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Increasing the Efficiency of Thermal Power Stations

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INCREASING THE EFFICIENCY OF THERMAL POWER STATIONS

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DIE ERHÖHUNG DES WIRKUNGSGRADES THERMISCHER KRAFTWERKE

KURZFASSUNG

Gestiegene Energiepreise, hohe Investitionskosten und ein stärkeres Umweltbewußtsein setzen neue Maßstäbe für die Beurteilung der Wirtschaftlichkeit von Wärmekraftwerken. Eine der wirkungsvollsten Maßnahmen sowohl Kosten- als auch Umweltfragen positiv zu beeinflussen, ist die Erhöhung des thermischen Wirkungsgrades. Der Einsatz moderner Kraftwerkstechnik in Österreich zeigt, daß durch den Bau von Kombi-Block-Kraftwerken (Gasturbinen-Vorschaltprozeß) eine wesentliche Einsparung an Primärenergie bei gleichzeitig hoher Verfügbarkeit der relativ komplexen Kraftwerkssysteme, erzielt werden kann. Eine weitere Erhöhung der Gasturbinen-Eintrittstemperatur führt zu keiner wesentlichen Erhöhung des Wirkungsgrades, in dieser Hinsicht sind Verdampfungskreisläufe Gasturbinenkreisläufen überlegen. In einem Temperaturbereich zwischen 85o-9oo°C, in dem die bekannten Hochtemperaturwerkstoffe eine noch ausreichende Festigkeit aufweisen, haben nur die Alkalimetalle Kalium und Caesium jene physikalischen und thermodynamischen Eigenschaften, die sie zum Einsatz von Rankine-Kreisprozessen geeignet erscheinen lassen. Basierend auf Erfahrungen, die während der SB-Entwicklung und im Rahmen des US-Raumfahrtprogramms gewonnen wurden, wurde ein Kaliumdampf-Vorschaltprozeß vorgeschlagen, der in einer Kraftwerksschaltung mit einem Wasser- und einem Diphenylkreisprozeß einen thermischen Wirkungsgrad von über 5o% erzielen läßt. Im Rahmen der IEA wird dieser Dreifachdampfprozeß in einem multinationalen Programm untersucht, wobei konkret an der technisch-wirtschaftlichen Realisierbarkeit dieses Prozesses gearbeitet

wird. Im Österreichischen Forschungszentrum Seibersdorf, wo bereits seit 1968 Flüssigmetallversuchsstände in Betrieb sind, wurden experimentelle Untersuchungen zu diesem Projekt begonnen.

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SUMMARY

High energy prices and an increased investment of costs in power plants as well as the necessity to minimize all kinds of environmental pollution have severe consequences on the construction and operation of thermal power stations. One of the most promising measures to cope with the mentioned problems is to raise the thermal efficiency of power plants. With the example of an Austrian electric utility it can be shown that by application of high efficiency combined cycles primary energy can be converted into electricity in a most efficient manner. Excellent operating experience has proved the high reliability of these relatively complex systems. Raising the temperature of the gas topping process still higher will not raise the efficiency considerably. In this respect a Rankine cycle is superior to a Brayton cycle. In a temperature range of 85o to 9oo °C where conventional materials with known properties can still be used, only the alkali metals cesium and potassium have the necessary physical and thermodynamic properties for application in Rankine topping cycles. Building on experience gained in the Fast Breeder development and from the US space program, a potassium topping cycle linked to a conventional water steam cycle with an intermediate diphenyl vapour cycle has been proposed which should give thermal efficiencies in excess of 5o%. In a multi-national program this so called Treble Rankine Cycle is being investigated under the auspices of the International Energy Agency. Work is in progress to investigate the technical and economic feasibility of this energy conversion system. Experimental investigations are already under way in the Austrian Research Center Seibersdorf where high temperature liquid metal test facilities have been operated since 1968.

L'AUGMENTATION DU RENDEMENT THERMIQUE DES CENTRALES À COMBUSTIBLE TRADITIONNEL

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RESUMÉ

Les hauts prix de l'énergie et les coûts d'investissement élevés des centrales electriques aussi bien que la necessité de minimiser toutes les espèces de pollution d'environnement ont des consequences graves sur la construction et l'exploitation des centrales thermiques. L'augmentation du rendement thermique des centrales thermique constitue une possibilité prometteuse pour fair face à ces problemes.

