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A SURVEY OF DEVELOPMENTS IN REACTOR TECHNOLOGY

(REACTORS FOR CATALYTIC GAS-PHASE PROCESSES)[1]

by

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Contents

Foreword

The field of catalysis is unique insofar as it requires the efforts of research workers of different disciplines: physical, inorganic, analytical, and organic chemists, the solid state physicist, biophysicist, applied mathematicians, and chemical and metallurgical engineering scientists as well as development chemists and engineers. There are electronic aspects of catalysis; the nature of the solid catalyst implies an inorganic chemical aspect, solid state problems and, as the porous or nonporous catalyst pellet operates in contact with another (usually gas) phase, the involvement of transport phenomena, thus inviting the attention of the chemical engineering scientist and reactor analyst.

Today the problem is not only finding the catalyst – rather the problem is to find the reactor and conditions to perform the catalytic task efficaciously. Today more catalysts are at hand to perform a required task, yet there are more aspects of the catalytic events recognized which must be engineered to optimize the catalytic reactor. As the heterogeneous catalytic reactor network consists of the catalyst (with carrier, promoters, inhibitors and the active substances), operating in what is usually a nonuniform field of temperature and concentrations within which may exist, short- and long-range diffusional gradients, then the problem of reactor design and engineering and of reactor analysis is indeed complex. These extra-catalytic phenomena have allways existed, however, they were not explicitly recognized decades ago when, the prime concern was to find the catalyst, not to engineer its environment. Indeed, the fact that modern catalytic plants operate more efficiently than their ancient parent units is mainly due to advances in reactor engineering as well as to advanced mechanistic studies.

The following survey deals with the developments in reactor technology and reactor engineering in the field of heterogeneous gas-phase catalysis, illustrated by the example of a fixed-bed catalytic reactor for the production of phthalic or maleic anhydride.

I. Introduction.
Original Developments in Reactor Technology.

The development of the modern advanced reactor technology is derived from two basic engineering conceptions, namely from the mercury cooled and from the salt bath cooled reactor

1. Mercury cooled reactors.

The mercury cooled reactor – known as the Downs-Type reactor in the US literature – was patented by Charles R. Downs in 1926 (US Patent 1 604 739, The Barrett Company, Application filed in 1921). This reactor consisted of 1300 square contact tubes, 18x1150 mm, containing 300 liters of catalyst and requiring a cooling bath of mercury of approximately 3000 kilos. The production capacity of this reactor was 30 to 35 tons of phthalic anhydride per month, the reaction temperature being within the range of 400–500 C, with a space velocity of 4000–5000 and a contact time of 0.6 sec. Reactors of this type were built and used in the USA and Europe even in the late fifties, so p.e. in the phthalic anhydride plants of ACNA/Montecatini in Italy or SOAB in Sweden.

The further development brought the change from square to round contact tubes. Such reactors are particularly suitable for production units up to 50–100 tons of phthalic anhydride per month. In such a case when the coolant is boiling mercury and the control of the temperature at wich it boils is assured by the pressure at which the mercury system operates a relatively simple pressure control is found to be highly effective. One other advantage in the use of mercury is that it is liquid at normal temperatures and does not solidify on shutting down the plant. It is also very stable and although expensive does not deteriorate in service.

Fig. 1 describes a mercury-cooled reactor (Downs-Type), **in Fig. 2 is shown a mercury-cooled reactor for the production of 1.000 t/yr of phthalic anhydride, designed by the author for Carbochimital SpA, Padova, Italy, and manufactured by Ariosto Rolle, Padova, Italy, in 1958.**
Fig. 3 illustrates a mercury-cooled reactor for the production of 600 t/yr of phthalic anhydride, designed by the author for Carbochimital, Padova, in 1953, for Petrocarbone-France, Paris, in 1954, for Chemische Fabrik von Heyden, Munich-Regensburg, in 1954, and others (Hibernia. in 1952; Reichhold, in 1956; Monsanto, in 1957, etc.).

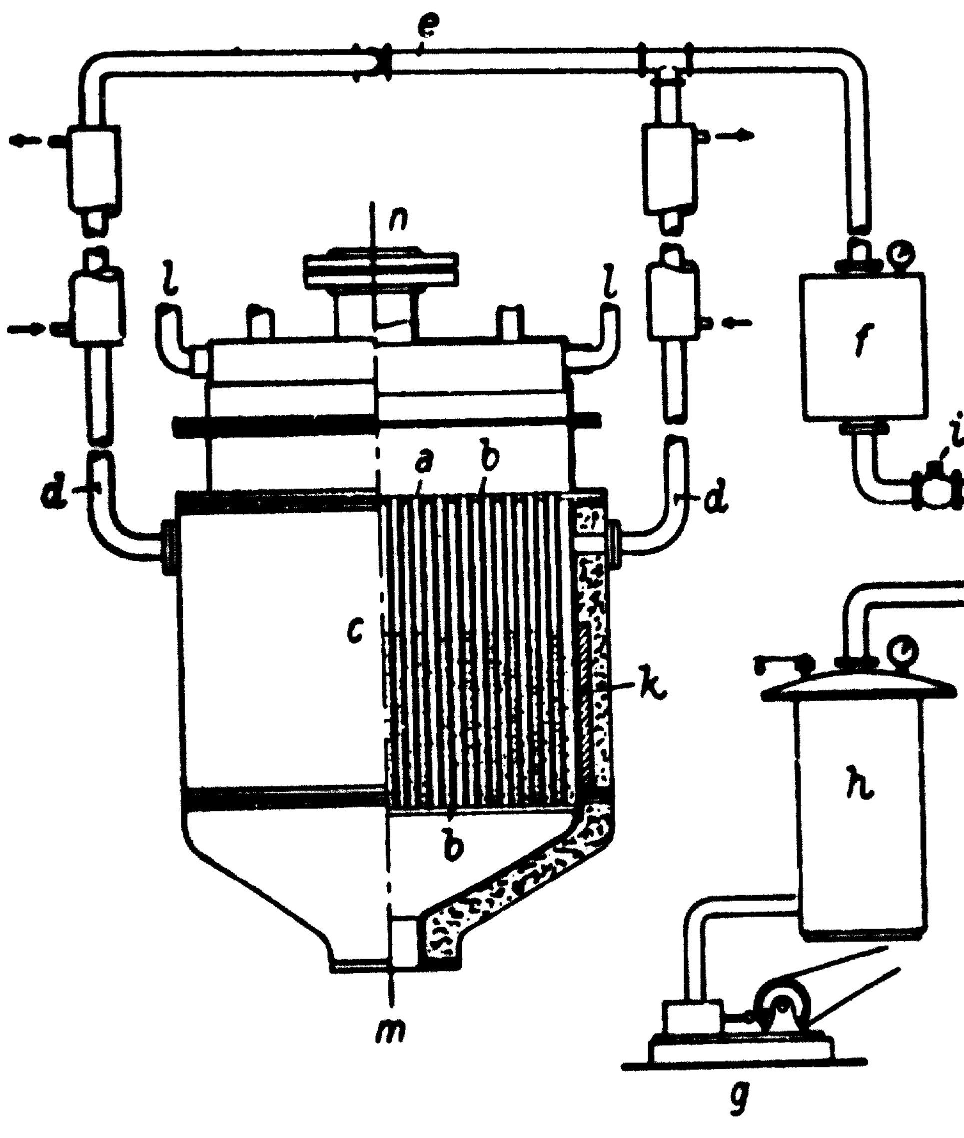


Fig. 1 Mercury-cooled Reactor (Downs-Type)

a – Catalyst tubes
b – Distancing rods
c – Mercury coolant
d – Reflux cooler
e – Ring collector
f – Pressure equalizing vessel
g – Compressor
h – Pressurized vessel
i – Regulating valve
k – Electric heating
l – Entrance of air-naphtalene mixture
m – Exit of the reaction gas
n – Explosion disc

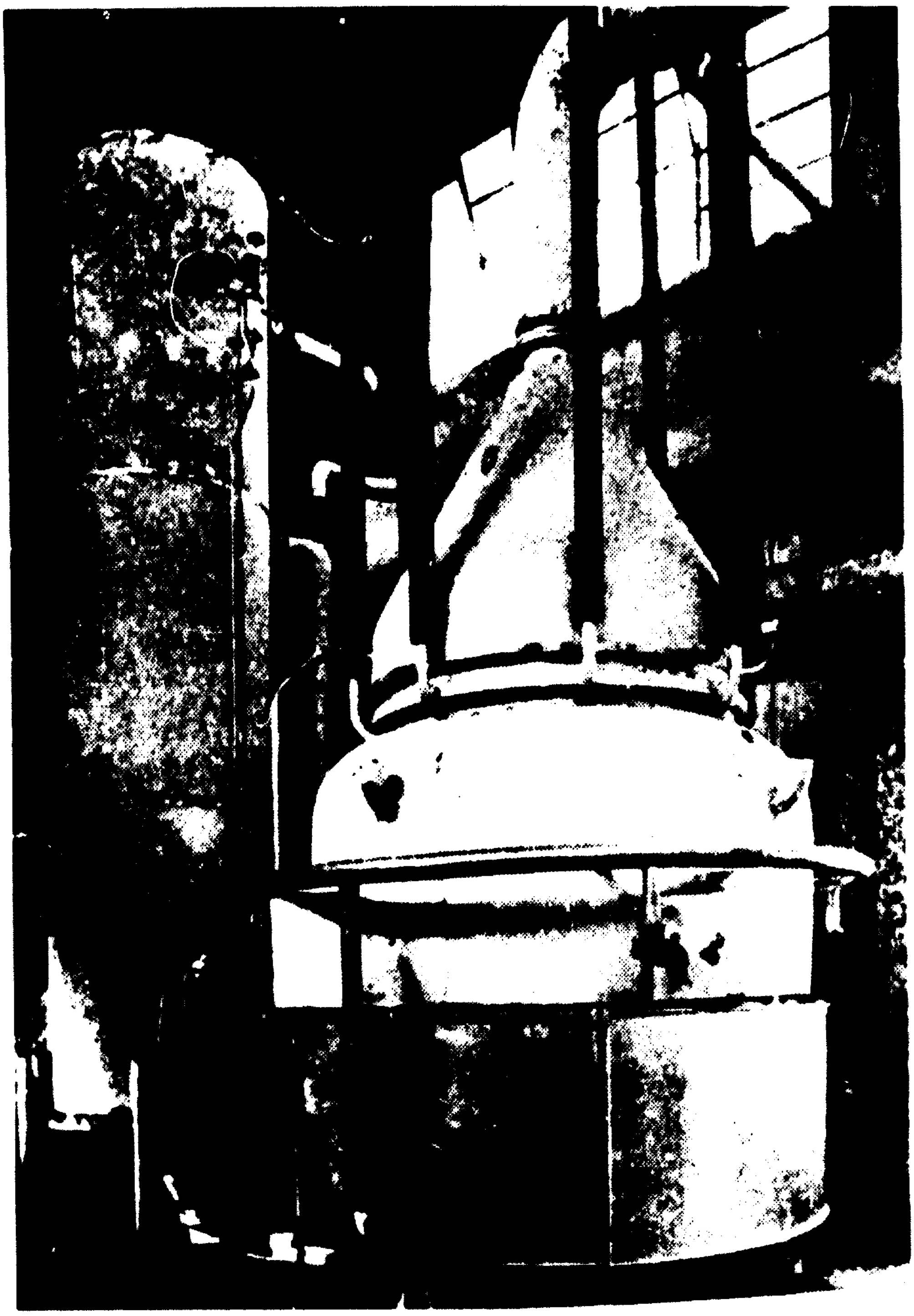
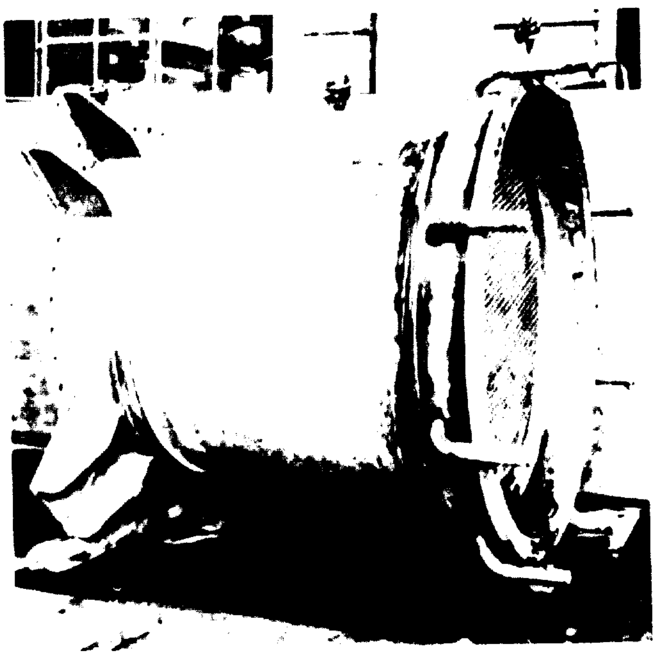
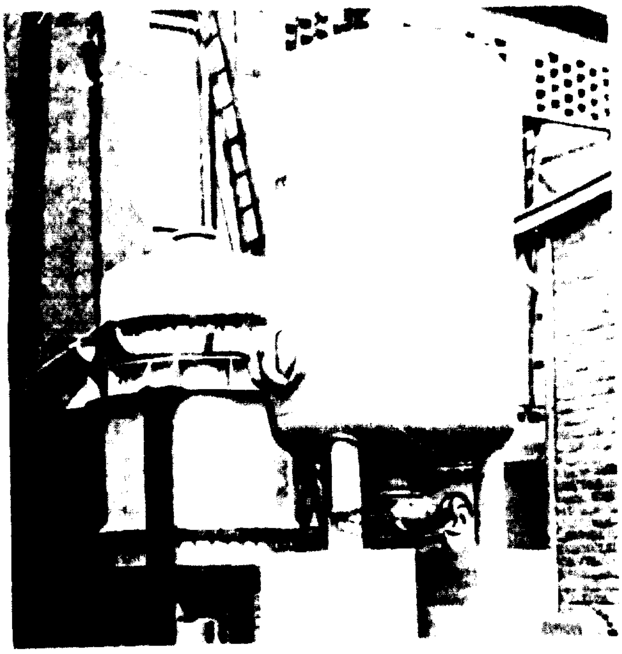
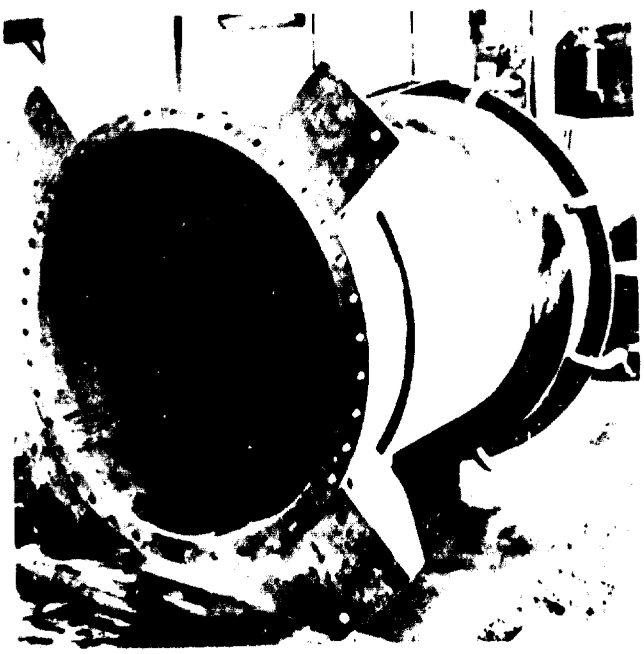


Fig. 2 Mercury-cooled Oxidation Reactor for Phthalic Anhydride, 1000 t/yr.

Manufacturer: Ariosto Rolle, Padova/ Italy, for Carbochimital SpA, Padova/Italy.







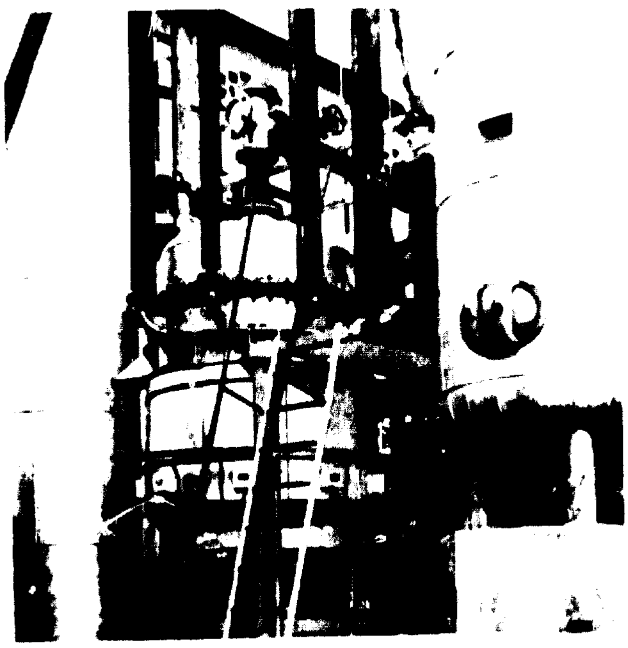


Fig. 3/3a Mercury-cooled Oxidation Reactor for Phthalic Anhydride, 600 t/yr.

