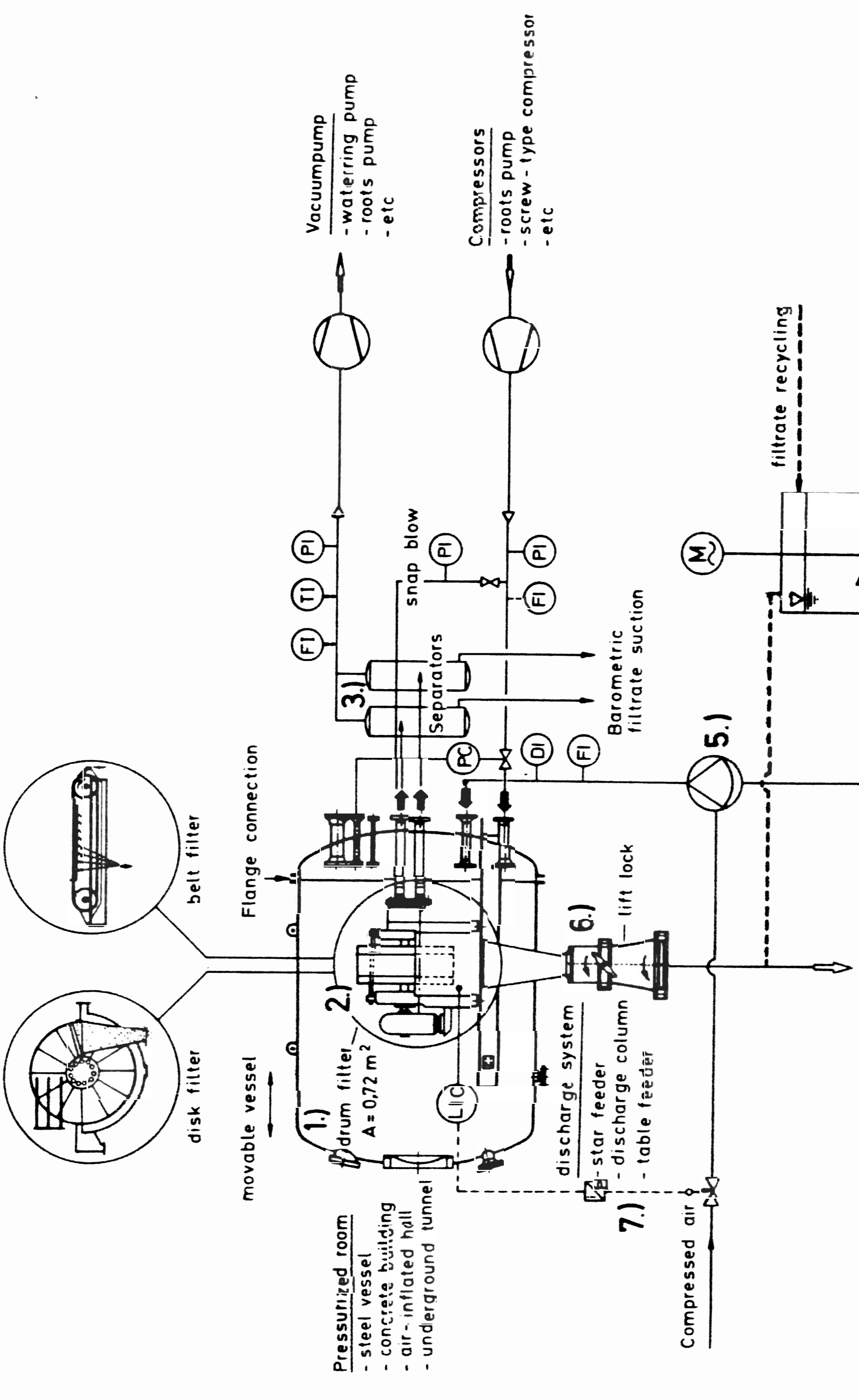

Figure 1: Flowsheet of the pilot plant for hyperbar Vacuum filtration

1.) pressurized room 2.) rotary filter 3.) separator
4.) suspension tank 5.) suspension pump 6.) discharge system
7.) filling level measurement ------ exclusive components
of the pilont plant

