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# WASTE HEAT RECOVERY AS A PART OF ENERGY CONSERVATION IN INDUSTRY*

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## 1 Abstract

Waste Heat or Secondary Energy is a common "byproduct" in any industrial process, where the material temperature is raised. The easiest form of waste heat to handle and utilize is hot water. Unfortunately cooling water streams often have too low a temperature for an economic and technically feasible process recovery solution.

Reasonably easier to implement are projects, where solid hot material is the Waste Heat source. This is the case because of the normally considerably higher temperature involved. Naturally large emphasis is thus put on the waste heat streams available in the metal industry, particularly iron and steel.

The paper is divided into a theoretical part explaining basics of waste heat recovery, equipment used and a section that refers some Finnish and European implemented Waste Heat Recovery projects in industrial subsectors that are of interest for African countries.

## 2 Introduction, what is Waste Heat

Energy generated from fossile fuels is called primary energy. Energy flowing out as warm water from a condenser after the turbogenerator is called secondary energy. The word secondary indicates that it has "done its work" when expanding in the turbine, and thus has not much energy left.
Energy Conservation, which in practice means conservation of natural resources, consists of several components. One significant part of it is Waste Heat Recovery. Utilization of energy means heat transfer to another medium either directly or via an intermediate liquid. The mechanisms of transfer should be well known to enable a successful design of the heat recovery equipment.

### 2.1 Definitions of Waste Heat

There are several definitions of the word Waste Heat. Synonyms to Waste Heat are thus Secondary Energy, or

Residual Enthalpy. In the following waste heat means generally energy flows and losses escaping from the process. Such energy flows that are directly utilized (e. g. generated and transferred steam, condensate, power, hot water and hot products as well as reaction energy required by the process) are, however, not generally regarded as waste heat. Waste heat consists thus primarily of energy resulting from cooling water and waste water, exhaust air, fumes, flue gas, other waste and radiation streams. Waste heat is generated in different parts of the process, where material is handled. It is also generated, where electric power is used (power loss) and where steam is used (when back-pressure generation is not utilized through bypass of the turbine).

## 2.2 District Heating

Recovered waste heat can be utilized e. g. in the form of hot water outside the mill where it is generated. This so called district heating is in Finland, with its cold climate, used for space heating. District heating could, however, be used for any kind of heat demand common in African countries, such as cooling purposes, process heat treatment needs, tap water heating etc. In the following is the term district heating used for any heat demand outside the process where it is recovered.

## 3 Environmental Aspects

Waste heat is an important source of pollution if exposed untreated to the environment. Thermal pollution of streams with hot effluents or excessive amounts of cooling water from industrial processes is the result of lack of proper waste heat recovery. Reference is made to a waste heat recovery study explained in section 5, that showed the connection between high water and energy consumption.

Heat recovery from exhaust gases frequently involves process solutions that include cleaning of the gas, sometimes even without additional investments. In many cases is it possible to add cost savings for environmental protection to the savings in primary energy costs as a result of successful waste heat management.

An additional great advantage of the fluidized bed technology is the environmentally efficient burning. By adding limestone to the fluidized (and possibly circulating) sand, emissions of sulphur dioxide can be considerably reduced. Combustion and temperature control is easier and thus emissons of nitrogen oxides can also be reduced. These are some of the reasons for the world-wide success of the Finnish innovation called Pyroflow.

## 4 How is Waste Heat Recovered?

The most efficient opportunity of recovering waste heat occures when the waste heat is available in gas, as cooling air or combustion gas, alternatively in solid or liquid form such as metal, minerals or glass at high temperatures. In such case are there two main principles for the recovery system.

### 4.1 Recuperators or Waste Heat Boilers

Any heat exchanger could also be called recuperator. Recuperators operate continuously with the waste heat on one side and the new primary energy medium (air, gas, water) on the other side of a heat exchanger wall, figure 1. Conventional recuperators are sheet metal heat exchangers. The most common application is to recover some of the heat from a furnace exhaust stream and transfer it to an incoming air stream, in a so called waste heat boiler. The heated air is then used for combustion or preheating incoming process raw material. The most efficient recuperators save 20 to 30 % primary energy and are used with gas temperatures below 800 deg.C (1500 deg.F). Above this temperature other materials have to be used or cold air mixed with the hot exhaust.

Ceramics present a realistic alternative to metal in high temperature recuperator design because of their increased resistance to oxidation and corrosion. Industrial applications for ceramic recuperators are for exhaust streams with temperatures of 870 to 1400 deg.C (1600-2600 deg.F), mainly in the primary metals or metal products industries. The unit operations here are annealing, heat treating, forging, rolling, melting, glass heating, calcining and ladle pouring, among others. American experience indicate an efficiency of 30 to 40 % in the form of fuel savings. For further details see section 6.3 Aluminium industry below.

### 4.2 Regenerators

The other basic principle of recovering waste heat is the discontinuous (alternating) regenerator, shematically shown in figure 2. The most common conventional application are the two underground tile storages built adjacent to the old open hearth (Siemens-Martin) steel furnaces. Through one tile storage the hot exhaust gases are first blown out and cooled down as the tiles get hot. Simultaneously cool combustion air to the furnace is blown through the other tile storage where the preheated tiles heat the air. After some time the gas and air flow is reversed.

A more common application of regenerative waste heat recovery is a gas heat exchanger with 2 flow passes as shown in figure 2, an example of air conditioning. The flow direction is alternated so that the metal walls of the exchanger is cooled or heated depending on which gas flows out.

### 4.3 Fluidized Bed Boilers

Heat transfer in a fluidized bed, where small particles of e. g. sand is floating because of an air stream, is significantly higher than from normal forced convection. This is due to the breakdown of the laminar flow that occur in the border layer that surrounds the particle. The heat transfer coefficient in a fluidized bed is normally between 200 and 500 W/sq. m deg.C.

As explained above in section 3 the comparatively expensive fluidized bed technology also has a positive impact on the environment.

### 4.4 Heat pumps

Generally speaking you can call any equipment that transfers heat from a low to a high temperature level a heat pump. The main objective of a heat pump is the high temperature heat generated. For a cooling device, which is a comparable piece of machinery, the extraction of heat from a low temperature level is the main goal.

This from a thermodynamic point of view reversed transfer of heat from a low to a high temperature level naturally requires addition of energy in the form of heat or mechanical work. Depending on in which form this energy is fed to the heat pump we talk about mechanically or thermally driven heat pumps.
As a rule of thumb the ratio between the price of electricity and the price of replaced fuel has to be below 3 to make a heat pump feasible.

#### 4.4.1 Compressor heat pumps

Mechanically driven heat pumps are usually called compressor heat pumps. In its most basic version it consists of an evaporator, a condenser, a compressor and an expansion valve. Figure 3 shows a simplified heat pump circuit, where the efficiency of the heat pump is improved by supercooling the heat transfer liquid, usually called refrigerant. The heat pump works on two different pressure levels. The evaporator has a lower pressure than the condenser. Energy from a waste heat source evaporates the refrigerant in the evaporator. The formed vapour is sucked away by the compressor whereby the pressure of the refrigerant raises. Due to the higher pressure in the condenser the vapour liquifies and transfers its heat at high temperature to the heat consumer. The condensed refrigerant is returned via the expansion valve to the evaporator. The refrigerant used in a heat pump has a great influence on its efficiency. The freezing point and the critical point set certain limitations for the selection of refrigerant.

Figure 4 shows how waste heat is recovered with a compressor heat pump from a stream of air, fumes or exhaust gases. The evaporator can be situated in the stream, or an intermediate liquid circulation between the evaporator and the heat source can be used. The indirect heat transfer is necessary in cases where the hot gases are contaminated or corrosive. Figure 17 shows details of the construction of a scrubber, which is the actual heat recovering unit in the third application pictured in figure 4. The first application shows an evaporator equipped with a fin battery also called heat pipe battery.

### 4.4.2 Absorption heat pumps

One type of thermally driven heat pump is the so called absorption heat pump, which also consists of an evaporator, a condenser and an expansion valve, like the compressor heat pump. The compressor is replaced by two heat exchangers, (an absorber and an evaporator) a pump and an expansion valve. Figure 5 shows a simplified flow diagram of an absorption heat pump.

The absorption heat pump needs in addition to the refrigerant an absorbent that circulates between the absorber and the evaporator. The refrigerant, which also is called working fluid, is evaporated at low temperature and the generated vapour is absorbed in the circulating absorbent, thus releasing heat. In order to recover this heat the absorber has to operate on a reasonably high temperature level, usually the same as the condensor. From the absorber the solution of absorbent and working fluid is pumped to the evaporator, where a part of the working fluid is separated from the absorbent at high temperature. The generated steam is piped to the condenser and further via the expansion valve to the evaporator. The rest of the mixture of working fluid and absorbent is returned to the absorber through the expansion valve.

### 4.4.3 Thermocompressors

If the compressor of a mecanically driven heat pump is replaced with a steam ejector it is called a thermocompressor and in fact becomes thermally driven. Only heat is necessary to produce the desired high pressure steam. Figure 6 shows the basic principles of a steam ejector.

If the compression efficiency is defined as the ratio between the compression work produced and the compression work consumed, steam ejectors have efficiencies between 20 and 40 %. The main advantage of steam ejectors is that they have a simple construction and are thus easy to build regardless of size. They are extensively used in multistage evaporators and cooling plants.

## 4.5 Heat storages

A heat storage is not actually a means of recovering waste heat, but an efficient way of making recovered heat feasible because of its flexibility. By storing heat from high generation periods to later rising high consumption needs the value of the heat is increased considerably. The fact that energy consumption varies clearly demonstrates the need for energy storage. Figure 7 presents typical daily load curves for Thailand and Finland. It is obvious that if the power plants are designed to match the peak load they will in both countries not be used to full capacity for most of the 24 hours of the day.

Many industrial processes have a considearble need of high pressure steam. The principle how to generate high pressure steam with a storage tank is shown in figure 8. The system involves two water tanks. Cold water from one tank is heated by waste heat, utilized in the process, condensed and pumped under pressure to a pressurized hot water tank.

# 5 Finnish Waste Heat Research

The Finnish National Fund for Research and Development (SITRA) and the Confederation of Finnish Industries had a comprehensive waste energy study conducted. The objective of the study was to explore the number, size and matters relating to the utilisation of different waste energy sources common in the Finnish process industry. Furthermore, the aim was to identify measures which can be undertaken by the process industry to decrease specific energy consumption by using proven techniques. The study especially concentrated on the following waste energy targets:

-from industry escaping solid, liquid and gaseous material flows; their quantity, composition, energy content (enthalpy and heat value), duration and influence on heat surfaces

-waste energy connected to the generation of heat and power, such as bypassing the backpressure turbine steam by using a pressure reduction valve or factors influencing the condensing turbine and energy generation efficiency

-factors influencing the efficiency of items powered by over 50 kW motors, mainly pumps and blowers

-quantity and quality of waste energy generated in different unit operations

-quantity and quality of available waste energy from process disturbances

-economical means of utilization of waste energy sources in the process or outside

The waste energy portion of the 8 investigated mills' total energy turnover varied between 40 and 100 %. With water escaping waste heat ranged from 0 to 71 % of the energy turnover, mainly because of differencies in production process. Energy turnover is defined as the total energy amount per production unit moving across the energy balance border of that particular mill. Based on a mills energy and material balance conclusions can be drawn on such waste energy flows that cannot actually be measured at all, or measured with great difficulties. It is thus of vital importance to establish the energy and material balances of a mill.

## 5.1 Results of the survey

Investigation of the recovery of waste heat proved to be difficult mainly because of the low enthalpy and energy content of the waste heat sources and the low temperature difference in relation to the surrounding. These facts makes utilization feasible within the mill only in exceptional cases, due to present primary energy and equipment costs and pay back periods. Because of low temperature, low energy content, corrosivity, contamination or intermittent occurrency only under 23 % of the waste energy was actually recoverable for use within the same mill at reasonable costs.

The survey showed among other things that the manufacture of inorganic industrial chemicals, cement, lime, iron and steel corresponded to about 84 % of the whole production of the industry investigated and about 67 % of its energy consumption. These industrial branches had thus a lower energy consumption per unit produced.