Designed and engineered for Carbochimital SpA Padova, Italy; ACNA/Montecatini, Cengio Savona, Italy; Destilacija Drva, Teslo, Yougoslavia; Petrocarbone-France, Paris, France; Chemische Fabrik von Heyden, Regensburg and Munich, Germany and others (Hibernia, Reichhold, Monsanto, etc.)

Fig. 3b A mercury-cooled reactor, 50 to 100 t/month, designed and engineered by the author, during the plant assembly.

Fig. 3c A mercury-cooled reactor, 50 to 100 t/month, designed and engineered by the author (ACNA/Montecatini, von Heyden, Monsanto, Carbochimital and others).

2. Salt bath cooled reactors.

The salt bath cooled reactor is based on the substitution of mercury as coolant by a high temperature salt (KNO_3NaNO_3) melt under forced circulation by an agitator or a pump. This principle was first realized in Germany by the IG-Farben at the beginning of the second World War (Viz. BIOS Final Report No. 649). The concentration of naphthalene in the feed was 63 g/Nm^3 (1 : 20), the reaction temperature being within the range of 420–550 C, the space velocity being 5000–7000, and the contact time of 0.4 sec. The production capacity was within the range of 300–600 t/month.

An example of a salt bath cooled reactor (IG-Farben) of a somewhat modified design is shown in Fig. 4. The catalyst volume is approximately 3000 liters. The temperature difference between the reaction temperature (360–400 C) is maintained at approximately 20–30 C. The space velocity (ratio air to volume of catalyst 3000 : 3) is 1000, the contact time 1,5 sec. The production capacity of this reactor is approximately 90 t/month.

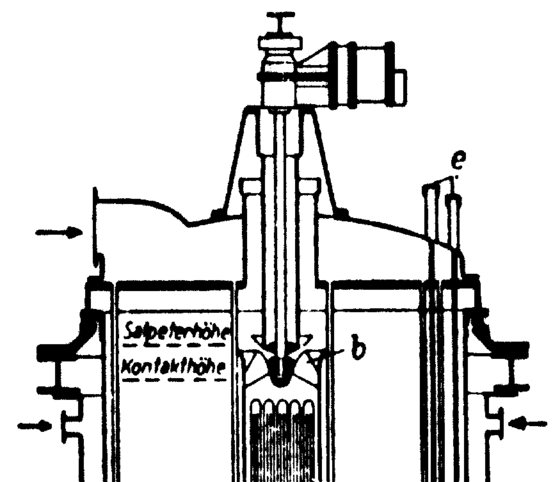


Fig. 4 IG-Farben (BASF) Reactor cooled by a mixture of potassium nitrate and sodium nitrate mixed in proportion to the molecular weights with a melting point of 141 C.

Size of Catalyst Tubes:

The tubes are of steel with the following size:

I.D. = 25 mm
O.D. = 30 mm
Length = 3288 mm

The ends of the tubes are turned down to a slightly smaller O.D. to make a tight seal in the tube plates. A reactor contains 2946 tubes and each tube is filled with the catalyst to a depth of 2500 mm.

The catalyst is supported in the bottom of each tube by a screen disc of V2A stainless steel wire 0.5 mm diameter. The screen mesh is about 1,0 mm. The screens are fastened inside of each tube by a suitable spring clamp or lock rings and are located just above the lower tube plate.

Reactor vessel:
Material: steel.

I.D. = 2580 mm.
Wall thickness = 16 mm.
The cooler, which is located axially in the reactor, is 650 mm O.D.
The I.D. of the cooler is 540 mm.
The number of tubes in the cooler is 37.
The tube length is 2500 mm (in the cooler).
Each of the tubes in the cooler is made up of two tubes, one installed concentrically in the other. The outer tube has an O.D. of 57 mm and a wall thickness of 2,75 mm and the inner tube has an O.D. of 40 mm and a wall thickness of 2,50 mm.

The salt mixture in the reactor is kept circulating from the catalyst zone to the inner zone, containing the tubular air condenser, by an agitator, with specially designed blades, rotating at 200 r.p.m. The inner tube 54 cms diameter, enclosing the air cooling tube, acts as a thermal barrier between the cooler central zone and the warmer catalyst zone. The salt bath is equipped with 14 pyrometer pockets, each pocket containing 8 couples giving temperatures at different dephts in the bath.

Production capacity:

Each reactor has a rated output of 75 tons of phthalic anhydride per month although this figure could be increased to 100 tons per month.

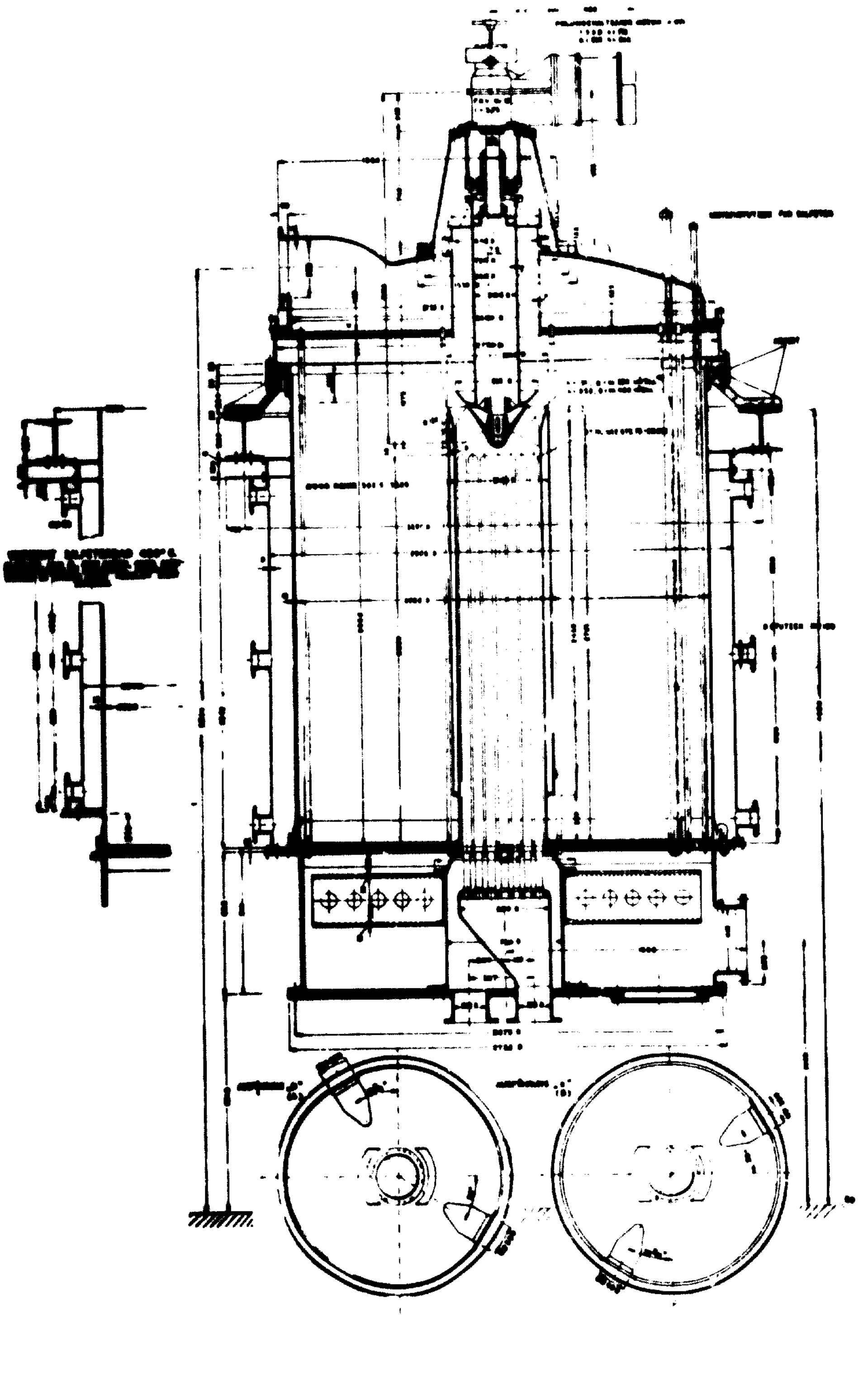


Fig. 4a The IG-Farben-BASF-Reactor

II. Further Developments in Reactor Technology.

1. The DWE-Reactor.

Further developments in the reactor technology led toward the design of a salt bath cooled oxidation reactor with a forced salt melt circulation by a central agitator combined with a steam generator and introduced into the reactor core by an opening in the upper tube plate. Design and engineering by Deggendorfer Werft und Eisenbau DWE, Deggendorf, Germany. These reactors are largely used in many phthalic anhydride plants operating on BASF or Von Heyden processes.

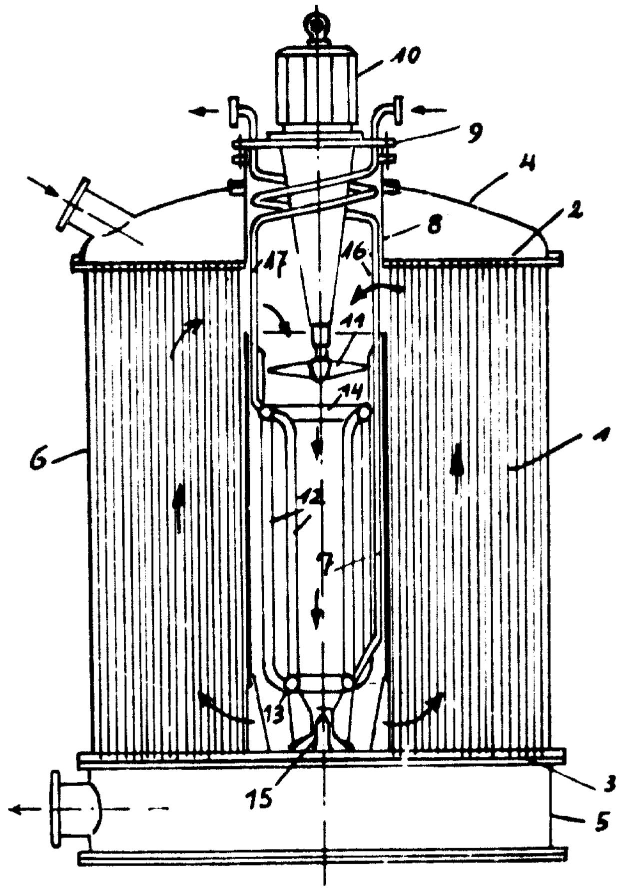


Fig. 5 The DWE-Reactor

Fig. 5 shows the basic design of the DWE-Reactor as specified in the relevant patent specification and Fig. 6 illustrates the execution of this type of reactor. The central molten salts agitator and steam generator are shown in Fig. 7. Fig. 8 shows a series of 4 oxidation reactors of a production capacity of 300 tons/month of phthalic anhydride each (total 14.600 t/yr), manufactured by the DWE in 1967 for Oesterr. Stickstoffwerke AG, Linz, Austria.

The DWE-Reactor. Oxidation Reactor (conventional design for BASF and Von Heyden processes) with central salts cooling and heat-exchange system. Manufacturer of the reactor: Deggendorfer Werft und Eisenbau DWE, Deggendorf, Germany, (German Patent 1 181 177).

1 – Catalyst tubes
2 – Upper tube plate
3 – Lower tube plate
4 – Upper cover
5 – Lower cover
6 – Reactor wall
7 – Central guidance tube
8 – Support for head plate
9 – Head plate
10 – Motor
11 – Agitator with special blades
12 – Boiler tubes
13 – Upper collector ring
14 – Lower collector ring
15 – Central support
16 – Connection tube
17 – Connection tube/steam exit
18 – Spiral winding

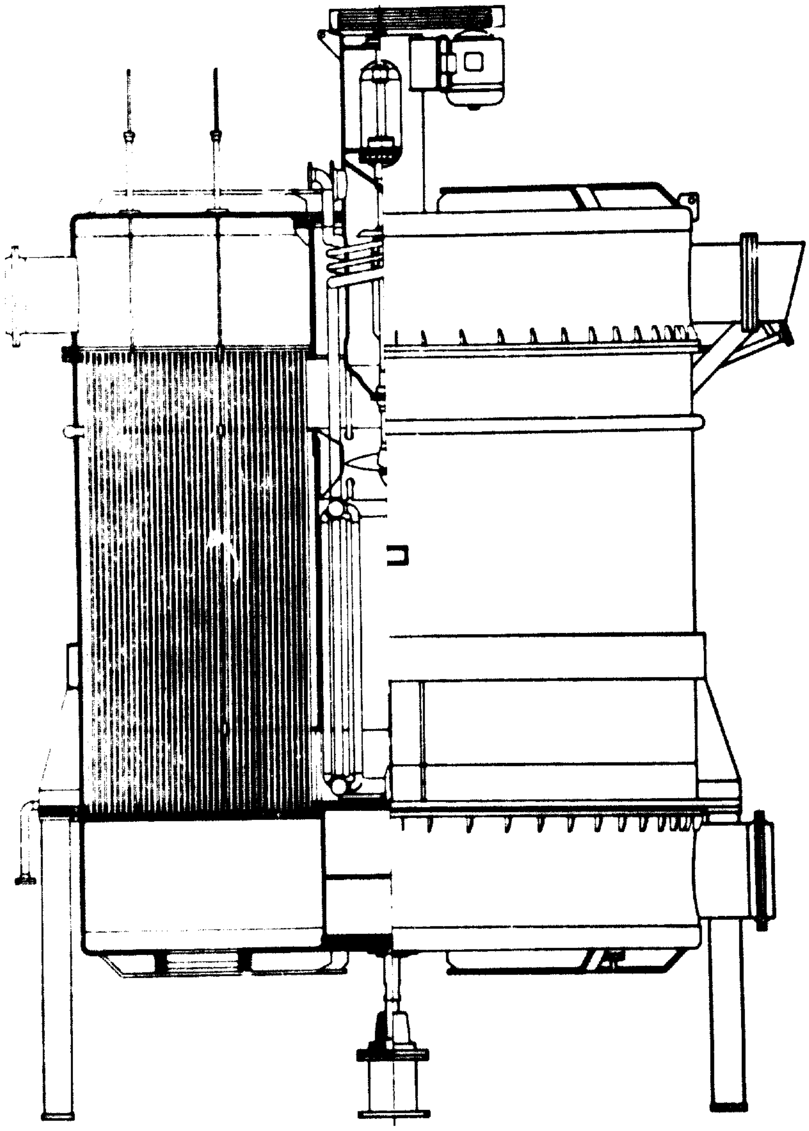


Fig. 6 The DWE-Reactor (300 t/month)

The DWE-Reactor. Oxidation Reactor (conventional design for BASF and Von Heyden processes) with central salts cooling and heat-exchange system. Manufacturer of the reactor: Deggendorfer Werft und Eisenbau DWE, Deggendorf, Germany.

8.928 contact tubes,	I.D. =	25 mm
	O.D. =	30 mm
	length =	3072 mm
Diameter of the reactor	=	4540 mm

Height of the reactor	= 6800 mm
Volume of the catalyst tubes	= 13500 liters
Weight of the catalyst	= 9450 kg
Weight of the reactor	= 62750 kg
Weight of the salt bath	= 38800 kg
Operating weight of the reactor	= 111000 kg
Production capacity of the reactor	= 300 t/month (3.600 t/yr)
Design temperature	= 450 °C
Reaction temperature	= 380 °C

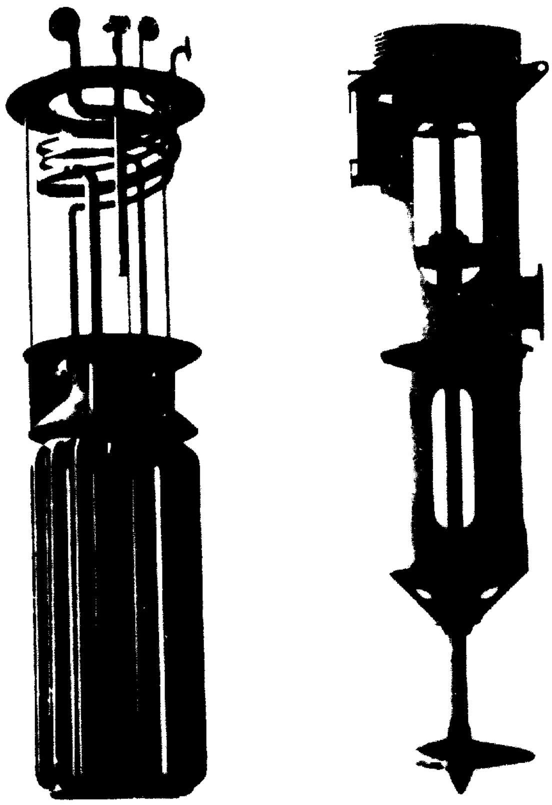


Fig. 7 The DWE-Reactor, central salts cooler – heat exchanger – steam generator.