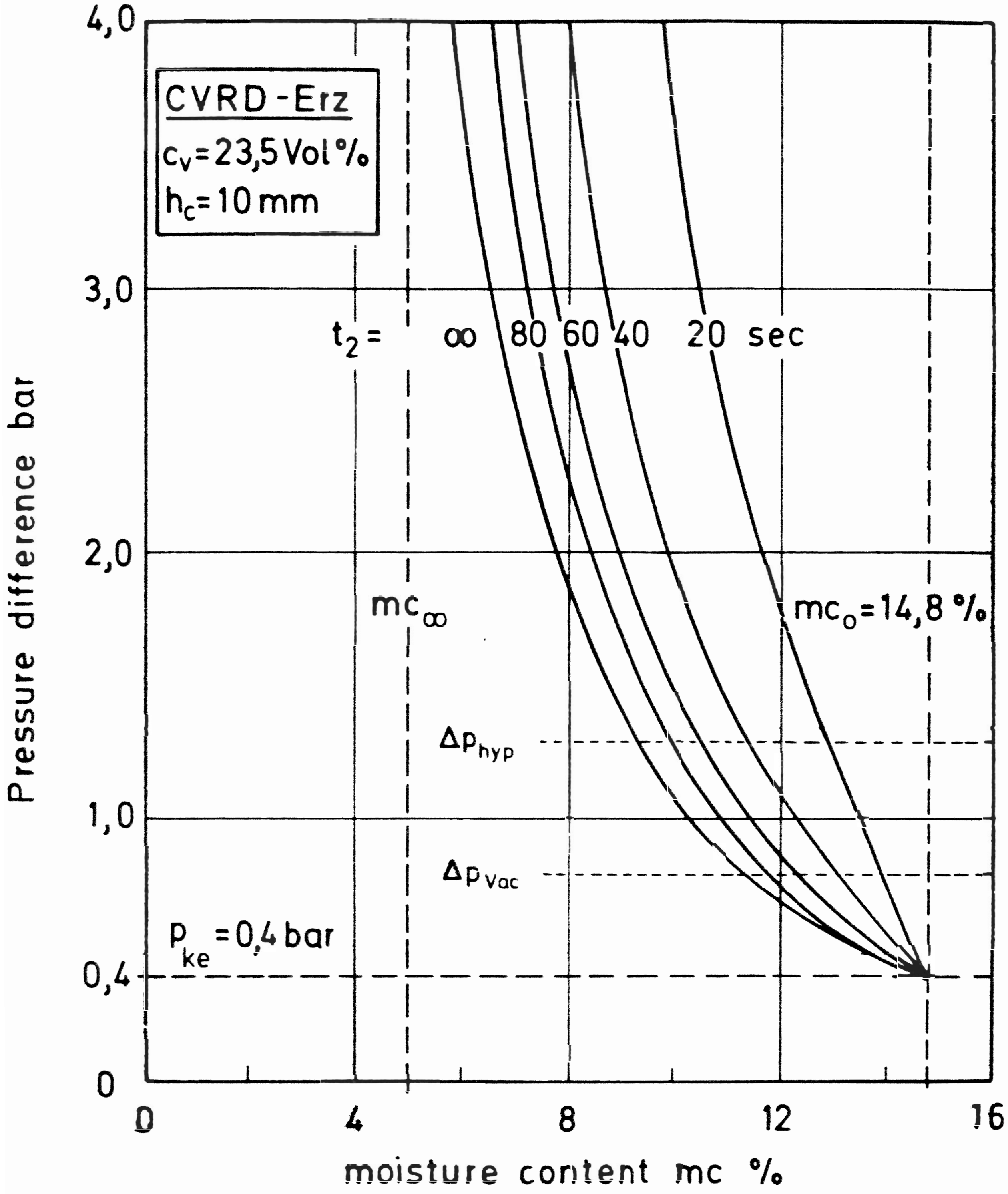

Figure 2: Capillary pressure diagram

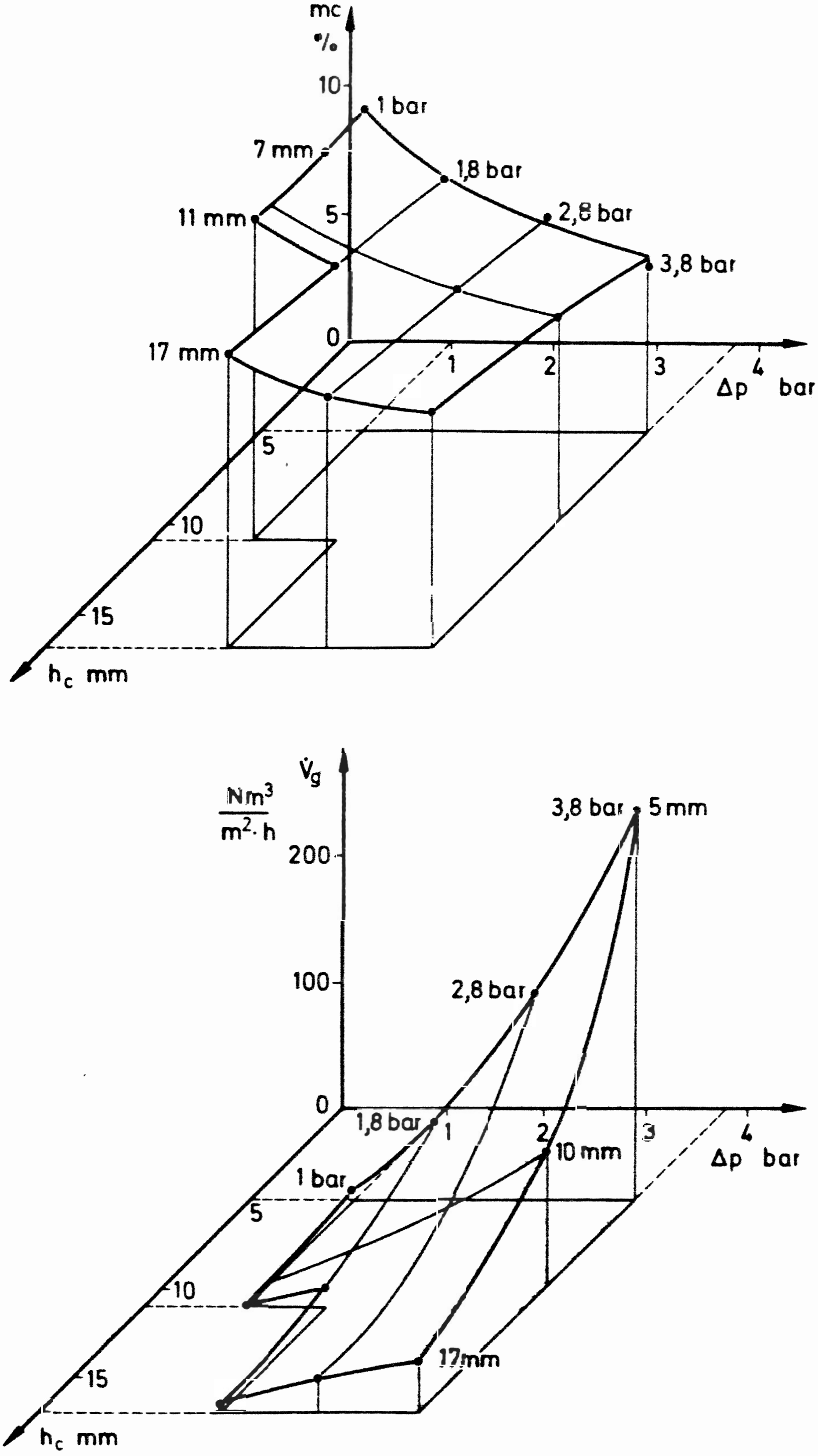

Figure 3: Dewatering diagram of the laboratory-type filter (filter cell)