## 5.2 Material and Energy Turnover

The power plants of the surveyed industries generated 41 % of the electric power needed, the rest 59 % had to be bought from outside. Of the selfgenerated power about 16 % was back-pressure power and 84 % condensing power generation.

Table 1 Material and energy turnover of surveyed industries

| mill | material turnover | water turnover | energy turnover GJ/t prod |
|---|---|---|---|
| | t/t product | | |
| 1 iron | 50 | 31 | 22 |
| 2 steel | 22 | 9.5 | 3.4 |
| 3 zinc | 595 | 95 | 43 |
| 4 cement | 2.9 | - | 3.5 |
| 5 pigment | 621 | 331 | 70 |
| 6 sulfuric acid | 50 | 31 | 10 |
| 7 clorine | 264 | 174 | 30 |
| 8 rayon | 942 | 666 | 76 |

The table gives a picture of the variation of material and energy turnover depending on product and manufacturing process. The portion of water of the material turnover is an important indicator. Normally increased water turnover means increased energy turnover because of the high heat storage capacity of water. The amount of waste heat increases with growing energy turnover.

Annex 2 lists the material and data necessary for the successful conduction of a waste energy study.

Annex 3 explains some Finnish recommendations for promotive measures that authorities should take to encourage waste energy recovery co-operation between industrial enterprises and municipalities.

# 6 Waste Heat Recovery in some Industrial Branches

## 6.1 Cement Industry

Energy conservation and fuel substitution are of special significance to the cement industry. It has one of the world's highest specific energy consumption (per unit of product manufactured). Energy costs generally average 30-40 % of total production costs. A good example of the ability to recognize the problems associated with high energy consumption is illustrated with respect to the cement industry. Generally almost half of the total heat demand is used in drying the raw materials in the cement production process. About 80 % of the energy used in the cement process is consumed in kiln operation. It has been estimated that 75 % of a plants power requirements could be met with an on-site waste heat boiler for power generation.

Within the Finnish industry much attention has been paid to the high energy consumption for drying. It has resulted in the adoption of the semi-dry and dry processing methods in which the excess moisture is mechanically removed, figure 9. The respective energy consumption figures can be seen with reference to figure 10. The success of this type of innovation and its subsequent implementation rely on close cooperation between industry and plant manufacturers. In the case in question the requirements of the mineral processing and cement industries led to the development of a variety of automatic pressure filters which have also been subsequently adopted by, for instance the food industry.

### 6.1.1 Heat Storage in Klinker Burning

Waste heat from cement klinker burning kilns (mainly from satellite product coolers) is naturally available only during normal operation, interrupted by maintenance work. At such time the necessary electrical power must be obtained from other sources for raw and final milling needs. Energy storage is one solution to the problem. Principal features of an energy storage connected to waste heat recovery in the cement industry are shown in figure 11.

The storage unit is designed for use with dry process kilns and constructed of magnesia brick or cement klinker. There are two storage units, one accepting high temperature kiln waste gases at 800 to 900 deg.C (1500-1700 deg.F). The other unit stores waste heat from the clinker at 200 to 300 deg.C (400-600 deg.F). The storages can be charged independently, but discharged in series.

### 6.2 Iron and Steel Industry

Particular attention has always been directed at the iron and steel industry due to its national significance. However, irrespective of this attention, large national differencies continue to exist in the energy used to produce steel. ICC conducted a survey of the most effective energy conservation techniques in the steel industry. Eight of eleven firms surveyed reported that they had given priority to recovery of furnace waste heat. Heat recuperation proved to be the single most compelling requirement for mills in both developed and developing countries. The techniques employed covered a broad spectrum of activities and included the following:

- waste heat boilers and air recuperators
- blast furnace top pressure recovery turbines and equipment for the recovery of waste heat in stoves
- recuperators for preheating of combustion air by flue gas
- self recuperative burners
- heat recuperators in the rolling mills

The emphasis on heat recuperation appears to indicate both its conspiciousness as a source of waste heat and the relative assurance that its implementation will result in rapid pay-off.

Figure 12 show the major sources of waste heat in the iron and steel industry. Recovery of heat from the waste gases has received some attention although the utilization has generally been in low calorific form such as warm water. The successful recovery of waste heat from the gases resulting from the smelting process in high calorific form e. g. steam, and re-use for electricity generation, heating of combustion air and scrap preheating can lead to overall savings of 10-15 % of the total primary energy requirement for steel production. The benefits that can be brought about by efficient waste heat recovery can be extended to the community. This is particularly applicable in combined power and heating systems which can be extended to local communities.

### 6.2.1 Waste Heat Recuperator for Sinter Cooling Gases

A good adaption of the concept is implemented at the Rautaruukki Oy, Iron and Steel Mill at Raahe, Finland, figure 13. Waste heat is recovered from the sinter plant. Rautaruukki has 3 sintering machines in operation. They all have a heat recovery system connected to their cooling air duct.

Cooling air at approximately 300 to 350 deg. C (570-660 deg F) is ducted to a fin tube type waste heat boiler. In the boiler circulates district heating water and it is in parallell connection with the old duct so that it can be bypassed.

In series with the waste heat boiler is the mill power plant back-pressure fed steam/hot water exchanger. Thus the generation of district heating is secured also during maintenance and shutdown time at the sinter plant. In practice the back-pressure heat portion is about 10 % of the whole heat supply. The power plant feed water preheating is also connected to the waste heat system thus giving a possibility to balance the consumption during low district heating load.

The district heat supplied to the town of Raahe, which has a population of 19 000 is maximum 15 MW. The annual energy is 70 GWh and covers close to 90 % of the total demand. The waste heat boilers recover approximately 14 % of the total sinter plant heat consumption.

## 6.3 Aluminium Industry

An American recently implemented application of Fluid Bed Waste Heat Recovery has proved successful. Waste flue gas from a 83 t Alcoa aluminium melting furnace in Massena, NY, is cooled down from 1200 (2200) to 590 deg.C (1100 deg.F) generating 4.1 t/h steam.

The key component of the unit is a shallow fluidized bed in which fine alumina particles enhance heat transfer from the furnace flue exhaust to a finned-tube steam generator. One years evaluation and testing has shown potential for a performance increase of 32 % in terms of heat recovery and a 70 % reduction in the volume of the fluidized bed. This reduction involved replacement of the stainless steel distributor plate and cleaning brushes with a ceramic distributor plate and ceramic hot-gas lance assemblies, figures 14 and 15.

## 6.4 Copper Industry

As the result of extensive research work during 40 years, Outokumpu Oy of Finland has developed the Flash Smelting Process for direct smelting of blister copper from concentrate in one step. The basic idea of the flash smelting process is very simple. Dry concentrate is burned in air or an air/oxygen suspension in such a way that the gained combustion energy is immediately recovered in the concentrate smelting. Three conventional sub-processes, roasting, smelting and partly converting, are combined in one unit of the process. The main advantage with the process from an energy point of view is the utilization of the concentrate combustion energy. This heat is partly used for concentrate smelting and partly utilized through waste heat recovery.

## 6.5 Chemical Industry

Examples of common waste heat recovery applications in the chemical industry are product coolers, vent air exchangers, hot water and hot air from other processes. In all Finnish fertilizer plants for example the evaporation of ammonia with primary steam has been converted to low grade secondary steam. A good general view of the energy conservation opportunities through integration of energy flows between different chemical plants is shown in figure 16.

### 6.5.1 Heat Recovery in Sulphuric Acid Production

Sulphuric acid is one of the basic chemicals for fertilizer production. There are both brimstone smelter and roster plants in Finland. The sulphuric acid process produces heat and consumes electricity. The heat released in the process can be utilized as shown simplified in table 2.

Table 2 Waste Heat Utilization in Sulphuric Acid Plants

COMBUSTION GASES
- steam generation
- hot air generation

CONVETER GASES
- steam generation
- feed water preheating
- hot air generation
- hot water generation

ABSORBER ACID
- hot water generation
- feed water preheating

The heat quantity released in a 1000 t/d sulphuric acid plant amounts to 60 MW and has a composition as per table 3.

Table 3 Heat of Reaction for Sulphur Burning in a 1000 t/d Sulphuric Acid Plant expressed as MW capacity.

| | |
|---|---|
| Sulphur combustion | 35 MW |
| Catalytic oxidation | 8 |
| Absorption and acid formation | 16 |
| Dilution | 0.1 |
| Total | 60 MW |

The combustion gases are cooled in waste heat recovery boilers. The boilers are designed for high pressure steam to increase power generation in back-pressure or condensing turbines. In smelter or roaster plant boilers steam generation and steam superheating is kept at a stable and desired level by efficient and continuous heat surface cleaning.

In smelter or roaster gas plants hot air could also be generated from boiler exhaust gases if the acid dew point is correctly taken into account in the plant design. As is the case in the steel industry, converter gas heat is recovered as steam, especially in sulphur burning plants. A more common application is, however, feed water heating.

In Finnish sulphuric acid plants the converter exhaust gases heat is used both for feed water preheating as well as hot air and water generation before the absorbers. Absorption heat is normally released to the environment through the plant cooling system. Finnish plants utilize the absorption heat in hot water generation reaching temperatures up to 90 deg.C (190 deg.F). This medium grade heat is then used for process and heating purposes.

Waste heat utilization reduces sulphuric acid production costs remarkably because of decreased primary energy costs.

## 6.6 Forest Products Industry

A general survey of the potential waste heat resources, analysis and study of feasible consumers in an integrated forest products mill site was made in the early eighties. The integrate consisted of mills manufacturing mechanical pulp, chemical pulp, paper, sawn timber and plywood. It is situated in Varkaus, Finland. Table 4 gives an overview of the various mills and their energy intensity.

Table 4 Summary of the Varkaus forest industry integrate energy flows expressed as MW capacity.

| Mill | incoming energy | | | | / | outgoing energy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | steam | power | hot water | total | /fume /air | other air | clean water | fiber water | recov. | waste heat |
| paper-mill 1 | 41 | 17 | 11 | 69 | 30 | 14 | - | 42 | 20 | 66 |
| paper-mill 2 | 26 | 11 | 1 | 38 | 16 | 18 | - | 3 | - | 37 |
| board+ CTMP | 10 | 3 | 1 | 14 | 7 | - | - | 5 | - | 12 |
| GW-mill | - | 24 | - | 24 | 5 | 2 | 1 | - | 1 | 7 |
| TMP-mill | - | 46 | - | 46 | 27 | - | - | - | 25 | 2 |
| chemical pulp | 68 | 11 | 2 | 81 | 8 | 4 | 30 | 28 | 14 | 56 |
| saw | 6 | 2 | 9 | 16 | 4 | - | - | - | - | 4 |
| ply-wood | 14 | 3 | 3 | 19 | 3 | 6 | 5 | 1 | - | 15 |
| wood handl. | 2 | 3 | 31 | 36 | - | - | - | 10 | - | 10 |
| Total | 167 | 119 | 57 | 339 | 100 | 44 | 36 | 89 | 60 | 208 MW |

As a result of the large and profound study not yet utilized secondary heat sources amounting to about 200 MW was found. This corresponds to about 70 % of the mills' total consumed primary energy. Main part of the waste energy flows were in the temperature range of 35 to 50 deg.C (95-120 deg.F). In addition about one sixth of the totally utilized waste energy in the separate mills was covered by waste heat transferred between mills. In terms of temperature level new feasible waste energy users amounted to only 17 % of totally determined waste heat.

One main objective was the rearrangement of thermomechanical pulping (TMP) waste heat recovery to heat the district heating system of Varkaus town. The shortage of heat because of this was covered by utlizing new waste heat sources between the mills. In this work the scrubber proved to be an efficint piece of equipment for waste heat recovery, figure 17. Based on the results of the study an investment program amounting to about 10 million FIM (2.4 M USD) was made. It was anticipated to save about 11 000 t/a of oil, which means a pay back time of one year.

In the appraisal of the future utlization of the low grade waste heat sources, the fuel supply of the integrate becomes important because as the steam consumption decreases the fuels produced as by-products within the integrate will be sufficient for the steam demand. Especially in summer time bark will not be burned because of low steam load.

