NASA TECHNICAL MEMORANDUM

NASA TM 75210

WASTE HEAT UTILIZATION IN INDUSTRIAL PROCESSES

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(NASA-TM-75210) WASTE HEAT UTILIZATION IN INDUSTRIAL PROCESSES (National Aeronautics and Space Administration) 35 p HC A03/MF A01 CSCL 10B

N78-25012

Unclas
G3/85 21213

Translation of "Abwärmenutzung in industriellen Prozessen", Technische Mitteilungen, vol. 70, No. 5, May, 1977, pp. 259-272.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 APRIL 1978

WASTE HEAT UTILIZATION IN INDUSTRIAL PROCESSES

M. Weichsel[1] and W. Heitmann[2] /259*

ECONOMIC UTILIZATION OF ENERGY AND WASTE HEAT IN INDUSTRIAL PROCESSES

Preliminary Notes

Today, everyone talks about "Economic Utilization of Energy". Everywhere, one can read about energy waste. It is allegedly a principal reason for the steadily-increasing energy demand. The impression is created that a gigantic potential exists for rationalizing energy utilization which is far from being exhausted. In these statements, industrial energy utilization is included.

It must be appreciated that the public at large is starting to become interested in questions of energy supply. Nevertheless, experts in energy technology warn against a "rationalization euphoria" [1, 2]. The danger lies in the unrealistic assumption that the energy demand can be kept constant or can be reduced by more rational methods of energy utilization. False assumptions are thus created for the basic considerations and decisions that are required for meeting the energy demand.

The Energy Demand in the Industrial Field

The energy technology and the energy economy is determined by the demand for service energy as broken down into the principal areas of demand, i.e., traffic, household, small-scale consumption, and industry. Service energy is defined as heat, mechanical energy, and lighting. Fuel materials or electrical energy are the so-called energy carriers

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*Numbers in margin indicate pagination in foreign text.

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM 75210		

4. Title and Subtitle	5. Report Date
Waste Heat Utilization in Industrial Processes	April, 1978
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
M. Weichsel and W. Heitmann	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
SCITRAN Box 5456 Santa Barbara, CA 93108	NASw-2791
	13. Type of Report and Period Covered
	Translation
12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, D.C. 20546	

15. Supplementary Notes

Translation of "Abwarmenutzung in industriellen Prozessen", Technische Mitteilungen, Vol. 70, No. 5, May, 1977, pp. 259-272.

16. Abstract

A survey is given of new developments in heat exchangers and heat pumps. With respect to practical applications, internal criteria for plant operation are discussed. Possibilities of government support are pointed out.

Waste heat steam generators and waste heat aggregates for hot water generation or in some cases for steam superheating are used. The possibilities of utilization can be classified according to the economic improvements and according to their process applications, for example, gascooling. Examples are presented for a large variety of applications.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22.
Unclassified	Unclassified	35	

NASA-HQ

and are converted into service energy by energy converters such as furnaces, motors, or lamps. The conversion losses in utilizing energy, together with the service energy constitute the final energy consumption (Figure 1). In 1971, it amounted to 718 x 10^6 MWh (88.2 x 10^6 t SKE)[1] in industry.

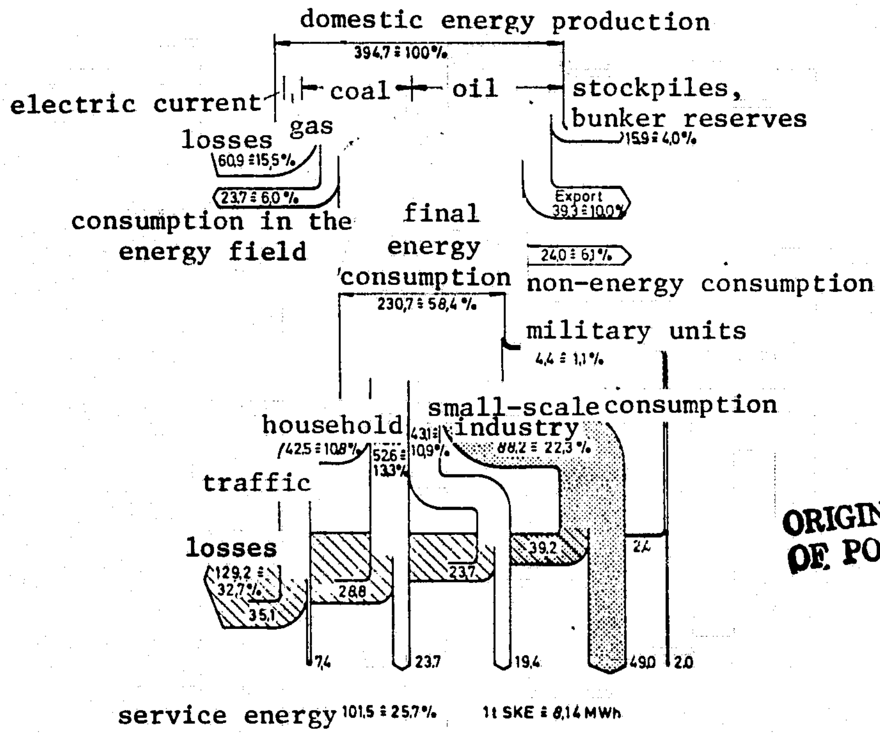

Figure 1: Energy Balance, 1971, in the BRD (Federal Republic of Germany)

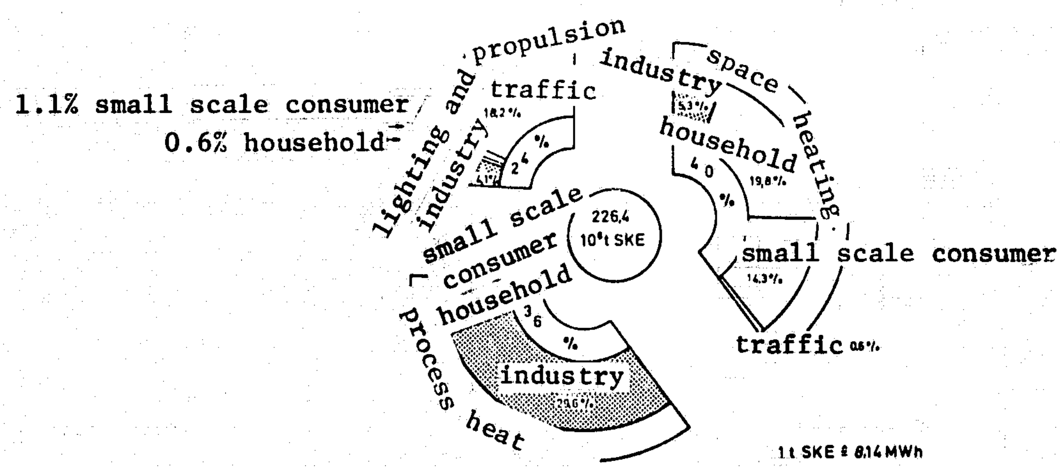

Figure 2: Balance of Final Energy, 1971, in the BRD.

[1] t = metric ton; SKE = Steinkohleneinheit = coal energy unit.

The economic energy utilization in industry must start with a better conversion of the final energy into service energy. In this case, the process heat has the greatest importance (Figure 2), which causes changes desired within or on the material. The demand of process heat in industry was: /260

1971: 545 x 10^6 MWh (67 x 10^6 t SKE)
1973: 627 x 10^6 MWh (77 x 10^6 t SKE)

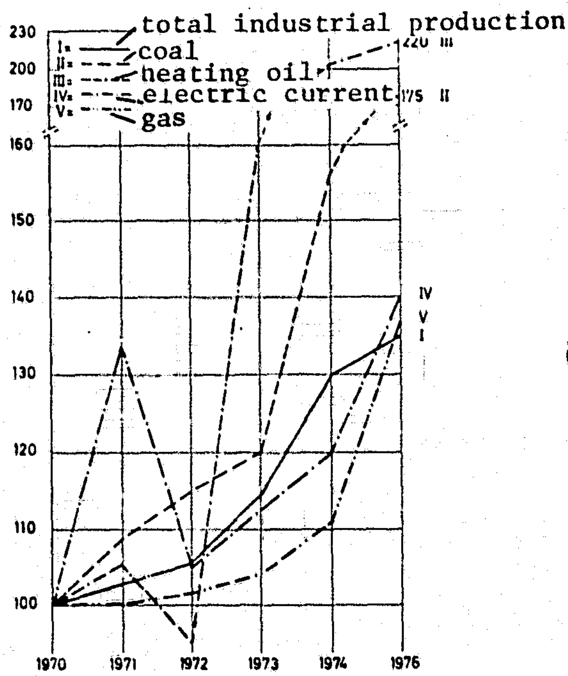

Figure 3: Price Index for Energy

Prognoses for Rationalizing

Various investigations estimate the final energy consumption in industry in 1985 to be 977 to 1078 x 10^6 MWh (120 to 132.4 x 10^6 t SKE) [1, 3, 5]. The potential savings are quoted as 114 to 127 x 10^6 MWh (14 to 15.6 x 10^6 t SKE). Concerning process heat in industry, Schaefer [1] expects that rationalization could possibly provide 65 x 10^6 MWh (8 x 10^6 t SKE) by 1985. The total demand for primary energy without energy savings in 1985 is forecasted as 4070 x 10^6 MWh (500 x 10^6 t SKE).

These simple figures show that potentials for rationalizing energy utilization in industry do exist. However, only modest successes can be expected in relation to the total demand for primary energy.