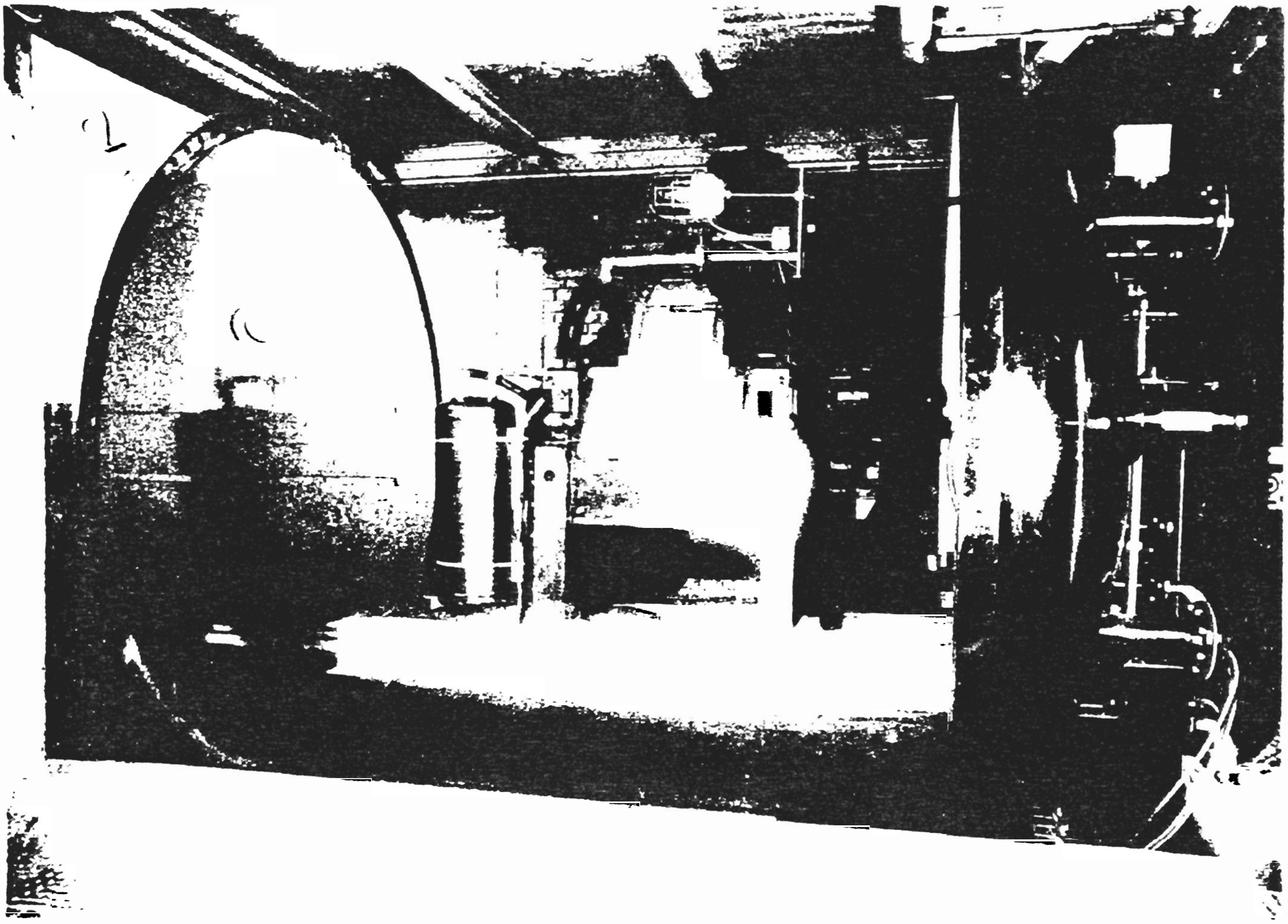

Figure 4: Photo of the pilot plant

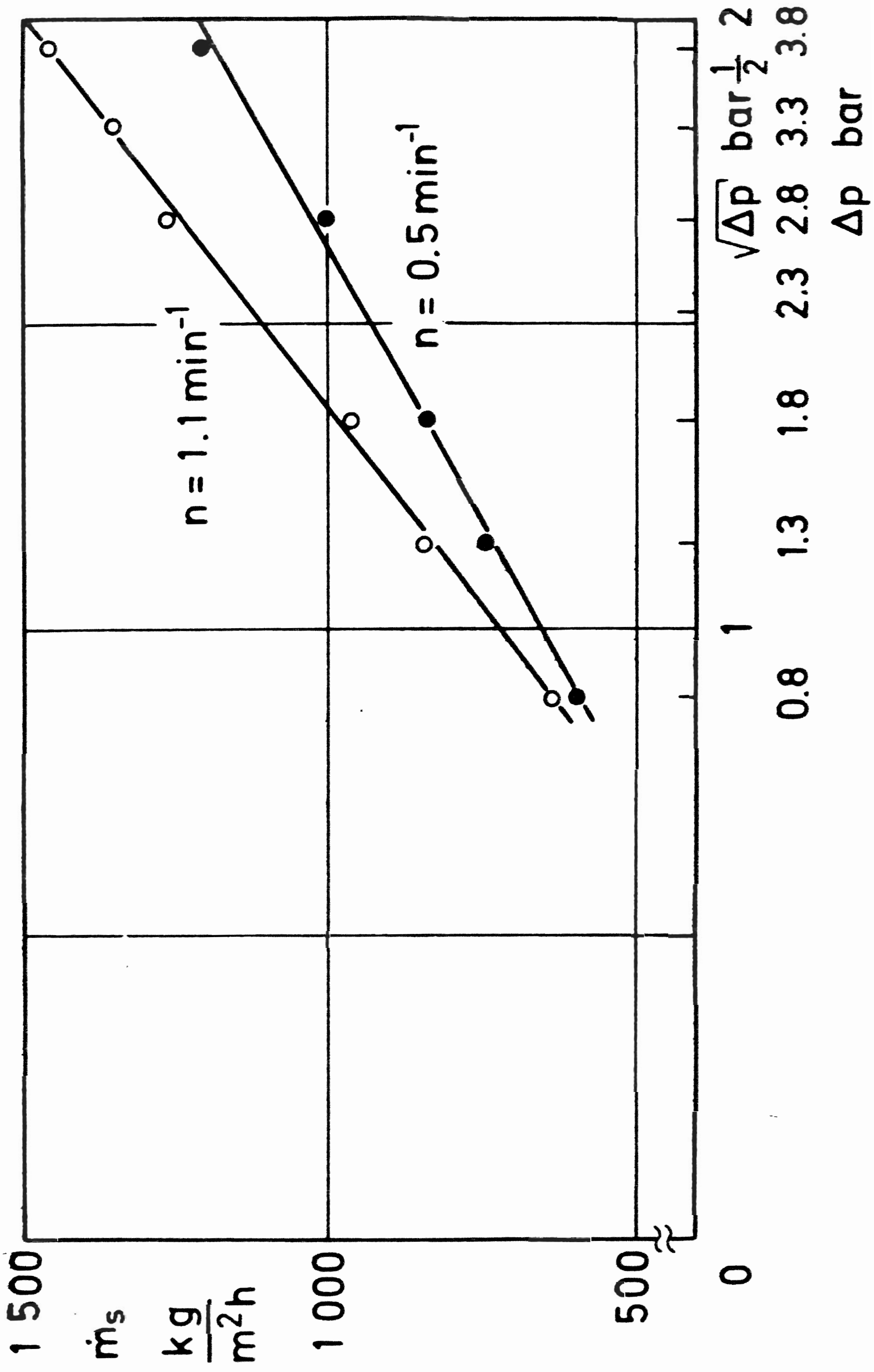

