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ENERGY CONSERVATION IN GAS AND REFINERY INDUSTRIES. IN EGYPT

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Prepared for the Government of the Arab Rebublic of Egypt by the UNDP, ececuting agency for the United Nations Development Programme

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This report has not been cleared with the United Nations Industrial Organization which does not necessarily share the views presented

Contents

BRIEF ABSTRACT

In gas and refinery industry of Egypt the most potential objects are to conserve energy are

-Furnaces by means of flue gas quality control, air-preheating, insulation, use of non sulphuric fuels

-Heaters by maintaning their efficiency good ,applying high quality feedwater, cleaning (off/on line) and cascading energy flows correctly

-Electric systems by applying frequency converters and improving the power factor individually or in plant scale

-Automation by optimized quality control, special instruments (IR, O2)-analyzer, start-up automation. This is often an inexpensive method.

-Low quality heat recovery by vacuum evaporation to prepare high quality process water

-Solar systems have few ecomically viable applications in petroleum industry

-Combi/co-generation of steam and electricity is an important energy conservation potential in company and national level. Investments about 600-800 USD/kW. This promotes the fuel efficiency 40% to 80%.

-Optimized reliability since run downs result in losses of the process latent heat.

-Application of right materials since this is often the constraint when trying to conserve energy.

-Preventive on corrective maintanance have potentials to conserve energy.

A cautios estimate is that nearly 70 M USD/a can be saved and the return on investment varies 0.5...5 years. Fastest results are obtained if concrete energy saving projects will be started in existing refineries.

ACKNOLEDGEMENTS

I wish to thank all of my partners that these results of this short mission have been obtained. Especially ENPPI, UNDP/Cairo, UNIDO/Vienna and my permanent employer Imatran Voima/Finland have assisted very much. The next step is to start applying energy conserving technologies in existing and coming plants.

1. INTRODUCTION

Egypt's one main source of energy is oil and gas and the known resources are estimated to last the next 15 years unless new discoveries will appear. Oil is one major item for exports and the country needs urgently foreign trade because of the rapid process of industrialization. Energy conservation promotes this objective, although the domestic prices of energy are only 30 % of the current world market price.

The present production level is 40 Mtons/a and the production of gas is increasing. About 18 Mtons/a are refined in Egypt and therefore there is a potential to increase the refining industry and to export refined products instead of crude. Egyptian crude is rich in sulphur which tends to decrease its value. Complete sulphur removal makes oil fuels incompetitive. The harms are reduced efficiency as fuel, environmental pollution and more inconvenient for further refining as rawmaterial for petrochemical industries.

Natural gas has the merit to be nearly sulphur free and it is therefore better for combustion and as rawmaterial. It is inconvenient to be exported and therefore domestic uses are vital. The gas production is growing in the near future because of new discoveries.

Energy conservation yields fringe benefits if correctly done like

- reduced pollution
- investment savings through lighter piping eg.
- reduced maintenance eg. heaters or electric motors run by frequency converters
- utilization of low quality heat may produce high quality water for communities
- it does not necessarily harm the domestic pricing policy of energy, it is a technological means
- energy conservation improves often the quality of products eg. improved level of automation

Petrochemical industry is a major energy consumer although it produces energy. 2-10 % is burnt depending on the level of refining. There is a number of means and process equipment where energy conservation is justified. The most potential areas in petrochemical industry are

- furnaces, heaters, electric drives, co-generation

It is estimated that 5 % of the total crude is burnt ie 0.9 Mtons in Egyptian refinery industry. By fairly straightfoward methods 10 % of this amount can be conserved ie. 0.09 Mtons/a. If this is converted into US dollars it means 17 M USD/a. One has to invest to obtain this conservation. In most cases the return of investment is less than 2 years. There are also cases where the return on investment is too long and therefore the ROI analysis is always necessary at a certain level. There might be some inaccuracies, because invitation of bids is sometimes too tedious to make correct estimations. One is often satisfied with rules of thumb to obtain a sufficient estimation. However, this estimation is always to be carried out although less accurate.

Energy conservation is possible when designing, operating or maintaining plants. When handling energy savings are possible in various phases like

- -generation
- -transmission
- -consuming

Enppi's role in this matter is to design energy efficient systems. This is an important phase since process changes afterwards are costly because of investments and outages when the latent process heat and production is lost and changes in this phase tend to be timeconsuming and tedious. However, upgrading existing processes is an important potential also for Enppi's activities. It is necessary to remember that energy conservation finally takes place in the processing plant after all. Enppi's role is to provide options for this.

There is no unique method to conserve energy. Instead there is a number of methods and a certain philosophy is to be assumed.Energy has quality in addition to quantity although the existing SI units poorly observes this feature. To develop this philosophy the concept of available energy has been introduced called sometimes exergy. Preparing exergy flow diagrams for process plants one is able to locate in detail the energy conservation potentials. This is also an illustrative method because of graphical approach. This is a more advanced method than the conventional energy balances, which are suffiecient in some cases. One has to realize that recovery of only available energy is worth consideration, when there is some value left and it is good for other purposes. This automatically leads to the correct energy cascading principle. The exergy concept does not replace the ROI calculations, on the contrary it complements.

The exergy principle maybe at first sight abstract and therefore the conventional energy balances can be used parallelly. This concept,however, provides a powerful means to calculate efficiencies uniquely and balance limits can be selected flexibly. This justifies this approach. It is applicable for existing and new plants. It gives a good insight of the energy consuming or generating processes.It was first intoduced by Z.Rant in 1956.

2. RECOMMENDATIONS

A detailed feasibility study on co-generation potentials in existing and coming refineries. This option has national interest in the short run to face the growing demand of electricity.

Automation seems to be the least expensive method to save energy. Fast results may be obtained in existing refineries. Furnace controls and on line product quality control are clear potentials to be started with. One should be ensured that the basic instrumentation is sufficient to monitor the performances of essential process components.

Gas should replace fuel in order to promote oil exports in Egypt. Gas has certain merits (low S-content)

Feedwater quality survey and its impact on heater performances.

Preparation of detailed Sankey diagrams (available energy principle) for coming and existing refineries to locate energy conservation potentials.

Feasibility study of the fitness of multiflash vacuum desalination technique for existing and new refineries. The potentials are evident.

Increased application of frequency converters instead of choking flows.

Training of Enppi's people abroad with clear objectives eg. study of preheater materials to lower the final outlet temperature or application of automation to conserve energy.

Developing preventive and corrective maintenance techniques to conserve energy.

Application of power factor control in refineries.

Feasibility study on what are Egyptian potentials to produce energy conserving equipment.

To start a selected project (eg. furnaces) jointly with refineries to get real results and training in energy conservation. Examples of activities are annexed.

Enppi's organization can be developed such that energy conservation is more clearly observed.

Enppi could start training refinery people on energy conservation.
Computers can be successfully used to prepare Sankey diagrams or to calculate efficiencies at Enppi.

Energy conservation should be activated in all feasible areas as

- automation
- maintenance
- process design (heaters, piping, boilers, etc)

In addition to training at Enppi it should get involved in a real energy saving project in some existing plant.

3. ACTIVITIES CARRIED OUT

Seminars were given in workshops and selected items are included in the appendices. The items followed the priorities in accordance with the initial program and they were

- -furnaces
- -exergy principle
- -inverters for electric motors
- -dew point of sulphuric acid in flue gas
- -heater efficiency calculations
- -power factor control to save energy
- -co generation of steam and electricity
- -on-line optimization
- -energy conservation by automation
- -Sankey diagrams
- -O2-control of fluegases
- -IR-technique to locate heat leaks
- -potentials of solar systems
- -vacuum desalination concept exploiting low quality heat
- -realiability for energy conservation
- -computerized compressor control
- -dynamic modelling of heaters
- -return on investment calculations in energy conservation

These items were furnished by suitable examples. Computer programs were prepared on the following items

- -ROI calculations for air preheater
- -flue gas composition as function of O2 %
- -heater performance as function of LMTD
- -efficiency calculations based on exergy for heaters

A visit to the Suez desalination plant and a short report of observations is included

In Alexandria seminars were given and discussions were on energy conservation with selected people from the local refineries. The annexed material illustrates the items discussed.

Material was left on
-exergy principle
-frequency converters
-power factor compensation
-boilers and materials
-Sankey diagrams
-heater efficiency calculations

4. ENPPI

Enppi is the engineering company for process and petroleum industries and is established 1978. The activities are

- general and detailed process design
- procurements in investment projects
- project control and management
- electric, instrument and mechanic design

Enppi is owned by Egyptian oil companies and the state The functional idea is to provide project manpower and design procedures for Egyptian and later to foreign clients. The need of these services is evident in Egypt since the petrochemical industry is rapidly growing and activities can be extended to other related process industries.

A number of Enppi's engineers has received training in the USA, Japan and Europe. Therefore they are familiar with many modern design procedures and they are constantly developing new ones. Also Enppi has had co-operation with some American and European design companies which promotes Enppi's capabilities. Enppi has about 12 personal computers (IBM and Vector) and an option a bigger one (IBM 4300 series) and is discussi. an own mainframe now. Also CAD and computerized project management methods are under consideration. Enppi has the computer based project time control in use. New computerized project control methods are under discussion and nowadays it should be a multiuser package. Computerized vendor lists partly exist. Linear programming is a known tool to optimize the petrochemical process. Static simulations for various processes have been performed. All this describes well Enppi's desire to be a modern engineering enterprise.

The refineries designed for Egypt have been joint ventures with an outside partner so far. There are coming projects like the Assiut refinery (2 Mt/a) and the Suez expansion and the Tanta revamping and the Abu Shannan gas pipe where Enppi will perform more alone. This is a sound objective in general, since foreign manpower also burdens Egypt's foreign balance.

Enppi has about 290 employees and is organized as follows

President	Dr. El-Rifai		
Chemical dpt	Mr. F. Youssef	34	emp.
Electrical "	Mr. M. El-Sayed	14	"
Piping "	Mr. Affia	72	"
Instrumentation	Mr. M. El-Sayed	16	"
Project dpt	Mr. S. Bahgat	15	"
Computer "	Mr. S. Fahmy	15	"adm.dpt
Construction dpt	Mr. S. Hassan	17	"
Civil "	Mr. M. Shaban	31	"
Administration dpt	Mr. A. Alaktash	73	"

In addition there are about 150 non technical people.

Energy conservation activities took place mainly in chemical, electrical and instrumentation departments and people involved are listed in the appendix 8.7.

5.ENERGY CONSERVATION AT ENPPI

Enppi is a design company. Therefore it can create favorable conditions to conserve energy. Energy efficient process design is a powerful tool, since upgrading afterwards is often very costly Enppi can contribute energy conservation in the following

-preoptimizing process component efficiencies eg pumps, blowers, heaters, furnaces, distillation towers etc.

-preoptimizing the overall efficiency and heat recovery by cascading correctly the energy flows

-designing water treatment such that minimizes the make up needs and scale formation

-in electric drives use of speed control when choking occurs eg in case of flow control and about 10% of the electric drives are good for this purpose. Power factor can be improved, too.

-designing co/combigeneration systems or to take into account this option for possible later actions. At least this is always worth a feasibility study when revamping or building new units.

-designing automation systems that optimize production within tolerable spec. limits and applying advanced sensor technology (O2-sensors, gas chromatographs)

-correct dimensioning, insulation optimization, piping with minimal pressure losses

-reliability engineering cab be applied in petroleum industry to reduce the number and outage time. This technique is widely used in aviation and nuclear industry.

-developing performance indices and to make sure that monitoring is possible either manually or on line by designing sufficient instrumentation. Reference values can be given for these figures.

-training operation and maintenance people

-performing ROI analysis of various energy conserving actions, since in some cases the investment is not justfied although energy is conserved

-developing methods to prepare energy or exergy flow diagrams to locate energy saving potentials.

-special techniques can be used like simulation to analyze transient situations since energy is lost due to rundowns and prompt start ups tend to conserve energy. The transient situations are the most difficult to control. The steady state is seldom problematic. Commissioning time of the plant can be reduced by this way, too

The above applies for existing and coming units.

Energy conservation must be recognized in all levels, but also a special group or unit, which is specially responsible for energy matters may be worth consideration or this responsibility can be taken within the departments. These people are obliged to follow the general progress of energy technology eg

- -desalination techniques
- -computer methods (CAD for Sankey diagrams)
- -organic rankine cycles
- -low quality fuel combustion (floating beds, pyroflows)
- -solar technologies although not yet very viable in petroleum industry
- -use of phase changes to conserve or store energy

Enppi qualifies in many regards. The development is question of priorization. Enppi's first objective is to perform billable work. Energy conservation should be included in this, else this concept suffers. Product development is necessary in this regard. It is also important to get a reference project with some client.

Enppi may suffer from the lack of feedback of existing plants, how the energy conserving actions work in reality. This is important for motivation reasons and to improve the techniques by experience. Co-operation between refineries and Enppi will remove this problem.

Enppi's major fields like chemical-, process-, electrical-, piping- and automation engineering can provide positive contributions for energy conservation. Enppi can provide these services on chargeable basis. The Sankey diagrams (computerized) could be one service.

Enppi ha capable people to perform the items above and capacity to develop energy conserving techniques further. The condition is, however, that energy conservation is recognized enough at Enppi and their clients.

In the near future the following actions can be taken at Enppi

-to develop standard routines to save energy (Sankey diagrams), efficiency optimizarion etc.

-to study all electric drives good for a frequency converter

-to standardize efficiency calculations based eg. on the exergy or available energy principle
-to optimize the outlet temperatures of furnaces
-feasibility studies on the backpressure power generation
-to ensure that optimal insulation is used
-to improve the return of investment analysis and to computerize the most common cases e heaters
-to check that energy use monitoring is possible in existing processes by proper instrumentation for auditing purposes

The material left at Enppi and the seminar material will give guidelines for this. To a certain extent energy conservation has been already observed at Enppi so many methods need only improvements.

6. PRESENT SITUATION OF ENERGY CONSERVATION IN EGYPTIAN REFINERY INDUSTRY

The existing Egyptian refineries date from the time when little attention was payed on energy conservation. From now on more systematic energy conservation will be assumed. Typical features for the present situation are

- -insulation can be better optimized
- -very few variable speed drives
- -no air preheating in furnaces
- -little or no power factor control
- -co- and/or combigeneration does not exist
- -gas turbines work without flue gas cooling
- -not until now systematic energy balances are prepared, these diagrams do not exist
- -feedwater is only handled by softening chemicals
- -powercuts may cause outages several times a year
- -automation has been little exploited to conserve energy
- -there are potentials for better cascading energy flows by detailed energy (exergy) analysis
- -low quality heat is totally wasted

The items above describe that energy conservation is starting in Egypt. The overall attitude is positive. The energy pricing policy has so far little encouraged to positive energy conserving actions, but now there have been nominated energy responsible persons for major process plants. Energy conservation is now looking for the way and organization to become real. Energy audits will be soon started in Egypt (El Tabbin Institute). In the Suez refinery a significant energy conserving action was carried out by an expert from the University of Cairo recently.

All symptoms indicate that soon many things will take place. However, the following is necessary

- -clear organization for national aims
- -organized training
- -technology transfer
- -systematic survey of the present situation
- -clear policy to promote cogeneration potentials
- -possibility to see selected energy conservation references since positive examples exist
- -it is important to start an complete a energy conserving model project in Egypt as a good example. Enppi can contribute this activity

It is worth noting that Enppi's possibilities are limited although important since energy is conserved in the refineries.The industrial sector and authorities (electric and industry) should fix the procedures for the items above, before positive results can be waited. Some acions have been taken already.

7. SUMMARY AND OBSERVATIONS

The most promising things to conserve energy and items to do are as follows

7.1 Furnaces

About 1.5...5% of crude is burnt in the refinery itself depending on the degree of refining. Therefore the furnaces form a very potential object to save energy. In Egypt now about 18 Mtons/a of oil are refined and about 0.5 Mtons are burnt. The saving potentials are

-Reduction of the flue gas temperature to 140..190 deg C depending on the sulphur content of the combustible

-The ZrO2 oxygen analyzer is recommendable possibly supplemented with a CO analyzer. This reduces the unburnt part and the absence of O2 tends to reduce high and low temperature corrosion and pollution. Energy is saved also because of more complete combustion. This analyzer is fast and requires little maintenance. The airfeed could be directly controlled by this signal. Also a model of the firing power can be developed. There are many reported successful experiences of this approach. Kent, Bailey, Combustion Engineering provide these analyzers. Even it may be worth having two to ensure the correct signal, which should control the air blower speed rather than the throttling damper. This approach improves the burner performance completing the combustion if atomizing or air/fuel mixing is poor.

-Air preheating is one means to reduce the flue gas temperature. Also air coolers could provide the air but the feasibility of this approach is to be analyzed. There are reported examples. Special materials are necessary if the final temperature is much reduced below 190 deg C like enamelling or cast iron, which tends to increase the costs. There is no unique solution for this problem. It must be analyzed individually for each case. Also there is universal discussion on the correct procedure.

-The residence time of gases, air injection, insulation, sooting, blowdowns and the temperature distribution are other potentials to conserve energy

The saving potential can be as much as 10 % of the fuel consumption, which means 0.05 Mtons corresponding 9-10 M USD/a. The investment is 3-6 M USD ie the return of investment is < 1 year. The furnaces are to be analyzed systematically allover in Egypt. This procedure is also good for other process industries.

7.2 Heaters

In petrochemical industry the proportion of thermal and mechanical energy is about 10:1. Therefore the performance of heaters forms a major factor in energy conservation. The things to be considered are

-Fouling, scale formation, leaks, poor insulation wrong sizing, blocking, poor cascading, sooting, blowdowns. Furnaces form one important type of heaters and therefore the phenomena are closely related.

-The heaters are to be analyzed together including the pumping energy the find an objective picture. The problem is not minimizing the heater surface, since at the same the sizes of pumps tend to grow. Generally the bigger heater is often optimal.

-Performance figures are suggested for heaters to monitor their performance and it can be based on audits or on a computerized system. The LMTD and the flow resistance are often good enough indicators.

-The feedwater quality is one vital factor in case of water or steam. The good quality reduces maintenance, wearing, maintains their capacity, extends the life time and reduces outages, which all positively contributes energy conservation. A general survey of feedwaters in refinery and process industry is a highly recommendable action to conserve energy. Presently the feedwater is only softened by aluna, flocked and gas removal is done. The low quality heat is good for relatively high quality feedwater preparation, which is else difficult to be exploited. The reduced heater performance definately increases energy demand or decreases the production capacity.

7.3 Performance figures

Energy and exergy (=available energy) diagrams are necessary to see the performance of individual components and these can be integrated to get an overall picture of the energy flows and economy. A graphical approach is far more illustrative and therefore recommendable. It is worth doing for existing and coming refineries. Computer aided design can be applied for this purpose. The exergy concept provides a powerful approach to calculate efficiencies, which should be compared the the following three levels

-Design-, initial-,real values and the last one is a timedependent variable, which can start sooting operation or is good for outage planning. This is an important concept to be understood in order to exploit the performance figures.

The performance figures provide a basis for computerized performance control. The design and initial values are used as references. The exergy efficiency is a universal approach for all process equipment (valves,pumps,fans,motors etc)

7.3 Co-/combigeneration of steam and electricity

This concept has been accepted globally where energy matters are of concern. It does not require much fuel to upgrade the steam such that reduction through turbines is possible. The quality of feedwater must be better than it is now often. The merits of this option are evident

-An alternative electric supply contributes the availability of the plant.

-The generation cost of electricity is advantageous.

-The necessary process steam can be bled from the turbine or the back pressure concept is good.

-The hot standby boilers will be in useful use. The steamsupply is ensured by increasing the number of the boilers. Reducing the number of outages is an efficient way to conserve energy. Therefore the reliability concept is to be included in the process design. This justifies the multiboiler and - turbine concept with several steam headers.

-The fuel is already present at the refinery ie transportation is avoided.

-In the short run this is the alternative to ensure the growing demand of electricity, since eg building a nuclear unit will take 5 years minimum and it would supply only the base load and hence reserve capacity is necessary. The hydro resources are nearly exhausted in Egypt. The sites next to the refineries seem to be the best place to build power stations. This concept requires co-operation between industrial and electric sectors. Even with subsidized prices this concept is competitive.

-The gas turbine can be added and then the overall efficiency will be improved. However, the plant must not trip in case of gas turbine failure. The organic Rankine process can retrieve the flue gas energy of alone gas turbines operating in an isolated place short of water. There are reported examples. The gas turbine is apt to high temperature corrosion because of vanadiumpentoxides and therefore the excess air is abundant to cool it. Also this is the reason why the flue gas can be conducted directly to a waste heat boiler with make up fuel. This concept is under discussion in Egypt.

To build this kind of capacity costs 500-800 USD/kW depending on the size and type ie eg a 20 MW unit would cost 10-16 M USD which is a significant part of the investment.

7.5 Waste heat sources

Nearly 50 % of waste heat is exhausted by air coolers right after the distallation column. The temperature is about 60..70 deg C. The reason is that aircoolers are inexpensive and require little maintenance. It could be used as combustion air to the furnaces, but the ducting will be costly compared with the possible yield. Often this cooling takes place with condensate return eg to the power station. The other major source is the cooling tower or condensors. This heat could be used to make process feedwater, the quality of which has direct and indirect benefits. Generally if the quality of heat is very low there are only few ways to recover it economically. It should be recovered when there is some value (exergy) left. This emphasizes the correct cascading principle. The cooling need is due to the fact that the incoming crude cannot absorb the evaporation energy of the oil. Fuel-, water-, air or the following streams preheating are other alternatives. In case of power station water could absorb more energy in the preheating processes.

7.6 Electric systems

A refinery in Egypt uses 10 MW/Mton/a of electricity. This is mainly used to run electric drives. Instead of throttling flows when controlling them this function can be replaced by thyristor controlled inverters ie motor speed is controlled. The following merits are obtained

- About 2.4 GWh of electricity/Mton is consrerved. It should be observed three times more energy is saved in fuel for every saved kWh of electricity

- Motor sizing is reduced

- Less motor wearing and maintenance

- Because of reduced pressure level the piping becomes lighter effecting savings in the investment.

-This technique makes easily possible the soft start up avoiding thus peak loads.

- Integration to automation is convenient

- replacement of choking control valves

Now this is a well proven technique and the units are fireproof. The investment is higher but operation will soon cover the difference.

The power factor control can be realized in plant or individual component level. The frequency converter impproves the power factor.This yields

- Reduced demand of electric power.

- Reduced sizing of many electric components like transformers, breakers etc.

- Promotes the stability of the electric network.

- 10-30 % energy savings are reported in feasible cases which are variable loaded induction motors mainly.

This technique requires co-operation between electrical authorities and industrial sector to obtain advantages in the national level.

7.7 Automation

This is often an inexpensive approach,since costly process changes can be avoided. The following potentials eg. exist

- Improvement of combustion control exploiting the fast ZrO_2 signal and stack gas analysis

- On line process optimization minimizing the steam demand/ton crude without violating the product specs.

- Performance figures can be monitored and compared with the nominal or designed ones and thus locating promptly possible malfunction.

- Maintenance functions can be controlled by a computer in order to systemize this function which has direct and indirect effects on energy conservation.

- Run downs and start ups can be shortened causing energy savings.

- Special measurements like infrared or the movision, ultrasonics,eddy currents, non destructive testing for quality control, vibration, shock pulses ,endoscoping promote energy conservation (auditing,preventive maintenance)

These activities are universal in all process industries. Automation is some time overdone, but it is an evident potential and cannot be neglected.

7.8 Solar systems

In Egypt insolation is about 4000 hrs/a and the radiation power is 4-8.5 kW/m2. 7-12 % can be converted into electricity provided that the panel or heater is constantly directed to the sun. This arrangement may be costly. In refinery industry this presents such small portion of the total energy demand that few economically viable systems exist. One of them is fuel or crude preheating before entry to the furnace. The problem that all possible energy available in the pumparounds cannot be absorbed,however, remains. The use could be possible in remote control stations without no permanent electric supply. Private households may use this option successfully. The action is,however,to follow the progress in this area.

7.9 Return on investment

In all cases this analysis is to be performed. It may some time to turn out that the investment is not economically viable although energy is conserved. This is often the situation when recovering low quality energy which is the main exhaust in refineries.

7.10 Suggestions for future activities

1.Case projects for a few of the items above like a selected furnace, desalination, power factor control etc. The plan should include the schedule, equipment to be acquired, man power,financing,object plant,costs and roi-analysis.

2.Materials form a constraint in energy conservation therefore capability in this sector is to be developed.

3.Energy or exergy analysis in selected refineries to locate recovery objects and to see how real performance deviates from nominal or designed values. Training to do this will be necessary. This will give a good insight of the energy situation and cascading.

4.Co-operation between oil and electric authorities in the co-generation and pfc-matter. This co-operation should cover other sectors except for gas and oil industry.

5.Training of energy conservation for designers, operation and maintenance people. The material should be prepared and training courses be arranged.

6.The progress should be gradual eg. one thyristor unit can first be acquired and with positive experiences this activity is to be extended.

7.Energy audits are to be started to find out of the real performances of energy conserving activities.

8.A feasibility study is adviced to start a more extensive activity including cost analysis, proposal of project activities and the roi analysis.

9.Maintenance programs (preventive,corrective) and check lists to promote energy conservation.

10.Water quality surveying in Egyptian refineries and measures due to the findings. This activity is good for other process and power industries.

11.Financing alternatives like national, development banks, multi- or bilateral development aid,UNDP etc. Preparation of detailed project proposals with the necessary schedule-,cost-,activity and roi information.
12.It suggested that the cases are selected in different fields like automation, electric systems etc.
13.Surveying co- and combigeneration potentials.
14.The potentials of Egyptian industry to make energy conserving equipment is worth a feasibility study, since this is one way to improve the the foreign balance. Sparepart supply and maintenance becomes easier with this policy reducing outages and repair times. Outage time is very costly for the refinery.

8.1 SUMMARY OF SAVING POTENTIALS

Item	Method	Potential USD/ton crude	Investment ROI years
Furnaces	O2 control	.05-.15	low
	Air preheating, forced draft	.05-.15	
Heaters	Cleaning,feedwater quality	.15-.3	1-3
Electric drives	Frequency converters Power factor control	.16-.3	1-2
Co-generation	Fuel efficiency 40 % to 80 %	1	3-4
Heat recovery	Recycle,cascading	.3-.6	1-5
Insulation	Optimal thickness	.05-.3	1-5
Process revamping	Eg. preflashing	.3-.6	1-5
Miscellaneous	Automation,lighting	.1-.3	.5-5
TOTAL		2.16-3.7	
TOTAL Egypt 18 Mton/a X		39.96-68.45	M USD/a

These are very cautios figures and may turn out much better when real cases are surveyed. Automation often yields the shortest ROIs and has the advantage of small investment. ROI means years for the return on investment ie. recycle time. 185 USD/barrel is used as reference.

8.2 ITEM	POTENTIAL ROI/years	METHOD AND REMARKS
Furnaces	.5-5	O2-control by ZrO2 analyzer. Complementary CO and unburnt part analyzer. Feedfoward control for fuel feed. Forced draft burners. Air feed blower control by speed according to O2 signal. Proper air mixing by a proper injector location. Residence time optimization of combustion gases. Optimal sooting based on performance figures. Air preheating and use of special materials to lower the outlet temperature. Optimal size, shape and insulation. Airfeed from the air coolers.
Heaters	1-5	Correct cascading. Feeadwater quality. Performance monitoring and actions accordingly (cleaning). On line cleaning. Correct dimensioning eg to minimize recycle pumping. Special instruments to locate deposits eg IR or ultrasonics or endoscoping. Optimal insulation.
Electric systems	.5-3	Frequency converters instead of choking flows. Improvement of power factor in plant scale or component level. Soft start up. Reported examples exist of use of frequency converters in petroleum industry. Capacitors and inductances are used to compensate the plant scale power factor yielding benefits for the total electric system. Reduction of lighting eg using pale colors.
Combi/co-generation	3-5	Upgrading the steam quality to reduce it by turbines and producing electricity, too. Redundant power supply. Bleeding type of turbines needed. Multiboiler and -turbine concept recommendable. Gas turbine and waste heat boiler option to improve the fuel efficiency. Several steam headers necessary. Merits obtained in the national level due to production of inexpensive electricity.
Desalination		The vacuum distillation provides the option to use low quality heat to produce feedwater. Sp.demand 6-8 kWh/m3/distilled water. Merits are

	better heater performance and the option to upgrade steam. Contaminated condensates can be used for this purpose, since the evaporator is epoxy coated.
Start-ups	Due to prompt start-up energy is conserved. Function group systems are used to program the start up procedure step by step.
Boilers	Reduction of blowdowns,reliefs. Flash heat recovery. Optimal insulation. Correct cascading. Feedwater preheating. Start-up automation. Minimal recycles eg mixing to control the final steam or crude temperature. Steady operation instead of variable. Minimum number of outages. Special instruments for performance analysis. Performance monitoring by proper figures.
Distillation	Heat recovery from intermediate reboilers. Use of analytical instruments to optimize the output quality. Minimal refluxes. Insulation. Optimal tray number. Preflashing. Heatpumps (compessors) for reboiling when coolin is needed. Avoidance of over separation.
Piping, armatures	Minimum number of vertcal outlets or elbows, minimum distances, optimal insulation. Flow control instead of throttling causing lighter piping. Close valves 100 % open position.
Pumps,blowers	Correct sizing, speed control, minimum refluxes, surge control.
Steam sunply	Feeadwater quality. Condensate recycling. Cascading. Flash and blowdown heat recovery. Avoidance of throttling. Reduction by turbines.
Turbines	Reaction or radial counter rotating turbines instead of impulse ones. Condensor sealing. Floating entry pressure. Correct bleeding system. Start-up automation. Labyrinth sealing to minimize bypasses.
Miscellaneous	Heat recovery of product storage tanks. Coking process optimization. Bottoming cycles. Organic Rankine process. Minimum flare. Improved level of maintenance. Special metering technology. Energy recovery by phase transformation. Multieffect evaporation.

8.3 PEOPLE INVOLVED

UNDP:	Dr. Frank Hartvelt, deputy resident
	Mr. Tharwat Sabry, senior programme officer
	Mrs. Mona Hetata, programme officer
	Mr. J.W.Szemeta, area officer,arab countries
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	Mrs. Mennel, information
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ENPPI:	Dr. M. A. Soliman, training
	Mr. F. Youssef, heater rating
	Mr. R. Duvall, process engineering
	Dr. M.S. Hassan, training
	Mr. M. El-Sayed, automation,elecctric systems
	Mr. M. El-Nagdy, electric systems
	Mr. M. Hafez, project manager
	Mr. A.A. Ghany, turbines
	Mr. J. Sedgeworth, tubing
	Mr. K.M. Khaled, chemical
	Mr. M.G. Sabe, project management
	Mr. T.A. Gawad, project management
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	Mrs. M.Wahby, chemical
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NATIONAL PAPER CO:	
	Mr. M.Zeki, energy conservation
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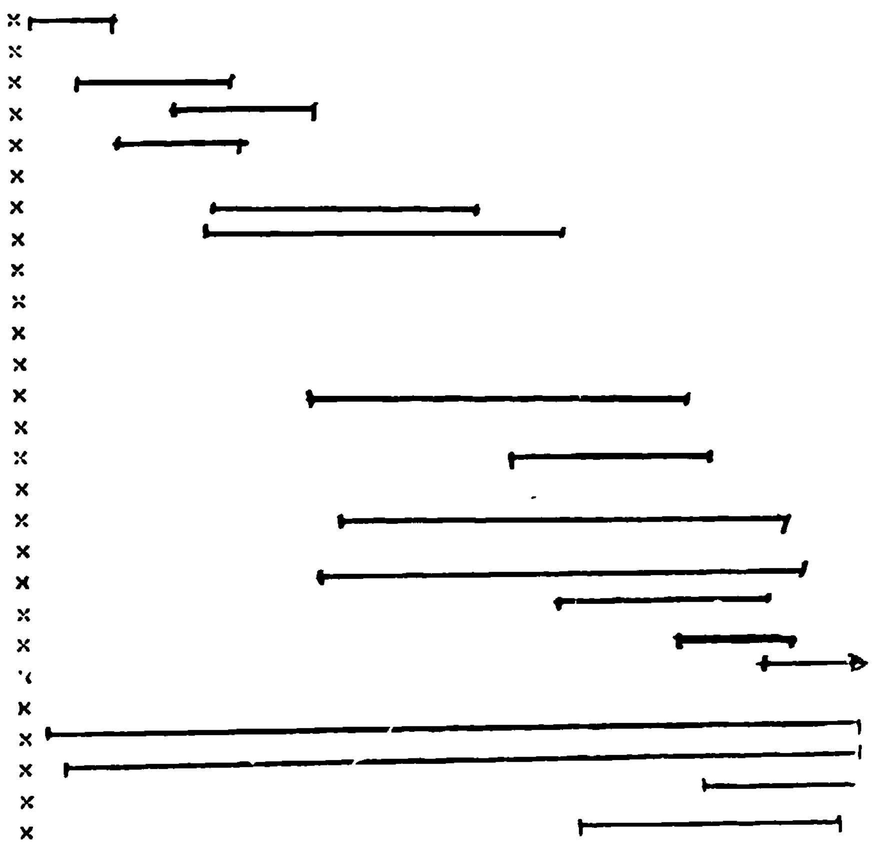
	Mrs. F.E.Hamada,energy conservation

8.4 ACTIVITIES FOR ENERGY CONSERVATION IN EXISTING PLANTS

Activity Relative position in schedule (.5-2 years)

1. Identification of objects
2. Priorization
3. ROI assesment
4. Choice of method
5. Hardware specs.
6. Purchase
   - bid enquiries
   - tenders
   - evaluation
   - procurement
7. Detailed engineering
8. Site preparations
9. Delivery control
10. Installation
11. Start-up tests
12. Acceptance
13. Guarantee
14. Project control
15. Training
16. Documents
17. Maintenance
18. Spare parts



8.5 SEMINAR

PRINCIPLES AND METHODS TO CONSERVE ENERGY IN PROCESS INDUSTRY

TIME : FEBRUARY , 1985

GIVEN BY : PEKKA SOININEN

DISTRIBUTION :

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ENERGY CONSERVATION
AT ENPPI

February 14, 1985

INDEX

GAP03 (11/86)

INDEX (CONT'D)

I BENEFITS OF ENERGY CONSERVATION

Egypt produces about 40 Million tons/a of crude and 18 Million tons/a are refined. About 3% of this amount is burnt in the refineries in the production process. This means 0.6 M tons. There are still some unused potentials to preheat the combustion air by cooling the existing stack gases of the oil burning furnaces. Now we can calculate what this case would mean for the Egyptian oil industry. Some of the initial figures are based on Finnish experiences. The stack recuperator recovers about 5-8% of the energy of the combustible. It is a well known value for many types of furnaces while the temperature is reduced from 220 °C → 140 °C or even lower, if glass or cast iron recuperators are used. Also, if the fuel is sulphur free, a lower reduction is feasible. NOW

average value for refined product

$$0.6 \times \frac{Mt}{a} \times 0.07 \times 185 \frac{\$}{t} = 7.8 \frac{M\$}{a}$$

recovery 7%

If further refining is included (ethene), these figures grow 70%, therefore a huge potential is in question, i.e. 1,7 x 7.8 = 13.3 M$/a.

One has to invest also to make this recovery possible. The investments are assessed following (based on figures in Finland i.e. about 800 $ specific construction cost of one kw electric power)

4.3 M$

Probably part of this potential has been used (2). This means that the payback time is less than 1 year. Certain costs are due to a possible outage, but this can be minimized by a careful project design. This is profitable in spite of operation and maintenance costs.

The following fringe benefits will be obtained :

1- If the combustion is complete by means of an O_2-analyzer, the overall efficiency improves and also the figure presented before ($7.8\frac{MS}{a}$)

2- About 0.05 m tons of refined product can be obtained, therefore 185 $/t may be justified because of the world price and this is the potential for the whole of Egypt

3- Amelioration of combustion reduces V_2O_5 oxides and formation of sulphuric acid because of reduced O_2-content. Both of these are corrosive agents.

4- Pollution abatement due to complete combustion i.e. the fraction of non-combustibles in the stack gases is diminished (organic+inorganic)

5- Availability of units and components will be improved due to less wearing.

The furnaces are the most promising potential in the refineries and this is the reason why they have been selected for the top priority. There are also a number of other potentials and they can be listed below :

1- Avoidance of irreversible processes, e.g. throttling (pipes, valves, atmospheric cooling, blending).

2- Reflux by-pass minimization

3- Separation within tolerable limits.

4- Heater performance improvement.

5- Better automation.

6- Online process optimization.

7- Maximum recovery of product heat by preheating crude.

8- Power factor control.

9- Condensate collection.

10- Piping (insulation)

Basically, majority of refinery processes are direct or indirect heating, mixing, pumping and cooling. These form the key areas for energy conservation.

II THE MOST PROMISING OBJECTS OF ENERGY CONSERVATION

2.1 FURNACES and the reasons are:

2.1.1 Most fuel is burnt in various furnaces, about 7...12% depending on the degree of refining.

2.1.2 To ensure complete combustion, e.g. by O_2-meters (ZrO_2) is an evident potential and fairly low cost and it does not cause outages of the plant necessarily

2.1.3 The recoverable heat is about 7-10% from the stack gases and in Egyptian refineries, there exist a number of furnaces good for this means, a supporting CO-measurement may be considered.

2.1.4 This technology can be applied in :

- all process industries.
- power stations.
- refineries.

2.2 HEATERS

2.2.1 A majority of the refining processes is direct or indirect heating.

2.2.2 There are many ways how heat is lost, like

- seals.
- scale formation.
- blocking
- flow resistances.
- poor insulation.
- refluxes and by-passes

If these are reduced, the performance and lifetime is increased.

2.2 HEATERS (Cont'd)

2.2.2 - This technology is also feasible in other industries.

- Vacuum distillation is a promising alternative because of :

. Low temperature levels.

. A lot of cooling water is discharged from refineries.

There is one pilot plant under commissioning in Suez.

2.3 ELECTRIC/STEAM CO-GENERATION

2.3.1 The combi process is the most economic process to produce electricity and steam.

2.3.2 This is a redundant steam and electric supply and thus has a positive contribution on the availability of the refinery.

2.3.3 The fuel is easily obtianed from the refinery and conversely the steam can be easily delivered to the refinery. Also pure condensates can be collected for reuse.

2.3.4 This kind of integration is highly recommended.

2.3.5 The power station has furnaces and heaters and then it is closely related to the items before.

2.4 ELECTRIC SYSTEMS

2.4.1 Poor power factor causes :

- Excessive transmission capacity
- Unstability
- Increased transmission losses
- Increased uemand for power generation
- Motor wearing

2.4 ELECTRIC SYSTEMS (Cont'd)

2.4.2 20...40% electricity can be saved if a pf-control is applied on individual motors in case of variable or part loads.

2.4.3 In case of throttling materials the variable speed concept conserves energy.

2.4.4 The ideas above also conserve equipment from wearing.

2.4.5 In some cases, use of electricity promotes the overall process efficiency e.g. heat pumps; a lot of compressors is utilized in petrochemical industry.

2.4.6 Automation is less cost effective for energy conservation and results may be obtained in the following areas

- On line optimization
- Sensor technology
- Better control strategies

These things offer possibilities for high technology development

III ACTIONS TO IMPROVE ENERGY ECONOMY

Energy conservation attitude must be assumed in all phases and levels :

- design
- operation
- maintenance

and various technologies can be used :

- process design
- automation
- co-genertion of steam and electricity
- performance monitoring
- combi processes
- solid state power factor controllers and inverters
- vacuum destillation, thermocompressors
- heat pumps
- materials
- sizing
- insulation optimization
- geometry and shape optimization
- modelling and process optimization
- solar

Quite recently a new method for desalination has been introduced (1 existing plant in Egypt, too) i.e a vacuum multieffect evaporation plant and the vacuum is generated by lifting the evaporators by 10 m. The production is 20 m^3/h which is enough to feed a 3000 people community or the water is good for the power plant process water without deionating. The driving heat is recovered from cooling waters of 30...40^oC and water boils at 18^oC and the pressure is 30 m bars. This is superior to the flash method because of lower temperatures and thus corrosion is prevented. A solar preheater could improve the performance, but due to direction to the sun and nights it has certain inconveniences the same as electric solar panels. These can be overcome by geometry or automatic direction which however increases the costs. Therefore sol energy is to be seen as a future potential in the refinery area, but not very soon

FIGURES ON SPECIFIC ENERGY USE IN REFINERIES

OIL PRODUCTION (Finland 1985)

YEAR 1985 (estimate)

Crude input	10.5	Mt/a
Electricity demand	0.386	TWH/a
Specific elec. demand	39	KWH/t
Production	9.9	Mt/a
Specific fuel demand	0.79	MWH/t
Fuel demand total	7.128	TWH/a

REFINING

	Prod. Mt/a	Sp.el.demand KWh/t	Fuel MWh/t	Resid.fuel MWh/t	Total fuel TWh/a
Ethene	0.18	278	18	7.22	5.033
Propene	0.073	24	0.0278	-	-
Butadiene	0.018	641	0.194	-	-
1-Buthene	0.009	1333	-	-	-
Penthene	0.08	195	1.1	0.972	1.36
Phenol	0.035	467	2.22	1.805	0.062
Aceton	0.018	467	3.61	2.917	0.062
Polyethene	0.155	1225	0.75	0.083	2.11
PVC	0.06	595	2.08	0.22	0.726
Polystyrene	0.02	450	0.972	-	0.239
Oil		0.386			7.128
	0.648	0.775 TWh/a			16.67 TWh/a
					(14.3 Gcal/a)

These products require a 85 MW power supply and 1.48 M tons of oil is burnt.

This also reveals the fact that savings in combustion processes probably yield maximum results. The figures above illustrate specipic consumptions. Discrepancies with Egypt are due to different level of refining and distribution of products.

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INDUSTRIAL ENERGY USE

PROCESS

Process steam	33 ... 40 %
Direct process heat	27 ... 43 "
Electric drives	~ 20 %
Feedstock for chemicals	9 "
Electrolytic	2.8
Other	0.8

INDUSTRY (ex.)	Total / pin	Th / Mech
Food	6.2 ... 8	4.2 : 1
Pulp & paper	4.1 ... 10	3.0 : 1
Chemicals	18.1 ... 23	8.2 : 1
Petroleum	23.5	10.5 : 1
Stone, glass, cement	11	1.4 : 1
Metals	17 ... 18	7.8 : 1
Other	15.2 ... 20	

USA 1980

The ratio th/mechanical indicates the way energy is used in the industry in question. Evidently ~~thermal~~ energy plays a major roll in ~~petroleum~~ industry.

Refect ~~profile~~ (10^{12} BTU) (USA 1976)

	~~Condensate~~	Process water	Product losses	Condensate	Boiler furnace
Food	290	175	260	14	255
Pulp & paper	100	231	350	12	339
Chemicals	125	60	425	26	260
Petroleum	50	380	1470	52	1085
Stone	170	[illegible]	440	14	[illegible]
Metals	140	463	80	18	749
Other	225	263	491	19.5	598.5
	1100	1692.5	4016	155.5	3709.5

FIGURES ARE RELATIVE

FIGURES ON SPECIFIC ENERGY USE IN REFINERIES (Cont'd)

energy conservation although other sectors may not be neglected. Respective figures would be for Egypt by multiplying $\frac{18}{10.5} = 1.714$ providing the same level of refining.

IV OBJECTIVES OF ENERGY CONSERVATION

The objectives are :

4.1 Energy conservation in economically feasible way including investment, outage, operation and maintenance costs.

4.2 The conservation action must produce a profitable result (ROI), alone it is not an objective.

4.3 Fringe benefits that energy conservation may yield :

- Less wearing
- Less pollution
- Investments can be reduced by correct sizing
  eg. lower pressures → thinner tubes

4.4 It must be checked that energy conservation takes place in reality e.g poor maintenance can delete easily the results, even impair the system.

4.5 To develop potentials for equipment and technology production in Egypt and hence indirectly to reduce imports to Egypt.

4.6 It is advisable to start with the most promising items (furnaces) although there are several other objects worth consideration.

4.7 To develop feasible indices or performance figures for monitoring or auditing purposes.

NA

V ENERGY CONSERVATION PRINCIPLES

GENERAL Energy can be conserved in :

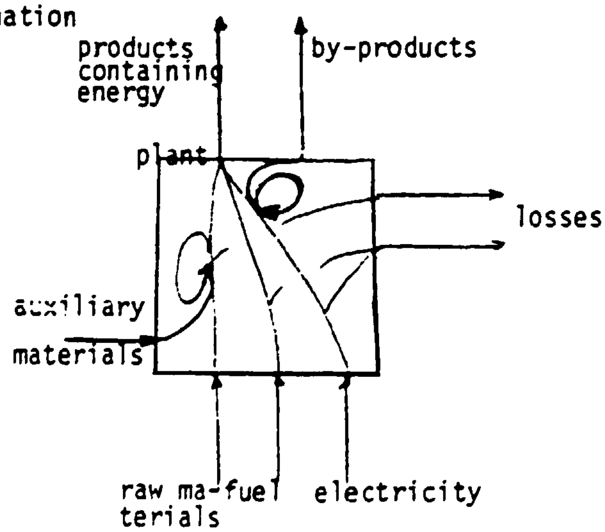
a. Production.
b. Transmission
c. Utilization

i.e almost everywhere

Waste heat can be recovered by a number of methods, e.g. :

a. Heat recovery exchanger
b. Heat pumps
c. Better automation
d. Insulation
e. Improving efficiencies

In fact, energy does not disappear. It is converted into another form and usually the quality deteriorates, i.e entropy increases. The schematic diagram below shows this plant real situation



V ENERGY CONSERVATION PRINCIPLES (Cont'd)

Losses take place in the following processes

5.1 Heating / cooling

a. Radiation
b. Temperature reduction
c. Heater insulation
d. Heater shapes
e. Reliefs to the atmosphere
f. Refluxes and by-passes
g. Poor performance of heaters

5.2 Pumping

a. Poor efficiency
b. Electricity is converted into heat by throttling
c. Poor pumping efficiency
d. Oversized pumps and motors
e. Poor performance due to wearing
f. Excessive choking due to design of piping
g. Apply speed control instead of choking

5.3 Evaporation, the same applies as to heaters, moreover

a. Refluxes are to be minimized
b. Product heat is to be recovered by preheating input crude
c. One has to avoid cooling to the atmosphere or to the sea as much as possible
d. By pass reduction

5.4 Condensing

a. Condensates should be collected to avoid heat and process-water losses
b. Leaks are to be detected
c. Dirty condensates are often difficult to be reused because of corrosion
d. Heat recovery may be problematic for the same reason (e.g stripping)

V ENERGY CONSERVATION PRINCIPLES (Cont'd)

5.4 Condensing (Cont'd)

e. Condenser or multieffect operator, vacuum must be insured
f. Condensate purification is sometimes non-profitable

5.5 Stack Gases and Combustion

a. O_2-content must be optimal
b. Variance of fuel
c. Combustion air must be preheated (air preheater)
d. Avoid lower temperature than the dew point of sulphuric acid.
e. The outlet temperature must be optimized within constraints
f. Stripping can be applied to heat recovery and then stack gases are purer and chemicals could be recovered and gases meet better environmental requirements.
g. Incomplete combustion
h. Sooting
j. Correctly directed air injection and proper mixing

5.6 Drying

a. Use mechanical drying, maximally
b. Avoid overdrying
c. Application of heat recovery
d. Utilization as low quality heat as possible

5.7 Steam Supply

a. Leaks in rotary joints, safety-by-pass valves and traps
b. Poor insulation : rule of thumb $10^{o}C$ temperatures difference between insulation surface and environment (skin temperature)
c. Exhaust control due to jammed dampers
d. Impaired heat transfer due to blocking, leaking and scale deposits
e. Lacking or malfunctioning performacne monitoring
f. Impaired steam traps

V ENERGY CONSERVATION PRINCIPLES (Cont'd)

5.8 FeedWater

a. Preheating by steam extraction or by other feasible actions is nearly always a correct measure
b. Quality must be controlled to reduce scale formation
c. Leaks must be minimized
d. Feasible condensates must be collected

5.9 MOTORS

a. Avoid unnecessary throttling
b. Correct sizing
c. Power factor controlling when partly loaded locally
d. Variable speed control (inverter)

5.10 Combustion Engines

a. There are stand by devices and uneconomic for continuous operation
b. Performance can be monitored and stack gas quality analyzed
c. Efficiency audits or monitoring

5.11 Miscellaneous

a. Slippery driving belts
b. Useless mixing
c. Quality of optimization within allowable limits

5.12 Distillation Towers

a. Useless refluxing or bypasses
b. Poor insulation
c. Insufficient heat recovery from the products
d. On line optimization is possible within constraints (20 pcs) and energy conservation has been reported plus other benefits

V ENERGY CONSERVATION PRINCIPLES (Cont'd)

5.13 Separators

a. Optimal separation within tolerable product limits, avoid overseparation
b. Reflux or by-pass minimization

5.14 Compressors

a. Energy savings can be obtained operating near surge line without omitting the protective actions
b. Minimized recycle
c. Variable speed drive

VI GENERAL PERFORMANCE CRITERIA AND RELIABILITY

The value of heat can be evaluated as follows :

$$E = H - H_e - T_e\,(S - S_e),$$ exergy or available energy

where

- E = ex ergy
- H = initial enthalpy
- H_e = final enthalpy = in the state of environment
- T_e = final temperature = in the state of environment
- S = initial entropy
- S_e = final entropy = in the state of environment

The objectives of performance figures are generally to assess the function of the unit or component in question.

One has to include also the investment, operation and maintenance costs due to the recovery equipment.

In other words this means, the higher temperature the heat has, the better it is. Also, the internal energy (e.g steam) can be converted into electricity by expansion. This justifies the back-pressure and extraction processes of steam turbines and combi processes where the high exhaust temperature and high O_2-content are exploited.

For refineries, however, safe steam and electric supply must be guaranteed. It means redundancies eg. the multiboiler concept. The national electric supply jointly with co-generation ensures the electricity safely for the refinery. Unavailability costs so much that this procedure is justified. Also, it might be tedious to start up after an unexpected outage. The normal and also optimal operation mode is maximum steady state production with minimum outages. A good coefficient of perfor-

VI GENERAL PERFORMANCE CRITERIA AND RELIABILITY (Cont'd)

mance is $\frac{\sum_i^i E_{out}}{\sum_i^i E_{in}}$ which should be unity in an ideal case, but deviations from the nominal level are to be checked , monitored or audited. This applies for heaters, pumps, etc. equipment.

The power system (electricity,steam) should be such that turbine or boiler trips do not cause outages for the refinery. Eg. boilers feed one or more headers and there are several turbines in addition to the national power grid.

VII SANKEY DIAGRAMS

The idea of sankey diagrams is

a. To follow energy flow in detail throughout the whole process.
b. Flows are illustrated by the width in the diagram.
c. Recyclesare clearly presented.
d. Temperatures and the heat transferring media must appear.
e. The flowing power is indicated in KW or MW or Gcal/h
f. Type of energy must appear
   - mechanical
   - electric
   - thermal

   Since this implies the quality of energy
g. Individual sub-processes and phases must be denoted in the diagram.

Sankey diagrams are fairly easy to design provided that there are available

a. process diagrams
b. temperatures
c. PI - flow sheets
d. technical information of the process equipment

The diagrams can be prepared in various levels

a. plant scale
b. unit scale
c. component scale.

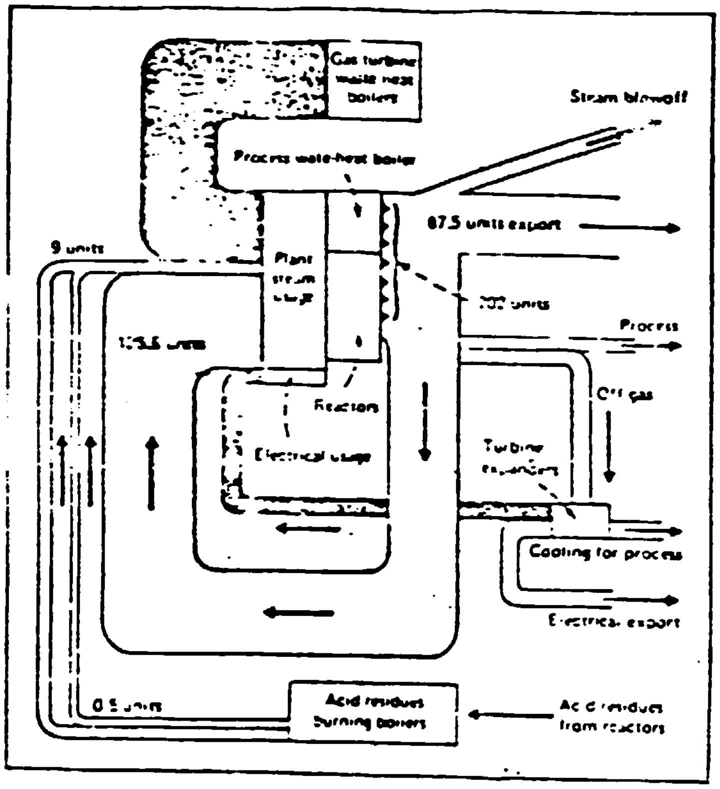
In many cases all these levels are justified.

The sankey diagram provides one model to design computerized energy management systems which might on line monitor the plant scale energy use.

Component performances can be monitored in the same way for energy demanding units.

These diagrams can be upgraded by computer using CAD technology.