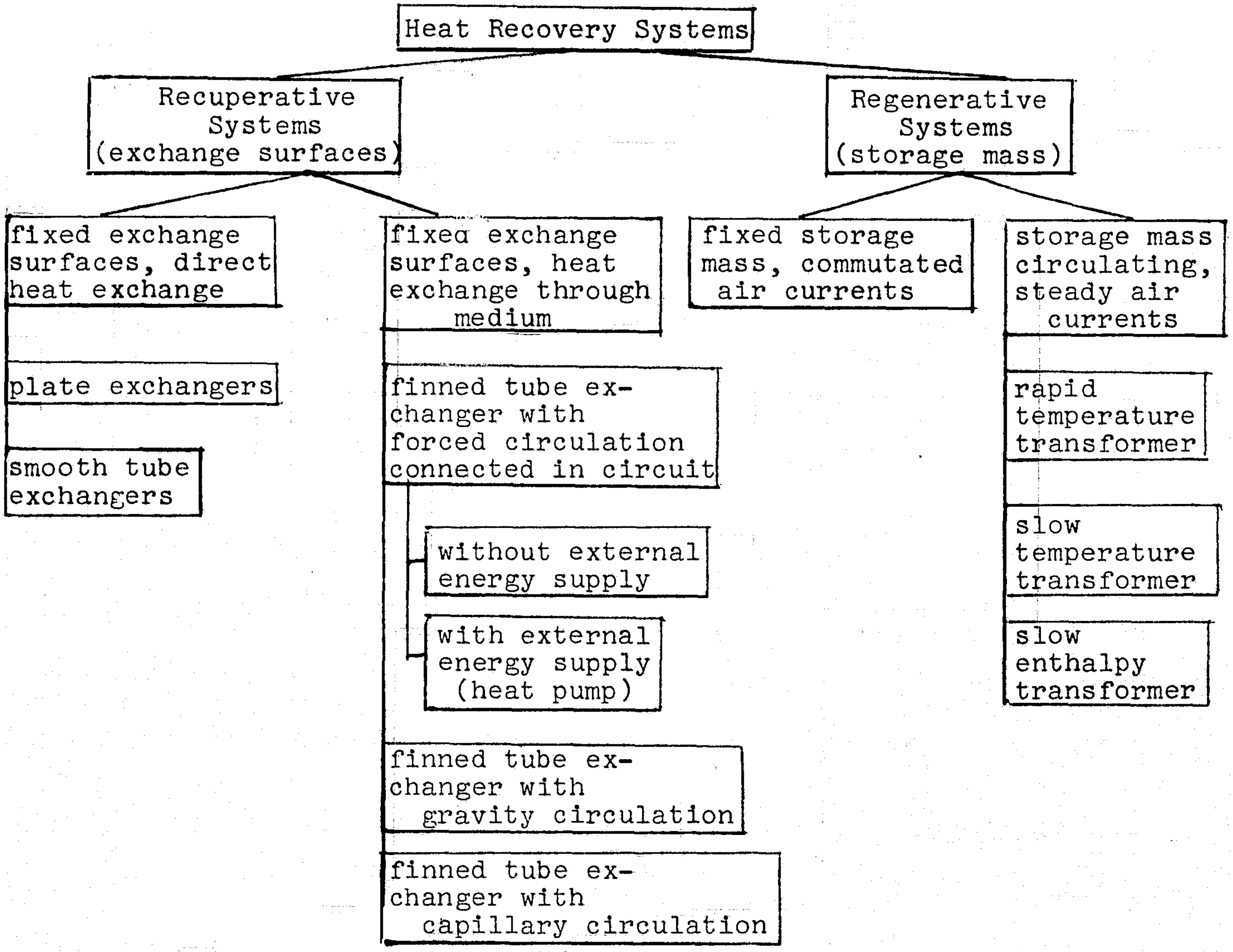

Figure 4: Classification of the Systems for Heat Recovery in the Low-Temperature Range (according to E. Dreher).

CONDITIONS FOR THE ECONOMY OF SYSTEMS FOR HEAT RECOVERY AND WASTE HEAT UTILIZATION

Changed Conditions for the Economy

Energy costs have a very variable meaning concerning production costs of industrial goods. Nevertheless, the energy factor was taken into account, always, in the general effort by industry for cost optimization. If in spite of this it is expected that further rationalization can be achieved in the industrial energy use, it is for the following reasons:

1. The increased energy prices:

Figure 3 shows that from 1970 to 1975 the prices for industrial products increased by a total of 35%, whereas the prices for

gas	increased by 38%
electric current	increased by 40%
coal	increased by 175%
light heating oil	increased by 220%.

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2. New developments in the area of systems for heat recovery and waste heat utilization which can be applied to improving energy efficiencies;

3. An increased energy consciousness in industry.

Nevertheless, investments for rationalizing energy use can nowadays be based only on economic calculations with a realistic assessment of investment needs and reductions in operating costs.

New Developments of Systems for Economic Energy Use

- -Overview of Systems for Heat Recovery in the Low Temperature Range

Figure 4 classifies the systems for heat recovery into the main categories, recuperative and regenerative systems. A special case is the heat pump, since it is associated with an energy increase on the service side by a supply of external energy.

- -Regenerative Heat Exchanger

The regenerative heat exchangers shall be considered in more detail, because they are not as well known as the recuperative plate or tube heat exchanger. Figure 5 shows the principle of such a heat exchanger. Two gaseous media flow in opposite directions through a storage mass that rotates in a housing. The storage mass absorbs heat from the warm medium and loses it while rotating through the colder gasflow. This principle has been established for decades in power plant boilers under the name Ljungström air preheater. It has been on the market for several years in modified forms for ventilating and air conditioning, and in industrial process technology applications.

Its main advantage consists in the higher areal density per storage mass volume (Figure 6). This causes a temperature transfer efficiency between 70 and 80% of the existing temperature difference between the two gas flows under normal circumstances. It has the disadvantage that it is suitable only for exchanging heat between gaseous media and that it is not possible to separate completely these media in the heat exchanger.

Figure 7 shows the integration of a high-temperature regenerator with a thermal afterburner. This results in a very compact arrangement- and in a low fuel consumption.

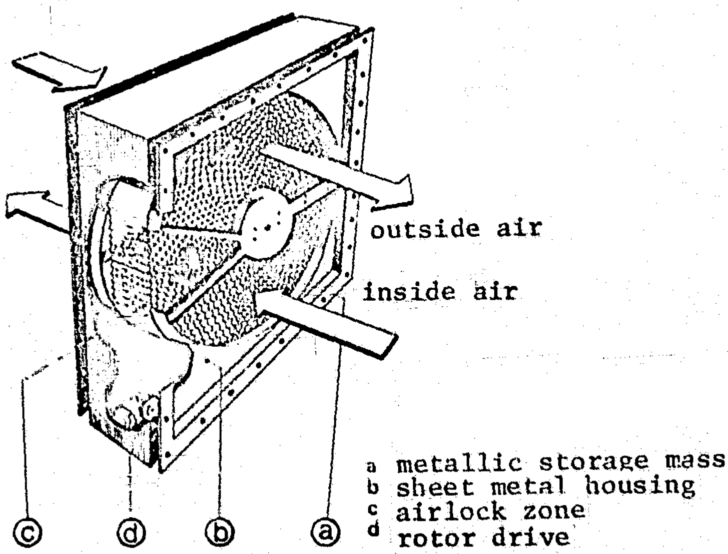

Figure 5: Regenerative Heat Exchanger "Rototherm"

Regenerators:

Wire mesh, d = 0.3 mm ø
Heating foils, s = 0.5 mm
Lamellae, s = 0.2 mm
Asbestos lamella, (air techn.)

Recuperators:

Finned plates, (casted)
smooth tube, d_R = 10 mm ø
plates (air technology)

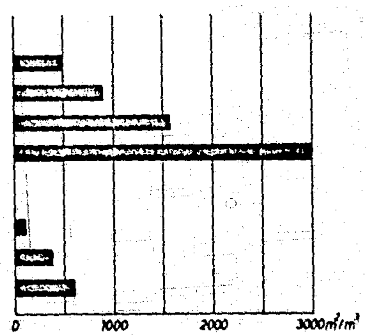

Figure 6: Specific areal density of gas-exposed exchange surfaces of various heat exchangers.

Compression Heat Pumps

In this paper, it is assumed that the reader is familiar with the heat pump process. It is evaluated by the so-called power ratio. This is defined as the ratio of the thermal power Q delivered by the heat pump to the power input W during compression.

$$\epsilon_{eff} = \frac{Q}{W} > 1$$

For the loss-free reference process, the relationship is

$$\epsilon_c = \frac{T}{T - T_o}$$

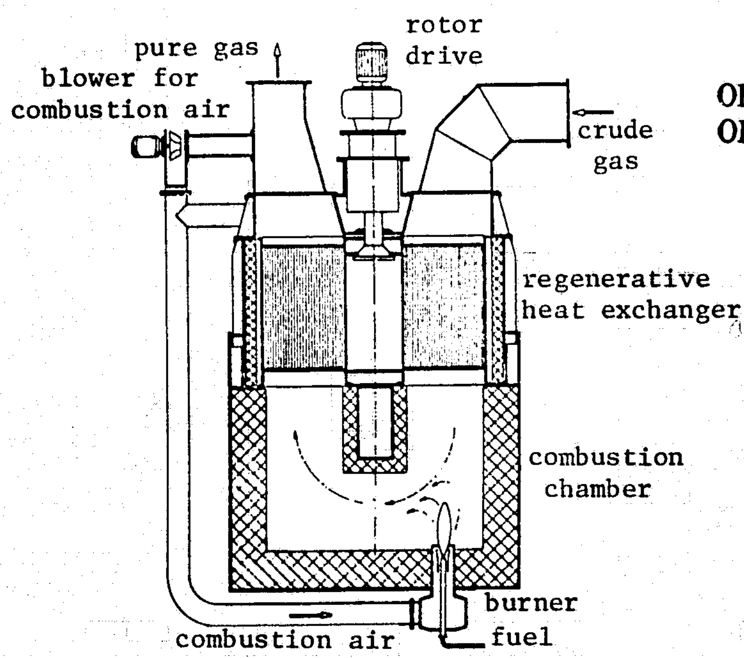

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Figure 7: Schematic Representation of a Thermal Afterburner with Integrated Regenerative Heat Exchanger.

Figure 8 represents the effective power ratio of water-water heat pumps as a function of the preheat temperature of the heating water. The temperature of the cooled water from the "cold" heat source is chosen as the parameter. The following practical application can be derived from this:

Heat pumps can be used advantageously, if waste heat exists in a state close to the ambient temperature and can be utilized in a state with slightly higher energy portions. The temperature on the service side should not exceed 50 to 60°C. Power ratios in excess of 3 are realized (under these circumstances). This means that the useful power is three times the driving power of the compressor. /262

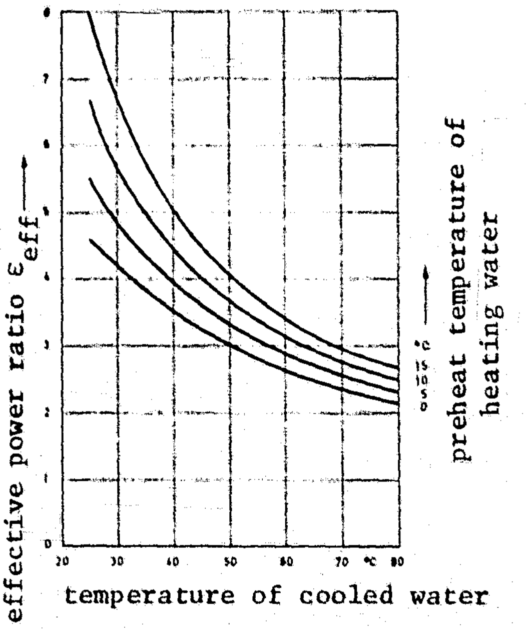

Figure 8: Power Ratios of Heat Pumps

Compression Heat Pumps with Combustion Motor Drive

If the compressor of a heat pump is driven by a combustion motor, a significantly higher conversion efficiency of primary energy to service energy is obtained than with an electric motor drive. This is achieved by utilizing also the heat contained in the combustion gases and in the cooling water for the motor.