Figure 5: Diagram $\dot{m}_s = f(\sqrt{\Delta p})$

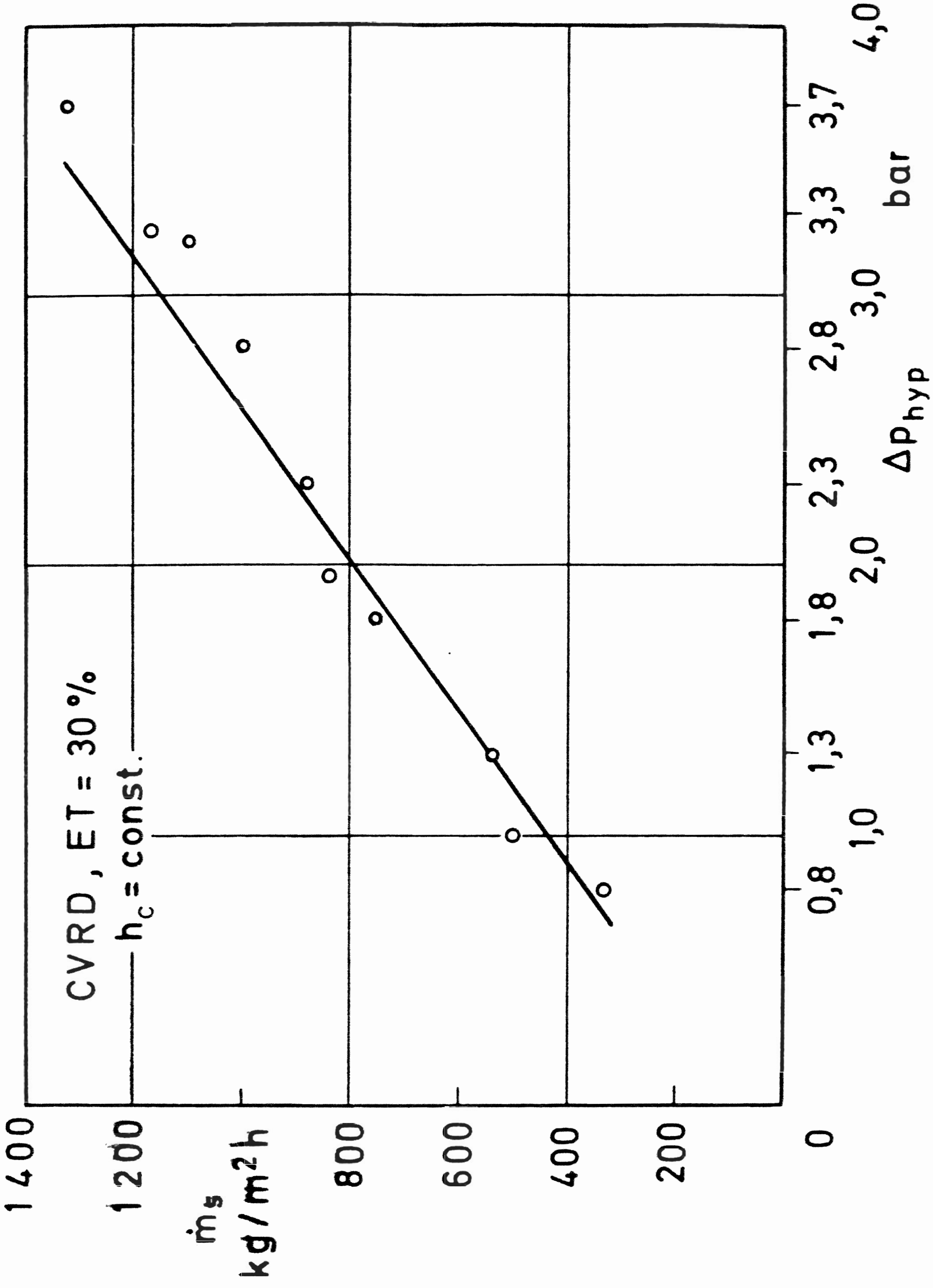