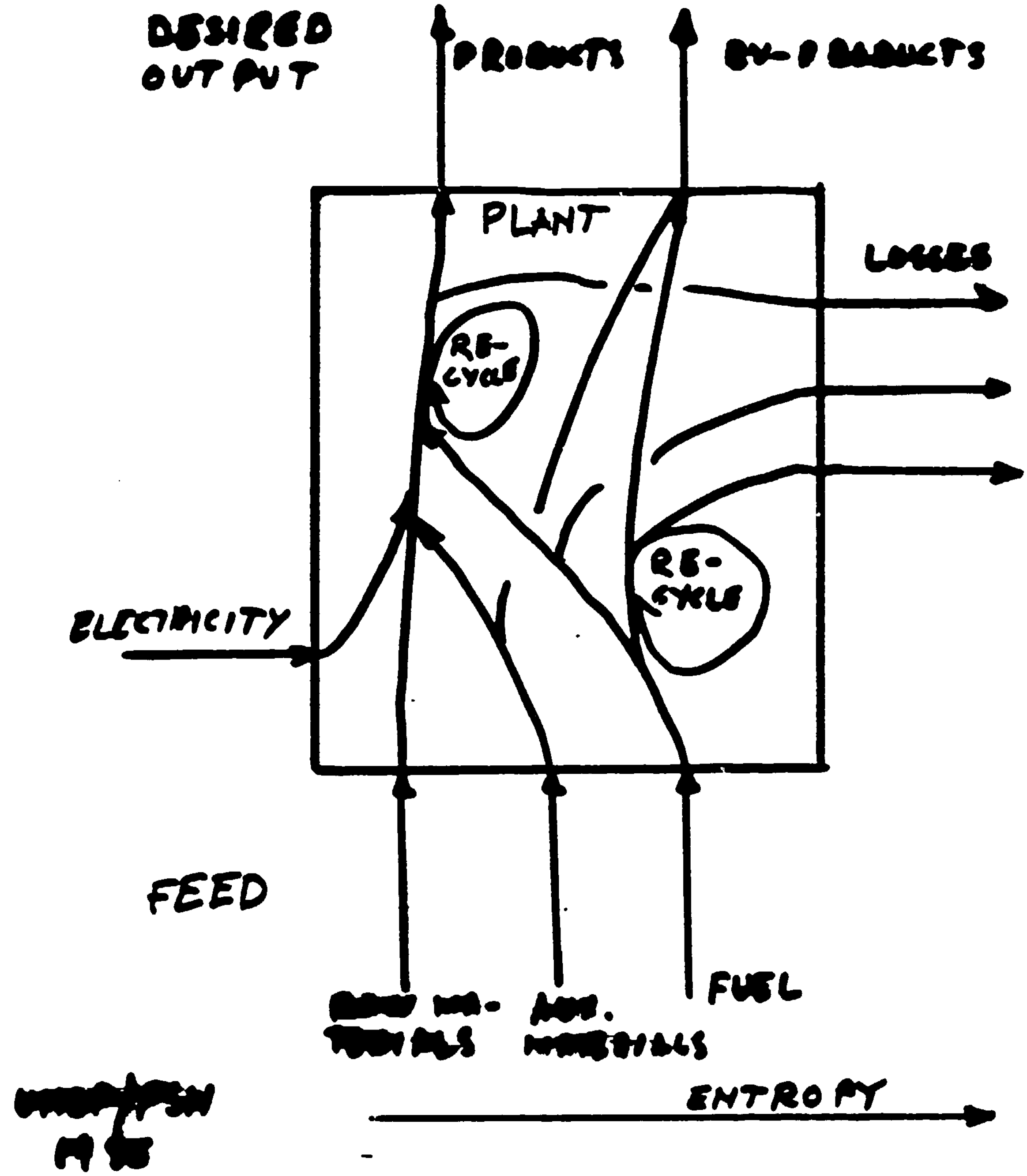
EXAMPLE OF BALANCE CALCULATION:

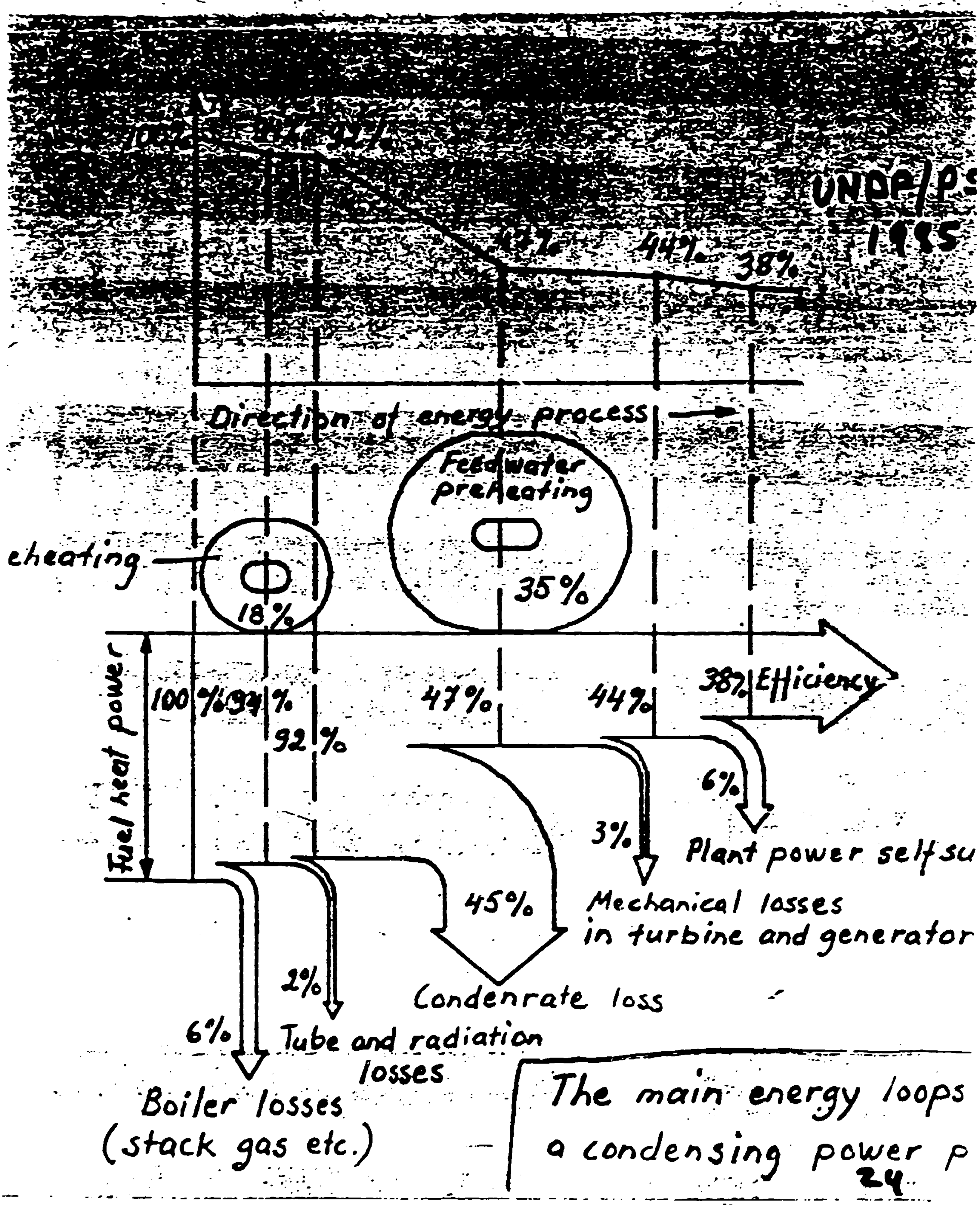


ENERGY BALANCE (electrical, steam, heat etc.) of the total system—Fig. 2

UNDP/PSN 1985

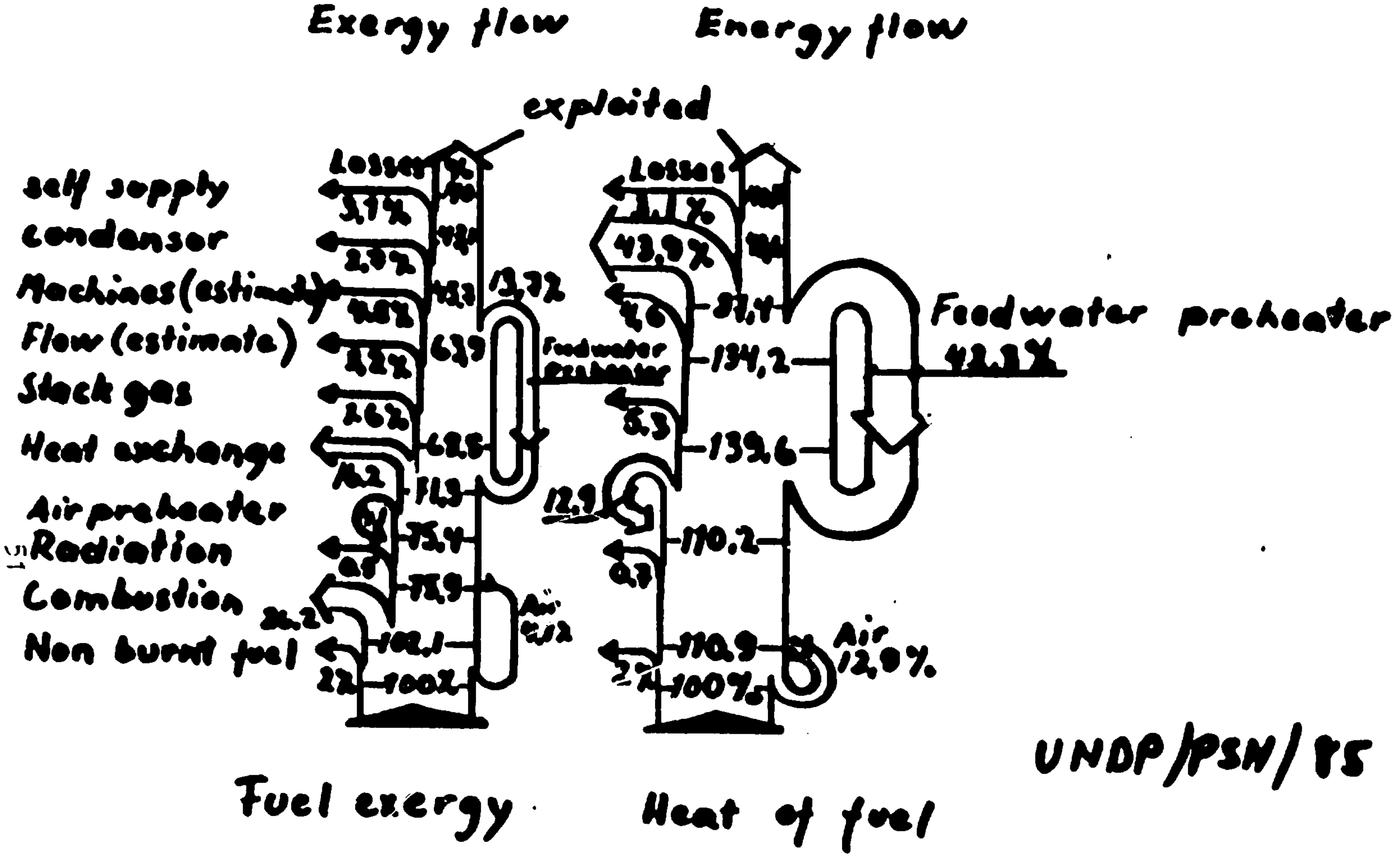
PLANT SCALE ANALYSIS OF ENERGY FLOWS





The main energy loops
a condensing power p
24

SANKEY DIAGRAM



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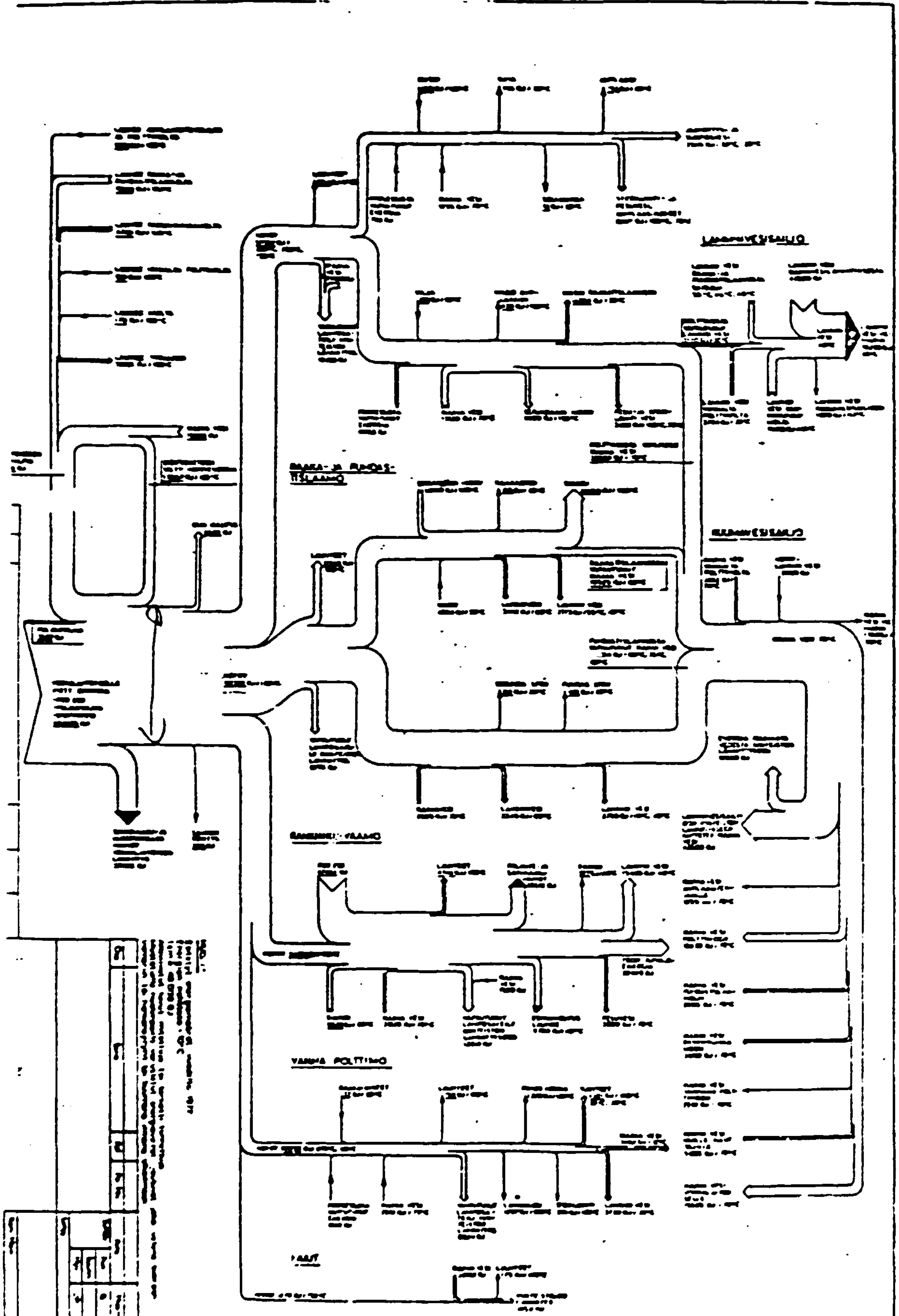
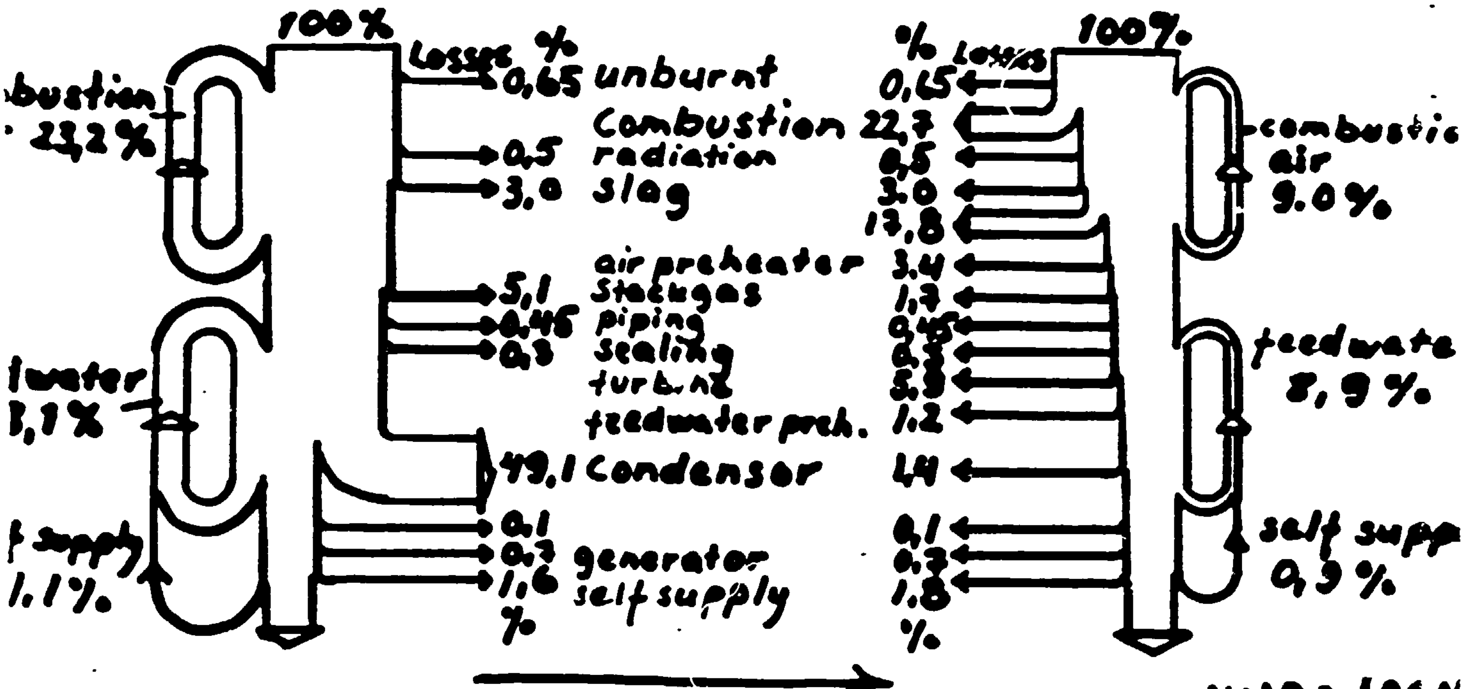


EXAMPLE OF AN OVERALL SANKEY DIAGRAM ENERGY BASIS

SANKEY DIAGRAM
EXERGY ANALYSIS



Energy flows are upgraded as exergy flows

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CAD can be applied to prepare those diagrams

VIII PERFORMANCE FIGURES

COMPONENT	FIGURE	REMARKS
VALVES	ΔP, $\Delta P \cdot \dot{V} = \Delta h \dot{m}$ power loss	ΔP = pressure reduction $\dot{m}$ = mass flow avoid useless throttling h=head
COMPRESSORS	Exergy increase driving power surge recycles minimal	vibration is one anti- surge means see turbines, heaters, valves, motors
HEATERS, COOLERS	$\overline{\Delta T}$ = temperature difference across the heating surfaces	$\overline{\Delta T}$ indicates heat transfer obstacles, it is an averaged value (LMTD)
	ΔP = pressure reduction between input and output of primary and secondary sides $= \dfrac{\sum(\text{exergies})_{out}}{\sum(\text{exergies})_{in}}$ = ideally 1, time dependent deviation progress is detected.	ΔP indicates blocking IR - photography indicates heat leaks Ultrasonic for scale formation and leak detecting Endoscope for pitting and scale formation and leaks. Other non-destructive methods are applicable cleaning internal optimization.
FURNACES	T_F = Flame temperature	The same as to heat exchangers applies
	O_2- contents of stack gases	Zirconium sensor is superior to others. Minimizes draft → energy conservation

VIII PERFORMANCE FIGURES

COMPONENT	FIGURE	REMARKS
FURNACES (Cont'd)		
	Stack gas temperature T_{sg} (final)	T_{sg} dew point of sulphuric acid but not much and within controllable limits
	Fuel quality control	Eg. - moisture - viscosity - sulphur - heavy metals - ash - slagging - non burnt components - junk
	ΔT = temp. diff. across heating surfaces (logarithmic)	Sooting can be initiated according to ΔT i.e heat transfer capacity, can be optimized
	T_z zonal temperatures	IR photography or pyrometers, the IR-photo nowadays gives direct indication of T (AGA) IR technology is worth deeper analysis at Enppi. IR is good also for outside photography to spot heat leaks.
	CO indicates it draft is too small	IR - absorption feasible and relatively inexpensive
	Dust	Optical device, electric filters will remove.
MOTORS	$\cos\varphi$ = power factor	It indicates full/partial load variable speed control now feasible at reasonable cost. (soft start-up possible)

VIII PERFORMANCE FIGURES (Cont'd)

COMPONENTS	FIGURE	REMARKS
BOILERS	R = steam rating	
	Q = heat absorption . superheater . evaporator . economizer . oil heater . fuel heater . air —"—	Specific values can be used as well i.e /m^2 /m^3
	QC = thermal load	
	F = furnace load	
	S = steam outputs	Losses - flue gas - unburnt - radiation - ash - blow downs - stops - start ups - condensate - partial load - fuel variations - leaks - flash steam - safety valves
	T = temperatures	
	P = pressures	
	efficiencies for the whole boiler	
	$\frac{\text{Energy increase of product/time}}{\text{Fuel power}}$	
FANS, BLOWERS	$\frac{\Delta P\,\dot{V}}{M}$, $\frac{\Delta h\,\dot{m}}{M}$ i.e enthalpy increase also $\frac{(\text{exergies})_{out}}{(\text{exergies})_{in}}$	$\dot{V}$ = volume flow ΔP = pressure difference across the fan M = driving motor power Speed control yields benefits special measurements indicate performance Δh = head
PIPING	ΔP pressure losses $\frac{\Delta T}{\Delta X}$ in axial direction Surface temperature	poor design, insulation about 10°C higher surface temperatures than the environment is a rule of thumb. Optimization is possible

NA

VIII PERFORMANCE FIGURES (Cont'd)

COMPONENTS	FIGURE	REMARKS
STACKS	T = outlet temperature O_2 = Oxygen %, 1...2 % CO = Carbon monoxide	For sulphuric fuels, 110...160 ^{0}C ZrO_2 sensor highly recommendable It supports O_2 measurement
PUMPS	$\frac{\Delta P \cdot \dot{V}}{M}$, $\frac{\Delta h \, \dot{m}}{M}$	Hydraulic coupling or motor inverters have energy saving potentials in case of control, special measurements applicable $\dot{m}$= mass flow = $\dot{V} S$
TURBINES	Real efficiency compared with the nominal and ideal one	- vibration - endoscope applicable to compressors
GENERATORS	P real (net powers) P nominal Mechanical power Electrical power	special measurements are useful
COMPRESSORS	$\frac{\Delta P \dot{V}}{P}$, $\frac{\Delta h \dot{M}}{P}$ Recycling %	AP = pressure drop $\dot{M}$ = mass flow = $\dot{V} S$ P = power Special instruments have potenials . vibration . endoscope
DISTILLATION TOWERS SEPARATORS STRIPPERS CRACKERS	Specific energy use of products By-pass reduction Refluxes Scale formation	IR- photography powerful to study temperature distributions Online optimization is one potential, sophisticated equipment ne[illegible]ec

VIII PERFORMANCE FIGURES (Cont'd)

COMPONENTS	FIGURE	REMARKS
SYNTHETIZING VESSELS	Insulation (surface temperature)	
CONDENSATE COLLECTION	Amount of returned condensate	IR powerful for steam traps, heaters and vessels
	Purity . conductivity . O_2 . pH . Na, K, PO_4, SiO_2	These figures vary depending on pressure and temperature levels

IX HEATERS, HEAT RECOVERY (Case)

A sankey diagram is recommendable to be prepared for a distillation unit with auxiliary processes (mainly heaters). The present level of recovery will be assessed and the possibilities for additional recovery and costs due to that.

The cost analysis covers

- investment
- operation
- maintenance
- fuels and materials
  for operation

Such potentials as

- refluxes and by-passes
- separation optimally within
  tolerable limits
- improved compressor control
- optimal allocation of automation
  e.g choking valves

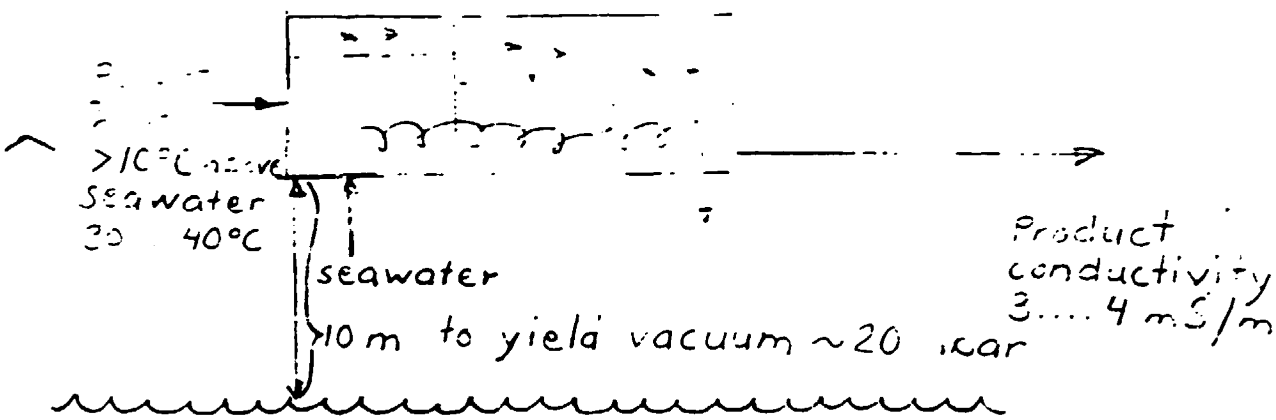
Performance figures describe the performance of a unit. If these deviate a lot from the nominal values, these actions are necessary to revamp or rehabilitate the unit. Also, these figures are useful to judge whether an equipment is to be opened. In big units great economical values are in question (outage, labor, etc.). Therefore, a number of this kind of indicators will be developed. Also, these provide a basis for automatic monitoring or for checks or audits in connection of preventive maintenance. This activity is good for instrumentation and chemical people.

X DESALINATION BY LOW QUALITY HEAT

There are now available a method to use reject heat to desalinate water. One exists in Egypt (Suez) and is now under commissioning. The idea is vacuum evaporation. There are three effects. About 4% of the rated flow is evaporated. The evaporating effects are lifted by 10m to create the vacuum. Water boils in about 18^{0}C and the final vacuum is about 18 m bars. The reported production is 20m^3/hr which is good for 2000 people community. The advantages are :

- less corrosion because of lower temperatures
- use of low quality heat
- the product water meets very high standards
  3-4 S/m
- the water is good for process use

The high input flow keeps the heat exchanging surfaces clean, The schematic function is as follows



Ratings: 20 m^3/h
4% evaporation
of raw water

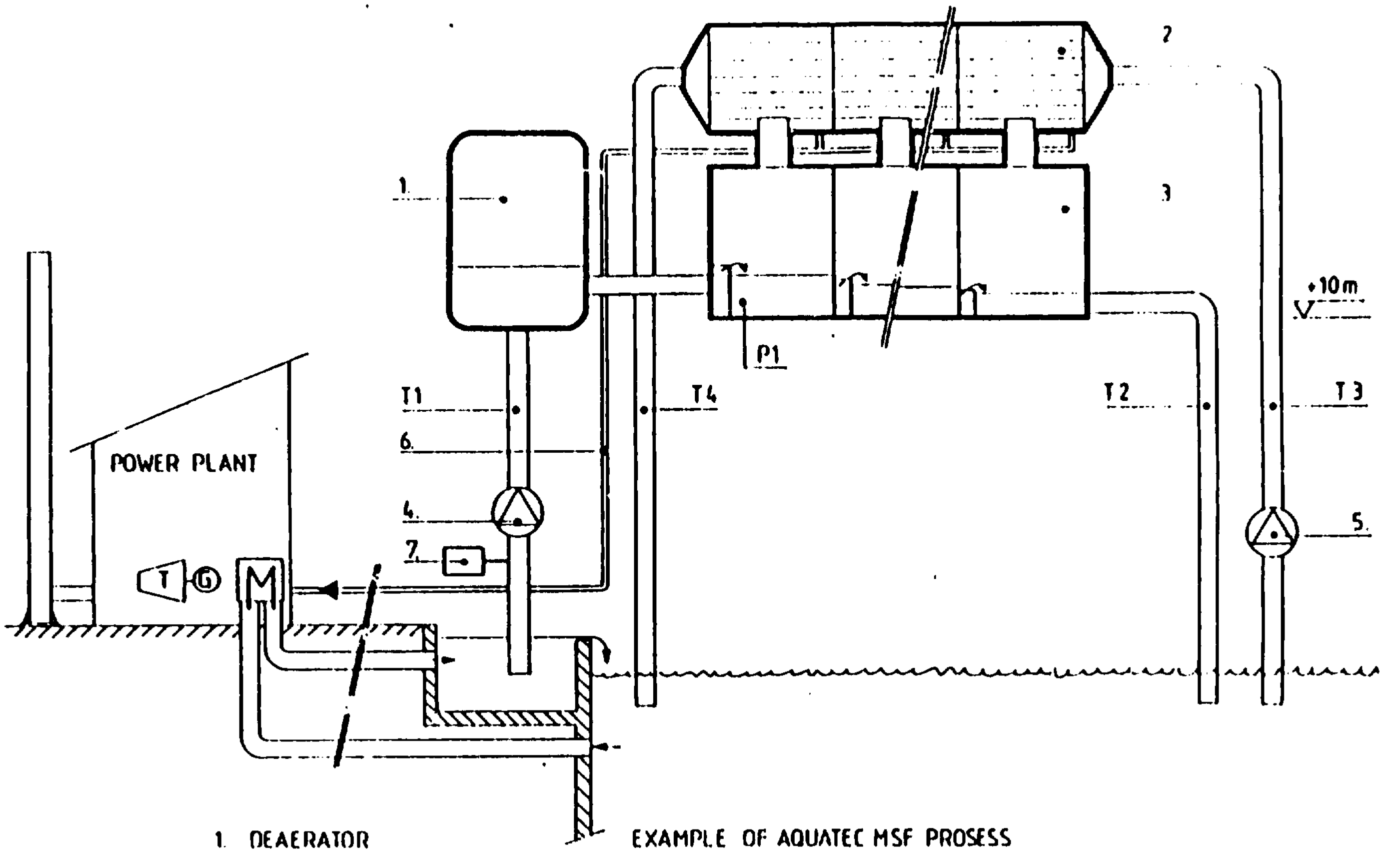
Because the water slightly concentrates the boiling point decreases which positively effects on the evaporation process. This system is evidently competetive with the flash or deionating methods. Because of epoxy coating contaminated condensates form one source of heat to be exploited.

THE DESALINATION CONCEPT

The Suez Refinery produces 2700m^3/hr cooling water. In addition, contaminated condensates are good for heat recovery since the primary side of the heater is coated by epoxy material which is resistant to corrosion. If these two sources of heat are utilized enough reject heat exists to run the desalination plant. This is only the expansion. If this cooling water from the original unit is included, a lot of waste heat is available to meet with the requirements of deionated feed water. The benefits are :

- Reduced corrosion because of high quality of feed water.
- Energy conservation because of more efficient heat transfer and reduced scale formation.
- Option to upgrade the steam for high pressurized boiler and turbine use.
- Low cost method to make feed water, no/little chemical costs.
- 6-8 kwh$_e$/m^3 product water = specific electricity demand.
- Reduction of blowdowns effecting energy conservation.
- Option to provide water to the surrounding community.
- This concept is good for upgrading and new units.

This option is at least worth a feasibility study and so far this technique is little exploited. The investment costs start from 0.1.....0.5 M$ corresponding 5....30m^3/h of production.



1. DEAERATOR
2. CONDENSER
3. EVAPORATOR
4. FEED WATER PUMP
5. COOLING WATER PUMP
6. DISTILLATE
7. CHEMICAL SOLUTION TANK

EXAMPLE OF AQUATEC MSF PROSESS

TEMPERATURES	T1	34°C	(93°F)
	T2	28°C	(79°F)
	T3	22°C	(72°F)
	T4	28°C	(82°F)
PRESSURE	P1	~30 mbar	

RAUMA-REPOLA OY
UUDENKAUPUNGIN TELAKKA
UUSIKAUPUNKI SUOMI

NIMITYS
AQUATEC WHD / MSF
FLOW DIAGRAM

MUUTOS | OSA NO | KENTTÄ | MUUTOS JA/TAI HUOMAUTUS | PÄIVÄYS | MUUTT. | HYVÄKS

AQUATEC DESALINATION PLANTS

Technical Data and Cost Estimate

	AQUATEC WHD/MSF (multi-stage-flash)	AQUATEC VC (vapor compressor)
1. Service life	20 years	15 years
2. Operation temperature	30°C	75°C
3. Distillate temperature	25°C	30°C
4. Energy consumption	5 kWh/m^3 dist.	15 kWh/m^3 dist.
5. Capacity	max. 100 m^3/h/unit	max. 20 m^3/h/unit
6. Applications	- thermocline (MSF) - power plant (WHD)	- turbocompressor - thermocompressor - compressor driven by diesel engine
7. Range of use	- power plants - process industry - drinking water preparation	- hotels - building sites - process industry - drinking water preparation
8. Costs	interest 10 %, time of payment 20 years	interest 10 %, time of payment 15 years
- investment costs	0,9 USD/m^3	0,7 USD/m^3
- operation costs	0,3 "	0,8 "
- other costs	0,2 "	0,2 "
Total	1,4 USD/m^3 distillate	1,7 USD/m^3 distillate
9. Advantages	- low operation costs - low operation temperature - minor corrosion problems - flow-through principle - utilizes waste heat - patented	- small size - low operation temperature - flow-through principle - easily transportable unit - easy cleaning - patented

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Banker
Kansallis-Osake-Pankki

RAUMA-REPOLA OY
Uusikaupunki Shipyard

AQUATEC DESALINATION PLANTS

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AQUATEC DESALINATION PLANTS

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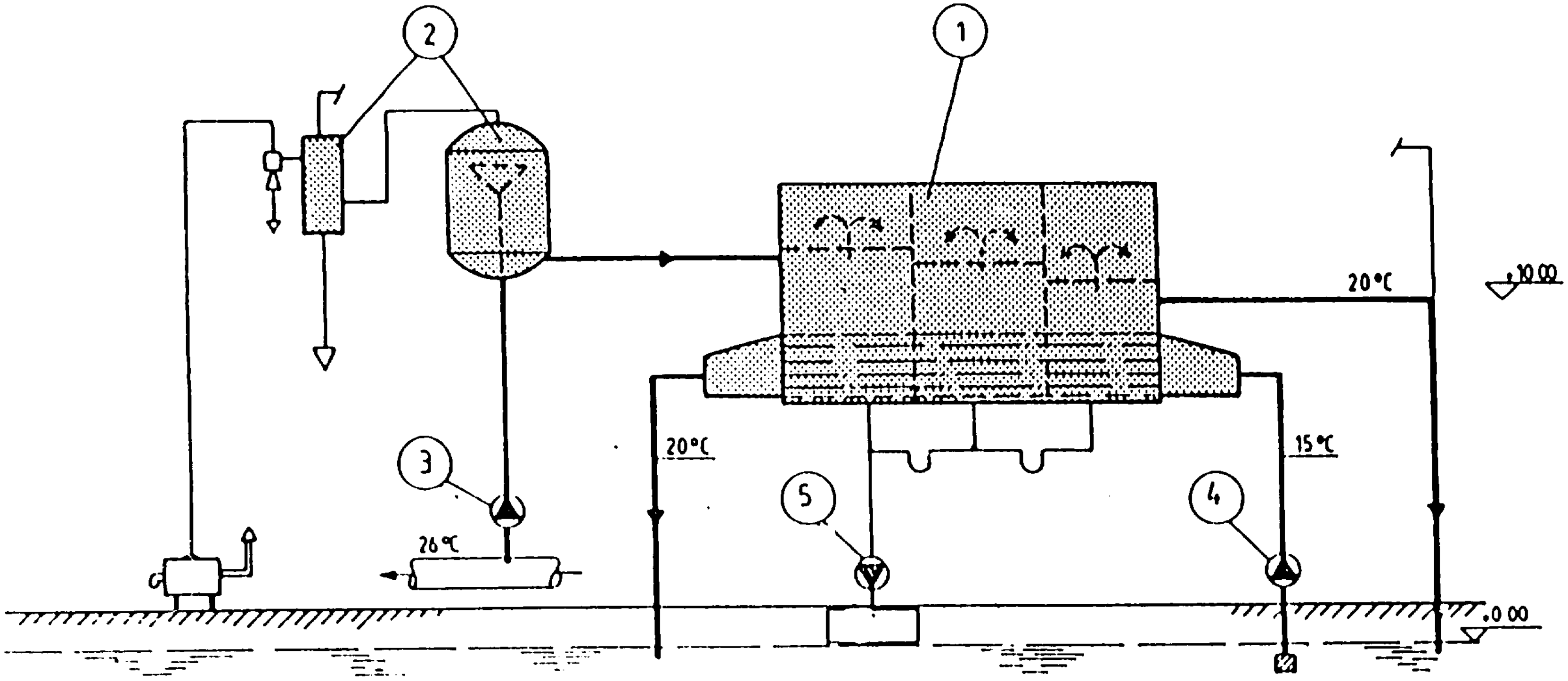
AQUATEC
RAUMA-REPOLA OY

AQUATEC MSF

Circuit Diagram



Mountings:

1 Evaporator/condenser
2 Aerator system
3 Sea water pump
4 Cooling water pump
5 Distillate tank and pump

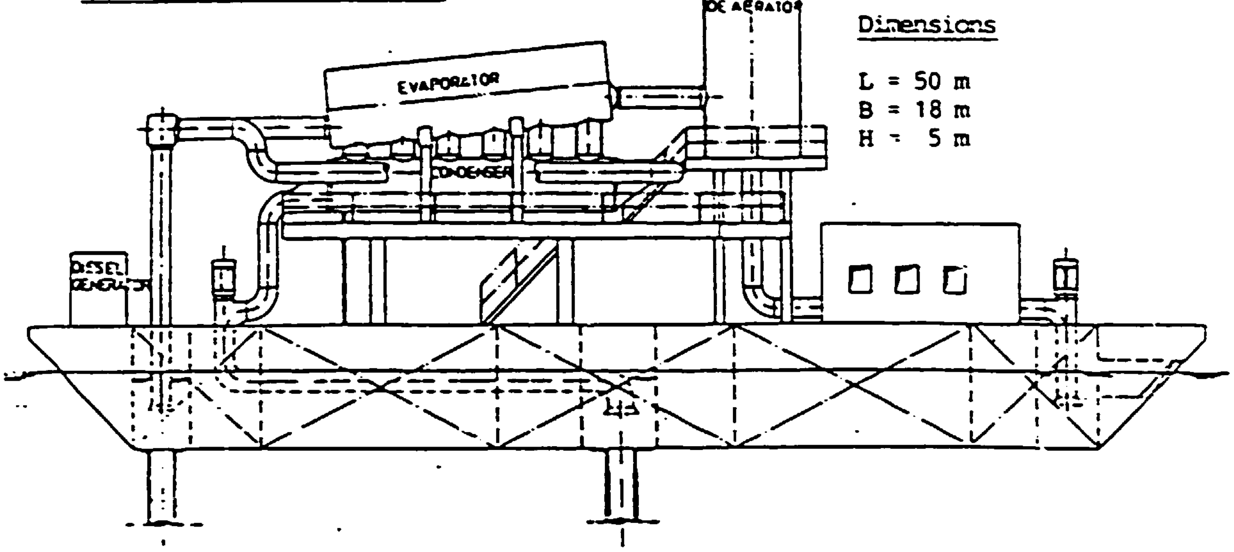
Characteristics:

- utilizes low temperature energies
- specific consumption 5...6 kWh/dist. m^3
- vacuum is achieved by siphon-phenomenon by lifting the equipment about 10 m from sea level

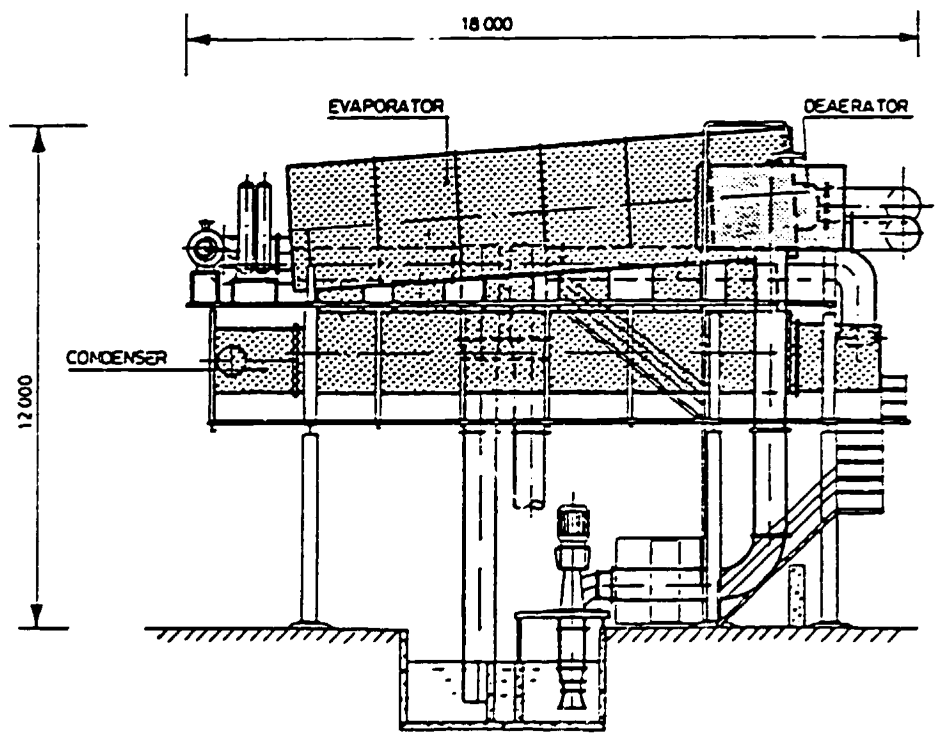
RAUMA-REPOLA OY

AQUATEC

TERMOCLINE BARGE (20 m^3/h)

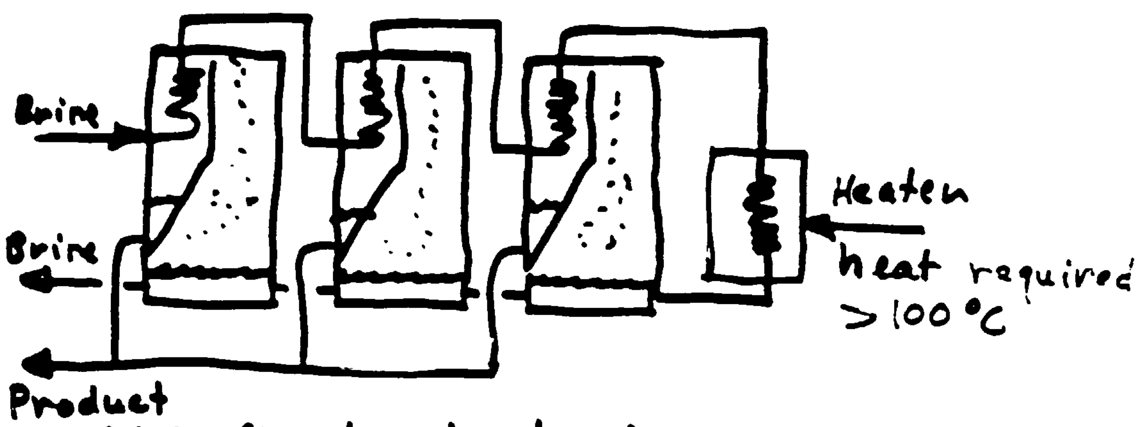


EXAMPLE OF WHD (20 m^3/h)



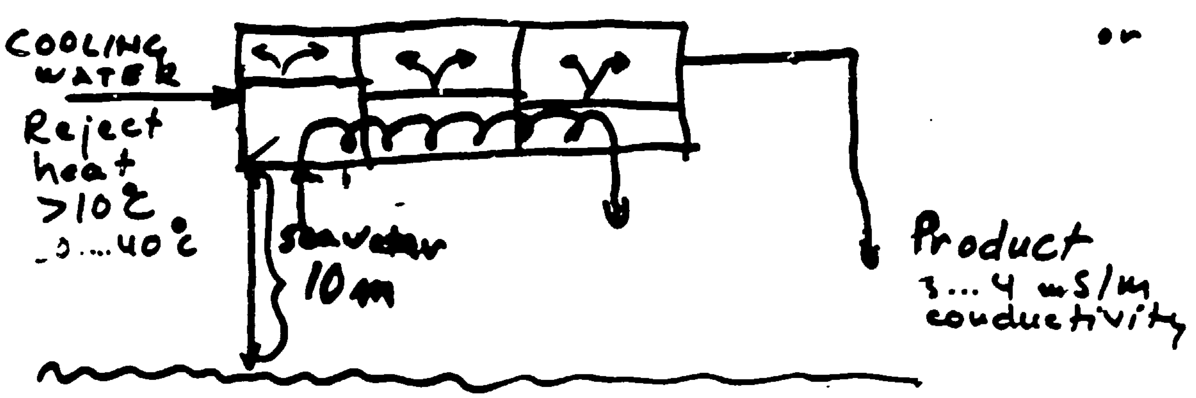
WASTE HEAT RECOVERY

UNDP/PSN
1985



Multiflash technique

... APPROACH



Ratings: ~20 m³/h
4% distillation rate
20 mbar vacuum
2...3 T/s need of reject cooling wate[r]

Vacuum multieffect evaporation

Merits:
- requires only low quality heat
- reduced corrosion because of temperature levels
- product water good for majority process purposes
- simple operation
- low quality reject heat recovery

One plant exists in Suez/Egypt in connection of a power station. This concept is good for refineries, too.

XI OUTLET STACK GAS TEMPERATURES IN FURNACES IN HEAT RECOVERY

If the contents of H_2SO_4 varies in stack gases

1....10 ppm

the outlet temperature respectively for the dew point

$110^{o}C......150^{o}C$

The H_SO_4 can also be neutralized by an appropriate base (NH_4OH) but this is a costly method and results in plumes which probably must be extracted by means of an electric filter. >180°C temperatures are applied when fuel contains >3% of sulphur.

The cooler must be sized such that approximately the desired outlet temperature is achieved. It can also be controlled

- by pass flows of air
- stack gas blower, but combustion conditions are affected by this means
- by passing stack gases
- by mixing warm and cold stack gases

The first method probably causes the least harm for other control systems. The heat conservation can be calculated approximately as follows

stack gas inlet, outlet T/C

$$(350 - 140) \quad \dot{M} \cdot \bar{C}_v \qquad (1.9\%S \text{ in fuel})$$

$\dot{M}$ = mean flow through stack

$\bar{C}_v$ = average specific heat of stack gases

5 −10% of the total heat energy is achievable in the stack gases.

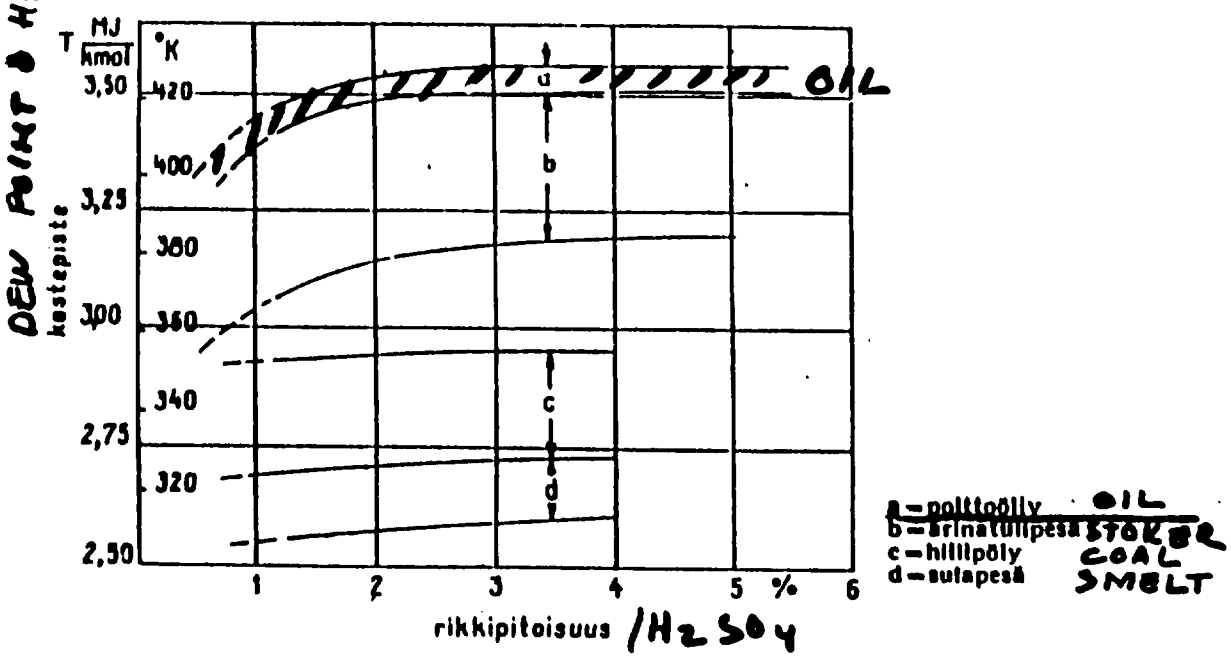
The enthalpy difference is approximately converted into the speed at gases.

NA

GA101 (1180)

XI OUTLET STACK GAS TEMPERATURES IN ... (Cont'd)

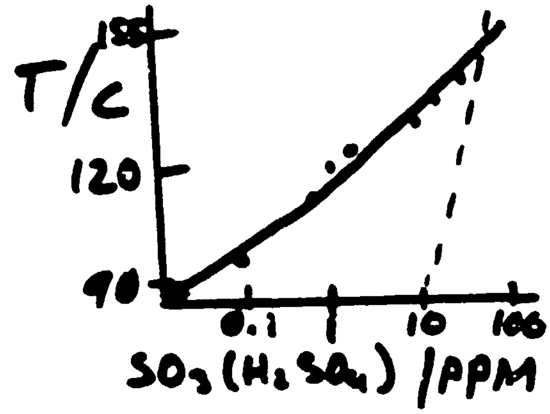
350/140°C presents a typical temperature reduction across the air preheater in an oil fired furnaces. Moreover, the reduction of O_2-contents also reduces formation of $Na_2O.V_2O_4.5V_2O_5$ which is a difficult corrosive agent. The sulphur contents of combustible must not exceed 3.8%. The sensors must be placed in the coolest spots. In case of glass or cast iron or stainless steel or enamelled cool part this prob- can be solved, costs get higher and a roi-analysis must be carried out.



Kuva 10 Kastepiste rikkipitoisuuden ja tulipesätyypin funktiona

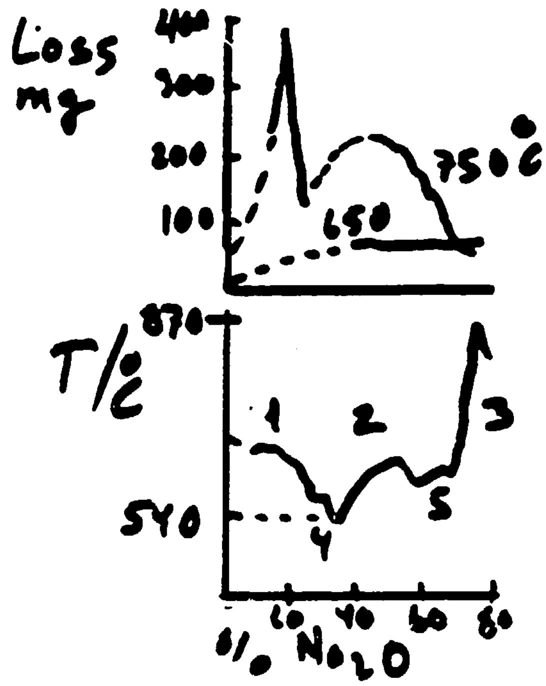
STACK GASES

DEW POINT



LOW TEMP CORROSION

oil ash corrosion



Effect of Na_2O_2/V_2O_5 mixtures

CORROSION HIGH TEMP.

FUSING POINT

1. Na_2O V_2O_4 $5V_2O_5$
2. Na_2O V_2O_5
3. $3Na_2O$ V_2O_5
4. $5Na_2O \cdot V_2O_4 \cdot 11V_2O_5$
5. $2Na_2O$ V_2O_5

UNDP/PSH/85

XII EQUIPMENT FOR HEAT RECOVERY (Example)

10% of the total heat is recovered by preheating air, therefore this discussion is worthwhile.

ROTARY TYPE OF HEATER (HEAT WHEEL)

Advantages :

- Resistances of flow small.
- Small operational energy demand.
- Low construction costs.
- Small, compact and light.

Drawbacks :

- Leaky, sealing may be problematic.
- Thermal expansion may cause disturbances.
- Risk of fire in case of unburnt materials.
- Outlet temperature control mandatory
- Sooting necessary.

GLASS TYPE OF AIR PREHEATER

Advantages :

- No corrosion problems.
- No sooting necessary.
- Interchangeable glass tubes.
- No outlet temperature control.

Drawbacks :

- Glass is a poor thermal conductor.
- Big in size and weight.
- Difficult probably to install to existing furnaces.
- Costs are high.

XII EQUIPMENT FOR HEAT RECOVERY (Cont'd)

CAST IRON PREHEATER

Advantages :

- Modular, tube elements are interchangeable.
- No risks of dew point.
- No outlet T control.
- Fairly good thermal conductor
- Better heat recovery due to low outlet temperature

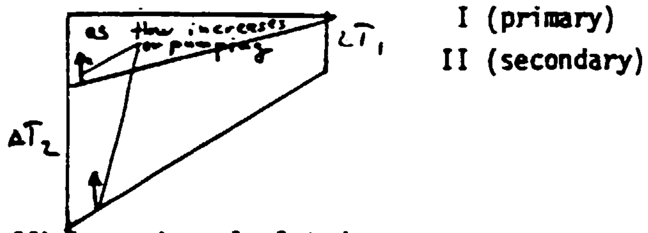
Drawbacks :

- Heavy and massive.
- Sooting necessary.
- Costly.

Stainless steel has the same advantages, but it is more costly. It is a better thermal conductor. Although some condensation at $H_2 SO_4$ was allowed, it must be removed in any case.

EFFICIENCY OPTIMIZATION OF HEATERS

To analyze the overall performance of heaters it is often justified to include the pumping energy since increasing the size of the pump is more costly than the heater. The capacity of the heater can be increased by pumping but only to a certain extent. The bahaviour is as below schematically :

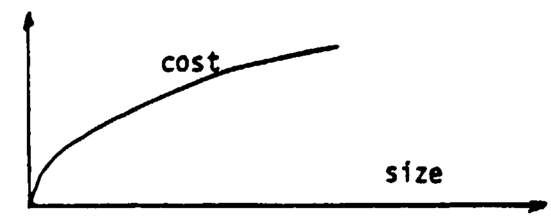


If the overall efficiency is calculated

$$\frac{\sum_1^1 \text{exergies out}}{\sum_1^1 \text{exergies in}}$$

a relative performance is obtained. There are constraints like minimum outlet temperatures or fouling,etc. Taking the pump and heater size and cost functions as parameters this optimization is possible. Increasing the pump size means mixing or recycling normally an irreversible process which is not necessarily economical. This model can be developed for various types of heaters and flows (laminar , turbulent, two-phase, etc.). The evident result is that minimized heater surface is not necessarily the optimal one.

Turbulence promotes heat transfer and bigger pumps work relatively more efficiently and the unit price decreases. This to be matched with the marginal benefit of gained energy. Such aspects like possible future expansion of the unit may be one constr-aint. The unit prices for pumping and heaters grow logarithmically or linearly with the exception that the initial rise is rapid, e.g.



The cost function is to be matched with some existing data. A logarithmic model can be chosen.The heater is to be handled individually since the flow conditions have a clear impact on the results. The model can be made interactive such that the necessary parameters are asked by the computer. Defaults can be applied for the user convenience. The plotting facility is highly recommendable to visualize the results as a function of the selected variable. The model can be updated as additional cost data is obtained. One updating is, of course, the inflation rate if the date of the cost data is known.

The input exergies can be calculated approximately

$$\frac{\sum_{o} \left[\left(1 - \frac{T_{amb}}{T_o}\right) \dot{Q}_o + F_o \right]}{\sum_{i} \left[\left(1 - \frac{T_{amb}}{T_i}\right) \dot{Q}_i + F_i \right]}$$

i = input

o = output

Q = heat flow

$F_{i,o}$ = pumping energy (electricity).The maximum available energy is a good estimate for this exergy ≥ real exergy. This efficiency provides a method to compare various solutions. The exergies out =. the recovered energy and it is to be evaluated to calculate the return of the investment. Computer model aids also to estimate the consequences of fouling or scale formation. When and if real values of the case are measured, the index can be compared with the initial or the design one. It helps to predict possible maintenance operations, sooting or cleaning under operation. One advantage of this approach is : it is relatively simple and straight forward and global. E.g., if the heater gets dirty, the flow resistance increases and the performance index automatically notes that.

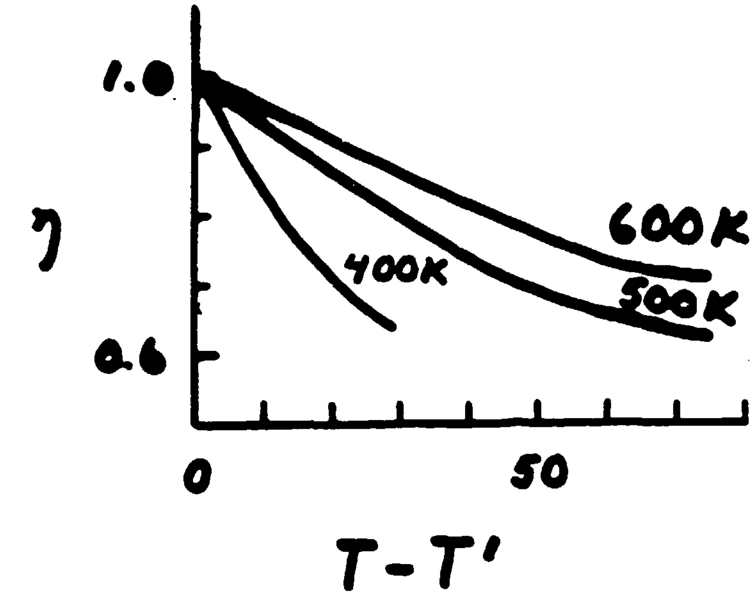
Distribution:

R Duvall

M Wahby

T Hussein

F Youssef



Heater performance as a function of MLTD

Capacity can be increased by additional pumping, but increasing heat size is less expensive

$$\Delta B_{oi} = \dot{m}_i \Delta b_{oi}$$

$$\Delta b_{oi} = h_{oi} - h_i - T_0 (s_{oi} - s_i)$$

$$\Delta b_{oi} = c_{P_i} \left(T_0 - T_i - T_0 \ln \frac{T_0}{T_i} \right)$$

$$\eta = \frac{\sum_{\substack{\text{exit} \\ \text{streams}}} \Delta B_{oi}}{\sum_{\substack{\text{inlet} \\ \text{streams}}} \Delta B_{oi}} \leq 1$$

UNDP/PSH/85

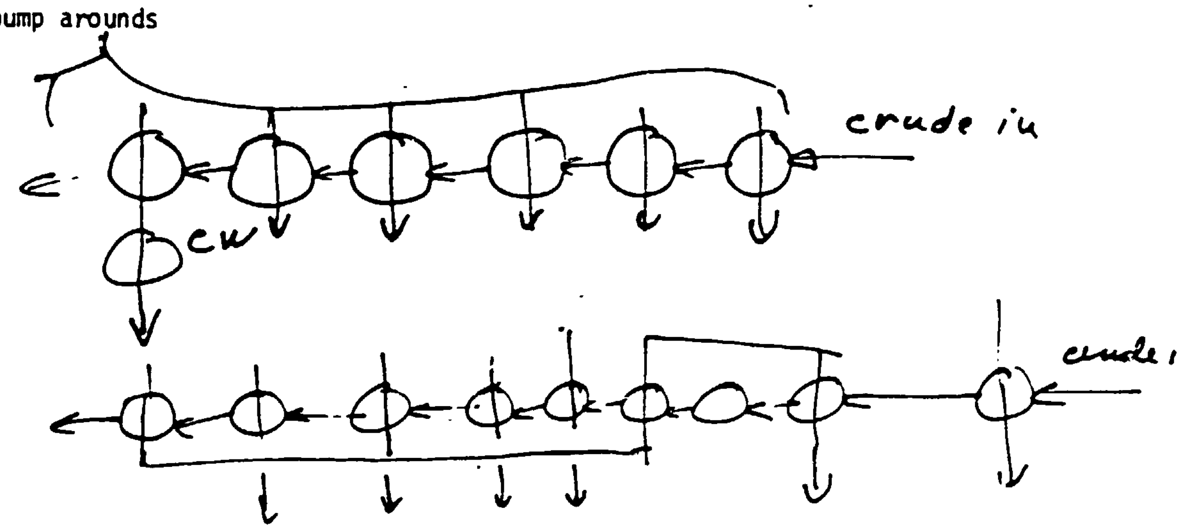
The advantage of the exergy principle is the applicability nearly anywhere

$$E = H - H_o - T_a \cdot (S - S_o)$$

environment

Exergy Flow $\dot{E} \leqq \sum \eta_a \phi \qquad \eta_a = 1 - \frac{T_{amb}}{T}$

This offers a simplified way to calculate exergies. Sometimes, however, T changes and an integration is needed to calculate the entropy. This concept has also the advantage that the system boundaries can be extended. In case of chemical energy the calorific heat is normally considered 100% as exergy. Electricity is likewise 100% available energy = exergy. The temperature levels are advices to be shown. This leads to the cascading principle e.g . in preheating train refluxes, products pump arounds



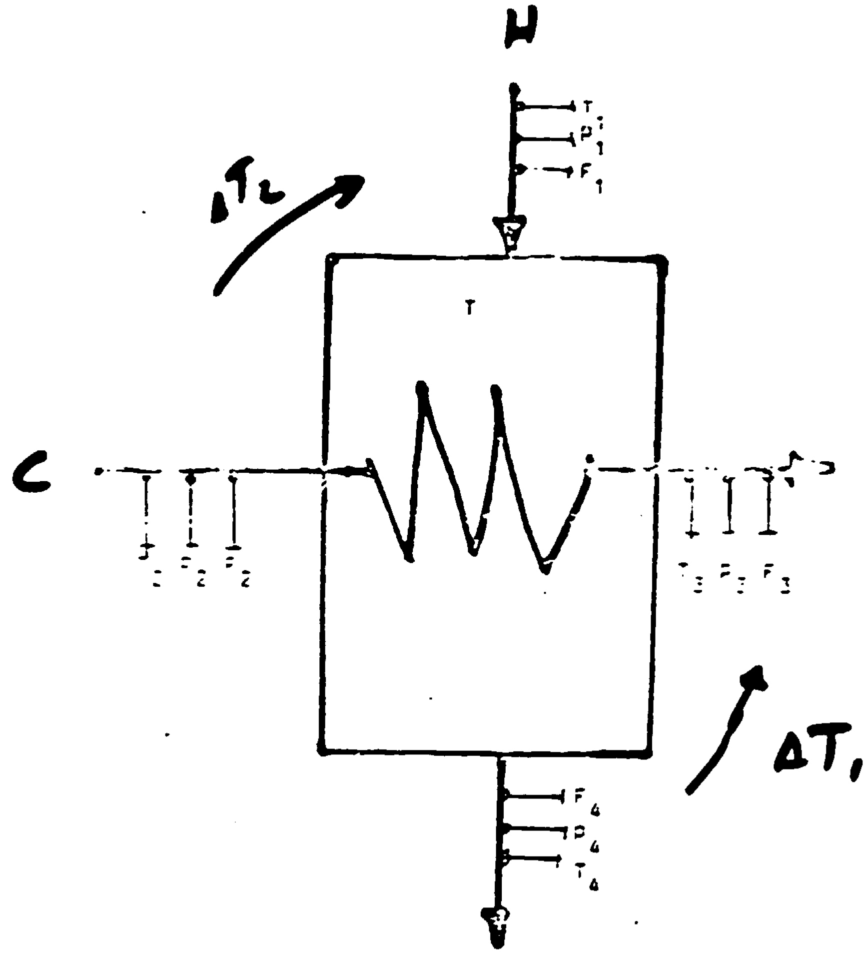
It means that there is available energy left in the last cooler to preheat again the crude. The exergy flow shows the available energies after preheating the crude to be used elsewhere. The rule of thumb hold that the warmer heat one has, the better it can be used for various purposes and it is consistent with the exergy principle. If one has gases steam and variance in temperature, then the energy calculation is more tedious. The approximation first presented in most cases gives an idea about available energy. Energy flows with temperature levels give the same idea, but energy itself without quality does not give the correct picture. This deficit (exergy) removes. The time dependent progress of exergy efficiency will reveal the the deteriorating performance of the heater. A permanent instrumentation can be installed to detect this behaviour. If an overall performance monitoring is selected e.g. for a computer, this principle guides how to do it. It reveals in case of heaters :

- leaks
- fouling
- deposits

if the result is correctly interpreted. This is valid for pumps, heaters, compressors, blowers,furnaces etc.Without this kind of figure of merit it is impossible to follow the real behaviour of a process equipment. Also, this is a unique method, widely applicable and simple. It is adviced to extend the exergy analysis allover the plant or refinery.