The additional advantage is that the temperature level of the service energy is raised to between 80 and 90°C. Thus, this kind of heat pump can be connected more easily to existing heating systems in which the heating surfaces are designed for the usual 90/70°C preheat/return temperature. The development of a heat pump driven by a gas motor is aggressively pursued and is supported by the Federal Ministry for Research and Technology (BMFT).

An extensive technical literature on heat pumps has been created within the past several years [6, 7, 8]. In addition, they represent one focusing point in the non-nuclear energy research program of the federal government in the area of "Economic Energy Utilization" [5, 9].

Absorption Heat Pumps

In contrast to the compression heat pump, the compression is created by a thermodynamic system without a mechanical compressor. The three individual components of a conventional cooling circuit, i.e., the condensor, the check valve, and the evaporator, are practically identical. The place of the compressor with its drive is taken by a circuit with the components absorber, solution pump, expeller, and check valve.

The working principle has the following advantages as compared to the compression heat pump:

1. There are no moving parts except the solution pump.
2. All energy carriers can be considered as the heat source. Process heat can be utilized in a directly-heated absorption heat pump.

The fact that the service heat is available on two different temperature levels in the condenser and the absorber must be counted as a disadvantage.

Unfortunately, the development and application of absorption heat pumps is still in its infancy. References in the literature on practical experiences are sparse. However, it is expected that this situation will change very rapidly within the next few years.

Conditions for Planning

-Energy Flow within a Plant

When industrial plants are visited, it is often found that a surprising ignorance exists concerning the flow of energy within the plant. Schaefer [1] characterizes the situation as follows:

"In many cases, the consumption data that the plant has available are only those measured by the utility companies or, in the case of liquid and solid fuels, the quantities purchased. Even the determination of reliable monthly consumption data is often only possible with great difficulty and considerable uncertainty. How the internal energy flow looks in addition to the total demand, which energy carriers are used in which plant sections, what kinds of service energy are generated, and with what efficiencies the energy is converted, how the heat demand is divided into space heating and process heat, and what portions of the process heat are high, medium, and low temperature, this is mostly the subject of guesses or, at best, estimates."

These statements can be fully confirmed from the standpoint of a designer and plant builder. They apply especially to small and medium-size industrial plants, and no so much to the energy intensive plants of the iron and chemical industry where these equations are studied in special departments.

Describing the Actual Condition

For the above reasons, any studies for utilizing waste heat must start with describing the actual condition by supplying the following data:

- Processes generating waste heat
  Temperature level of the waste heat
  Quantity of waste heat
  Daily and annual variations of waste heat generation
  Local Conditions

- Heat demand
  Temperature level of heat demand
  Heat Quantity
  Daily and Annual Variations of Heat Demand
  Local Conditions

Technological Possibilities of Waste Heat Utilization or Heat Recovery

In considering technical realizability, a tendency exists to find first possibilities for heat recovery. Heat recovery is defined as recycling heat into the same process that generated it. In doing so, /263
part of the heat is forced into a circuit, as for example, in preheating combustion air by the waste heat contained in flue gases. Heat recovery is thus equivalent to creating energy circuits (Figures 9 and 10).

This has the advantage that:

1. Waste heat availability and heat demand are simultaneous all the time.
2. The waste heat can be utilized during the entire operating time of the plant,
3. The heat recovery system can be integrated as a component into the total plant.

Waste heat utilization shall be defined as utilizing waste heat for the purposes not related to the processes, for example, heating of a factory hall by waste heat from a process furnace. In this case, energy is branched off from a process that generates waste heat. (Figure 11).

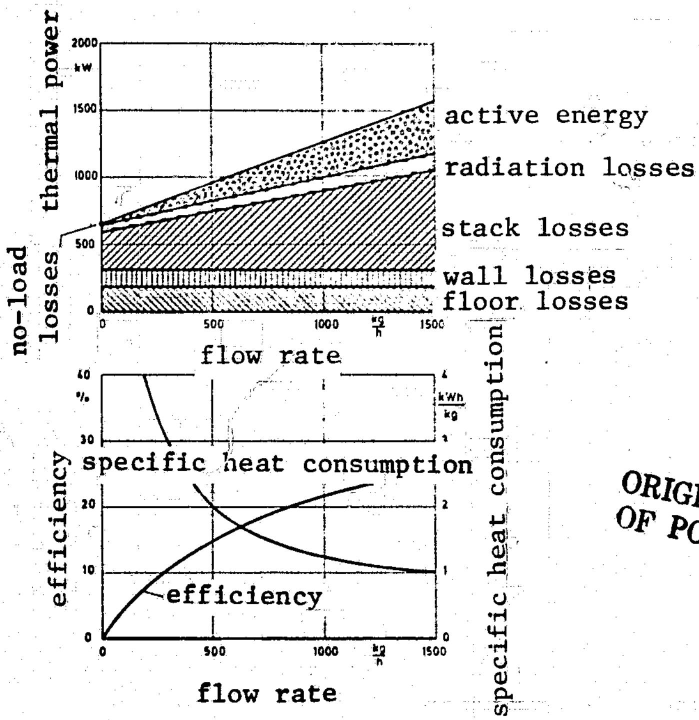

Figure 9: Energy Characteristic of a Gas-Fuelled Forging Furnace

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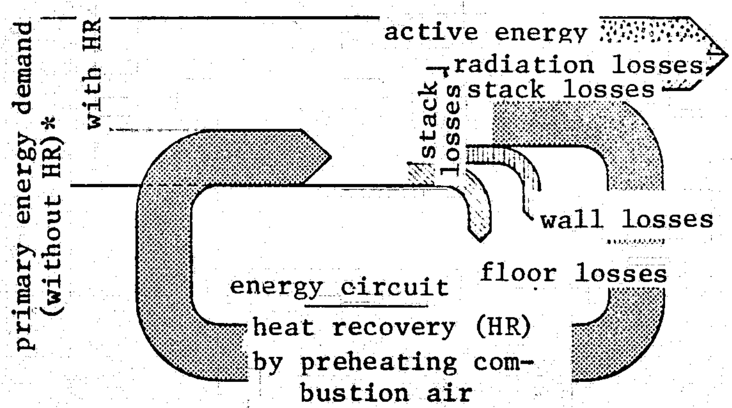

Figure 10: Energy Flow Chart of a Gas-Fuelled Forging Furnace with Heat Recovery.

Disadvantages are that:

1. Waste heat utilization is limited by the heat demand of the consumer (for example, demand for space heating only in winter);

2. Functions are combined that must be satisfied independently (for example, production and space heating);

3. For safety reasons, a heat source must be installed that is independent from the process plant (for example, conventional heating system in addition to the device for waste heat utilization);

4. Heat demand and waste heat supply are frequently not synchronized and consequently, the waste heat can be utilized only by installing a thermal storage between the waste heat sources and the heat consumer.

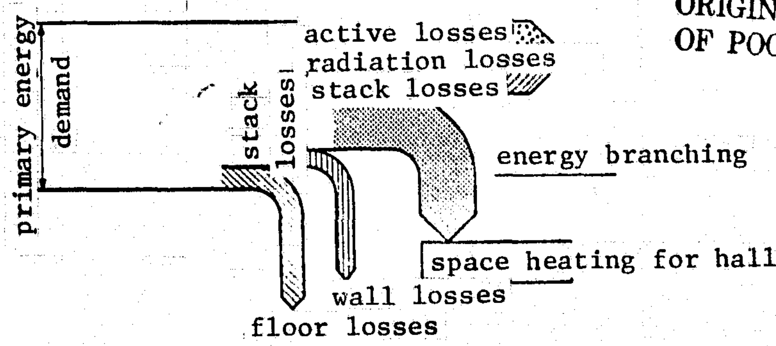

Figure 11: Energy Flow Chart of a Gas-Fuelled Forging Furnace with Waste Heat Utilization.

Investment Calculation

The investment calculation must furnish possibilities of evaluation for technical alternatives. It is broken down into the following steps:

- determining the investment requirements of the proposed alternatives,
- determining reductions of operating cost, taking energy price increases into account, and
- determining the most favorable alternative by applying, above all, the dynamic methods of investment calculation.

Government Support of Efforts for Economic Energy Use

The government supports in various ways the efforts for economic energy use. The following support programs are mentioned in particular:

1. Investment credit for Energy-Saving Plants
   §4a, Section 1 of the Investment Credit Law specifies an investment credit of 7.5% for energy-saving plants. There is no time limit.
2. Non-Nuclear Energy Research Program of the Federal Government
   As part of the energy research program of the federal govern-

ment, research and development work in this field is supported. Studies and investigations are supported, but also the construction of demonstration plants is considerably subsidized in part.

3. §7d of the Income Tax Law.

Plants utilizing waste heat are causing a smaller impact on the environment regarding waste heat and pollutants. For this reason, they are generally recognized by the trade control boards and the respective state ministries as plants contributing to a reduction in air pollution. For the investor, this opens the possibility of realizing depreciation advantages (60% of the investment in the first year, 10% in each of the following years) according to §7d of the Income Tax Law.

EXAMPLES OF PROJECTED OR CONSTRUCTED PLANTS FOR WASTE HEAT RECOVERY /264

Waste Heat Utilization with Bell-Type Annealing Furnaces of a Cold Reduction Mill

After cold rolling, the cold worked sheet metal coils are soft-annealed in bell-type annealing furnaces.

Figure 12 represents schematically a typical annealing cycle. The energy in the flue gases and the cooling air and the supplied energy are listed in the figure. In the heating and hold phases, the energy contained in the flue gases is about 2.49 MWh (2.14 Gcal) and has the same order of magnitude as the energy stored in the annealing material and the cooling air.