Fig. 8 Four oxidation reactors for phthalic anhydride, 300 t/month each = 1200 t/month (14.400 t/yr).

Manufacturer: Deggendorfer Werft und Eisenbau, DWE, Deggendorf, for Österreichische Stickstoffwerke AG, Linz/Donau, Austria (1967).

2. The Polimex-Cekop Reactor.

The DWE-Reactor design has been taken up by other manufacturers later on. Fig. 9 shows a very similar design offered by Polimex-Cekop of Warszawa, Poland, and realized p.e. in phthalic anhydride plants in Poland (Zakłady Azotowe Kędzierzyn) and in the Soviet Union (Awdiejewka/Donieck, etc.), the production capacity of the plant in Poland being 4000 t/yr and the production capacity of the phthalic anhydride plants supplied by Polimex to the Soviet Union in 1967 amounting to 24.000 and 16.000 t/yr.
Two new phthalic anhydride plants using the same type of reactor have been contracted recently by Polimex-Cekop for supplies to the Soviet Union in 1973. The manufacturers of these reactors are Zakłady Urządzeń Chemicznych i Aparatury Przemysłowej in Kielce and Zakłady Urządzeń Przemysłowych in Nysa, Poland. The new phthalic anhydride reactors supplied by Polimex-Cekop will use a new catalyst developed by the author and permitting higher conversion rates as in the ancient parent units.

Volume in the contact tubes	18.500	liters
Volume outside the contact tubes	25.500	liters
Volume of the catalyst mass	13.400	liters
Working pressure in the contact tubes	0,7	at
Working pressure outside the tubes	0	at
Working pressure in the steam generator	24,0	at
Temperature at the contact tubes entry	140,0°	C
Temperature at the contact tubes exit	380,0°	C
Temperature in the contact tubes	420,0°	C
Temperature outside the contact tubes	370,0°	C
Agitator for molten salts, motor	40,0	kW
r.p.m.	725,0	
total head	7,0	mWG
capacity	1100,0	m^3/h
Steam generator, heat exchange area	21,0	m^2
Contact tubes	8540	
Weight of the catalyst	8300	kg
Diameter of the reactor	4070	mm
Height of the reactor (without support)	9500	mm
Total height of the reactor	11500	mm
Weight of the reactor	88200	kg
Weight of the salt bath	38800	kg
Total weight of the reactor (working)	135300	kg
Material of construction	C – Steel	
Contact tubes, 30 x 2,5 x 4000 mm	C – Steel	
Production capacity of the reactor	4000	t/yr

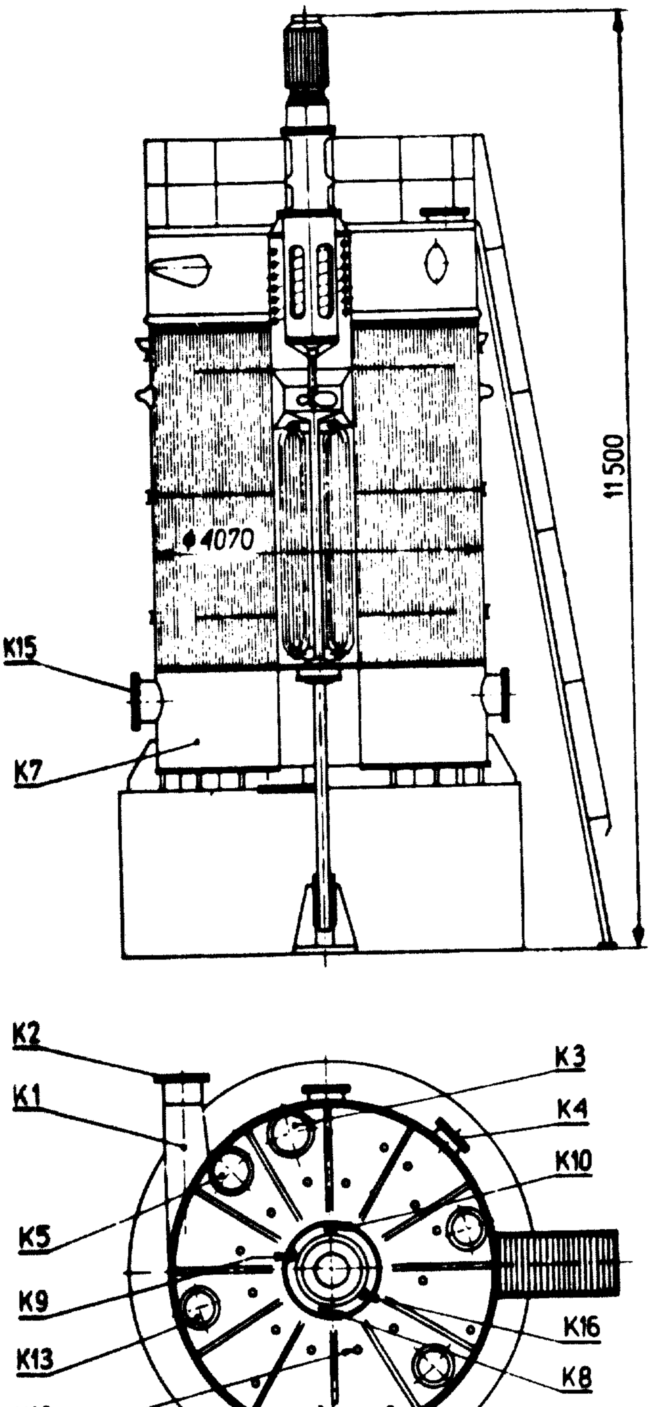


Fig. 9 The Polimex-Cekop Reactor.

3. The Rolle-Reactor

Another type of an oxidation reactor with a central molten salts agitator has been suggested by the author already in 1960. A reactor of such a design, following this suggestion, has been engineered and manufactured by Ariosto Rolle, Padova, Italy, in 1968 and 1969 for Plastifay Kimya Endüstrisi A.S., Istanbul, Turkey, the production capacity of this reactor being approximately 7000 t/yr. This reactor uses the Joklik-Catalyst. Fig. 10 shows this reactor and in Fig. 11 is illustrated the transport of this reactor.

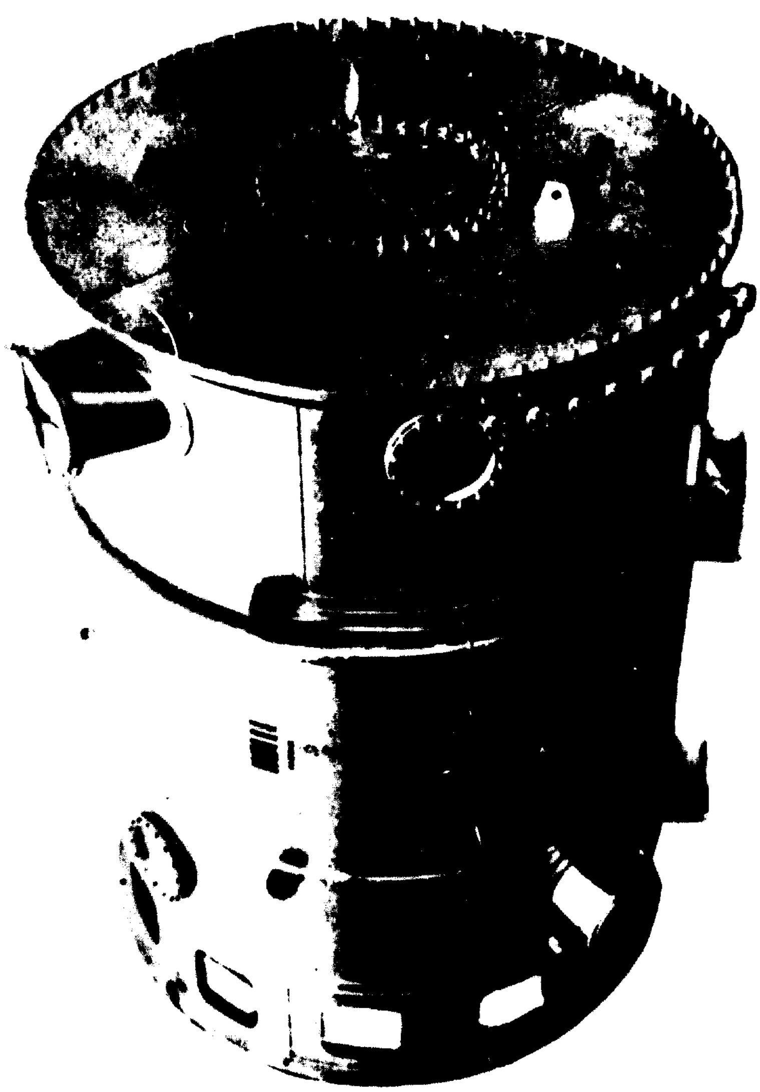


Fig. 10 The Rolle-Reactor, 7000 t/yr.

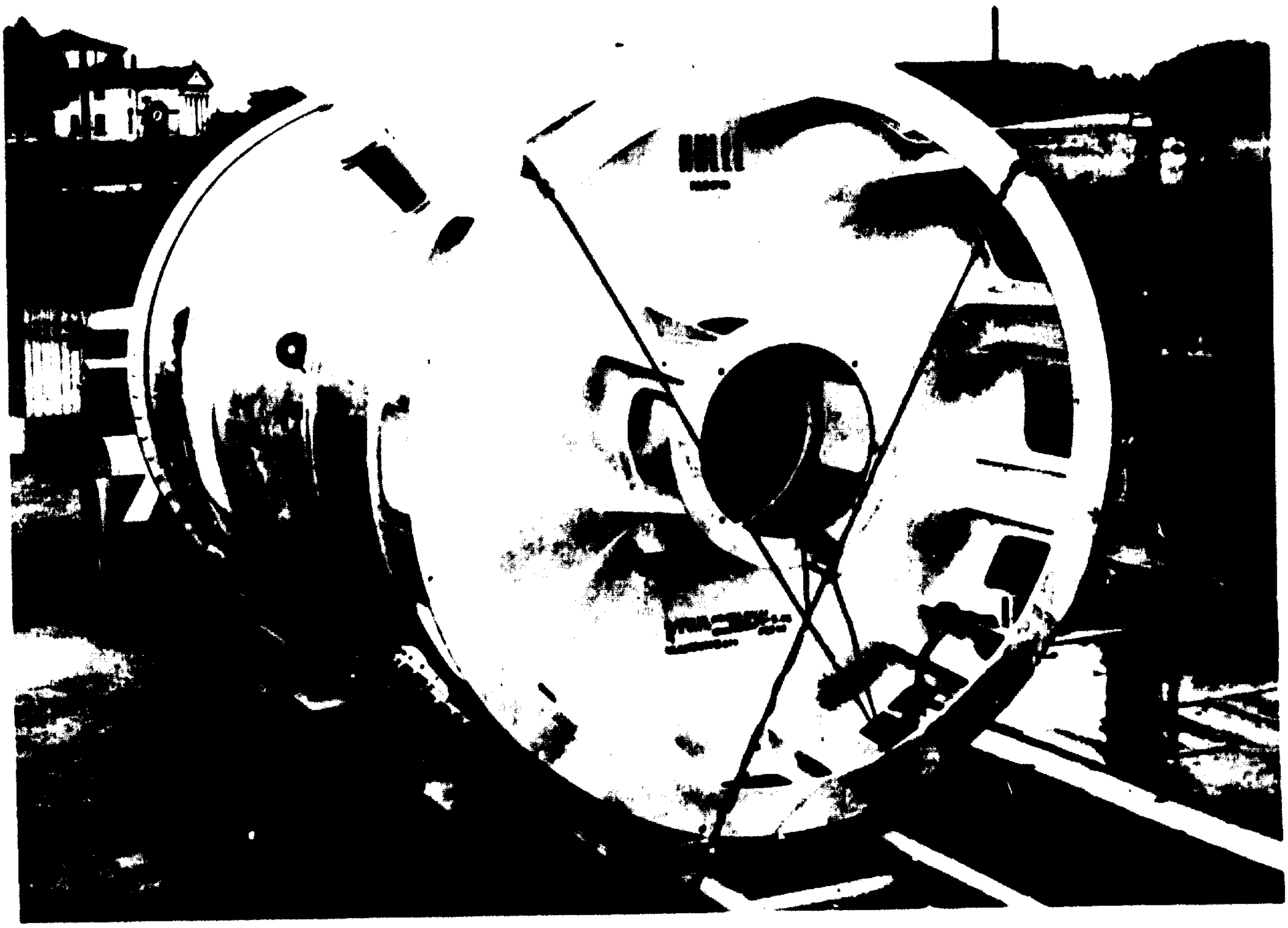


Fig. 11 Transport of the Rolle-Reactor, 7000 t/yr.

The Rolle-Reactor, designed for the Joklik-Catalyst.

Contact tubes, number	7497	
I.D.	25	mm
O.D.	30	mm
length	2110	mm
Diameter of the reactor	3950	mm
Height of the reactor	5626	mm

Weight of the reactor	48850	kg
Volume of the catalyst	4000	liters
Weight of the catalyst	7500	kg
Weight of the salt bath	25000	kg
Total weight of the reactor (operating)	81350	kg
Production capacity of the reactor	7000	t/yr
Design temperature	450	C
Reaction temperature	450	C
Salt bath temperature	420	C

III. Oxidation Reactor Design Incorporating Radiation Technology.

1. The Joklik-Reactor

An advanced oxidation reactor design has been engineered by the author for a process utilizing high energy gamma radiation from a cobalt 60 gamma source for the catalytic conversion of crude naphthalene and/or o-xylene to phthalic anhydride or for the conversion of benzene to maleic anhydride. (O.F. Joklik: Process and apparatus for the production of phthalic anhydride, Austrian patent 258 892, 1967).
This reactor is described in Fig. 12.

The Joklik-Reactor

1 – Reactor wall
2 – Lower tube plate
3 – Upper tube plate
4 – Contact tubes
5 – Lower reactor cover
6 – Upper reactor cover
7 – Support of the lower tube plate
8 – Support of the lower tube plate
9 – Support of the lower tube plate
10 – Expansion element
11 – Gas inlet
12 – Turbulence device at the gas entrance
13 – Distributor for the gas stream
14 – Gas exit
15 – Contact tube closing device
16 – Gamma radiation source
17 – Gamma radiation shielding

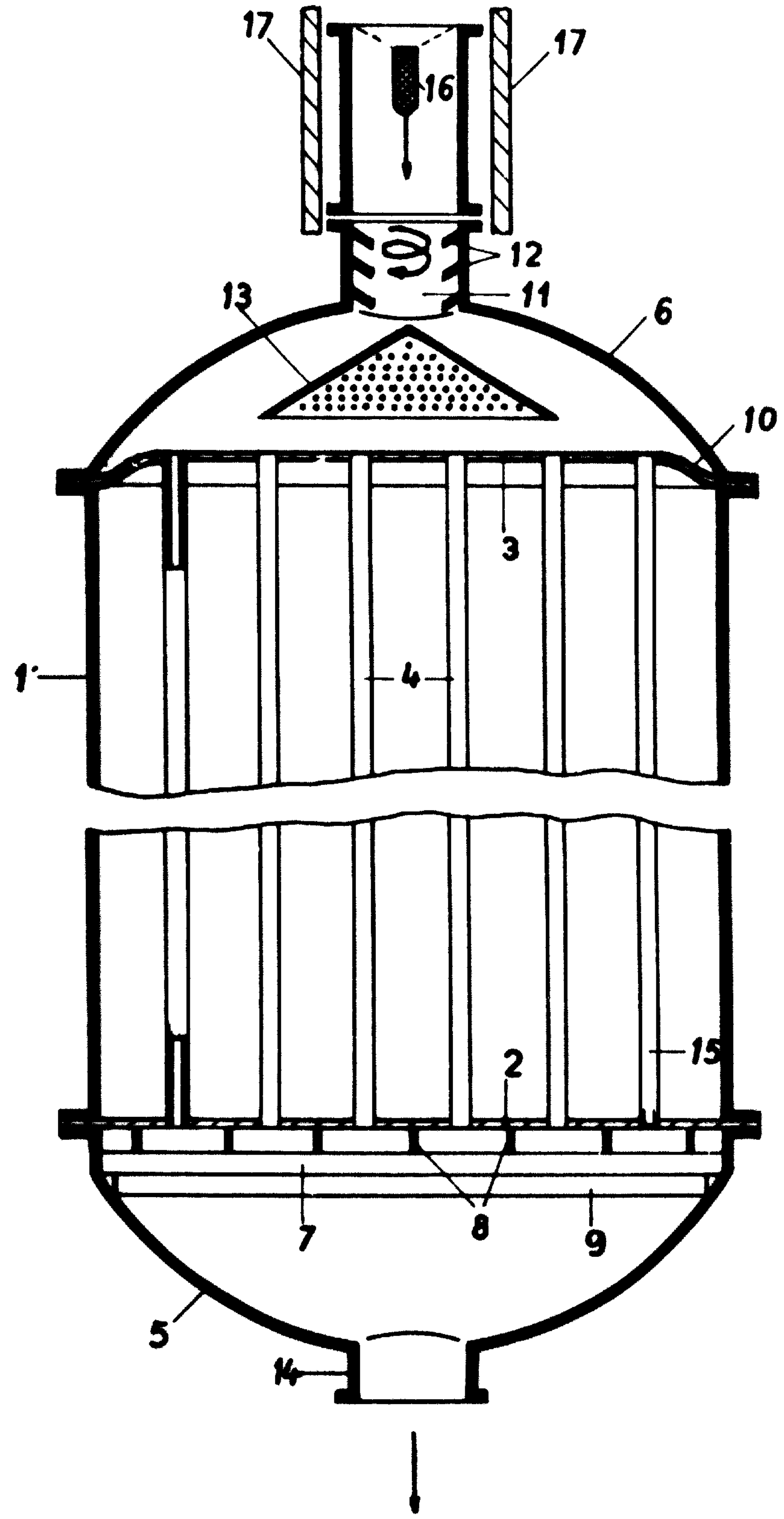


Fig. 12 The Joklik-Reactor

IV. New Developments in Reactor Technology.

Reactors with lateral salt bath cooler

1. The Rolle/Joklik-Reactor

The reactors with a central salt bath agitator with an incorporated steam generator have the disadvantage that a considerable number of contact tubes is occupied and replaced by the agitator and steam generator. Owing to the rather complicated design of such reactors, their cost is quite elevated. A further disadvantage is, especially when using catalysts on carriers of a weak mechanical resistance, that the vibration provenant from the agitator and transferred to the whole reactor, causes an undesired effect of increased catalyst erosion and settling with consequent partial or total obturation of the contact tubes.