HEAT EXCHANGER:

UNDP/PSN
1985



Performance figures:

$T-T_3$	heat transfer or MLTD = mean logarithmic temp. difference
P_2-P_3	scale deposits, blocking → flow resistance
P_1-P_4	- " -

Following trends of these figures will reveal gradual deterioration of the heat exchanger. Endoscope is good for detection of scale deposits

More accurately $\frac{\Sigma \text{ exergies}_{out}}{\Sigma \text{ exergies}_{in}} \leq 1$

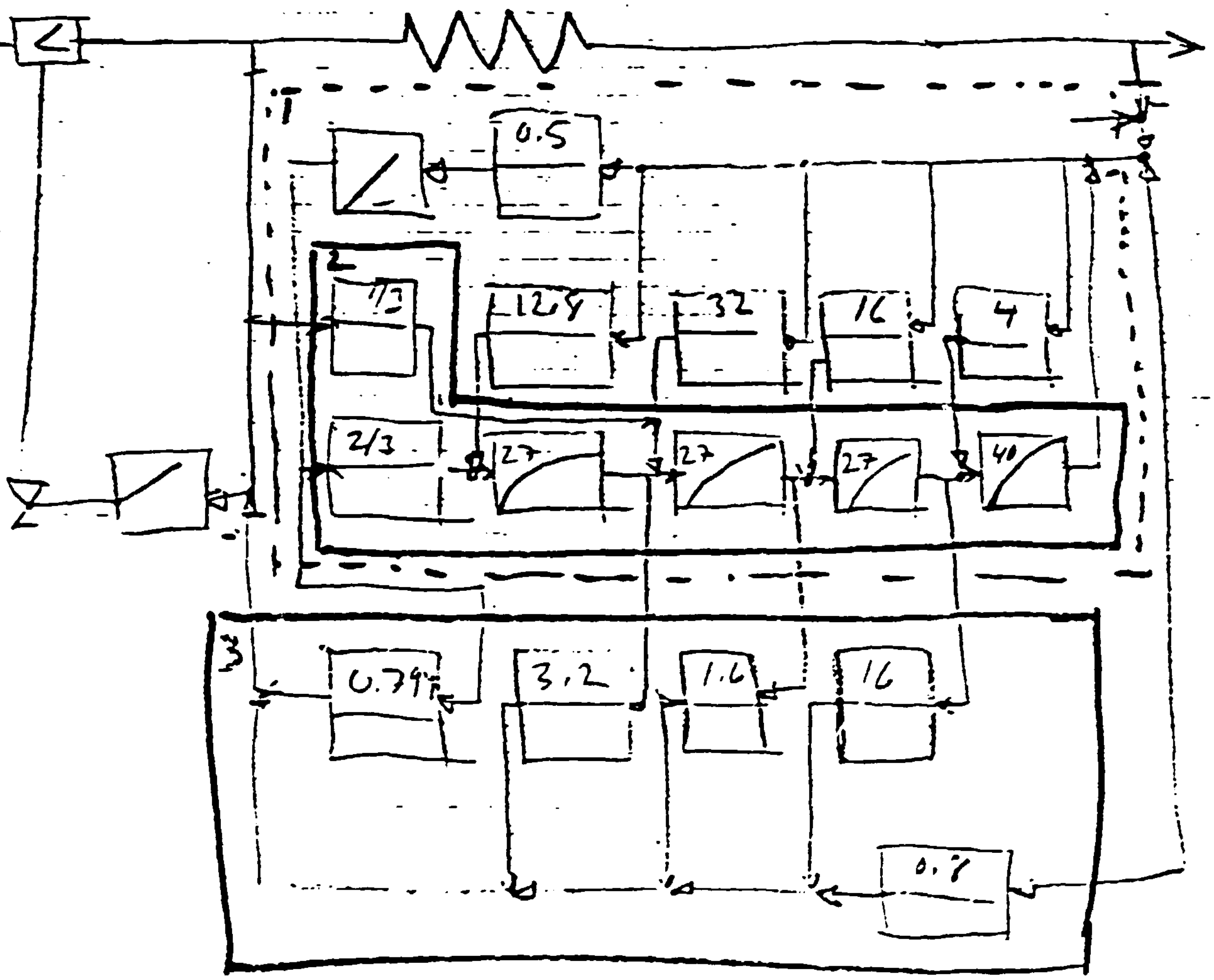
Automatic monitoring / alternatively auditing are ways to control the heater performance

Enppi

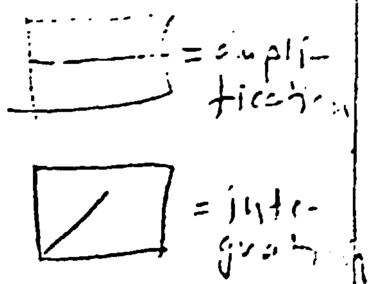
CALCULATIONS

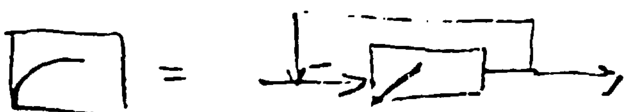
Customer	ENPPI / UNDP	Pages	Page
Subject	Energy conservation	By	SOININEN
Project		Date	

SUPER HEATER CONTROL
ADVANCED CONCEPT



1 OBSERVER
2 PROCESS MODEL
3 STATE AND FEEDBACK CONTROLLER





Performance ±2.5° instead of 5°C
→ less thermal stress and a better efficiency

FORMULAS FOR HEAT TRASFER

BOILING WATER [illegible] TUBE

$h\ [W/m^2\,°C]$ h_{fb} [illegible]

$$C\left[\frac{q/A}{S_l \gamma_l L_H}\left(\frac{\sigma_l}{g(S_l - S_v)}\right)^{1/2}\right]^{1/3} \times (P_r)^{1.7}$$

C = [illegible] ... [illegible] to [illegible]

CONDENSING SAT. STEAM (FILM CONDENSATION)

$$h = \frac{A + B\,(t_f + t_w)}{\left(l\,(t_s - t_w)\right)^{1/4}}$$

	A	B
vertical pipe	8234	20.59
Horizontal -"-	35265	-74.05

or $h = 1.38 \cdot 10^5\, l^{-1/4}\, \Delta t^{-1/3}$ vertical (SI-units)

$1.07\ 10^5\, d^{-1/4}\, \Delta t^{-1/3}$ horizontal

WATER

$h = 2480(1 + 0.0125\, t_w)\, v^{0.8} / d^{0.2}$

CHIMNEY GASES

$A + Bv^n$ = forced convection — SI-units

$h = 0.62\ v^{0.8} / d^{1/4}$ smooth pipes

$= \frac{Nu \cdot \lambda_u}{L}$ $Nu = 0.057 \cdot (R_e \cdot P_r)^{0.78}$

TWO PHASE SYSTEM

$q_{max} = \frac{\pi}{24}\, \lambda\, S_v \left[\frac{\sigma g (S_l - S_v)}{S_v^2}\right]^{1/4} \left[\frac{S_l + S_v}{S_l}\right]^{1/2}$

$h = 1.86 \cdot q^{0.72}\, p^{0.24}$

$\frac{hd}{\lambda} = 0.0225$ [illegible]

$q = C_{12}\left(\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right)$ $h = 62.100$ [illegible]

[illegible]:
- μ = [illegible] viscosity
- σ = surface tension
- L_H = latent heat
- g = gravity
- P_r = Prandl's figure
- S = density
- d = tube diameter
- A = surface, constants
- t = temperatures
- q = heat flow
- l = path length

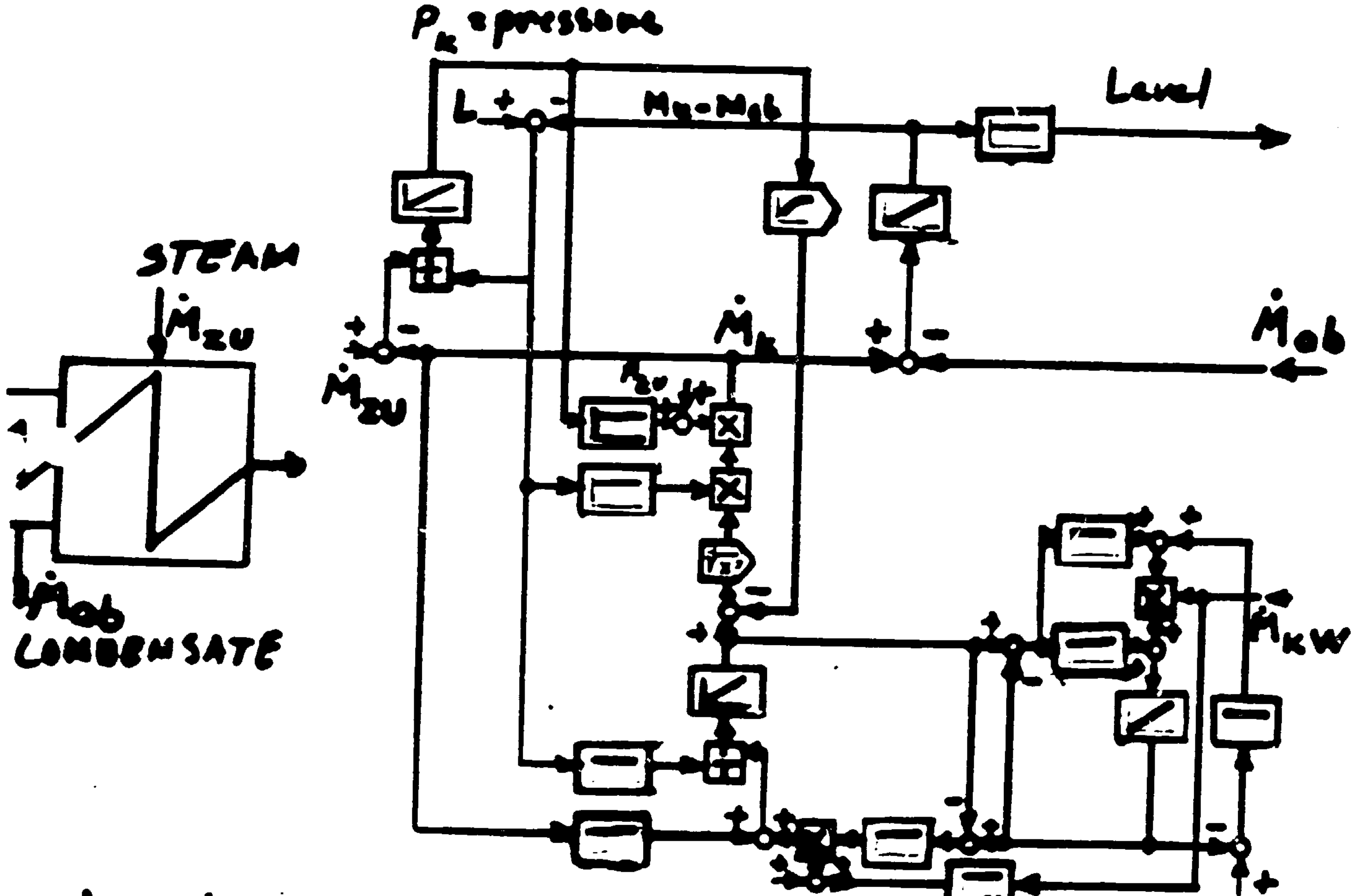
subscripts:
- w = water
- s = steam
- l = liquid
- f = film
- v = vapor
- g = ... gas

- cp = heat content
- λ = thermal conductivity
- Nu = Nusselt's figure
- P_r = Prandl's -"-
- Re = Reynold's -"-
- λ = heat conduction [illegible]

$h_{nb} = .0065$ [illegible] K

$(T_w - T_s)^{0.69} (p_w - p_s)^{0.75}$ [illegible]

This model implyis storage effects and heat transfer is different in vapor and liquid phases (film condensing and liquid to liquid heat transfer)

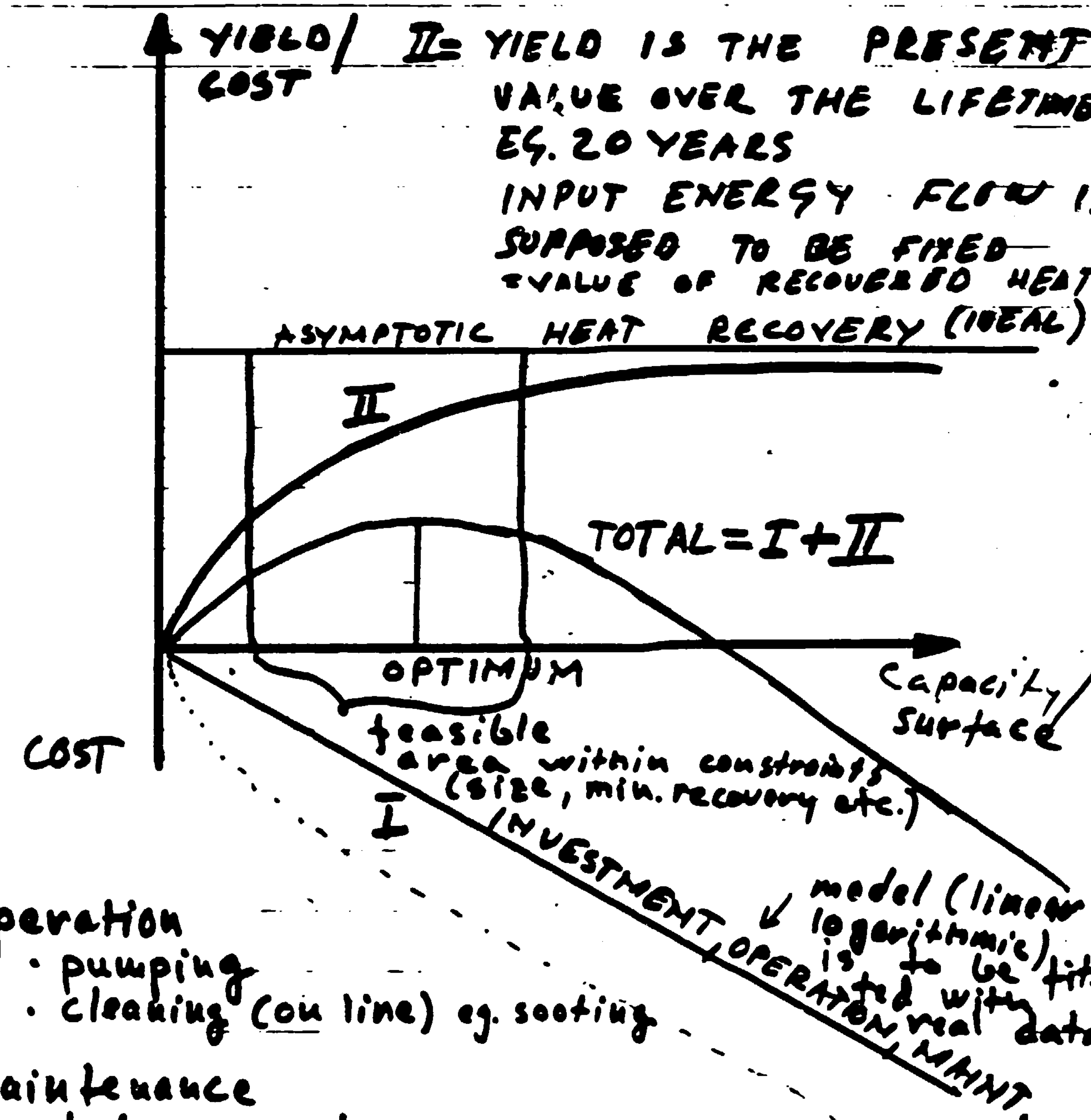


DP/PSN/1985

Mathematical model of a counter-flow heat exchanger to analyze its dynamic behaviour e.g. start up and run down situations (CONDENSOR)

Ṁ = coolin water
Ṁ_ab = tapped —"—
Ṁ_zu = flow in (steam)

PRINCIPLES TO DIMENSION A HEATER



Operation
- pumping
- cleaning (on line) eg. sooting

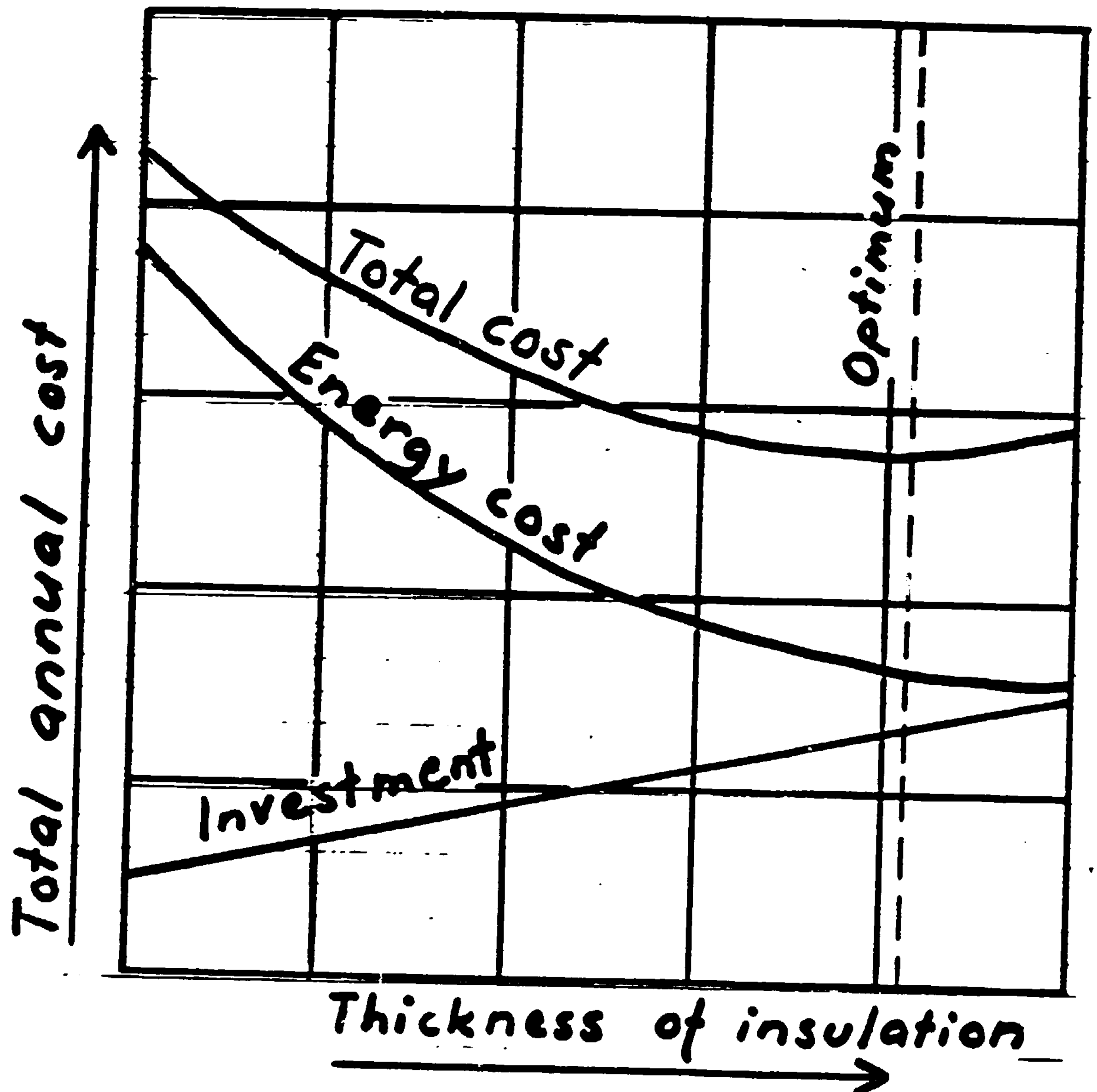
Maintenance
- tube renewals
- scale removals
- performance audits (IR, US, EC, etc)

The heater cost may be logarithmic or linear and for small units the unit price first rises rapidly. This approach does not necessarily minimize the heater surface.

UNDP/PSN 1985

A COMPUTERIZED MODEL TO DIMENSION HEATERS CAN BE DEVELOPED

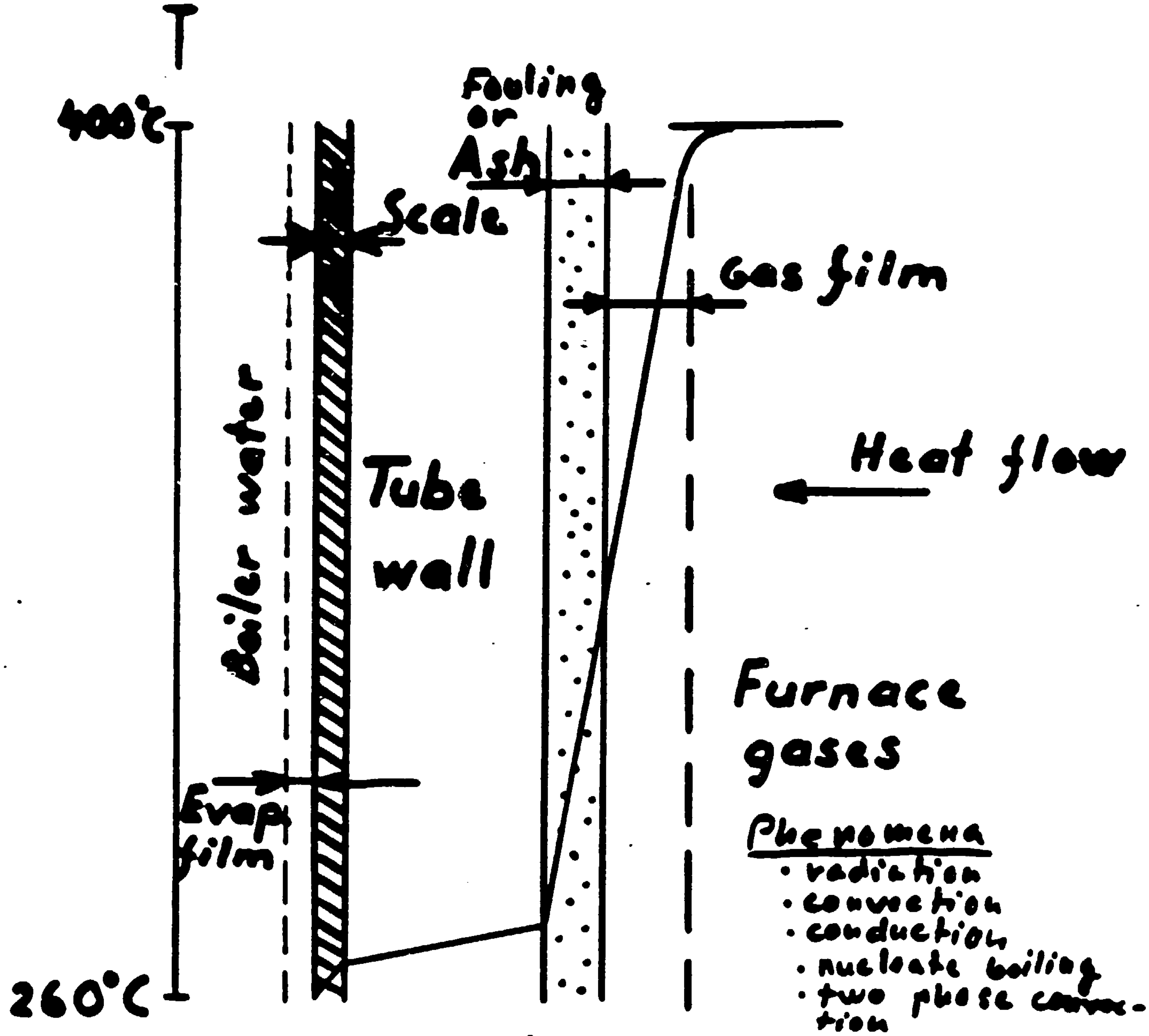
INSULATION



Rule of thumb: the skin temperature = ~10°C > the environmental temperature

UNDP/PSN/83

Temperature gradient for furnace wall tubes

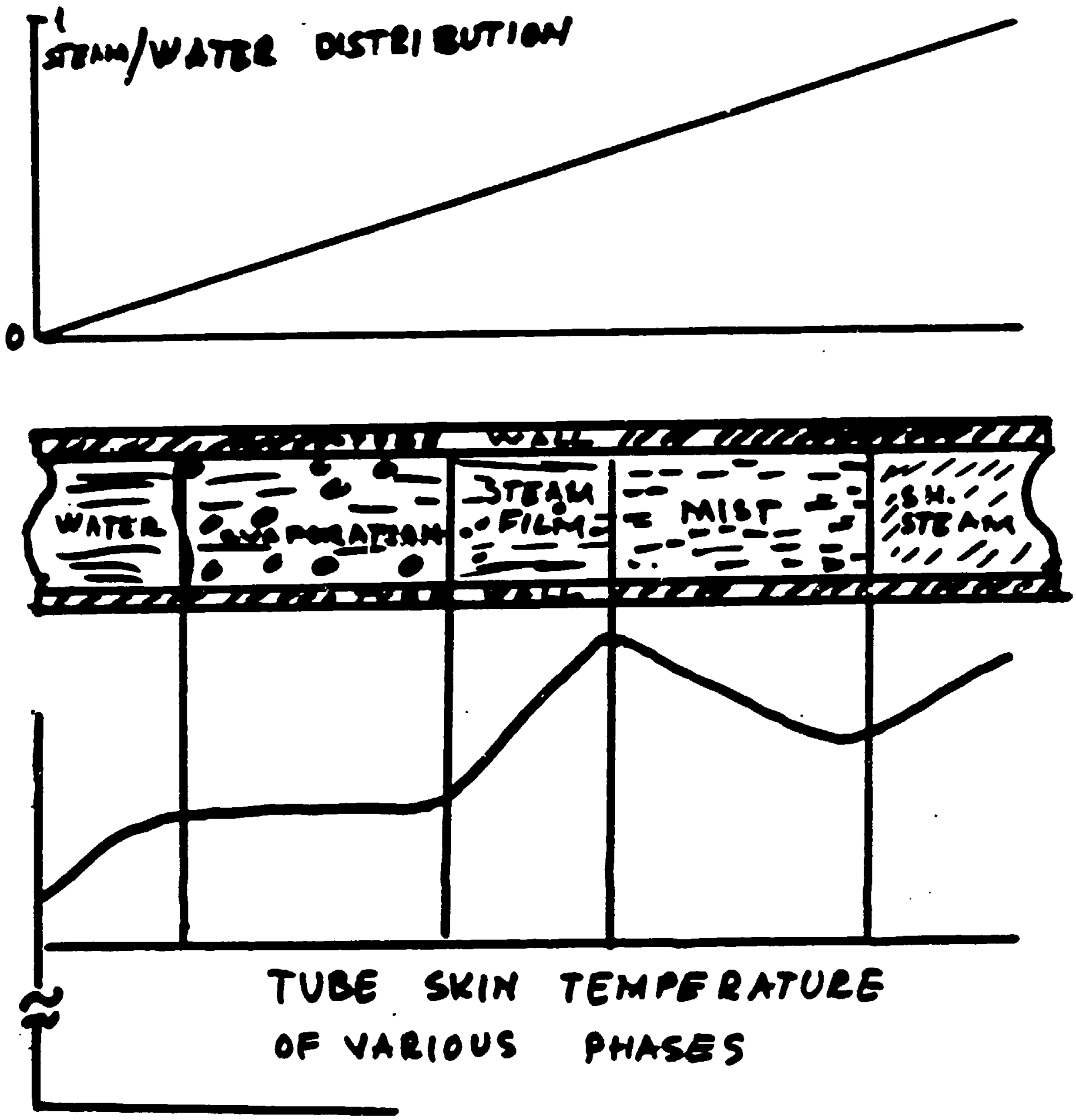


- radiant heat
- slag accumulation
- scale accumulation

$$\text{LMTD} \quad \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

UNDP/PSN

EVAPORATION PHASES AND TUBE SKIN TEMPERATURES



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1985

XII EQUIPMENT FOR HEAT RECOVERY (Cont'd)

CAST IRON PREHEATER

Advantages :

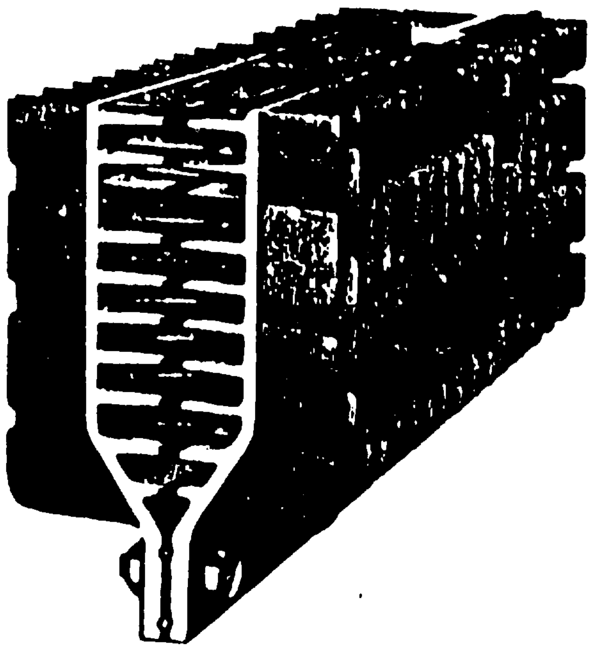
- Modular, tube elements are interchangeable.
- No risks of dew point.
- No outlet T control.
- Fairly good thermal conductor
- Better heat recovery due to low outlet temperature

Drawbacks :

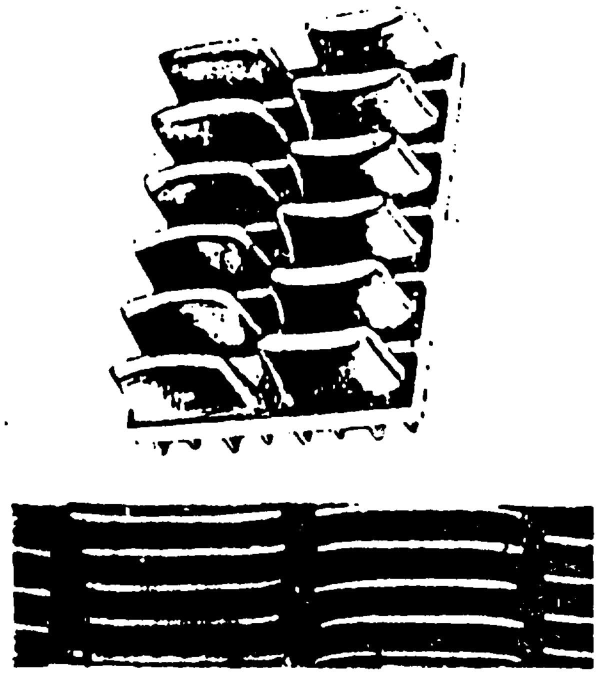
- Heavy and massive.
- Sooting necessary.
- Costly.

Stainless steel has the same advantages, but it is more costly. It is a better thermal conductor. Although some condensation at $H_2 SO_4$ was allowed, it must be removed in any case.

Modular interchangeable finned Kablitz elements

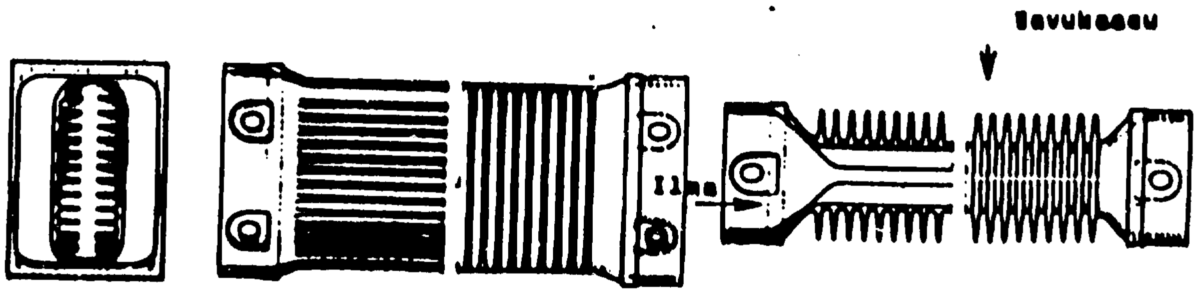


Kuva 6 a. Osa Kablitz-tyyppisestä ripalevyelementistä.



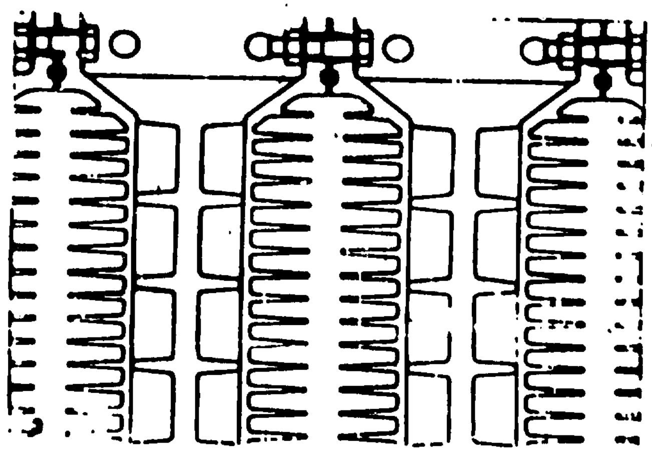
Kuva 6 b. Kablitz-ripalevyelementin ulkopuolisia ripalevyjä.

Kuva 7 esittää Kablitz-ripalevyelementeistä valmistettua N-tyyppistä (3 läpivientiä) ilmanesilämmitintä.



Kuva 3 a. Molemminpuolisilla riveillä varustettu ripaputki.

Kuva 3 b. Ulkopuolisilla riveillä varustettu ripaputki.



Both sides finned

One side finned

XIII TEMPERATURE CONTROL OF AIR PREHEATERS

Things to be remembered

- Several T sensors to ensure that the temperature does not reach the dew-point of H_2SO_4.
- The coolest places within the heater must be selected.
- By means of a proper material choice these problems could be avoided.
- Temperature can be controlled, e.g
  - By passing air/or stack gases
  - Mixing hot and cold stack gases
  - Stack gas blower can be controlled, but not good because it affects simultaneously combustion conditions
  - Correct sizing of the preheater
  - Part loads are to be considered,too

Maintenance

- Sooting under operation
- Opening if performance figures indicate

Types Available

- Ljungstrom	Swedish	} heat wheels
- Rothemuhle	German	}
- Kablitz	Mixed	expensive
- Deka	glass, little sooting and low final temperature	

Boro silicate glass + teflon → small thermal expansion.

Materials

- Smooth steel 0.17....0.18% C, Si 0.15....0.55 M_n 0.4....1.2
- Glass.... no condensing but worse heat transfer.
- Finned (cast/welded construction) type.
- Cast iron stands well H_2SO_4.

XIV FUELS (QUALITY SPECS)

Typically fuel oil contains the following compounds or element, (Finland)

Al	mg/kg	3.2	Mn	0.6	mg/kg
As	"	1.4	Ni	24	"
Hg	"	0.005	Fe	123	"
Cd	"	0.002	Zn	8.7	"
Cr	"	4.9	Ti	-	"
Pb	"	0.3	Th	0.4	"
Mg	"	250	V	42	"
U	"	0.9	S	%	1.9....2.8
C	%	86	N	%	0.3
H	%	11	O	%	0.4
Moisture	%	0.01			
Ash	%	0.02....o.5			

S and V are inconvenient as to corrosion.
Average heat contents (effective) 40.5 MJ/kg = 11.25 $\frac{MWh}{ton}$.
Al or Mg oxides can be added to raise the melting point at harmful V_2O_5. The ash obtained in oil conservation has a certain value in steel industry. Fuel for gas turbines can only contain 0.05 % vanadium because of high temperatures, Na reduces the melting point of Na-,V- oxides and thus is harmful. It can be dissolved by water and separating it , but it is costly. It might be necessary, however, in gas turbine use. There are no economically feasible method to remove vanadium out of the fuel. The worst proportion is 1:3 Na / V and this level must be reduced until some benefit can be achieved. V_2O_5 melts at 625^oC and by impact of Na 540^oC can be reached. O_2 minimization in all cases is desirable to reduce these harms. Hence O_2-control of stack gases is highly recommendable. Also, H_2SO_4 formation is more unlikely in absence of O_2.

PROPERTIES OF OIL ASHES

O_2 contents should be reduced

$Na_2O \cdot V_2O_4 \cdot 5V_2O_5$

melting point 898 K (625°C)

$5 \cdot Na_2O \cdot V_2O_4 \cdot 11V_2O_5$

melting point 813 K (540°C)

$2S + 3O_2 \rightarrow 2SO_3$ $\quad$ $S + O_2 \rightarrow SO_2$

Oxygen content contributes this process

$2SO_2 + O_2 \rightarrow 2SO_3$

at 700°C, FeO catalytic

$SO_3 + H_2O \rightarrow H_2SO_4$ impact of water

XV Co-/combi generation of steam and electricity

The gas turbine has typically the features below :

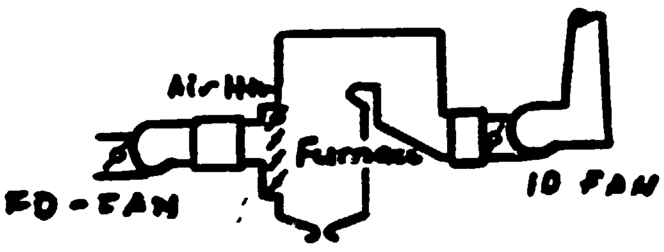
- Fast start up.
- The fuel must be low sulphuric.
- Excess air is used to control the temperature of the combustion chamber.
- Exhaust gases can be conducted to a waste heat boiler to improve the efficiency.
- Vanadium can cause problems because oxides may be formed and the furnace temperature is enough to melt the oxides.

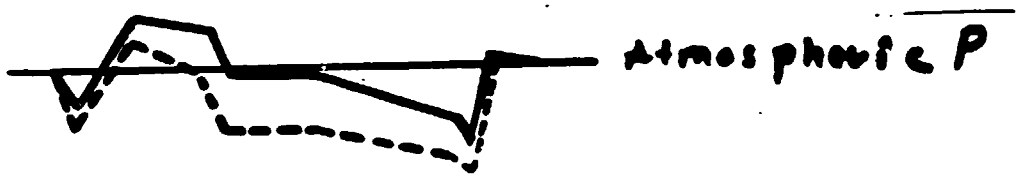
The combi process improves the overall efficiency clearly and up to 42-47 % efficiencies can be reached in condensing modes, i.e electricity is generated. Higher utilization is achieved if the back pressure concept is adopted.
It means

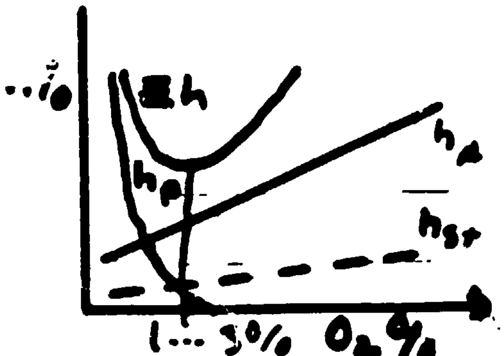
- Steam is extracted in the turbine or/and the back-pressure steam is utilized in the refinery.
- Production of electricity is reduced depending on the degree of extraction and condensing.

The energy economy of this process is any way very efficient and always an alternative worth consideration. The schematic process is

FURNACE PRESSURE PROFILE

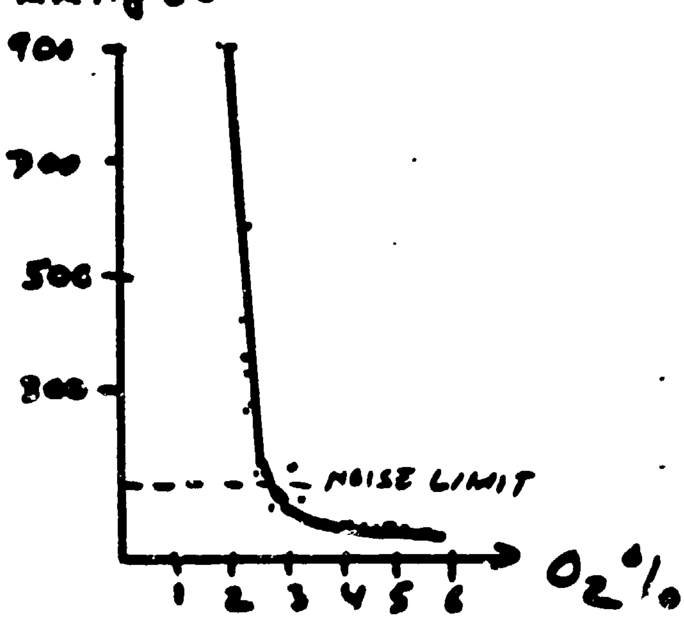






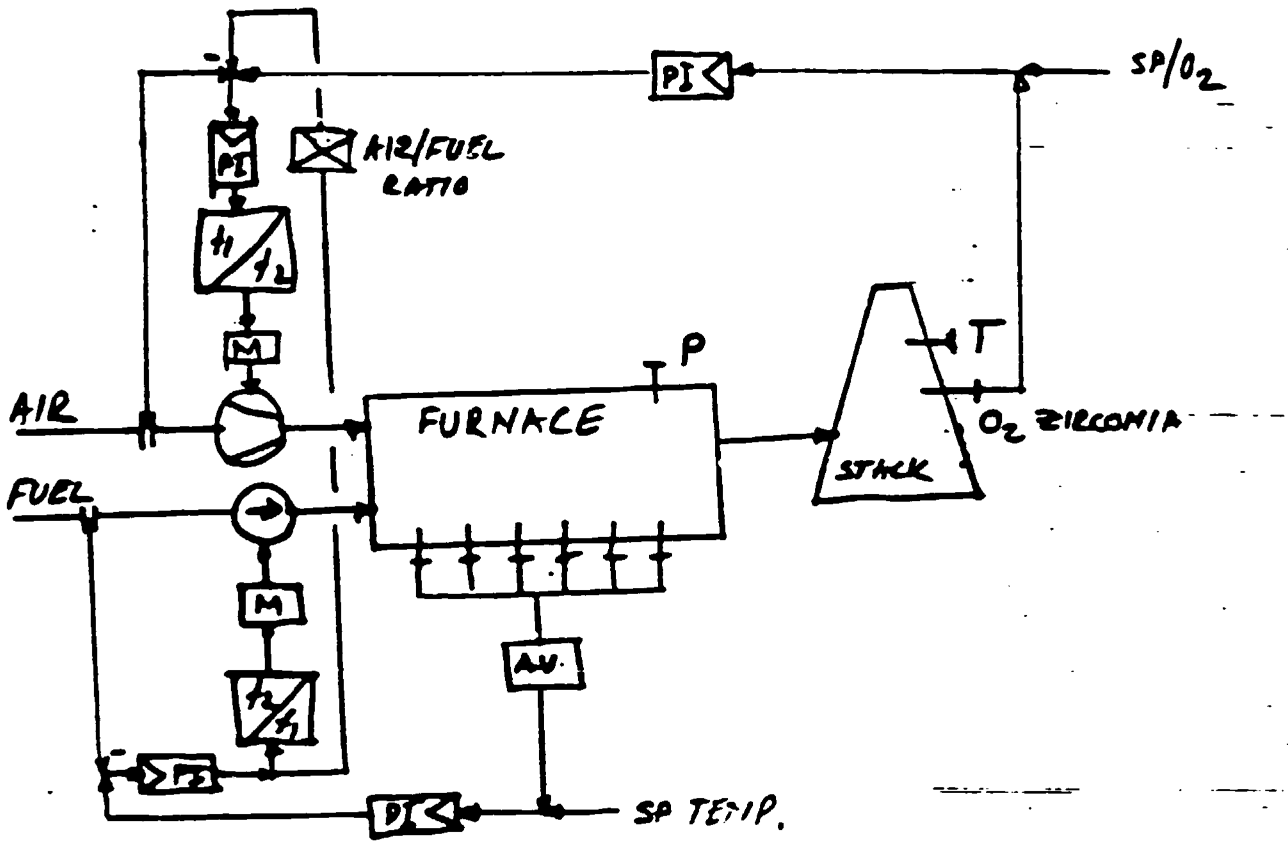
h_A flue gas losses
h_p non burnt
h_{st} radiation
Σh total

— less H_2SO_4
—·—·— V_2O_5 Na



CO/O2 relation
UNDP/PSM/85

BASIC FURNACE CONTROLS

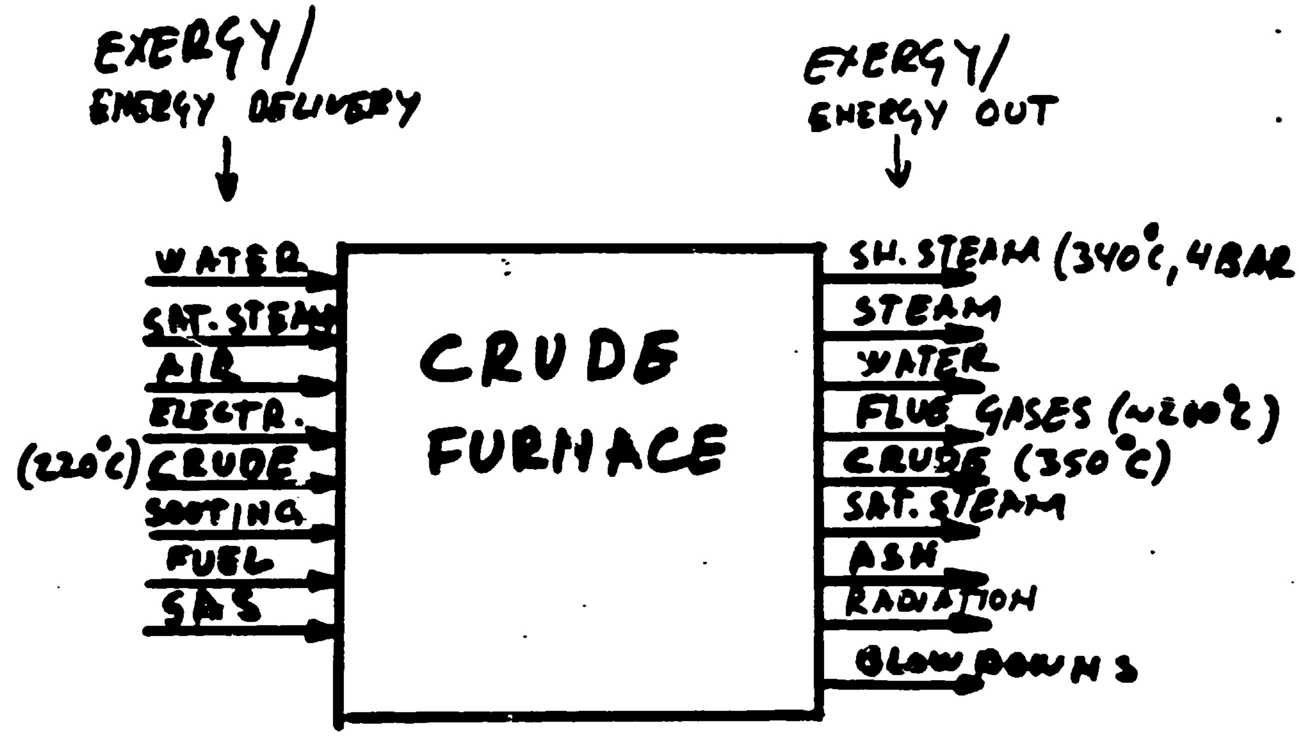


- feedfoward for fuel/air ratio
- feedback for air flow according to O_2-sensor
- merit: fast and conserves energy

Frequency Converter Approach

The controllers may be replaced by a microprocessor

INPUT/OUTPUT MATERIALS OF A CRUDE HEATER



ACTIONS:

- check quality of feedwater
- air preheating
- speed control instead of choking { fuel, air, crude
- O_2 sensor → setpoint to air blower + other control actions
- Supporting CO measurement
- Option for possible inlet air from air coolers (there are examples)
- performance monitoring/audits
  - air heater (special measurem
  - water —"—
  - steam —"—
  - crude —"—
- optimal insulation (check skin temp.)
- steam reduction through a turbine and bleeding of steam (merits must be checked) after upgrading
- ROI analysis of each item above

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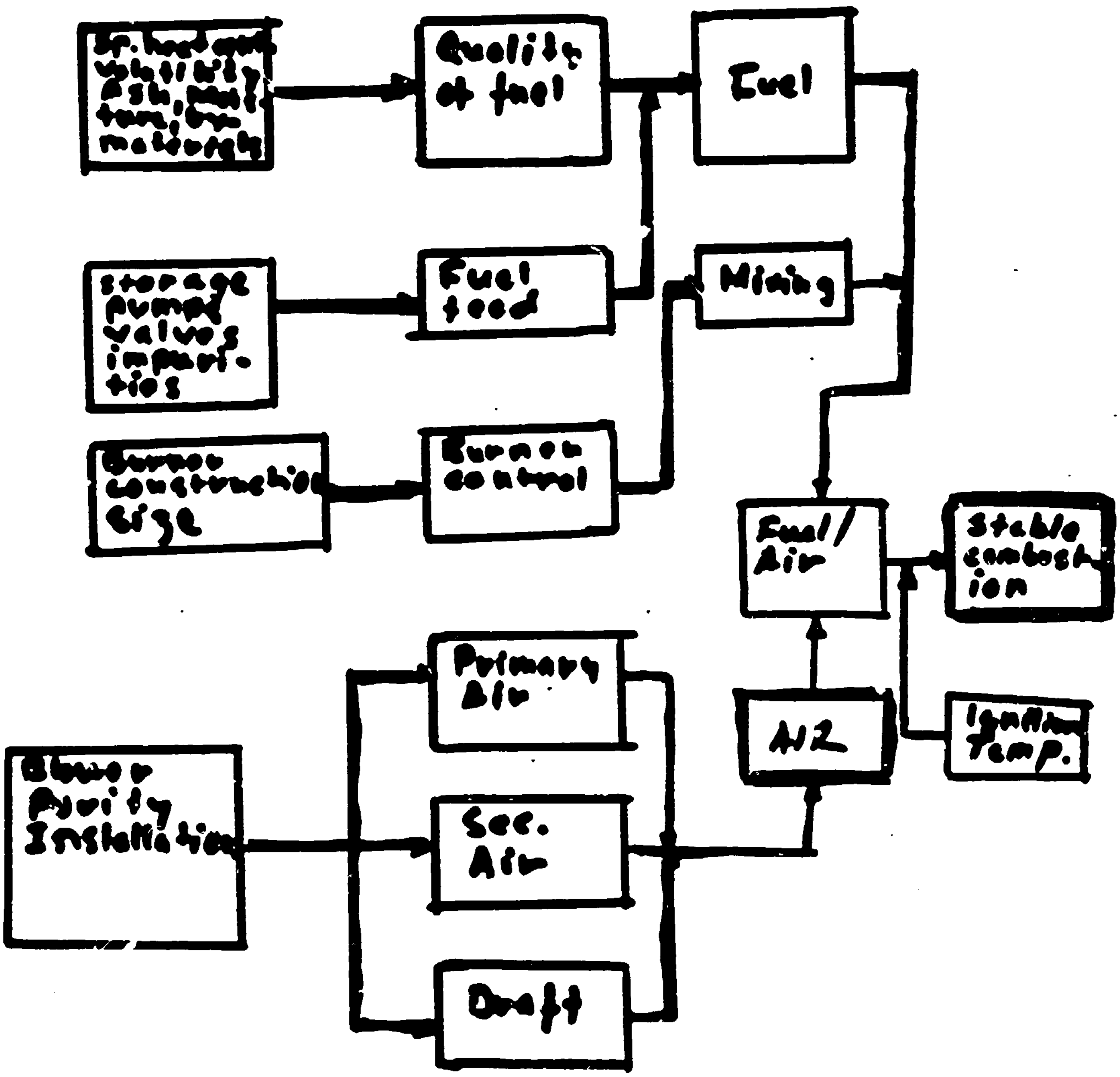
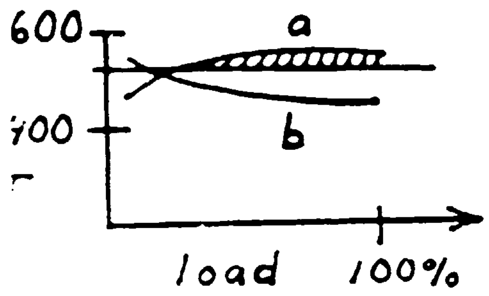
Forced draft yields
- better convection
- reduced airfeed
- cleaner combustion
- smaller furnaces



FACTORS AFFECTING ON STABLE COMBUSTION

UNDP/PSH

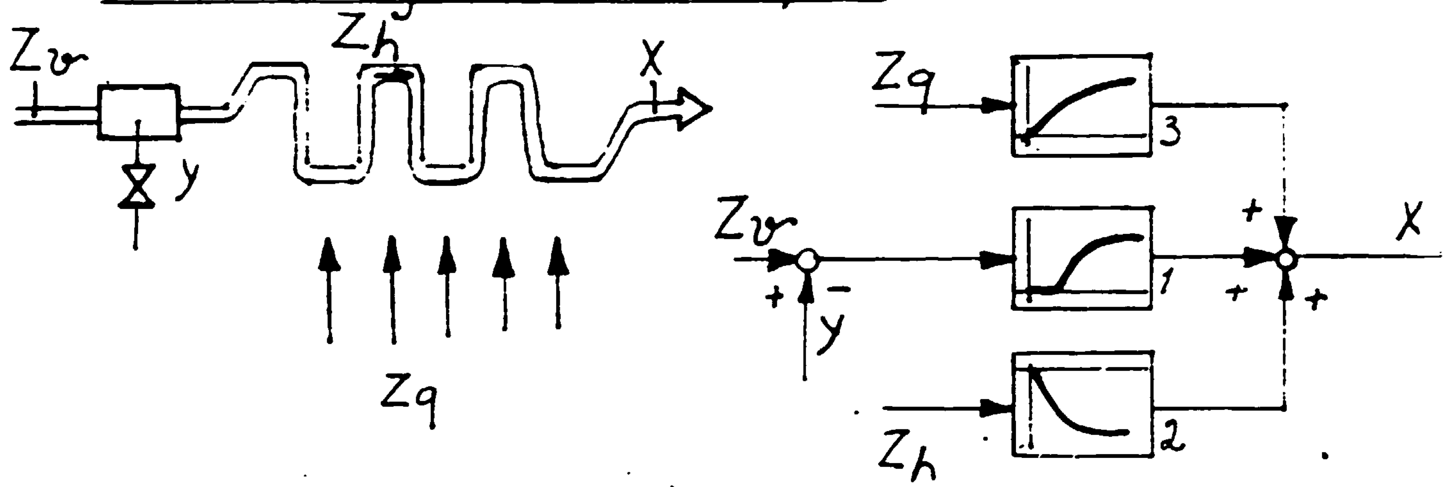
The characters of superheaters



a = convection

b = radiation

Block diagram technique



hange in temperature before heater = Zv) (disturban...

change in steam flow = Zh

change in heating power = Zq

y = injection water

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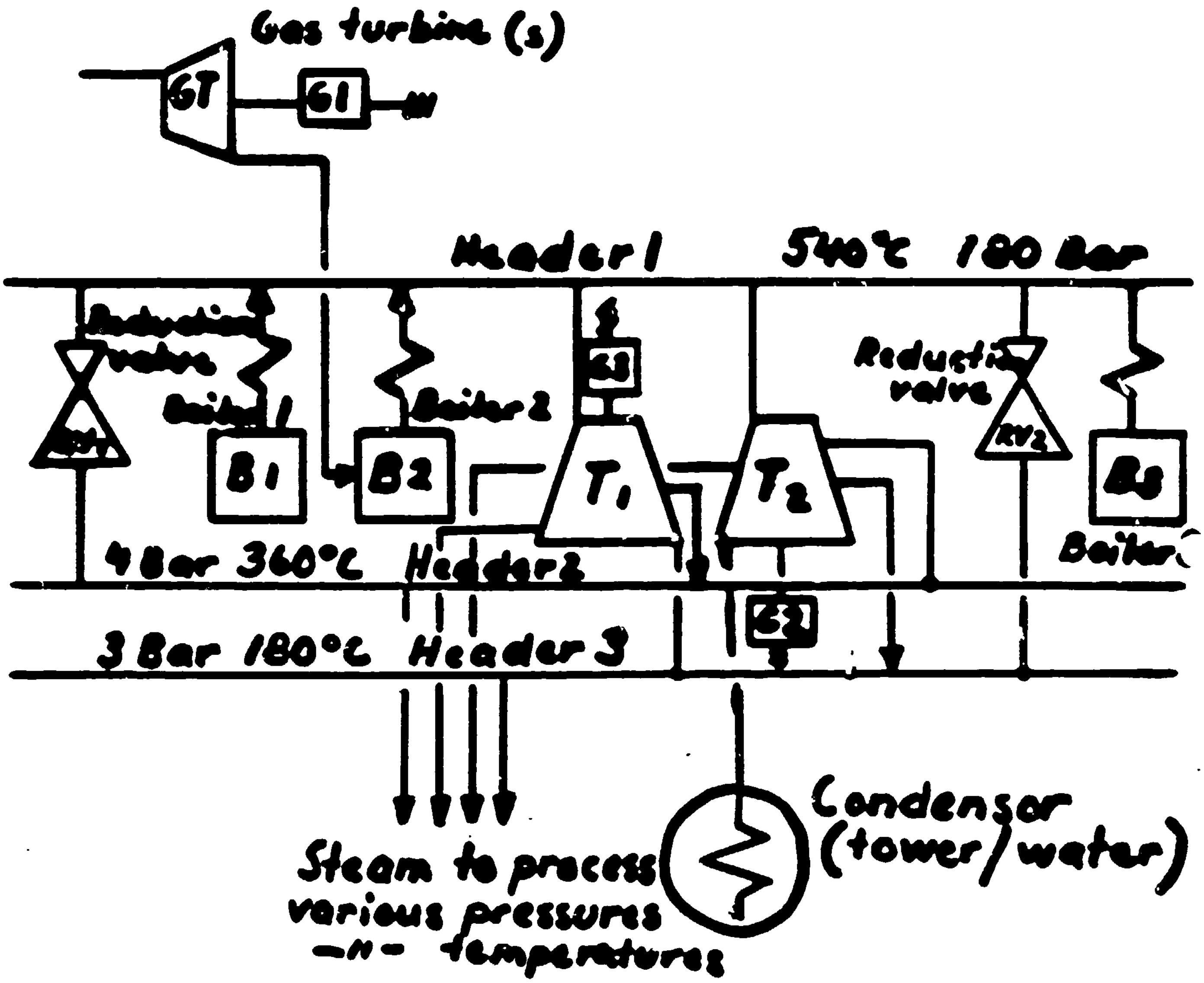
X = temperature to be controlled

PLANT SCALE STEAM SUPPLY



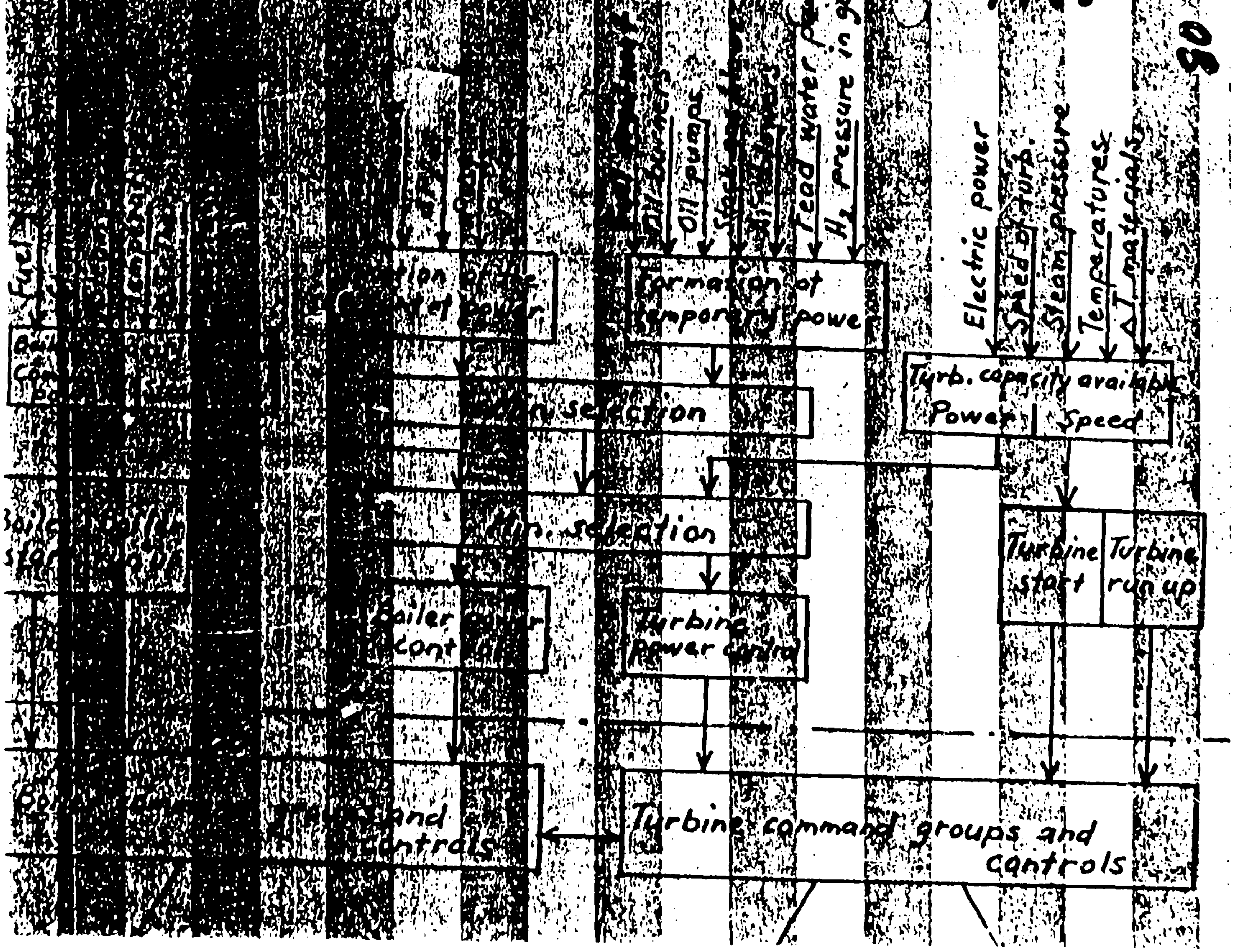
Overall steam supply system for a refinery. It works in spite of single unit trips. This principle offers on overall optimal energy economy.