The recordings of the annealing phase were evaluated and it was determined how often the individual sections were simultaneously in the heating and hold phase, or in the cooling phase.

The quantity and temperature of the flue gas was also measured from which an average waste heat energy of 0.53 MW (0.46 Gcal/h) was calculated. The waste heat of the cooling air that can be utilized is about 0.35 MW (0.305 Gcal/h).

Figure 13 shows the arrangement for waste heat utilization. The flue gases are conducted over a regenerative heat exchanger with metallic storage mass, and the air from the outside is heated by the counterflow. This air, together with the cooling air and the room air is conducted into a mixer which controls the temperature of all three air currents at about 60°C.

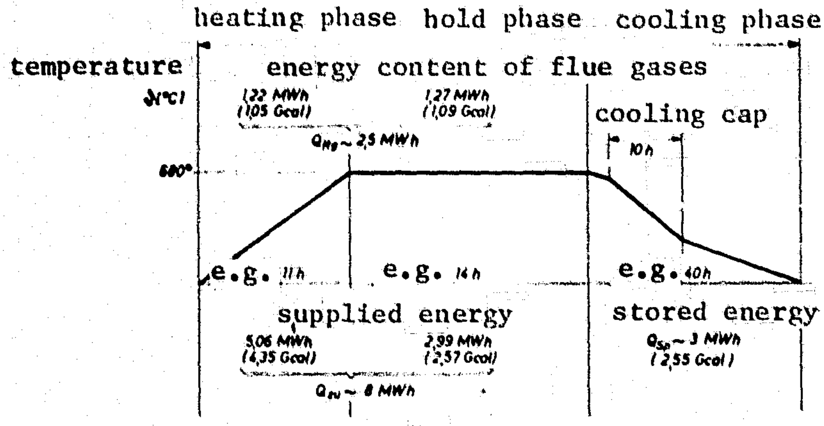

Figure 12: Thermal "Time Table" of a Bell-type Annealing Furnace.

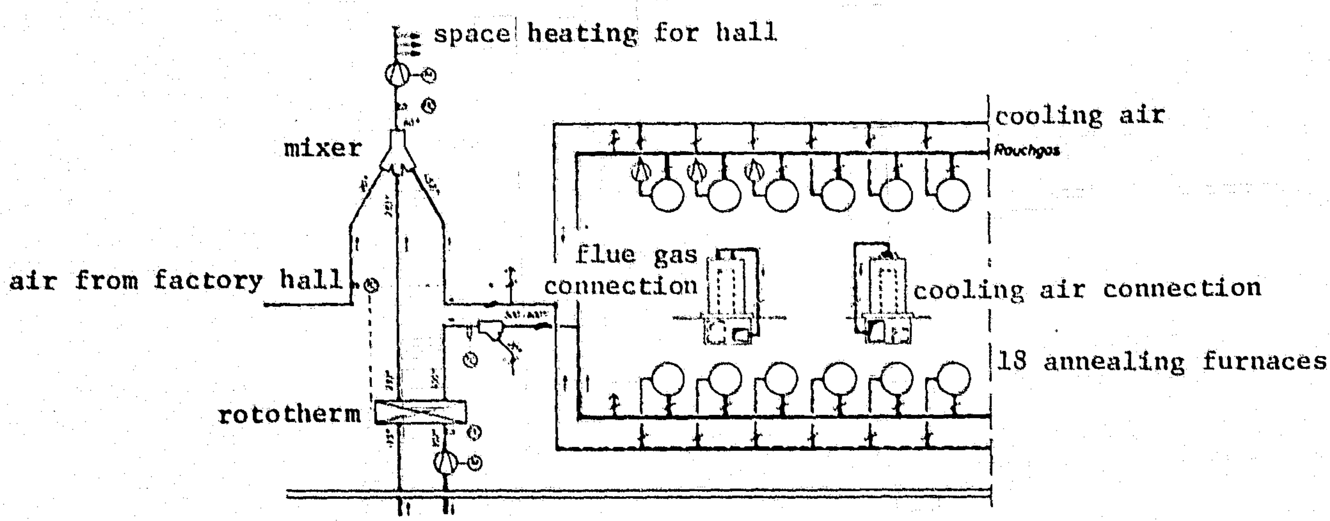

Figure 13: Waste Heat Utilization with Bell-Type Annealing Furnaces

Waste Heat Utilization from the Pure Gases of a TNV Plant for the Central Hot Water Supply of a Chemical Factory

The pure gases of two TNV plants in a chemical factory enter the stack at a temperature of 330°C. The waste heat can be utilized quite obviously for the central hot water supply of the plant by means of a recuperative heat exchanger (Figure 14). The power output of the two waste heat utilization plants is between

2.09 and 3.26 MW (1.8 and 2.8 Gcal/h)

If the heat exchangers are connected in such a way that the waste /265
heat can be brought also into the adjacent plant No. 1, the total demand for process heat can be satisfied during the summer by waste heat.

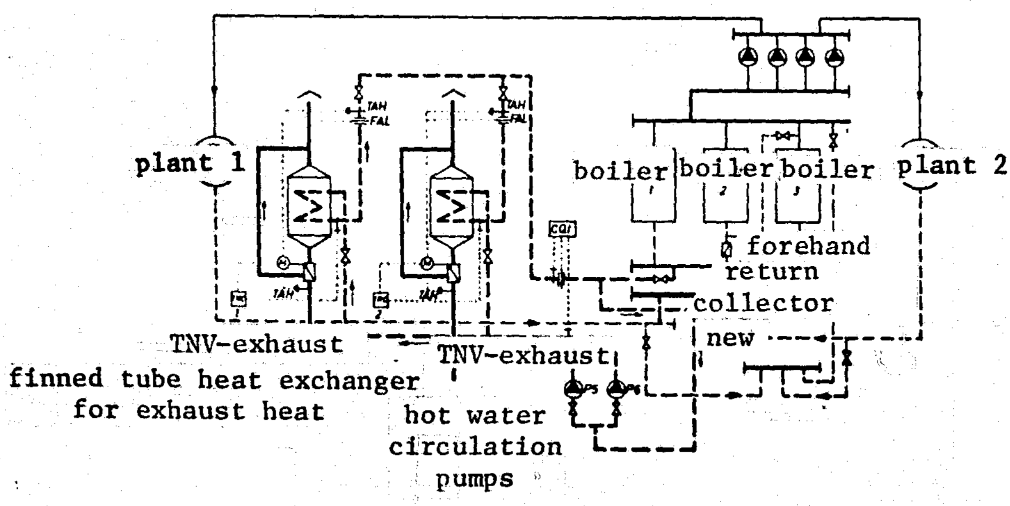

Figure 14: Waste Heat Utilization in TNV plants

With an investment of

about 450,000 - DM

savings in operating costs are expected that will result in a payback period between one and two years. This favorable result is mainly due to the fact that the heat distribution system exists already, and that process heat is needed all year around.

Waste Heat Utilization with Induction Furnaces of a Foundry

A foundry operates four induction melting furnaces with an average electrical power of 4000 to 4400 kW per furnace, of which three can be operated simultaneously. The furnaces and the associated condensers are cooled by cooling water in the primary circuit (Figure 15). The cooling water in the secondary circuit absorbs heat from the cooling water in the primary circuit through counterflow heat exchangers, and is cooled back in two cooling towers. The temperature level of the cooling water is between 30 and 50°C.

The temperature of the cooling water is so low because the exit temperature from the electrical condensers may not exceed 38°C. It appears reasonable, therefore, to separate the cooling circuit of the condensers from the cooling circuit of the furnace coils and to use an exit temperature of 75° C at the coils (Figure 16). At the same time, both cooling circuits are converted on the secondary sides from the open cooling tower system to air-cooled heat exchangers. The existing cooling tower system remains as a backup.

The heat supply from the three induction furnaces under full load is 2.24 MW (1.925 Gcal/h). It is to be used for satisfying the demand from space heating, ventilation, and water heating.

The administration building, various factory halls, and washrooms were connected. Even with an outside temperature of +5°C, the total energy demand of the plant is 2.19 MW (1.88 Gcal/h).

Separating the cooling circuits and constructing the warm-water distribution network requires an investment of about 1.9 million DM. The annual savings in operating costs are between 250,000 and 300,000 DM.

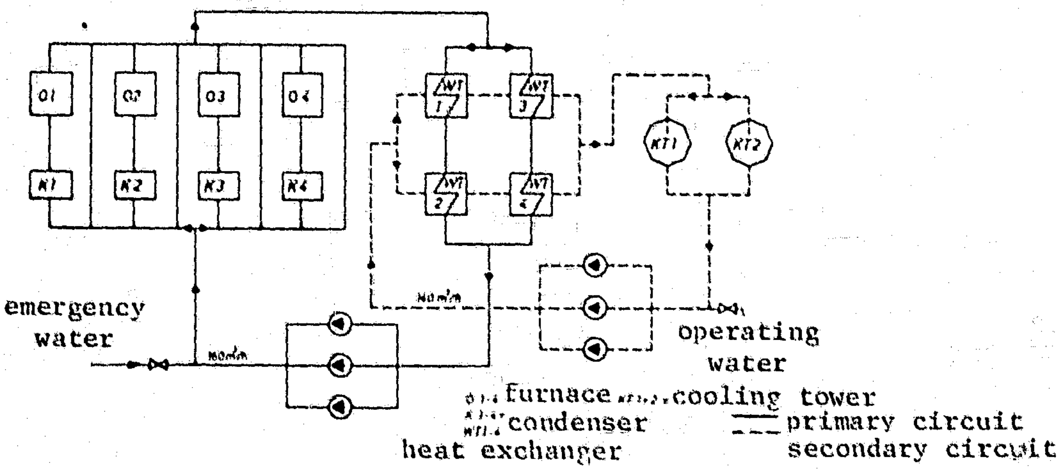

Figure 15: Cooling water state of an induction area (actual state)

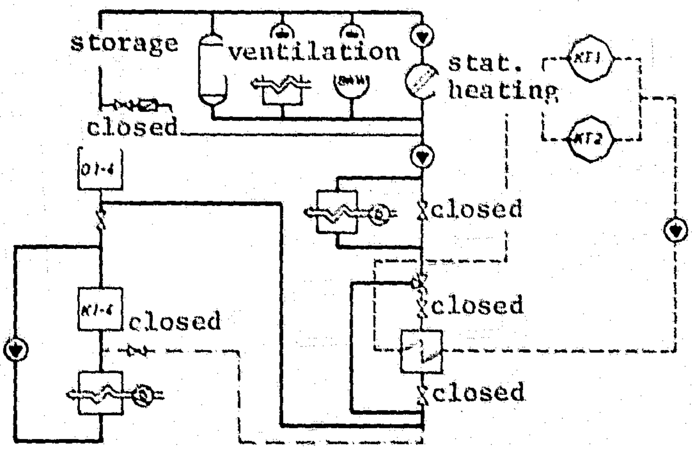

Figure 16: Cooling water Diagram of an Induction Furnace Installation with Waste Heat Utilization

Assuming an interest rate of 10% and a 5% increase in the cost of energy, the dynamic investment calculation shows a positive capital value between the tenth and the eleventh year after the investment was made.