L'exemple d'une societé d'electricité autrichienne met en évidence que l'application des cycles combinés permet une utilisation très efficace de l'energie primaire. L'excellent fonctionnement démontre la qualité du system assez complexe. Une augmentation de la temperature du gaz dans la turbine au dessus du niveau actuel ne resultera guerè dans une amelioration du rendement thermique. A cet ègard le cycle Rankine est superieur au cycle Brayton. Dans une bande de temperature de 85o^{o} à 9oo^{o}C compatible aux materiaux conventionels de proprietés connues seulement les metaux alcali cesium et potassium sont utilisables pour les cycles Rankine. Basant sur experience du program des surgenerateurs et du program spacial des Etats Unis on a proposé de combiner un cycle à potassium avec un cycle à eau à l'intermediaire d'un cycle à vapeur de diphenyl visant à un rendement de plus de 5o%. Ce dit Treble Rankine Cycle est investigé dans le cadre d'un program international sous les auspices de l'Agence Internationale d'Energie. Des traveaux pour la demonstration de la fiabilité technique et econonmique de ce system de conversion progressent. Des investigations expermentals se deroulent au centre autrichien de recherches de Seibersdorf ou les installations experimentals destinées aux metaux liquides marchent depuis 1968.

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Introduction

The sudden end of a low-cost energy situation has brought great problems to the industrialized as well as to those developing countries which lack hydrocarbon resources. The transition to a high-cost energy economy entails direct and indirect effects the consequences of which are still difficult to evaluate. There is certainly a need to conserve energy as much as possible and to diversify into alternative sources of energy to counteract an over-dependence on limited or unreliable energy sources. In the past it was possible to conduct an intense energy research and development effort in the industrialized countries but the availability of low-cost energy bared the carrying out of R&D at the largest possible scale. The situation now is more difficult, since R&D on alternative energy sources or new conversion technologies is costly and often very complex so that, with the given financial and monetary situation, decisions for a long-term program will be difficult to initiate. A further imperative in the development of new conversion technologies is the necessity to minimize all kinds of environmental pollution with the highest technical skill available. This means that the marginal conditions essential in judging the profitableness of a new development in energy conversion technology have changed considerably and are still changing. Under these difficult conditions technologies with high investment costs can reasonably be developed only through international cooperation. This presentation will deal with an international research project for the realization of potassium topping cycles for the improvement of the thermal efficiency of thermal power stations. This program has been started under the auspices of the International Energy Agency, whose main objective by definition is cooperative research, demonstration and development in conservation technologies.

Short Summary of Technical Achievements

- Rankine Cycles

  The thermal efficiency of electric utility steam plants was increased nearly tenfold from their inception in the 188os up to 195o. This was done mainly by increasing the peak temperature and pressure of the steam in accordance with the fundamental law delineated by Carnot 15o years ago. The strength of alloy steels drops rapidly above 5oo °C, so that the 565 °-25o bar steam conditions reached in the early 195os represented the practical upper limit obtainable with structural alloys that can be fabricated at reasonable costs. A gain in efficiency with the given temperature limits between 565 °C and ambient conditions can only be achieved by a very complete "Carnotization" of the thermodynamic process. This means, ultimately, that the heat of the combustion gases has to be transferred to the process at the highest possible temperature, that is, the maximum process temperature. In /1/ it could be shown that a Rankine cycle with an evaporating fluid as the process medium and with saturated steam conditions should give a better efficiency than any other process using a Brayton cycle or superheated steam conditions between the same temperature limits. Taking alternative working fluids into consideration /2/ it turns out that the rapid increase in vapour specific volume with a reduction in temperature makes the size of the equipment, especially the last turbine stages, and the condenser volume too large to be practicable if the temperature range covered in a Rankine Cycle is more than approximately 5oo °C for any given working fluid. A good solution is to employ a compound cycle with a high temperature, but a low pressure cycle, superimposed on a conventional steam cycle. This was realized in the USA between 192o and 195o with the so called Emmet process /3/ where a conventional steam cycle was topped by a mercury cycle. The efficiency of these plants was 3o to 38%, that is, about 5 points higher than the contemporary power stations. The scarcity and toxicity of mercury made the further development not practical, especially since improvements in conventional steam plants raised their efficiency to comparable values.