Figure 6: Diagram $\dot{m}_s = f\ (\Delta p)$

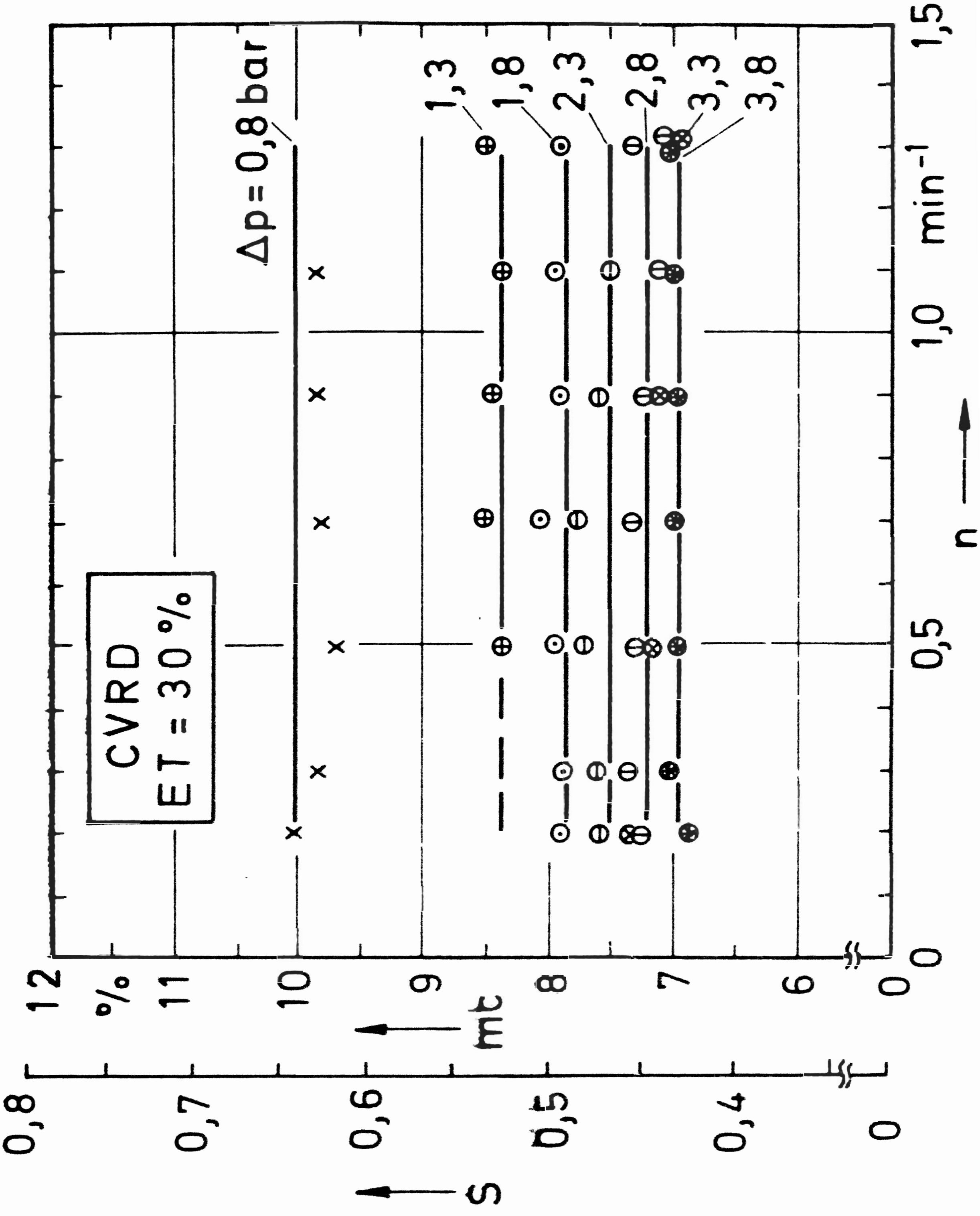

Figure 7: Diagram mc = f (n)