## 7 Cases with particular relevance for developing countries

### 7.1 Scrap melting

Heat recovery is implemented in a simple and straight forward way in electric induction smelting furnaces for iron scrap, figure 18. These furnaces are wide spread also in developing countries. Of the consumed energy 60-70 % is used for smelting of the iron, 10 % is lost in radiation and transformer losses and 20-30 % is transferred to the cooling water of the furnace. To storage furnace cooling water is 30-40 % of the used energy transferred, depending on the condition of the brick lining.

In a Finnish foundry with three 8 t induction furnaces only one is in use at a time. As storage furnace it has a 28 t grate induction furnace. In 1980 the smelting shop of the foundry used electric energy 9300 MWh for smelting and 2100 MWh for storage. Of the smelting and storage energy, approximately the following was recovered in cooling water:

0.25 x 9300 MWh + 0.35 x 2100 MWh= 3000 MWh equals 270t oil

This energy is used to preheat combustion air in the foundry. It can also be used to preheat scrap before smelting, which is the most profitable use of recovered waste heat in this context.

### 7.2 Lumber drying

The "dry-absorb" process: drying with air dehydrated by absorption in a hygroscopic solution, was outlined by Ms H. Desmorieux from Ecole Nationale Superieure des Industries Agro-Alimentaires du Cameroun at the sixth international drying symposium IDS'88 at Versailles in September 1988.

A similar process called ADIAC has been developed in Sweden. The ADIAC absorption process is based on a technology employing a chemical heat pump, using absorption technique as described above in paragraph 4.4.2. The heat pump increases the energy potential by transfering energy from a low to a high heat level without changing the entalpy, figure 19. The "engine" in this process is a highly hygroscopic and concentrated salt solution with a considerable boiling point raise. The adiabatic process starts immediately, when damp gas touches the salt solution in the absorber.

The water vapours in the gas condensates, because the salt solution has a lower vapour pressure than the gas. The condensation heat of the moisture raises the temperature of the salt. Because of the good thermal contact between the gas and the salt the higher salt temperature raises the temperature of the gas wihout changing the enthalpy. The final result is raised temperature and lowered moisture content of the gas.

The heated and dried gas then flows back to the dryer, where it is cooled and absorbs moisture through evaporation from the material beeing dryed. After the dryer the gas is again returned to the absorber. The result of the sequence is that the heat consumption of the drying process is only what is lost through convection from the equipment.

The water in the salt solution is evaporated in single or multiple stage evaporators depending on the need for secondary heat. The energy economic basis of the ADIAC process is that the water from the solution is removed in a multistage evaporation plant, which has a low energy consumption. Thus the heat consumption is only 1/2 - 1/3 of a conventional dryer.

A great advantage of the ADIAC process is that for lumber drying purposes the normal compartment kilns can be used. It only needs a replacement of the conventional air conditioning and heat recovery equipment with an adsorption unit and change in mode of air heating. Additionally the lowered heat demand causes a surplus of dryed fuel byproduct, which can be sold as a high grade fuel. It is also possible to increase the biodryer capacity to some extent which would emphasize the central role of the sawmill as waste wood fuel supplier.

An example from Sweden shows in figure 20 how the process works in a lumber dryer of the Bygdsiljum sawmill. It has a capacity of 60 000 cu. m/a. Drying is made to 70-75 % DS in four lumber and one bark dryer with a total capacity of 4-4.5 t/h evaporated water. The heat demand for the compartment kiln is transferred so that the heat flow also takes care of the function of the compartment kiln and the biofuel dryer. The transfer of the high grade heat coming from the boiler to low grade heat needed in the compartment kiln is thus made in such a way that change of grade is utilized in the regeneration of the absorption liquid.

The investment in Bygdsiljum was approximately 1.3 million USD, the price for sold dried fuel 10 USD/cu. m and thus the pay back time around three years. Because the price of the evaporation does not grow with capacity, the economy improves with the size. The economy of the process is heavily depending on the value of the sold dried fuel, and has to be evaluated for each saw mill separately. The ADIAC process is marketed by Ahlström-Rosenblad Heat Engineering, Stockholm.

## 8 Summary and Conclusions

Waste heat recovery is feasible only if the recovered heat can be utilized in such a way that it decreases primary energy consumption. Consequently this means that the higher the temperature level at which heat recovery is implemented the better the prospects are for a feasible project. Additionally this primary energy should be generated with the most expensive fuel used. There is no sense in utilizing recovered waste heat in processes that are fuelled with for example byproduct fuels.

Recovered energy is valuable if it is controllable. If controllability is not possible, then the recovery must form a part of the base load of plant requirement. The compatibility of a recovery system requires careful consideration. The operation of the primary energy generator, from which the waste heat is recovered must be consistent with the operation of the end users of the recovered heat. If that is not possible suitable heat sinks, or alternative uses must be available. Should neither of the above cases be guaranteed, a heat storage need to be provided, though it should be used as little as possible.

It is important to bear in mind the positive impact waste heat recovery has on the environment. Internal process adjustments in combination with secondary energy utilization can raise considerable cost savings for environmental protection as well. Latest combustion technology especially involving fludized bed technique combines decreased emissions with efficient energy utilization.

## ANNEX 1

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Waste Heat Recovery as a part of Energy Conservation in Industry

## ANNEX 3

## Industrial and municipal co-operation recommendations to national authorities

### Promotive measures for waste heat recovery

Governemental action should create improved opportunities for the industry to recover its waste energy and use it for district heating on the following basis:

1 Equipment for waste heat recovery is purchased, installed and maintained by the industrial enterprise.

2 The district heating network is constructed and maintained by the municipality.

Necessary action from the governement include following items:

1 The price of the waste heat used for district heating is determined uniformly and in relation to the price of oil when the waste heat recovery is replacing energy in part or completely from a heating plant run by the municipality.

2 The investment in waste energy equipment is covered by favourable state guaranteed loans. The investment should have free deduction rights.

3 For the construction of the district heating network favourable state guaranteed loans should be available.

4 Costs for studying the feasibility of waste heat recovery sould be covered by the state.

5 The terms of financing should encourage co-operation between the surrounding community and the industrial enterprise.

6 The decision making boards should include representatives of municipality authorities.

**ANNEX 2**

5.5 hot water
5.6 secondary heat

6 Electric power consumption situation
6.1 installed electric power
6.2 specification, efficiency and utilization factor for electric power consuming devices over 50 kilowatts

7 Power generation specifications
7.1 capacity and efficiency of boilers and turbines
7.2 fuel quality and consumption
7.3 steam generation
7.4 steam to turbines
7.5 steam to process
7.6 back pressure steam to process
7.7 electric power generation efficiency
7.8 condensate reclamation
7.9 feed water make up
7.10 flue gas composition, flow and temperature

8 Millwide compressed air system
8.1 list of largest consumers of compressed air

Waste Heat Recovery as a part of Energy Conservation in Industry

## ANNEX 2

## Waste Energy Conservation studies

The following material and data of a mill, plant or production unit are necessary for a succesful Waste Energy study:

1 Flow sheets for:
1.1 main production process
1.2 by-product process
1.3 power generation
1.4 steam lines
1.5 electric power system
1.6 fresh water and sewer system
1.7 plant ventilation system

2 Monthly production, or consumption for a fixed 12 month period of:
2.1 main products
2.2 by-products
2.3 raw-materials
2.4 heat; steam and hot water
2.5 electricity
2.6 fuels; oil, gas, solid fuels
2.7 fresh water
2.8 compressed air
2.9 waste products
2.10 waste water
2.11 exhaust gases
2.12 ventilation exhaust
2.13 flue gases

3 Composition, flow distribution, temperature, temperature distribution, corrosive properties, enthalpy and heating value for:
3.1 raw materials
3.2 products
3.3 main solid waste, water and condensate streams
3.4 main exhaust gas and steam flows