These considerations induced the author already in 1960 to suggest a new design of a catalytic oxidation reactor, in which the central molten salts agitator and steam generator has been removed from the central zone of the reactor and placed outside, i.e. laterally from the the reactor itself. The first reactor of this new design has been engineered in Italy in 1964 and manufactured in 1965 by Ariosto Rolle, Padova, for Carbochimital SpA, Padova, where it is in continous operation since 1966. The production capacity of this reactor is 3000 t/yr.

Fig. 13 shows this type of reactor, in Fig. 14 are shown two salt bath circulators and steam generators of the new lateral design. Further reactors of this design followed in the years 1968—1969 for the 12.000 t/yr phthalic anhydride plant of Vulcan Material Plastico S.A., Sao Paulo, Brasil (a subsidiary of the W.R. Grace & Co., New York). Fig. 15 shows the 3000 t/yr oxidation reactor of Carbochimital SpA of Padova, Italy and Fig. 16 shows the 3000 t/yr oxidation reactor in the Vulcan Material Plastico S.A. plant in Mogi das Cruzes, Sao Paulo, Brasil.
A similar reactor has been supplied to Carboquimica, Bogota, Colombia (then a subsidiary of W.R. Grace & Co., New York). All these reactors use the polyvalent Joklik-Catalyst.

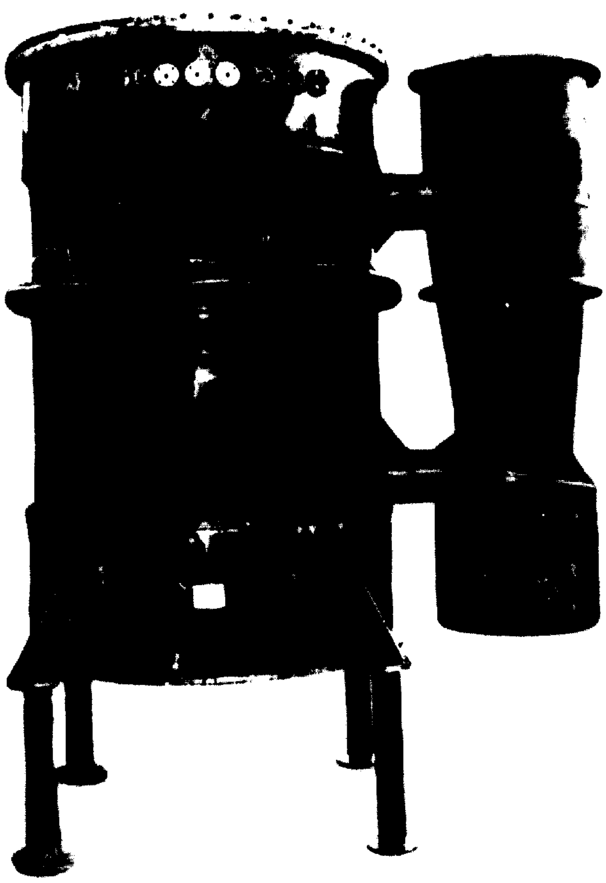


Fig. 13 The Rolle/Joklik-Reactor with lateral salts circulator.

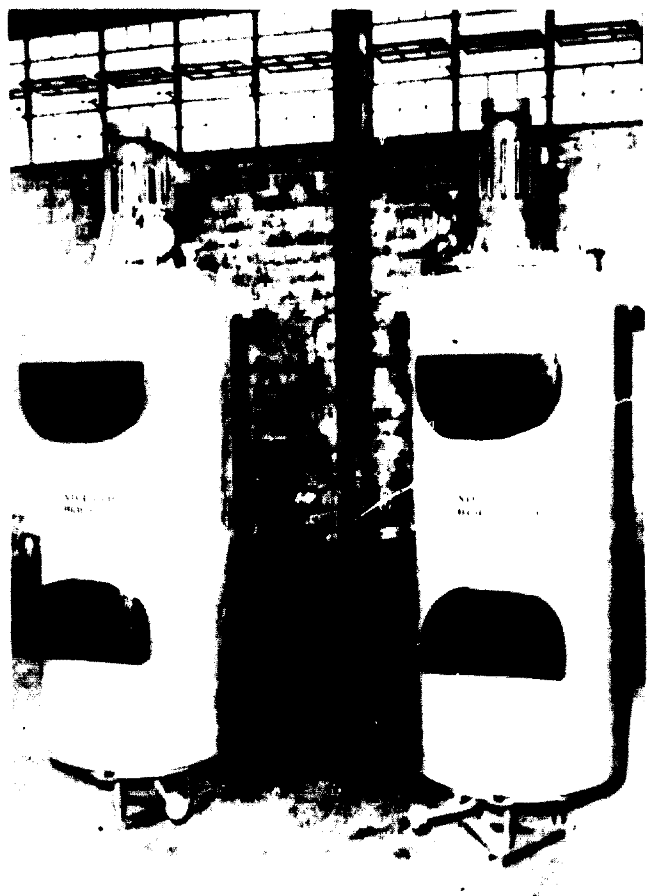


Fig. 14 Lateral salts circulators for the Rolle/Joklik-Reactors.

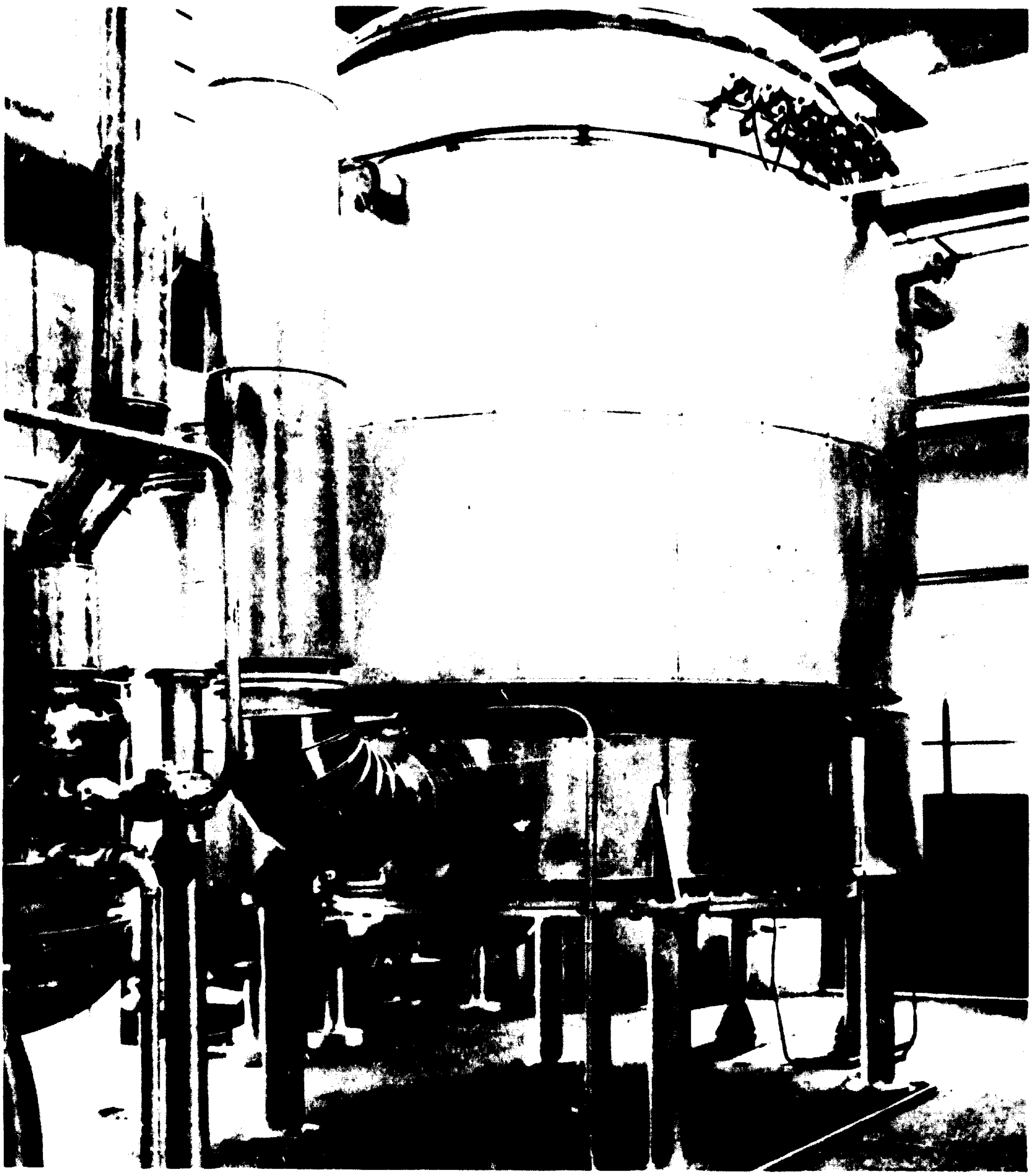


Fig. 15 The Rolle/Joklik-Reactor in the
Carbochimital phthalic anhydride plant.

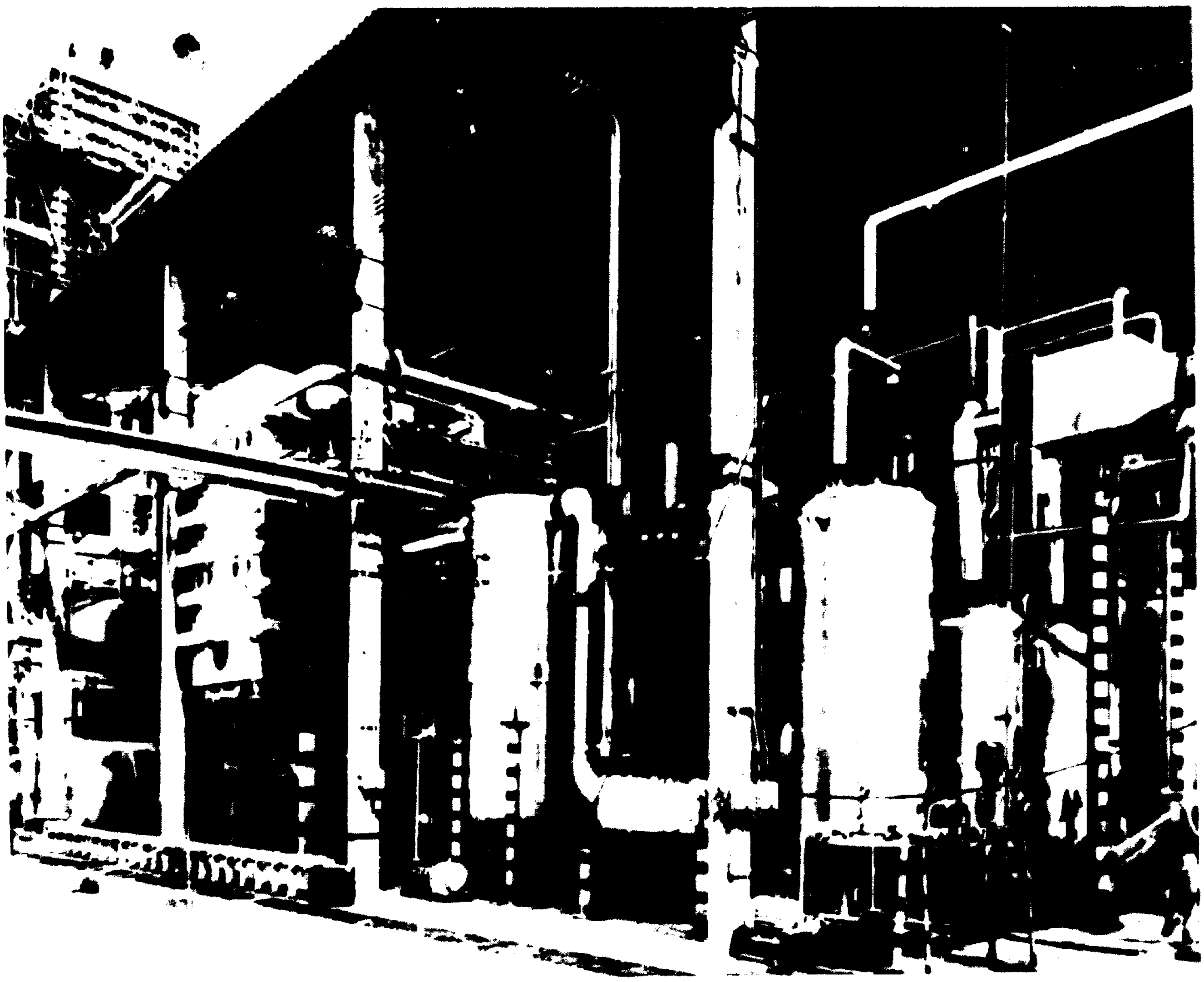


Fig. 16 The Rolle/Joklik-Reactor in the Vulcan Material Plastico phthalic anhydride plant.

2. The new BASF-Reactor

The idea of the lateral salts circulators has been taken up by others later on. So presented p.e. the BASF in 1968 a new type of an oxidation reactor which is since that time in use in many plants using the BASF processes. The new BASF-Reactor is manufactured by the Deggendorfer Werft und Eisenbau DWE, Deggendorf, Germany. (Viz. Ellwood P., „New Life for Fixed-Bed Phthalic Anhydride Route", Chem. Eng., June 1969, p. 80 etc.).

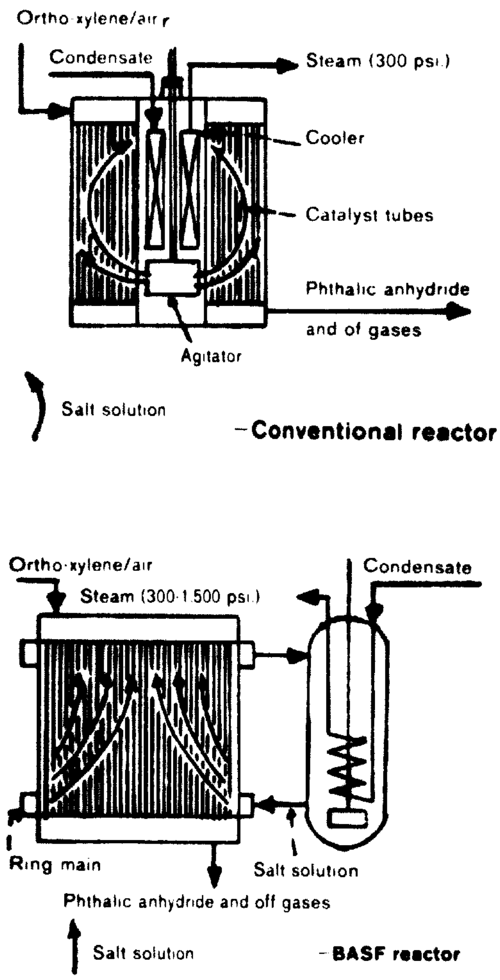


Fig. 17 Comparison of a conventional and the new BASF-Reactor.

Fig. 17 demonstrates the comparison of a conventional (central agitator) and a new BASF-Reactor with a lateral agitator and steam generator. Fig. 18 shows a model of such a reactor.

The reactor itself is a departure from tradition in the sense that the heat-exchange system is located outside the vessel. This allows the reactor core to pack in additional catalyst tubes, and thus increases reactor throughput.