- Combined Cycles

The idea of combining a gas turbine and steam cycle is old. It was applied for the first time in the Velox boiler of 1932, where a compressor was put before the combustion chamber and a gas turbine after it. The turbine output required was only about sufficient to drive the compressor. A basically simpler idea was to put a suitable, separately fired gas turbine in front of an existing boiler, thus providing the boiler with hot combustion air. Another approach to the same basic solution is to recuperate exhaust heat of an existing gas turbine in a steam boiler. In the high-efficiency combined cycle the ratio of gas turbine output to steam turbine output is ideally fixed at something like 2o percent. In the recuperation cycle the steam cycle may produce roughly half the output of the gas turbine; with additional fuel burnt into the exhaust gases the output may be about equal or higher. For both types of these "energy cascading processes" there is ample construction and operating experience in Austria /¯5_/.

The construction of thermal power plants with hitherto unknown thermal efficiency was preceded by a thorough theoretical discussion about the prospects and merits of these installations /¯6, 7_/.

Table I shows the combined cycle power plants constructed so far in Austria.

TABLE I. HIGH EFFICIENCY POWER PLANTS IN AUSTRIA

	Year of Operation	Type[1)]	Output in MW_{el} Gas	Steam	Total	Max. Temp. °C	Efficiency %
Korneuburg A	196o	B	25	26	51	625	32
Hohe Wand	1964	A	11	78	89	75o	43
Theiss B	1976	A	72	25o	322	83o	38
Simmering 1/2	1977	A	66	377	443 314+28o[2)]	92o	45 69[2)]
Korneuburg B	198o	B	46	79	125	945	46

1) A "high efficiency combined cycle"
B "recuperation cycle"

2) Operation with heat cogeneration

In Fig. 1a the typical flow scheme and in Fig. 1b the thermodynamic cycle are given for the power station "Hohe Wand" which shall be a representative example for all the "high efficiency combined cycle" plants.

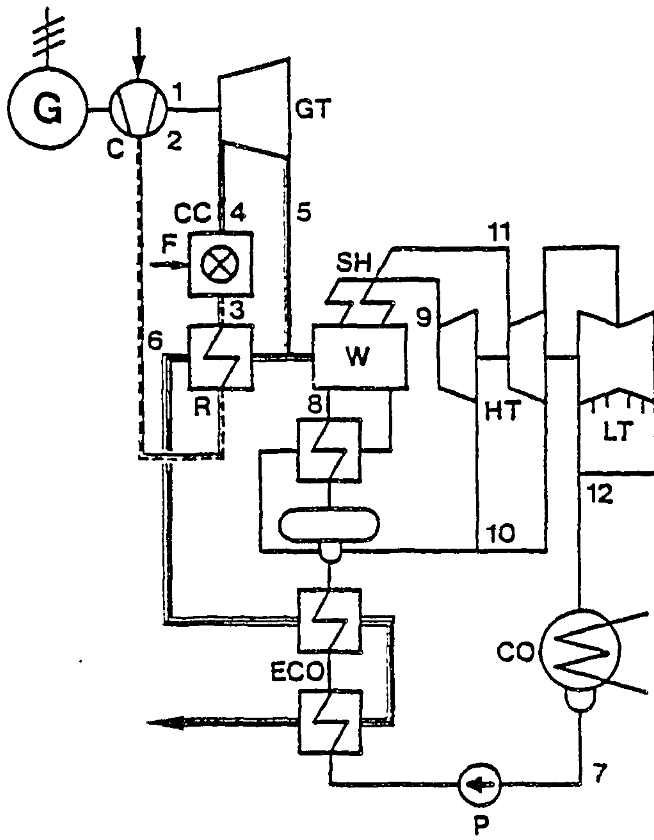

FIG. 1a: Simplified Flow Scheme of Combined Cycle "Hohe Wand"

Schéma simplifié d'une centrale combinée "Hohe Wand"