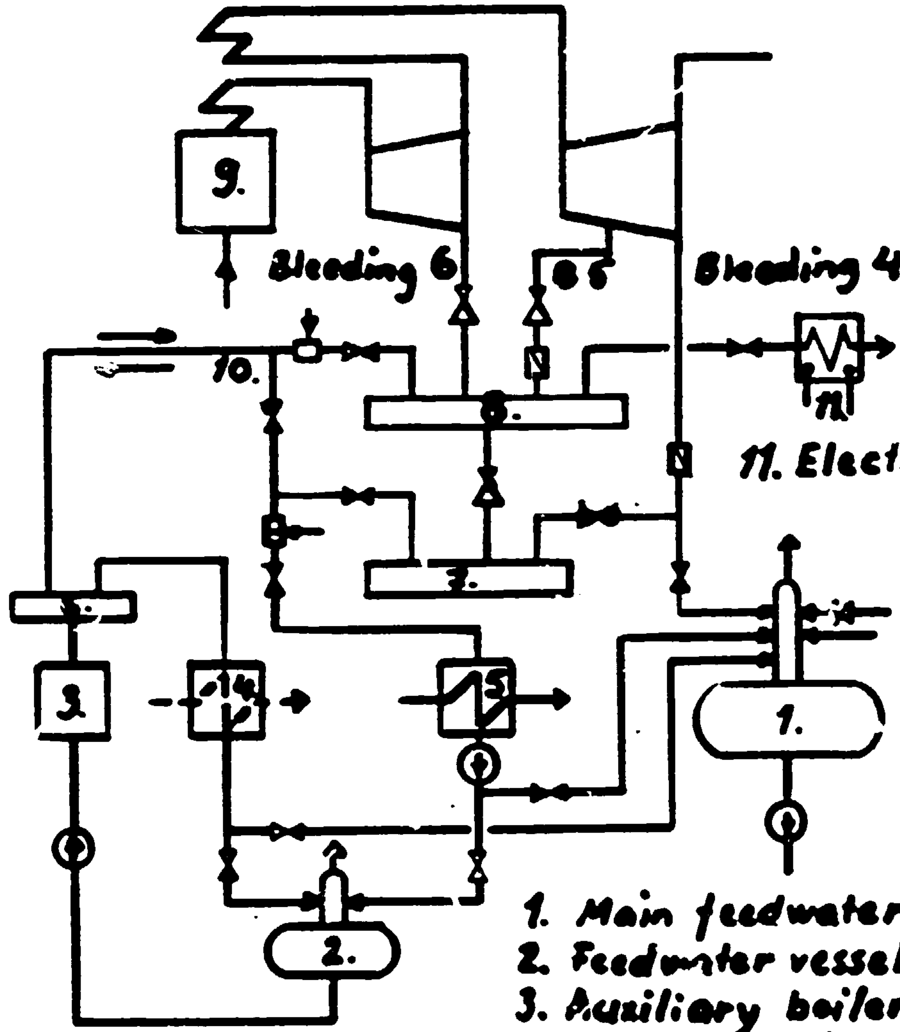
UNDP/ PSN

GROUP AUTOMATION FOR A POWER STATION

U-IOP/PSN 1985

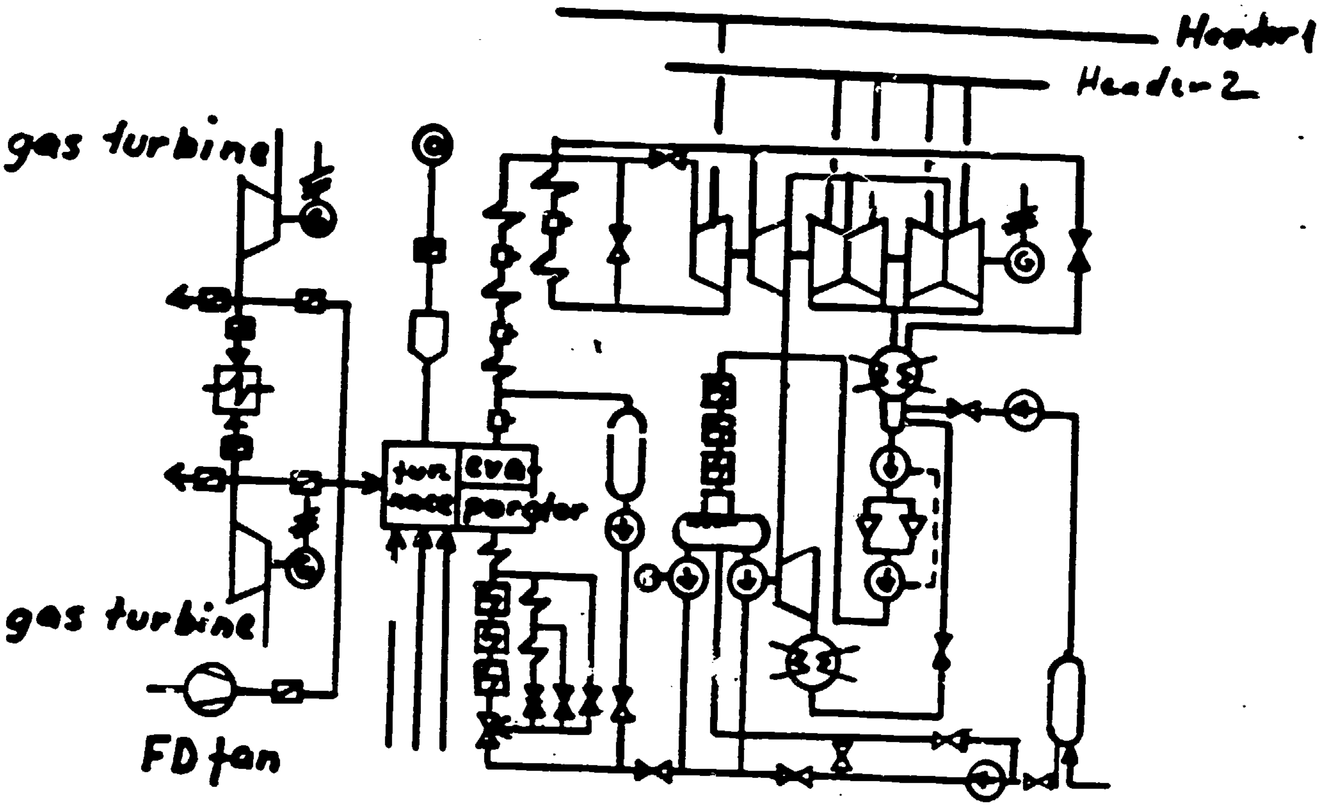
80





11. Electric superheater

1. Main feedwater vessel
2. Feedwater vessel for auxiliary boil.
3. Auxiliary boilers
4. Fuel oil preheater
5. Air preheater (steam operated)
6. Auxiliary boiler steam header
7. Lower pressure steam header
8 Upper — " —
9. Main boiler
10. Connection steam header for the auxiliary boiler



Process diagram of a gas turbine combin unit

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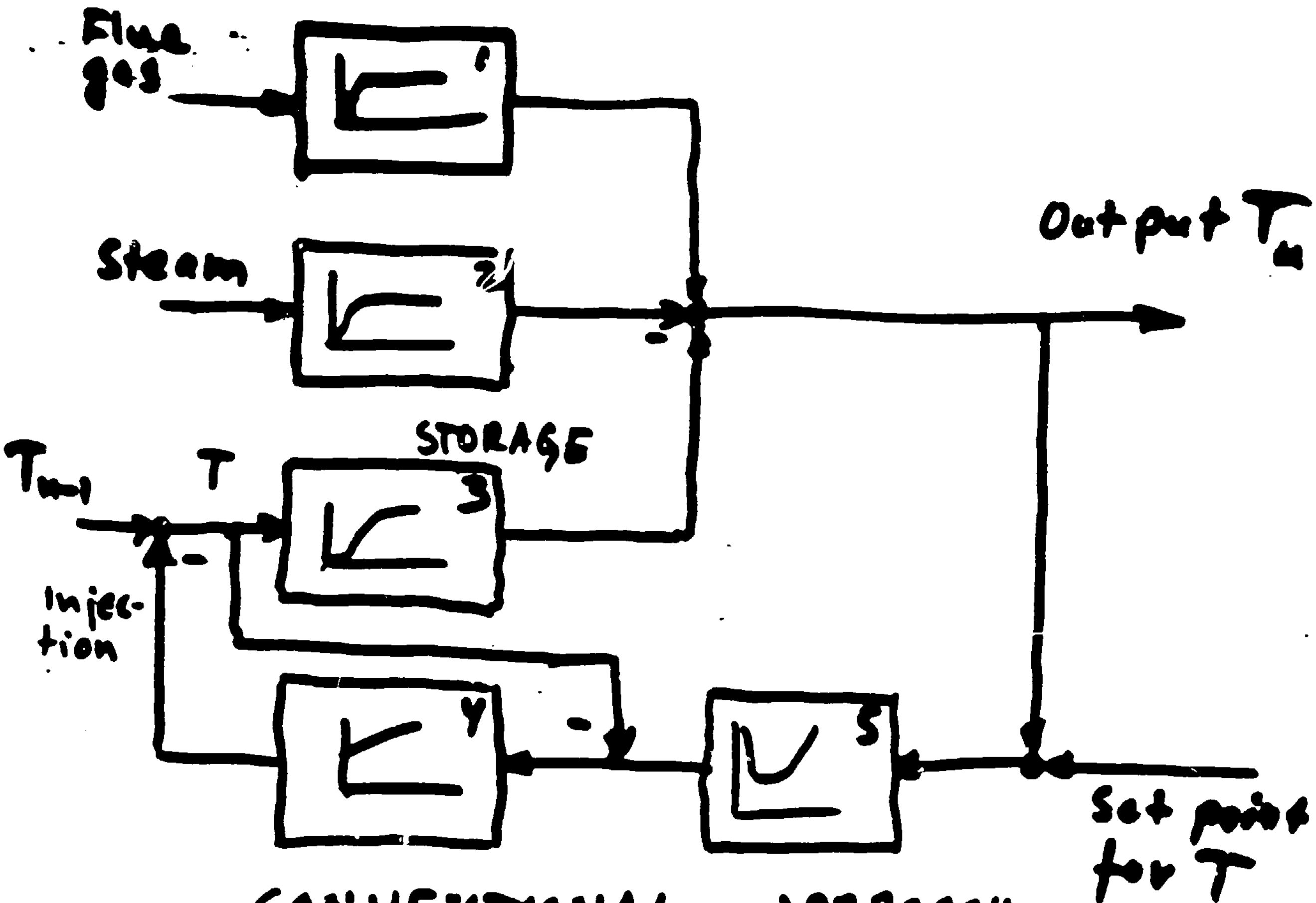
1985

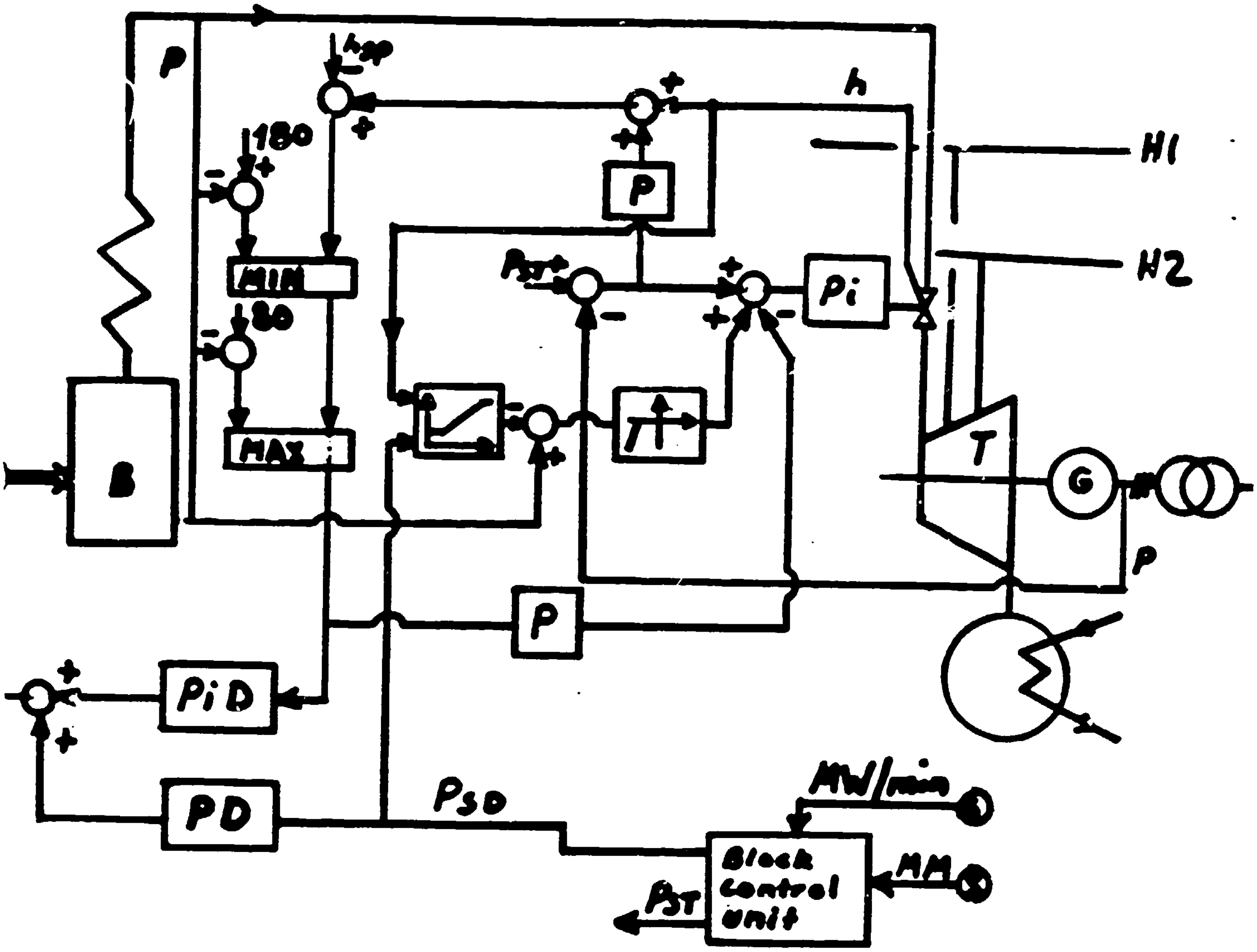
DYNAMIC MODEL FOR A SUPER HEATER



CONVENTIONAL APPROACH

1. Heat transfer stack gas → steam
2. Effect of steam flow
3. Storage effect of heat in the sh.
4. PI
5. PID

Main control loops of power plant
(example)



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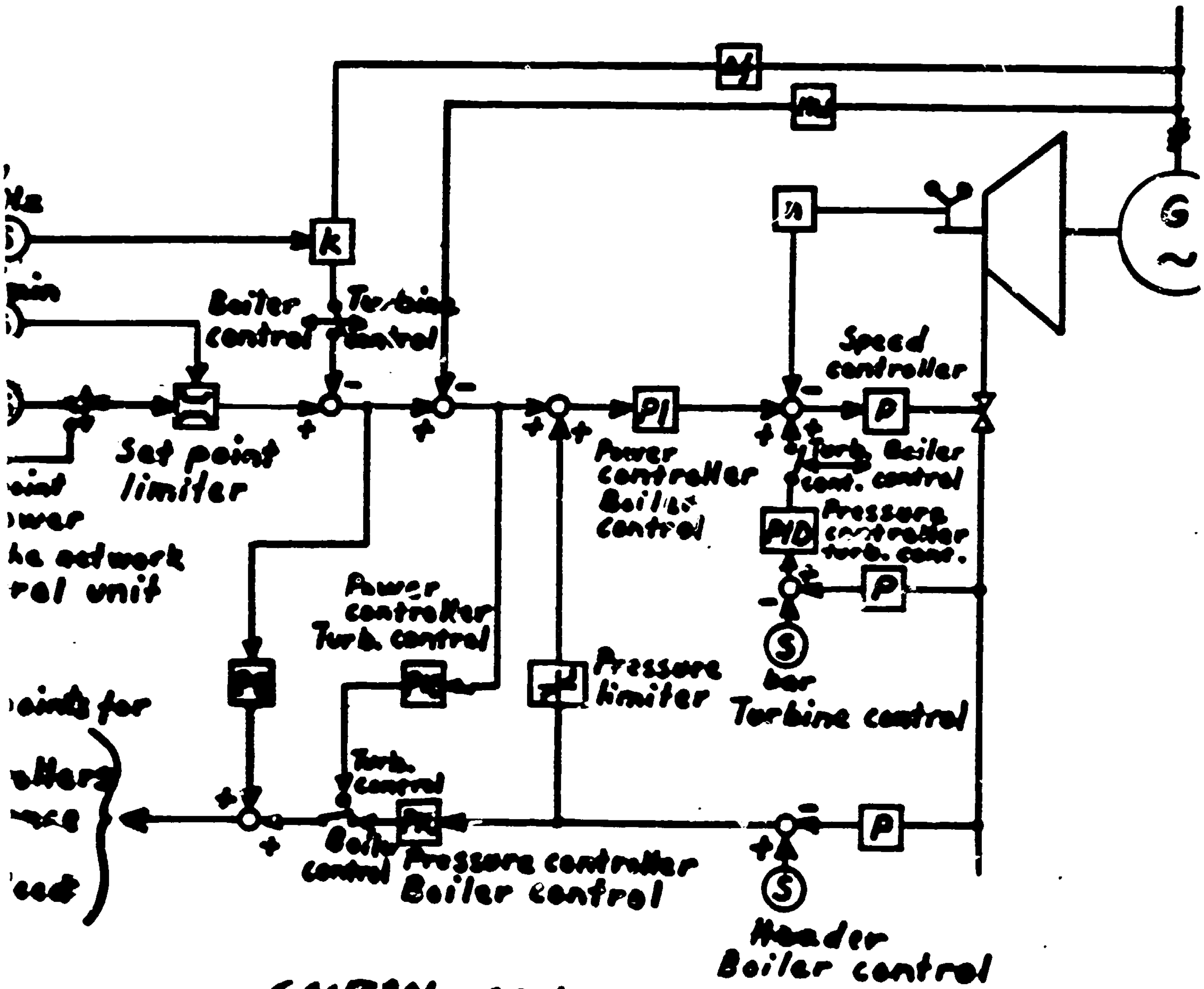
Combined power plant block control



CONTROL CONCEPTS

XV STEAM ELECTRICITY CO-GENERATION (Cont'd)

Although the energy economy of the combi process is superior, certain things are to be considered :

- Safe steam supply is necessary for the refinery and this means that if

  . gas turbine trips
  . steam turbine "
  . boiler "
  . combined units "

  the refinery must not trip. This means the multiboiler or -turbine concept or steam generators standing by hot. Moreover, the refinery must have electric supply from the national power grid.

The benefits of this process, however, are that electricity is produced at an optimal efficiency. Operational reliability is improved for the refinery due to alternative sources of electricity and steam. The production cost of electricity is nearly the same as the fuel cost minus losses.

Requirements of the reliability are high, which tends to increase the costs. Therefore a ROI analysis is necessary which includes

- investment costs
- Operation and maintenance
- Fuel and auxiliary materials
- benefits due to improved availability of that refinery
- minimal transportation of fuel

Demand of electricity tends to grow nation widely in Egypt as industry develops. This is one reason for joint production of steam and electricity.

High demands on the automation will be important. It should cover

- variable operation modes
- automatic start up/run down
- protection functions

XV STEAM ELECTRICITY CO-GENERATION (Cont'd)

The combi process and back pressure turbine concept are normally superior to condensing units provided that co operation with electric authorities work well, i.e surplus can be sold and deficit can be obtained from the general net work. This means energy conservation for the refinery and for the power company.

T e back-pressure concept would yield electricity as follows

90 L.E/ton oil /11.2 MWh/ton /0.85 = 0.945 p/kWh

as production costs. Investment should be taken in addition.

NA

XVI ZrO_2 SENSOR IN STACK GAS MONITORING

The ZrO_2 sensor is to be required for stack gas monitoring for the reasons below

- better combustion because this is the promptest indicator of the combustion process and actions can be taken at once.
- Minimizing O_2-contents ⟶ less
  $Na_2\ V_2O_4 . 5V_2\ O_5$ or
  $5\ Na_2O.\ V_2O_4 . 11V_2\ O_5$
- less pollution due to less unburnt and H_2SO_4
- no moving parts unlike the conventional paramagnetic device, recording possible simultaneously

Simulataneous CO may be considered for the reasons below

- if different fuels are used the set point of O_2- varies depending on
  . load
  . the state of combustion chamber
  . type of fuel
- air leaks ⟶ careful placement of O_2-analyzer

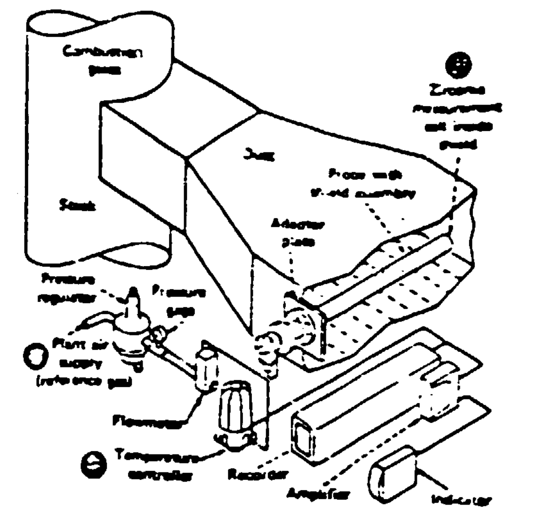
Both of these yield a positive result,

CAF01 (1186)

NA

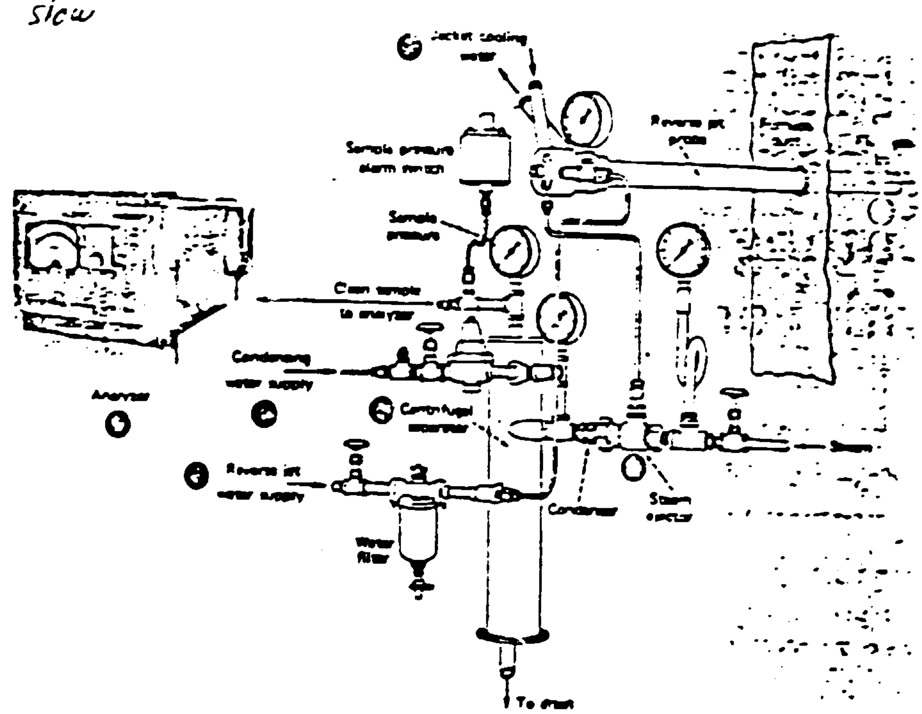
UNDP/PSH/85

ALTERNATIVE O_2-SENSORS: recommendable



New type oxygen analyzer avoids sampling system Fig. 2

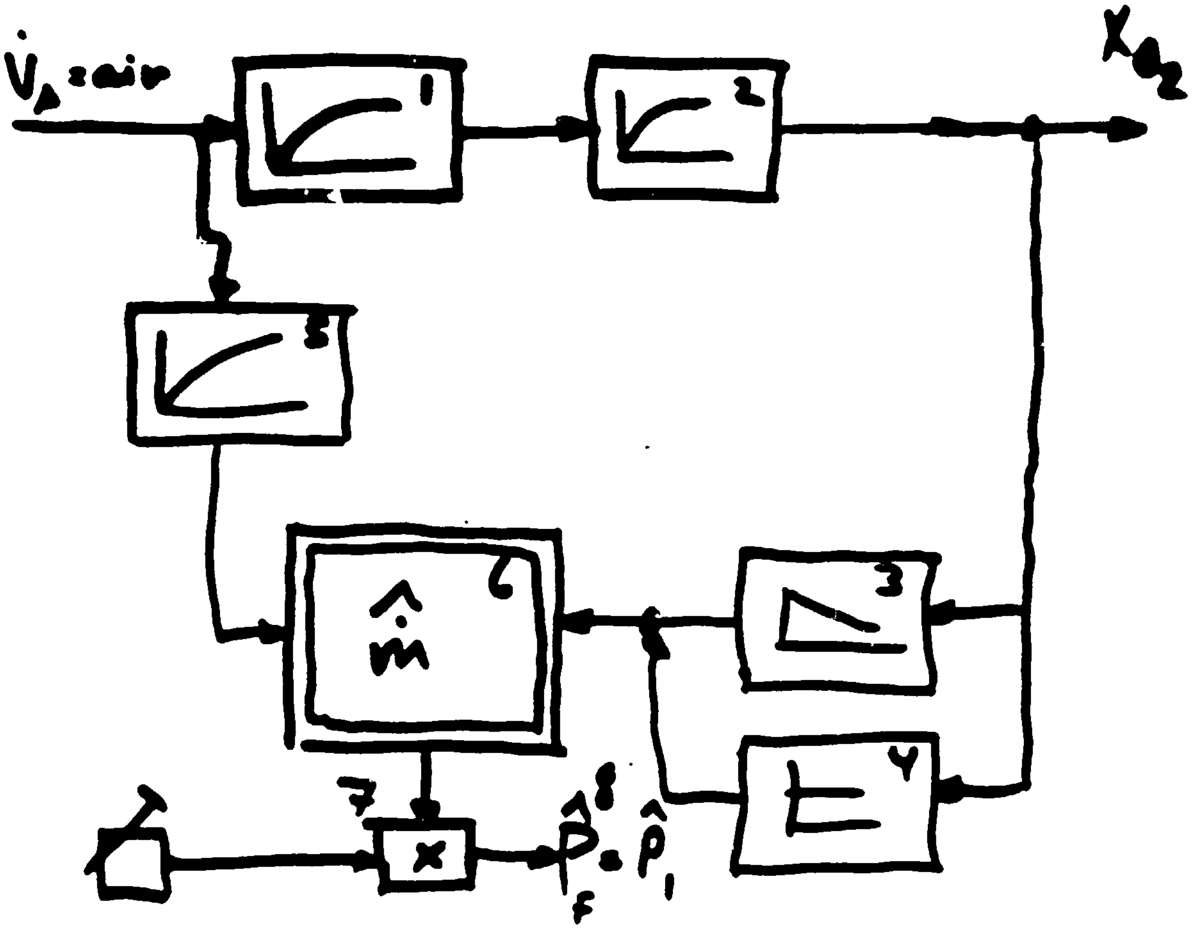
old fashioned
slow



Typical sample conditioning system requires continual maintenance Fig.

UNDP/85
PSN

DYNAMIC ESTIMATION MODEL FOR FLAME POWER



1. Furnace T = 30 s Timeconstant
2. O_2 sensor T = 5 s —"—
3. O_2 sensor delay compensation
4. O_2 signal conversion
5. Air flow signal delaying
6. Fuel flow calculation
7. Estimation of calorific value of fuel
8. $\hat{P}_F = \hat{P}_1$ flame estimate ≈ heating power

XVII ENERGY RECOVERY IN ELECTRIC SYSTEMS

Typically 85MW/10.5 Mt/a = 8.1 MW/Mt oil/a is the electric supply. In a 2Mt/a (typical case) refinery one typically has 200 motor drives.
10% of the motors drive flows for control purposes. This means that there are

1.6 MW 8.6 K hrs = 13.76 GWhs

recoverable energy. Utilizing power factor controllers and inverters 20....30% of this energy can be conserved, i.e

3.44 GWhs

The oil equivalent is about 0.921 KT/a ≈ 170 k$/a and if back pressure concept is applied then the saving potential is

60 k $/a

On the other hand 20 (10%) inverter units are to be acquired 2...20 k $/each.

Roughly the payback time is some 1 year. The installation of these units causes only little outage unlike in case of furnace upgrading. This is a smaller potential but, however, a porfitable one. Other benefits are

- longer life for motors
- peak loads can be reduced, ie soft start ups
- pumps or fans, etc. are less loaded
- investment savings in transmission equipment (transformers, etc.)
- " " due to replacement of valves or dampers

It must be ensured that the frequency converter produces sinusoidal waves to avoid harmonics and losses.

Power factor control yields the benefits below

- transmission capacity can be reduced
- transmission losses are reduced
- stabilized supply voltage
- reduced power generation

XVII ENERGY RECOVERY IN ELECTRIC SYSTEMS (Cont'd)

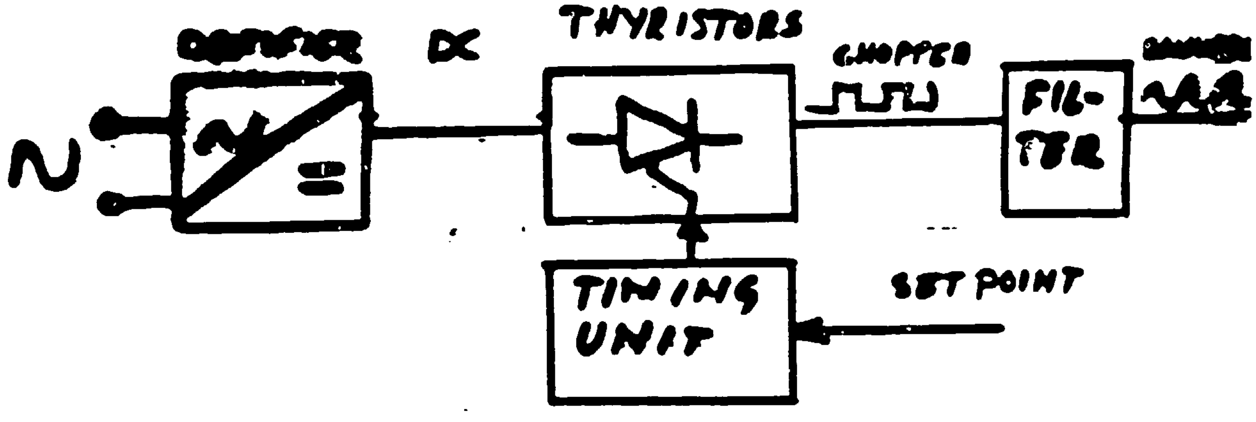
This is indirect energy conservation. If an induction motor is variably loaded, a solid state power factor controller which drops the current feed according to the power factor is justified. It is reported that savings up to 30% are feasible. The price of this kind of unit is reasonable, 200...3000 $ and it ranges up to 100 KW. The fringe benefit is longer operational life of the motor. The harm may be harmonics which can be filtered. In refineries, however, this has a limited number of applications because the normal optimal running mode is even maximum load. This reduces peaks also when starting up.

A thyristor driven plant scale power factor compensator could be worth consideration. This depends on the policy of the power company. Anyway, this offers the same benefits as above in the national level.

Typically, if this is installed in the correct place, the reimbursement time is less than 2 years. These equipment do not have any moving parts and hence, little maintenance is required.

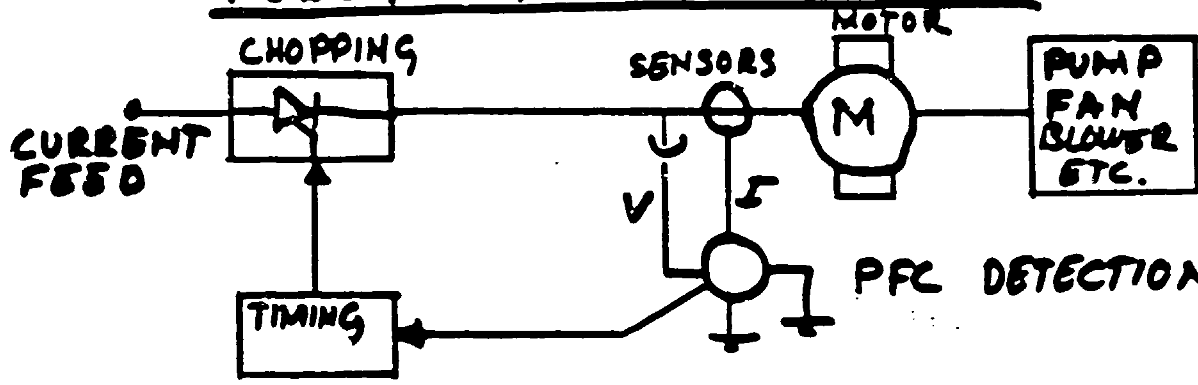
One important saving potential is smaller piping due to reduced pressures which is clear but not easily calculated.

ENERGY CONSERVATION, ELECTRIC SYSTEMS



BLOCK DIAGRAM OF AN INVERTER
(No breaking)

POWER FACTOR CONTROL PFC

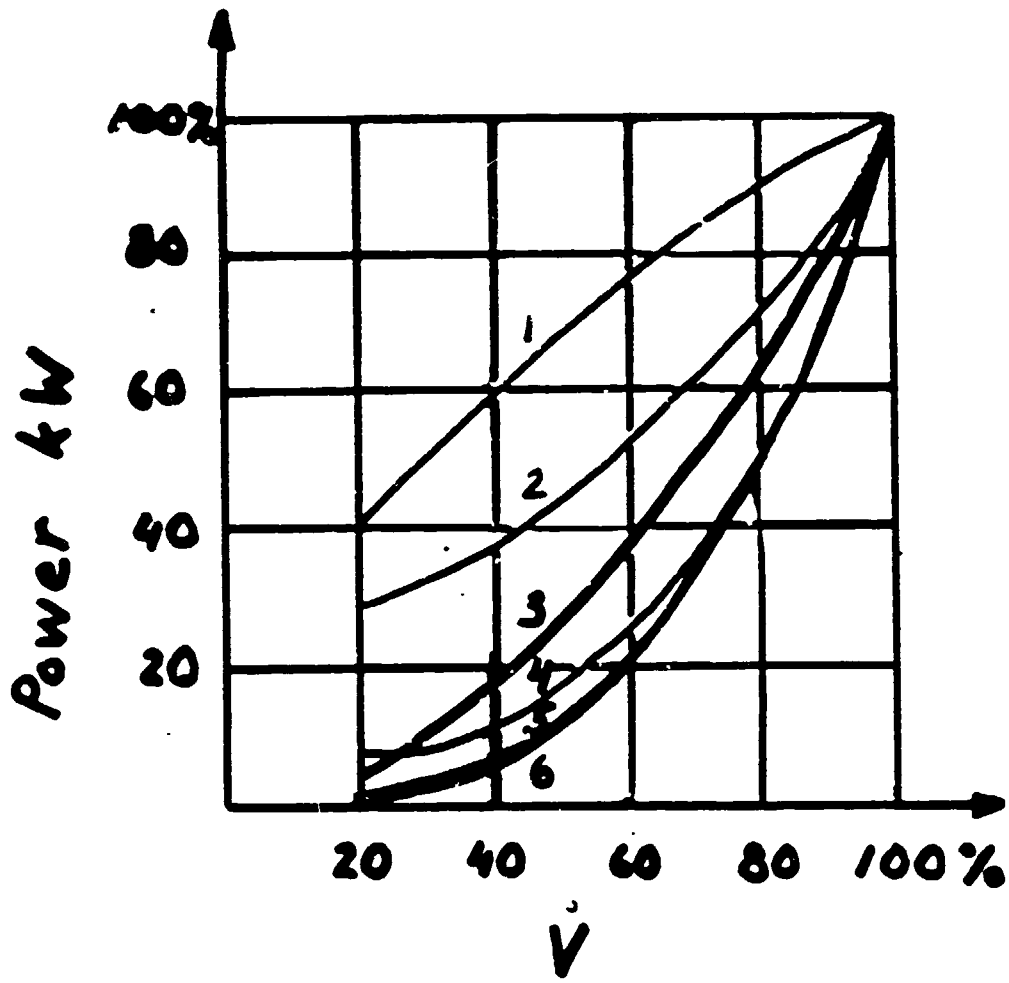


Advantages:

- less motor wearing
- energy consumption 10...30%
- solid state → no moving parts
- reduction of peak loads
- reduced siging for wiring and breakers and transformers
- fairly inexpensive
- disadvantage: harmonics removal

ALTERNATIVELY PLANT SCALE POWER FACTOR COMPENSATION

Effect of different control modes on the power need



1. Throttling damper
2. Guide blade control
3. Hydraulic coupling
4. Blade angle control
5. DC-motor, voltage control
6. Inverter (thyristors)

UNDP/PSN/85

STATIC COMPENSATOR CONTROL SYSTEMS AND THEIR SIMULATION ON A TNA

Nokia Corporation, Finland

INTRODUCTION

Optimizing the equipment rating and its control system for a specific power system application is critical in applying a static-var system successfully and economically. The SVS user must establish criteria for the transient performance of the power system and develop performance specifications based on his criteria for procuring SVS equipment. This paper describes the functional characteristics of three types of static compensator control systems and introduces a hybrid static-var system simulation method that combines the flexibility of digital simulation with the real-time computation advantages of a TNA. Until the development of this real-time hybrid SVS model, only two simulation techniques were available for evaluating static-var system applications:

1. The actual static-var system controller is connected to a TNA model of the power system and the response to system disturbances is evaluated. While this method takes advantage of the economical real-time computation inherent in a TNA, the optimization of the SVS control system is limited to the number of different manufacturers' SVS controls that can be economically interfaced to a TNA during the course of the study [1].

2. The entire power system and the static-var system controls are represented in a digital transient analysis computer program [2, 3, 4]. While this method provides the flexibility for analyzing many control systems, the absence of real-time simulation capability severely limits the number of control systems and system disturbances that can be investigated economically.

The new simulation method described herein combines the advantages of both the analog and digital methods in a real-time hybrid simulation of the compensator and the power system.

TYPES OF STATIC-COMPENSATOR CONTROL SYSTEMS

Both the static-compensator configuration and control system characteristics must be designed to fit the primary application requirement: voltage regulator, reactive-power regulator, or flicker suppressor.

Voltage Regulator

A voltage-regulator compensator (Figure 1) is usually employed for transmission system applications. Control is based on an error signal derived by comparing a reference voltage with a measured voltage which is usually based on an average of the three phase voltages. A static compensator used to regulate the system voltage:

- Controls system voltage during system disturbances, especially large changes in power flows. To damp oscillations and control system voltage during switching operations, the compensator must have a response time on the order of 2–4 cycles. The rating of the compensator may range from tens to hundreds of MVAR.

- Controls steady-state voltage. To control system voltage during all steady-state conditions, a large MVAR range is usually required, resulting in the use of switched capacitor banks and/or switched reactors.

- Controls transmission line power flows. A static compensator permits higher power flows by providing voltage control at key transmission system locations.

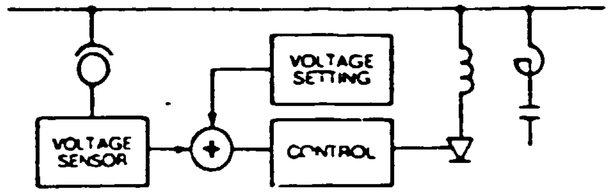


Figure 1 Basic voltage controller.

Reactive-Power Regulator

Static compensators used to regulate reactive power (Figure 2) are applied primarily for industrial applications. The basic principle is the same as for a voltage regulator except that reactive power is the measured quantity. Reactive-power regulators are used to:

- Compensate varying reactive power of industrial loads (arc furnaces, rolling mill plants, mine lifts). Since the reactive-power variations for these loads can be on a cycle-to-cycle basis, response time of the static compensator control must be on the order of the 1 cycle.

- Compensate for unbalanced loads (requires individual phase control).

- Provide a degree of voltage regulation. By compensating for the reactive-power requirements, the static compensator also reduces voltage fluctuations.

Compensator rating ranges from a few to tens of MVAR. An average power factor at the load of 0.99 or better can be obtained even for the most rapidly varying loads.

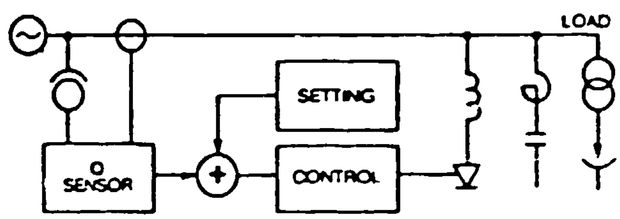


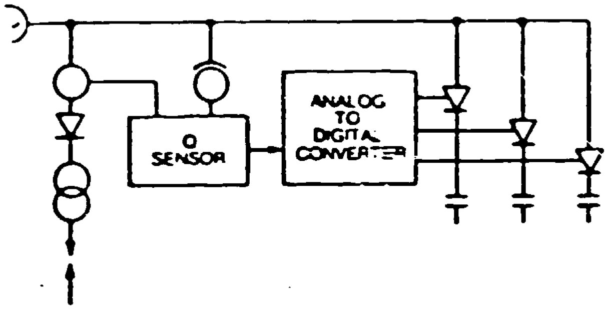
Figure 2 Reactive power controller.

Flicker Suppressor

A flicker suppressor (Figure 3) controls voltage flicker caused by rapidly changing loads fed by fairly weak power supplies such as disc and spotwelding machines.

The static compensator control must be extremely fast to be effective for flicker reduction. A maximum control delay of approximately one-half cycle is typical. With this response time, voltage flicker can be reduced by as much as 80 percent. Response times of one cycle or more in the static compensator can actually result in increased voltage flicker.

A static compensator for flicker reduction usually controls based on the reactive-power requirements of the load. Thyristor-switched capacitors are suitable since fine tuning the voltage is not required. Compensator ratings range from 10 kVAR to 1 MVAR. Due to the load characteristics, individual phase control is always required.

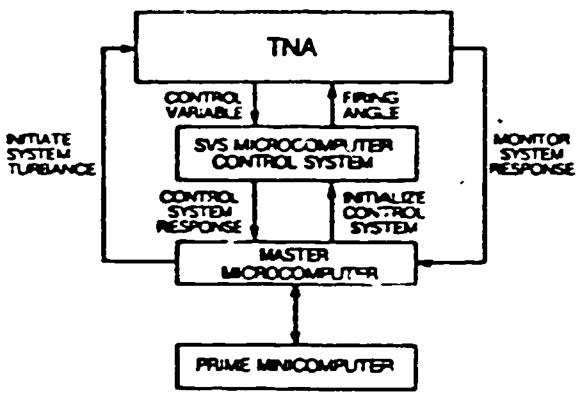


gure 3 Flicker suppressor.

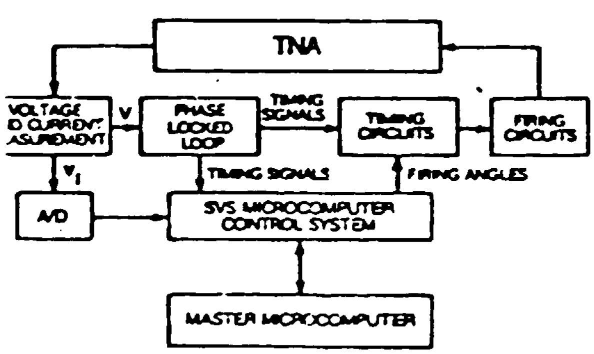
4E HYBRID SVS MODEL

ıe primary requirement for a TNA static-var system model is at it must be capable of representing—in real time—a thyristor ing-angle control system. Since the optimum control system different for each application, the model must be extremely xible to evaluate many different kinds of control systems.

ıyr model of the static-var system (Figures 4 and 5) is the ost ... able configuration possible. By modeling the SVS con-ıl function digitally, the control system being represented can varied by a master microcomputer programmed with in-uctions determining which parameters in the SVS control stem are to be varied over what ranges. Using this informa-n, the control system parameters are incremented over their tire ranges for a specific disturbance in the power system odeled on the TNA (switching on a load, load rejection, line ergization, fault initiation, etc). The response for each set of ·ameters is then evaluated. In minutes, hundreds of control stems can be studied for a specific disturbance and the op-al control response can be quickly determined and specified.



ure 4 Hybrid representation of a static-var system on a TNA.



ure 5 Individual components of a hybrid static-var system model.

The control system software functions with a wide variety of static-var configurations and the reactive components—modeled with actual capacitors and reactors—can be configured in any way desired. Among the systems which can be represented using this new hybrid static-var system model are

- Thyristor-controlled reactors;
- Thyristor-controlled reactors with thyristor-switched capacitors (variable number of steps);
- Thyristor-switched capacitors.

The control system transfer function is simulated on the dedicated SVS microcomputer; all other model components are represented by hardware. TNA voltage and current signals are measured using precision instrumentation amplifiers and these signals are input to the microcomputer control by an analog-to-digital converter. The power-frequency voltage controls a phase locked-loop circuit from which all timing signals are derived. The phase locked loop itself is a feedback control system; therefore, it is essential that its response to change in phase angles be stable and that it can operate in the presence of harmonics in the power-frequency voltage. [5] The SVS microcomputer outputs a digital signal proportional to the desired thyristor firing angle and the digital signal is latched into the timing circuits. The phase locked-loop system initiates operation of the clock in the timing circuit. The firing-angle and clock signals are compared and, when they are equal, the firing circuits are activated. The thyristor firing circuits are optically coupled to the thyristor models which include electronic circuitry to compensate for the voltage drop in the models.

THE CONTROL ALGORITHM

Figure 6 is a simple static-var system feedback voltage controller. The controller transfer function is expressed as a function, G(S), which describes the locations of poles and zeros on the complex S-plane.

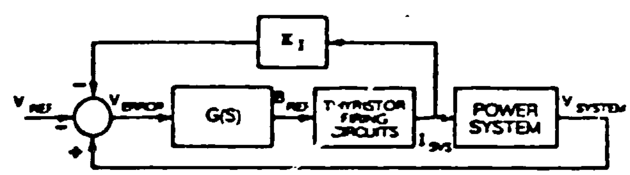


Figure 6 A simple voltage-regulator SVS control.

In digital signal processing, the Z-transform is used to obtain a discrete time representation of a continuous transfer function. [6] The new transfer function has the form G(Z) where each factor Z^{-1} represents a time delay of one sample period. For implementation on a computer, the function of Z is converted to a difference equation:

$$Y_n = \sum_{k=0}^{M} A_k X_{n-k} - \sum_{k=1}^{L} B_k Y_{n-k}$$

Where

Y_n = Present output value;

$Y_{n-1}, Y_{n-2}, \ldots$ = Past output values;

$X_n, X_{n-1}, X_{n-2}, \ldots$ = Present and past input values,

A_k, B_k = Constant coefficients which are a function of the sampling rate and the continuous transfer function being simulated;

M, L = Positive integers which depend on the transfer function being simulated.

In the compensator controller algorithm, the input i an error signal (voltage or reactive power); the output is a sign al proportional to the desired reactor current used to obtain the firing angle for the thyristors.

The accuracy of the simulation depends on the input signal to the controller and the time required to process each data sample. [7] To make the simulation accurate for any input signal, the sample period must be as short as possible. The most time-consuming portion of the control algorithm is the multiplication and summation required in the difference equation. Special dedicated hardware to perform each multiplication/summation in less than one machine instruction cycle was developed. The control algorithm (Figure 7) is also capable of representing current droop and thyristor-switched capacitors.

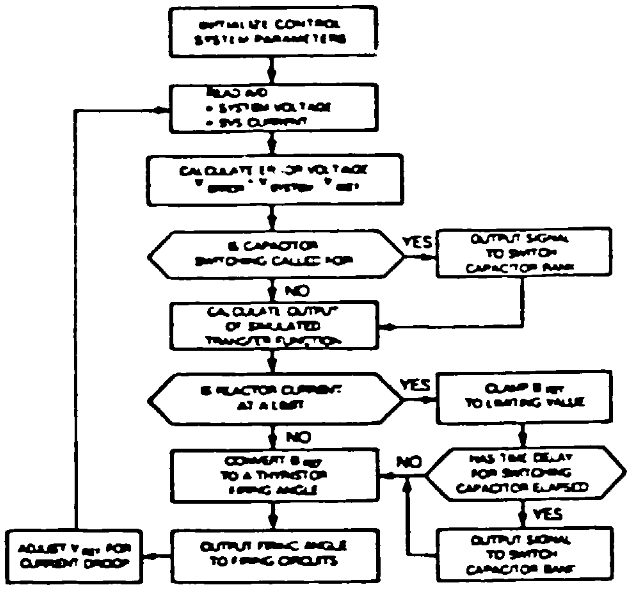


Figure 7 Flow chart of SVS model control algorithm.

Additional logic in the control algorithm represents current droop. A signal proportional to the net SVS current—obtained from actual measurement or output of the controller—is fed back to the summing junction and the reference voltage for obtaining the error signal is adjusted accordingly.

Control for thyristor-switched capacitors is also included in the control algorithm:

1. Fast capacitor switching is required if the error signal is greater than a predetermined value. This facilitates quickly removing capacitor banks from service following a large increase in the system voltage (such as that caused by load rejection).

   Normal capacitor switching can occur when a reactor reaches one of the limits of its control range. A variable-time delay can be used to avoid hunting and unnecessary switching caused by the reactor control overshooting the steady-state value.

EXAMPLE SIMULATION

The voltage regulator control system shown in Figure 6 has a transfer function of [8].

$$G(S) = \frac{K}{S}$$

Where

K = Controller gain.

The digital simulation of this transfer function is

$$B_{REF_n} = KT\,V_{ERROR_{n-1}} + B_{REF_{n-1}}$$

Where

T = Time between samples of the voltage error signal

Each simulation gives the SVS response to a specific system disturbance for one set of control parameters; for example, a voltage-regulator compensator was simulated in a simple circuit with a switched load (Figure 8) and the response was

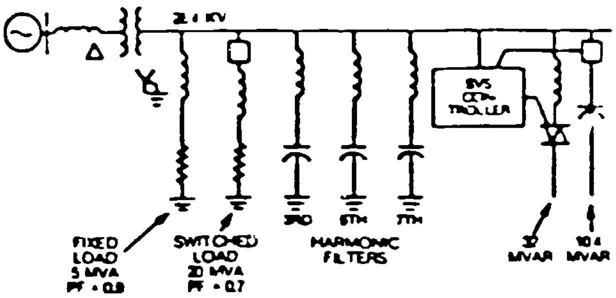


Figure 8 Example system investigated.

Figure 9 illustrates the response of the SVS when the load is switched on for three controller gains. When the load is switched on, the bus voltage decreases and the SVS must increase the voltage by reducing the reactive compensation. For a gain near the optimum (100 percent), the controller has only a very slight overshoot and reaches a new steady-state operating point in about two cycles. With a gain of 30 percent, there is no overshoot, but the response is very slow. As the gain is increased to about 200 percent, significant oscillations in the firing angle occur.

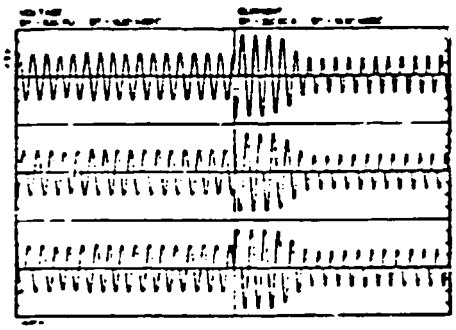


Figure 9A SVS controller with gain of 100 percent bus voltage, reactor current.

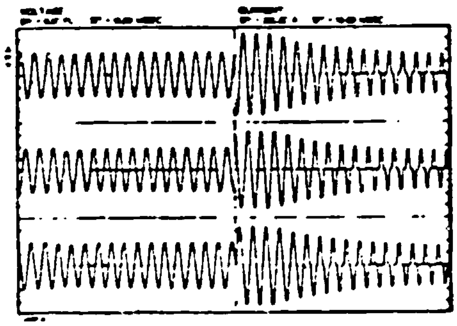


Figure 9B SVS controller with gain of 30 percent bus voltage, reactor current.

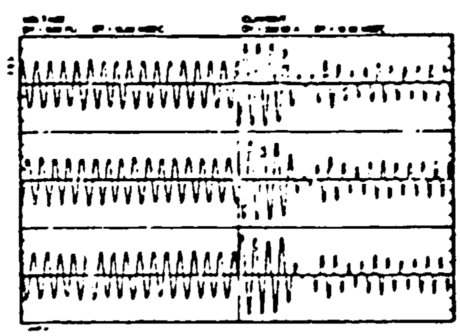


Figure 9C SVS controller with gain of 200 percent bus voltage, A key feature of the hybrid SVS model is its ability to remember the error signal it measured and the output response to that signal. This information is gathered as shown in Figure 4 and processed by the minicomputer. The results are plotted in Figure 10 for the optimum gain. The plot consists of the instantaneous measured error voltage, the instantaneous SVS susceptance (B_{REF}), and the instantaneous firing angle.