4 Ambient air and water temperature distribution

5 Energy prices for:
5.1 fuels
5.2 by-products used as fuel
5.3 electric power
5.4 steam

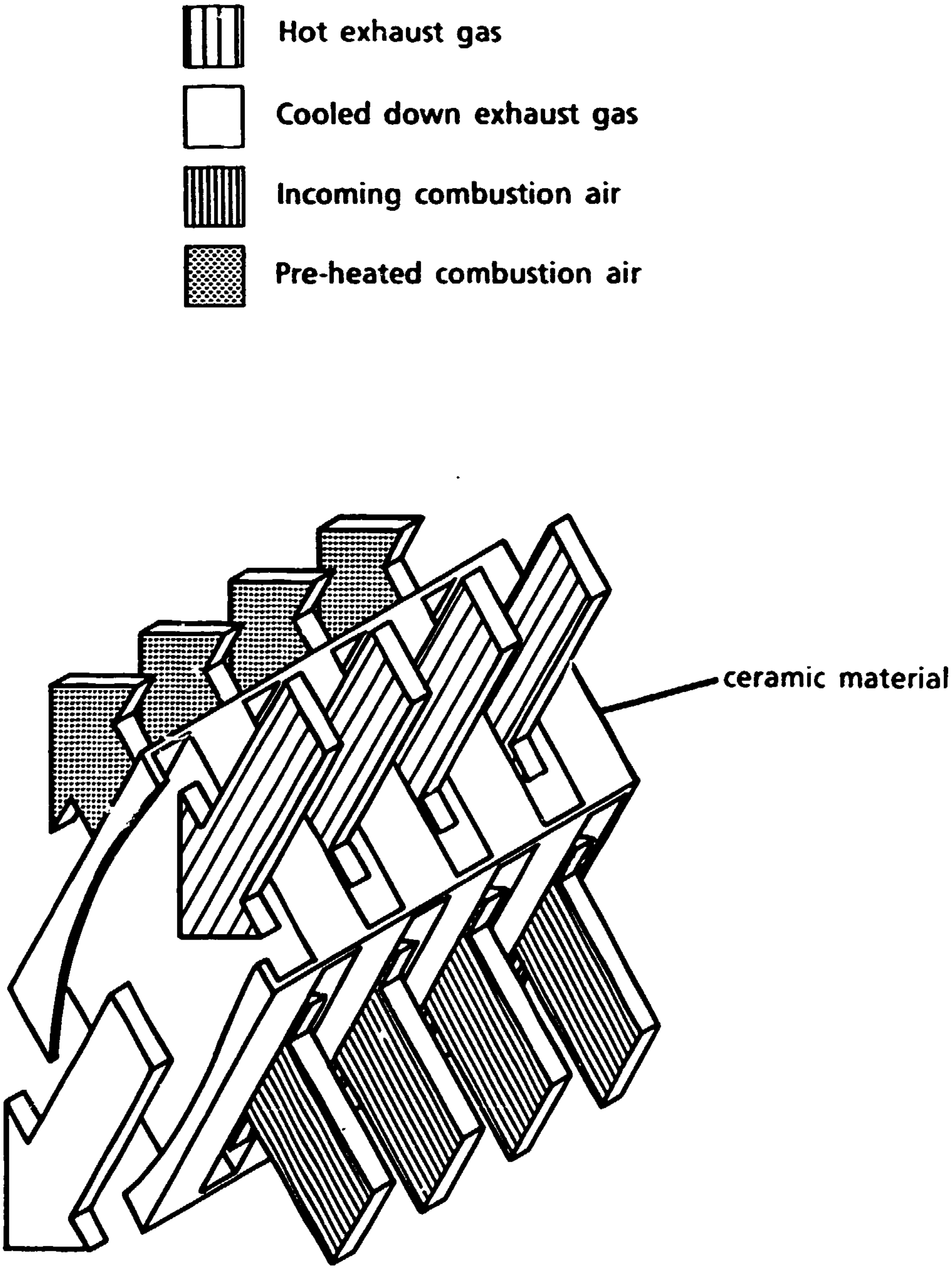


Figure 1. Recuperator

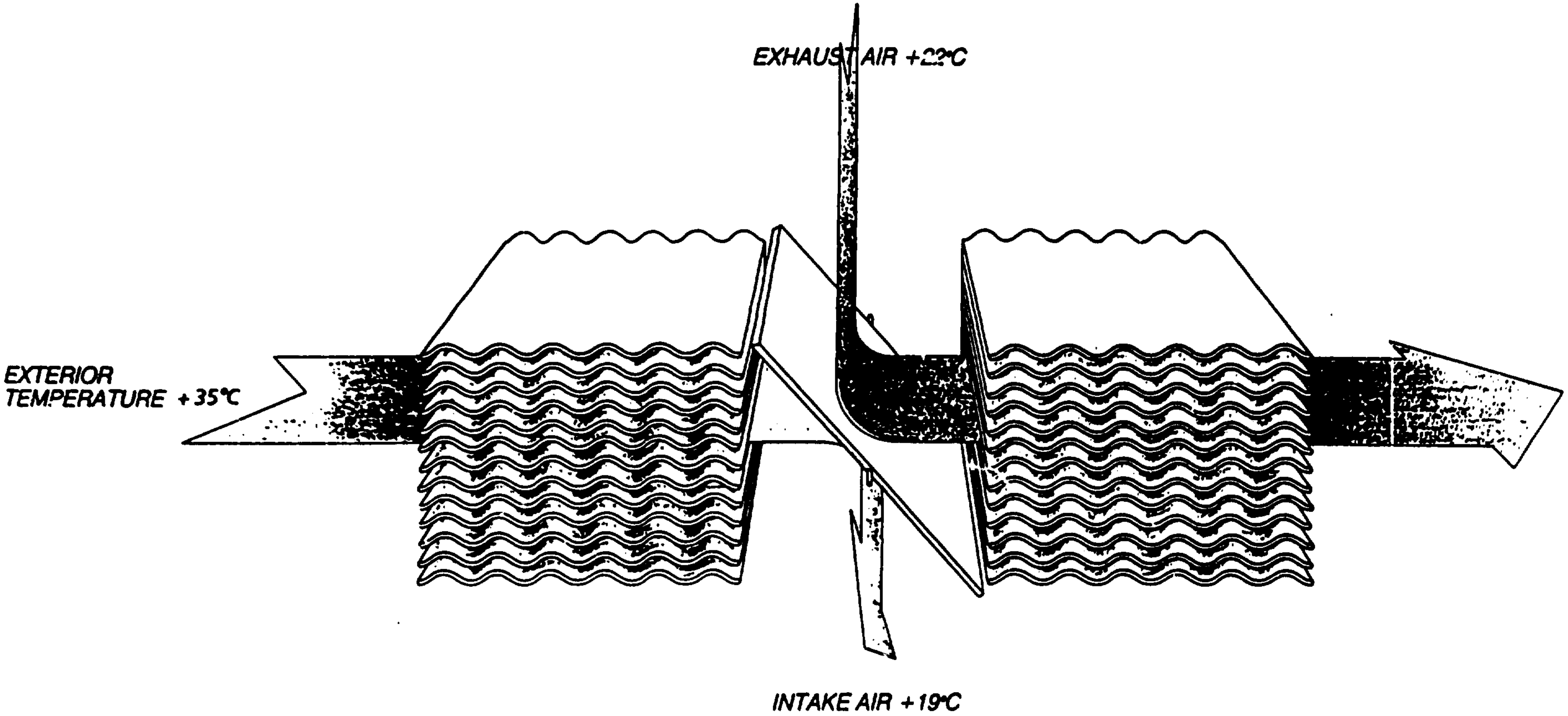


Figure 2 Principle of heat regeneration

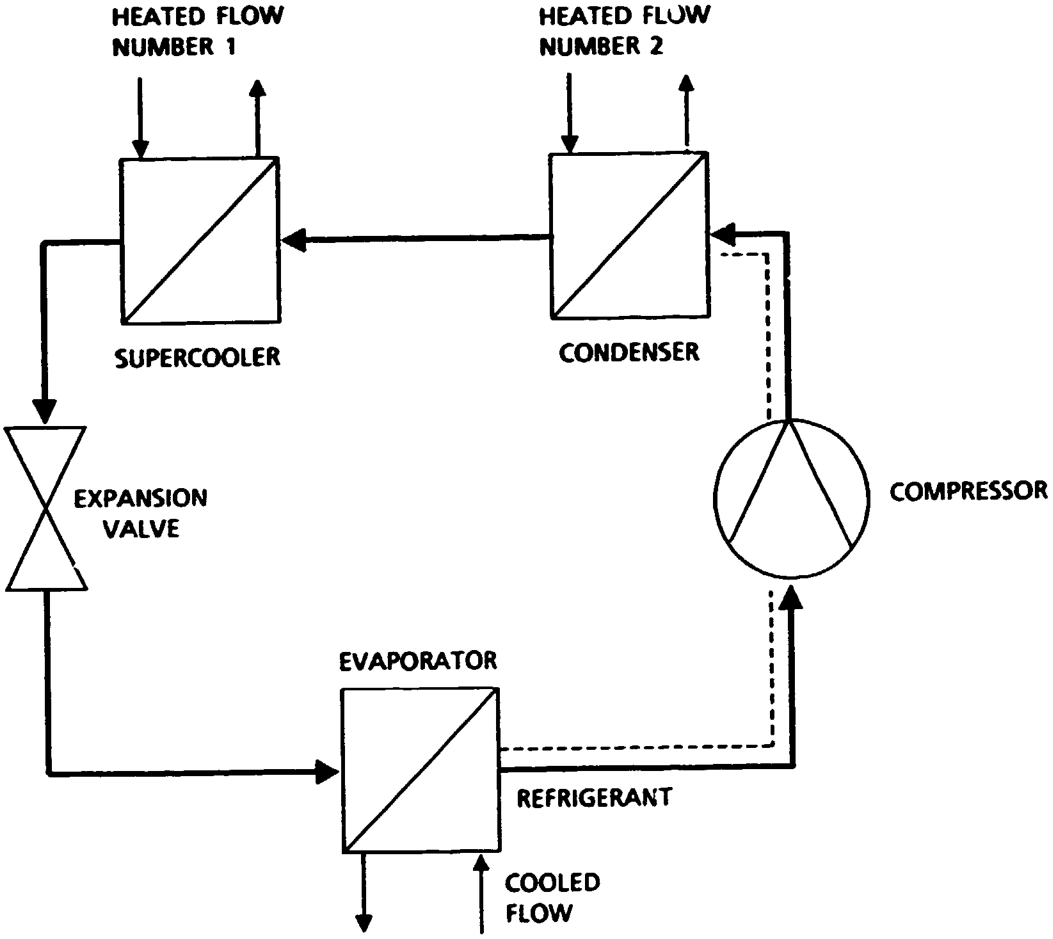


Figure 3 Simplified compressor heat pump circuit

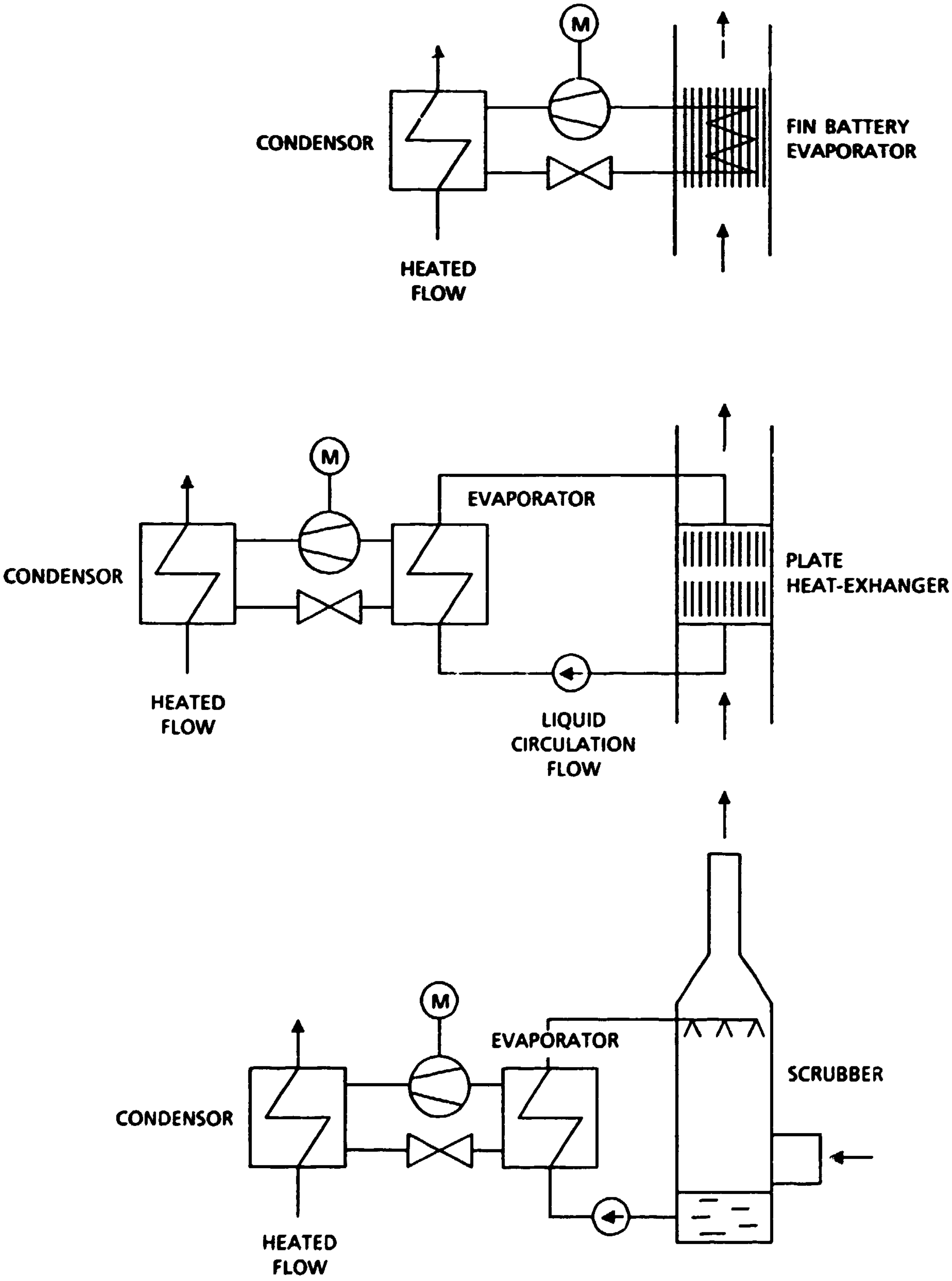


Figure 4 Waste heat recovery from gases with a compressor heat pump