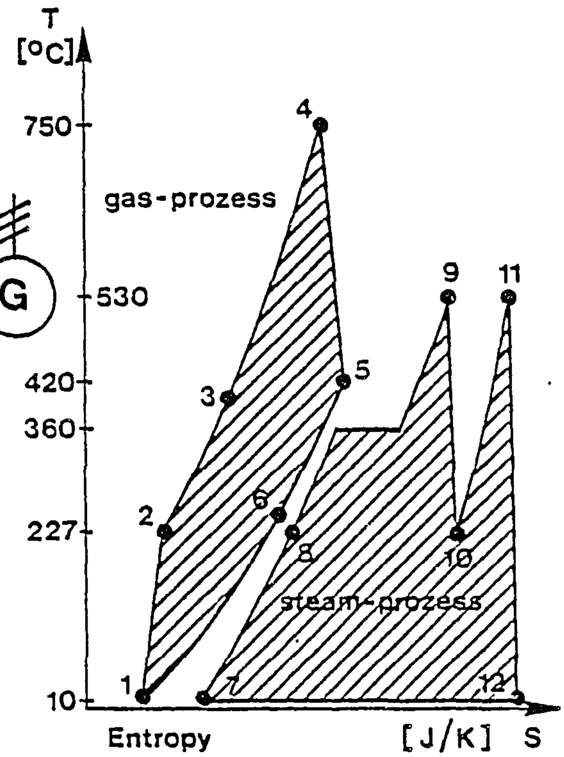

FIG. 1b: Temperature-Entropy-Diagram of Combined Cycle "Hohe Wand"

Diagramme temperature entropie pour la centrale combinée "Hohe Wand"

C	Compressor	Compresseur
CC	Combustion Chamber	Chambre à combustion
CO	Condenser	Condenseur
ECO	Economizer	Préchauffeur
F	Fuel	Combustible
G	Generator	Generateur
GT	Gas Turbine	Turbine à gaz
HT	High Pressure Turbine	Turbine à haute pression
LT	Low Pressure Turbine	Turbine à pression basse
P	Feed Pump	Pompe d'alimentation
R	Regenerator	Récupérateur
SH	Superheater	Surchauffeur
W	Windbox of Boiler	Chambre à suréchauffement

New Developments in High Temperature Technology

A gas turbine is a good solution for extracting mechanical energy from high temperature gas, and developments are under way to raise this temperature to more than 12oo °C. Because of the bad approximation to the ideal Carnot conditions theoretical thermal efficiencies of less than 5o% will be achievable even with these high temperatures. A Rankine cycle operating within the same temperature limits will give a much higher thermal efficiency. Let us assume that presently available austenitic stainless steels and high temperature alloys can be used for construction in a temperature range up to 85o to 9oo °C. The question now is what fluid will satisfy the conditions of a low pressure high density saturated vapour at these temperature limits. What at first guess seems to be a wide range of possible working fluids is reduced to the alkali metals potassium and cesium / 8 / as the most reasonable candidates for a working medium. The vapour pressure of potassium is only 2.4 bar and that of cesium 4 bar at 85o °C, with a corresponding vapour density of 1.16 kg/m^3 and 1.35 kg/m^3, respectively. Fortunately a lot of experience has been gained with these fluids in different research and development projects. During the US space program extensive materials research and component tests of alkali metal vapour cycles were conducted. This work included corrosion experiments with FeCrNi-alloys in boiling and condensing liquid metal systems, investigations into the stability of boiling and condensation and even component tests of small vapour turbines. This work was extended to fossil fuel plants in 197o.

The Fast Breeder Reactor uses sodium as heat transfer medium. Experience was generated world-wide in component and material behaviour. The main phenomenon of corrosion of Fe-base alloys in liquid metals is the dissolution of alloying elements and interstitial elements of the steel into the liquid metal with a catalytic action of oxygen and other non-metallic impurities. Solubilities of these elements in potassium are very small, but they increase strongly with temperature so that there is a tendency of mass transport in non-isothermal systems. Although maximum operating temperatures in Fast Breeder research were in the range from 65o to 73o °C the extensive knowledge of the influence of different parameters on material compatibility make extrapolations to higher temperatures possible. Calculations indicate that aside from alloy stability questions there should not be a major material problem as has been assumed before, though the designer is confronted with some subtle thermal stress problems.

Energy Cascading with Treble Rankine Cycle

The US approach to the realization of a high efficiency Rankine system with the maximum process temperature of 85o °C was a dual cycle with a potassium Rankine cycle topping a conventional supercritical steam process. Superheating of steam with the isothermally condensing potassium includes a relatively high exergy loss with a consequent loss of efficiency. Moreover, the direct coupling of the steam system operating at a pressure of more than 2oo bar to the potassium vapour system at a temperature of about 5oo °C involves a considerable risk in case of a leak and poses severe construction problems. These problems may be solved by the use of a third intermediate Rankine cycle. For this cycle diphenyl, a relatively stable organic medium, for which exists extensive operating experience as a heat transfer medium in chemistry plants, appears to be the optimum working fluid. The configuration of such a system as presented for the first time in /9/ is schematically given in Fig. 2a. Fig. 2b shows the thermodynamic cycle of the TRC without the gas turbine which is only responsible for a very low fraction of the total power output. The main reasons for this flue gas turbine/compressor set are the pressurization of the gas side of the potassium boiler and the necessity of a low temperature drop of the heating gas, which can be realized by a high recirculation rate of the flue gas. The main operating parameters of the TRC are summarized in Table II.