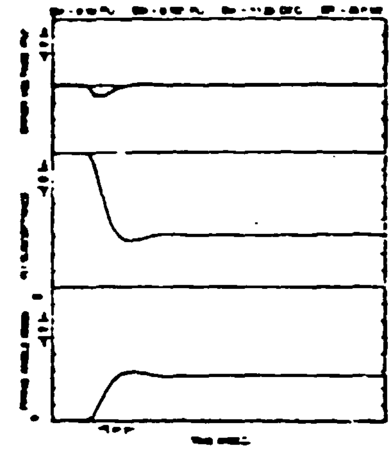


Figure 10 SVS controller with gain of 100 percent firing angle, pu susceptance, error voltage.

The SVS microcomputer controlled by the master microcomputer in Figure 4 can be operated in the parametric mode to study the sensitivity to a particular control system variable. In Figure 11, for example, 19 control systems were simulated and the overshoot and the settling time were plotted as a function of gain. This parametric study was completed in a few minutes, allowing rapid evaluation of the control system performance.

Figure 11 Overshoot and settling time as a function of gain. (Gain of 300 corresponds to 100 percent.)

USING THE HYBRID SVS MODEL TO DEVELOP A SPECIFICATION

Simulation studies are critical in the successful application of a static-var system; a well-performed study assures the user of:

1. An equipment specification optimized for the application.

2. The successful operation of the installed static-var system.

Prior to a study, all disturbances to which the static-var system will be subjected must be determined and a set of performance criteria established. Once preliminary equipment and inductive/capacitive var ratings have been selected, a family of control systems should be evaluated for each disturbance and a range selected that optimally controls all disturbances within the performance criteria (Figure 12).

The new hybrid microcomputer-controlled SVS model is ideal for these studies because of the speed at which it can simulate many different control systems and transfer data to a minicomputer for detailed analysis. The flexibility and versatility of the new hybrid SVS model will facilitate implementation of new control systems as the technology develops.

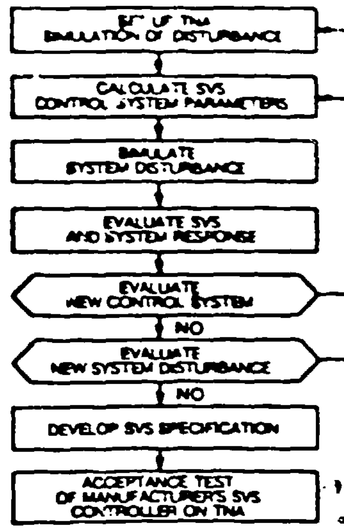


Figure 12 TNA-SVS study procedure for the development of a specification.

CONCLUSIONS

1. Optimum static-compensator control characteristics depend on the specific application. In specifying control system characteristics, the compensator response must be optimized for all possible system disturbances.

2. A programmable static-var system model has been successfully interfaced to a Transient Network Analyzer (TNA). Operating in real time, the microcomputer-based model—commanded by a master microcomputer—simulates a thyristor firing-angle control system. Many control systems can be simulated for various power system disturbances and the responses analyzed by a minicomputer.

3. The TNA simulator system is an invaluable tool for users planning to apply static-var systems. Because of the nature of the real-time hybrid TNA simulation, a complete specification for an SVS control system can be developed in a short time using a single SVS model.

4. The digital control technology can be applied to actual control systems for static-var system applications. The same programmable feature that has so much appeal for simulation also offers similar advantages (the ability to optimize the performance of a general control system for a particular application and the ability to modify the controller as a system changes) in a field installation.

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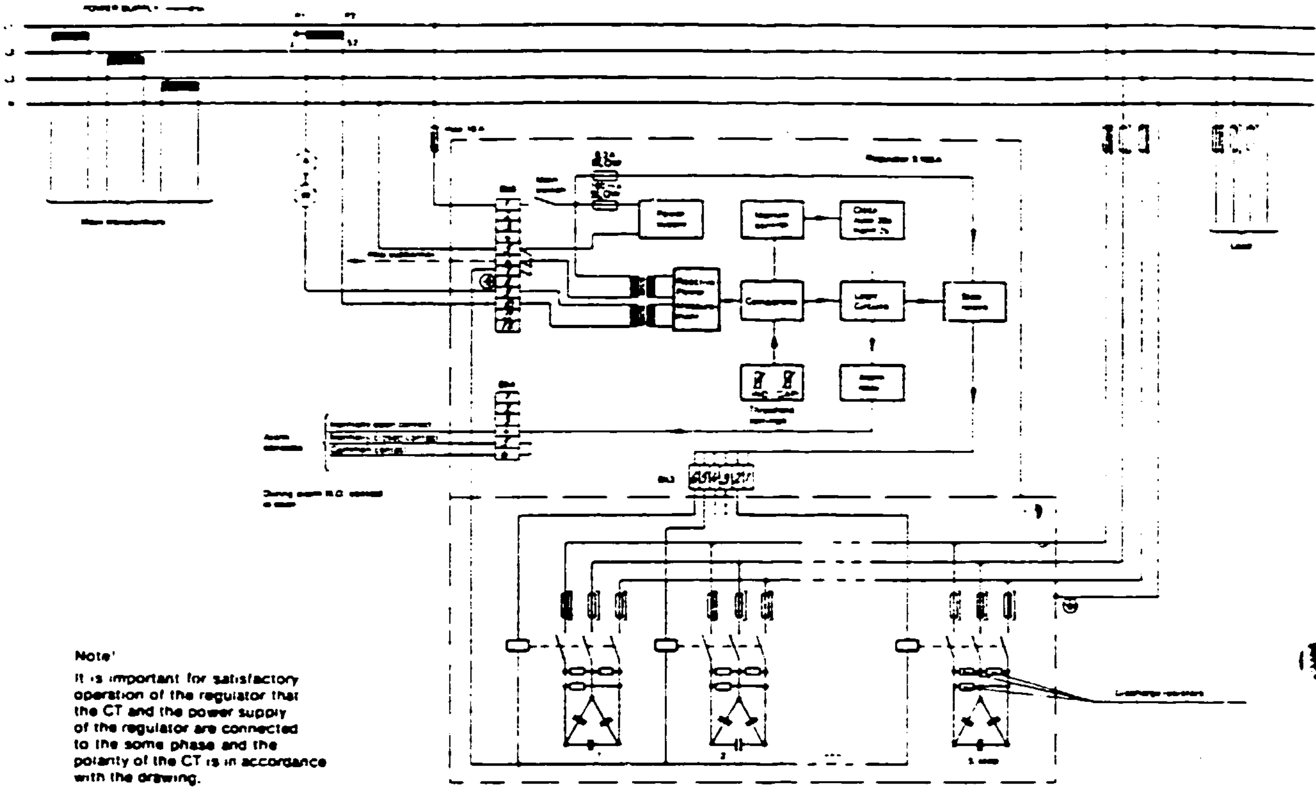


Fig. 17.
Schematic diagram of an automatic capacitor bank with reactive power regulator.

Harmonic filters

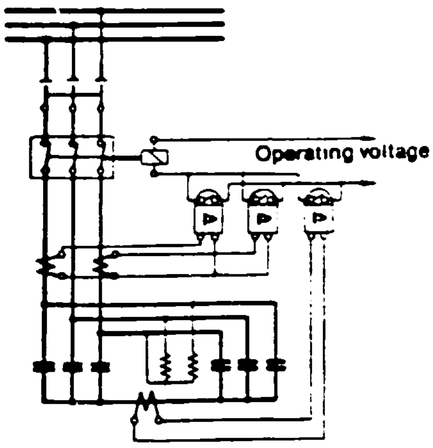
Harmonic filters are another source of compensation. In a filter, an inductive coil is connected in series with a capacitor bank. The inductance of the coil is such that the capacitor and reactor series circuit offers a low impedance to a certain harmonic frequency. Thus, the harmonic flows into the filter where it is absorbed and does not affect other parts of the plant, or the network. At the same time the filter provides reactive power at the fundamental frequency.

Among the problems caused by harmonics are interruptions to telecommunications, disturbances to the control and protection systems of the network, malfunctioning of relays and dangerous overvoltages due to resonance. The extra losses that occur in cables, transformers, motors and generators are also of significance; they cause loss of energy and excess temperature rise in the equipment.

Harmonic filters can be connected to either LV or HV circuits. Where there are several harmonic generating loads, each fed by a distribution transformer, it is often more economical to eliminate the harmonics by installing filters centrally at the HV busbar, rather than to have separate filters on the LV side of each transformer.

A filter is normally designed so that each of the lower harmonics has an individual circuit and the higher harmonics a common high-pass filter. The most frequently encountered and potentially harmful harmonics are the 5th and 7th, which are generated by 6-pulse rectifiers.

These also produce 11th and 13th harmonics. In such a case the filter would consist of separate circuits for the 5th and 7th and a wide band filter for elimination of the 11th, 13th and higher harmonics.



ıg. 19.
;chematic diagram of an HV capacitor ·ank connected in double star with un- ·alance protection.

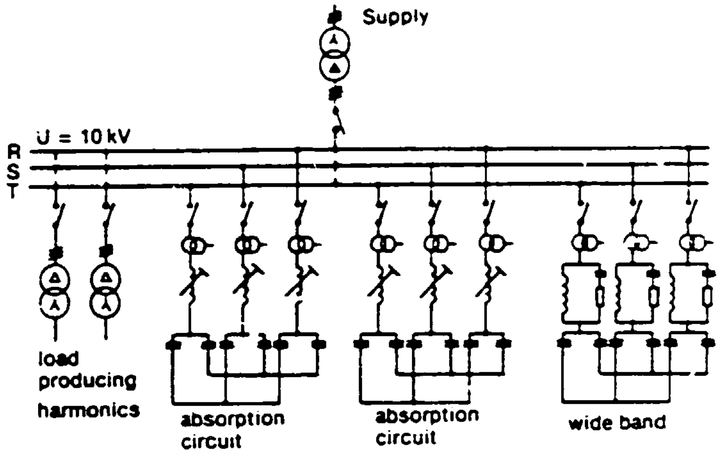


Fig. 20.
Typical filter construction of the plant.

)

hyristor controlled capacitors

hyristor controlled capacitors, which are :ore simple in construction than the fast :atic compensators described above, are ›ry suitable for fast reactive power com- ›ensation. The capacitor is equipped with thyristor switch, which replaces the tra- ›tional contactor. Requlator operations ·e combined with the automatic thyristor ›ntrols. This equipment can rapidly com- ›nsate for fast reactive power fluctuations · welding machines and the consequent ›ltage variations.

ast ›ic compensators

ı some instances, for example arc fumaces nd welding machines, there are very rapid uctuations in reactive power within a short eriod — i.e. a few cycles. Traditional ıethods of reactive power control are not uitable since they are too slow for such ›nations.

he fast static compensator has been de- eloped to deal with this problem.

he NOKIA Fast Static Compensator con- ısts of a fixed shunt capacitor bank, nor- ıally tuned as a filter, and a thyristor- ontrolle‹' shunt reactor. By controlling the ›actor current, the total reactive power upplied by the f.s.c. into the network is orrespondingly adjusted.

'hus the harmonics generated both by the ›ad and the thyristors are eliminated. ‹ence, the disadvantages of fluctuations in ›active power and the harmonics are both ıinimized.

;tatic compensators are also used to reduce ›ltage variat.ons caused by power changes › transmission lines

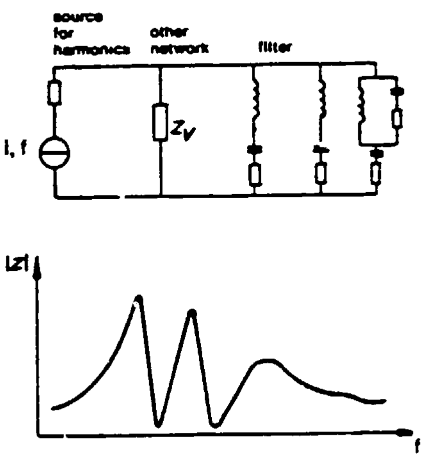


Fig. 21.
Impedance curve and substituting connection of the harmonic filter and of the network in accordance with the figure 20.

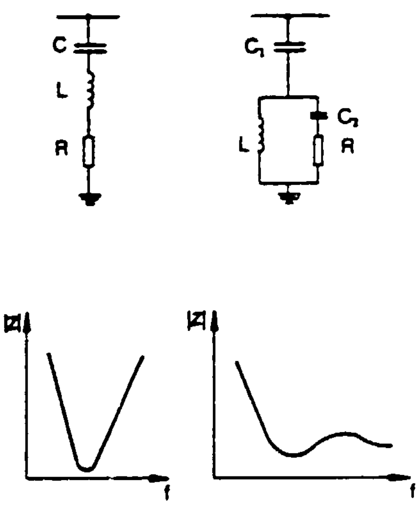


Fig. 22.
Absorption circuit of one harmonic and high pass filter of higher harmonics and their impedance curves.

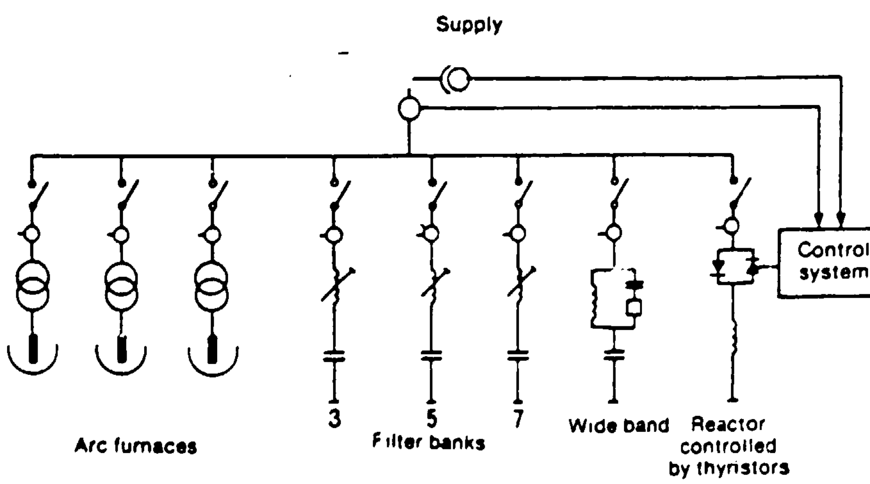


Fig. 23.

Operation and Construction of SAMI Frequency Converter

Pulse width modulated inverter

The speed of a motor can be controlled by varying the frequency of the supply voltage. The speed is directly proportional to the frequency. The flux and the torque of the motor can be kept constant by also varying the voltage in proportion to the frequency.

In the SAMI Frequency Converter the frequency and the voltage are controlled by means of the Pulse Width Modulation (PWM) method. The main circuit of SAMI comprises a diode rectifier for rectifying the mains supply voltage, an LC circuit for filtering the d.c. voltage, and a PWM inverter. In regenerative SAMI types, the diode rectifier is replaced by an anti-parallel thyristor bridge to feed the braking energy back into the supply network.

The dependence of the SAMI output voltage on the frequency is shown in Fig. 6. The frequency range is 0.5 to 100 Hz, consisting of two sub-ranges:

- 0.5 to 50 Hz. The constant flux range in which the widths and the number of pulses are varied to control the voltage in proportion to the frequency.
- 50 to 100 Hz. The field weakening range in which the voltage is constantly at its rated value and there is a single voltage pulse only per each half-cycle.

Low supply current

Thanks to its principle of operation, SAMI draws from the supply a current that consists almost entirely of active current. The power factor in relation to the supply is approx. 1 throughout the control range. The power factor of a motor drive supplied from a SAMI is therefore better than that of a motor supplied directly from the mains.

Fig. 7 shows the supply current I_1 of the SAMI drive at different motor load torques T_M. The current decreases in almost direct proportion to the frequency and the speed, while in a d.c. drive, for example, the current drawn from the supply remains at the rated value within the entire control range if the load torque is constant.

The low supply current of SAMI means a considerable advantage in starting. The starting current is always almost zero, whereas in direct starting on the supply it will be 6 to 7 times the rated current.

Economical standard construction

The varying requirements of different applications are provided for by the modular construction of SAMI. The standard construction will be sufficient for many applications, and can be supplemented with optional accessories as necessary. The standard unit includes the converter unit itself, complete with supply connection, fuses and contactors, with control circuit connections for manual setting. Different applications require different numbers of control devices; these are not included in the standard unit but can be ordered as required.

Versatile optional features

Several optional features are available for SAMI, including:

- Different control and transducer connections
- Process controller (e.g. pressure controller)
- Reference integrator
- Torque limiting and increasing
- Stall protection
- Tachometer connection
- By-pass circuit
- Thermal protection of motor
- Control box

For details of the options, see pages 8 to 11

Main parts of SAMI

Figs. 5 and 8 show the main parts of the SAMI Frequency Converter:

1 Mains connection
2 Control connections included in standard construction
3 Control connections for optional accessories
4 Protection switch unit
5 Main contactor
6 Supervision panel
7 Fast fuses
8 Fuse-switch
9 Rating plate
10 Cooling air outlet
11 Cooling air fan
12 Diode rectifier (or anti-parallel thyristor bridge
13 Optional application cards
14 Frequency Converter control cards
15 Pulse amplifier and inverter
16 Auxiliary voltage source
17 Current measuring transducers
18 Commutation unit
19 D.C. choke

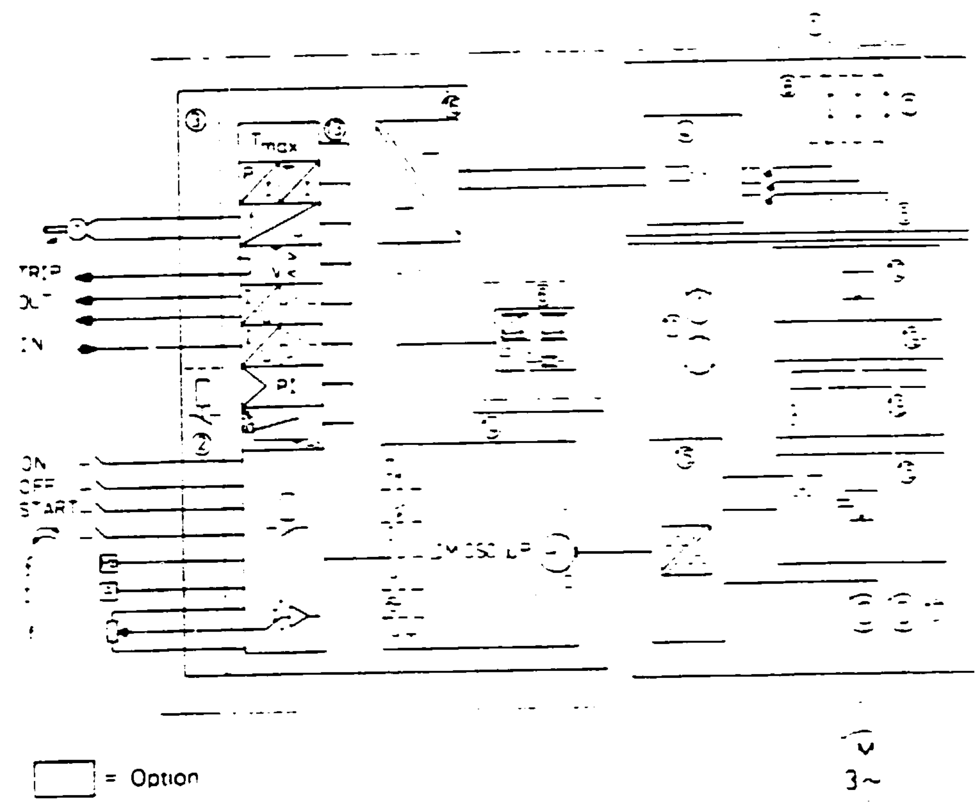


Fig. 5
Block diagram of SAMI B Frequency Converter

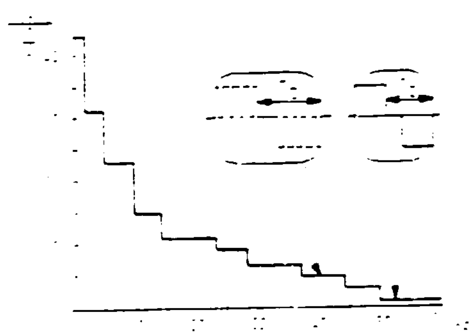


Fig. 6
Dependence of pulse number N on frequency f

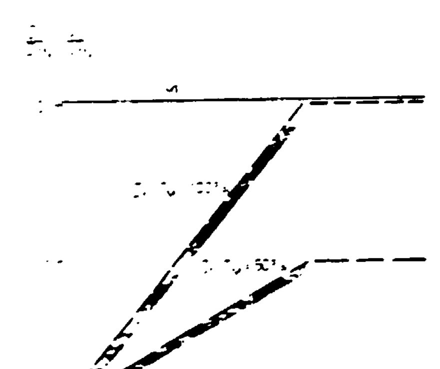
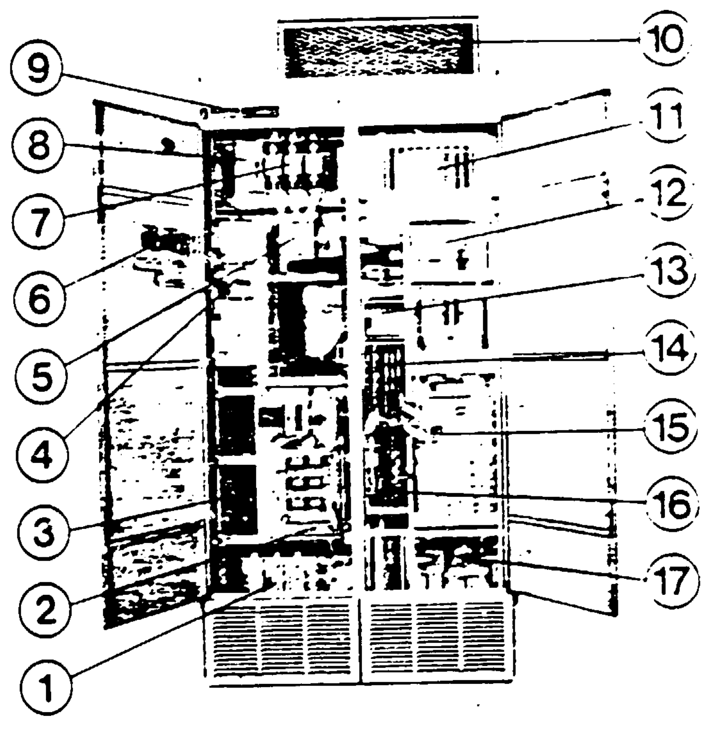


Fig. 7



Technical Data

1. Specifications common to all types

- Supply voltage, continuous and momentary, 3 phase supply — U [illegible] ± 10 %
- Supply frequency — 50 Hz ± 3 %
- Power factor for basic harmonic
  - B types — Approx. 1
  - BQ types — Approx. 0.95
  - BG types — 0.7 ... 0.95 (35 ... 50 Hz)
- Efficiency at rated load — ≥ 0.97 [illegible]
- Output voltage — [illegible] = U [illegible]
- Output frequency, U/f = constant — 0.5 ... 50 Hz
  - U = constant — 50 ... 100 Hz
- Braking power
  - B and BQ types — [illegible] losses
  - BG types — Up to SAMI rated power
- Permissible ambient temperature — [illegible] ... +40 °C
- Cooling medium (with integral fan) — [illegible] less than 93 [illegible]
- Enclosure class — IP 21
- Paint colour — RAL 5013
- Standards — Applicable IEC and VDE norms

2. Principle of type designation

[illegible]

▲ ▲ ▲

Power rating kVA ———

Construction: B = standard, BQ = fans and centrifugal pumps only, BG = regenerative braking type ———

Rated voltage V ———

2. Specifications for individual types

- Load power ratings permitted for SAMI:
- Motor to be selected as described on page 12
- In addition to the types listed below, other types are also available on special order

NORMAL TYPES B AND BQ

SAMI type	Rated current of SAMI (input and output)	Constant-torque load: Highest rated power of the motor	Constant-torque load: Max SAMI power at 50 Hz	Pump/Fan – Torque Limiter Card: Highest rated power of the motor	Pump/Fan – Torque Limiter Card: Max SAMI power at 50 Hz	Pump/Fan – Torque Limiter Card: Max SAMI power at 70 Hz
	A	kW	kVA	kW	kVA	kVA
380 V						
SAMI [illegible] B	[illegible]	37	38	45	33	[illegible]
[illegible] B	[illegible]	45	50	[illegible]	43	50
[illegible] B	[illegible]	[illegible]	63	75	[illegible]	66
[illegible] B	[illegible]	[illegible]	79	90	[illegible]	[illegible]
[illegible] B	[illegible]	90	109	[illegible]	94	109
[illegible] B	[illegible]	[illegible]	135	160	119	[illegible]
[illegible] B	[illegible]	160	179	200	158	192
[illegible] B	404	200	224	250	191	[illegible]
333 B	[illegible]	250	275	315	242	[illegible]
450 B	664?	315	378	400	321	[illegible]
2 × 333 B	961?	500	536	630	465	[illegible]
2 × 450 B	[illegible]	630	720	900	523	720
415 V						
SAMI [illegible] B	[illegible]	[illegible]	39	45	33	39
[illegible] B	[illegible]	[illegible]	[illegible]	55	45	[illegible]
[illegible] B	[illegible]	55	62	75	57	[illegible]
[illegible] B	[illegible]	[illegible]	80	90	70	[illegible]
[illegible] B	[illegible]	[illegible]	106	110	94	[illegible]
[illegible] B	[illegible]	[illegible]	135	132	118	[illegible]
[illegible] B	[illegible]	[illegible]	[illegible]	200	153	[illegible]
[illegible] B	[illegible]	[illegible]	[illegible]	250	191	[illegible]
333 B	[illegible]	[illegible]	[illegible]	315	242	[illegible]
[illegible] B	[illegible]	[illegible]	376	400	321	[illegible]
2 × 333 B	[illegible]	[illegible]	[illegible]	630	465	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	900	[illegible]	[illegible]
500 V						
SAMI 18 B 500	[illegible]	[illegible]	13	15	[illegible]	[illegible]
40 B	46	30	30	37	27	[illegible]
60 B	69	45	45	55	41	46
80 B	92	55	61	75	55	63
100 B	115	75	79	90	70	[illegible]
120 B	138	90	94	[illegible]	85	95
160 B	185	110	130	132	116	[illegible]
200 B	[illegible]	132	164	160	144	165
250 B	[illegible]	[illegible]	219	250	186	[illegible]
340 B	[illegible]	250	280	315	247	283
420 B	485	315	351	400	300	345
520 B	600	400	428	500	374	430
2 × 420 B	[illegible]	630	680	800	590	680
2 × 520 B	[illegible]	800	785	1000	680	795
660 V						
SAMI [illegible] B 660	59	45	45	[illegible]	[illegible]	46
[illegible] B	116	90	128	[illegible]	[illegible]	[illegible]
[illegible] B	175	132	165	[illegible]	143	[illegible]
[illegible] B	234	[illegible]	226	[illegible]	192	[illegible]
[illegible] B	[illegible]	250	275	315	[illegible]	[illegible]
[illegible] B	[illegible]	315	335	[illegible]	[illegible]	[illegible]
[illegible] B	[illegible]	400	443	[illegible]	387	[illegible]
[illegible] BG	[illegible]	–	–	630	567	[illegible]
2 × [illegible] B	[illegible]	800	845	[illegible]	[illegible]	845
2 × [illegible] BG	[illegible]	–	–	[illegible]	[illegible]	[illegible]

[illegible]

REGENERATIVE BRAKING TYPES BG

SAMI type	Rated current of SAMI (input and output)	Constant-torque load: Highest rated power of the motor	Constant-torque load: Max SAMI power at 50 Hz
	A	[illegible]	[illegible]
380 V			
SAMI [illegible] BG	[illegible]	37	38
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
[illegible] BG	[illegible]	[illegible]	[illegible]
415 V			
SAMI [illegible] BG	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
500 V			
SAMI [illegible] BG 500	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
660 V			
SAMI [illegible] BG 660	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

4. Control connections, standard SAMI

Description	Voltage Current	Symbols and terminals	Notes
Reversing	48 V	REVERSE — X2: 141, 142	Open circuit corresponds to sequence [illegible]. NC contact opens switching contactor [illegible]
Contactor off		CONT OFF — 143	Impulse (3 sec) starts charging of in- termediate circuit [illegible]
Contactor on		CONT ON — 144	
Starting prevented		CHARG INTERL — 145, 146	Open circuit prevents charging of in- termediate circuit
Running and starting prevented		CONT INTERL — 147, 148	Open circuit prevents running and trips main contactor
Stop		STOP — 149	Opening contact stops SAMI
Start		START — 150, 151	Impulse starts SAMI
Running prevented		RUN INTERL — 152, 153	Open circuit prevents running
Frequency reference setting	+6.67V	F REF — 154	Max. signal 6.67 V corresponds [illegible]
	0-6.67V	155	Potentiometer 2 k... 5 [illegible]
	= 0V	156	= 0 V earthed
Measurement of load current	0-1mA	157	1 mA corresponds [illegible] SAMI's [illegible] specified
	0-1mA	158	
Measurement of frequency	0-1mA	159	1 mA corresponds [illegible]
	0-1mA	160	
Ext. fault signal	48 V	FAULT — 161; X3 188	48 V DC [illegible]
Auxiliary voltage	0	X1: 111 (0)	[illegible]
	220-240V	112 (220-240V)	
Fault signal out	Max	113	[illegible]
	250V	114 — K[illegible]	
	2A	115	
Running signal out	Max	116	[illegible]
	250V	117 — K3	
	2A	118	

Optional Features

1. Optional application cards, placed in Control Unit

Option card	Purpose	Remarks
INPUT CARD SAMC 21 INP/35 INP	• Galvanic isolation for external analog signal. • Input for Manual/Auto change-over signal. • Galvanic isolation of pulse inputs.	• For input signals of 0...5 V, 0...10 V, 0...20 mA, 4...20 mA, 0...50 mA and 10...50 mA. • ± 10 V measurement connection for Manual/Auto signal difference. • Maximum pulse — 15...+ 15 V or 0...20 mA.
OUTPUT CARD SAMC 22 OUT (2 ch.) SAMC 34 OUT (1 ch.)	• Galvanic isolation amplifier for SAMI output signals such as frequency reference, power, torque, intermediate circuit voltage, motor current or speed.	Output signals are 0...1 mA, 0...5 V, 0...20 mA and 4...20 mA. The signals can be scaled and their zero levels can be changed.
TORQUE AND ACCELERATION LIMITING CARD SAMC 23 TAL	• Torque limiting at low frequencies in pump and fan drives. • Limiting of rise and fall times of a desired internal signal. • Linear limiting of minimum and maximum frequency.	This card is used if constant acceleration or deceleration is desired for the motor, where reversing from a high speed is required or if it is desired in pump drives, to use an over-dimensioned motor.
CONTROL CARD SAMC 24 CON	• A PI controller for controlling e.g. speed, pressure, or liquid level.	Reference signal for this card can be obtained from a potentiometer, via the Input Card or via the Speed Actual Value Card SAMC 25 SAV. Requires other option cards e.g. SAMC 21 INP and SAMC 23 TAL.
TORQUE MAXIMIZING CARD SAMC 25 TMX	• Used in heavy-start drives to maximize starting torque of motor.	Simultaneous use of Stall Protection Card SAMC 27 STP is recommendable.
SPEED ACTUAL VALUE CARD SAMC 26 SAV	Converts the tachometer pulse signal or a DC signal into a suitable signal for the SAMI in e.g. speed control or start to a running motor.	Maximum pulse frequency is 15 kHz, maximum height 24 V. No galvanic isolation.
STALL PROTECTION CARD SAMC 27 STP	• Monitors motor for stalls. Gives an opening or closing contact signal after the torque limiting circuits have controlled the frequency down.	Operates after a delay of about 30 seconds.
POWER AND TORQUE MEASUREMENT CARD SAMC 28 PTM	• Uses current and voltage to produce signals proportional to power and torque.	Output signal 0...20 mA, 4...20 mA, 0...1 mA or 0...5 V. No galvanic isolation.
MULTIPLIER CARD SAMC 30 MLT	• Used with the SAMC 24 CON card in control systems where the regulator signal is summed to the basic reference in desired proportion.	
MOTOR THERMAL PROTECTION CARD SAMC 31 MTP	• Used to protect motor against overheating if no other thermal protection (e.g. thermistor) is provided. Makes allowance for reduced cooling at low frequencies.	Alarm and tripping limits can be adjusted separately. If the tripping limit is exceeded, the SAMI stops.
COMPARATOR CARD SAMC 32 CMP	• Used in drives consisting of parallel pumps or fans (PFC control) in conjunction with the SAMC 24 CON card to start parallel pumps, fans or compressors as needed. • Can be used also for indication of overstepping set limit values.	Four closing contacts, capacity 0.75 A/60 V each.
LIMITER CARD SAMC 36 LIC	• Limiting regulator, which can be used to limit the speed of the SAMI drive depending on the current or power of some other motor. • Minimum or maximum value selector circuit; for the reference value can be chosen either higher or lower of two values. • Filtering circuit to smooth oscillations in the actual value signal.	
BUS CARD SAMC 37 BUS	• This card is used if the desired option cards cannot be accommodated in the SAMI's Control Unit and an extension rack is required.	
PULSE CONTROLLED REFERENCE CARD SAMC 42 PCR	• Used like a motor-potentiometer to generate reference signals. • Input signal also supplied as a pulse train from computer. • During a power failure, the reference value can be retained in a memory.	• Input signals +24 V, +48 V, 20 mA. • Max. pulse train frequency 5 kHz. • Rate of change of the reference value can be set between 5 s and 150 s.
CRITICAL FREQUENCY PROTECTION CARD SAMC 46 CFP	• This card produces up to 5 stepped changes to the desired points in the frequency reference range to avoid damages due e.g. to resonances.	
RUNNING START CARD SAMC 48 SPS	• Used to start and synchronize the SAMI to a running motor without a tachometer.	
LOAD SUPERVISION CARD SAMC 47 LSV	• Over- and underload supervision. • Function circuit y = a (x^b). • Supervision of the actual value of frequency.	• NO contact 0.75 A/60 V. • Integrator 0.12 s . . . 280 s.
TERMINAL BLOCK CARD SAMT 21 TBC	• Used to connect signals of certain option cards out of the SAMI.	The Input and Output Card channels are protected against external overvoltages (max. 105 V)
DC TACHO MATCHING CARD SAMT 22 TMC	• Used to match the DC tachometer signal to the SAMC 26 SAV card.	Maximum input voltage 600 V DC.
INDICATING CARD FOR SAMC 31 MTP SAMT 24 MTP	• Used in conjunction with the SAMC 31 MTP Motor Thermal Protection Card. LED indicators for motor overtemperature.	Placed in the SAMI Control Unit onto the SAMC 31 MTP card.

2. Control Panels and Control Box

CONTROL PANEL SAMI 1 PAN

The control panel can be mounted, for example, on a control room desk or a SAMI 1 BOX control box. The panel contains the following control and monitoring devices:

- Push-buttons ON and OFF for contactor control.
- Push-buttons START and STOP for starting and stopping SAMI.
- Push-button AUTO for selection of automatic control mode.
- FAULT lamp for fault indication.
- Potentiometer 2 kΩ/5 W for frequency setting.
- Frequency indicator f [Hz], scale 0...100.
- Power meter I [%], scale 0...100
- EMERGENCY-STOP push-button
- REVERSE push-button for selection of motor's rotation direction

The dimensions of the panel are: width 252 mm, height 185 mm, depth 80 mm. The dimensions of the cut-out for the panel are: width 225 mm, height 160 mm.

0878-82 MON

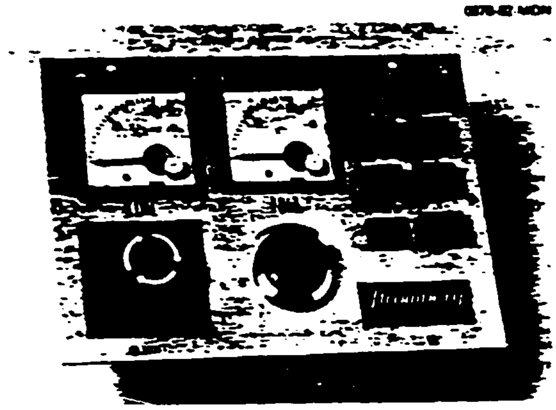


Fig. 9.
Control panel SAMI 1 PAN.

CONTROL PANEL SAMI 11 PAN

The control panel SAMI 11 PAN is installed in the door of the SAMI. The panel is identical with the SAMI 1 PAN, only it has no frequency or current meters.

0880-82 MON

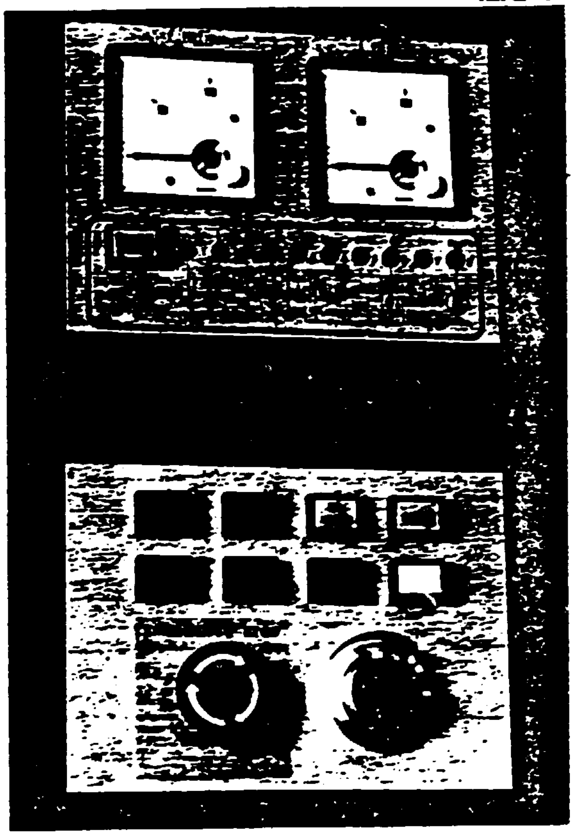


Fig. 10.
Control panel SAMI 11 PAN installed in the door of the SAMI.

CONTROL BOX SAMI 1 BOX

The control box includes a control panel SAMI 1 PAN, which is mounted in a steel box. The box may be placed where required and fixed with four bolts. The dimensions of the box are: width 300 mm, height 200 mm and depth 200 mm. The enclosure class of the steel box is IP54, but the devices mounted on it make the enclosure class of the SAMI 1 BOX to IP21.

0872-82 MON

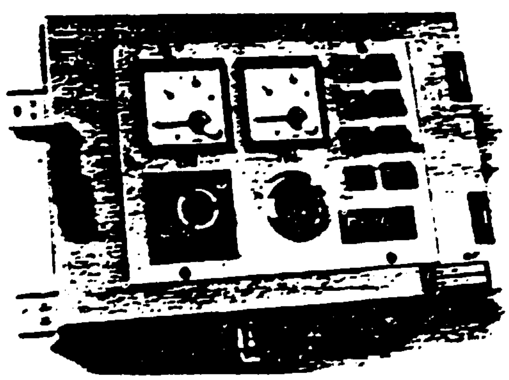


Fig. 11.
Control box SAMI 1 BOX

3. Other optional equipment

BY-PASS CIRCUITS

By-pass circuits can be used to provide a direct mains supply past the SAMI; the motor will then run without control. The use of a by-pass circuit may be justified by reasons involving the process or maintenance. The SAMI can be serviced while the motor is running. The by-pass circuit is mounted in an additional cubicle beside the standard SAMI.

Two alternative circuits are available:

a) Manually controlled by-pass circuit employing isolators.
b) Circuit for automatic by-pass or remote control, employing contactors.

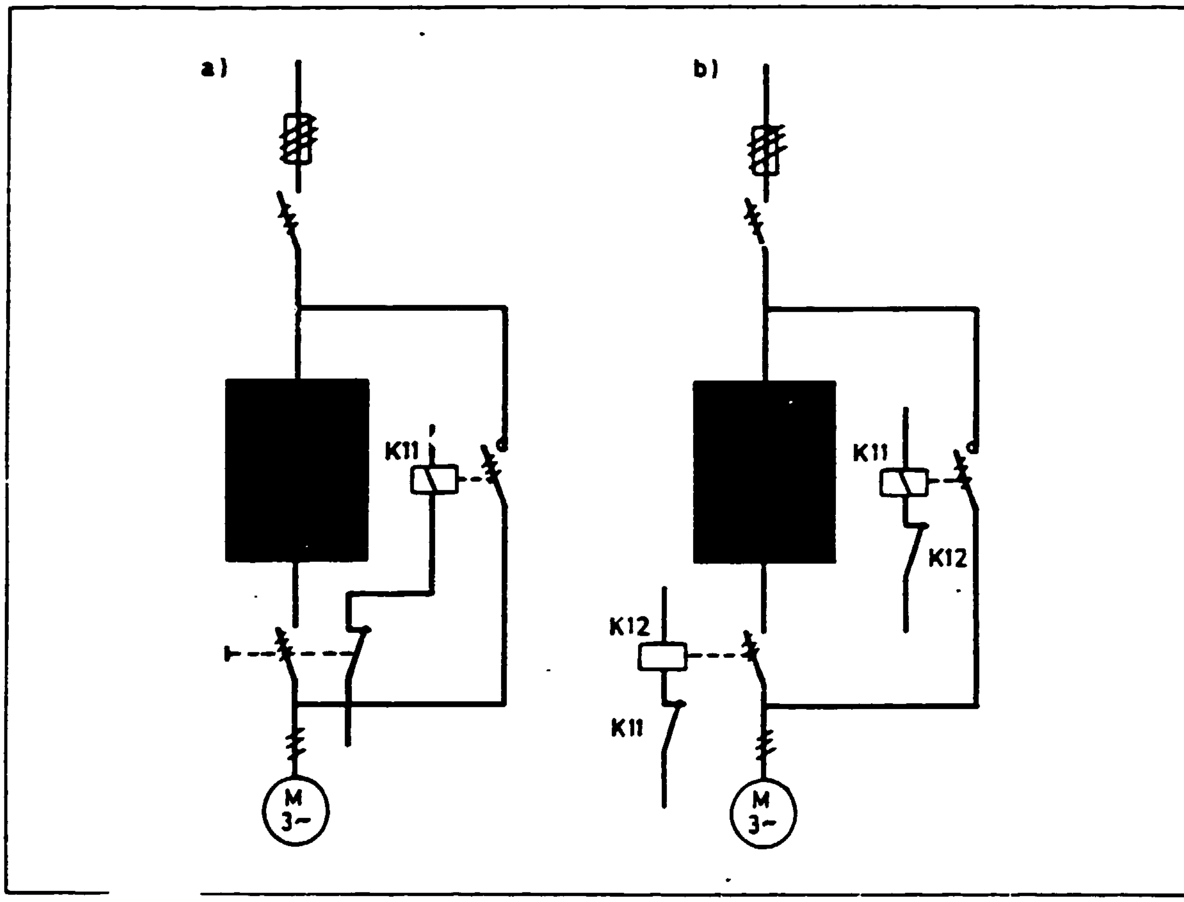


Fig. 12.
By-pass circuits. a) Manually controlled. b) With provision for automatic control

SYNCHRONIZING BY-PASS CIRCUIT

By using a synchronizing by-pass circuit it is possible to synchronize a motor supplied by the SAMI with the mains frequency, and then change it over to mains supply without any jerk. Thus, the SAMI can be used to start parallel motors smoothly to the mains according to need, as the current drawn by the SAMI at sta… is very low.

The synchronizing circuits are placed in an additio… cubicle beside the SAMI cabinet.

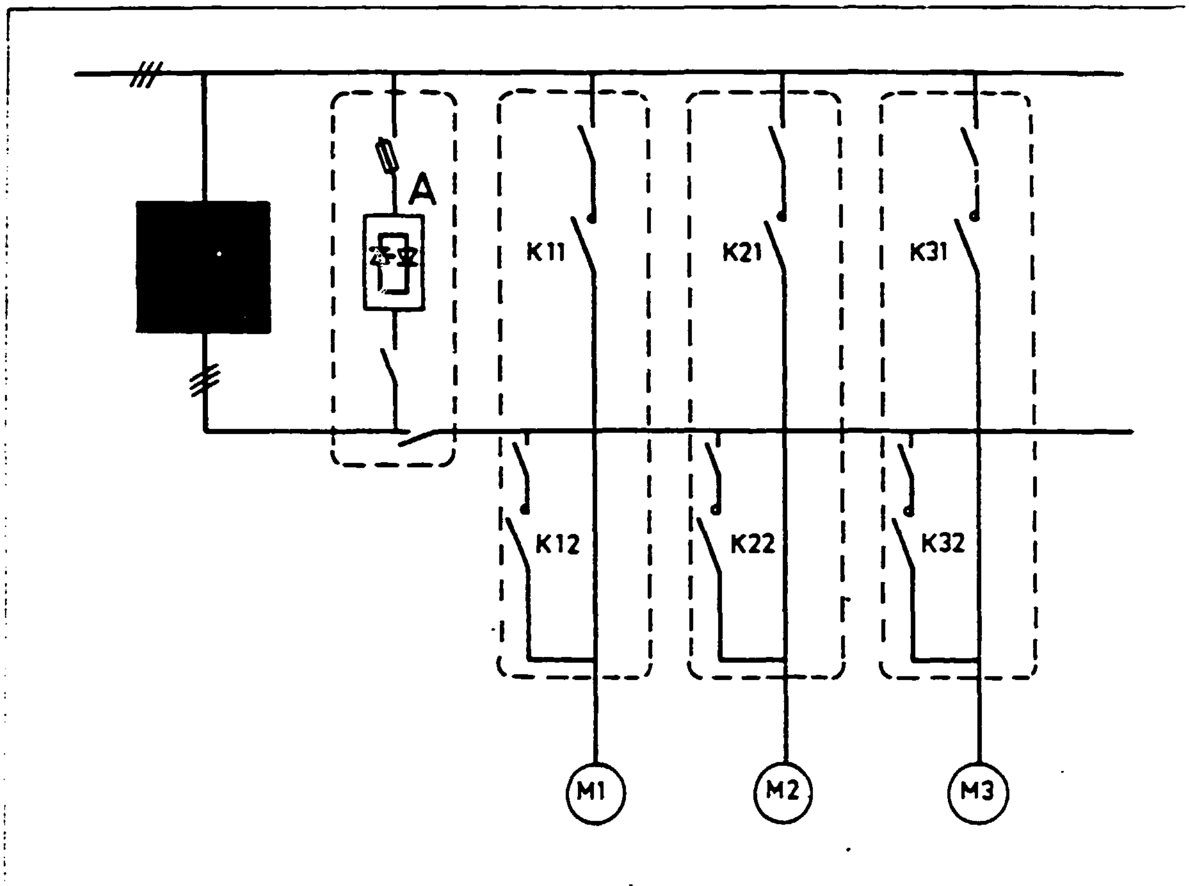


Fig. 13.
Synchronizing by-pass equipment for connecting motors smoothly to the supply line. A = synchronizing unit, K11 to K31 = line supply contactors and K12 to K32 = SAMI supply contactors.

EARTH FAULT PROTECTION UNIT SAME

The SAME Earth Fault Protection Unit monitors the motor side of the SAMI for possible earth leaks. The SAME unit is installed in the SAMI cabinet. In the even… of an earth fault, the unit gives a change-over contac… signal which can be connected either as an alarm or tc trip the SAMI.

4. Converter Unit SAMU

The SAMI's power pack with the associated control electronics are built as a compact unit provided with wheels, so it can be pulled out of the SAMI cabinet. This SAMU Converter Unit (see photo on back cover) can be supplied separately to be installed in the customer's cabinet.

In order to use the SAMU Converter Unit as a frequen-cy converter, it must be provided with auxiliary devic… such as a DC choke, fuses, switching equipment an… relays. These must be dimensioned as in a correspon…ing SAMI. Strömberg will supply these auxili… devices on special order as required.

Selecting SAMI type and motor

1. Specify initial data

In order to select the right SAMI-motor combination, the following information must be available:

- Mains supply voltage U [V]
- Speed range of drive $n_{min} - n_{max}$ [rpm]
- Load torque T [Nm] and its dependence on speed. The most common cases are constant torque and torque which increases in proportion to the square of the speed (pump and fan drives).

2. Specify the number of pole pairs on the motor

The number of pole pairs p, which determines the synchronous speed n_s of the motor, is usually selected according to n_{max}. In SAMI drives, however, over-synchronous speeds are also permitted, as the frequency range extends up to 100 Hz. Over-synchronous speeds are in many cases advantageous in constant-torque drives.

3. Specify motor power rating

The power rating of the motor can be selected quickly with the aid of the motor selection nomogram of Fig. 14, which makes allowance for the reduced cooling and subsequent heating of the motor in frequency converter drives. Proceed as follows:

- In quadrant 1, select the speed n_{max} on the scale corresponding to the chosen number of pole pairs p (1, 2, 3 or 4).
- Trace horizontally to quadrant 2 up to the M curve.
- From the intersection of the horizontal trace and the M curve, trace vertically downwards into quadrant 3 up to the line corresponding to the load torque T.
- From the intersection of the vertical trace and T, trace horizontally left to the power scale corresponding to the chosen number of pole pairs.
- The intersection of the horizontal trace and the power scale now yields the power required.
- If a pump or fan drive is involved, select the standard motor next largest to the required power.
- In case of a constant-torque drive, specify the power corresponding to n_{min} in the same way as for n_{max} in the above.
- For constant-torque drive, select the motor according to the larger of the two power ratings: n_{max} or n_{min}.

4. Select a suitable SAMI

The SAMI appropriate for the motor is selected according to

- the supply voltage,
- the duty type (constant-torque/pump drive), and
- the design current I_r of the SAMI.

The design current I_r can be calculated from

$$I_r = (0.565 + 0.15 \cdot T_{max}/T_N) \times I_N = k_r \times I_N$$

I_N and T_{max}/T_N are both obtained from the motor list.

Table 1 lists some values of the coefficient k_r.

T_{max}/T_N	k_r	T_{max}/T_N	k_r	T_{max}/T_N	k_r
2.0	0.865	2.7	0.97	3.4	1.075
2.1	0.88	2.8	0.985	3.5	1.05
2.2	0.895	2.9	1.00	3.6	1.105
2.3	0.91	3.0	1.015	3.7	1.12
2.4	0.925	3.1	1.03	3.8	1.135
2.5	0.94	3.2	1.045	3.9	1.15
2.6	0.955	3.3	1.06	4.0	1.165

Table 1. Selecting values of design coefficient k_r for different values of the ratio T_{max}/T_N (obtained from motor list).

After calculating I_r select a SAMI type from Tables on page 6 so that:

- In the case of a constant-torque drive the rated current of the SAMI is higher than I_r.
- In the case of a pump or fan drive plus a SAMC 23 TAL card the rated current of the SAMI is higher than $0.9 \times I_r$.
- The SAMI selected on the basis of the design current is capable of giving sufficient power (see table on page 6).
- If regenerative braking is desired, choose a suitable SAMI BG type.

The table on page 6 lists the power ratings suitable for motors in which $T_{max}/T_N \leq 2.9$.

5. In case of any special requirements, contact the nearest Strömberg representative

Certain special requirements make a more detailed selection procedure necessary. SAMI salesmen will be happy to assist you in problems such as

- high accuracy speed control
- starting large-inertia loads
- high starting torque
- high speed
- high power requirement
- especially high braking power requirement
- multiple-motor drives etc.

6. Selection example

Drawn on the nomogram is a selection example for a drive in which n_{min} = 600 rpm, n_{max} = 1500 rpm, and a constant torque of 360 Nm is required throughout the operating range.

1. Number of pole pairs chosen as p = 2. The motor will be P = 90 kW/1500 rpm.
   n_{min} requires 90 kW; n_{max} would require 75 kW only.
2. Number of pole pairs chosen as p = 3. The motor will be P = 75 kW/1000 rpm.
   n_{max} requires 75 kW; n_{min} would only require 55 kW.

Selection of SAMI for 380 V supply:

1. For a 90 kW motor: SAMI 133 B 380.
2. For a 75 kW motor: SAMI 100 B 380.

Alternative No. 2 is the most economical in initial outlay.

Motor Selection Nomogram

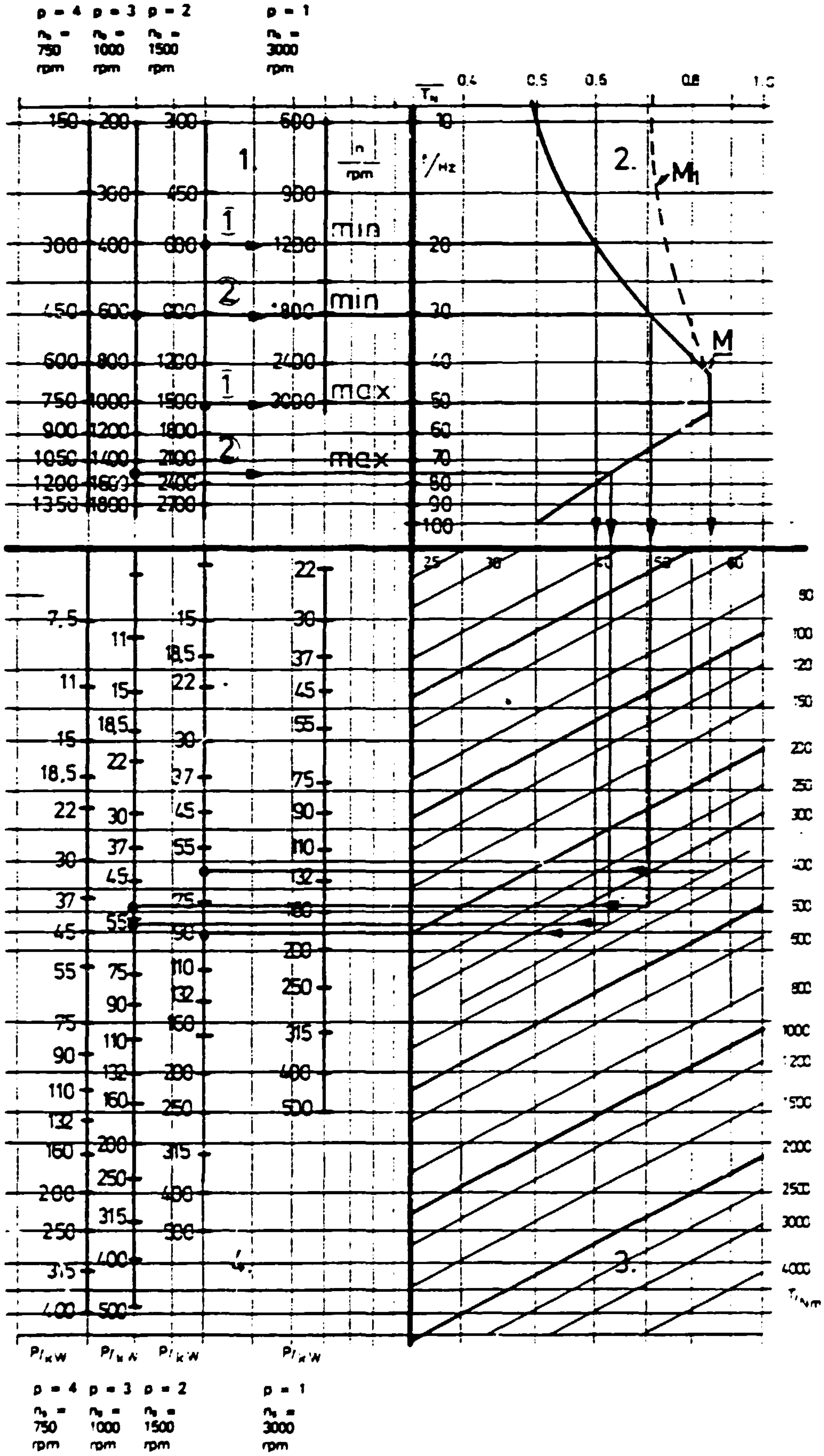


Fig. 14

Selection nomogram for motors of SAMI drives. Curve M is based on measurements carried out on Strömberg motors but can well be applied to other manufacturers' motors. Maximum load capacity at 50 Hz is 85 % of rated torque. M_1 (dashed line) applies for sep. fan-ventilated motors

XVIII BENEFITS OF ON-LINE OPTIMIZATION

A computerized system could work in a refinery by adjusting set points. Typically, (ethene plant) interfacing includes :

528	AIS	analog inputs
160	DIS	digital inputs
252	AOS	analog outputs
32	DOS	digital outputs

Moreover, there are readings of special instruments like gas chromatographies A 500 KB CPU and 2 x 67 x 1B discs with auxiliaries has been sufficient for this purpose.

The fuctions included are

- Data base
- Interfacing and data collection programs
- Post mortem analysis
- Man macnine operations
- reports
- Process control
- Self diagnostics

Scanning periods vary between seconds up to 1 month. Auxiliaries include color CRTs with graphic facility. Manual operation is possible parallelly.

The hierarchy is

- Analog controls
- Stabilizing level
- Limits control
- Local optimization
- Unit optimization

XVIII BENEFITS OF ONLINE OPTIMIZATION (Cont'd)

Adaptivity is applicable in stabilizing control, compensations, interactive feed toward, non-linear models and multivariable concepts have been applied.

Optimization take place for the following

- Ethene plant
- Quality control
- Energy optimization
- Pressure optimization

In the ethene plant, the profit function is maximized. Models exist for pyrolysis reactions and yields for various product flows. The model considers

- energy
- fuel of pyrolizing furnaces
- changes in separation phase
- energy in furnaces

This system covers

- 9 cracking furnaces
- 4 distillation towers
- 2 cooling compressor systems
- 2 acetylene converters

The application areas are

- methane removal
- ethene removal
- C_2 fractioning

Temperatures vary -100....+[illegible] ^{o}C

XVIII BENEFITS OF ONLINE OPTIMIZATION (Cont'd)

Quality control is realized with the following principles

- products are kept optimally within tolerable limits.
- gas chromato-graphic analyses are exploited
- feed forward and interactive controls are extremeiy used
- specific product prices are implemented in the models

Energy optimization is closely related to the optimal purity at by-products and it requires limiting control actions and stabilizing control at the steam flow.

The separation improves if the internal steam flow grows and if the main product control is active, it results in less impurities in the secondary product. However, the internal steam flow can grow only to the level where flooding or oaming will be harmful. There are other constraints like the capacity of the overhead condensor or the maximum of bottom boiler with valve positions. Typically 10....20 constraints. The limit control tends to minimize the impurities maximizing the internal steam flow within the constraints. This depends on

- feed amount
- feed quality
- impurities of the main product
- loads of compressors
- etc. variable factors

The steam flow is calculated based on energy optimization based on

- energy costs
- value of the product depending on its purity

Energy prices are calculated in the cooling compressor system and this way towers and compressors are intercoupled.