BASF-Reactor with external cooler, 16.4-ft high x 13.8 ft. dia, contains nearly 10.000 contact tubes. Its capacity is 15.840 t/yr. In the BASF design the molten salts, previously cooled in the external heat exchanger, enter the reactor through several wall ports simultaneously fed from a circumferential wall ring. This provides better cooling near the walls, as well as more uniform heat transfer throughout the reactor. Manufacturer: Deggendorfer Werft und Eisenbau DWE, Deggendorf, Germany.

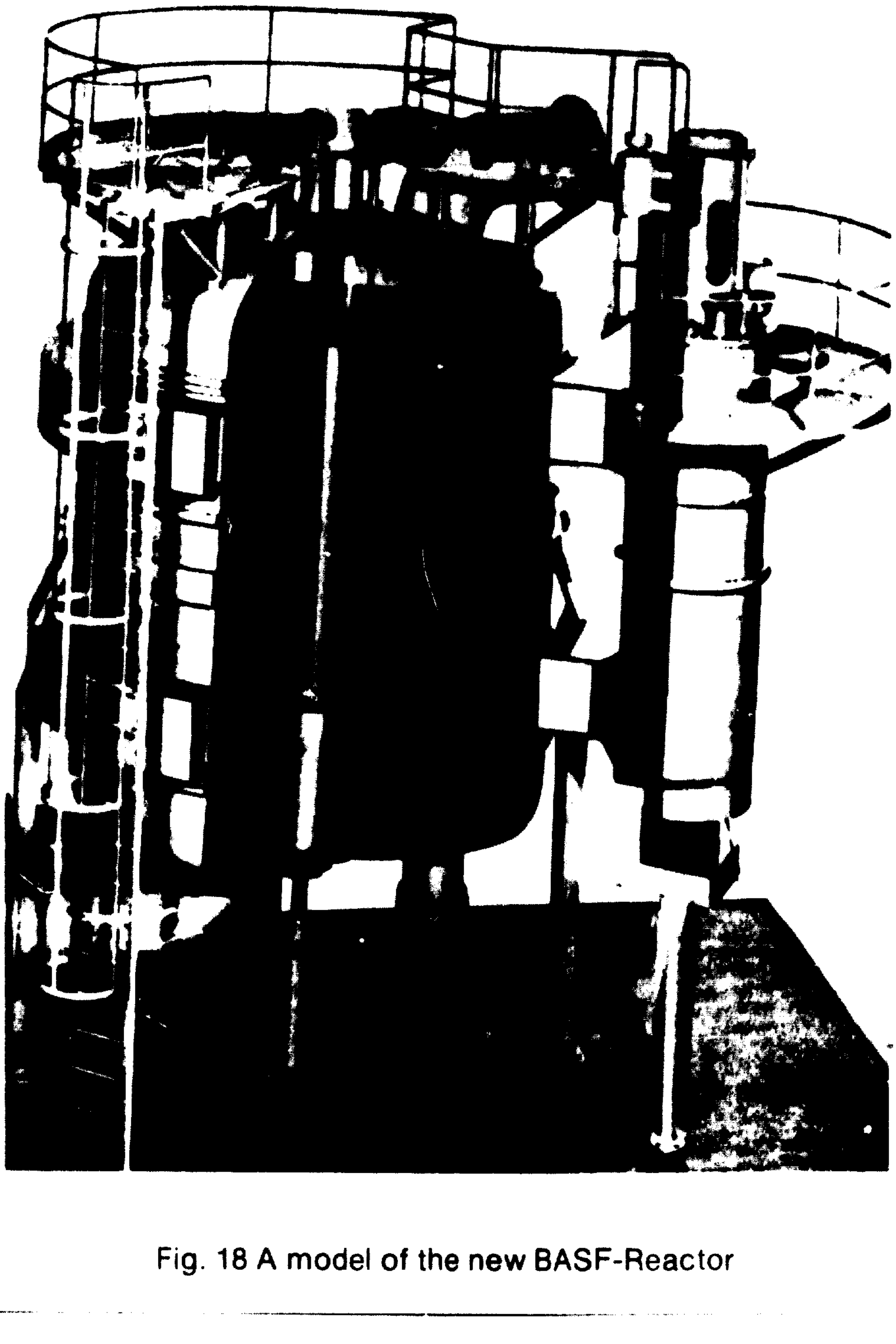


Fig. 18 A model of the new BASF-Reactor

V. Advanced Reactor Technology.

1. The Rheinstahl/Joklik Reactor.

The result of intensive mechanistic studies, the design and engineering experience of some twenty years and the manufacturing skills of a major manufacturer of chemical apparatusses are incorporated in the advanced design of the Rheinstahl/Joklik Reactor, which represents the latest development in this particular field. A simplified, but yet very robust construction increases the reactor life and minimizes its weight and cost. The salt bath circulator and the steam generator have been entirely removed from the reactor core, thus leaving additional space for more contact tubes and thus increasing the capacity of the reactor. The salt bath circulator and the steam generator form an independent unit together with the salts storage container and the salt bath circulating pump. The reactor itself becomes thus very easily accessible and the assembly of the whole oxidation unit is very simple and easy. The salt bath is circulating radially to the contact tubes in an ideal stream and at a high velocity, thus ensuring an optimized heat removal of the excess oxidation heat resulting from the highly exothermic reaction. In Fig. 19 is shown this new type of reactor, suitable for a wide variety of high-temperature gas-phase heterogeneous catalytic reactions over fixed-bed catalysts, as p.e. the conversion of naphthalene and/or o-xylene to phthalic anhydride and the conversion of benzene to maleic anhydride.
In processes requiring a longer contact time and consequently longer contact tubes as 3000 mm, the reactor can be supplied in two separated sections with separate salt bath cooling circuits, so that an overall length of the contact tubes up to some 6000 mm can be assured. The two separately delivered and separately transported reactor parts are assembled on the site of erection of the plant.
Fig. 19b shows such a type of reactor.
The Rheinstahl/Joklik Reactor is designed and engineered in two versions. The one is applicable to reactors up to some 9000 contact tubes, the other one to reactors up to 11000 contact tubes and more. A reactor with p.e. 11000 contact tubes would be suitable for a production capacity of approximately 16000 tons of phthalic anhydride per year. The large size reactors are designed in such a way that a road transport even for the biggest sized reactors becomes feasible. (Viz. Benton A., „Selection of Projects and Production Processes for Basic and Intermediate Petrochemicals in Developing Countries", UNIDO Petrochemical Industry Series Monograph No. 2, p. 24, 1969).
A new fast clamp-spring lock has been developed for the support of the catalyst in the contact tubes, thus ensuring a safe and yet easy and uncomplicated containment of the catalyst in the contact tubes. To abbreviate the rather long times required up to now for the filling of the catalyst into the contact tubes, a new automatic device has been designed, which ensures a most uniform distribution of the catalyst in the contact tubes in a fraction of time only hitherto required for this task.
Finally, especially for large reactors of a considerable weight, the reactor can be placed upon a special carriage support on wheels and rails which are a part of the whole oxidation group, to ensure an easy movement or displacing of the reactor for eventual maintainance etc. without the necessity of employing heavy cranes or other similar equipment.

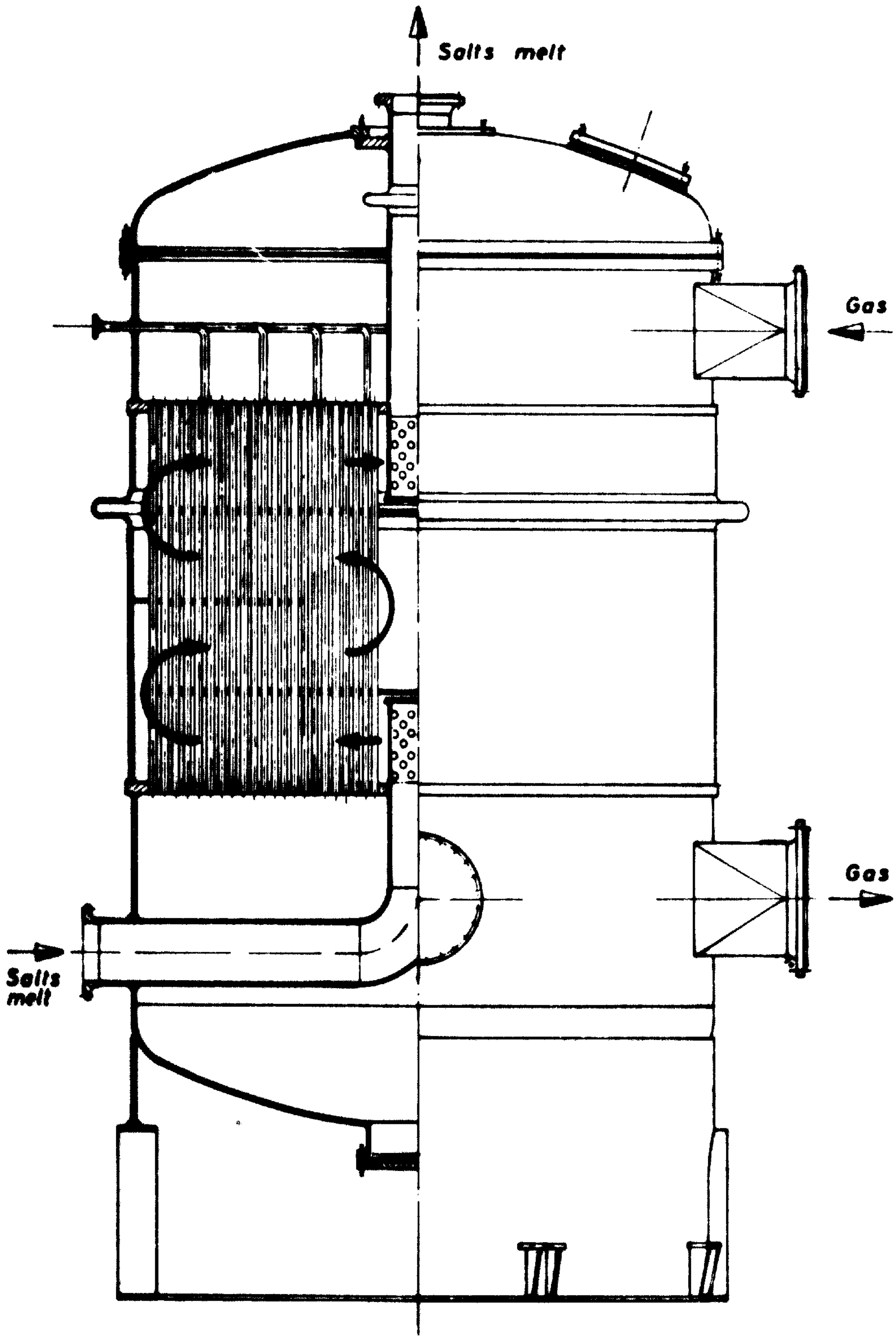


Fig. 19 The Rheinstahl/Joklik Reactor
for productions up to 13000 t/yr.

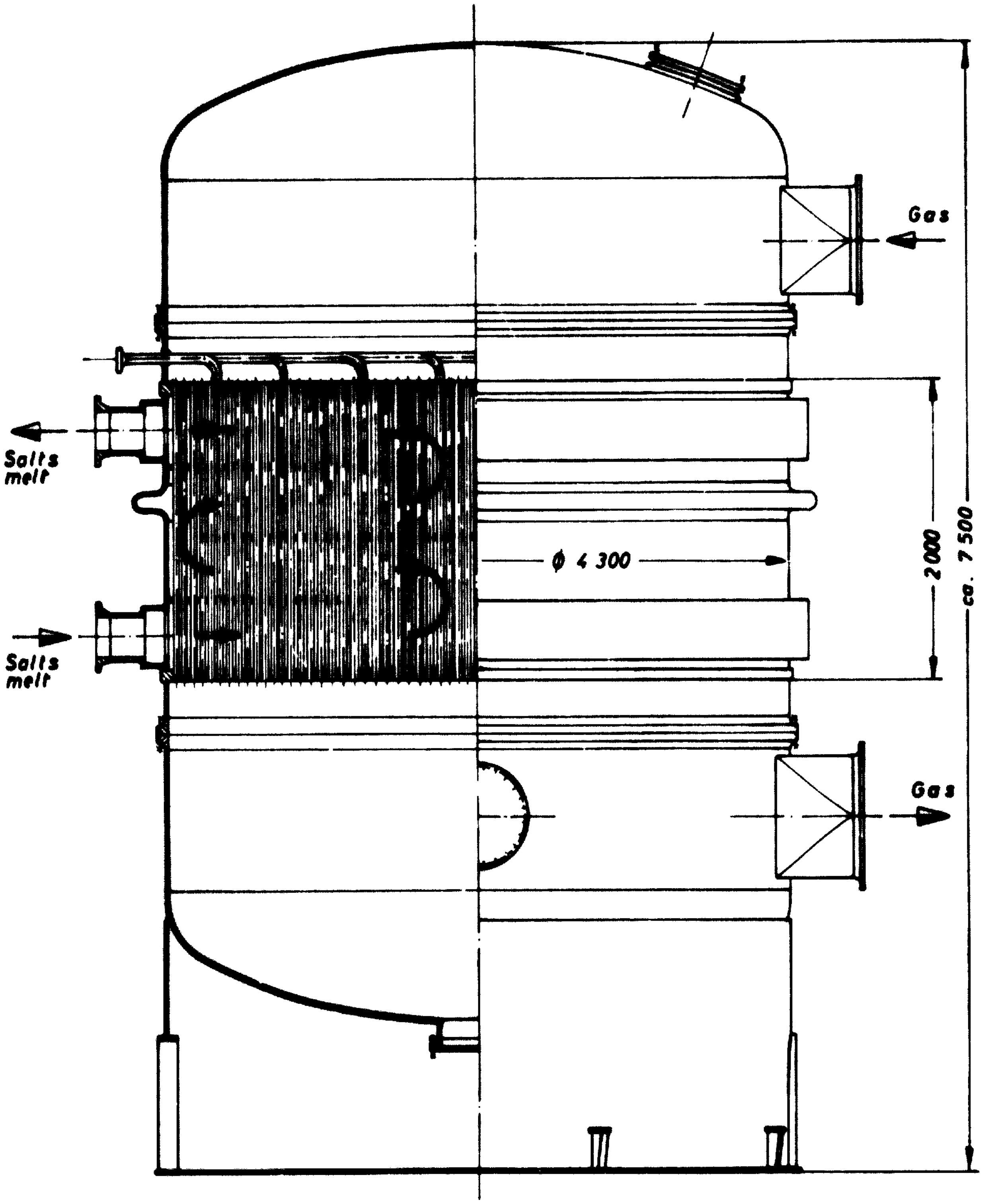


Fig. 19a The Rheinstahl/Joklik Reactor
for productions up to 16000 t/yr.

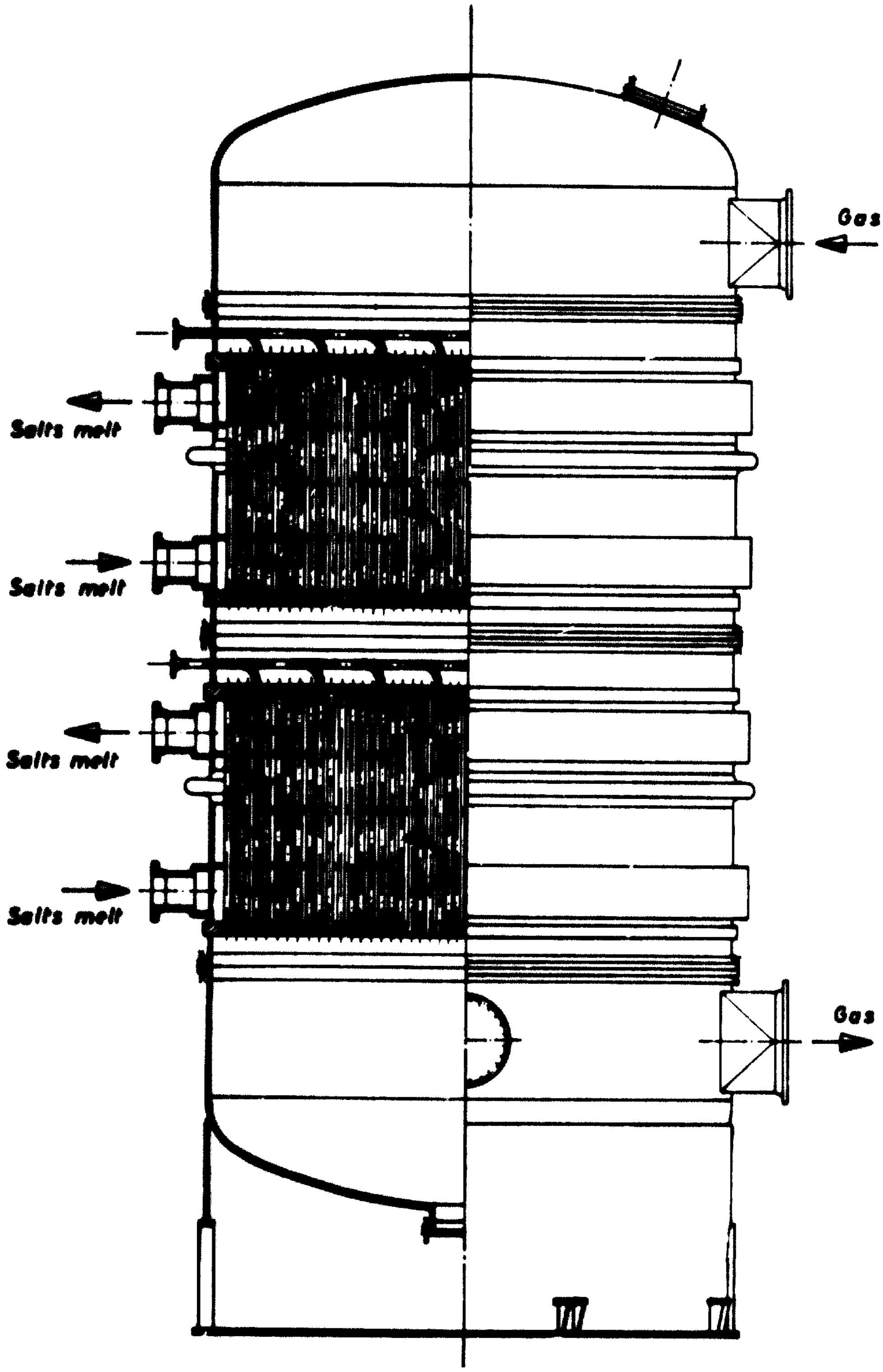


Fig. 19b A two-stage Rheinstahl/Joklik Reactor.