TABLE II. MAIN PARAMETERS OF TREBLE RANKINE CYCLE FOR 1ooo MW THERMAL INPUT ACCORDING TO /9/

Cycle	Upper Limit	Lower Limit	Power of Turbine MW_{el}
potassium	89o °C/ 3 bar	477 °C/o.o27 bar	291.o
diphenyl	455 °C/2o.9 bar	287 °C/2 bar	119.5
water	27o °C/55 bar	33 °C/o.o51 bar	198.1
			6o8.6
combustion gas	18oo °C/ 3.1 bar	14o °C/1 bar	6.7
total			615.3

The individual processes of this Treble Rankine Cycle process are operating almost totally under saturated or wet steam conditions, so that heat absorption and heat rejection through the heat exchangers takes place nearly isothermally. Thus the individual processes come very close to Carnot conditions. Since heat transfer coefficients by evaporation and condensation are the highest possible the necessary temperature differences to transport the heat are extremely low and the resulting exergy losses are minimized. Therefore the Carnotization of the total process between the maximum heat input temperature and ambient conditions is extremely high and reaches 97% of an ideal Carnot process between the same temperature limits. In contrast modern steam power plants usually have a maximum approximation of 8o% to the comparable Carnot cycle.

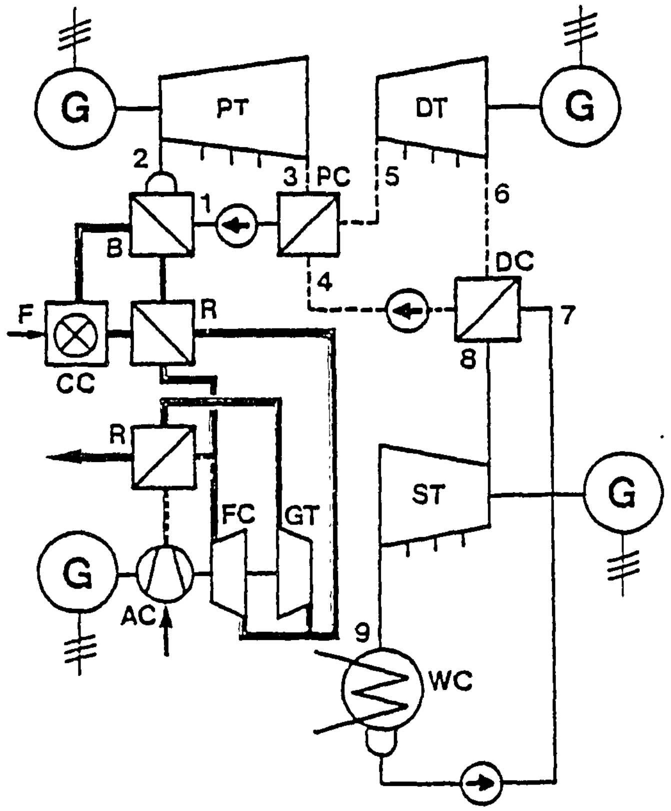

FIG.2a: Simplified Flow Scheme of a "Treble Rankine Cycle"

Schéma simplifié d'une "Centrale à Trois Circuits Rankine"