XVIII BENEFITS OF ONLINE OPTIMIZATION (Cont'd)

The pressure is controlled within constraints;optimal pressure depends on the valid constraint of the steam flow. The pressure is varied to minimize energy costs.E.g. if bottom boiling is the constraint by reducing the pressure, the energy demand and the temperature are reduced. i.e energy use is kept at minimum level without violating constraints. If,on the contrary,the overhead condensor is the limiting factor by increasing the pressure, more condensing capacity can be obtained which results in better separation.

The following results are reported yields given as weight % of the feed

	before	now
Burning gas	19	21
Ethene	32	34
Propene	19	17
C4-products	8	7
Gasoline and heavier	21	20
Availability of pyrolizing furnaces	25	30 days
Energy		reduced demand
Ethene losses	2	0.3
Quality (300-1600 ppm)	0.4	0.1
The return on investment		2 years

This project took 2 years, all included

- computers
- instruments
- strategies
- commissioning

This is beyond the scope of this mission, but could be started and if desired a co-operation is possible.

XIX COMPRESSORS

Compressors are widely used in refineries and therefore their proper function promotes

- availability of the plant
- energy conservation
- reduction of maintenance costs

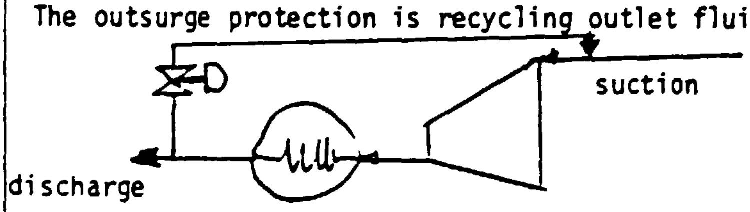
To avoid surging the conventional mthods are e.g

- hydraulic coupling
- adjustable inlet vanes
- throttling of suction
- a power wheel
- adjustable diffuser vanes
- resistance control of the induction motor
- DC motor, the speed of which is controlled by voltage

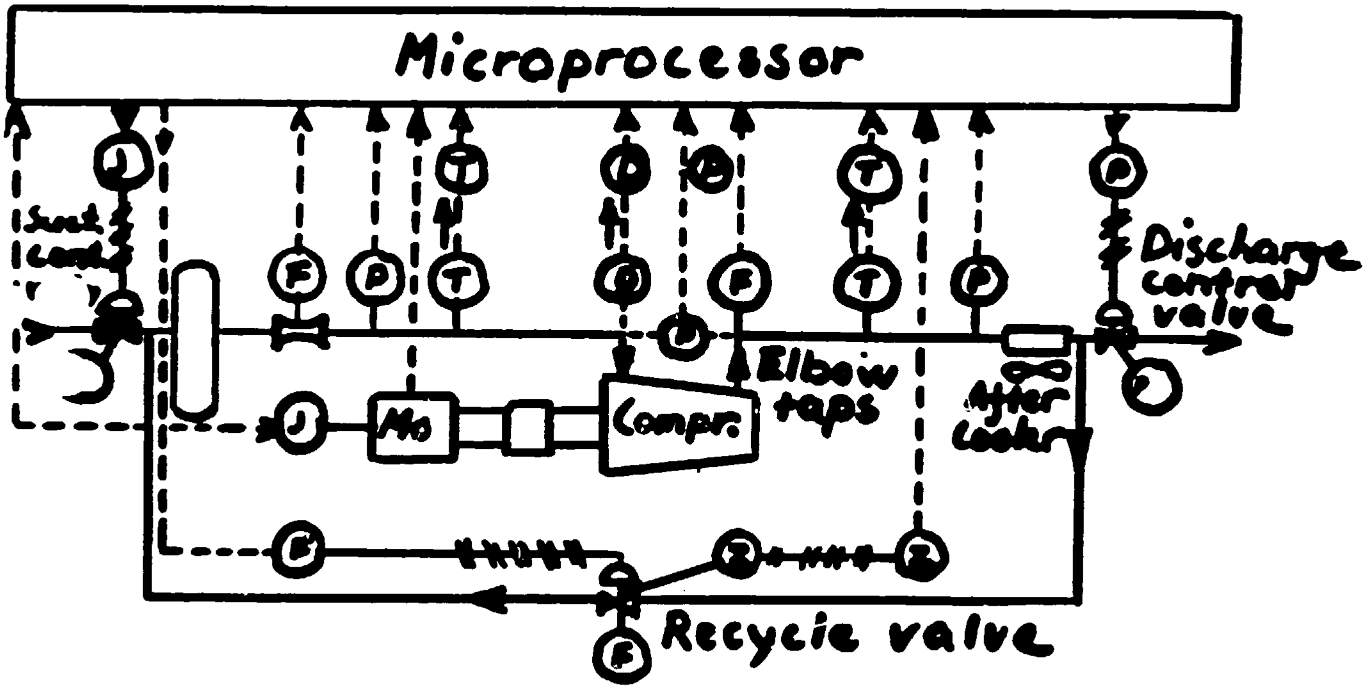
All of these have disadvantages, like

- complexity
- require maintenance
- energy wasting
- corrosion problems

The outsurge protection is recycling outlet fluid



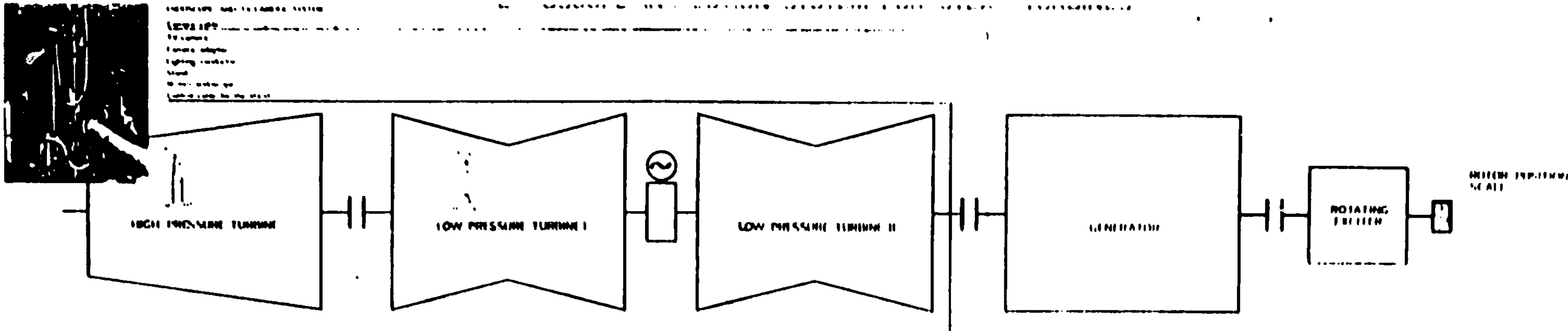
Under constant circumstances the surge can be predicted, but in varying case the error may reach 40....50%. This may cause useless recycling and energy wastes. A common principle is to minimize recycling. Variations can be due to several factors :

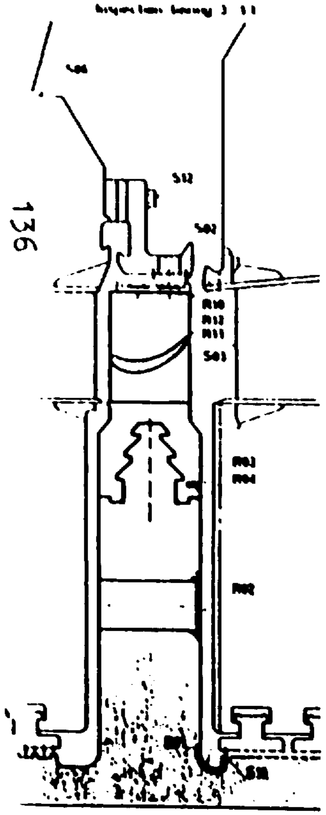


Example of interfacing acompressor to a microprocessor

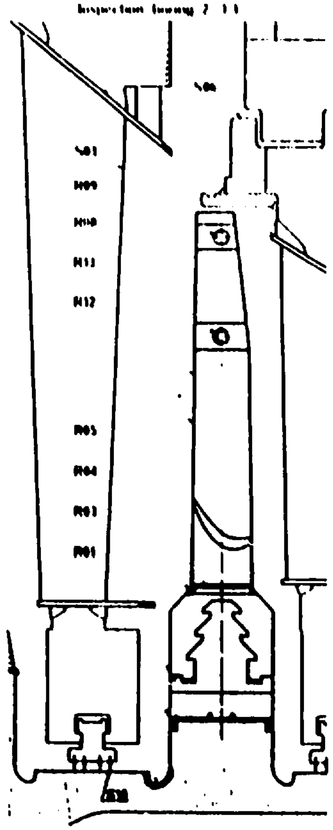
- surge protection
- recycle minimization
- speed control preferable for motors

UNDP/PSN 85

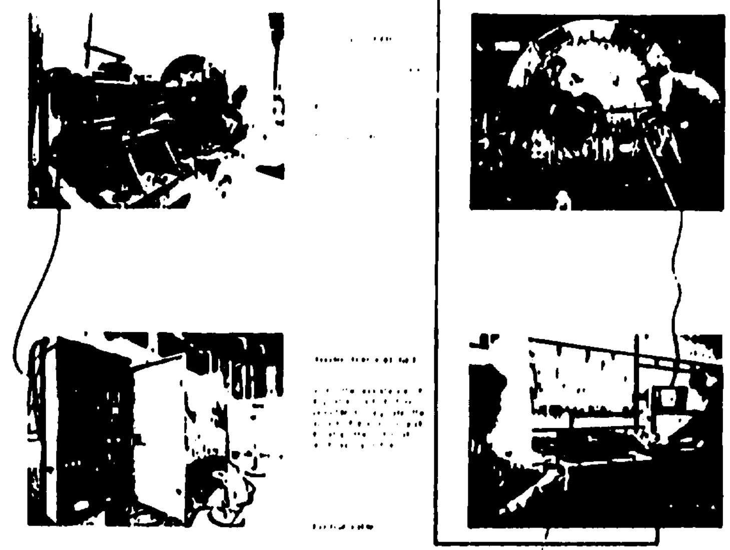




HIGH PRESSURE TURBINE



LOW PRESSURE TURBINE I AND II



THE ENDOSCOPE INSPECTION AND ITS BENEFITS

Inspection interval	2 years
Inspectors	2 inspectors with special training
Duration of the inspection	A 100% inspection (micro faults) 2 6 h/inspection boring Macro faults (damage incidents) about 1h/inspection boring

The benefits of the system

The revision interval of the high pressure turbine changes from 3 years to 6 8 years

It is not necessary to open the low pressure turbine at definite intervals

At damage incidents the extent of the damage can be controlled before making the decision to disassemble the turbine

The condition of the inner parts of the turbine can be determined without disassembling it

IVO

XIX COMPRESSORS (Cont'd)

- ambient temperature
- summer / winter

In this case, a control concept based on a microprocessor is justified because :

- surge can be predicted better
- recycling is minimized
- start up and shut down logics
- parallel compressors

The control options are

- minimum flow - simple for surge protection provided that circumstances are constant.
- minimum flow with speed control
- flow speed system (inverter + induction motor)
- ΔP - control
- Guide vane adjusts flow setpoint

Simulation can be applied when searching control strategies. If there are parallel compressors, the cases have to be studied individually. The digital approach has resulted in best results, because protection can be easily implemented for various situations.

Typically 8 measurement and 3 controls are required for a compressor. The models and quantities

$\Delta P = f\,(\text{flow})$

$P_i/P_o = f\,(\dot{V})$

$\Delta P = f\,(\dot{m})$

$P_i/P_o = f\,(\text{Mach number})$ -v/c c= sonic speed

incipient surge

min. flow control

surge detection

XIX COMPRESSORS (Cont'd)

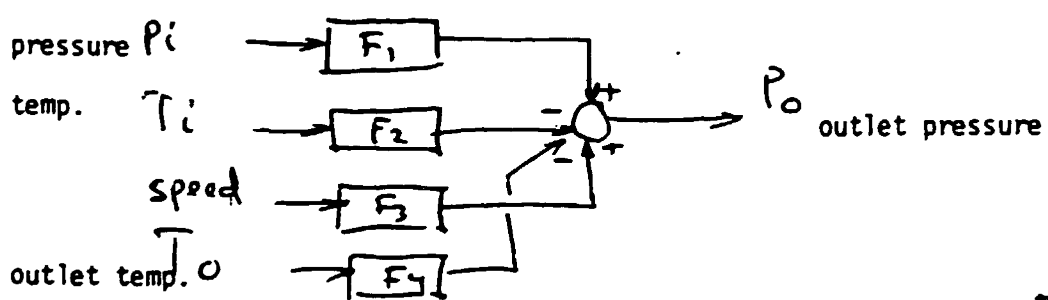
enough for the digital system. The compressor supplier is expected to provide this information. In the control schemes ramp and step responses are detected and also parallel operation.

This is one of the best methods to take the control system. First, parameters are chosen cautiously. Their validity can be checked by process experiments. After this the parameters can be safely optimized.

The model will contain, for one or parallel compressor

- input/output pressures, temperatures volume/mass, flows, head, pressure differences and speeds
- a control approach is selected
- tramp and step responses are studied as fuctions of variable control parameters
- several models are inspected

The model approach is as follows



F_1....F_4 are transfer functions and very often of the model of $\frac{e^{-\frac{t}{\tau_i}}}{1+sT_i}$ is of sufficient accuracy. τ_i and T_i can be calculated according to the dimensional data of the compressor or alternatively by means of simple process identifications tests. In some cases, suppliers can give them. When the model and the control strategy is established, the system will be discretized and the model program is prepared. Any high level language can do, but also there are special simulation languages available like MIMIC or ANAGOL and the working is faster. However, this is no necessity because the programs will not be very complex in case of compressors.

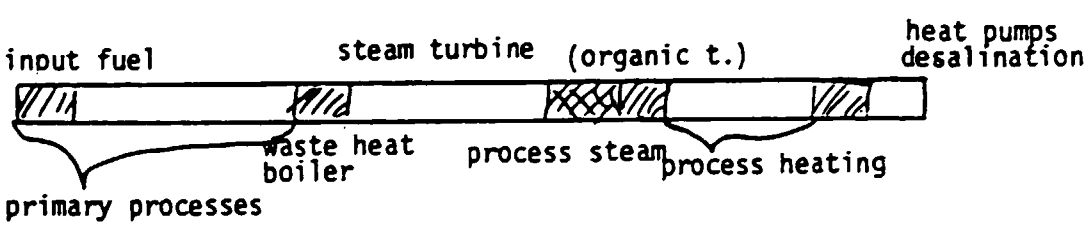
XIX COMPRESSORS (Cont'd)

Actually using FORTRAN or PASCAL, the constraints can be included more easily (e.g surge). The initial parameters can be selected by rules of thumb. They can be gradually improved by repeated simulations. Visual inspections of responses can be used as performance criteria , e.g because the final settings are a question of taste to a certain extent. The simulation approach is universal to any process. Submodels can be assembled for a plant scale system or they can be studied separately if desireable. If the models are well designed, the results are reliable. A multivariable approach can be chosen and there are several quantitative performance criterias which are chosen depending on the case. Graphics and plotters are useful to visualize the results. This is a very attractive method to study control problems, however, an insight of the process is mandatory to obtain correct results. A case example can be taken at ENPPI.

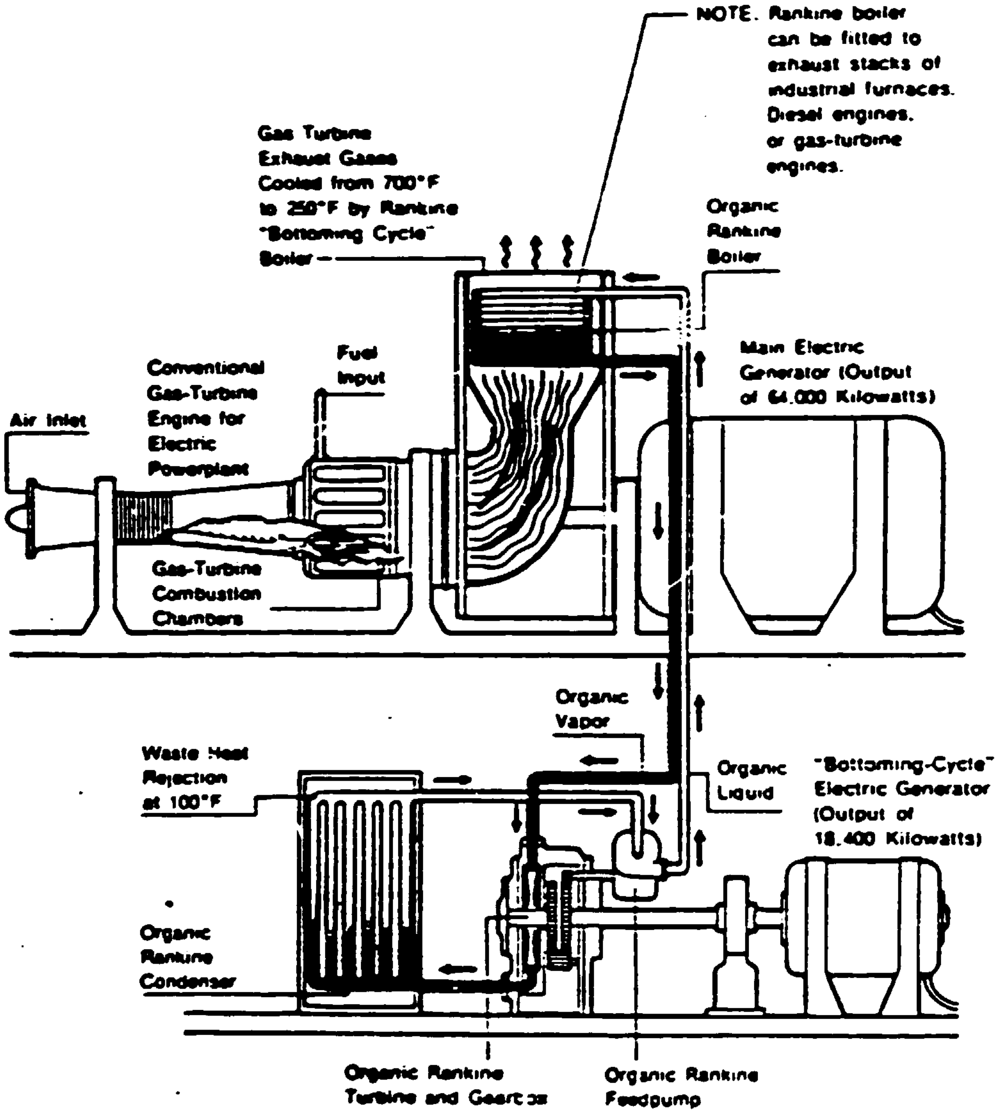
XXI BOTTOMING CYCLES

A fairly new concept is to use organic work fluids. For instance, the temperatures at gas turbine exhaust gases can be lowered 480°C ....150°C and overall efficiency of 47% is achievable for electric output,but if steam is required, then the waste heat boiler with a possible auxiliary fuel fits better. Condensor losses are less because of the smaller latent heat for evaporation. The organic liquid may be valuable (Taluene, freon, fluoranol, methyl -pyridene). However, in industry waste heat sources 315.6°C are scarcely available. Exhaust gases from the furnaces meet with this condition. Also because this is a brand new concept it is not widely used.

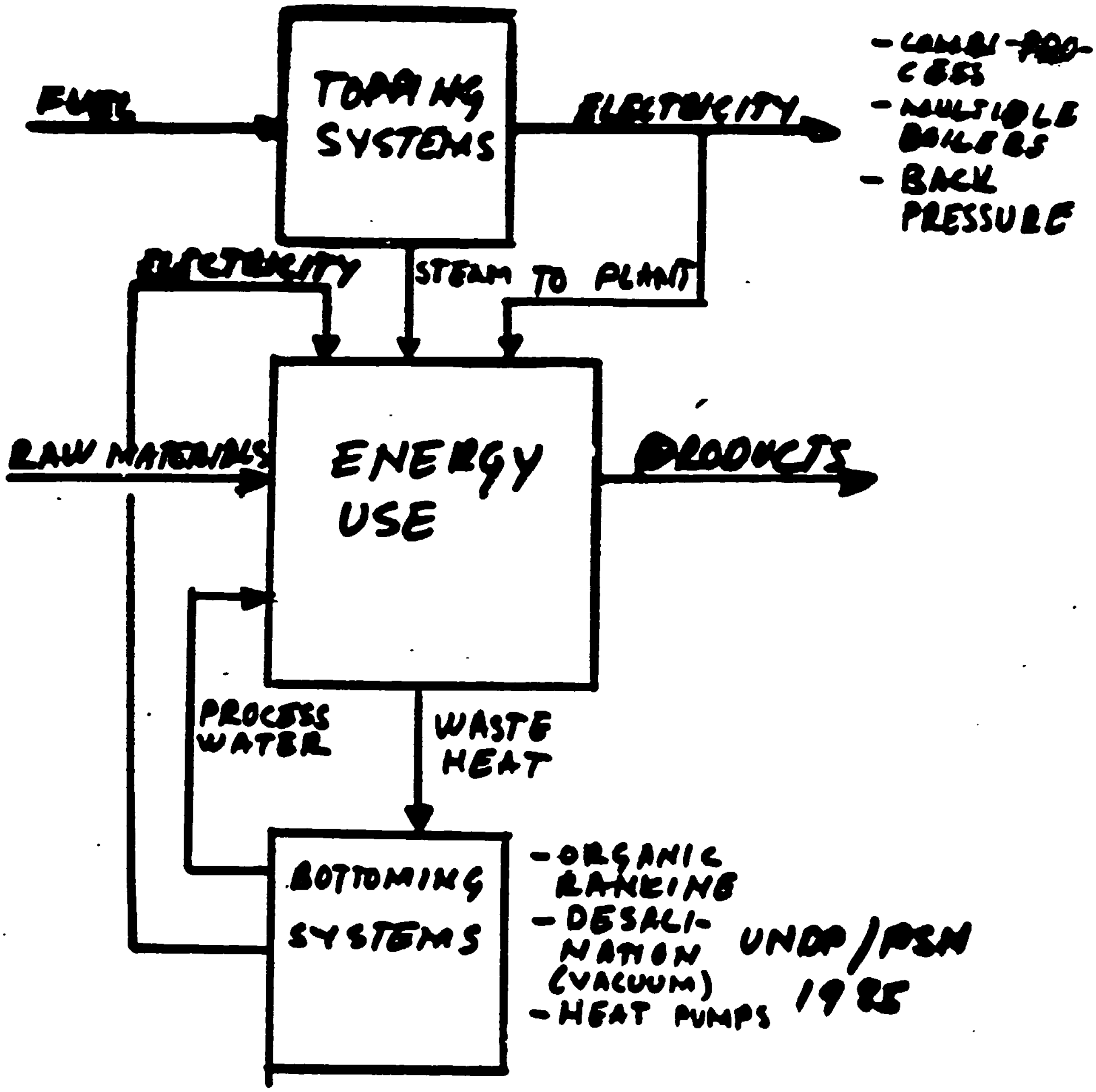
The possible losses of the work fluid tend to raise the operational costs, unlike the cost of water. The economic size starts at 0.6 MW and resulting in savings 8600 k x 0.6 MWh = 5.16 TWh ~ 150 k$/a. Petroleum and chemical industries are the most potential in this regard. Catalytic reforming, hydroheating, vacuum or atmospheric distillation processes are feasible. In chemical industry dehydrogenation of ethylbenzine e.g provides a great potential. The optimal energy economy should be cascading as below



It means that the output energy is always tried to be fed as an input to an exploiting process. This is generally a good engineering principle. Conventionally, these areas overlap each other.

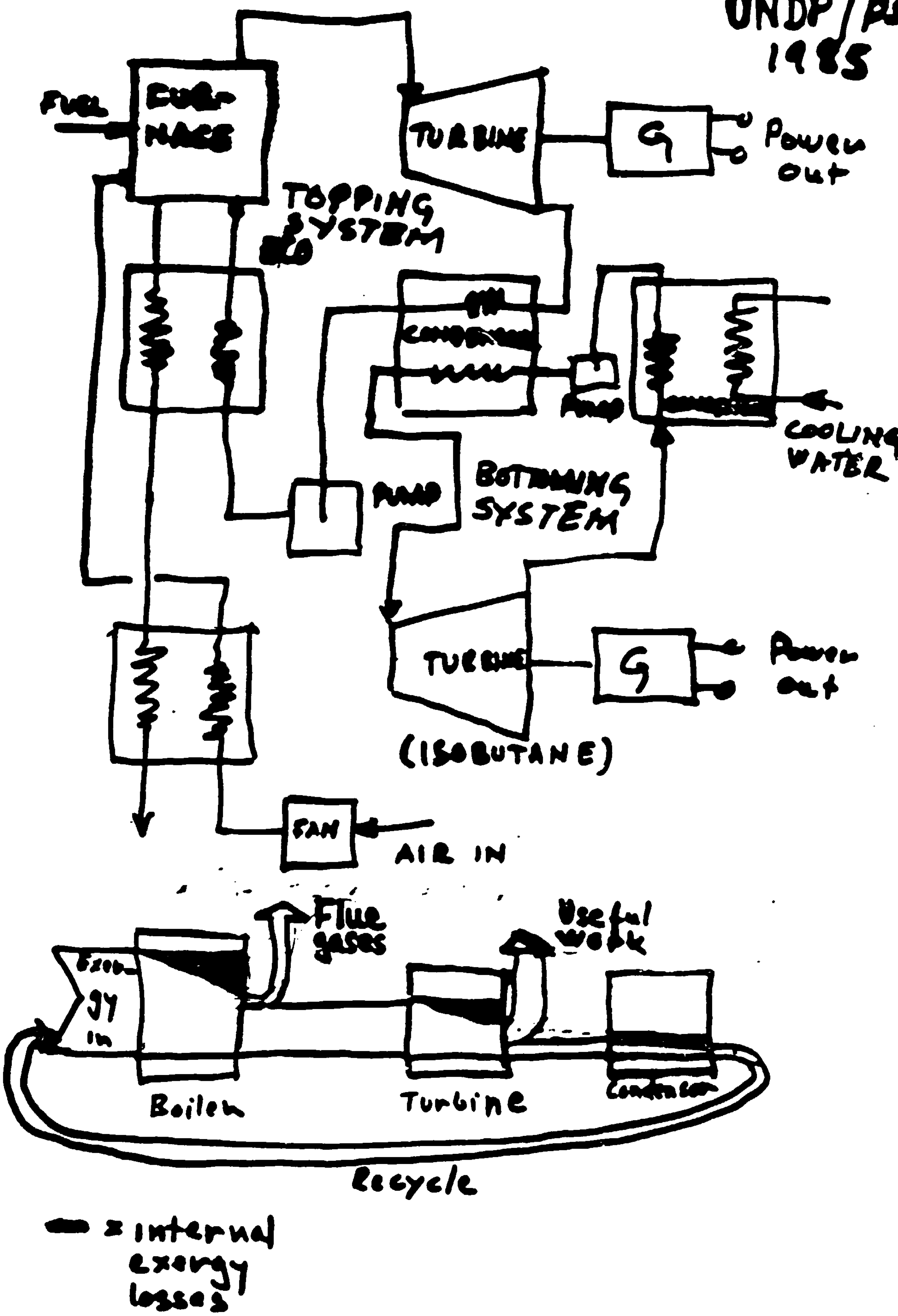

NOTE. Rankine boiler can be fitted to exhaust stacks of industrial furnaces. Diesel engines, or gas-turbine engines.
Gas Turbine Exhaust Gases Cooled from 700°F to 250°F by Rankine "Bottoming Cycle" Boiler
Organic Rankine Boiler
Main Electric Generator (Output of 64,000 Kilowatts)
Fuel Input
Conventional Gas-Turbine Engine for Electric Powerplant
Air Inlet
Gas-Turbine Combustion Chambers
Organic Vapor
Waste Heat Rejection at 100°F
Organic Liquid
"Bottoming-Cycle" Electric Generator (Output of 18,400 Kilowatts)
Organic Rankine Condenser
Organic Rankine Turbine and Gearbox
Organic Rankine Feedpump

CONCEPT OF CO-GENERATION

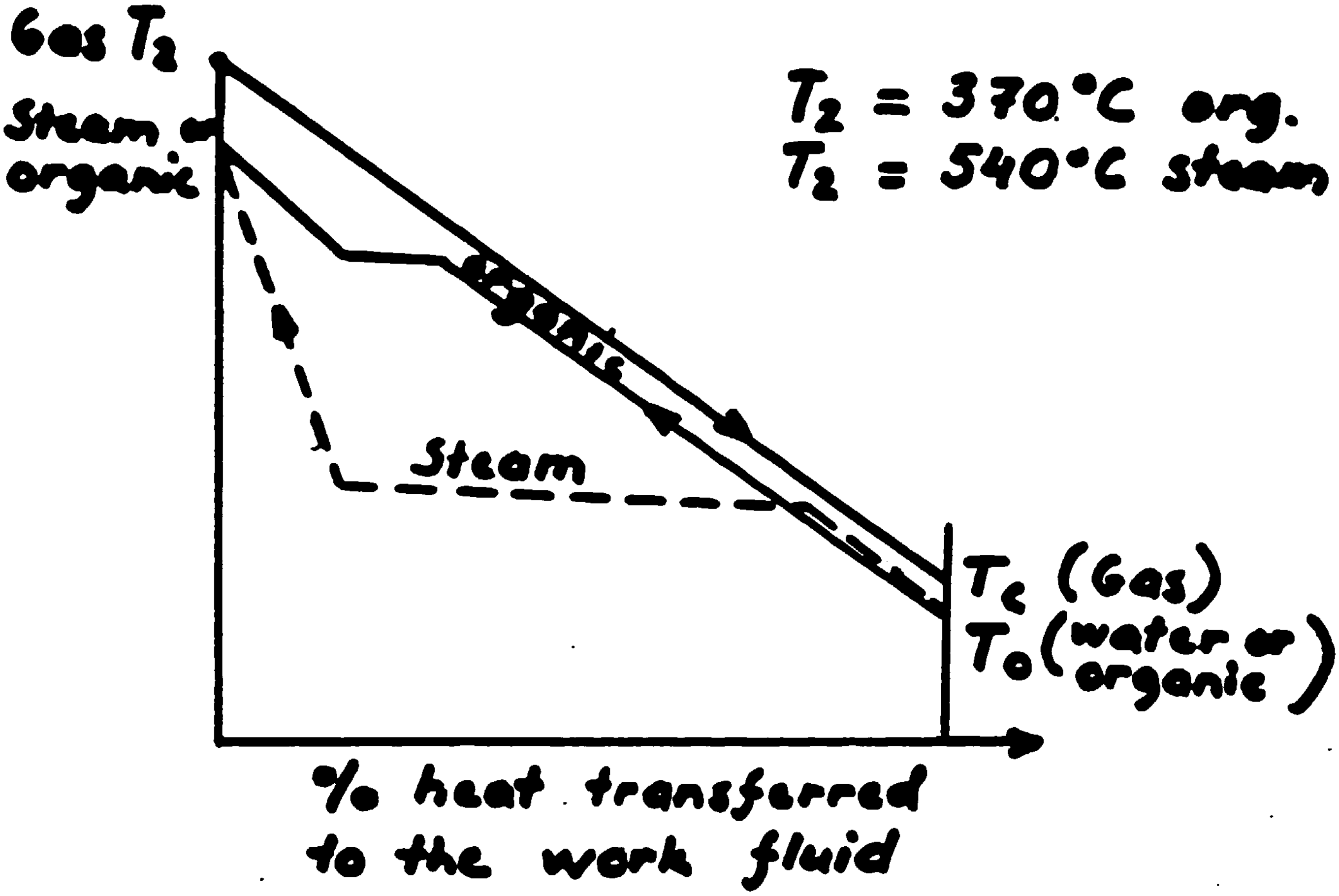


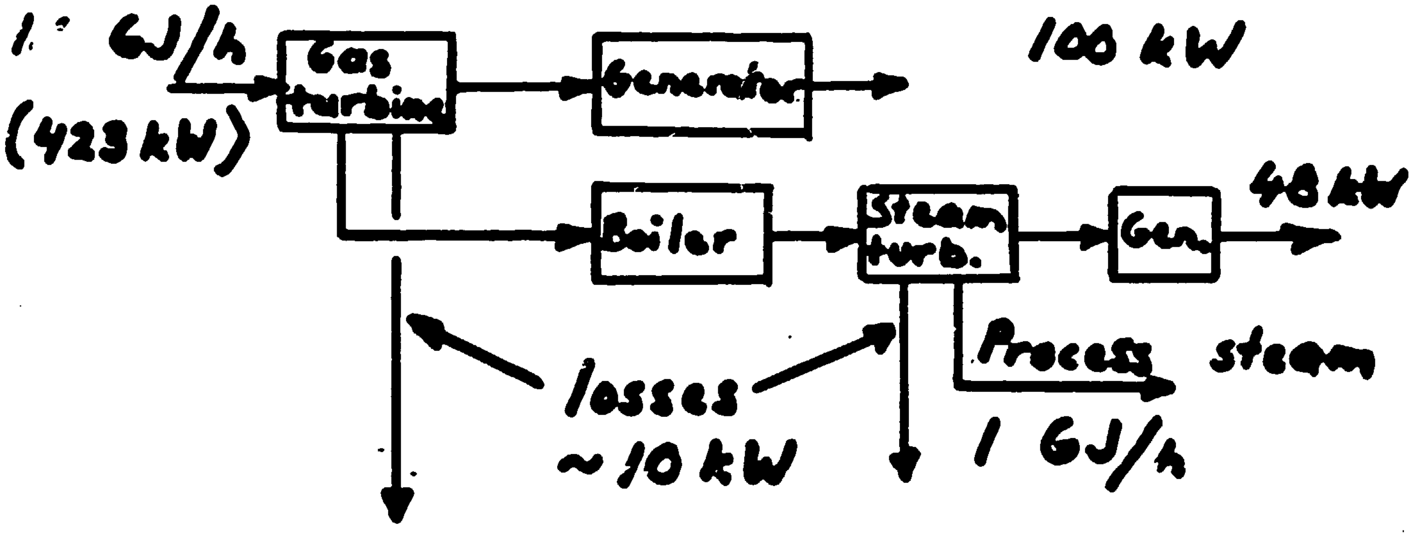
EXERGY ANALYSIS

UNDP/PSN
1985



ORGANIC/STEAM RANKINE CYCLE





UNDP / PSN

XXII GENERAL CHECKLIST FOR A HEAT RECOVERY SYSTEM

1- Location of sources and uses of heat

- composition
- flow rates
- temperatures (levels)
- contaminants
- operation hours
- operation cycles
- sizes of components
- energy (possible reduction)
- by-passes and recycles

2- Environment

- access
- structure
- obstructions between use and supply

3- Matching

- minimum distances eg piping
- reasonable uses for recovered heat
- removal of contaminants
- minimum outage due to installation
- usable temperature ranges

4- Recovery methods

- exchanger or recuperator
- insulation
- construction
- automation
- modes of operation
- optimization
- upgrading by a heat pump

XXII GENERAL CHECKLIST FOR A HEAT RECOVERY SYSTEM (Cont'd)

5- Financial

. layout heat recovery system
. estimate of system costs
. savings
. operation and maintenance
. financial ratios and decision process

6- Installation

. detailed drawings, purchase of equipment
. contracts
. start up
. performance checks

GAF03 (11/81)

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ENERGY PROJECT EVALUATION FORM

YEAR	1	2	3	4	5	6	7	8	9	10	TOTAL
SAVINGS											
OPERATION											
MAINTENANCE											
DEPRECIATION											
INVESTMENT											
START-UP (Outage)											
CASH FLOW											

PERFORMANCES :

- Simple payback
- Net payback
- Return on investment
- Average investment
- Internal rate of return

P Soininen

UNDP/ENPPI
Cairo
Egypt

ENERGY CONSERVATION
COMPUTER CONTROL FOR A DESTILLATION UNIT

March 13, 1985

I THE DESTILLATION PROCESS COMPUTER CONTROL

The inexpensive way to conserve energy is to raise the level of automation. The object is (figure) a destillation tower with :

1- Preheaters to heat input crude by pump arounds and product streams.
2- Desalters.
3- Furnaces where nearly 50% of oil evaporates before the destillation column.
4- Destillation column with:

- Overhead condensers
- top pump around utilizing bottom reboilers and cooling and power plant recycle water.
- Lower pump around to cool the middle part of the column exploiting crude and other pump arounds.
- 4 evaporation columns where the lightest part of the products is returned to the column.

The feed sp.w is 0,82....0.89. The quality of the feed varies.The products are:

- Gasoline
- Light gas oil
- Heavy gas oil
- Bottom product

The following product specs are kept valid

- The final point of gasoline destillation is dependent of the market situation and the crude.
- The solidification point is stabilized.
- The color of heavy gas oil is kept below a certain maximum limit such that it is good for feed to the cracking unit.

II THE OBJECTIVES OF BETTER AUTOMATION

The process analysis took 0,5 years.

Energy Optimization :

The specific energy consumption is reduced by maximizing the heat recovery to the crude. The load is distributed for parallel heaters such that the output temperatures are equal thus maximizing the heat transfer.

The feed was distributed for various furnaces such that specific demand combustion fuel/crude ton was equal. This minimizes the total fuel demand.

The middle part of the column must be cooled maximally by transferring heat from the bottom pump around to the crude. This reduces the heat loss to the cooling water in the top pump around.

The power plant recycle water can recover part of this heat loss or alternatively increasing the boiling of other bottom reboilers. These action yielded 8 - 9 % savings in the fuel feed / crude ton.

III MAXIMIZING THE DESTILLATION YIELD

The separation capacity is to be kept maximal in order to maximize the yields of products. This separation increases by reducing the partial pressures of hydrocarbons which effects on the proportional volatility and also by increased internal recycles of liquids and gases. This results in minimizing the pressure of the column The temperature of the feed is to be maximized to maximize the volatility. This is possible without risk of cooling by uniforming the outlet temperatures of various tube branches and stabilizing the temperature control of the furnaces by feed forward (fast approach).

III MAXIMIZING THE DESTILLATION YIELD (Cont'd)

The specs. of products are to be optimized such that more valuable product yields can be maximized. This also results local separation maximizing where price differences are significant. This is one reason for the maximum cooling of the central part of the column. The quality control minimizes the loss of products when the feed ion product specifications change.

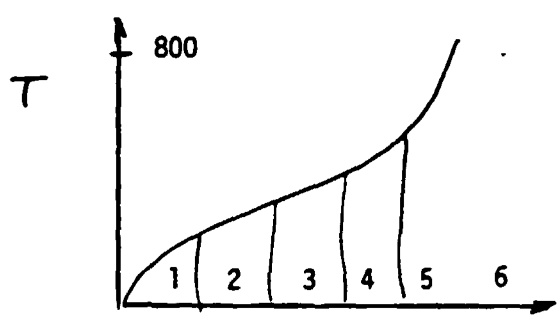
These action resulted in 1.5-2% increase of yield.

The analyzers exploited

- Color of heavy gas oil
- Solidification of gas.oil
- Gasoline final point

IV BALANCES AND QUALITY CONTROL

The TBF behaves as below



1 = Gas
2 = Naphtha
3 = Light g.o
4 = g. o.
5 = Heavy g.o.
6 = Bottom

An optimum criterium can be developed for yield when the unit prices and crude properties are known. This takes place on line. Energy and material balances are used.

IV BALANCES AND QUALITY CONTROL (Cont'd)

	THE CONTROLLED QUANTITY	MANIPULATED QUANTITIES
1	Gasoline TBF	Output of naphtha and the top temperature
2	Naphtha/light gas oil TBF	Naphtha and light gas outputs
3	Light gas oil/gas oil TBF	Bottom pump around cooling power and light and normal gas oil outputs
4	Gas oil/heavy gas oil TBF	Outputs of these products

METHODS

The true boiling point concept was selected because specs. closely corrolate with this.

The quality analyzers have the disadvantage of big delays. These are also apt to fouling and defects.

The system contains

- 77 analog inputs
- 60 digital inputs (T-sensors)
- 36 pulse outputs

The algorithms were

- PID
- non linear PID
- feed forward
- dynamic compensation
- constrained control

The feed forward fastens the process operations. The nonlinear algorithm utilized a amplification proportional to feed back difference (set-observed value). This stabilizes the levels of buffer tanks.

IV BALANCED AND QUALITY CONTROL (Cont'd)

The constrained control maximizes or minimizes the control action (flooding, foaming, cavitation, full valve opening) without violating the constraint.

The unit must be operational when the computer fails. Therefore the computer gives guide values to the controllers only.

This principle avoids the decoupling effect on other TBFs.

The top temperature is a manipulated variable. The light gas oil on the other hand depends on the bottom around cooling power and thus it divides the column into two parts. The dynamics of the column will be taken into account such that the flows are stable before the outputs are changed.

The analyzers slowly change the set points of TBFs (delays of overhead tank and evaporation column of gas oil are observed).

THE FOLLOWING PERFORMANCE WAS OBTAINED

1 The pressure of the column is now 75 KP instead of 150.

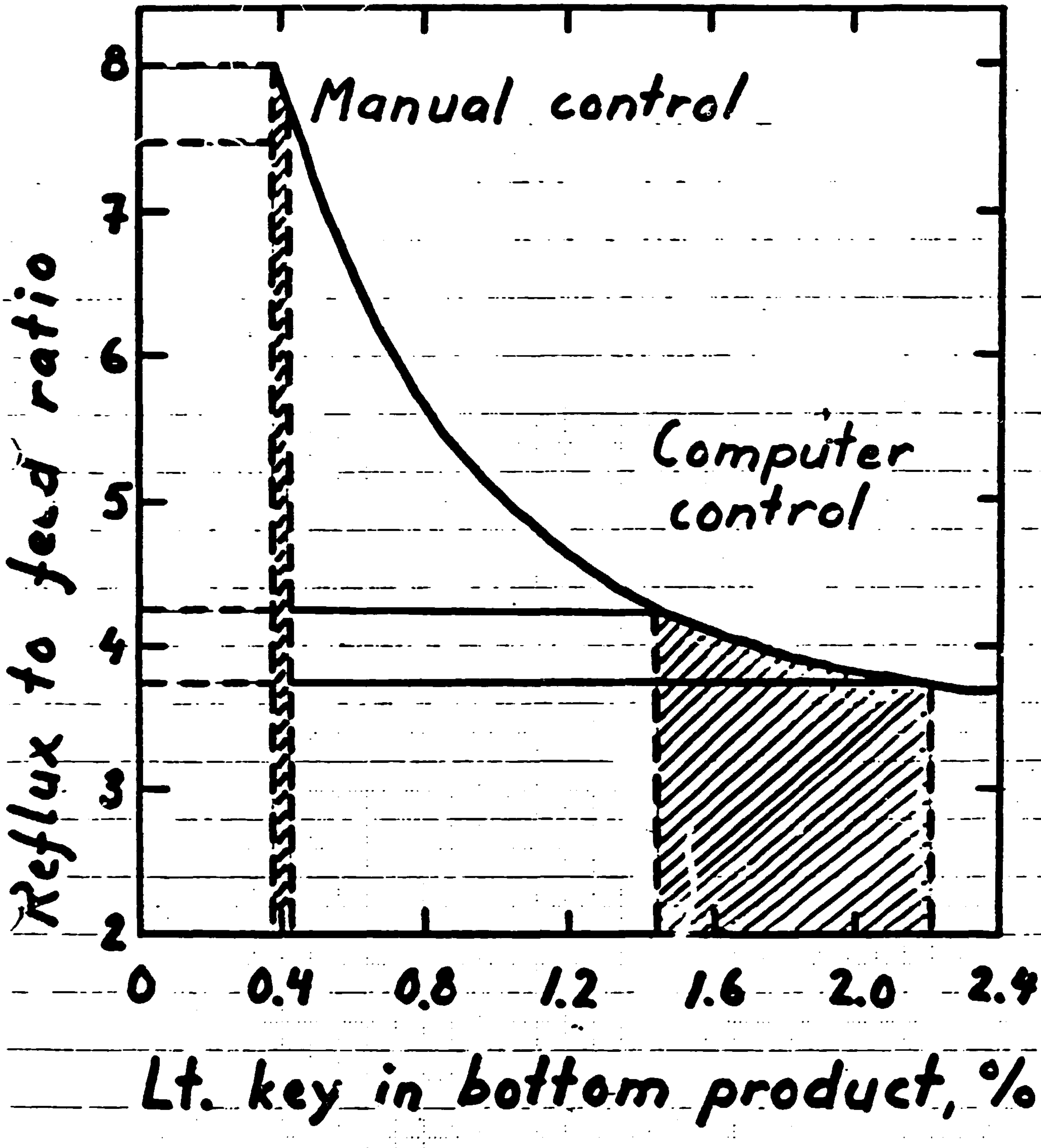
2 The temperature differences were within 2.5....33°C instead of 5... 6°C in the furnace outputs.

3 The std. deviation of gasoline final point is 1.5°C.

4 The solidification point of gas oil 1.3°C respectively. (std. dev.)

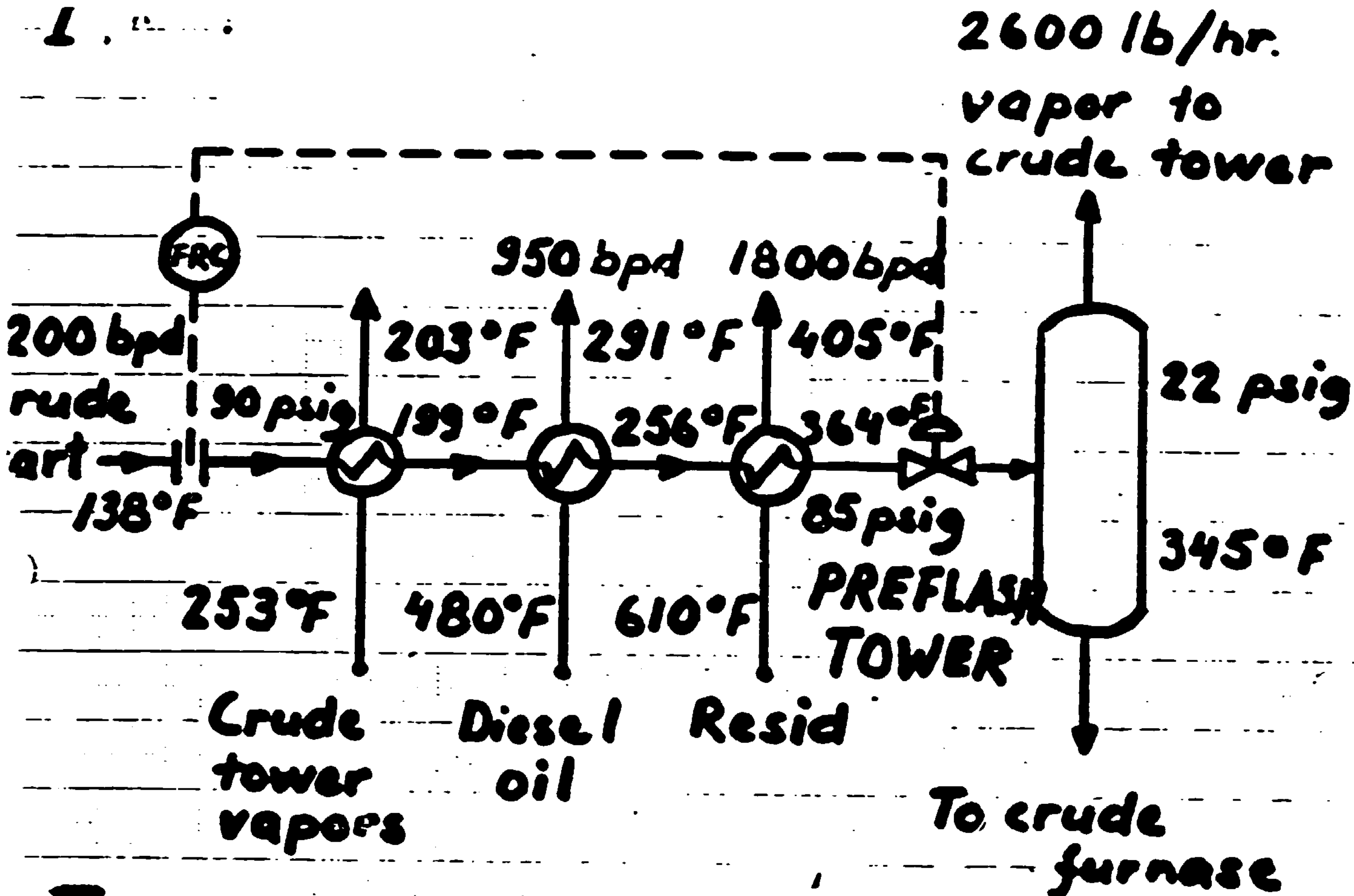
5 Radical changes get uniformed within one shift instead of several days before,

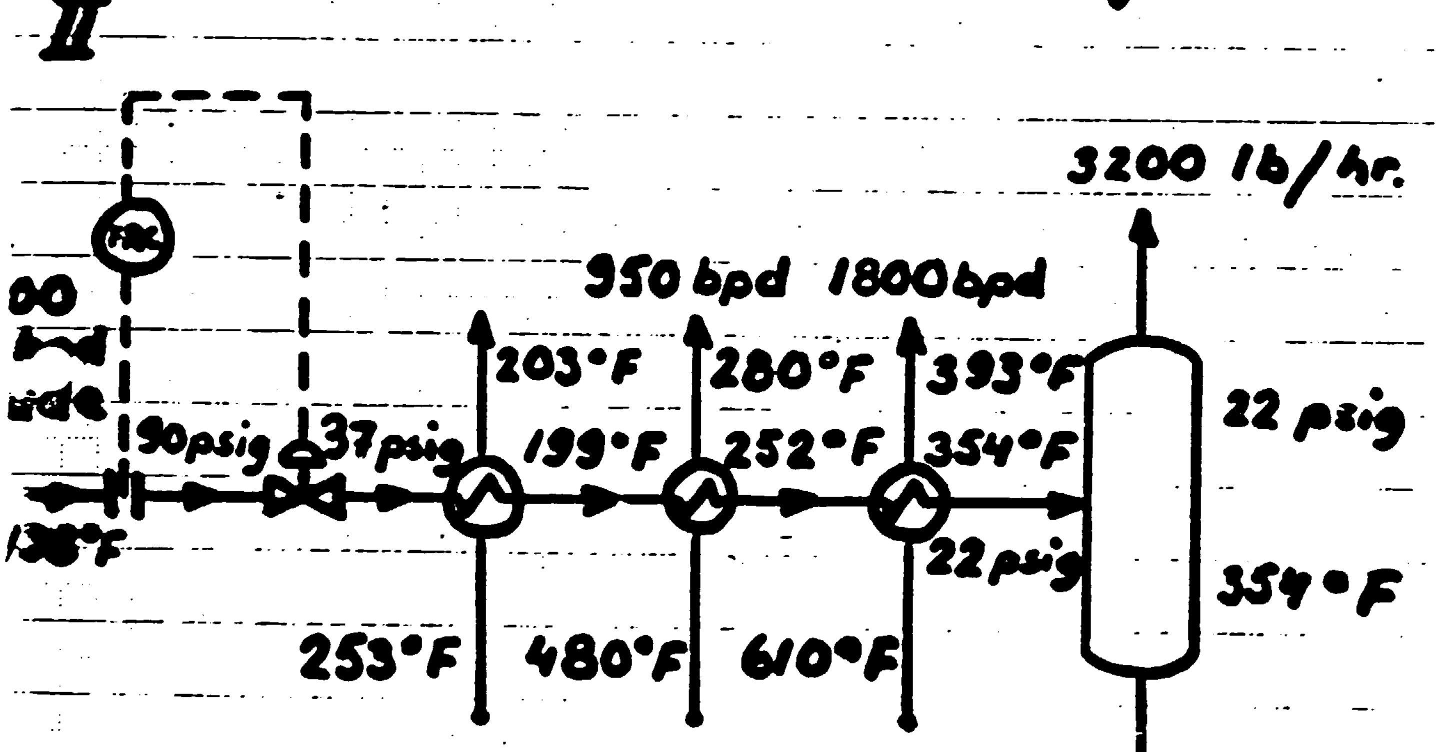
GA101 (1186)



Manual control
Computer control
Reflux to feed ratio
8
7
6
5
4
3
2
0
0.4
0.8
1.2
1.6
2.0
2.4
Lt. key in bottom product, %

UNDP/PSH/85



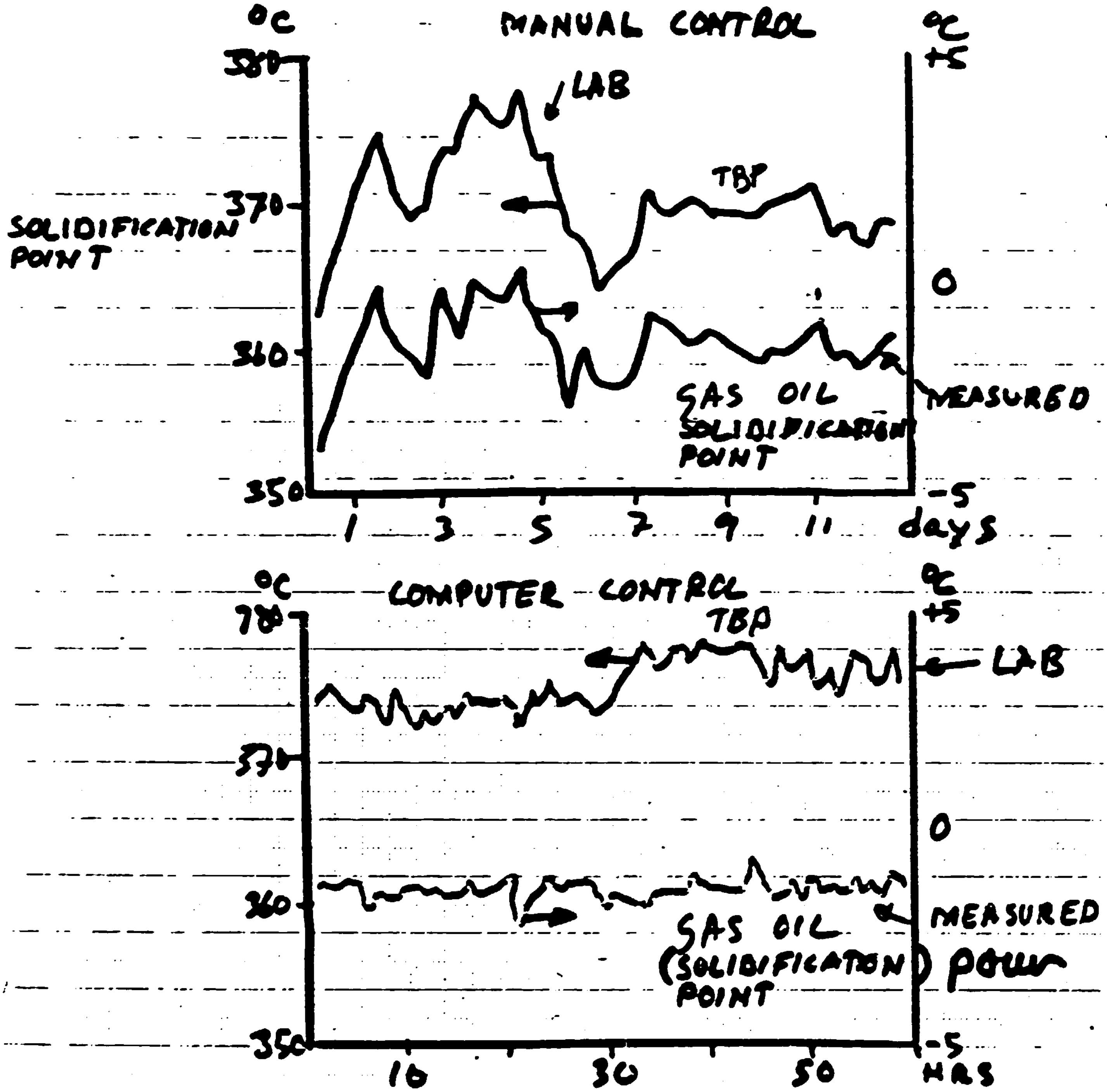


Relocation of control valve

→ reduced temp. → energy conservation

UNDP/PSH/PS

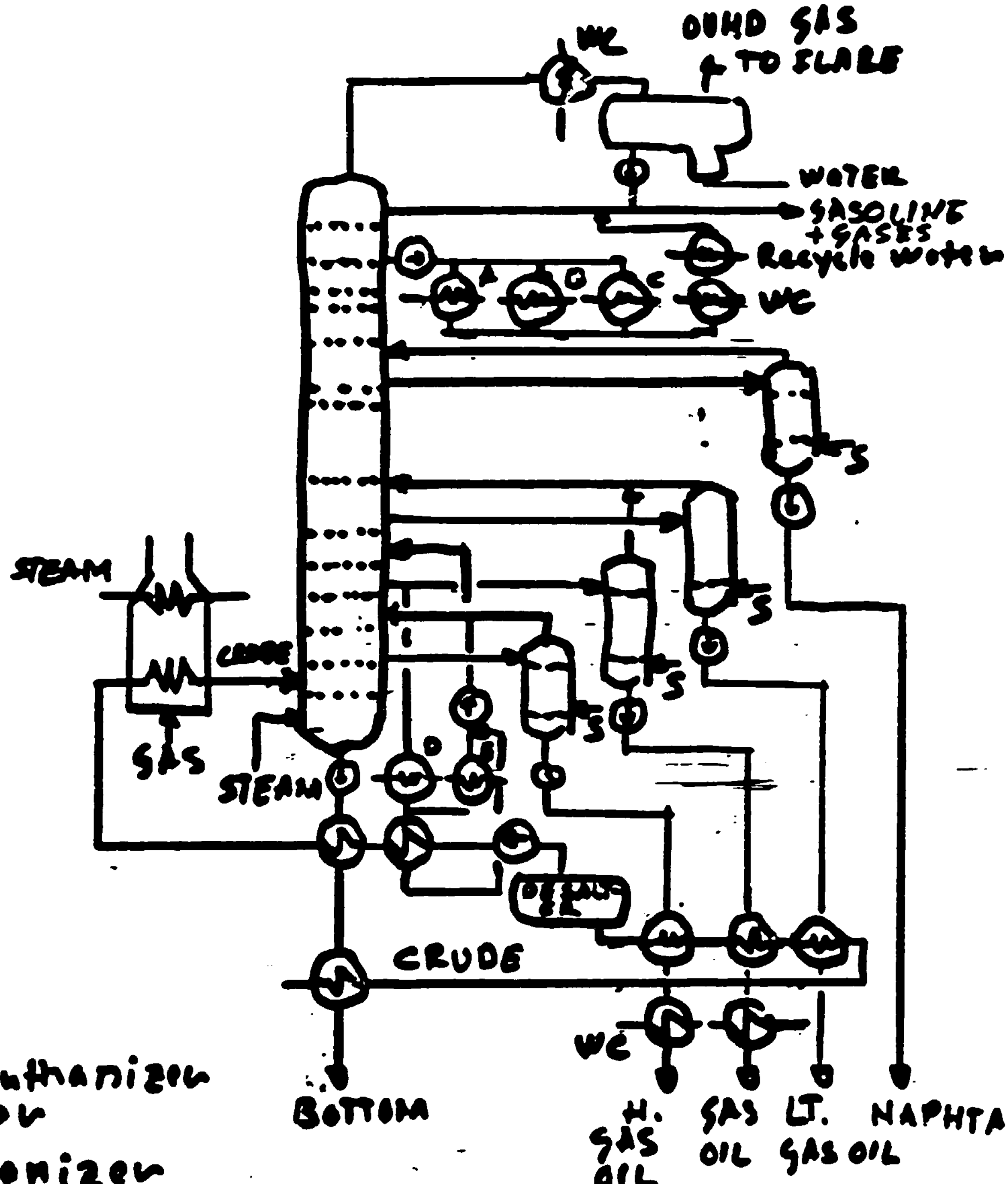
CORRELATION OF SOLIDIFICATION AND TBP POINTS