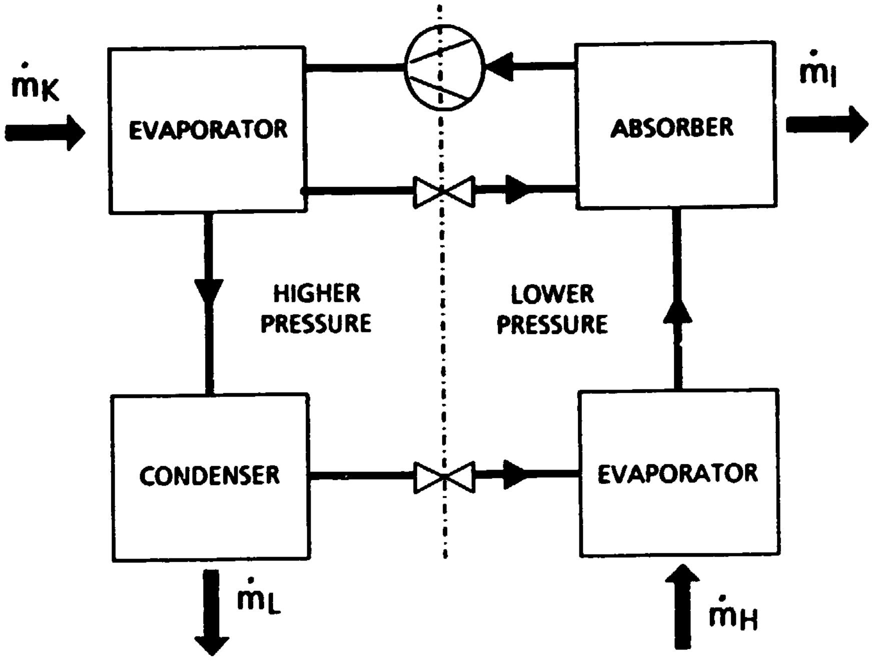


Figure 5 Simplified absorption heat pump circuit

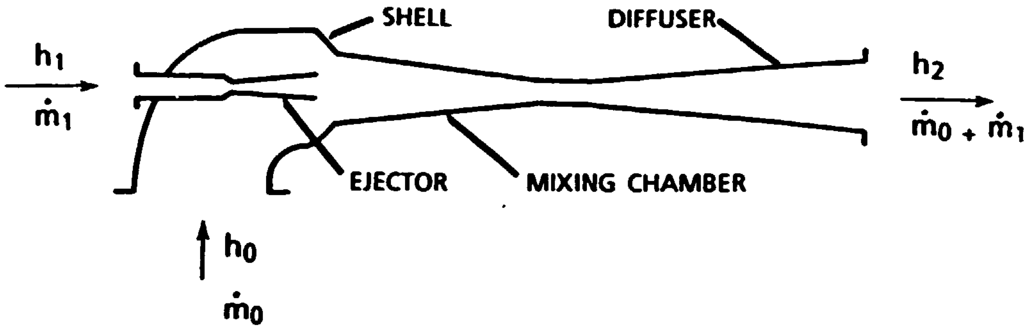


Figure 6 Steam ejector assembly

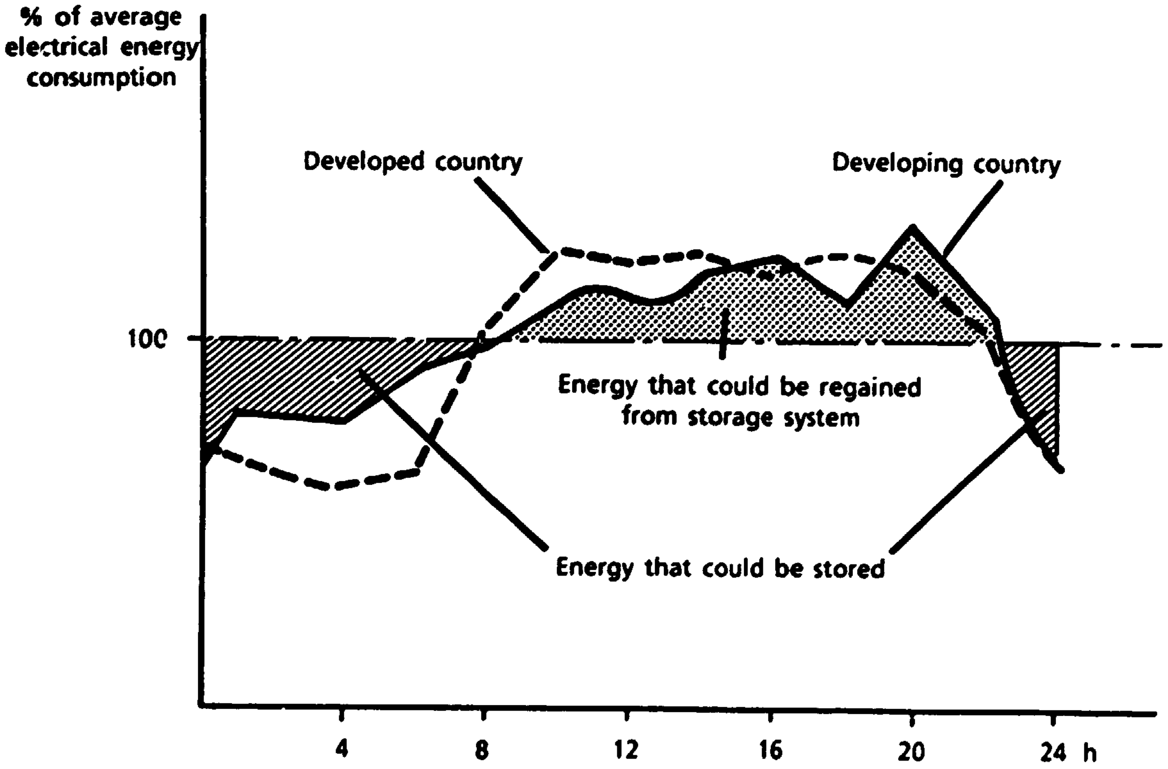


Figure 7 Typical electricity load curves in medium load season in a developing country (Thailand), and a developed country (Finland)

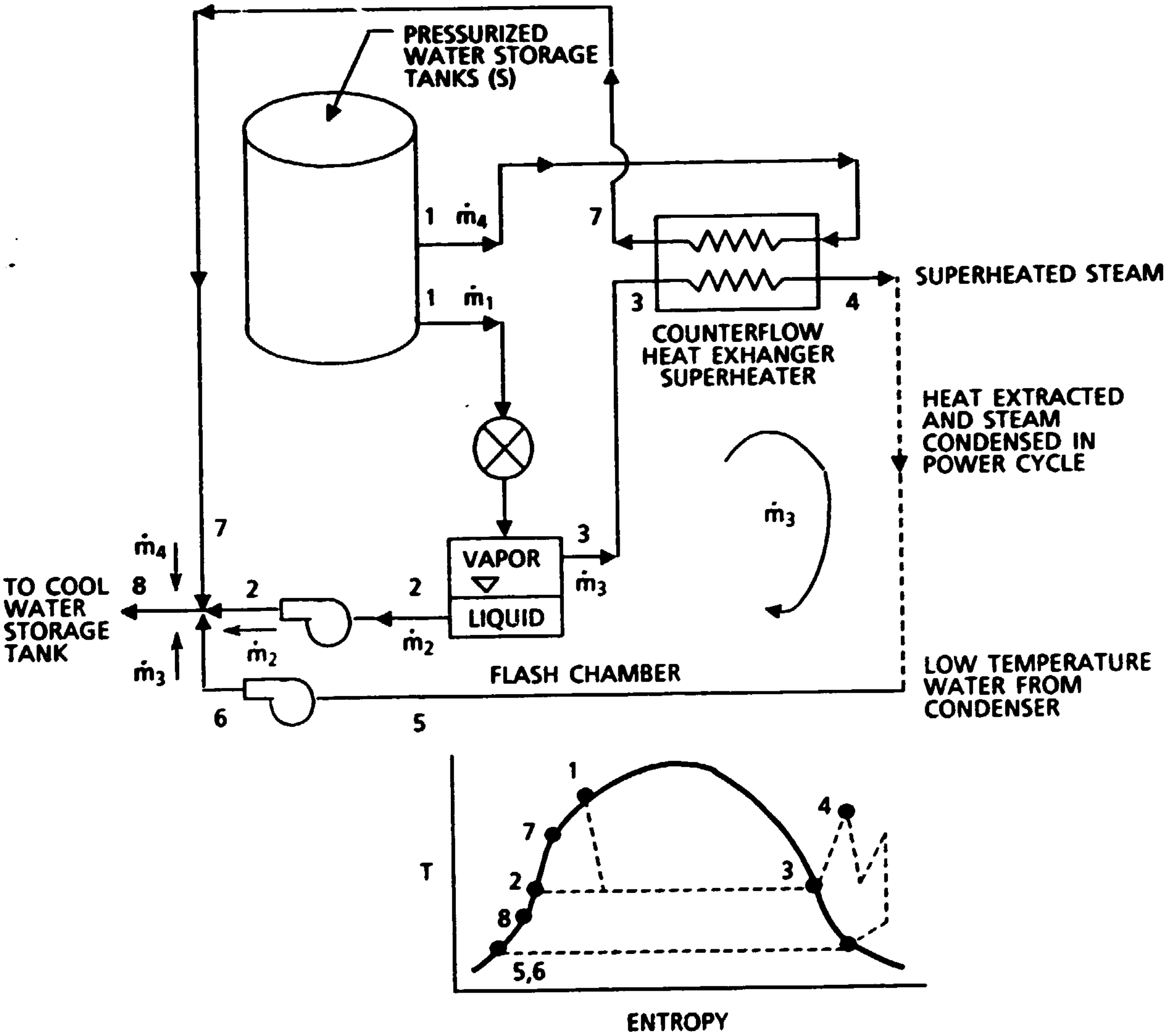
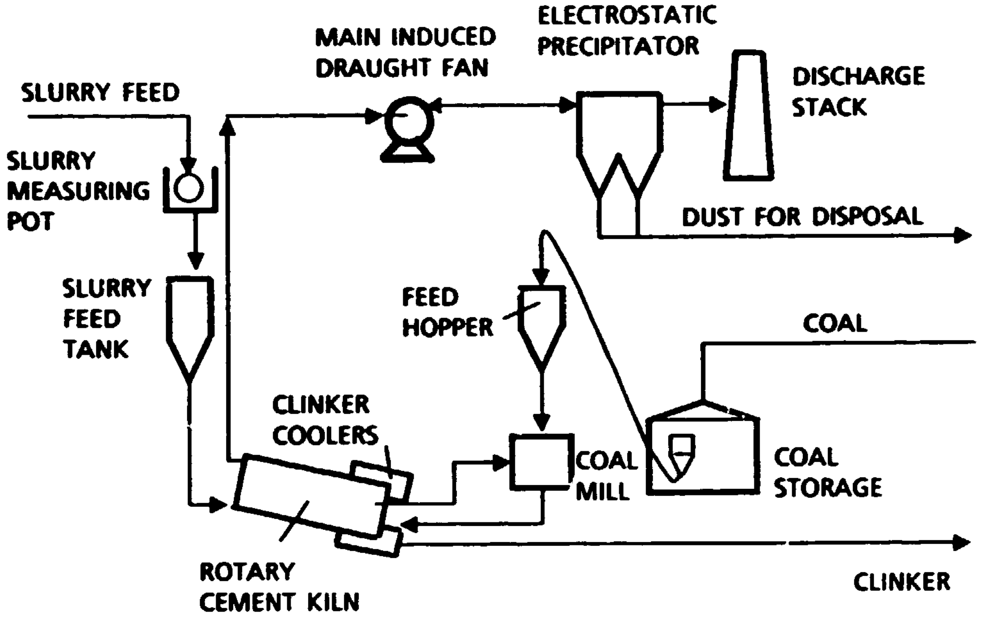