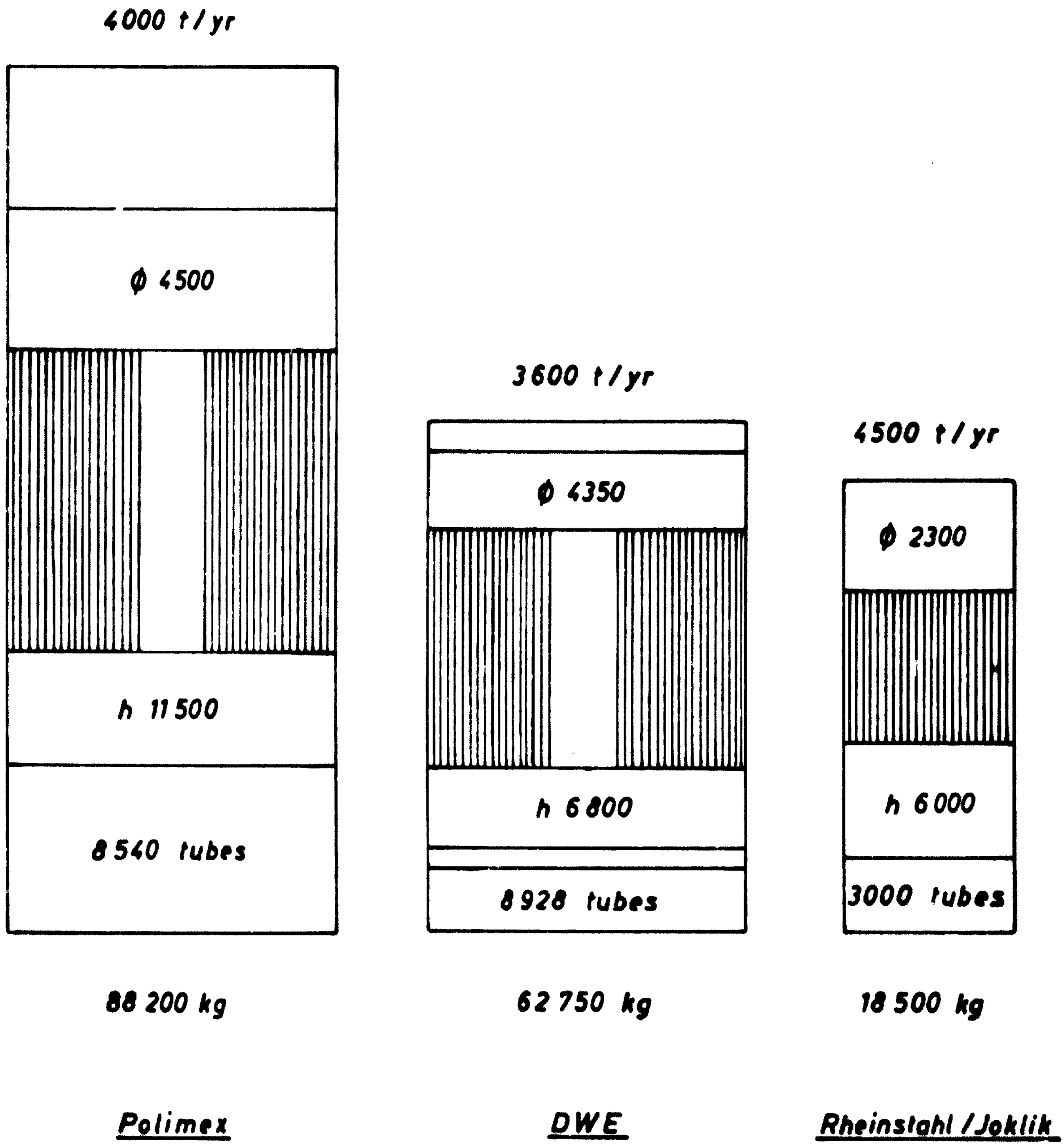


Fig. 20 Comparison of reactor sizes and weights for a production capacity of 3600 to 400 t/yr of phthalic anhydride.

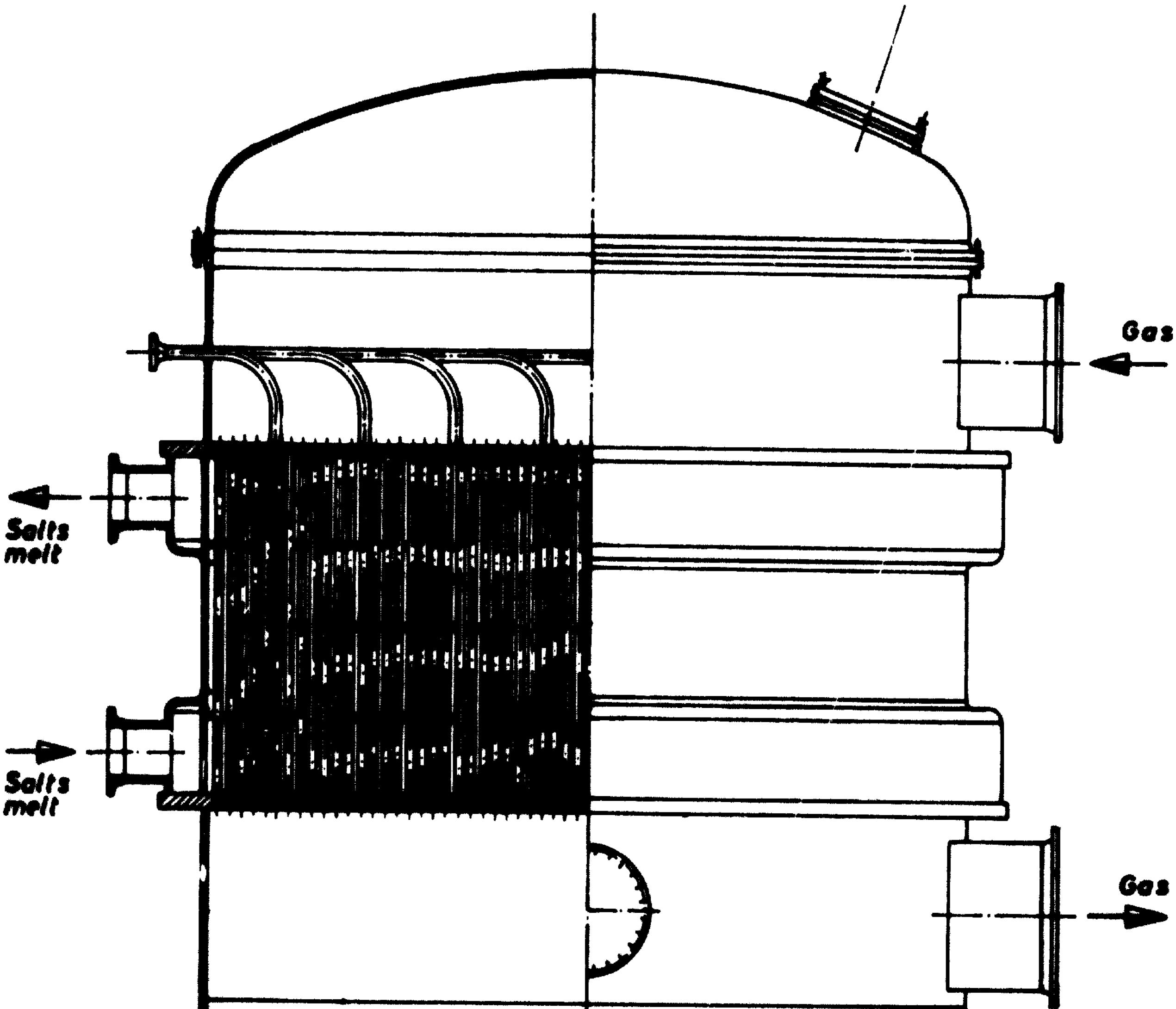


Fig. 21 The Rheinstahl/Joklik Reactor
for production of MSA

2. The oxidation group.

The oxidation group forms a complete unit consisting of the reactor itself, the salts storage and melting container, the salt bath circulator, the steam generator, the gas cooler/heat exchanger and the steam drum.

In Fig. 22 is shown a typical schematic diagram of the oxidation group. Fig. 23 gives more details of the assembly of the oxidation group.
The same principle can be applied to phthalic anhydride and maleic anhydride plants.

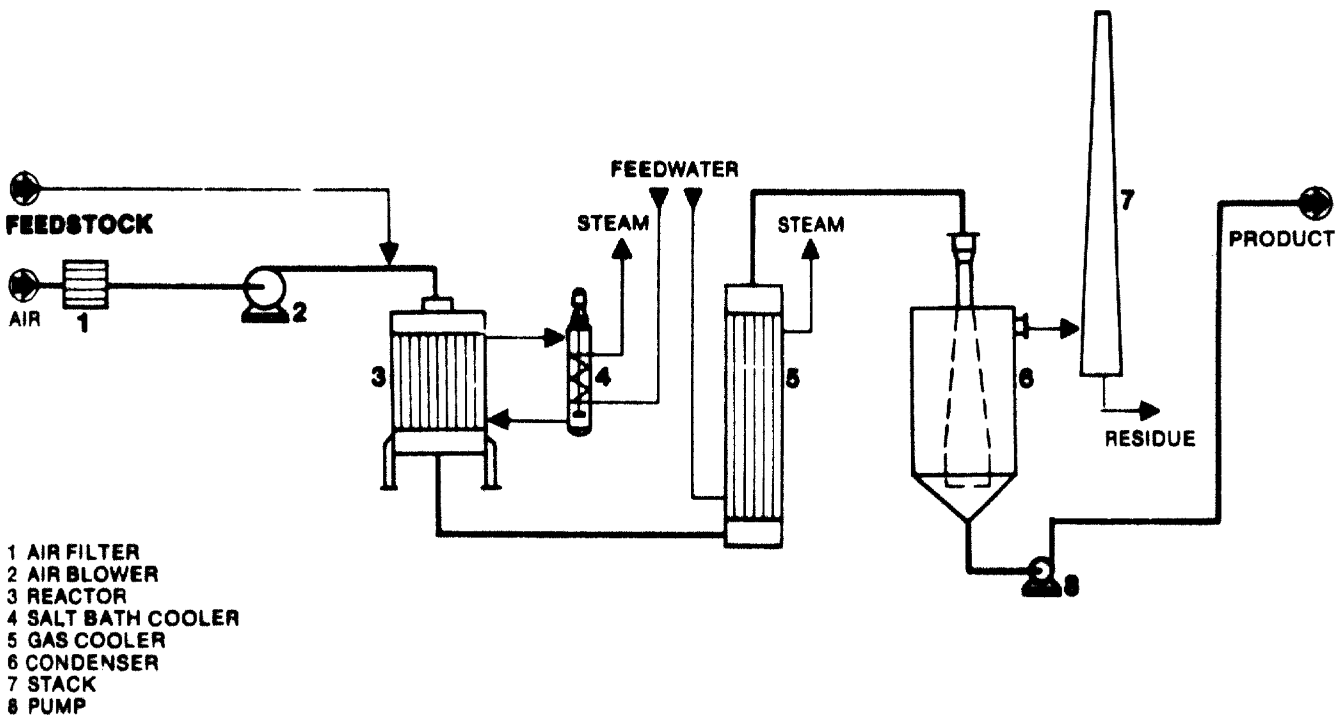


Fig. 22 Simplified schematic diagram of the oxidizing section and the oxidation group of a phthalic anhydride plant.

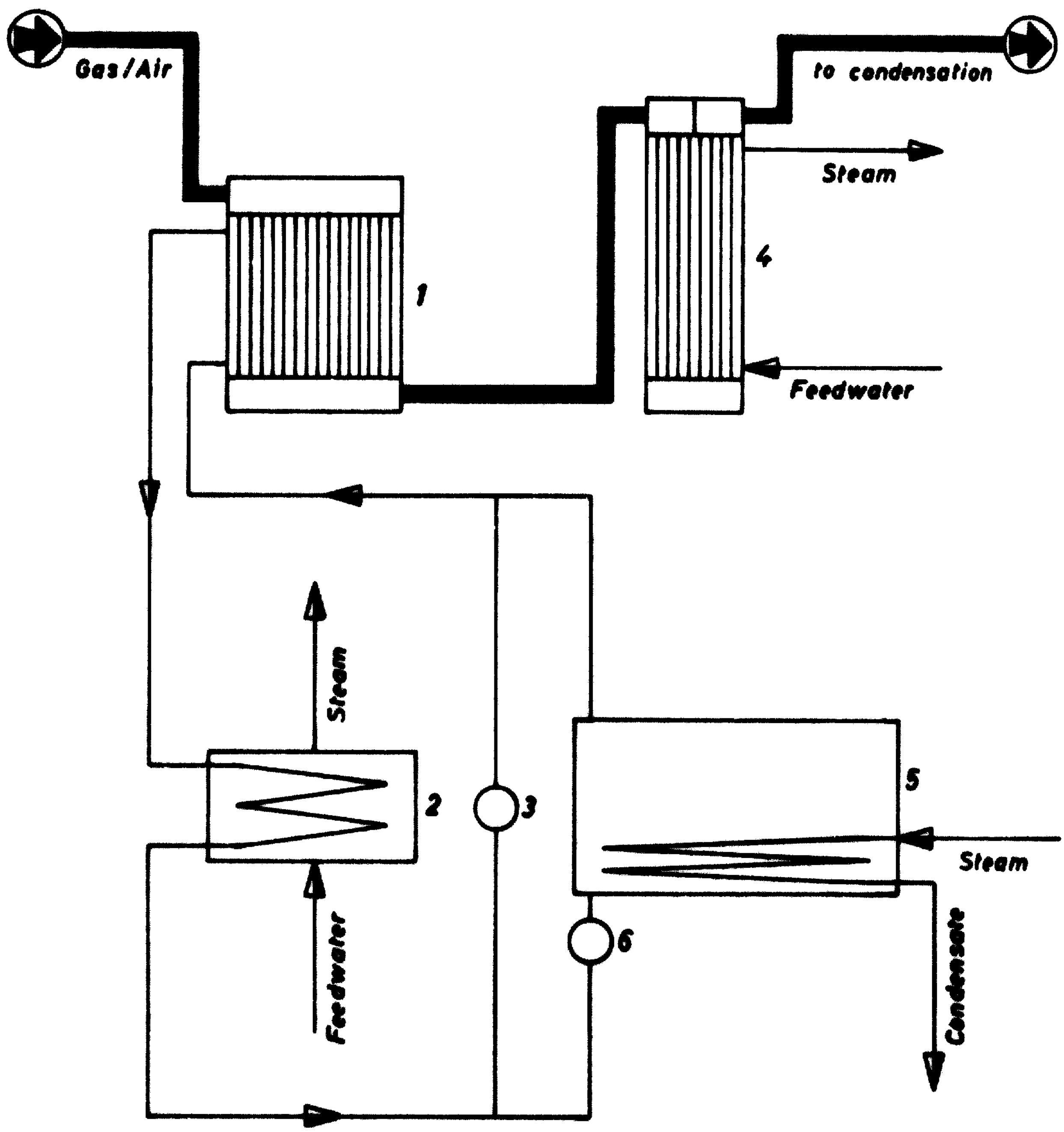


Fig. 23 The oxidation group – detailed schematic diagram.