Presently, the installation is being built as a demonstration plant with financial support from the BMFT (Federal Ministry for Research and Technology, transl.)

Utilizing Heat from the Flue Gas Exhaust of Heat Treatment Furnaces for Warm Water Heating

The flue gases from ten forging furnaces and three start-up furnaces of a spring factory are collected by a central duct system, and fed by a flue gas blower into a flue gas - hot water - recuperator (Figure 17). The recuperative heat exchanger preheats the return water of a heating system to 90°C. /266

The additional investment for the waste heat utilization plant is 195,000 DM. Assuming a useful plant life of 15 years, 10% interest rate, and an annual price increase for energy of 5%, the capital value of the investment becomes positive after 5.5 years, i.e., the plant has been amortized in this time.

The plant is presently installed. The investment decision was influenced considerably by the depreciation provisions of §7d of the Income Tax Law.

WASTE HEAT BOILERS AND WASTE HEAT AGGREGATES

Definition and Classification

As a supplement to the area of waste heat recovery in small amounts and with low temperatures, the following is a representation of the better known area of heat recovery and waste heat utilization in large-scale processes of all kinds. Due to the large amounts of waste heat, and to the high temperature level, the waste heat utilization was already economic at the time of low energy costs. Consequently, untapped heat sources are an exception.

One must distinguish between waste heat steam generators or boilers and waste heat aggregates that are used for superheating steam or for heating water. A combination of several units is called a waste heat plant.

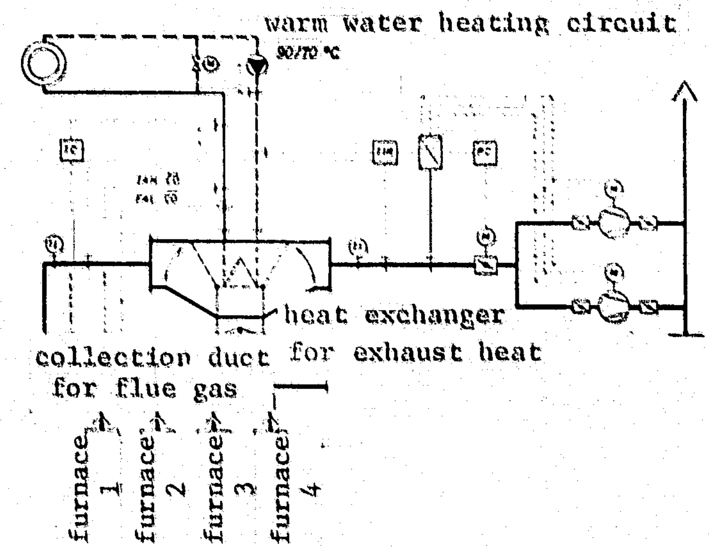

Figure 17: Connection diagram Showing the Function of a Recuperative Waste Heat Utilization Plant.

A common criterion is the fact that the generation of heat is not used primarily for utilization of heat, and that the waste heat leaves the considered process with a sufficiently high temperature level and heat content. Design and construction of the waste heat boiler or the waste heat aggregate must follow the requirements of the process. The applications can be classified according to Table 1.

Table 1: Classification of Waste Heat Utilization and Recovery with Examples.

Waste heat recovery		gas cooling for		cooling of hot components
not integrated	integrated	process	dust removal	
gas turbine		gas cooler	converter cooling stack	grates of pusher-type furnace
glass mfg.	waste heat aggregate in ethylene plant			
incineration of refuse	reformer in ammonia plants	sulfuric acids	carbonizer non-catalytic gasification	Siemens-Martin furnaces

In contrast to the definitions given earlier, the definitions in Table 1 refer to the heat generating process and therefore, "waste heat utilization" and "recovery" may sometimes have the same meaning.

Waste heat utilization in the narrower sense is following the heat generating process which, however, functions independently and works without utilization. The heat is generally not recycled into the process. The objective here is to increase the efficiency by reducing the total energy consumption.

In certain cases, the waste heat utilization is an independent operation and is integrated into the process. An energy circuit is created such that the concept of heat recovery can be applied here according to the definition given previously.

With gas cooling, the waste heat plant is serving primarily process purposes, for example temperature adjustment for subsequent operating steps like solution, reaction, or purification.

Utilization is possible by recycling waste heat into the circuit, as, for example, in gas cooling, or by using waste heat for purposes that are independent of the process, as, for example, in convertor cooling stacks. In these cases, the improvement of the process economy is a by-product.

Cooling of hot construction elements applies to such plant components, that are exposed to big mechanical loads at high temperatures, as in steel mills. Pressureless water-cooling that was generally used in the past is substituted occasionally by evaporation cooling. Also in this case, the recovered steam is used for purposes other than the process itself.

Various manufacturers are offering waste heat economizers for the applications mentioned above. Systems with natural convection, forced convection, and - less frequently - forced-through flow are being used. The great differences between the properties of the heat transporting media, i.e., temperature, pressure, mass, corrosion behavior, give rise to a great variety of types. A few examples will be described in the following.

EXAMPLES OF CONSTRUCTED UNITS

Waste Heat Utilization

Gas Turbine Process.

Due to its excellent start-up characteristics, the gas turbine has been used since the war for satisfying peak electrical demand. The low efficiency of 25% could be neglected in this kind of application. /267

In further developing gas turbines, the operating temperatures were increased such that nowadays the exhaust gas temperature falls between 480 and 570°C. Because of this, and because of a planned extension in the annual period of utilization, the waste heat is now used in most cases. Figure 18 shows the visual plant schematics.

After leaving the gas turbine, the exhaust gases scrub the surfaces of the following waste heat unit, thus generating high-pressure steam for the following steam turbine or for process purposes. Especially in municipal applications, waste heat aggregates are being used for hot water generation.

The second diagram shows the combination between gas turbine and a radiation boiler. In the following boiler which is mostly a large power unit, the exhaust gases from the turbine are used as preheated "combustion air" for the firing. Therefore, the waste heat utilization is a by-product in this case, and will not be considered any further.

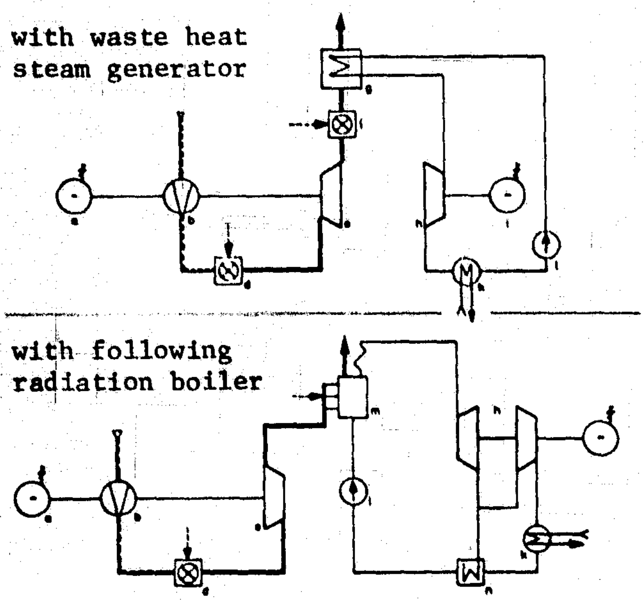

Figure 18: Diagram of Combined Gas Turbine - Steam Generating Plants.
a) Gas turbine generator b) air compressor c) air preheater d) combustion chamber of gas turbine e) gas turbine f) supplementary firing g) waste heat boiler h) steam turbine i) steam turbine generator k) condenser l) feed pump m) radiation boiler n) preheater for feed water

Figure 19 shows a hot water waste heat aggregate with forced circulation having a thermal power output of 116 MW to be used in municipal applications. The flow of exhaust gases from the gas turbine scrubs the heat exchanger when used for heating and bypasses it only when electricity is generated.

The heat exchanger itself is exposed from below to two gasflows and consists of 12 x 106 finned double tubes and is operated in the continuous flow mode. The heating surface is suspended from uncooled

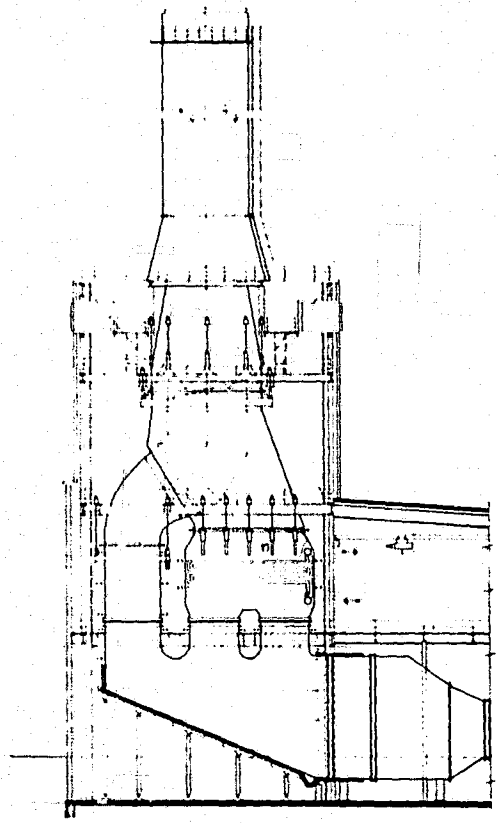

Figure 19: Hot Water waste Heat Aggregate, 116 MW, water throughput 2415 tons/h, entrance temperature 140°C, exit temperature 180°C,

iron beams. The dampers in front of the inlet and the bypass are constructed as safety dampers such that the gas turbine will never work against them in the closed state.

The exhaust gases from the gas turbine contain about 15 to 16% oxygen and can be used in the waste heat boiler as preheated "combustion air" for supplementary firing, if higher steam values are desired.