Figure 8 Heat storage system for producing super-heated steam

"WET" PROCESS



"SEMI-DRY" PROCESS

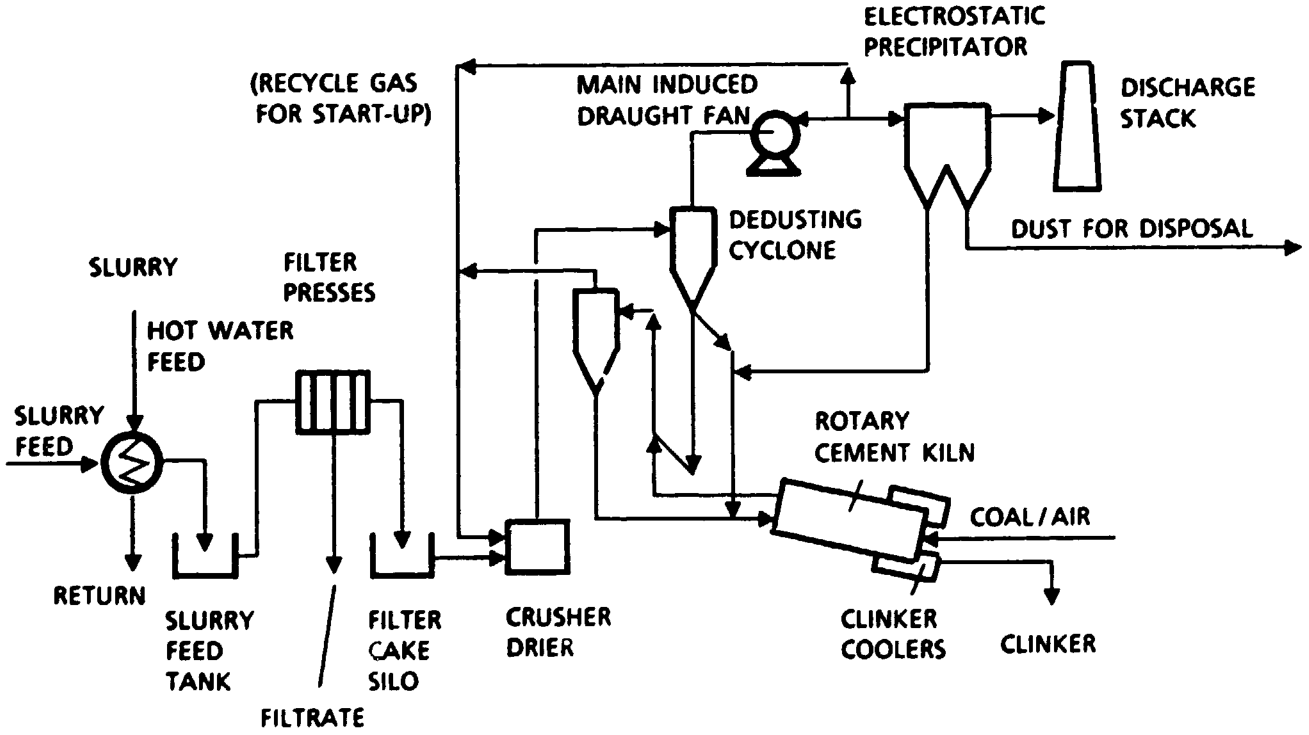


Figure 9 Prosess flow sheets for wet and semi-dry cement production

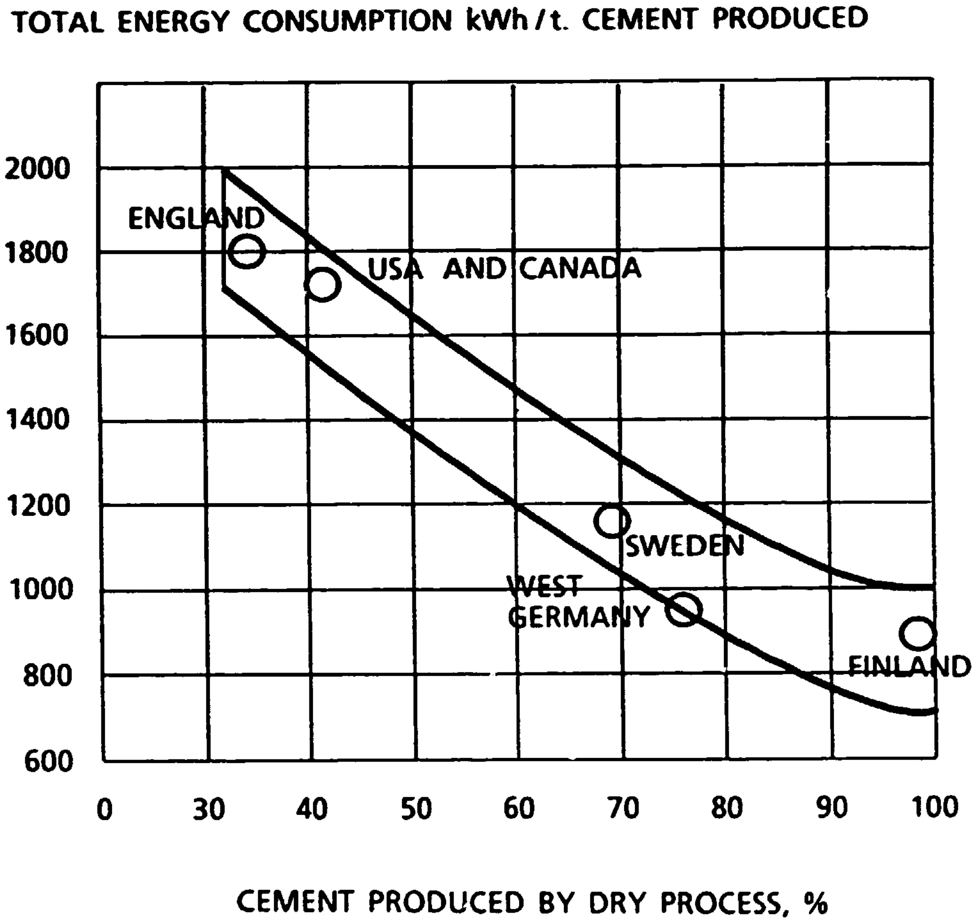


Figure 10 Specific energy consumption for cement production

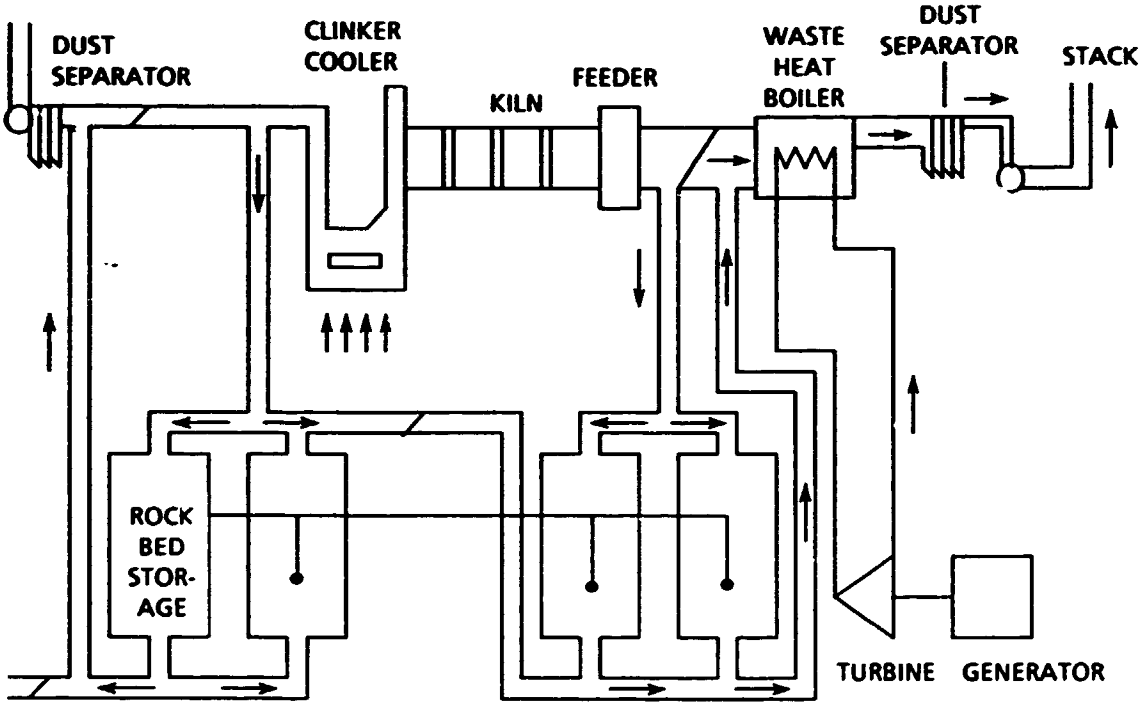
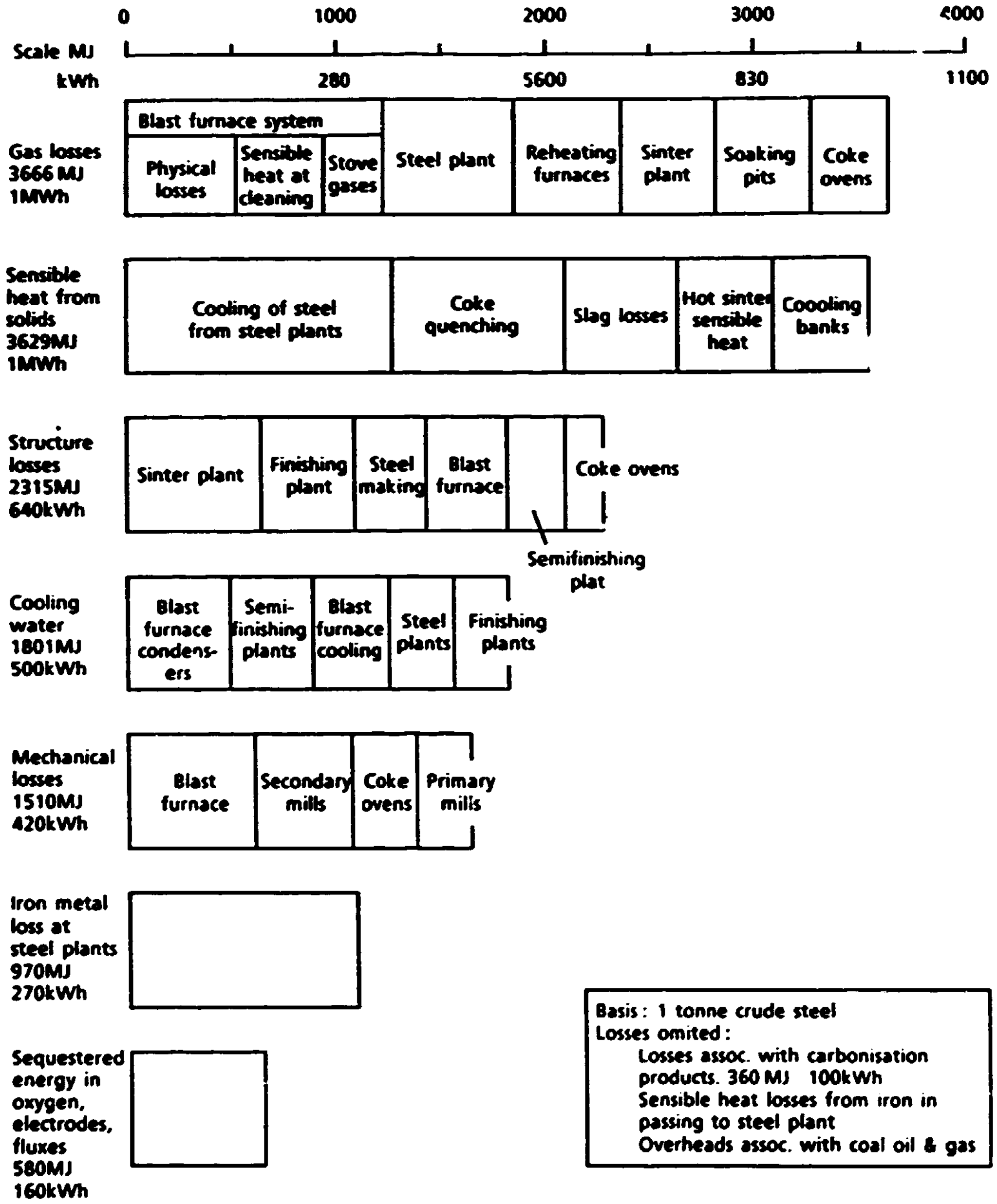


Figure 11 Principal features of waste heat recovery and storage in the cement industry



Basis: 1 tonne crude steel
Losses omited:
Losses assoc. with carbonisation products. 360 MJ 100kWh
Sensible heat losses from iron in passing to steel plant
Overheads assoc. with coal oil & gas