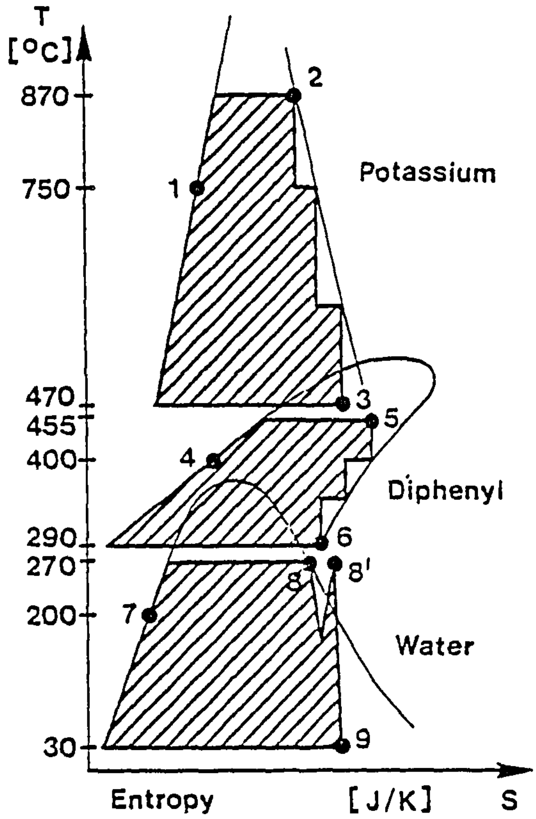

FIG.2b: Temperature-Entropy Diagram of a "Treble Rankine Cycle"

Diagramme temperature-entropie pour la "Centrale à Trois Circuits Rankine"

AC	Air Compressor	Compresseur à l'air
B	Boiler	Chaudière à vapeur
C	Compressor	Compresseur
CC	Combustion Chamber	Chambre à combustion
DC	Diphenyl Condenser	Condenseur à diphenyl
DT	Diphenyl Turbine	Turbine à diphenyl
F	Fuel	Combustible
FC	Fluegas Compressor	Compresseur à gaz combustion
G	Generator	Generateur
GT	Gas Turbine	Turbine à gaz
PC	Potassium Condenser	Condenseur à potassium
PT	Potassium Turbine	Turbine à potassium
R	Regenerator	Récupérateur
ST	Steam Turbine	Turbine à vapeur d'eau
WC	Water Condenser	Condenseur d'eau

From Figs. 2a, 2b and Table II it can be seen that the water/steam system is of a very conventional design. The operating temperatures in the diphenyl system are low enough so that probably no design and material problems will be encountered. The only question of importance may be the thermal stability of the diphenyl and the amount of cracking products released at maximum operating temperature. This may give rise to operational limitations or higher costs for a necessary inline purification. If problems in the design and construction of a Treble Rankine Cycle exist they will have to be looked for in the potassium topping cycle.

Material Considerations for the Potassium Topping Cycle

The designer of a potassium topping cycle will have to rely on proven material behaviour for which reliable data are not available at present. Nevertheless it is possible to extrapolate existing know-how to the operating conditions of the topping process. This will be discussed in more detail subsequently.

Most of the corrosion data referred to above have been generated in experimental facilities with the liquid metal flowing only in the liquid phase. It is important to recognize that with respect to the corrosion potential there exist basic differences between boiling and nonboiling systems. In nonboiling systems there is continuous flow through the circuit. Therefore, depending on loop geometry, heat transfer rates and other characteristic parameters, an euqilibrium between corrosion and deposition will result in a solute concentration which is unsaturated at the maximum loop temperature. Test sections are situated in this region and measure normally maximum corrosion rates.

The situation in a recirculating boiling liquid metal circuit, the flow scheme of which is given schematically for the potassium topping cycle of the TRC in Fig. 3, is contrary to that situation in the following points:

- Since in the boiler region the liquid fractionates into pure vapour and impure liquid at the maximum system temperature an increase in corrosion product concentration will occur causing eventually supersaturation rather than undersaturation.
- Transport of corrosion products will only occur in the wet fraction of the vapour which should be only 1% of the total mass flow.
- The main temperature drop in the system occurs in the turbine by expanding the vapour. An extremely pure condensate, which has a high solubility potential for metallic elements, will be generated only at relatively low temperatures.

These favourable operating conditions of a boiling system with respect to corrosion phenomenon lead to the following conclusions:

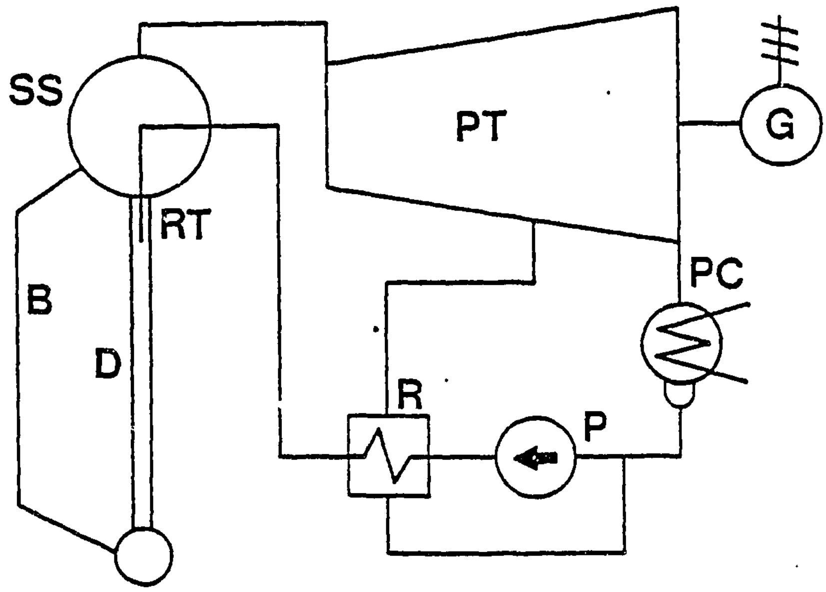

FIG. 3: Simplified Flow Scheme of the Potassium System
Schêma simplifiê du système potassium

B	Boiler	Tubes de chaudière
D	Downcomer	Retour
G	Generator	Generateur
P	Feed Pump	Pompe d'alimentation
PC	Potassium Condenser	Condenseur à potassium
PT	Potassium Turbine	Turbine à potassium
R	Regenerator	Récupêrateur
RT	Reentry Tubes	Tuyau de retour
SS	Steam Separator	Sêparateur de vapeur

Boiler region: The design of a recirculating boiler will take full advantage of the situation so that there will be an oversaturation of corrosion products in the boiler. A high recirculation rate will make the boiler nearly isothermal and saturated with corrosion products near the liquid/vapour interface. The vapour leaving the boiler will carry almost no corrosion products since their vapour pressure is orders of magnitude less than the vapour pressure of potassium at 89o°C. The same forces that build up solute in the boiler will also build up other impurities in this region. For this reason oxygen, carbon, nitrogen and all other contaminants introduced anywhere in the system will eventually migrate to the boiler and influence the corrosion behaviour of the constructional material. Ultimately corrosion will be inhibited and mass transport will be reduced. The best choice for a constructional material is a high-temperature high-strength material, for example Incoloy 8oo, which should be stable enough at 89o°C and which has already proved its applicability in liquid metal systems /‾8, lo_/. The main problem of the boiler seems to be corrosion product deposition which could lead to flow restrictions and consequently to unbalanced flow distribution and boiling instabilities in the boiler tubes.

Vapour lines and turbine: Given dry vapour, the only corrosion effects imaginable should be associated with sublimitation of surface material. As the unavoidable moisture content which may be saturated with corrosion products is carried through the vapour lines to the turbine, it could give rise to problems associated with erosion and corrosion product deposition. This will have to be considered in the design of the vapour carrying system and the turbine entrance to avoid unbalanced wheels rotating at high velocities. In the turbine the situation changes considerably since the potassium vapour expands; and with desuperheating of the vapour, condensate is generated in the turbine stages with an extremely low overall solute content. Therefore the first turbine blades will have to be manufactured from a corrosion resistent Mo-alloy. With falling temperature, solubility of alloying elements becomes lower and concentration in the condensate rises because of upstream corrosion. Therefore the driving force for dissolution will be reduced accordingly, so that below a temperature of approximately 7oo°C high strength Ni alloys can again be used for stationary and rotating turbine parts.

Condenser and boiler feed lines: Although the condensate in these components should have a high dissolution potential, it is noteworthy that at a temperature of 45o°C the solubility of Fe in potassium is only half of that in sodium and Ni is less soluble in potassium than in sodium /11/. In addition, since oxygen should be completely retained in the boiler section, no corrosion due to an oxygen reaction should occur during normal operating conditions. Therefore it seems possible that austenitic stainless steel is an adequate constructional material for condenser and feed lines. Still, one important question has to be settled: How and how much the condensate is preheated before entering the boiler. From thermodynamic reasons it is not necessary to make a rigorous Carnotization of the process. Therefore injection of subcooled liquid into the downcomer of a natural circulation boiler will alleviate most of the problems connected with preheating the condensate to a temperature level where solubility of alloying elements cannot be neglected anymore. The reason for this design solution is that the recirculation rate in the boiler can be maintained high enough so that undersaturation will be avoided.

Summing up, it can be stated that there is good evidence that the construction of a potassium topping cycle can be undertaken successfully with existing materials and today's technology.