Figure 20 shows a boiler with natural convection having the capability of supplementary firing with natural gas/process gas in a cooled combustion chamber (1). The exhaust gases are stagnated to a pressure of 80 mm water column (8 mbar) by means of a slotted wall at the boiler entrance in order to generate the necessary pressure for the combustion.

The design of the combustion chamber allows the boiler to be refitted for operation with pure air. The superheater [2, 3] is next, protected by a radiation screen of evaporator tubes. The tubes are arranged horizontally to compensate for lopsidednesses on the side of the exhaust gases. The exhaust gas passes through an evaporator bundle of finned tubes (4) and a finned tube economizer (5) and enters a condensate preheater with a temperature of 200°C. The undegassed condensate is preheated by this two-piece heating surface from 60 to 110°C. Due to the poor quality of the feed water a surface cooler (7) is provided.

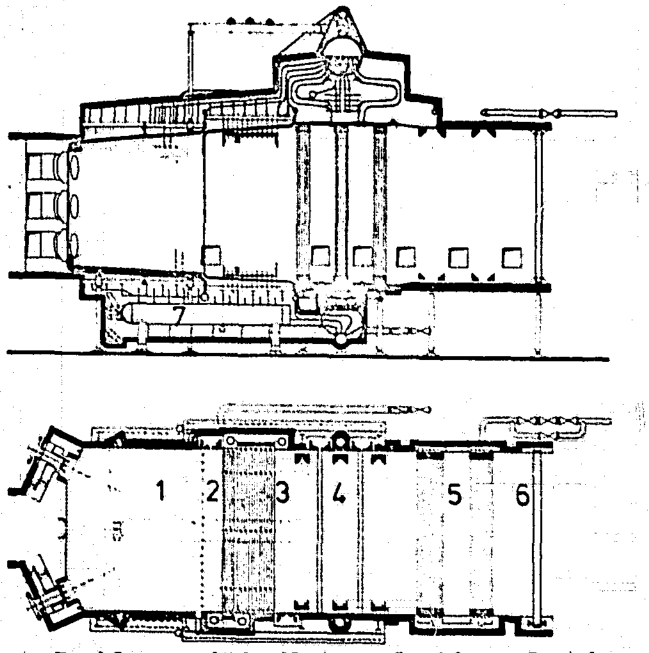

Figure 20: Waste Heat Boiler with Natural Circulation; 100 tons/h, 94 bar, 510°C, feed water 121°C.

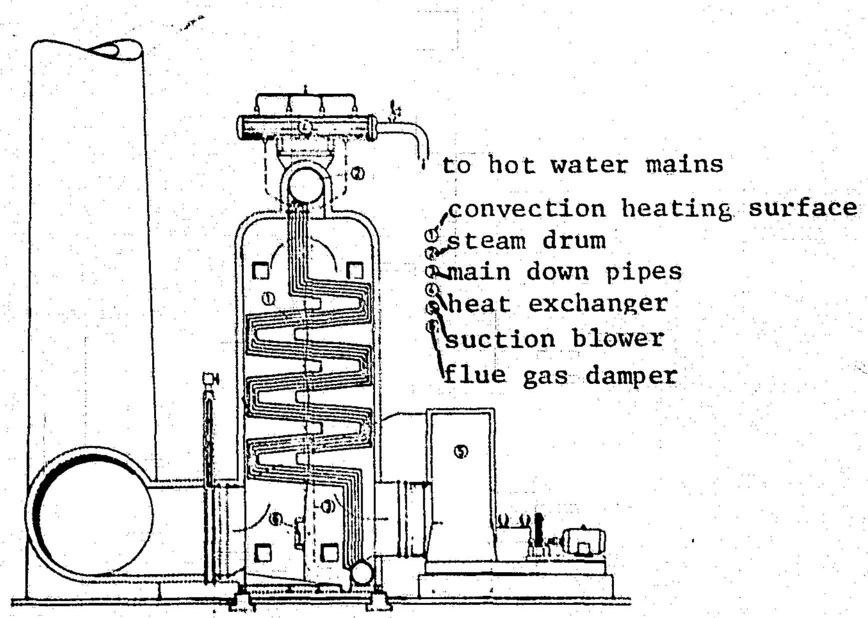

Figure 21: Waste heat Boiler Behind Glass Furnace (Standard).

Waste Heat from Non-Integrated Processes

- Glass Manufacture

In a plate-glass plant, 500 tons per hour of glass are melted with an hourly production of 80,000 m^3 of exhaust gas at roughly 500°C. Due /268 to the high sulfure dioxide content, the dewpoint is around 170°C, the pressure at the exit of the trough is -6 mbar and must be kept constant.

In view of the high dewpoint, the two-circuit system of Figure 21 was chosen. The convection heating surfaces of the double flue boiler with natural convection generate saturated steam of 13 mbar, 190°C, which raises the temperatuer of the heating water from 130°C to 170°C in a heat exchanger. With appropriate suction control, the pressure at the exit of the glass trough is kept constant. The produced quantity of steam can be controlled also by means of a shorting damper in the center wall.

- Special Refuse Plant

In a special refuse plant, liquid and solid residues of all kinds are burnt in a rotary oven. Due to fluctuations in the charge, the combustion cannot be controlled exactly; therefore, the heat supply to the following waste heat boiler, Figure 22, is subjected to large fluctuations.

Since boilers with natural circulation present restrictions regarding the admissible rate of load change, the forced circulation principle was chosen for the heating surfaces that are heated on both sides. The container walls are welded gas-tight and cooled by natural convection. The high rate of circulation is cooling the boiler, even in the presence of strong deposits.

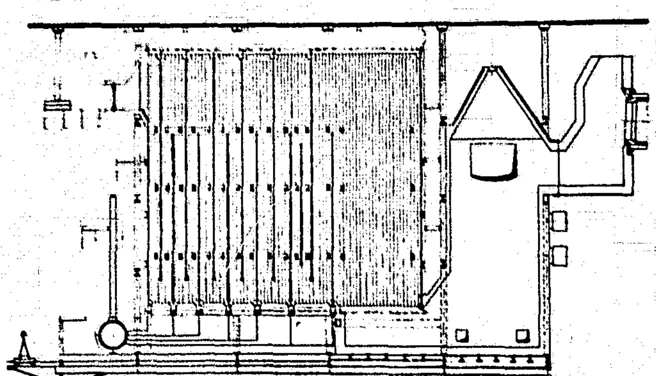

Figure 22: Waste Heat Boiler Behind Special Refuse Incineration; 30 tons/h, 31 bar, 250°C, (Lantjes).

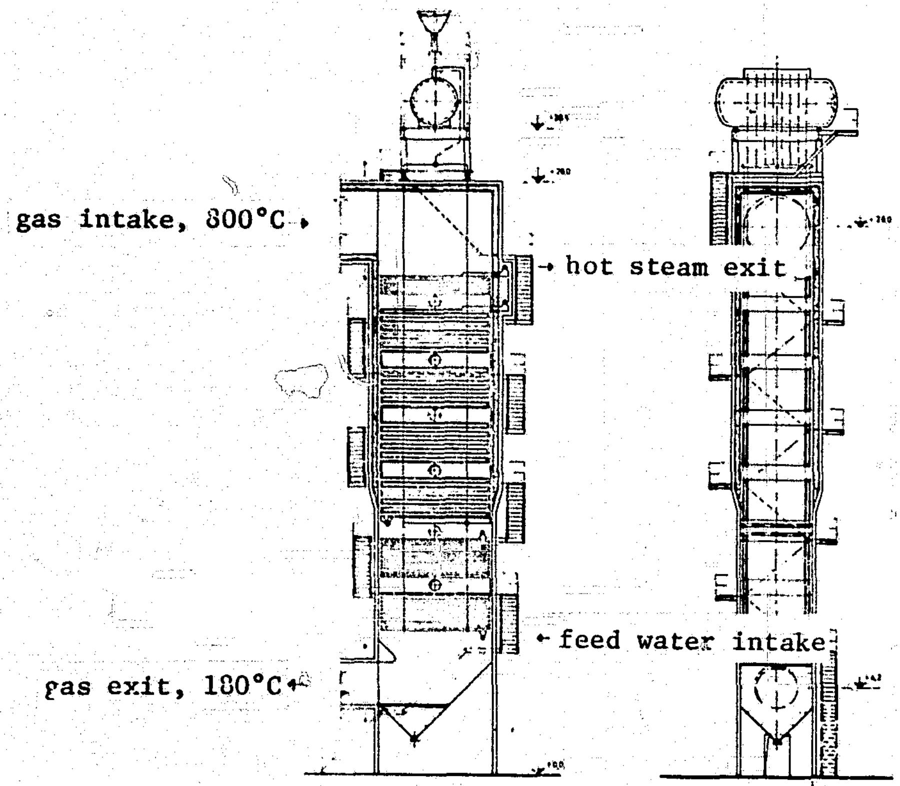

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Figure 23: Coke Cooling, 40 tons/h, 16 bar, 350°C.

- Coke Cooling

To improve the heat economy of coal carbonization coking, the idea of dry coke cooling is presently revitalized. The coke is transported in a closed wagon from the battery into a lined cylindrical shaft cooler. It is cooled down from 1000°C to 200°C by a flow of inert gas which is warmed by this process from about 180 to 800°C.

After a coarse dust removal, the inert gas is guided in a closed circuit into a waste heat boiler (Figure 23), and cooled down to about 180°C.

The cooling period of roughly three hours is adjusted to the rate of emptying this furnace. The generated heat decreases while a charge is cooled. These variations are smoothed out by bypassing the coke cooler with an adjustable partial flow of the inert gas which is mixed with the main flow at the boiler entrance in order to keep the temperature constant during the cooling period. Approximately 0.4 to 0.45 tons of superheated steam can be generated per ton of coke. With a battery of 1500 tons of coke per day, 25 tons/h of steam are produced.

Waste Heat from Integrated Processes

- Generation of Ethylene

In generating ethylene, considerable thermal energies are created, not only from gas cooling in the process itself but also from waste heat utilization.