GAS OIL SOLIDIFICATION POINT

UNDP/PSN
1985

PROCESS DIAGRAM OF THE EX. UNIT



1 Deisopenthanizer reboiler

3 Depropenizer reboiler

C Deethanizer heater

D Debutanizer reboiler

E Depenthanizer reboiler

UNDP/PSN
1985

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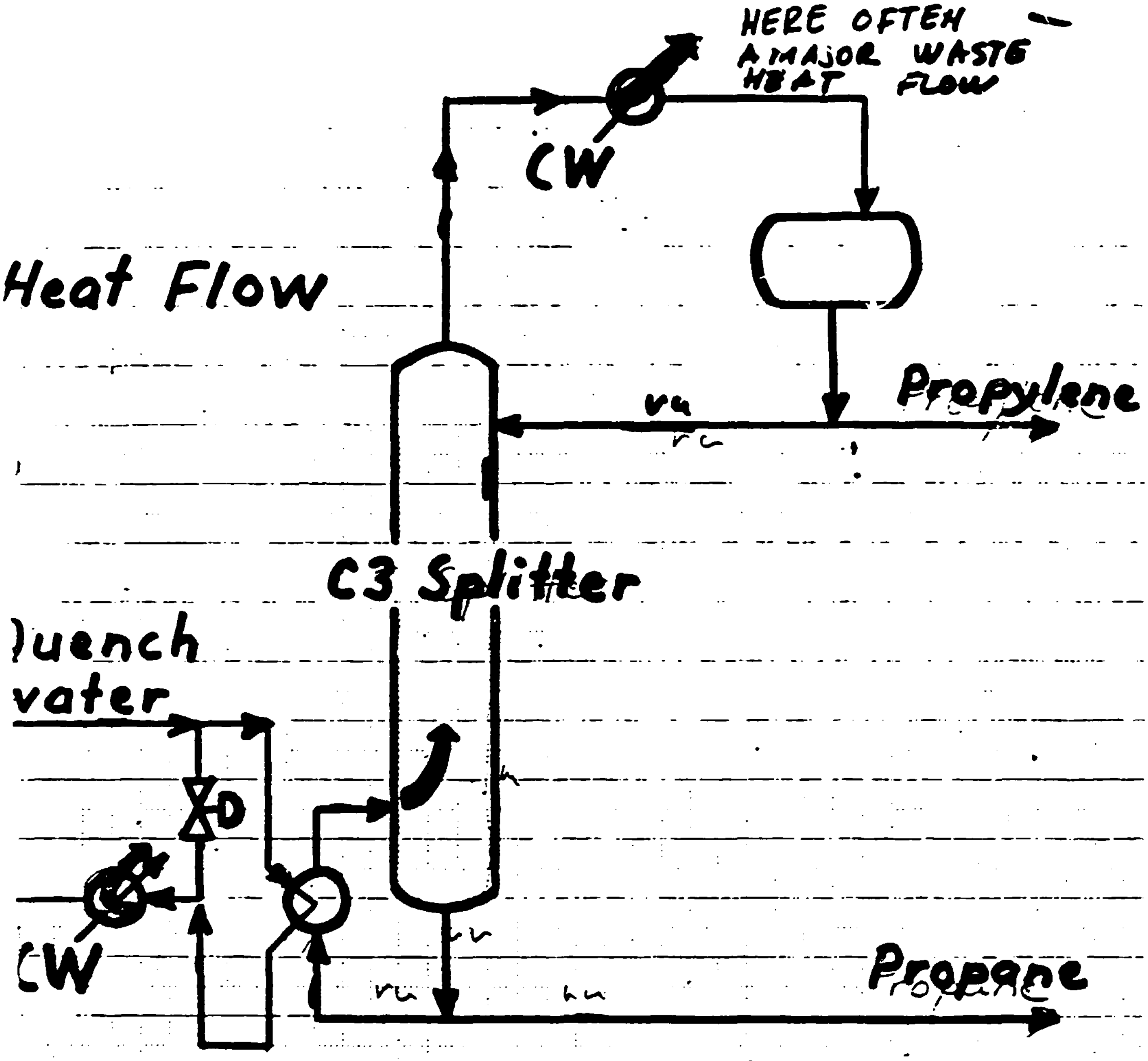
Heat Flow



UNDP/PSN/85
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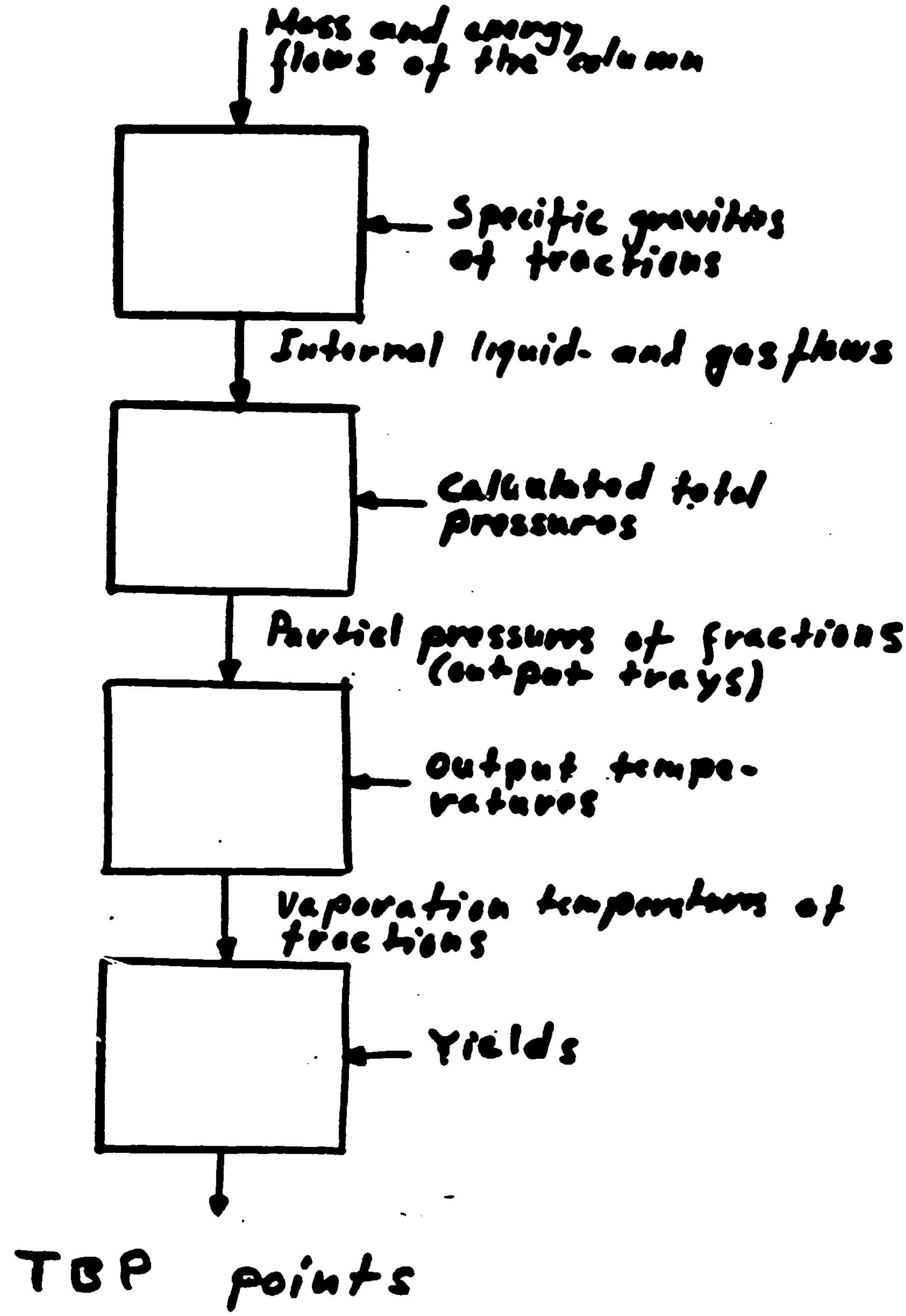
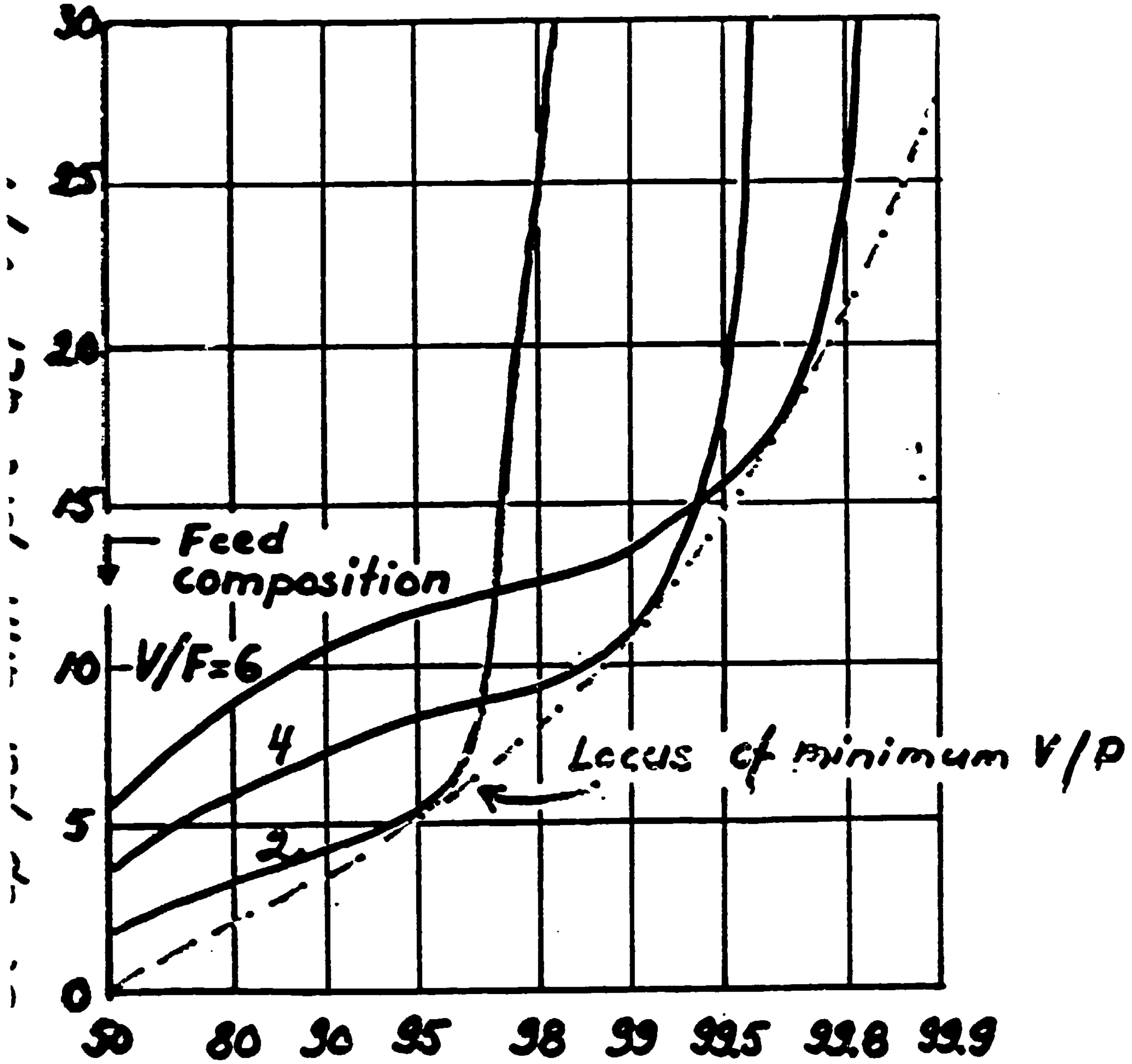


FACTORS INCLUDED FOR CALCULATION OF TBP POINTS

UNDP/PSN
1985

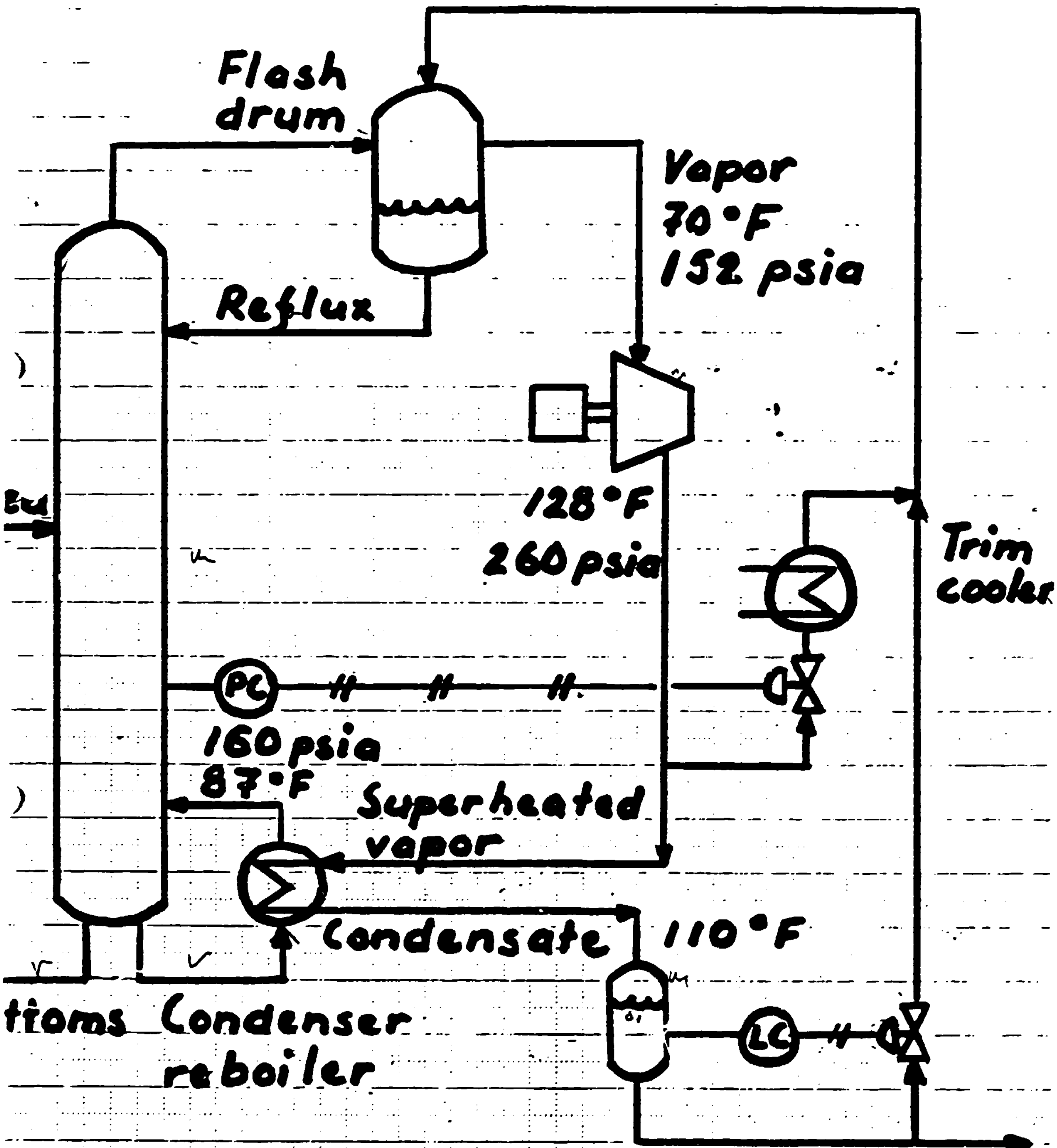


V= vapor
P= product

Purity, percent

Optimization with tolerable specs

UNEP/FSM/85



EXPLOITING HEAT PUMPS TO SEPARATE PRODUCT WITH CLOSE BOILING POINTS

UNDP/PSN/85
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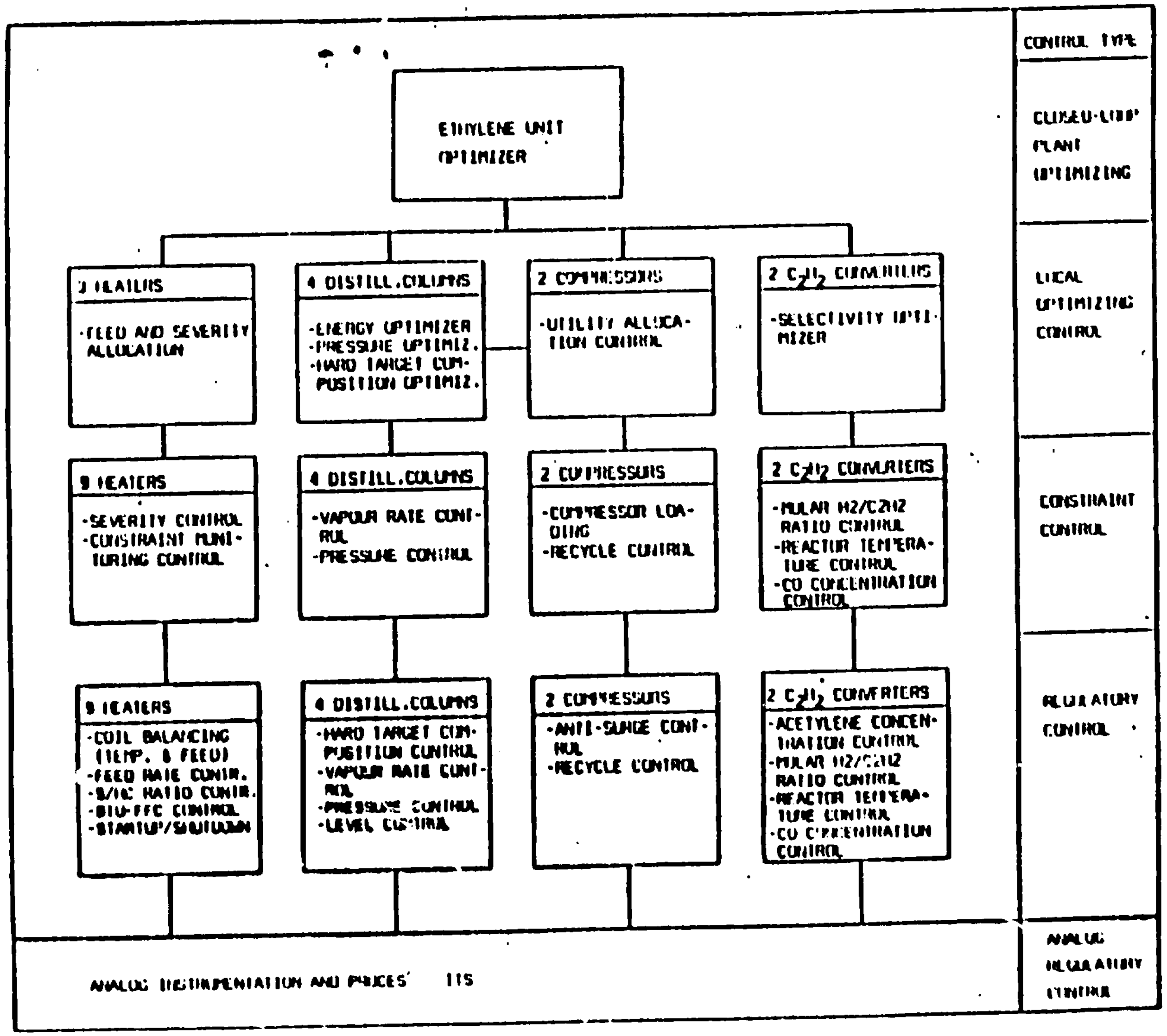
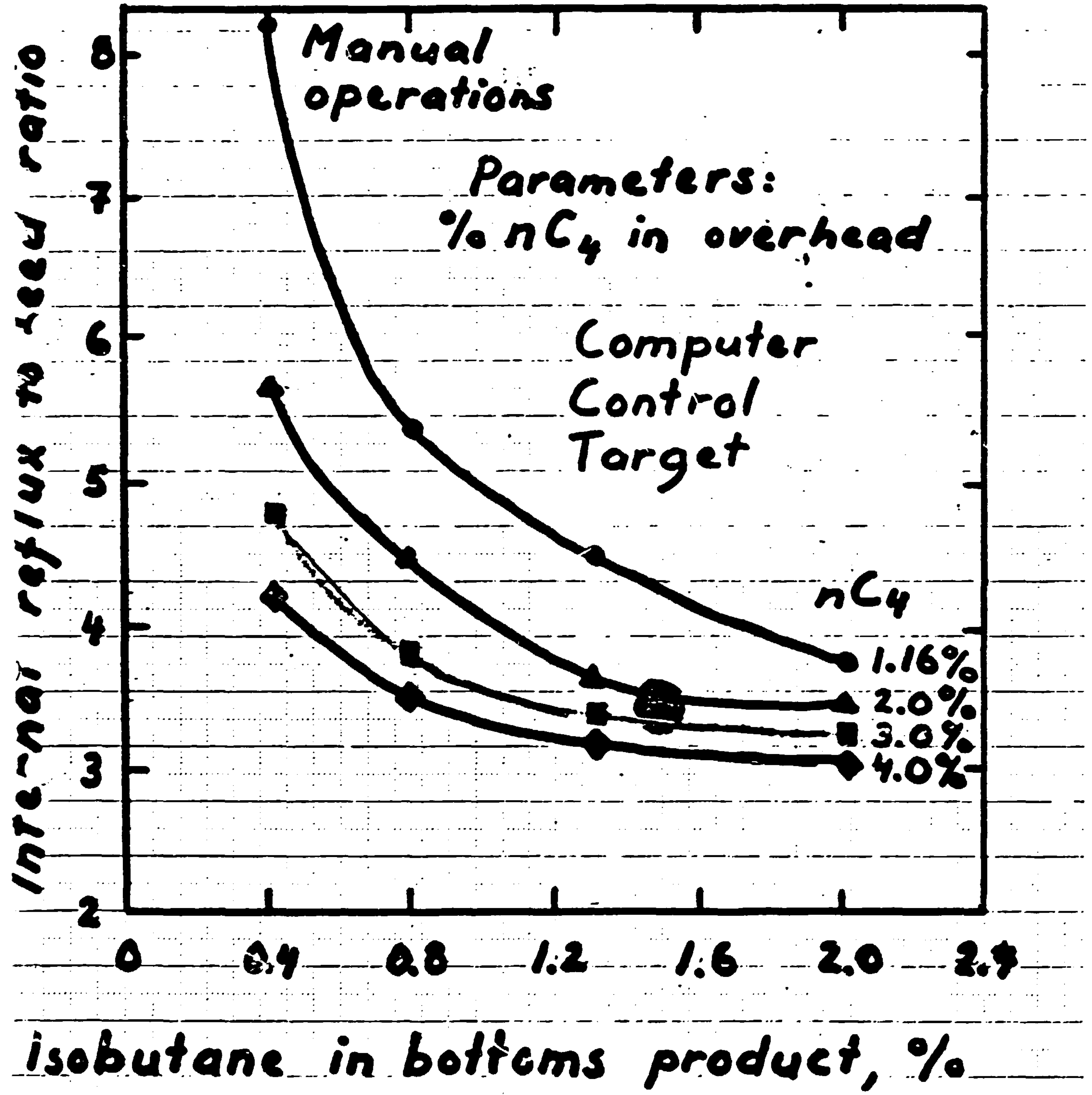
NESTE FINLAND

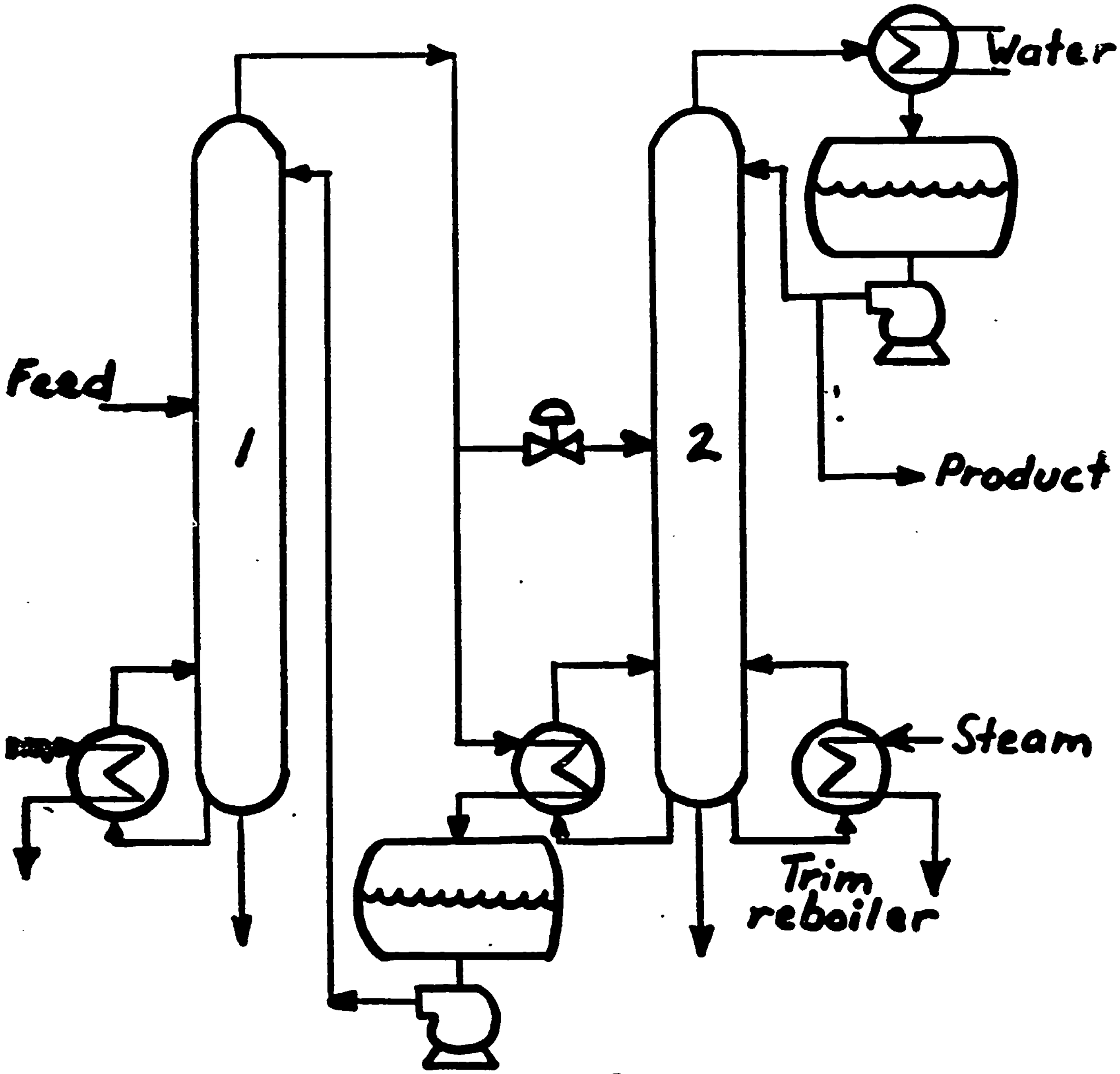
UNDP/PSY 1985 122




Manual operations
Parameters: % nC_4 in overhead
Computer Control Target
nC_4
1.16%
2.0%
3.0%
4.0%
Internal reflux to feed ratio
8
7
6
5
4
3
2
0
0.4
0.8
1.2
1.6
2.0
2.4
isobutane in bottoms product, %

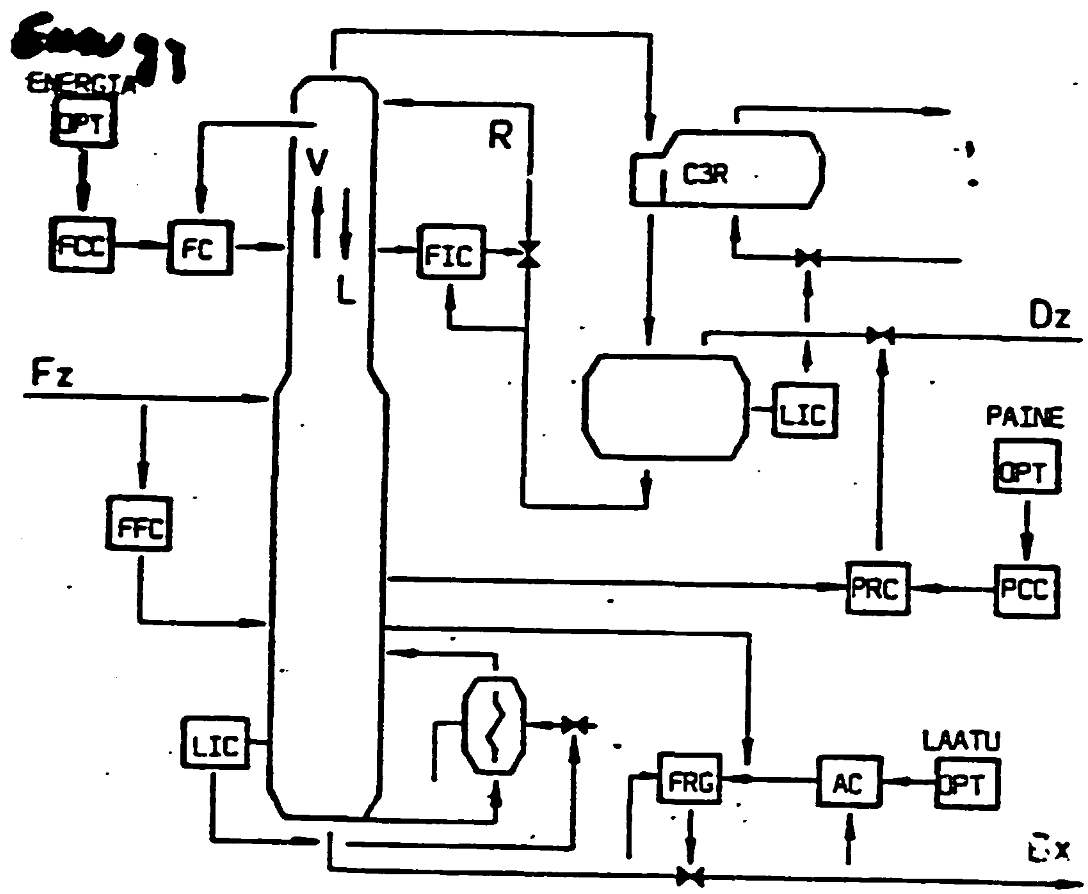
UNDP/PSH/85

by combining reboiling and condensing



UNDP/PSN/85

n.s



KUVA 5. YLEISEN KOLONNIN SÄÄTÖ

COLUMN CONTROL

NESTE
FINLAND
1985

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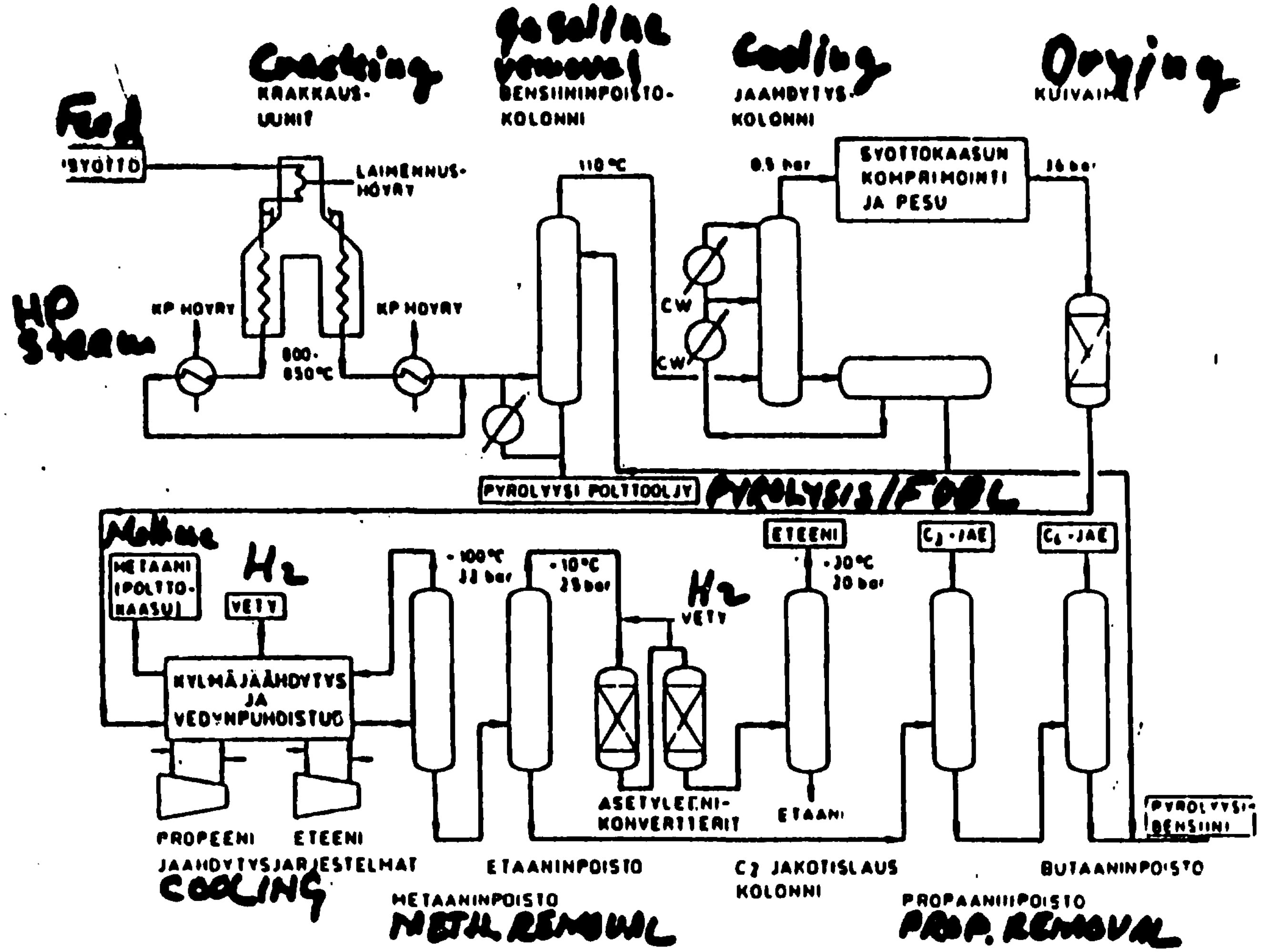

KUVA 1 ETEENIYKSIKÖN YKSINKERTAISTETTU VIRTAUSKAAVIO

SIMPLIFIED ETHENE PLANT FLOW DIAGRAM

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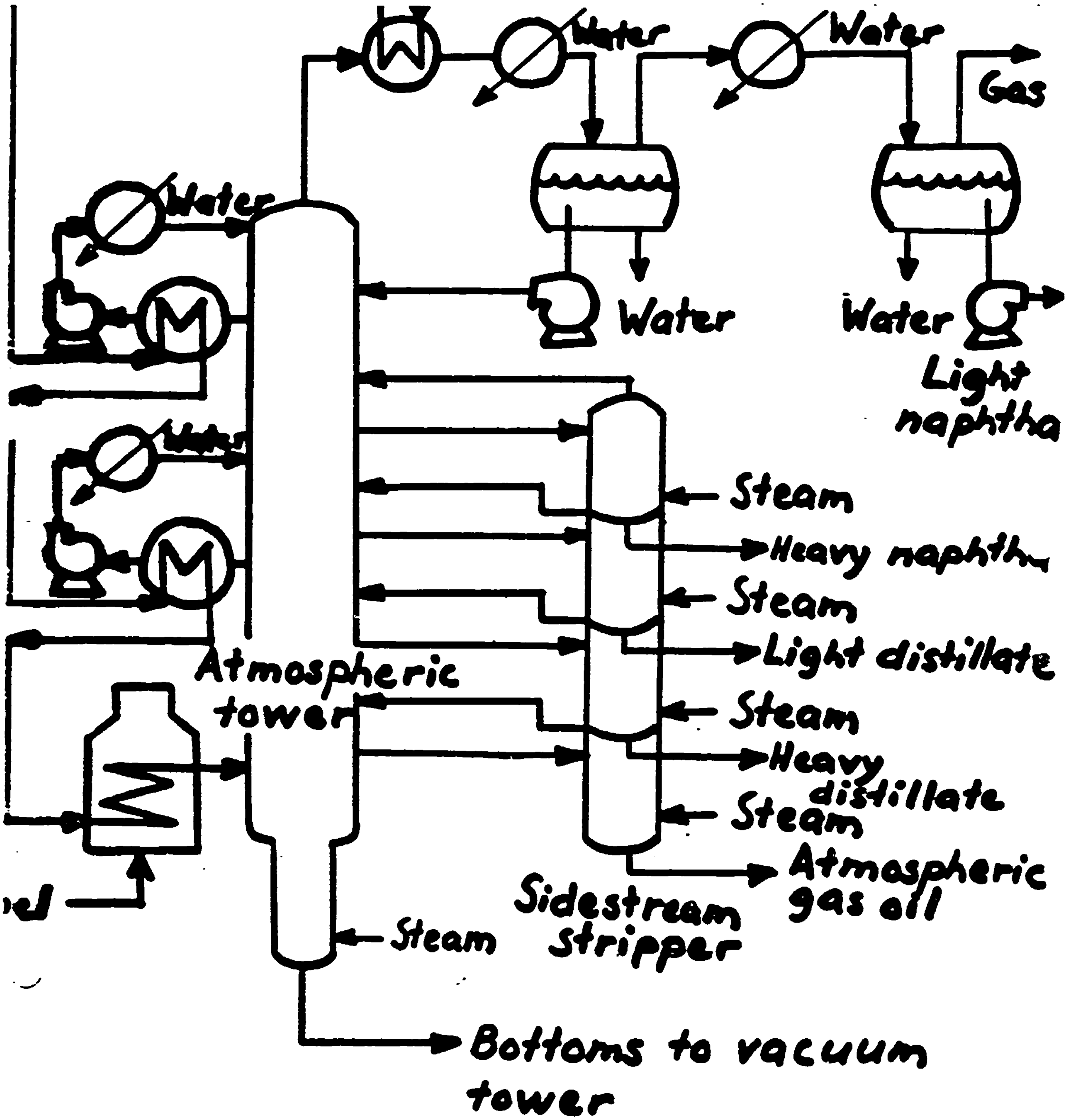
NESTE FINLAND
UNDP/LASK
128



All the heat used in crude-oil distillation enters with the feed.

UNIDO/ISED/85

Enppi

P Soininen

UNDP/ENPPI
Cairo
Egypt

DESALINATION PLANT IN SUEZ
ENERGY CONSERVATION

March 31, 198

The feed water quality (Suez Power Station) used to be 700 ppm of TDS (total d olved solids). As I visited the meter indicated less than 1 TDS. The production was about 20 m^3/hr. It evaporates directly the cooling water of the power statior in three effects.

There was some discrepancy in manual sampling and metering results, but the reas was that a pure iron tube was used in the sampling system which naturally dissove Fe ions. The cost of this plant was 0.8....1 M$ and the specific demand is 6..... KWhe/m^3. An inverter driven pump was used which has improved the reliability of operation and decreased the specific electricity demand. The plant is under comm ioning. Reference persons are Mr. Mohamed Sayed Ibrahim or Abdel Monein if addit al information is needed. The product water meets very high standards and is good for power generation. The good quality of water is energy conservation, because

- reduced deposits maintain the capacity of heaters.
- better availability of heat exchangers.
- exploits very low quality heat (>10°C above environmental temperature).
- Operation and maintenance is easy, the plant operates unmanned.

The Suez refinery. , is in the next site. This concept is good for that, too. The same merits will be obtained. This concept is worth consideration at refineries next to the sea. In this particular case, the water of the Nile will be replaced.

R Duvall
T Hussein
K M Khaled
F M Youssef
M Wahby

P Soininen

GA(03 (1181)

Enppi

P Soininen

UNDP/ENPPI Cairo Egypt	O_2-ANALYZER ENERGY CONSERVATION	April 7, 1985

ZrO_2 - sensor has turned out to be by far the best analyzer to detect the O_2-content at flue gases. The following points are to be considered.

- Leak proof installation.
- Several sensors to be insured of the O_2-content.

The advantages are

- Fast response.
- Easy mounting with little auxiliaries.
- A combustion model or flame-power model is possible.
- Reduced $H_2 SO_4$.
- Reduced pollution.
- Energy conservation due to optimal O_2-content.
- Complete combustion.
- Inexpensive.

The analyzer can directly control the air flow to the furnace. A feed forward with slight feedback is good to control the fuel flow since for changing situations the reaction is fast. There is a tentative flare power model included in the seminar material. There are such many examples of this approach that it can be recommended to direct flame control even in case of difficult fuels. A diagram of the analyzer is also included in the seminar material. ENPPI's present approach is only to monitor the O_2-content. Such vendors like Bailey, Kent or Combustion Engineering supply feasible analyzers. The flame power model requires some level of computerizing.

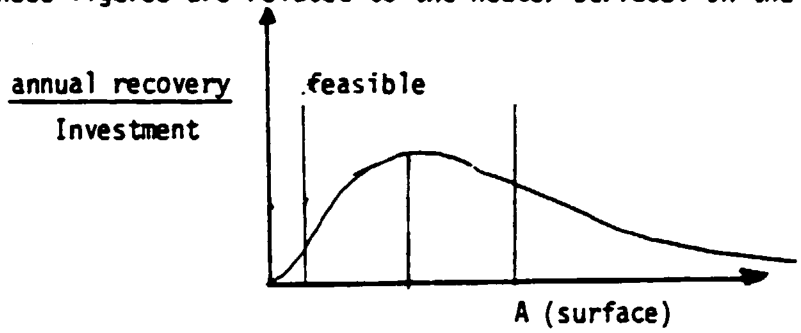
M El-Nagdy	A Sary
M El-Sayed	F M Youssef
T Hussein	M Wahby
K M Khaled	
A Soliman	P Soininen

GA103 (8/84)

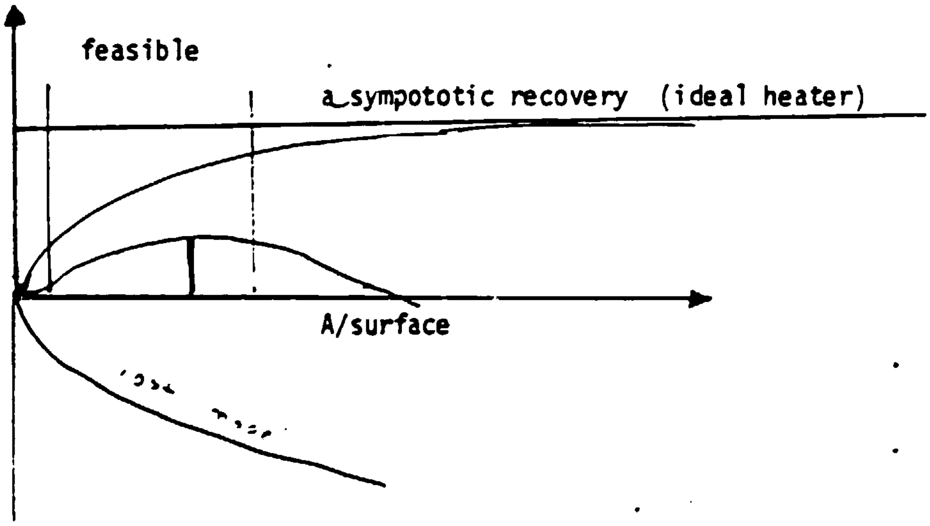
There are a number of methods to optimize the heater size, e.g.:

- Return of investment i.e. the manual recovery is compared with the investmer and this ratio can be maximized.
- The present value of the lifetime heat recovery is calculated and summed wi: the investment, operation and maintenance costs (present value) and this fig is minimized.

Both of these figures are related to the heater surface. In the first case :



In the second case :



The cost model is chosen, e.g. logarithmic and experimental data is to be fitted statistically and it can be updated with inflation rate and when new information obtained.

This approach does not minimize the heater surface. It depends also on :

- Internal interest rate.
- Estimated lifetime.
- Cost of fuel.
- Constraints that may exist, i.e. the feasible area.

In case of constraints, the optimum exists in between or on either extreme side. All of these are to be checked. To computerize this model is not difficult. I.e. the necessary parameters are fed to the computer and an optional heat recovery is obtained, which on the other hand, is related to the surface. It can be a tinned tube and the flow can be turbulant to improve the heat transfer. If the optimal heat recovery is only calculated, it is a separate problem to dimension the heater. It is advised to handle these problems separately because the surface of the heater depends heavily on :

- Type
- Turbulance or flow conditions.
- Liquids or gases.
- Heater materials.

The recovery optimization gives an initial value to the heater sizing and therefore these things can be combined although the phases are handled separately. It is suggested that this approach will be selected at Enppi, unless it exists. Pumping can be integrated in this procedure , if desired.

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In practice for monitoring purposes :

- Flows
- Temperatures
- Pressure differences

are enough to see the heater performance. This can be completed with special metering technique like infra red to spot local deposits which has been successfully applied, as reported.

Because energy has also quality in addition to quantity, therefore this exergy (available energy) efficiency has been introduced.

$$E = h = h - h_o - T_o (S - S_o)$$

0 = environment
h = specific enthalpy
s = " entropy

There are several alternatives to calculate this heater performance index, e.g. (computer programs are prepared to illustrate these figures).

- (1) $\dfrac{\sum E \text{ out}}{\sum E \text{ in}}$
- (2) $\dfrac{\sum E \text{ increase}}{\sum E \text{ decrease}}$

(1) and (2): Indicate the deterioration of the quality of energy in the process in question, i.e. availability decreases

- (3) LMTD (logarithmic mean temp. diff.)
- (4) $\dfrac{\text{pressure losses}}{\text{flow}}$
- (5) $\dfrac{\text{annual heat recovery}}{\text{(investment + operation + maintenance)}}$ i.e. recycle time
- (6) availability = $\dfrac{\text{uptime}}{\text{annual operational time}}$
- (7) $\dfrac{\text{Number of rundowns}}{\text{Year}}$

- (8) $\frac{\text{heat transferred}}{\text{nominal capacity}}$

- (9) $\frac{\text{lifetime heat recovery (present value)}}{\text{(investment + maintenance + operation)present value}}$

- (10) MTDF = meantime between failures

- (11) quality of in/output flows (H_2O e.g)

Figures 1 and 2 denote to the physical performance and it is 1 in case of an ideal heater. It means that no exergy losses occur,in other words, the transferred energy is equally reusable for other purposes. Because the heat transfer is as follows :

$$(12) \quad Q = k\ A\ \Delta\ t_{LMTD}$$

the ideal heat transfer means a small LMTD and a large surface. Economical cosntrai ts limit the increase of heating surface. Therefore, indices 5 and 9 are optimized to find out practical solutions for the heaters.

The indices 1, 2, 5 and 9 also provide the advantage of expanding the balance limit Pumping can be integrated since heat transfer can be improved by recycling and increasing the pumping speed, which is in general not an economic way to promote the heating capacity. Such advantages may be obtained like reduced heater or furnac size, ie. sometimes it is worth consideration. The simple reason is that pumping costs tend to increase more rapidly than those of a greater heater. Constraints lik a desired outlet temperature are always to be included in the optimization procedu It is essential to understand the concepts

- design value
- initial value
- real value.

Comparisons of these values for the same quantity makes possible conclusions, e.g to start sooting or cleaning, possible outage, etc..

For oil heaters (liquid one phase), the specific heat can be approximated as follo

- (10) cp = 3,856 - 2,345.S + 0,0023 t/^{o}C 97.9kg/ ^{3}

- (11) cp = 2,897 - 1,293 + 0,0023 t/^{o}C $\frac{MJ}{ton^{o}C}$ " < " "

If the available energy is referred to the environmental temperature and condition one can calculate it as follows

- (13) $$\int_{T_o}^{T} c_p dt - T_o \int_{T_o}^{T} \frac{Cp}{T}$$

and an explicit efficiency is obtained for formulas 1 and 2. In case of water a similar approximation can be made and it follows

- (14) $E = Cpw \; (T - T_o \; (1t \log (\frac{T}{T_o}))$

This approach is relatively easy to computerize. The alternative approach is to tabulate the entropies within a feasible region and more accurate results can be obtained.

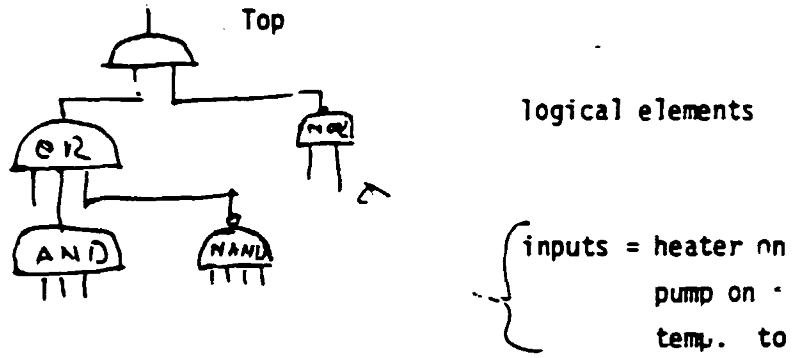
The economic performance differs in the regard that if heat recovery replaces fuel it is equally of value independent on the temperature (i.e energy quality).

The availability figures and the number of shutdowns give another approach. If an outage occurs, the latent heat is lost and energy is wasted. An outage day is wort much if it is due to a heater. Therefore, the reliability is justified in energy conservation. The method is to specify e.g this figure.

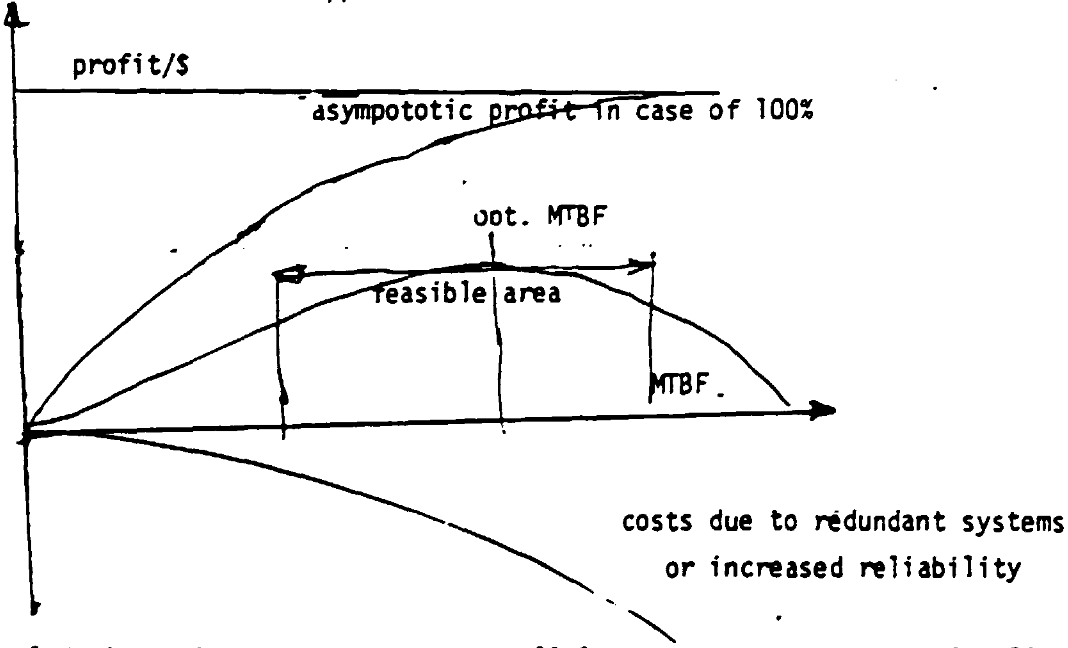
- (15) MTDT = mean timebetween failures

If this figure is known for each component, the total MTBF can be estimated by construction of fault trees which give the MTBF for the top incident.

E.g.



Knowing the MTBFs of each item and the logical relations necessary that the whole system works the total MTBF can be obtained. Simple cases can be calculated explicitly but plants like refineries can be estimated only by simulation. Because outage costs a lot also increasing the reliability by redundant systems, therefore an optimum criterium can be developped.



In practical design this means bypasses, parallel heaters or pumps, e.g 3 x 50% steam driven pump drives. An outage results in lost latent heat and production.

NA

If phase changes occur, the evaporation heat for hydrocarbons can be evaluated

$$- (16) \quad L = \frac{1}{S} \, (251.5 - 0.3768 \; t/{}^{o}C) \quad \frac{MJ}{ton}$$

The corresponding values for water are generally known. If the water contains impu ties or salt, this has an effect on specific heats and evaporation properties. The exist extensive tables and approximate formulas for th4 properties of water which be exploited when computerizing the efficiency calculations. When the phase change occurs, the temperature is constant which in fact simplifies the exergy calculatic

If only cooling is the objective and the removed heat is of low quality, the effic ncy is estimated differently. The availability figures can be applied. The perform is simply cost minimization for the desired performance. There are two components:

- pumping or blowing
- cooler

Aircoolers have the advantages of low cost and good corrosion resistance. There a also reported examples that the air is fed to the furnace as combustion air (Kello Houston/USA) to conserve energy in which case the optimization is like heaters. He recovered in the cooling process is sometimes useful. There are examples that the heat in the compression process can be used for reboiling purposes.

If this exergy is well maintained and the cascading is correct, the makeup fuel a cooling need decreases yielding

- energy savings
- investment savings (furnaces, coolers)

A performance decrease of heaters causes immediate demand of fuel. The designers ca influence on that there will exist the option of performance monitoring when the plant is operational. It means in practice:

- existance of necessary measuring pockets
  - . flows
  - . T-sensors
  - . P-sensors

- possibly installed sensors.
- big heaters may deserve a permanent performance monitoring system (microprocessor) when special instruments can be connected like H_2O analyzer or chromatographs

The minimum action is that this option exists and it is a question of costs how far it is proceeded in this respect. A general trend is that these kinds of devices tenc to be less expensive and therefore their justification increases.

When optimizing efficiencies, one must not neglect safety and availability. There are examples that efficiency increase has resulted in less availability and the net result has been negative (Stal-Laval counter rotating radial turbines a classical example). These demands set preconditions or constraints for the optimization.

It is noteworthy that there is no unique performance index. These figures complemen each other and new ones can and should be developped depending on the objective of the heater or process equipment.

The performance figures must be interpreted correctly, else they are of little valu Also simplification is one target as in case of heaters, the pressure and temperatu differences in many situations give the sufficient information.

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GAR03 (8/84)

Enppi

P Soininen

UNDP/ENPPI Cairo Egypt	DEW POINT OF H_2SO_4 ENERGY CONSERVATION	March 31, 1985

The outlet temperatures of the flue gas depends on the following factors :

- Sulphur content of the fuel.
- Material of the heater (each has merits and drawbacks).
  . Stainless steel AISI316.
  . Enamelling.
  . Glass.
  . Cast iron.
  . Titanium or something like that.
- O_2 content of this flue gas since the absence of O_2 inhibits H_2SO_4 formation. A good control contributes this.

200.....190°C is a safe temperature level. Very low temperatures have been reported too. Power stations using sulphuric fuel apply 140°C. There is no unique answer for this final outlet temperature. The case has to be studied individually performing a ROI analysis.
This is such an important question that may be ENPPI's experts can visit selected refineries or/and air preheater manufacturers to solve this problem. The economic values are of that order that working for this question is not wasting efforts. The results can be applied outside petrochemical industry, since there is a number of furnaces in Egypt burning sulphuric fuel.

The transient situations are dangerous. E.g. starting the furnace by gas not containing S is one alternative to avoid this condensation.

My proposal is the detailed study on this question. It is still under discussion worldwide since this problem has become acute lately. It can be suggested for the UNDP to finance this study (?). The Sulzer book probably gives hints on the materi to construct the air preheater.

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GA/01 (1084)

NA

BASIC DEMANDS AND THINGS TO BE CHECKED

Steam requirements.

Electricity requirements.

Feedwater quality and supply requirements (deionating).

Cooling requirements (tower / condenser).

Connection to the national network.

Fuel quality (analysis organic, inorganic).

Steam load (variations).

Steam headers (340, 14 bar)
(180, 4 bar)
(... ....)

How to sell surplus electricity when necessary.

Capacity demand:

- Own requirements.
- External supply.
- External delivery.
- Alternative steam supplies.

Extra fuel needed to upgrade the steam 520°C, 100....180 bar.

Turbine types = bleeding, back pressure, condensing } combination

. action }
. reaction }

Piping refinery ◄-----► power station

Number of turbines.

Number of boilers.

Operation modes = steady, variable (how large variations).

Option for a gas turbine.

Added cooling need (condensor).

Boiler type = drum
once through
forced circulation

Changes to existing or suggested boilers.

An average cost to build a power station is 500....800$/KW depending on the size ar type. The least expensive one is the gas turbine with poor efficiency. E.g. 20MW · 10....16 M$.

The power station consists of

- Turbine section.
- Boiler section.
- Water treatment section.
- Feedwater section.
- Generator section.
- Electrical equipment.

The advantages of this concept are as follows :

- Redundant electric supply.
- Inexpensive fuel.
- Condensates can be preheated by the refinery waste heat.
- Improved energy efficiency.
- Need of electricity tends to grow in Egypt ---▶increased overall capacity demand.
- Because some extra capacity of electricity production is normally recommended this concept is interesting in Egypt.
- Because of the bleeding and back pressure concept, and the gas turbine, the fuel efficiency may be 80....90%.
- Because of better feedwater quality,merits are achieved for the refinery too.
- If sulphur free gas is the primary fuel, the energy economy is still better.
- Integrated maintenance operations.