3. The control of the reactor.

An advanced reactor technology is incomplete without an efficient control of the reactor and of the reaction. Conventional processes use the variation of the salt bath temperature as a means to control the reaction temperature. This method is somewhat inconsequent insofar as by this procedure are influenced the symptoms only and not real reasons for the variations of the reaction temperature. It is more appropriate to control the reaction temperature by a variation of the feedstock concentration in the air stream prior to the entrance of the mixture air – feedstock into the reactor. When the reaction temperature surpasses a preset maximum value, then the concentration of the feedstock in the air is automatically reduced and vice versa. This is the most efficient and most simple way to control the reaction and the reactor. Another automatic control ensures that the ratio air: feedstock remains even under varying concentrations of the feedstock constant, to avoid explosive mixtures. The same principle of automatic control can be applied to every start-up or running-in operation and thus the full production capacity of the plant can be achieved in a shorter period of time as usual. By an advanced electronic level control of the feedstock intermediary storage vessel there can be ensured a much more precise dosage of the feedstock. This newly developed electronic control system enables a fully automatic control of the reaction and of the reactor as well as a reliable control of the production itself by comparing by this digital system the exact quantity of the feedstock with the precision measured quantity of the liquid crude technical product coming out of the switch condensers. By this system a maximum of process and production optimizing can be achieved. This process control computer of advanced design ensures an optimal production of the plant even under rough and adverse operating conditions and when using off-specification feedstocks. Fluctuations of the tension at the mains are compensated and overcome by this system, too and thus a maximum reliability and operating safety can be achieved.

Fig. 24 and 25 shows the control system of the reactor and of the reaction, designed by the author. The process control equipment is manufactured and engineered by Ingenieurbüro Eugen Rapp, Bremen and Rapp GmbH, Germany.

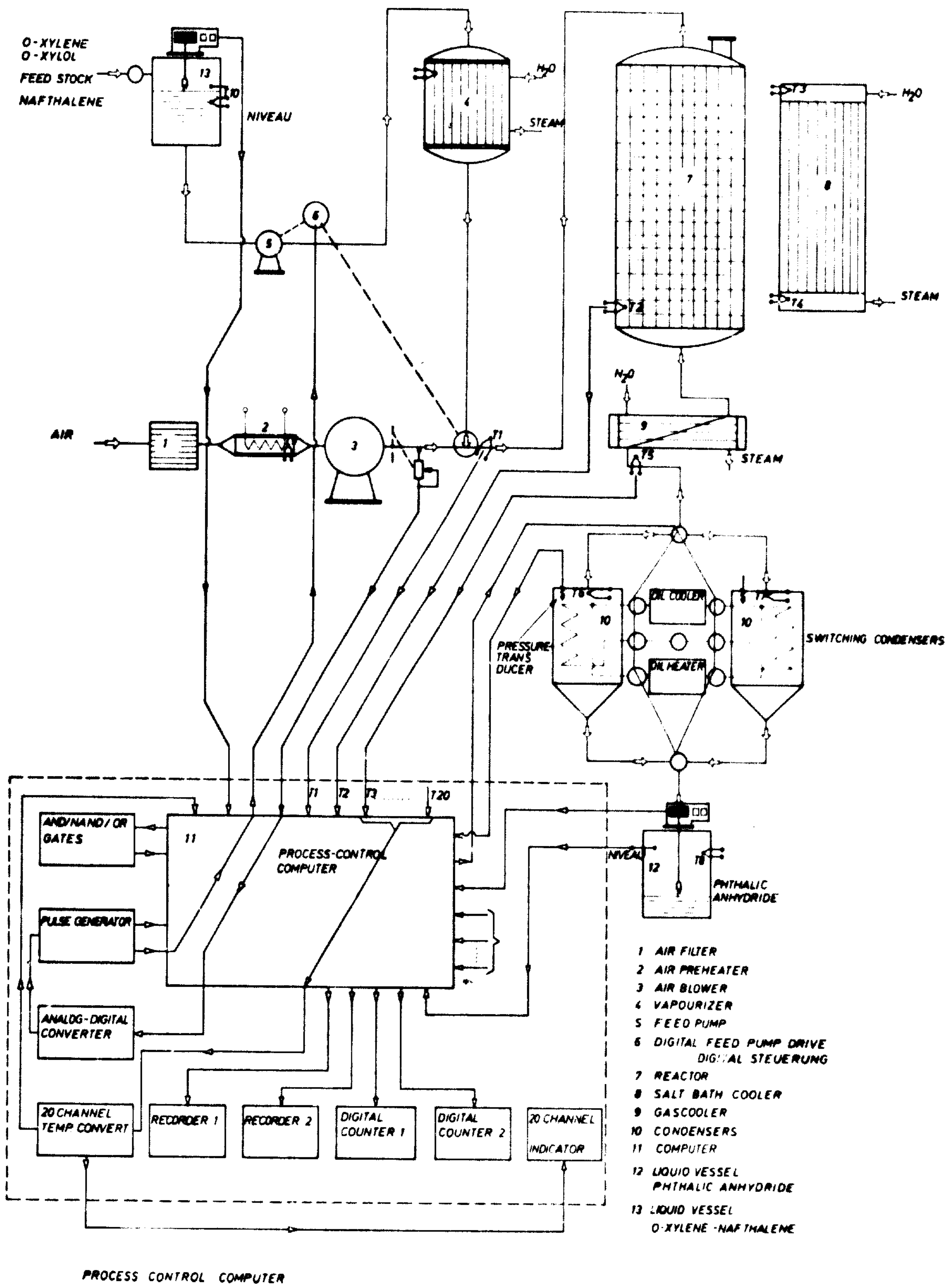


Fig. 24 The schematic diagram of the reactor and reaction control.

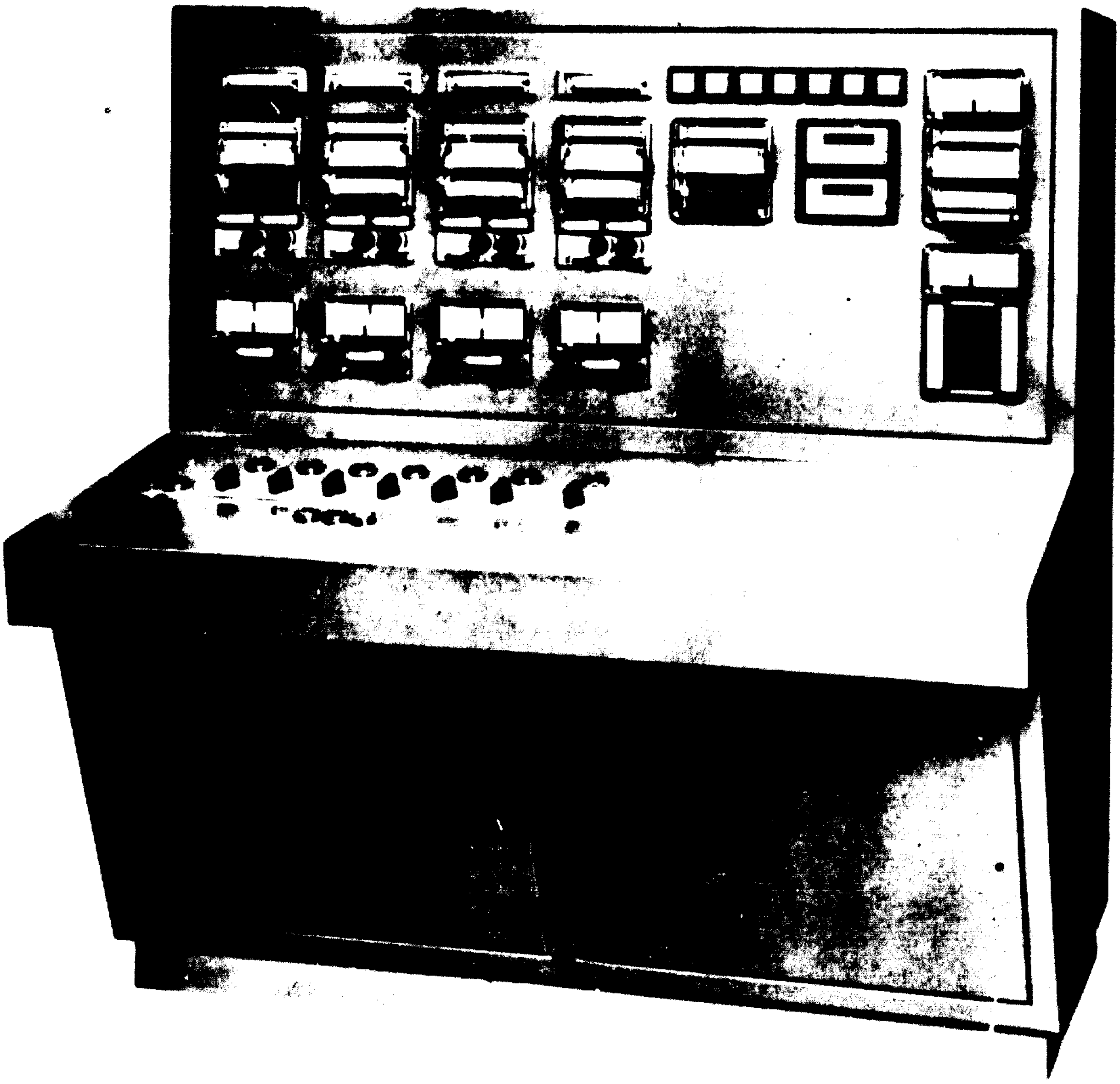


Fig. 24a The Rheinstahl/Joklik Reactor Control desk.

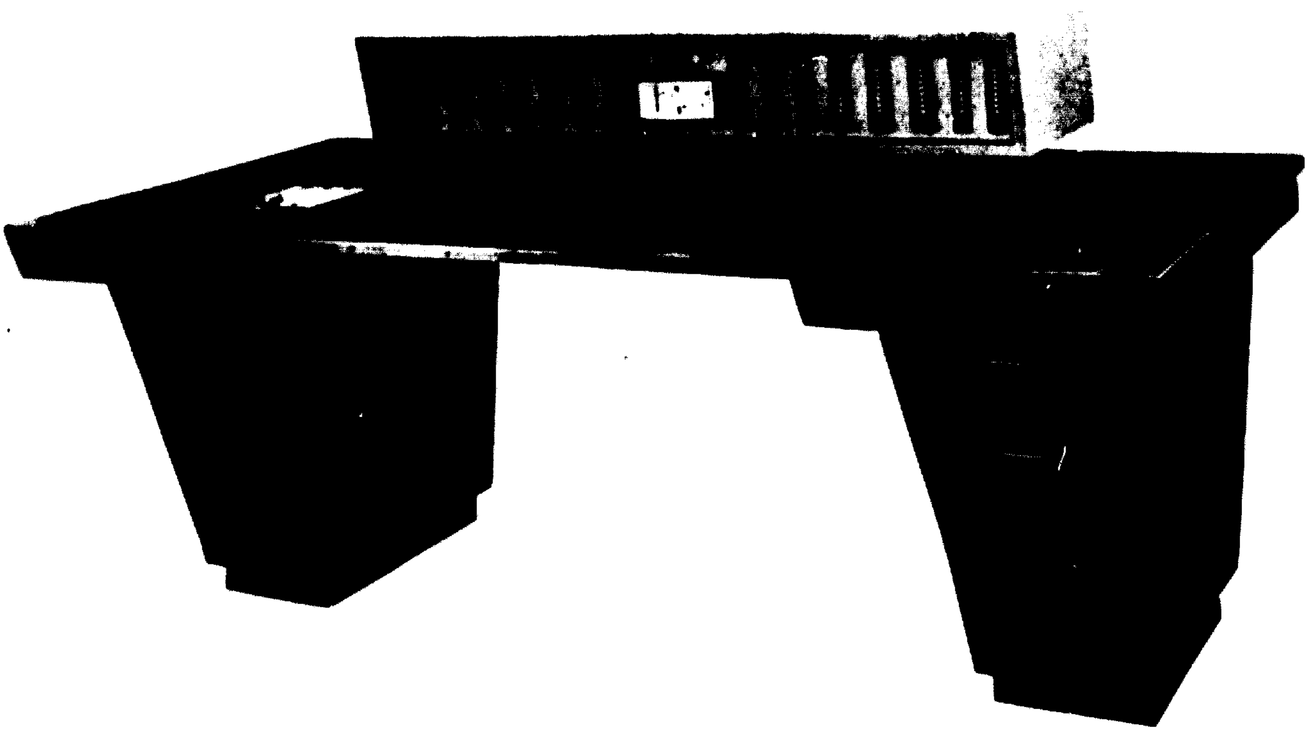


Fig. 24b Reactor control and reaction temperature control computer of the Rheinstahl/Joklik reactor.

VI. Pilot Reactor.

For pilot plant operations there has been developed a particular pilot reactor with a combined multipurpose melter-pre-heater-carburettor and an universal condensation system using flexible multiple cooling-heating tubes made of Teflon.

Fig. 25 illustrates a smaller pilot plant reactor designed by the author for Hibernia AG, Germany and for Reichhold-Chemie AG, Germany. Fig. 26 illustrates another pilot plant reactor designed by the author for the Monsanto Ltd.

In Fig. 27 is shown an advanced multi-purpose pilot plant for high-temperature gas-phase catalytic heterogeneous reactions over fixed-bed catalysts with the prototype of a Rheinstahl/Joklik pilot reactor.

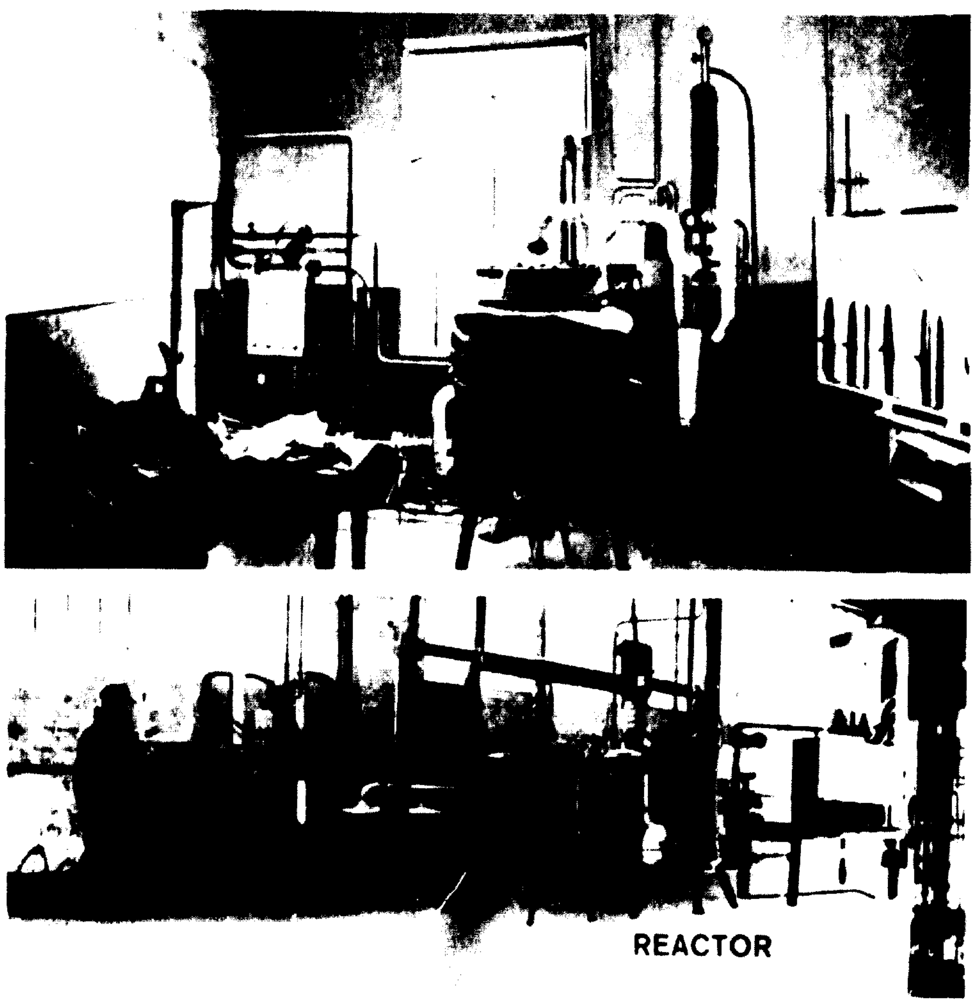


Fig. 25 Pilot plants with pilot reactors.
(Above: Hibernia AG, below: Reichhold Chemie AG and Chemische Fabrik von Heyden).