Figure 12 Sources of energy loss in iron and steel production

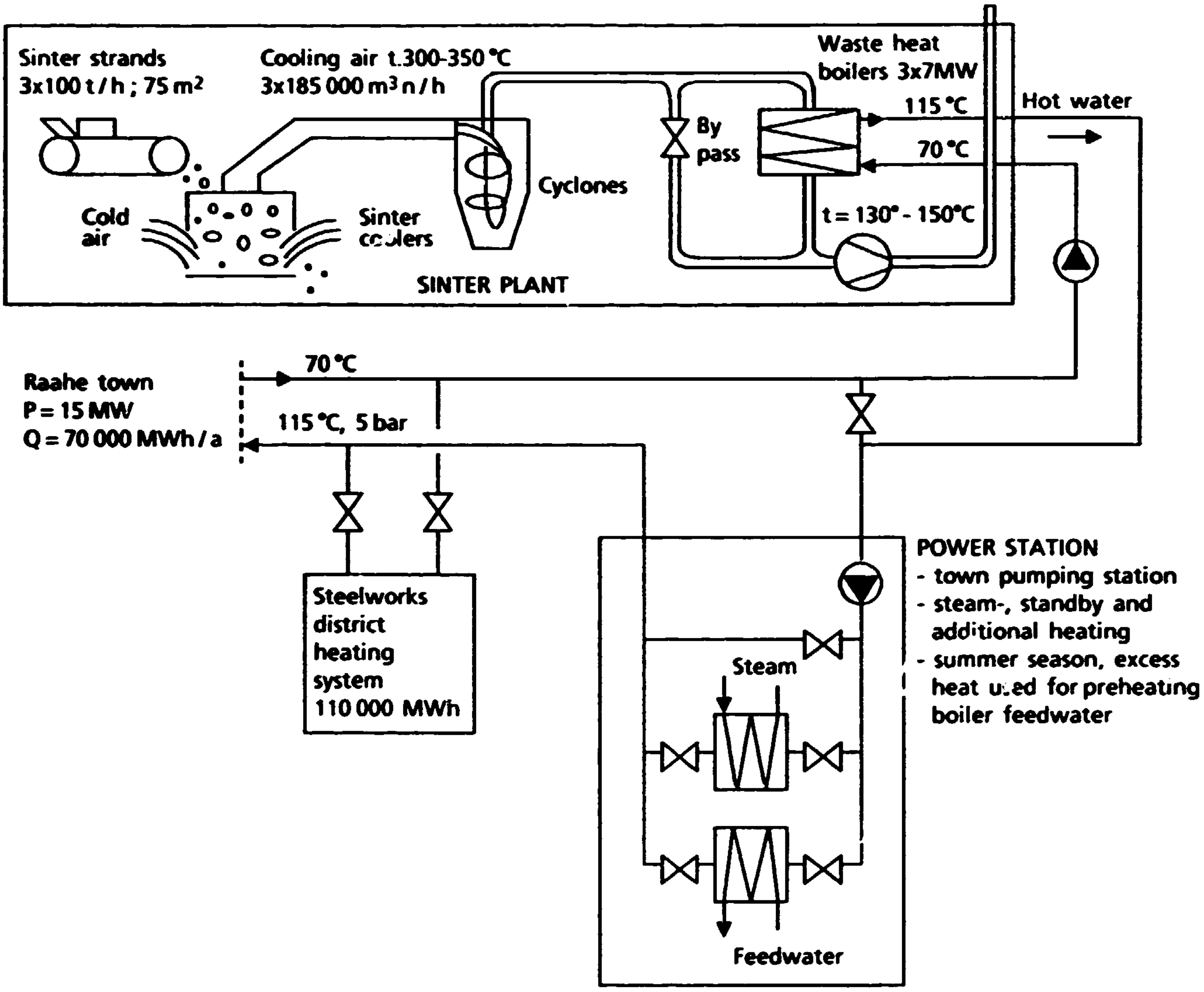
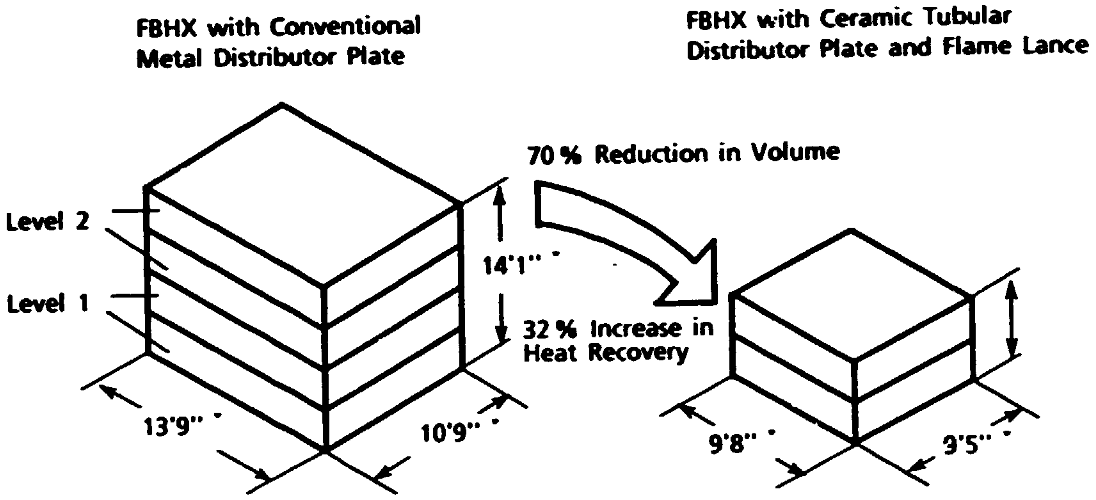


Figure 13 Waste heat recovery at the sinter plant of Rautaruukki



FBHX with Conventional Metal Distributor Plate

FBHX with Ceramic Tubular Distributor Plate and Flame Lance

73% of Theoretical Heat Recovery
(Because of Air Dilution to 600°C Inlet)
17m2 Active Bed Plan Area
(Requires Two Levels in Parallel)
Simple Payback of 20 Months
59m3

.96% of Theoretical Heat Recovery
No Air Dilution Required
4,6m2 Active Bed Plan Area
Simple Payback of 13 Months
18m3

Figure 14 Comparison of conventional metal and ceramic tubular (with flame lance) distributor plates.

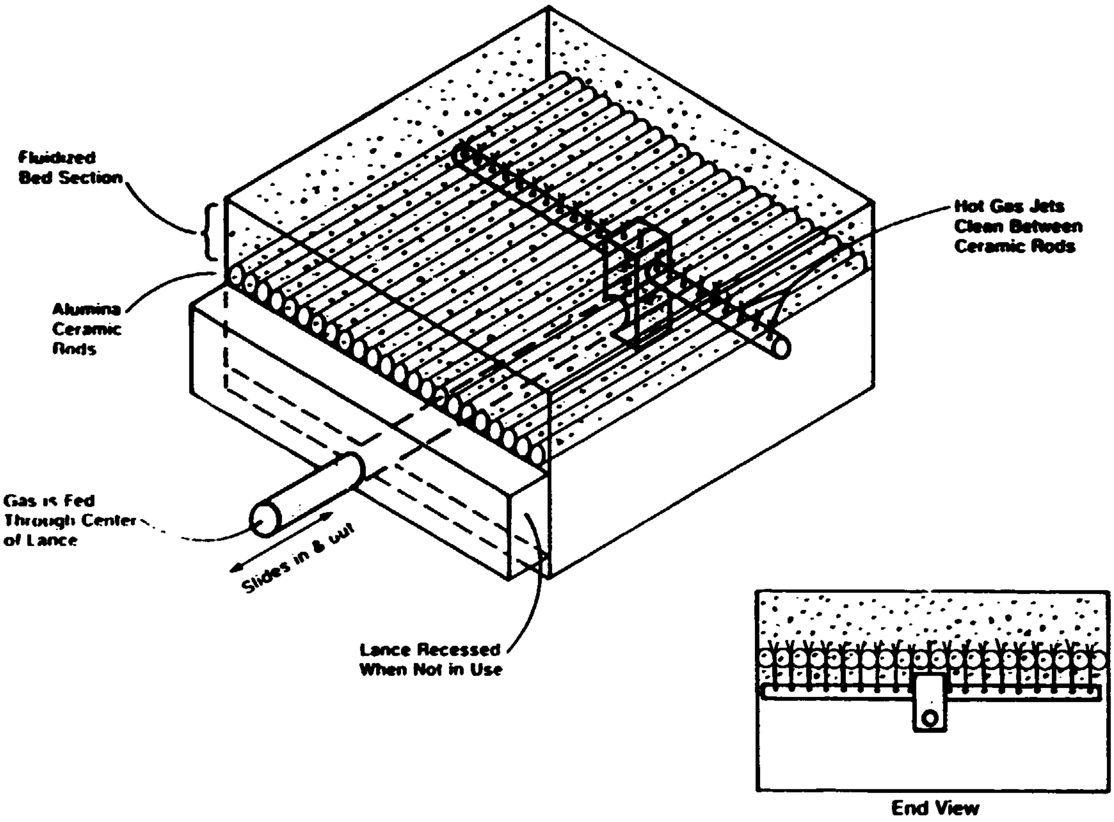


*Fig. 15 Perspective drawing illustrating function of ceramic hot-gas lance assembly.*