This is a quite extensive project and a careful preliminary study is suggested to carried out. The advantages are :

- National
- For the refinery itself.

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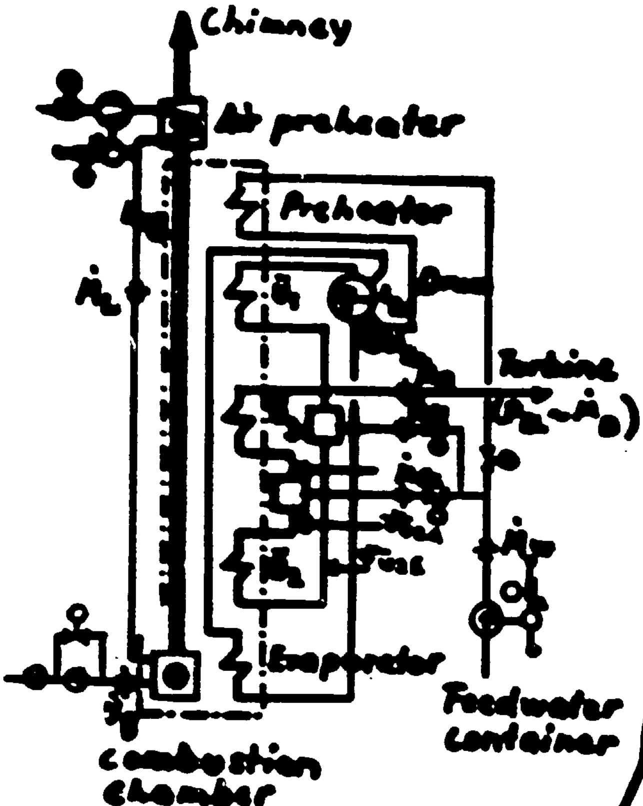


UHOP/PSH/85

$u_1 = \dot{M}_W$ feed water flow (max. 64 t/h)

$u_2 = \dot{M}_D$ steam flow (max 64 t/h)

$u_3 = \dot{M}_{E1}$ injection water flow 1 (max. 5 t/h)

$u_4 = \dot{M}_{E2}$ injection water flow 2 (max 5 t/h)

$u_5 = \dot{V}_B$ oil flow (max 5,5 m³/h)

$u_6 = \dot{M}_L$ combustion air flow (max. $60 \cdot 10^3$ Nm³/h)

$y_1 = \vartheta_{Ü2E}$ steam temperature at superheater 2 inlet

$y_2 = \vartheta_{Ü3E}$ steam temperature at superheater 3 inlet

Y_R

$y_3 = \vartheta_{Ü2A}$ steam temperature at superheater 2 outlet

$y_4 = \vartheta_{Ü3A}$ steam temperature at superheater 3 outlet (live steam)

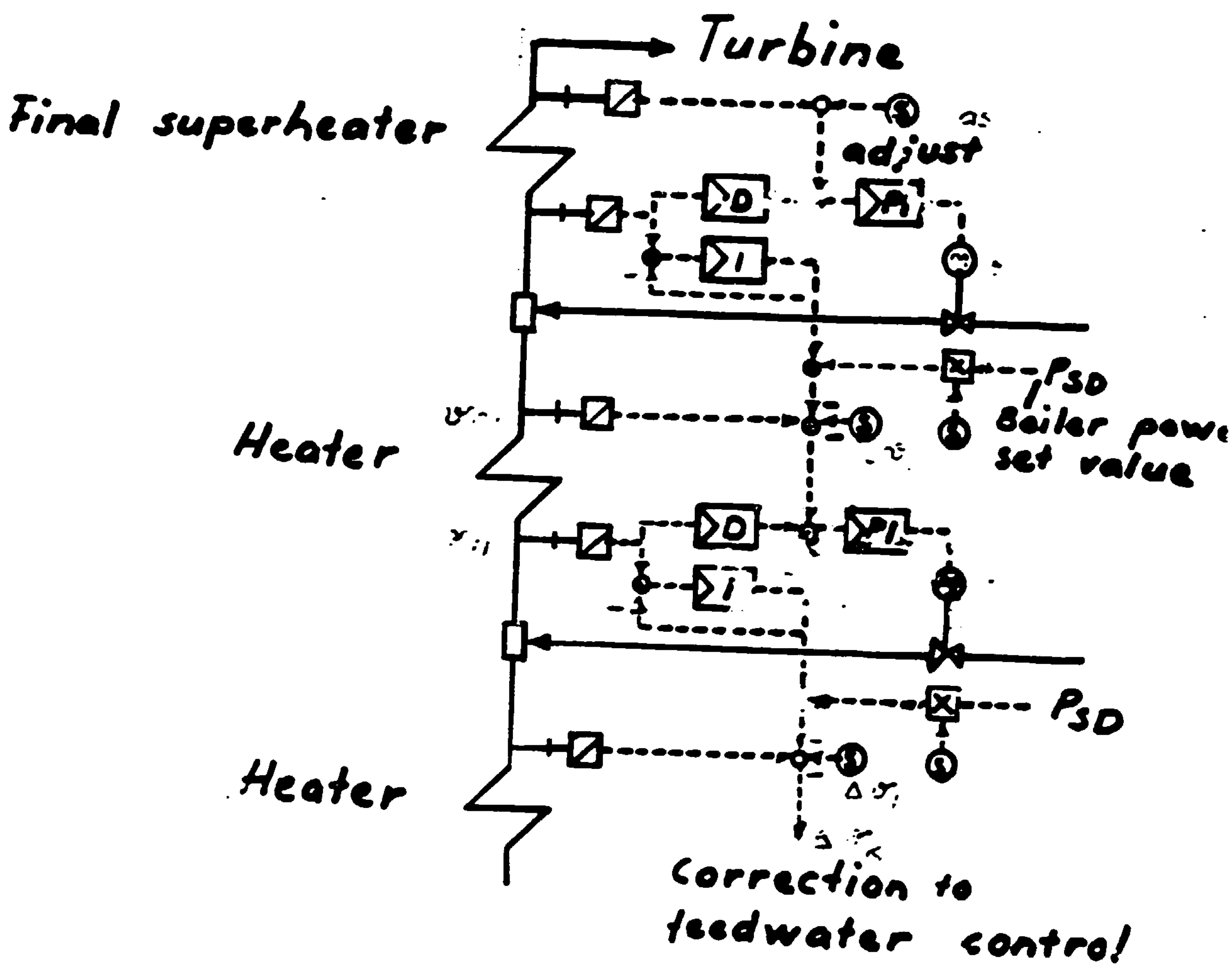
$y_5 = p_{Tr}$ drum pressure

$y_6 = l_{Tr}$ drum water level (0 = drum center)

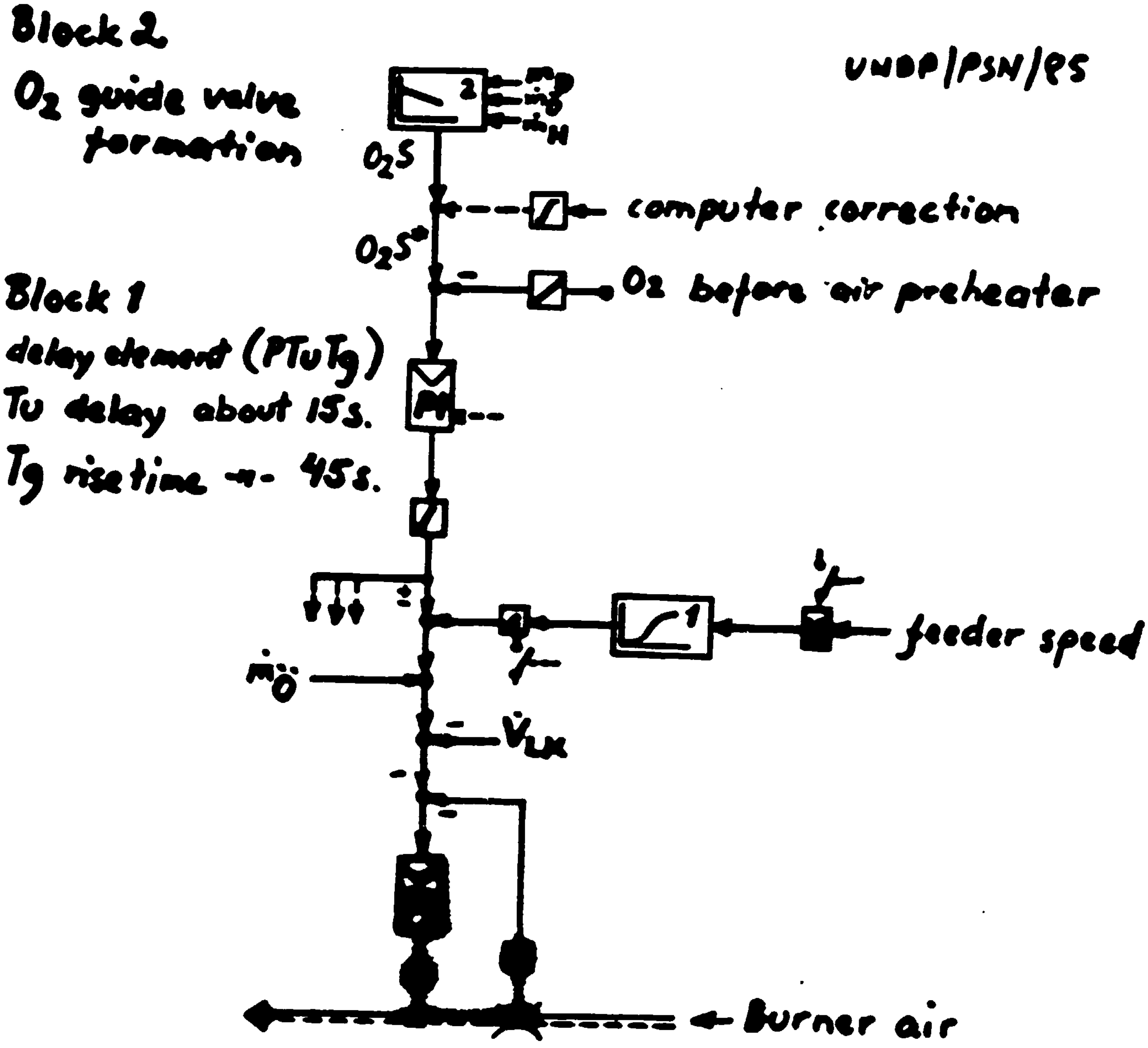
$y_7 = k_{O2}$ oxygen content of flue gas

$y_8 = P_{el}$ generator electric power ($\sim \dot{M}_D$)

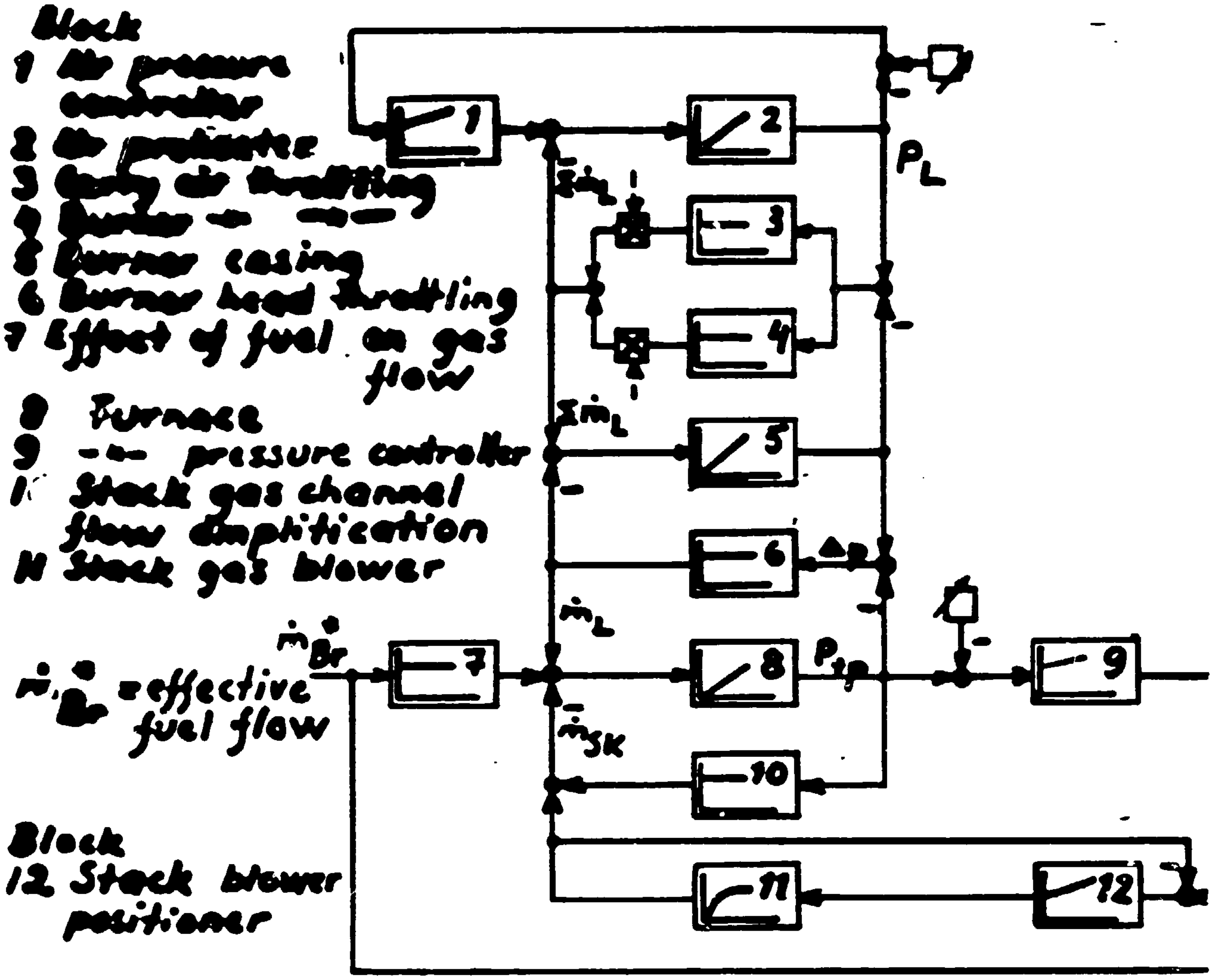
Dynamic model of a steam and electricity generating unit



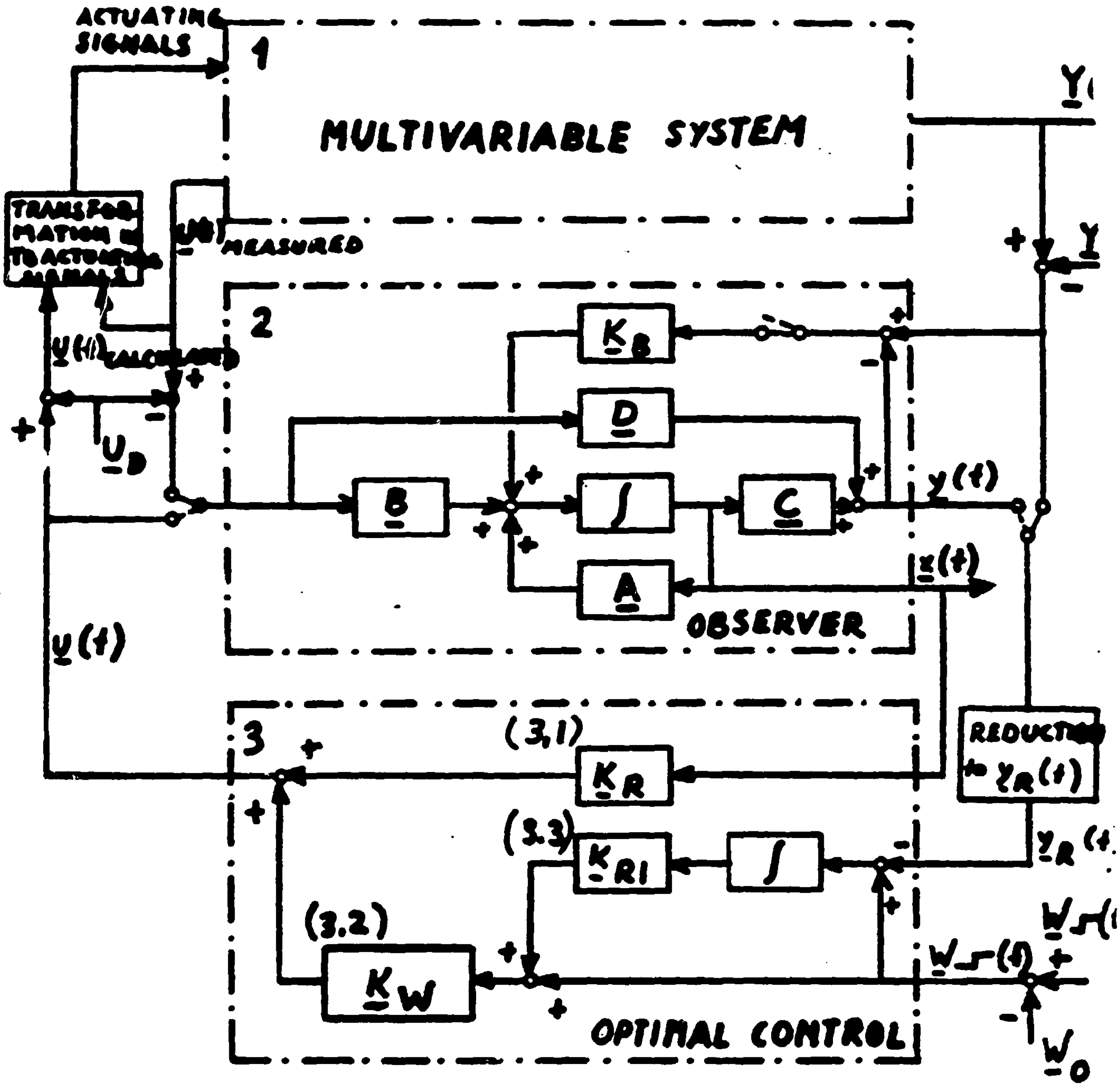
Turbine
Final superheater
adjust
D
PI
I
P_{SD}
Boiler powe
set value
Heater
D
PI
I
P_{SD}
Heater
Correction to
feedwater control



O_2 correction and formation of guide value of burner air



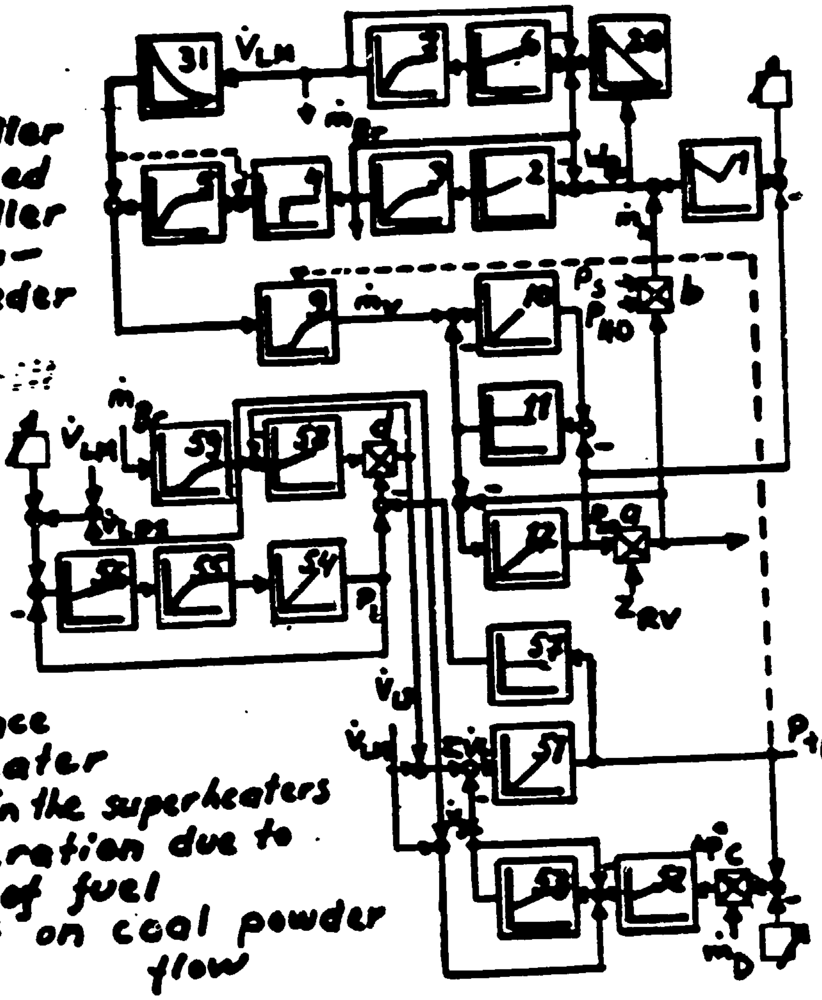
Extended, dynamic control model for furnace pressure control UNDP/PSH/85



Block diagram of complete control system

UNDP/PSN
1985

MODEL FOR A BOILER



Block

1 Steam pressure controller

2 Feeder rotation speed controller

3 Feeder speed —"—

4 Delay from the feeder to the mill

5 Storage effect

6 Mill air controller

7 —"— air blower speed

9 Thermal steam generation

10 Storage effect of the drum

11 The flow resistance of the superheater

12 Storage effect in the superheaters

20 Mill air accelleration due to the set point of fuel

3 Mill air effect on coal powder flow

51 Furnace pressure

52 Furnace pressure controller

53 Stack gas blower positioner

54 Air preheater (pressure

55 Air blower heat

56 Air pressure controller

57 Furnace pressure effect on the burner air flow

58 Burner air controll

59 Delayed guide va for the burner air controller

UNDP/ENPPI
Cairo
Egypt

DYNAMIC MODELS
ENERGY CONSERVATION

April 7, 1985

W H Y

- To analyze start-up and rundown and transient situations.
- Start-ups and rundowns waste energy because there is normally latent energy present.
- To tune control parameters and to simulate various control approaches.
- Dynamic models can even be used for process operator training since this kind of training is very costly or sometimes impossible, this concept is now coming to petrochemical industry. The purpose is to train people for emergency situations. These kind of simulators are expensive, but, however, worth acquisition.
- The phenomenas are often so complex that this is the only means to analyze the:
- Dynamic simulation means that time is involved unlike static simulation which normally is material or energy balances varied by different parameters. Both approaches have their reasons.
- Commissioning can be speeded up by simulation.
- A tool for design e.g process alternatives.
- Separate models can be integrated together to create an extensive model or even a plant scale models.
- The accuracy is to be matched with real needs. Too accurate models are wasting work and time. Often the delays and time constants are enough for extensive dynamic models. A reasonable accuracy is advised, since simplifications are achieved and the computing time is reduced.

GAF03 (8/84)

- Complex phenomena can be analyzed, like
  - Convection and two phase flows.
  - Non-linearities.
  - Discontinuities.
  - Mucleate boiling (phase transitions)

  and it gives a unique numeric solution when desired for complex constrained differential equations.

- Optimization can be added in regard to desired process parameters and constraints.

- It gives a better insight or idea of the process behaviour.

- Online simulation is sometimes justified that the process operator can first see the possible consequences of his action.

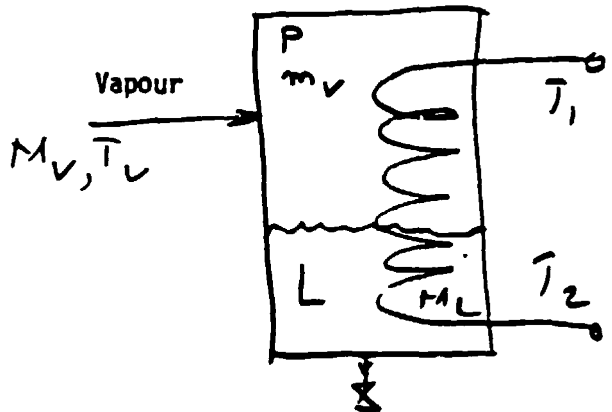
- This technique can be extended to many fields.

- Before doing simulation, its merits have to be considered in view of work, man-power and other necessary input resources.

HOW TO SIMULATE

One has first to establish the formula governing the natural phenomena. This is normally the material and energy or force balance or like balance equations. These equations can contain differential equations. The simulation is carried out by discretizing the differentials. Care must be taken that only essential formulas ar included since simplifications may save a lot of work. The normal procedure is tha after establishment of equations the analysis of reduction is necessary. A usual approach is to linearize the equations near the operational point and this approximation is often good for e.g stability analysis. A multi-variable approach can be taken and then the problem is reduced to analysis of the properties of the state matrix the eigen values of which characterize the dynamic behaviour and time constraints. These on the other hand depend on material and constructional constants by means of which analysis can be done for these quantities. If some existing system is under consideration small tests are performed to find out these time constants. Conversely material properties can be studied applying this method reversely (ultra-sonics).

A conclusion is selected as an example



material balance

$$\dot{M}_V = \dot{m}_V - \dot{m}_L$$

energy balance

$$\dot{M}_V h_V + m_w c_p (T_1 - T_2) = -\dot{m}_L c_{pL} T_L + m_v h_v (p, T) + \dot{C}$$

$h_V = h_V (T_V, P_V)$ and can be approximated.

$\dot{C}$ = heat capacity of the heater.

Heat transfer : the flow is supposed to be turbulant, i.e. temperature is uniformly distributed. The additional formulas are detained for heat transfer.

$$Q = K_L A_L \Delta T_L + K_V A_V \Delta T_V = \dot{m}_w (T_2 - T_1) C_{pw}$$

The equilibrium inside the heater is established by state equations of steam or hydrocarbon. If pressure is increased e.g by choking, the outlet stream the level is increased. The dynamics can be studied by discretizing the differential equations Also, they are linearized around an operational point i.e small changes are analyzed The time constants can be determined based on material constants or alternatively if possible small step changes are applied to determine them experimentally. The latter procedure gives a more reliable information and is widely used because of simplicity. The graphical symbols can be used to present visually the situation on

Utilizing the symbols below :

 = integration

 = amplification

 = function

 = division

 = multiply

 = 

 = delay

The model can be presented graphically. The example annexed does not have the necessary parameters, but a corresponding model can be developped for one selected heater here.

Time constant is approximately

Vapor $\frac{\bar{M}_V}{\bar{\dot{m}}_V}$ $\bar{T}, \bar{M}$ = average values

Liquid $\frac{M_L}{\dot{m}_L}$

Heater $\frac{4k\tau}{L^2 C_p \rho}$

k = heat conductivity
L = thickness of plate
ρ = density
C_p = specific heat

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F M Youssef
M El-Nagdy
A K Sari
M Wahby

P Soininen

GAR03 (8/84)

Programs for energy conservation PSN/85 UNDP 1

```
type heater.bas
3 INPUT "TO AND T2";TO,T2
4 CLS:SCREEN 3,1,0
5 LINE (0,0)-(150,50),,B,61680!
10 FOR T=T2-300  TO T2 STEP 50
13 FOR N=1 TO 150:DT=N/3
20 L=50*(T-TO*(1-LOG(TO^2/(DT+TO)/(T-DT))))/(T-TO*(1-LOG(TO/T)))
25 Y=50-L
40 PSET(N,Y)
45 NEXT:NEXT
50 LOCATE 26,1,1: PRINT "TO=",TO
52 LOCATE 26,2,1: PRINT "T2=",T2
55 LOCATE 30,3,1: PRINT "EFFICIENCY OF HEATER"
77 LOCATE 26,6,1: PRINT "50 DEG C TEMP.DIFF"
```

Heater efficiency

```
A>type cost1.bas
7 INPUT "HEAT DUTY GCAL/H AND FLUE GAS AND OUTLET TEMP C ";G,T,XO
8 P=(T-XO)*10/190
9 IF T<XO  THEN P=0
10 A=(.93+1.01)/2
20 B=(9.525+9.77)/2
30 C=28/(156.476*A)*1000
50 D=G/B*P/100*325*24*C
51 E=P/10*.05*800*.5*G/B*11.2*.38*1000
  PRINT "HEAT RECOVERY FROM STACK GASES"
53  =D/C
55 PRINT "DENSITY","GCAL/TON","USD/TON/FUEL","PROFIT/USD/A","INVESTMENT/USD"
70 PRINT A,B,C,D,E
72 PRINT "TONS SAVED FUEL/A ",F
75 RUN
```

Air preheater: 201

```
A
10 INPUT "TEMP. DEG C ";T
11 SCREEN 3
12 LINE (0,0)-(150,150),,BF
13 FOR N=1 TO 150
15 K=EXP(40*(1100-T)/1420/(T-273.15)*120.27)
20 A=3*(1-N/150)
25 X=(K*A/(1-K)+((1+K)/(1-K)/2-A/2)^2)^.5
30 X=X-(1+K)/(1-K)/2+A/2
31 S=1/(2+N/150*5.65)
34 PRESET (N,50*S*X)
35 PRESET (N,50*S*(A-X))
   PRESET (N,50*S*(1-X))
3_ PRESET (N,50*S*(1-A+X))
38 PRESET (N,S*N/3*5.65)
39 NEXT
```

Plotting of stack gas composition

```
A>plotting program of molar propositions of stack gases of hydrocarbons
3 INPUT "TO AND T2";TO,T2
4 CLS:SCREEN 3,1,0
5 LINE (0,0)-(150,50),,B,61680!
7 T2=T2+273.2:TO=TO+273.2
10 FOR T=(TO+T2)/2 TO T2 STEP (T2-TO)/5
13 FOR N=1 TO 150:DT=N/3
20 L=50*(T-TO*(1-LOG(TO^2/(DT+TO)/(T-DT))))/(T-TO*(1-LOG(TO/T)))
25 Y=50-L:PSET(N,Y)
45 NEXT:I=I+1: LOCATE 26+I*6,1,1:PRINT L/50,T:NEXT
50 LOCATE 26,2,1: PRINT "TO=",TO
52 LOCATE 26,3,1: PRINT "T2=",T2
55 LOCATE 30,4,1: PRINT "EFFICIENCY OF HEATER"
77 LOCATE 26,6,1: PRINT "50 DEG C TEMP.DIFF"

A alternative heater efficiency program
```

Heater efficiency

PSN/85 2
UNDP

```
A R
3 INPUT "TEMP. DEG C ";T
4 CLS:SCREEN 3,0,0
5 LINE (0,0)-(150,50),,B,61680!
13 FOR N=1 TO 150
15 K=EXP(40*(1100-T)/1420/(T-273.15)*120.27)
20 A=3*(1-N/150)
25 X=(K*A/(1-K)+((1+K)/(1-K)/2-A/2)^2)^.5
30 X=X-(1+K)/(1-K)/2+A/2
31 S=1/(2+N/150*5.65)
34 X =50*(1-S*X)
35 X2=50*(1-S*(A-X))
36 X3=50*(1-S*(1-X))
37 X4=50*(1-S*(1-A+X))
38 X5=50-S*N/3*5.65
40 S1=2*X1+28*X2+18*X3+44*X4+20*X5
41 X1=2*X1/S1:X2=28*X2/S1:X3=18*X3/S1:X4=44*X4/S1:X5=20*X5/S1
44 PSET(N,X1):PSET(N,X2):PSET(N,X3):PSET(N,X4):PSET(N,X5)
45 NEXT
50 PRINT "H2","CO","H20","CO2","N2"
55 X1=-X1/50+1:X2=-X2/50+1:X3=-X3/50+1:X4=-X4/50+1:X5=-X5/50+1
60 PRINT X1,X2,X3,X4,X5
```

stack gas composition plotting/advanced version

```
A R
1 PRINT "efficiency for oil heaters (liquid)"
5 INPUT "in/out,t1,t2,t3,t4,t0";TT1,TT2,TT3,TT4,TT0
10 INPUT "densities,d1,d2,d3,d4";D1,D2,D3,D4
15 INPUT "flows tons/h,f1,f2";F1,F2
16 T1=TT1+273.2:T2=TT2+273.2:T3=TT3+273.2:T4=TT4+273.2:T0=TT0+273.2
20 DE1=(3.524-1.29*D1)*(T1-T0)+.00115*(TT1^2-TT0^2)
25 DE1=DE1-T0*(2.897-1.29*D1-273.2*.0023)*LOG(T1/T0)
30 DE2=(3.524-1.29*D2)*(T2-T0)+.00115*(TT2^2-TT0^2)
35 DE2=DE2-T0*(2.897-1.29*D2-273.2*.0023)*LOG(T2/T0)
40 DE3=(3.524-1.29*D3)*(T3-T0)+.00115*(TT3^2-TT0^2)
45 DE3=DE3-T0*(2.897-1.29*D3-273.2*.0023)*LOG(T3/T0)
50 DE4=(3.524-1.29*D4)*(T4-T0)+.00115*(TT4^2-TT0^2)
55 DE4=DE4-T0*(2.897-1.29*D4-273.2*.0023)*LOG(T4/T0)
 PRINT "exergy MW", F1*DE1/3600,F1*DE2/3600,F2*DE3/3600,F2*DE4/3600
 PRINT "heater efficiency",(F1*DE2+F2*DE4)/(F1*DE1+F2*DE3)
 RUN
```

Heater efficiency oil/oil

```
A
1 PRINT "efficiency for oil/water heaters (liquid)"
5 INPUT "in/out,t1,t2,t3,t4,t0";TT1,TT2,TT3,TT4,TT0
10 INPUT "densities,d1,d2";D1,D2:D3=1.02:D4=D3
15 INPUT "flows tons/h,f1,f2";F1,F2
16 T1=TT1+273.2:T2=TT2+273.2:T3=TT3+273.2:T4=TT4+273.2:T0=TT0+273.2
20 DE1=(3.524-1.29*D1)*(T1-T0)+.00115*(TT1^2-TT0^2)
25 DE1=DE1-T0*(2.897-1.29*D1-273.2*.0023)*LOG(T1/T0)
30 DE2=(3.524-1.29*D2)*(T2-T0)+.00115*(TT2^2-TT0^2)
35 DE2=DE2-T0*(2.897-1.29*D2-273.2*.0023)*LOG(T2/T0)
40 DE3=(T3-T0*(1-LOG(T3/T0)))*3.88646
```

Heater efficiency oil/water

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```
45 DE4=(T4-T0*(1+LOG(T4/T0)))*3.88646
46 PRINT DE3,DE4,F2,T0,T4,T3
56 PRINT "exergy MW", F1*DE1/3600,F1*DE2/3600,F2*DE3/3600,F2*DE4/3600
60 PRINT "heater efficiency",(F1*DE2+F2*DE4)/(F1*DE1+F2*DE3)
65 RUN

A>
1 PRINT "efficiency for oil heaters (liquid)"
5 INPUT "in/out,t1,t2,t3,t4,t0";TT1,TT2,TT3,TT4,TT0
10 INPUT "densities,d1,d2,d3,d4";D1,D2,D3,D4
15 INPUT "flows tons/h,f1,f2";F1,F2
16 T1=TT1+273.2:T2=TT2+273.2:T3=TT3+273.2:T4=TT4+273.2:T0=TT0+273.2
20 DE1=(3.524-1.29*D1)*(T1-T0)+.00115*(TT1^2-TT0^2)
25 DE1=DE1-T0*(2.897-1.29*D1-273.2*.0023)*LOG(T1/T0)
30 DE2=(3.524-1.29*D2)*(T2-T0)+.00115*(TT2^2-TT0^2)
35 DE2=DE2-T0*(2.897-1.29*D2-273.2*.0023)*LOG(T2/T0)
40 DE3=(3.524-1.29*D3)*(T3-T0)+.00115*(TT3^2-TT0^2)
45 DE3=DE3-T0*(2.897-1.29*D3-273.2*.0023)*LOG(T3/T0)
50 DE4=(3.524-1.29*D4)*(T4-T0)+.00115*(TT4^2-TT0^2)
55 DE4=DE4-T0*(2.897-1.29*D4-273.2*.0023)*LOG(T4/T0)
56 PRINT "exergy MW", F1*DE1/3600,F1*DE2/3600,F2*DE3/3600,F2*DE4/3600
60 PRINT "heater efficiency",ABS((F1*DE1-F1*DE2)/(F2*DE3-F2*DE4))
65 RUN
```

Alternative efficiency

```
A>heater efficiency calculation exergy principle
10 INPUT N:K=N*N:DIM A(K),B(K):FOR I=1 TO K:PRINT "a";I;:INPUT A(I):NEXT
20 B(1)=1/A(1):FOR I=2 TO N:S0=0:I1=(I-1)*N+I:FOR J=1 TO I-1:S1=0:S2=0
30 FOR M=1 TO I-1:S1=S1+B((J-1)*N+M)*A(I+(M-1)*N)
40 S2=S2+A((I-1)*N+M)*B((M-1)*N+J):NEXT
50 B((I-1)*N+J)=S2:S0=S0+S1*A((I-1)*N+J):B((J-1)*N+I)=S1:NEXT
60 B(I1)=1/(A(I1)-S0)
70 FOR J=1 TO I-1:B((I-1)*N+J)=B((I-1)*N+J)/(S0-A(I1)):NEXT:FOR J=1 TO I-1
80 FOR M=1 TO I-1:B((J-1)*N+M)=B((J-1)*N+M)-B((J-1)*N+I)*B((I-1)*N+M):NEXT
82 B((J-1)*N+I)=-B((J-1)*N+I)*B(I1):NEXT:NEXT
115 PRINT:PRINT "original matrix              inverse matrix"
120 FOR J=1 TO N:PRINT:FOR I=1 TO N :PRINT A(J*N-N+I);:NEXT:PRINT "
125 FOR I=1 TO N:PRINT B(J*N-N+I);:NEXT:NEXT
140 RUN

A>matrix inversion program for dynamic modelling
```

Matrix inversion for modelling

M El-Nagdy

T Hussein

A K Sari

F M Youssef

M Wahby

P Soininen

File

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8.6 Activities and schedule

Four main items have been selected :

- Furnaces.
- Heaters.
- Electric/steam co-generation.
- Electric systems.

The work will take place in small teams and these activities will be carried out within the time scope (10...12 weeks).

RESOURCES (Full/part time)

- Chemical- 3...5
- Instrumentation- 1...2
- Electrical- 1...2
- Computer- 1 (if time available)

oriented persons involved in the items listed in the bar charts annexed. The cases are selected such that they serve ENPPI's direct needs in the short run. A distillation unit with auxiliary processes will be one. Seminars will be given on related topics. In certain cases optimization and modelling is possible because this is one potential . Participants should qualify in thermal, electrical, automation and process engineering and have a capacity for cost analysis. A great emphasis will be in training to prepare sankey diagrams for a deeper energy and cost analysis. Detailed and rough examples will be included in this respect. The result will be a plan for actions in the case in question. The people are expected to work part time. Resources needed are (manhours) :

- 900 Manhours Chem.
- 200 Manhours Elect.
- 300 Manhours Instr.

These figures are estimates and can be less depending on experience.

RESOURCES (Cont'd)

The case definition phase means that each activity is defined in detail. When the case has been selected, all possible energy conservation actions will be analyzed, and how they can be done . A return on investment analysis is part of it. If more time will be available, further cases can be taken.

For example, in case of furnace (one of the most promising objects), the following may be analysed :

1. Assign the furnaces
2. Fuel preheating.
3. Recovery of heat from stack gases (dew point of H_2SO4, Na, V, O_2..etc.)
4. Combustion control.
5. Instruments for energy conservations
6. Fuel/air preheating.
7. Final temperature optimization of stack gases.
8. Constructional effects.
9. Materials of the heaters.
10. Insulation.
11. Start up/run down situations.
12. Sooting (how and when).
13. Performance figures.

It is expected that the activity will be finished within the period indicated in part time basis. This bar chart includes the tities of activities because only 10 weeks are available and too much time cannot be used for the program design. Details will be given in introductionary seminars. The number of main activities is about 40 and about 50 workdays are available. This evidently explains the accuracy of the schedule. The result will be a plan of actions for the selected case in :

RESOURCES (Cont'd)

1. Automation.
2. Process.
3. Insulation.
4. Construction.
5. Cost analysis.
6. Materials.

Visits to selected refineries will be arranged. General seminars on these topics will be given at ENPPI - Alexandria.

VIEWS ON PRIORITIES

The furnaces are considered the most important because it overlaps power stations refineries and can be extended elsewhere. Also it is a current problem:

- for existing refineries more than 20 furnaces without proper heat recovery.
- boilers have furnaces and a concept to build power stations in connection with existing refineries is viable.
- energy conservation potentials are evident.

If reducing the programs is necessary, the furnace is the last one.

The sankey-diagram concept is introduced because of its illustrating nature to locate energy conservation potentials in existing plants and it is also a general approach for other industries.

Solar and desalination are treated briefly because in the near future few potentials are seen in refinery area.

VIEWS ON PRIORITIES (Cont'd)

Automation is also to a certain extent a general approach to save energy. In developing countries, it may be overdone but the potential is evident. In the electric side power factor control and inverter control at motors are the most promising items. Also, special measurements especially when maintaining the plants, provide potentials to discover heat leaks, improper operation and hence energy conservation.

It is also important to get started with the items as soon as possible.

ACTIVITIES FOR ENERGY CONSERVATION

FURNACES

ITEM	1	2	3	4	5	6	7	8	9	10	11	12	Week
1. Case definition i.e to assign the furnaces.	A												
2. Fuels - Properties - Variations		C											
3. Heat recovery systems of furnaces - Preheating			C										
4. Stack gases - Dew point - Cooling				C									
5. Thermal insulation					C								
6. Sankey diagram models													
7. Operation modes - Steady state - Variations							C						
8. Fouling, slagging scale deposits,sooting							C						
9. Furnace, construction - Materials - Shape - Size					C								

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ACTIVITIES FOR ENERGY CONSERVATION

FURNACES (Cont'd)

ITEM	1	2	3	4	5	6	7	8	9	10	11	12	Week
10. ROI Analysis - Investment - Operation and maintainance											C, I		
11. Automation - Special instrum-ents - Control concepts - Start up/run down - Perormance monitoring								I					

A = all I = Instrumentation C = Chemical

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ACTIVITIES FOR ENERGY CONSERVATION

STEAM/ELECTRICITY CO GENERATION

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
1. Case definition -Assignment of plants	A											
2. Boiler concepts - Drum type - Once through		C										
3. Turbine - Extraction - Type		C, E										
4. Auxiliary systems - Feed water - Superheaters				C								
5. Operation modes - Start ups - Run downs - Load variations				C, I								
6. Fuels - Quality - Sulphur + V,Na		C										
7. Automation - Level - Performance monitoring						I						

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ACTIVITIES FOR ENERGY CONSERVATIONS

STEAM/ELECTRICITY CO-GENERATION (CONT'D)

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
8. Steam demand and distribution - Condenser - Condensates						C						
9. Sankey diagram - Balances - Material flows - Heat flows							C					
10. Reliability - Alternative supplies supplies								I, C				
11. Combi units - Operation - Efficiency							C					
12. Condensate treatment and make up water				C								
13. Auxiliary steam generator									C			
14. ROI Return on investment											C	

A = All C = Chemical E = Electrical

I = Instrumentation

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ACTIVITIES FOR ENERGY CONSERVATION

HEATERS, HEAT RECOVERY (Distillation unit)

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
1. Case definition - Destillation unit and auxiliaries	A											
2. Performance figures - Definition			I, C									
3. Unit Sankey diagram - Heat and material balances					C							
4. Scaling, fouling Blocking, leaks					C							
5. Peformance monitoring - Based on figures above						I, C						
6. Constructional effects - Insulation - Geometry - Size							C					
7. Operation modes - Start ups - Run downs						I,C						
8. Materials							C					
9. Reliefs to the atmosphere or condensor		C										

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ACTIVITIES FOR ENERGY CONSERVATION

HEATERS, HEAT RECOVERY (Distillation Unit) (CONT'D)

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
10. Refluxes - Minimization							C	C				
11. Solar desalination - Vacuum evaporation						C	C					
12. Condensates - Collection/treatment - Heat recovery					C							
13. ROI Analysis - Investment - Operation - Maintenance										C	C	

C = Chemical I = Instrumentation

ACTIVITIES FOR ENERGY CONSERVATION

ELECTRIC SYSTEMS

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
1. Case specification - Listing potential objects	A											
2. Power factor control - Single components - Capacitors - Reactances - Plant scale - Measurement - Solid state			E									
3. Peak load control - Start ups/run downs - Power factor					E							
4. Variable motor speed controls - Inverters - Other means - Benefits - Potential objects						I, E						
5. Inspection technique - Eddy current - Ultrasonic - Vibration - Endoscope - IR							I, E					

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ACTIVITIES FOR ENERGY CONSERVATION

ELECTRIC SYSTEMS (CONT'D)

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
6. Automation									I			
7. Computers, micros e.g. compressor control									I, C			
8. Solar - Panels - Potentials						E						
9. Lighting, air conditioning, miscellaneous									E			
10. ROI analysis											A	

E = Electrical   I = Instrumentation

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I FURNACES

1.1 THE MATERIAL REQUIRED

- PI diagram of an existing furnace with
  - a Instrumentation data
  - b Process data
  - c Material data

- Physical pictures of the furnace (directly fired heater).

- Quality of fuels
  - a Sulphur contents
  - b Metals V, Na
  - c Non burning parts (inorganic)
  - d Moisture
  - e Fuel/gas alternatives

- Desired flare power

- Start up/run down times

- Dimensional data.

1.2 THE OBJECTIVES

This will be a case for existing and future furnaces. Energy conservation options will be studied in the following way :

- Instrumentation and automation
  - a Sensors
  - b Location of sensors

I FURNACES (Cont'd)

1.2 THE OBJECTIVES (Cont'd)

- Instrumentation and automations (Cont'd)

  c Control concepts
  d Protection (start up/run down)
  e Stack gas analysis
  f Simple model for simulation
  g Performance monitoring
  h Special instruments

- Sankey diagram

  a Material and energy flows
  b Temperature levels
  c Loss analysis
  d Recovery possibilities

- Process improvements

  a Addition of combustion air preheater
  b Dimensioning of the heater
  c Materials (glass, cast iron, inert, ... etc.)

- Economical analysis

  a Assessment of investment based on available bids
  b Assessment of energy conserved
  c Profitability analysis

- Insulation is analyzed

  a Optional insulation

I FURNACES (Cont'd)

1.3 TENTATIVE PROPOSAL

Items for investment to conserve energy are listed so that bid enquiries are easily prepared if a decision on it will be made.

1.4 RESOURCES

ENPPI will provide the necessary initial data. A group of three people will do the job and the members are

- Chemical engineer
- Instrument engineer
- PSN (UNDP expert)

1.5 SCHEDULE

A bar chart exists and it gives the mainframes for the job

II STEAM/ELECTRIC CO-GENERATION

2.1 INITIAL DATA

a Steam requirements for the refinery
b Electric supply for the refinery
c Water supply
d Data on possible fuels
e Expected up-time

2.2 OBJECTIVES

a A specification of a combi or/and back pressure power station that supplies heat and electricity to the refinery.

II STEAM/ELECTRIC CO-GENERATION (Cont'd)

2.2 OBJECTIVES (Cont'd)

- b A sankey diagram in a principle level.
- c Economic justification by energy conservation
- d Reliability analysis (alternative supplies).
- e Requirements on automation.
- f Operation modes.

This case will not be as detailed as the furnaces, but if time is enough, this will be extended.

2.3 SCHEDULE

The bar chart annexed.

2.4 RESOURCES

- a 2 chemical, 1 electrical engineers (may be the same for the furnaces).

III HEATERS ON HEAT RECOVERY

3.1 INITIAL DATA

- a PI-diagram of a destillation unit and auxiliaries. (see furnaces).

3.2 OBJECTIVES

- a A detailed sankey diagram is prepared
- b Energy conservation potentials are identified
- c Profitability analysis is prepared on each potential to a sufficient extent.

III HEATERS ON HEAT RECOVERY (Cont'd)

3.2 OBJECTIVES (Cont'd)

d The main performance figures are listed such that continuous monitoring or checks in connection of preventive maintenance is possible.

e Insulation and its ROI is analysed.

f Scale deposits, blocking, size etc. are discussed which has impact on energy economy.

g Solar energy and desalination are briefly handled.

h ROI analysis

3.3 SCHEDULE

Bar-chart annexed:

3.4 RESOURCES

a 1....2 Chemical engineers

b 1 Instrumentation engineer

IV ELECTRIC SYSTEMS

4.1 INITIAL DATA

List of motors and their functions

a Control system driving motors

b Motors partly loaded

4.2 OBJECTIVES

a Power factor control yields energy savings in

- Unit level
- Plant scale level

IV ELECTRIC SYSTEMS (Cont'd)

4.2 OBJECTIVES (Cont'd)

b Methods for this are presented.

c Variable speed control apportunities are analyzed versus conventional throttling (inverters).

d Solar panels are treated briefly

e Peak load analysis is carried out.

f Solar panels and lighting are briefly discussed as to energy conservation.

g Potentials by automation.

h Related economic analysis.

i Effects of pfc on equipment sizing.
k ROI analysis

4.3 SCHEDULE

See the bar chart.

4.4 RESOURCES

a 1 electric, 1 instrument engineers

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SUMMARY

The same instrument engineers will serve all needs of automation.

Chemical engineers also participate all projects because they are so much overlapping.

If time is enough, a computer model could be developed for the furnace process and simulation of various strategies is possible.

The total need 1400 manhrs.

Maximum 10 people are involved.

Four lines

- Furnaces 1st priority
- Heaters
- Co-generation
- Electric systems

Further details are given in introductionary seminars for teams.

The bar chart is a frame of operation. Energy conservation and its economic realization is to be kept in mind.

The extent of activities will be matched with 11 weeks.

Reports on progress is made regularly to participants and ENPPI's direction as below :

M M El-Rifai	M El-Sayed
R Duvall	M A Soliman
K M Khaled	F M Youssef
M Nagdy	U N D P

DETAILS ON ENERGY CONSERVATION

FURNACES

1. Case definition means

   - Listing existing furnaces with technical characteristics.
   - Auxiliaries if there exist such as fuel preheating or stack gas heat recovery
   - Existing control philosophies

2. Fuels

   - Types gas/fuel or both
   - S, V, Na..etc. contents
   - Moisture
   - Variations (T, viscosity, etc.)

3. Heat Recovery

   - Various recuperator options
   - Materials (cast iron, glass, stainless steel)
   - Possibilities to install and outages due to it

4. Stack gases

   - Corrosive components
   - Ash
   - Inorganics
   - Non combusted components
   - Temperature levels
   - O_2, Co, etc. monitoring

FURNA'ES (Cont'd)

5. Performance Figures

- List of figures that describe the function of the furnace and that are feasible for continuous monitoring.
- Figures are for single components heaters, fans, pumps and an overall performance can be determined

6. Sankey Diagrams

- An illustrative sankey diagram is prepared with material and heat flows and temperatures.

7. Operation Modes

- Constant/variable
- Expected start ups and run downs and related losses

8. Insulation

- Optimal thickness
- Methods to detect the optimality

9. Foulings

- Fouling, slagging and scale formation is analysed (V-oxides,carbon, etc.)
- By means of performance figures it si possible to predetermine cleaning, sooting and possible opening during outage

10. ROI Analysis

- Return on investment analysis can be done to justify the investment

11. Automation

- The purpose is that complete combustion is insured without excess air, therefore a suitable instrumentation and control concepts are proposed

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FURNACES (Cont'd)

11. Automation (Cont'd)

- Performance monitoring is possible during outages, e.g.
  - . eddy currents
  - . endoscope
  - . ultrasonic
  - . vibration (during operation, too)
  - . IR photography
- Start up and run down group function logics

12. Construction

- is the furnace thermodynamically correctly constructed.
- materials are analyzed too.

GAF03 (11/84)

COGENERATION

1. Case Definition

   - A feasible refinery is chosen (refinery)

2. Boiler Concepts

   - Sizing
   - Type of boiler considering operational demands and availability (drum, once through, forced circulation, etc.)
   - Pressure/temperature levels
   - Loading modes
   - Start up/run down
   - Efficiency estimates

3. Turbo Generator

   - Extraction points
   - Loading modes
   - Type
   - Condensor
   - Sizing

4. Auxiliary Systems

   - Fuel feed
   - Feed water vessel
   - Super heater low/high pressure preheaters
   - Auxiliary boilers
   - Air feed

COGENERATION

5. Operation Modes
    - Even/variable load
    - Possible feed to national net work
    - Start up/run down (cold/warm)
6. Fuels / Gas / Fuel / together
    - Same as to furnaces
    - Stand by fuels
7. Automation
    - Control modes (floating/fixed pressure before turbine)
    - Degree of automation
    - O_2, etc. measurements
    - Performance monitoring
8. Steam
    - Temperatures and quantities
    - Extraction points
    - Variations
9. Sankey Diagram
    - Energy, material flows and balances
    - Temperature levels
10. Reliability
    - Alternative steam/electric sources
    - Boiler, turbine, generator trips

COGENERATION

11. Combi-processes

- Integration of a gas/fuel turbine with the boiler
- Economy
- Situation with turbine trips
- Efficiency estimates

12. Condensate Treatment and Make up Water

- Water supply
- Water quality (chemicals to be added)
- Condensate purification
- Demand of make up water
- de-ionating
- Quality of returned condensates
- Alternatives (vacuum desalination)

13. Auxiliary Steam Generator

- Capacity
- Modes at standing by
- Change over

14. ROI

- Analysis of return on investment

HEATERS

1. Case Definition
   - Lists of feasible unit
   - Feasible refinery
2. Performance Figures
   - Selection of figures that describe the function of heaters
   - Feasibility for continuous monitoring
3. Sankey Diagram
   - Material and energy flows and temperature levels
4. Scaling, Fouling, Blocking, Leaks
   - Formation of deposits and reasons
   - How to detect these
5. Performance monitoring
   - Instruments necessary to monitor the performance
   - Possible connection to a micro or computer
6. Construction
   - Optimal insulation
   - Minimal flow resistance
   - Maximal heat transfer
   - Heat leaks
   - Size and shape optimization

HEATERS (Cont'd)

7. Operation Modes
   - Conservation
   - Start ups/run downs
   - Load modes

8. Materials
   - Corrosion
   - Heat conductivity
   - Mechanical resistance

9. Reliefs to atmosphere or to a condenser
   - Possibilities to minimize by pre heating input materials
   - Utilization of optimal heating media, i.e. energy loss minimization

10. Refluxes
    - Minimization without lowering acceptable product quality
    - Optimization of heat usage under constraints
    - Possibilities for on-line optimization

11. Solar Desalination
    - Possibilities for economical use of these items

12. Condensates
    - Utilization of dirty condensates (heat recovery possibility)

13. Return an investment
    - Estimates of feasible profits

ELECTRIC SYSTEMS

1. Case Specification
   - Listing feasible motors
   - Assignment of the case refinery

2. Power Factor Control
   - Plant scale options
   - Component level options
   - Methods
     . capacity
     . reactive
     . solid state
   - Measurement
   - Spark proof of PFCS

3. Peak Load Control
   - Situation (e.g. power plant trip)
   - Actions to avoid it

4. Variable Speed Motor Control
   - Feasible objects
   - Benefits
   - Alternatives (DC-motors, hydrocouplings)
   - Inverter technology
   - Integration of an inverter to a control system
   - Spark proofness

5. Inspection Technique
   - Eddy currents
   - IR-photography
   - Ultrasonics

ELECTRICAL SYSTEMS (Cont'd)

5. Inspection Technique (Cont'd)

- Vibration analysis (shock pulse technique)

6. Computers, Micros

- Feasibility of advanced control systems, e.g. compressors
- Computer control
  . benefits, eg, on-line optimization or multi variable control

7. Solar

- Feasibility of solar panels
- Average yield
- Applicability
- Costs

8. Lighting, Airconditioning, Miscellaneous

- Energy conservation possibilities with these items

9. ROI

- Profits to be recovered with these methods

GAF03 (11/84)

UNITED NATIONS

8.7 UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO

17 October 1983

PROJECT IN THE ARAB REPUBLIC OF EGYPT

JOB DESCRIPTION

INTERNAL

DP/EGY/81/016/11-04/32.1.E

Post title	Expert in Energy Conservation
Duration	Three months
Date required	As soon as possible
Duty station	Cairo
Purpose of project	To improve the engineering capacity of the Egyptian Petroleum and Chemical Industries through man power development of the sole national engineering firm (ENPPI).

Duties

The expert will be attached to the Engineering for the Petroleum and Process Industries (ENPPI) and will specifically be expected to:

1. Assist in the preparation of the technical study tak: into account that preservation of the country's Petroleum and Gas reserves is of vital importance.

   Studies should be directed at better usage of low pressure steam, combined cycle gas turbines, use of solar energy cells, and sea water desalination plants.

2. Assist in setting procedures systems and manuals for design, engineering specifying said facilities as well as training ENPPI's Engineers to apply same and design said facilities.

The expert will also be expected to prepare a final report setting out the findings of the mission and recommendations to the Government on further action which might be taken.

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Applications and communications regarding this Job Description should be sent to:

Project Personnel Recruitment Section, Industrial Operations Division

Qualifications	Several years' experience is required in design, engineering and specifying energy conservation systems and facilities is required.
Language	English
Background information	The development of chemical and petroleum industries in the country follows a favourable trend because of the availability of basic and most important feedstocks for chemical processing which are: Crude Oil and Natural Gas.

Large capacities of crude oil refining facilities are in operation, while downstream processing of petroleum products, refinery intermediates and by-products are being developed on the basis of imported technology and equipment. Similarly, the use of natural gas for the manufacture of basic chemicals such as amonia, urea, methanol and various petrochemical derivatives is increasing as many new plants are under construction, in the planning stage, or under consideration. Also the use of natural gas and associated gas as fuel for industrial and domestic purposes is in increasing demand. This justifies the establishment of a national engineering firm to serve the growing industrial demand for engineering services.

It is generally known from past experience of the industrialized world that establishing engineering firms is not an easy task. It requires the accumulation and development of engineering know-how and experience.

ENPPI, as the first engineering firm of the country, has been through this difficult task since its establishment in 1978. The main constraint facing ENPPI is the lack of experienced specialists and designers in the country. To overcome this shortcoming, ENPPI is conducting an intensive training programme for professional growth. This programme needs all the support in order to reach the national goal of establishing a sound engineering base in the national Industrial Sector. For this reason the Ministry of Industry has recommended the allocation of UNDP assistance to ENPPI.

8.8 Production data on Egyptian oil industry

(000. Tons)

ITEM	1952	1977	1978	1979	1980	80/81	81/82*
Benzine (Gasoline)	186	1524	1711	1763	1951	1984	2091
Kerosene	219	1502	1652	1640	1724	1475	1571
Jet Fuel	-					158	167
Gas Oil	120	1961	2190	2280	2519	2159	2018
Diesel Oil	11						
Fuel Oil	1702	5254	5437	5536	6413	6781	7724
Butane Gas	4	64	72	99	139	153	165
Asphalt	51	148	193	211	273	291	304