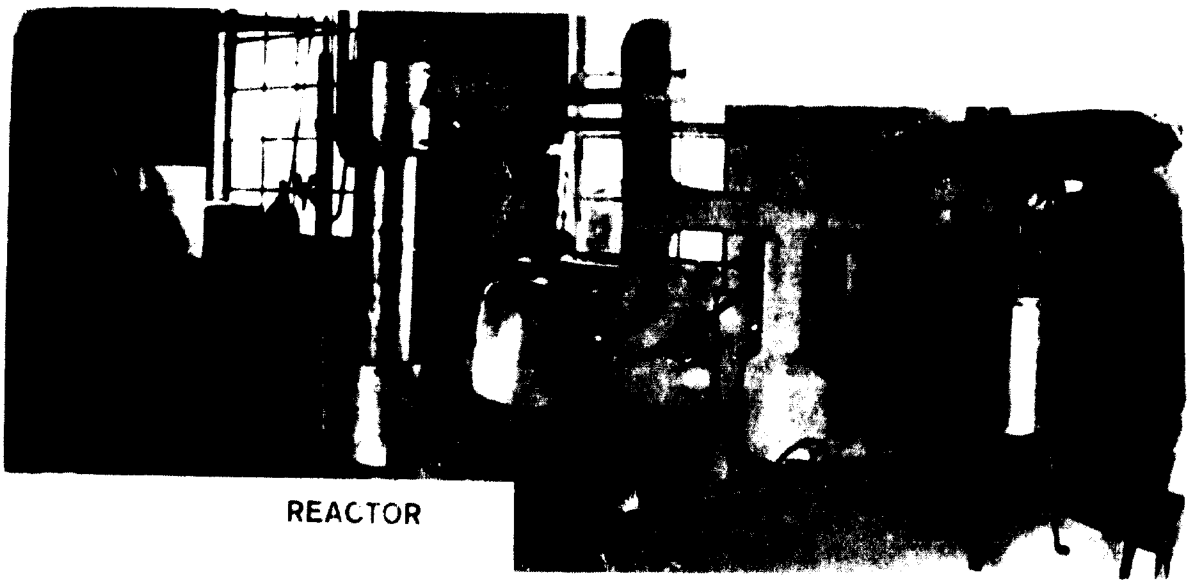


Fig. 26 Pilot plant with pilot reactor (Monsanto Ltd.).

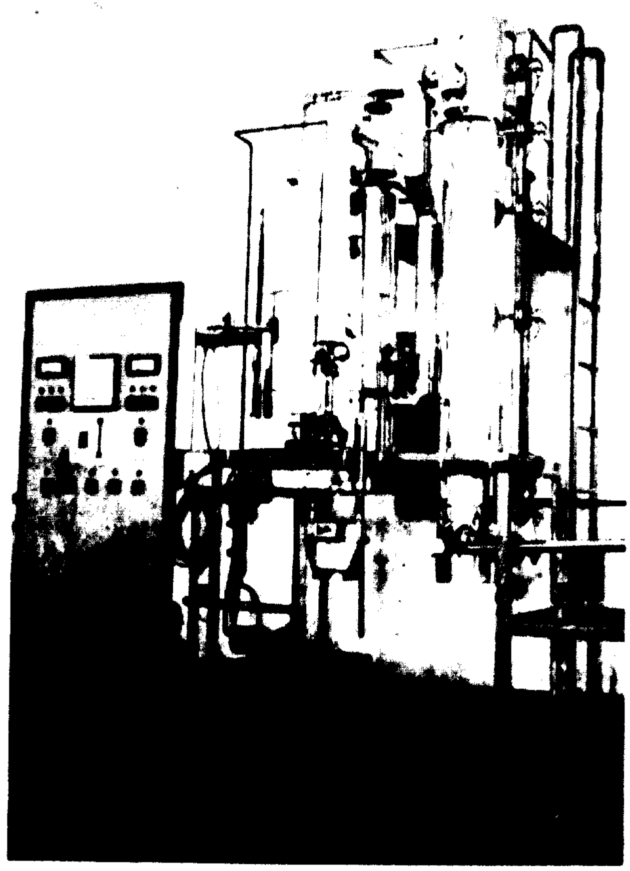


Fig. 27 Multipurpose pilot plant with the prototype of the Rheinstahl Joklik pilot reactor.

VII. Conclusions.

From the survey of developments in reactor technology covering tubular vertical fixed-bed reactors for high-temperature catalytic gas-phase reactions it results that the newly developed Rheinstahl/Joklik Reactor is suitable for a wide variety of catalytic reactions, as p.e. the conversion of naphthalene and/or o-xylene to phthalic anhydride or the conversion of benzene to maleic anhydride etc. This reactor has been particularly designed and engineered to meet all requirements for high-temperature and high space velocity catalytic processes and it represents the ideal environment of an advanced oxidation catalyst. The design of the reactor is equally suitable for plants with a small production capacity of some 50 to 100 tons per month as for large scale industrial plants with production capacities ranging up to some 18.000 tons per year and more per one single unit. This is considerably more than as it is claimed for other oxidation reactors of conventional design, where the maximum production capacity is reported to be15.000 tons per year.

VIII. Recommendations.

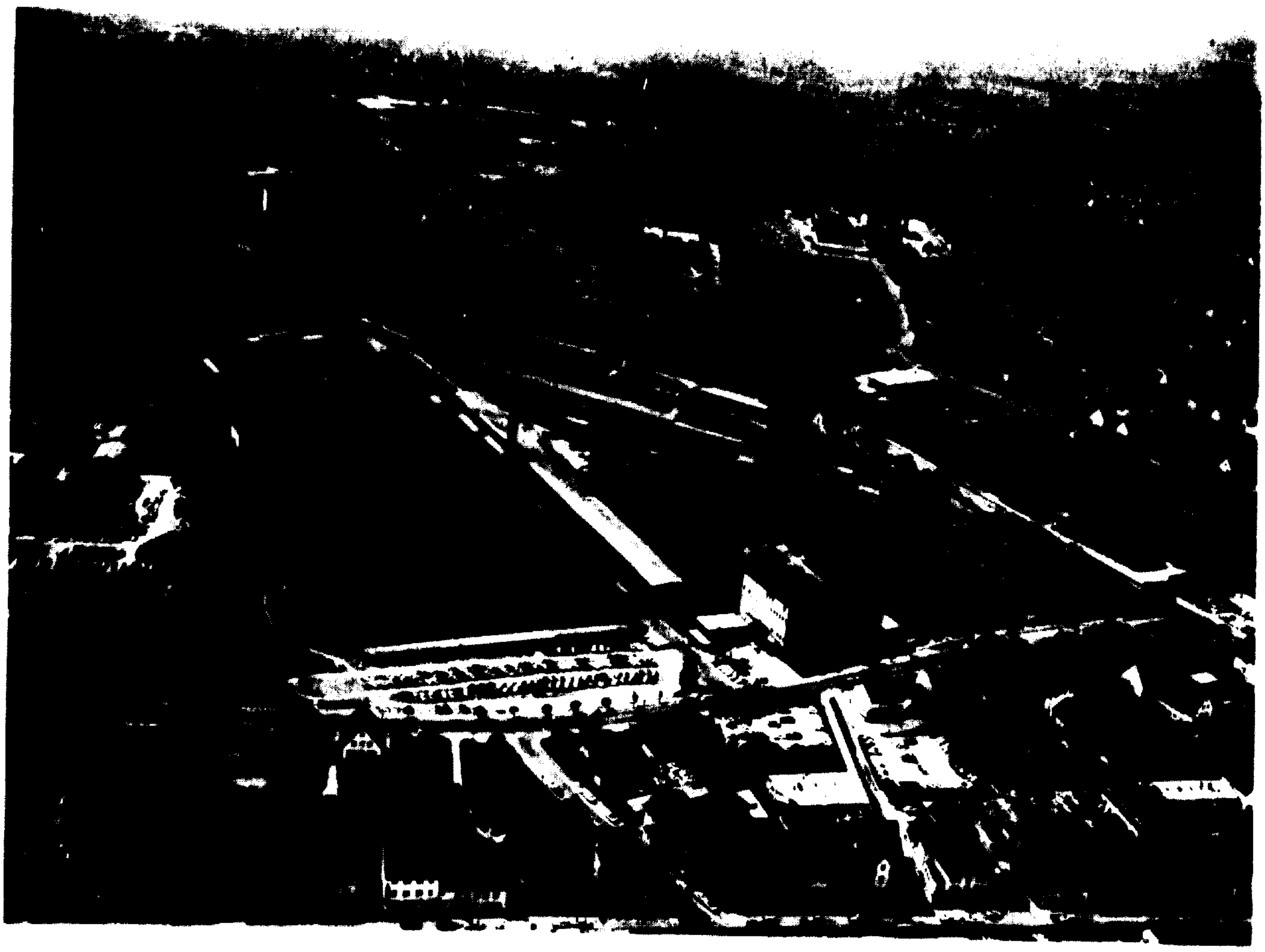
From the presented survey it results that today the problem is not only to find the catalyst – rather the problem is to find the reactor and the conditions to perform the catalytic task efficaciously. The reactor – the catalytic environment – should obtain more attention and increased efforts in reactor design and reactor engineering should meet the advances in the development of catalysts.

UNIDO should therefore – possibly in the near future – organize a meeting of experts to present and to discuss new developments in advanced reactor technology as a complementary meeting to the discussion on transfer of know-how in production and use of catalysts, which would be only a logic continuation of the divulgation of technology and knowledge in this particular field.

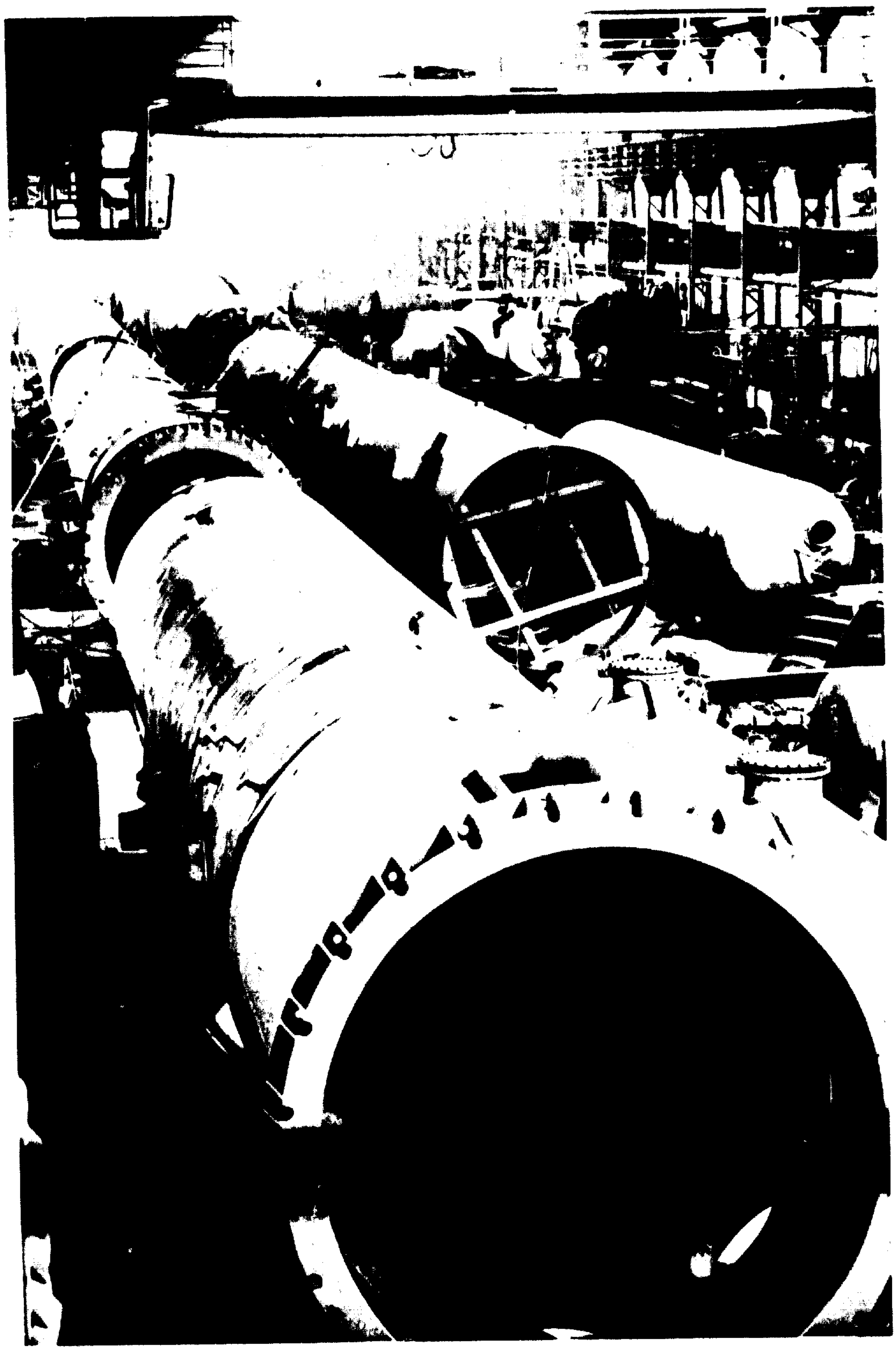
Another meeting should be organized by UNIDO to deal with advanced methods of control equipment suitable for an optimized control of the reactors and the reactions, which is another important feature of this particular field of activities, closely linked together namely the advanced development of catalysts, the reactor and the reaction engineering and the reactor and the reaction control.

UNIDO should finally sponsor the establishment of pilot reactors at various technical centers in development countries to contribute by the divulgation of this advanced reactor design to the increase of the knowledge in the field of reaction and reactor engineering and to promote further developments in catalytic reaction processes, which are particularly necessary for every development country in a wide variety of potential applications during the continuous expansion and industrial development.

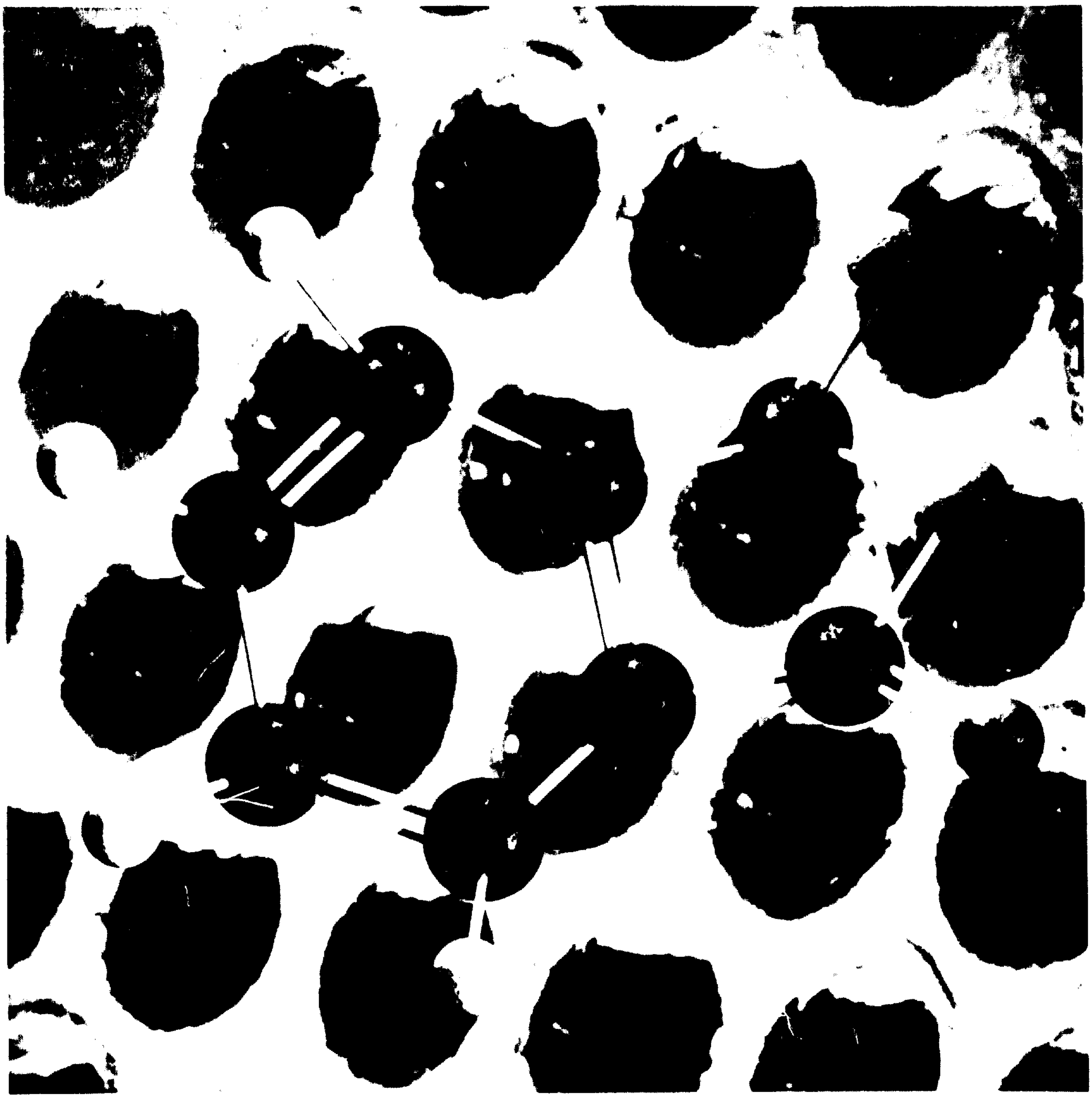
Figures



The Rheinstahl AG works in Brackwede/
Germany, the manufacturing site for the
Rheinstahl/Joklik-Reactors.



Manufacturing premisses for the
Rheinstahl Joklik-Reactors.



The Rheinstahl AG administration
building in Essen/Germany.

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