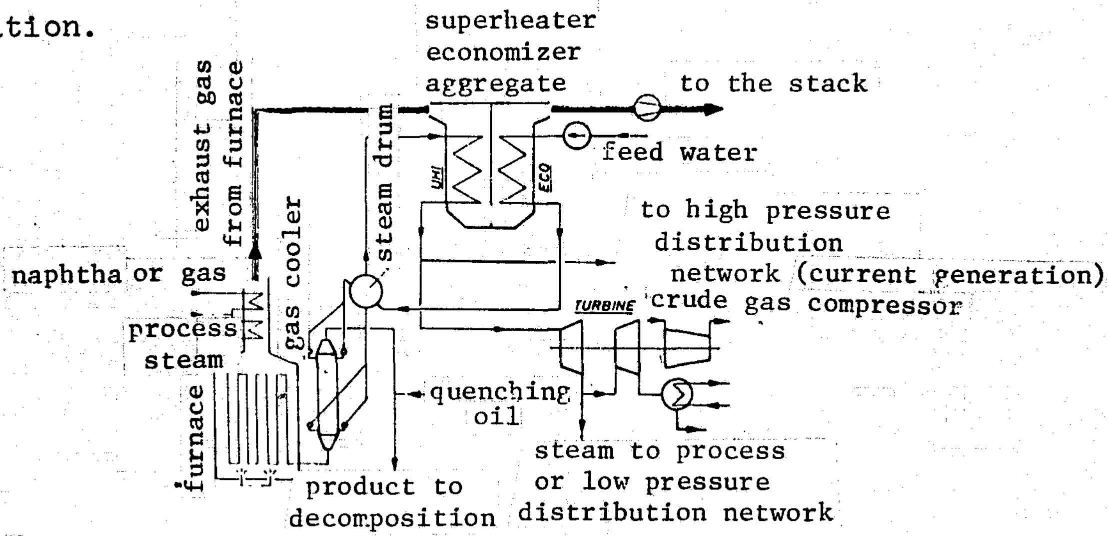

Figure 24: Waste Heat Plant in Ethylene Plant, Schematic Diagram

Figure 24 shows the process diagram of the waste heat plant. The hydrocarbon-steam mixture is heated from 800 to 1000°C in several cracking furnaces operating in parallel and quenched to about 350°C in the gas coolers. High pressure saturated steam of 80 to 125 bar is generated in this process which is superheated to about 450 to 520°C either in the following waste heat aggregates that are heated by the exhaust gases from the furnaces, or in separately fired superheaters. It is then used for driving turbo motors or for current generation. /269

The gas coolers are the waste heat boilers. They are subjected to large loads due to the high temperature drop and the intentionally high cooling rates. Accordingly, they are constructed in many different types, for example, as a standing flue gas boiler or as a double pipe cooler (Figure 25).

The cooler consists of a system of double pipes that are connected at the entrance and exit by oval collectors. The gases are conducted through the interior pipes and cooled by water or mixtures of water and steam flowing uniformly in the annular space between the exterior and interior pipes. The saturated steam precipitates in the steam drum and is superheated in a waste heat aggregate according to the diagram shown (Figure 26). In front of the array of heating surfaces, a combustion chamber is installed that is lined with superheating surfaces. The

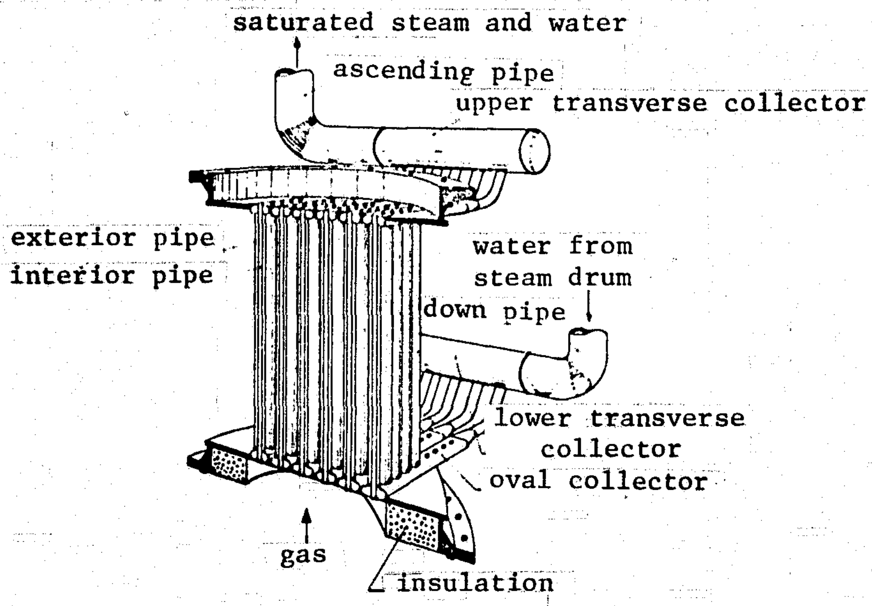

Figure 25: Double Pipe Gas Cooler for an Ethylene Plant (SHG)

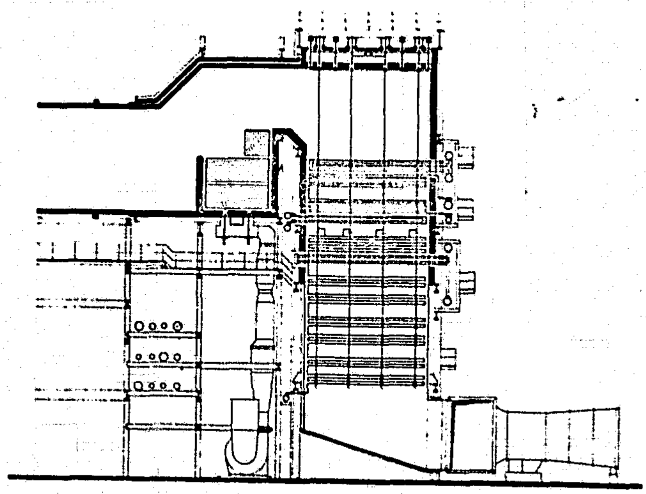

Figure 26: Waste Heat Aggregate with Supplementary Firing; 316 tons/h 113 bar, 505°C.

desired hot steam temperature of 505°C requires a supplementary firing, because an operation with exhaust gases alone would only achieve about 450°C. The firing and injection cooling of the superheater must be provided with a broad range of controls, in order to compensate for any changes of heat supply to the steam or the exhaust gas as a result of deposits in the furnaces or gas coolers.

The combustion chamber can also be constructed as a supplementary evaporator. In this case, the superheater surfaces are also arranged for downward flow. The feed water for the quenchcoolers and the supplementary evaporator is preheated in the economizer.

- Ammonia Synthesis

Similar to the generation of ethylene, a great number of possibilities for utilizing waste heat exist also with the synthesis of ammonia in the catalytic gas generation (steam reforming) and the synthesis process itself.

1. Cooling of flue gases from the gas generation (first stage of reforming, see Figure 27) from 900°C to 200°C. The heat is used not only for superheating the high and low pressure steam, but also for preheating the feed water and the combustion air for the reformer.

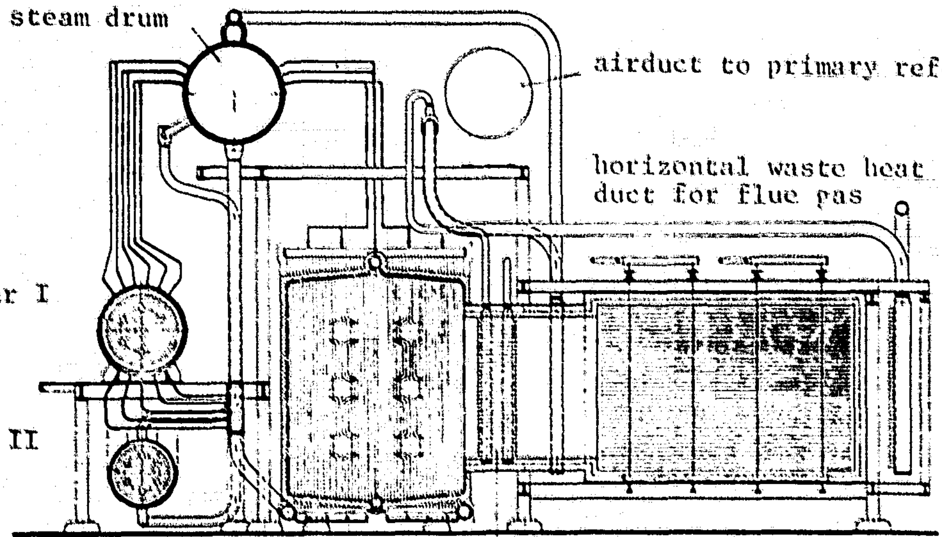

Figure 27: Waste Heat Aggregate for Generating NH_3 at a rate of 1000 Tons per Day (Steinmueller)

2. Cooling of the Reformed Gas. After the primary reformer, the process gas may have a temperature of 850°C at 20 to 30 bar and is cooled down to about 350°C in gas coolers (Figure 28). The cooling must take place rapidly. The gas cooler shown contains an evaporator system with forced circulation which is wound like an involute. The water flows through the tubes. The exposure of the heating surfaces can be controlled by a damper in the central gas pipe.

3. Cooling of the Synthesis Gas. The synthesis gas leaves the convertor with 400°C and 30 bar, and must be cooled down to about 200°C. Heat exchangers are used for this purpose, whose bundles contain the /270

flowing synthesis gas. Cooling is achieved by evaporation of ammonia, or by generating medium pressure steam.

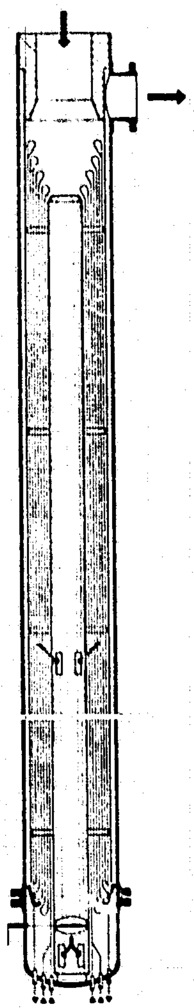

Figure 28: Gas cooler in the synthesis of Ammonia.