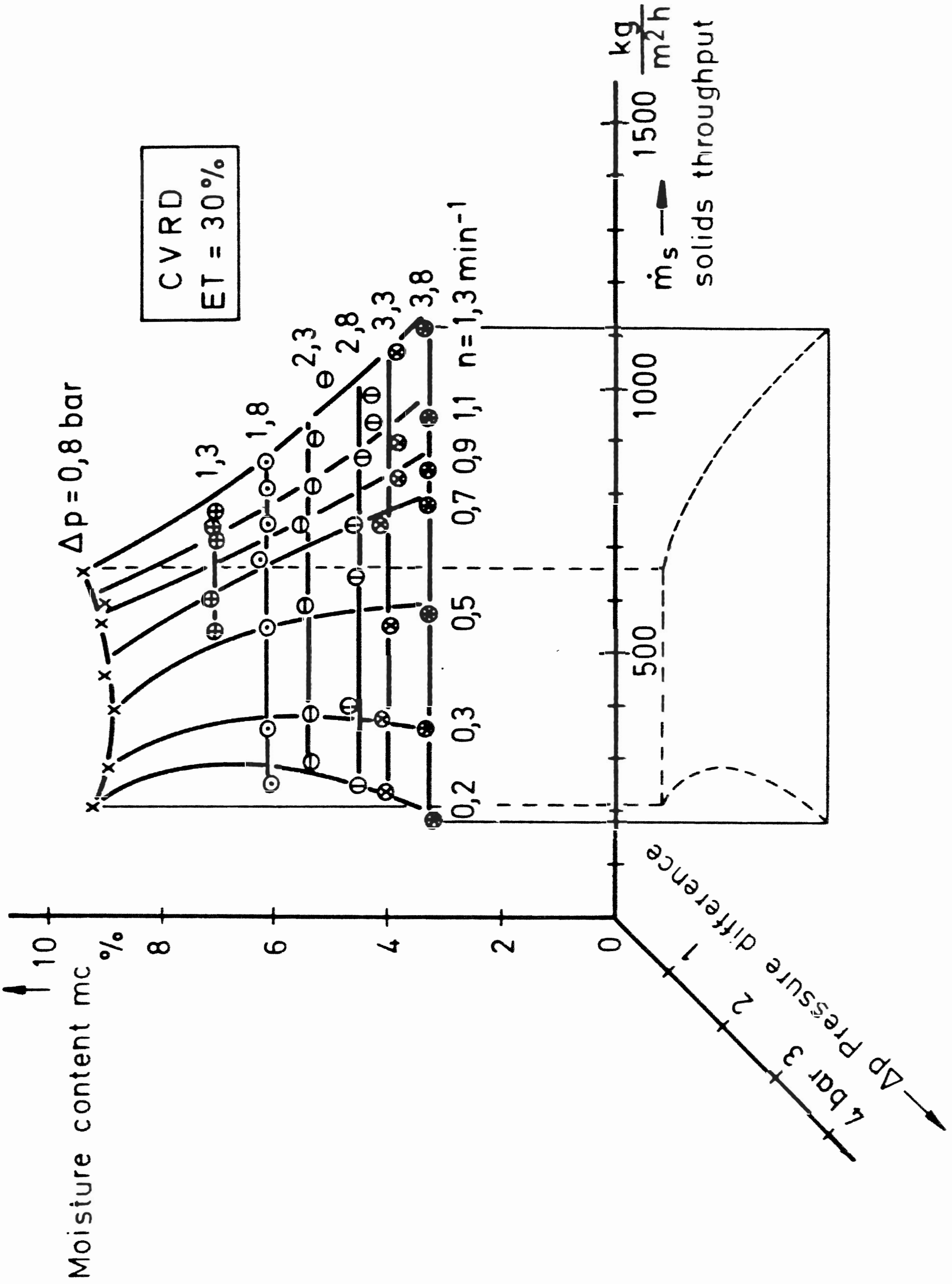

Figure 8: Diagram mc = f (Δp , $\dot{m}_s$)(profit)