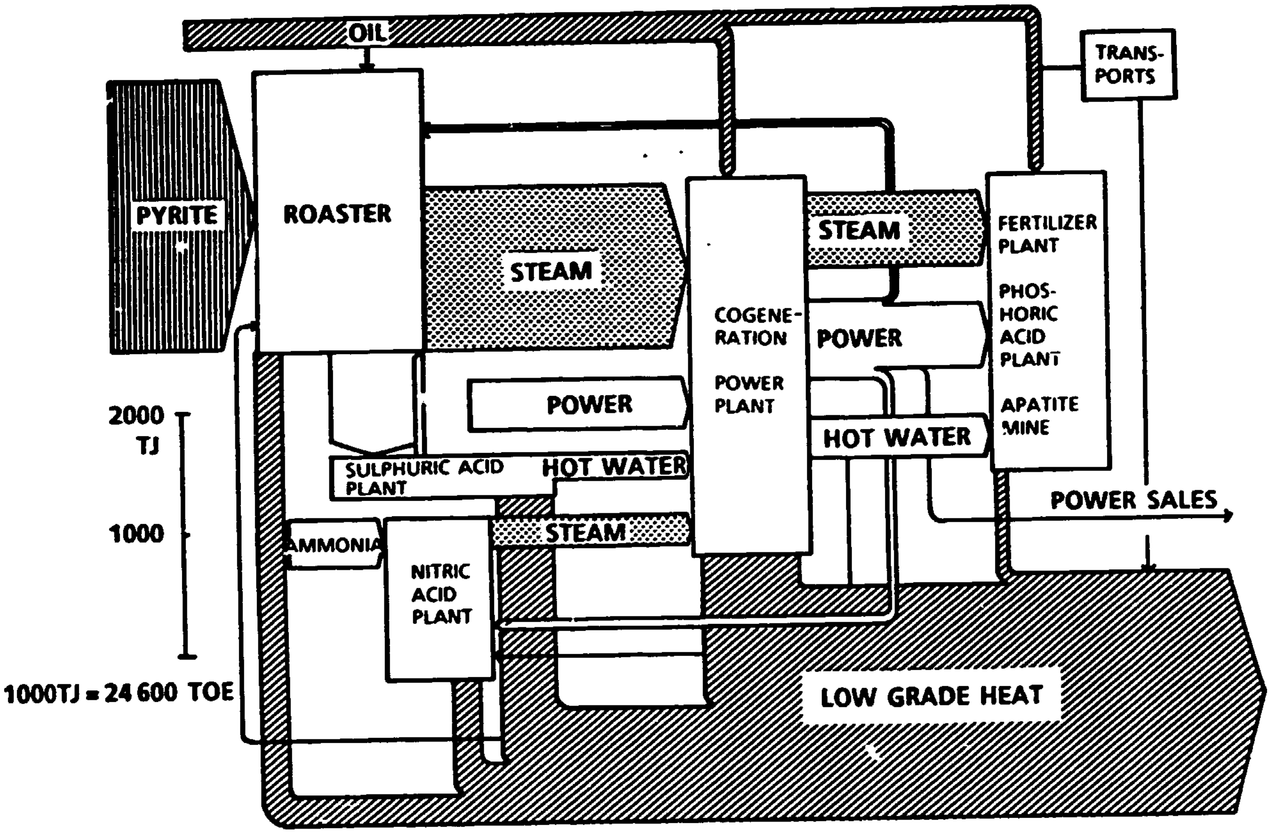


Figure 16 Kemira Oy Siilinjärvi works and mine energy balance 1982

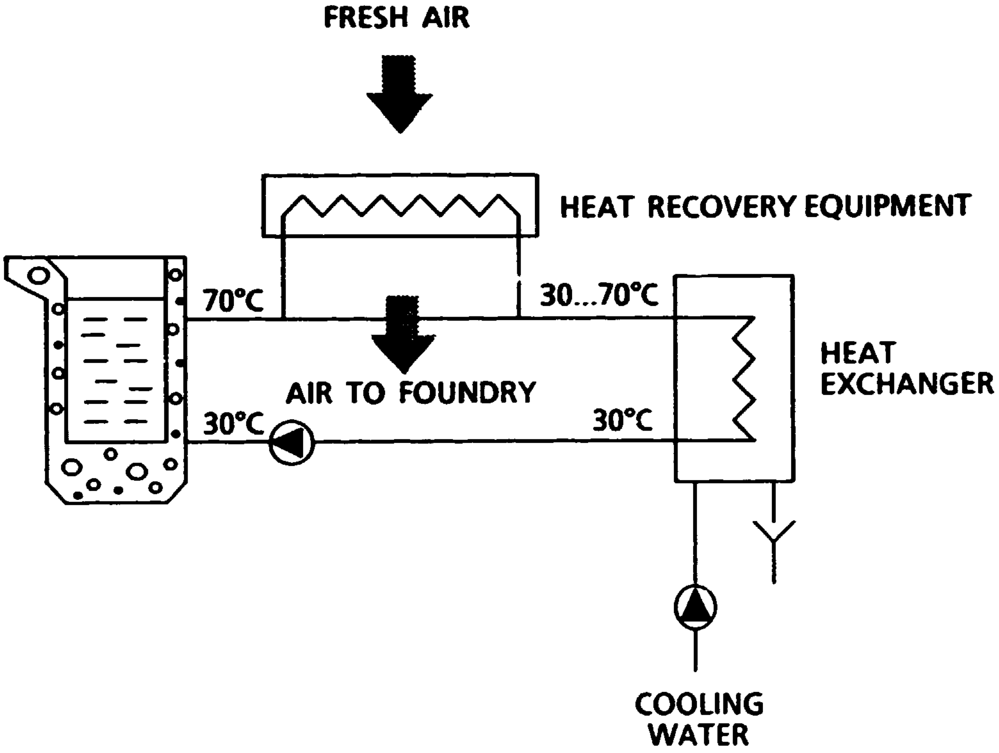


Figure 18. Principle of a foundry circulating water system

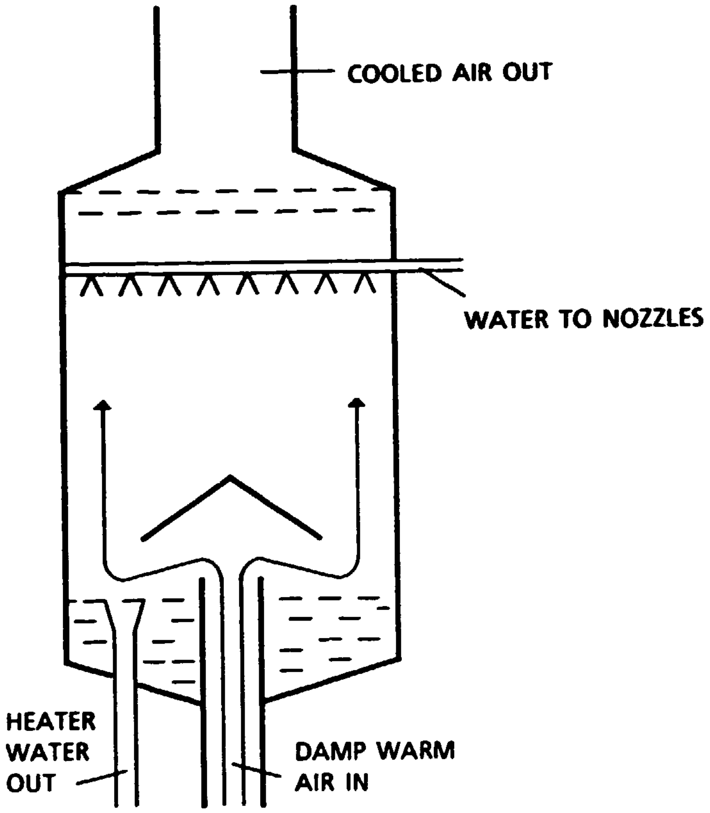


Figure 17 Principle design of a scrubber where the heated water is dispersed to droplets that act as heat transmission surfaces

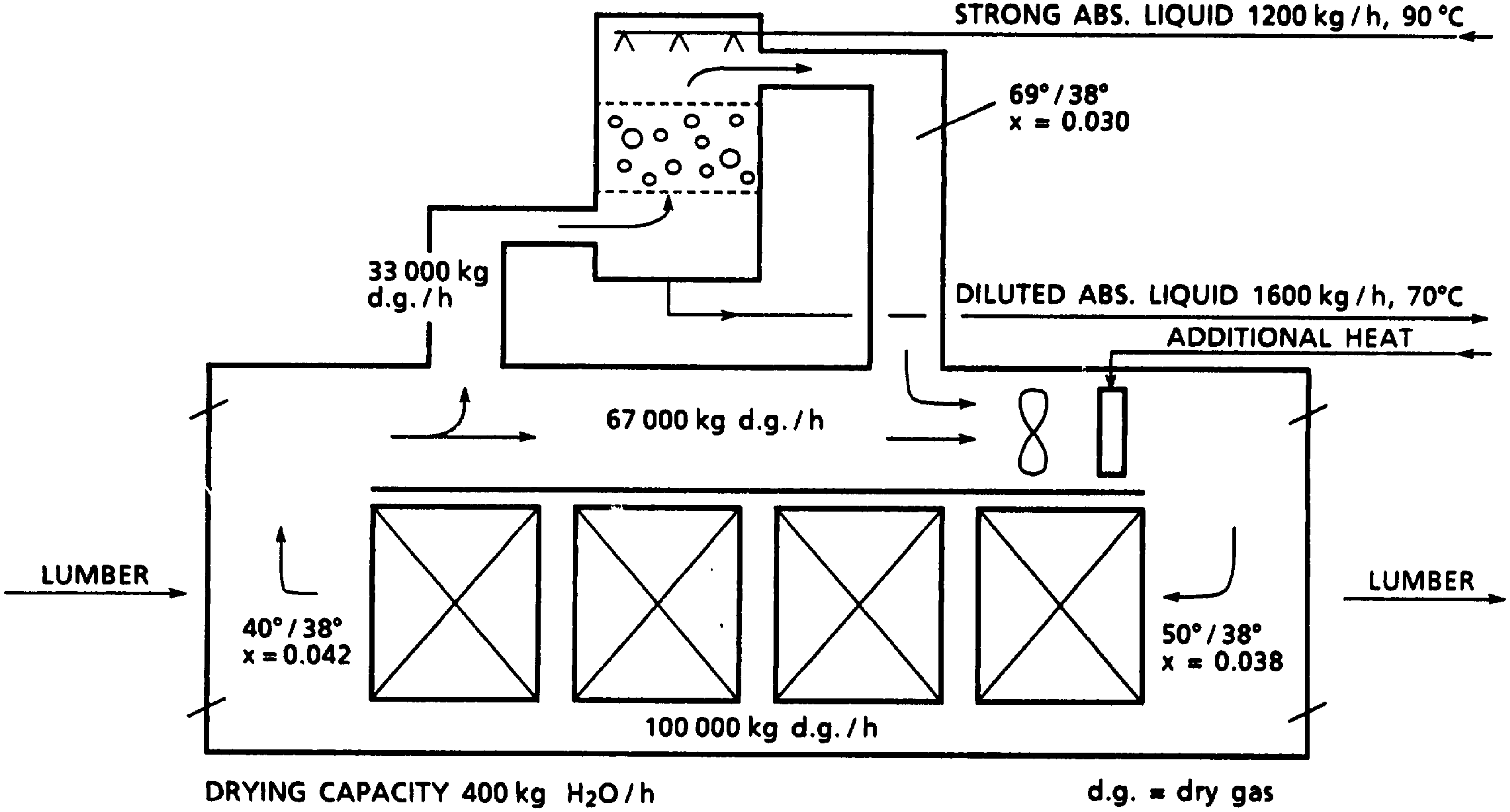


Figure 19. ADIAC absorption dryer

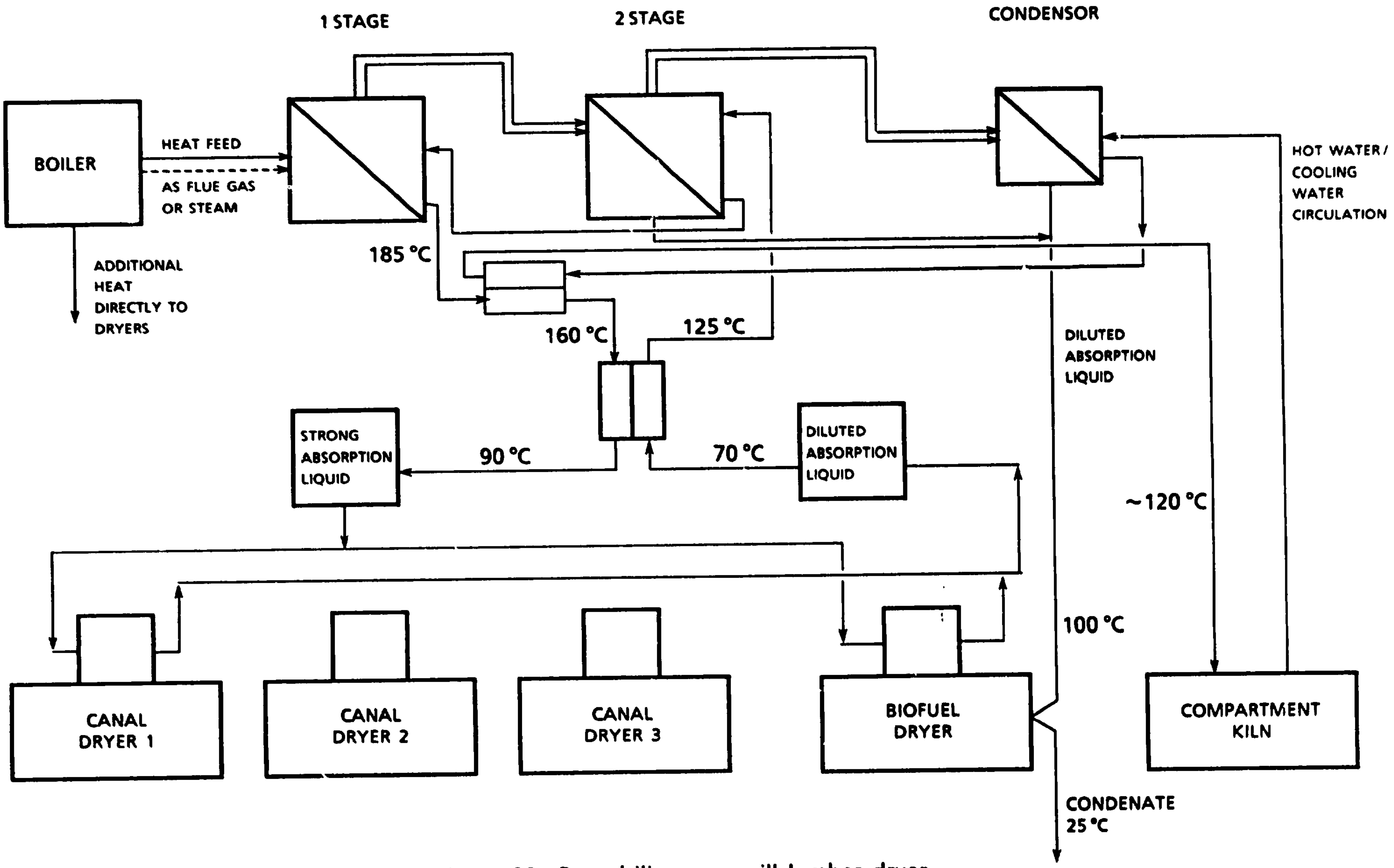


Figure 20. Byggdsiljun saw mill lumber dryer