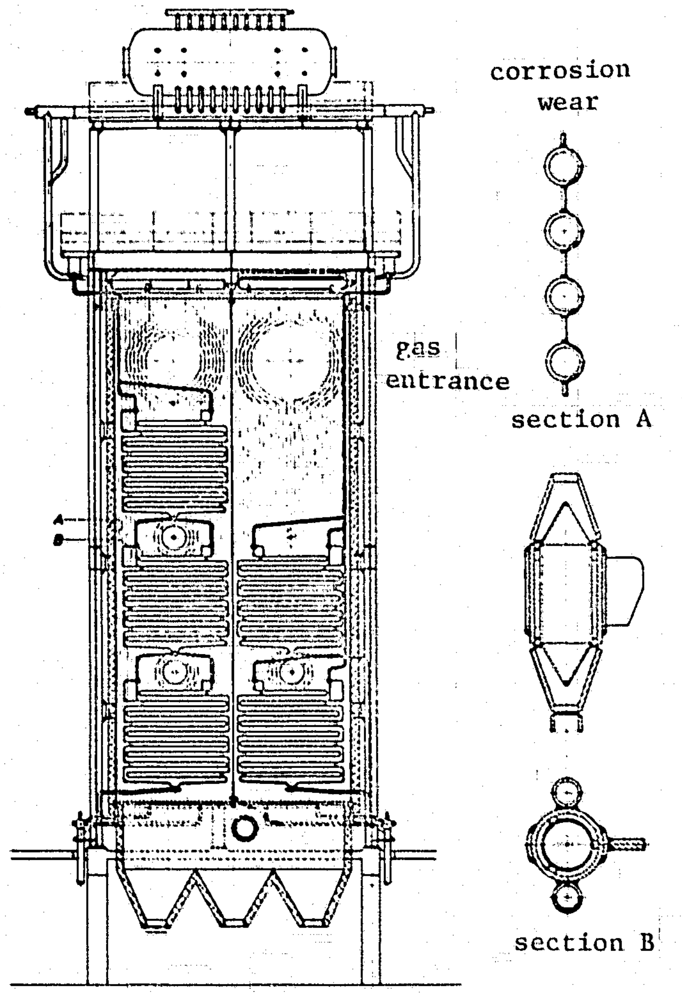

Figure 29: Waste Heat Boiler Behind Combustion of Used Acid, gasflow 50,000 m^3/h, 1100°C, D = 25 tons/h 75 bar (SAG).

Gas Cooling

To this group belong not only the gas coolers of ethylene and ammonia plants as described in the previous section, but also the heat recovery in, for example, the process of the following:

- Sulfuric Acid Production

Other than by roasting sulfurous pyrites (FeS_2) into sulfur dioxide (SO_2) with subsequent oxidation to sulfur trioxide (SO_3) and hydrating to sulfuric acid (H_2SO_4), waste sulfuric acid from chemical processes can be used as a raw material. The used acid, which is contaminated with residues and water is sprayed into an oil or gas flame and broken up at 1100° to 1200°C to sulfur dioxide. The combustion gases that are strongly enriched with sulfur dioxide are guided into a waste heat boiler and cooled down to a temperature of about 330°C which is favorable for the catalytic generation of sulfur trioxide. Since the flue gases contain dust particles and acid mist, special provisions in the construction are necessary. In order to avoid dewpoint damages, the wall temperature of the pipes should be above 250°C. Since a tendency towards corrosion does exist, the heating surfaces should be easily replaceable. The possibility of deposit formation should be reduced by wide branchings in the piping and by facilities for cleaning. The boiler shown in Figure 29 gives an interesting answer to these requirements.

The assemblies of heating surfaces are all equal and easily exchangeable. The walls and the ceiling can be inverted after the corrosion allowance has worn off.

Converter Cooling Stack

In decarburizing steel with the LD and LDAC process, the carbon content of the pig iron that was melted in the converter is reduced from about 4% to between 0.1 and 0.2% by oxidation. If the combustion is incomplete, a gas is obtained containing much dust, 80 to 90% CO, 10 to 20% CO_2, and $H_{u,\ N}$ = 11.3 MJ/m^3 (2700 kcal/m^3), and having a temperature between 1700 and 1800°C at the exit of the convertor. This gas must be combusted in the cooling plant for the exhaust gases and cooled to a temperature that is appropriate for subsequent dust removal. The design of such plants is determined by the discontinuous rhythm of blowing, 20 minutes for example, andthen blowing of about 40 minutes. In addition, the heat generation and carbon monoxide content fluctuate during the blowing period.

Depending on the power of the converter, the number of plants, and the utilization of waste heat, many different designs are possible, of which the following were realized.

- water cooling with cold water flow or pressurized water circulation. The removed heat is dissipated in cooling towers.

- Heat generation in a forced circulation system or in a combined system of forced and natural circulation. The generated steam is cooled in a condenser without utilization, or is stored in steam accumulators to compensate for intermittent operation. The steam is then reduced by the pressure in the accumulator and superheated in the operating exhaust gas cooler or by a separately-fired superheater.

Figure 30 shows the diagram of a plant with steam accumulator. A steam quantity of 30.2 tons per charge is achieved, corresponding to 50 tons/h, by using a converter with the following data:

- quantity of pig iron 100 tons/charge
- carbon content pig iron/steel 4.2% / 0.1%
- blowing time 14 minutes
- decarburizing time 12 minutes
- charge time 36 minutes
- primary gas CO/CO_2 56,000 m^3/h, 90%/10%
- feed water temperature 105°C
- sludge 10%.

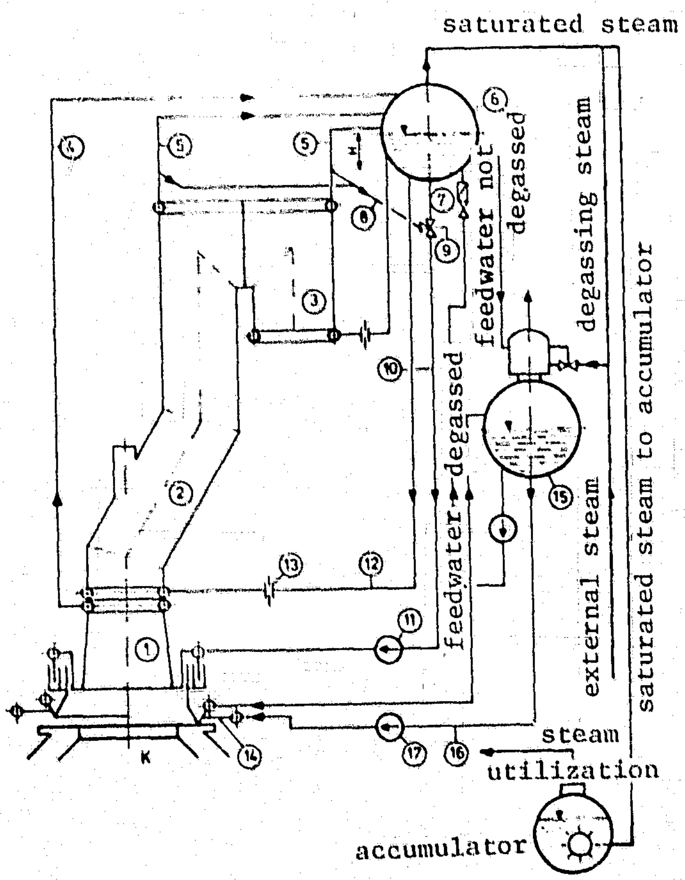

Figure 30: Converter cooling stack with steam utilization.

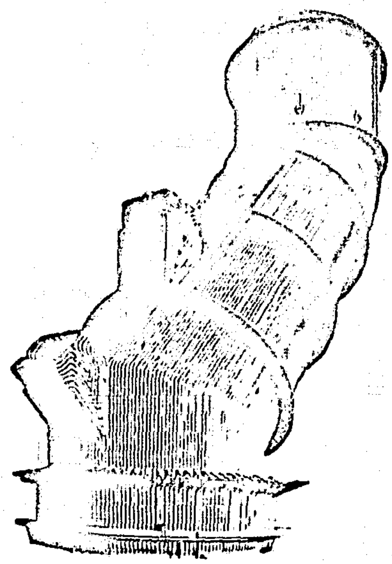

Figure 31: Cooling Stack, entrance part to LDAC convertor for 150 tons of pig iron per charge.

The stack part shown in Figure 31 is welded gastight. The stack is delivered in three sections.

The evaporator tubes are welded together on-site. The rounded cross-section represents optimum explosion protection and the smooth walls reduce the tendency for deposits.

Cooling Hot Building Components

Building components of plants, for example, in steel manufacturing that are subjected to high thermal and mechanical loads, are cooled by evaporation cooling. Compared to water cooling with a high consumption of water and the danger of the cooled surface dropping below the dew point, evaporation cooling offers economic and technical advantages.

Figure 32 shows the cooling diagram of a pusher-type furnace. The feed water of the system is preheated in the preheater 1 by the flow of the exhaust gas from the furnace and fed into the drum 2. The surfaces to be cooled and the parts of the grate form the first evaporator surface and are cooled by forced convection. The convection heating surface 4 is the second evaporator stage and is arranged in the exhaust gas flow behind the superheater 5.

SUMMARY

The savings potential of heat recovery and waste heat utilization is frequently overestimated. Only 30% of the total annual energy consumption or 226 million tons of SKE (1971) are needed to satisfy the industrial demand for process heat, of which 8 million tons of SKE at the most can be saved annually until 1985 by improvements in utilization.

A survey is given of new developments in heat exchangers and heat pumps. With respect to practical applications, internal criteria for plant operation are discussed. Possibilities of government support are pointed out.

Four plants are presented as examples of operation in the low and medium temperature ranges.

In large-scale industrial processes with large quantities of waste heat and high temperatures, waste heat utilization was already practiced intensively before the steep increase in fuel cost.

Waste heat steam generators and waste heat aggregates for hot water generation or in some cases for steam superheating are used. The possibilities of utilization can be classified according to the economic improvements and according to their process applications, for example, gascooling. Examples are presented for a large variety of applications.

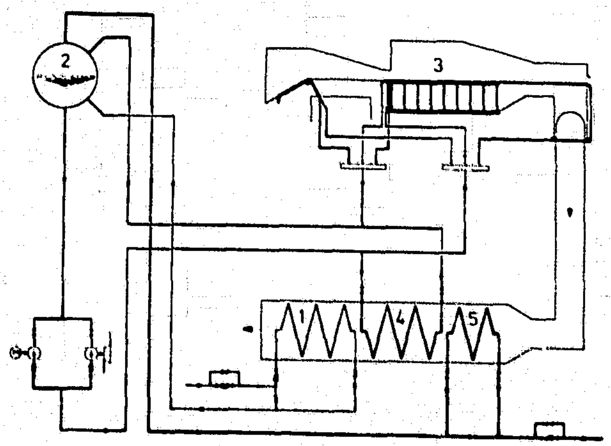

Figure 32: Evaporation cooling of a Pusher-Type Furnace (Steinmueller)

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Figures 1 through 17 - Kraftlangen AG, Ratingen;

Figures 18 through 32: EVT Energie - und Verfahrenstecknik, GmbH, Branch Office, Cologne.