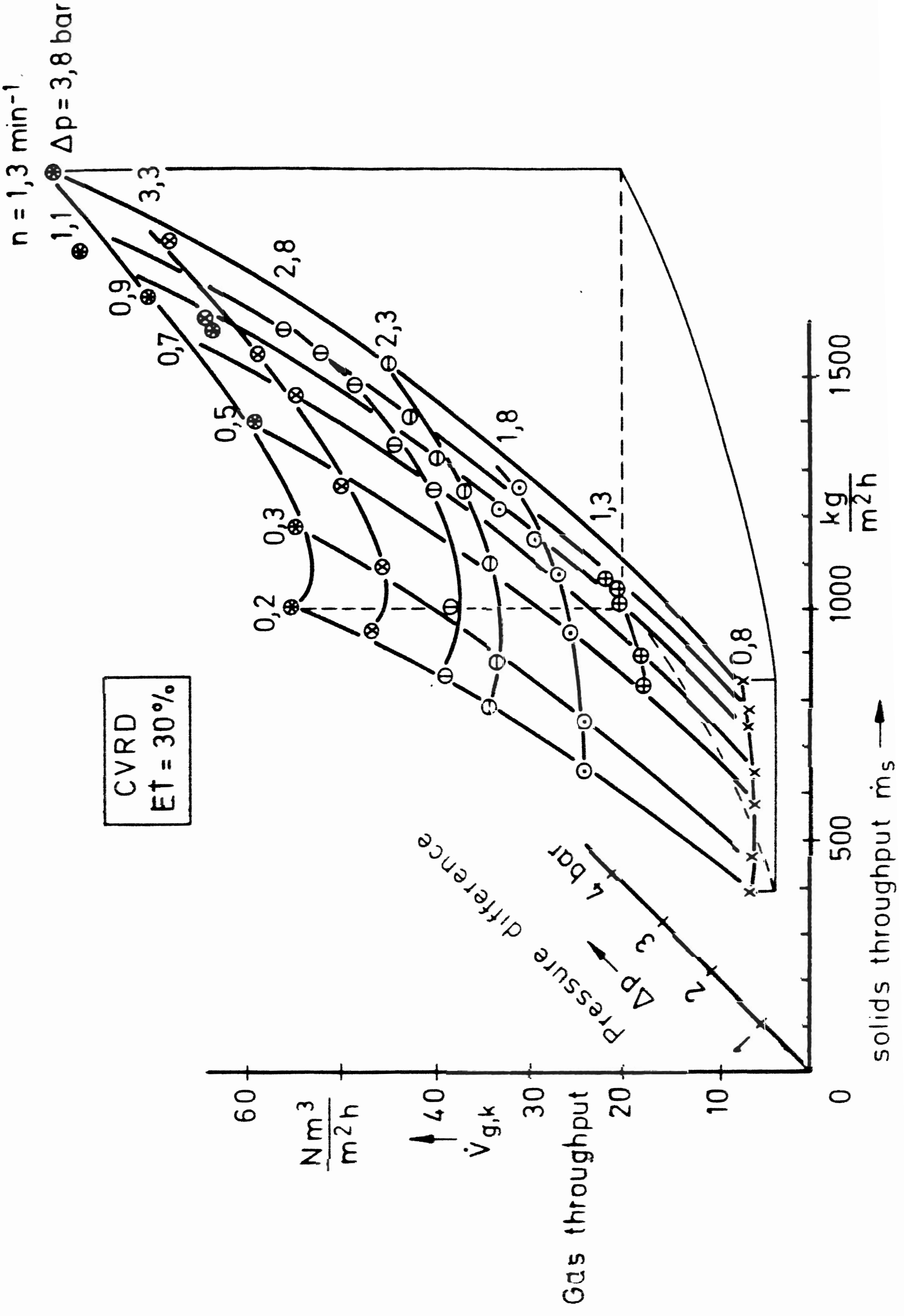

Figure 9: Diagram $\dot{V}g = f\ (\Delta p,\ \dot{m}_s)$ (cost)

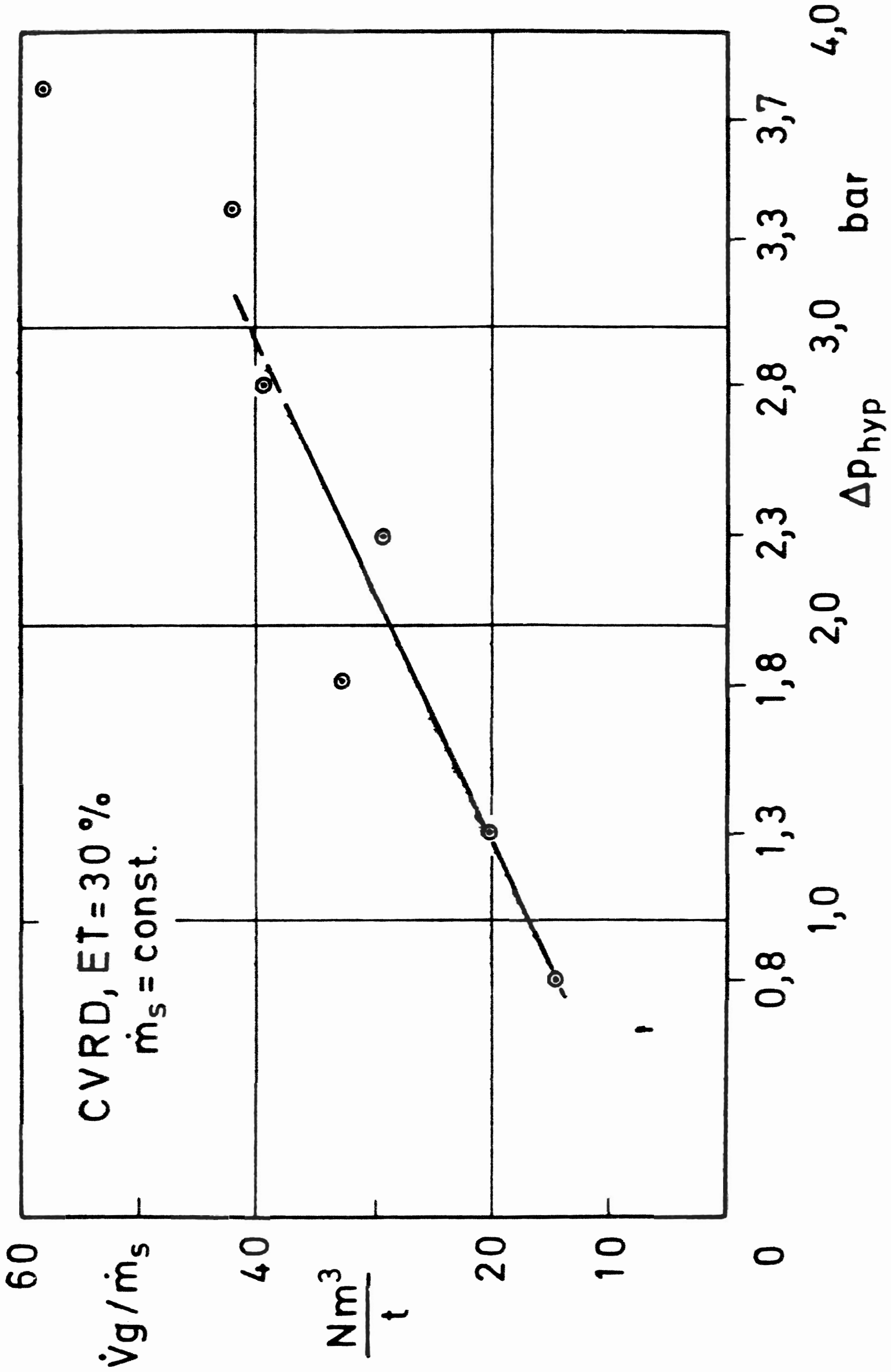

Figure 10: Diagram $\dot{V}g/\dot{m}_s = f\ (\Delta p)$