High efficiency and a good chance of feasibility as far as materials are concerned are still not sufficient reasons to realize such an advanced system. Above all it has to be shown that such a system can be built on an economic basis and can be operated reliably as a base load or intermediate load power plant.

International Cooperation for the Realization of a TRC

In 1977 an "Implementing Agreement for a Programme of Research and Development on Energy Conservation through Energy Cascading" was signed by 9 countries in accordance with the general directives put forward by the International Energy Agency on cooperative energy research in 1975. The realization of this Implementing Agreement takes place in so-called Annexes. The Annex I, "Common Study", was carried out between 1977 and 1979. In this first approach some advanced technologies under development were evaluated. According to a proposal from the Austrian government the investigation of a TRC was included into this task. The methodology was roughly the same for all technologies: to find the theoretical technical potential, to find the economic potential by estimates founded on today's knowledge, and finally by investigating the implementation possibilities and barriers to find the actual market potential and the energy savings. Although the conclusions of this task, presented in a final report, were still based on estimates, the TRC proved to be interesting enough to be investigated more thoroughly. For this purpose an Annex II Study, "Treble Rankine Cycle Project - Design Analysis Study and Establishment of an R&D Programme", was put into action in 1979. Participants in this study are the Federal Republic of Germany (FRG), the Netherlands (NL) and Austria (A), the operating agent being the Federal Republic of Germany. This Annex II Study is aimed to be a "pre-design study", including actual technical solutions with main dimensions and a cost estimate on a technical basis for a 6oo MW_{el} power station. Industrial partners from each of the participating coutries are involved in the actual design work and also in giving additional financial support. It was soon decided that in a first run of Annex II the really crucial components rather should be dealt with in sufficient depth instead of doing everything, but noting really thoroughly enough. Therefore the following frame of participation was put into operation:

FRG: potassium turbine, high temperature fittings

NL: high temperature pipe work, potassium pump, potassium/diphenyl heat exchanger, auxiliary and safety systems

A: potassium evaporator including coal fired furnace. (Supported by an industrial partner of the FRG).

Additional work in the field of the diphenyl system and with respect to the reliability of the total plant is being done by Austria. Since at the time of completion of this paper work on this project is still under way and a detailed presentation of results will be confined to the participants in the task, only a short statement can be given on the progress of the Annex II:

The change of fuel from oil in the first presentation /¯9_7 to coal in this study gave rise to complications in the furnace-boiler configuration to which technical solutions could be found. The turbine is said to be expensive but feasible. Heat exchangers, pumps and pipe work pose no serious problems. It is still too soon to add up total costs to make the necessary economic calculations and to make realistic assumptions about reliability.

Parallel to this work being done in an international cooperation and in anticipation of R&D work which will have to be executed on a semi-technical scale as a result of this study, an experimental program has been started already in the Austrian Research Center Seibersdorf where liquid metal test facilities are operated for R&D work for alternative energy conversion systems.

Experimental Facilities in the Austrian Research Center Seibersdorf

The experimental foundations which made possible the proposal of a potassium topping cycle for power plants have been described in preceding chapters. A short overview will be given now about the research work being conducted meanwhile on potassium problems.

Continuing with the project idea that started in 1974, in addition to sodium test facilities which have been in operation since 1968, a potassium high temperature loop has been constructed and operated. Details of this facility are given in /¯12_7. Fig. 4 gives a simplified flow scheme of this test facility.

Highlights of first operating results may be summarized as follows:

- 7oo l of industrial grade potassium were transferred from barrels into the loop by distillation, considerably reducing the content of sodium and non-metallic impurities in the potassium.
- The purification and control of impurities could be demonstrated with components analogous to those used in other liquid metal systems, e.g. sodium.
- Operational problems may be induced mainly by the very high solubility of all kinds of impurities, including the cover gas in the potassium.
- First results of corrosion and mass transport investigations in a temperature range of up to 7oo°C indicate that under

comparable test conditions corrosion rates will be in the same order of magnitude as measured in sodium systems.

One of the greatest barriers to the development of alkali metal vapour cycles is the fear of leaks. Hot alkali metal leaking into the atmosphere will ignite spontaneously; air leakage into the alkali metal system will cause severe corrosion of constructional materials. Experience has shown that small changes in impurity concentrations in the alkali metal can be measured readily so that a leak into the system (for instance into the low-pressure portion of a topping cycle) can be discovered at an early stage of failure propagation and countermeasures can be taken. A leak to the outside will be detected by aerosol formation and the system should then be shut down.

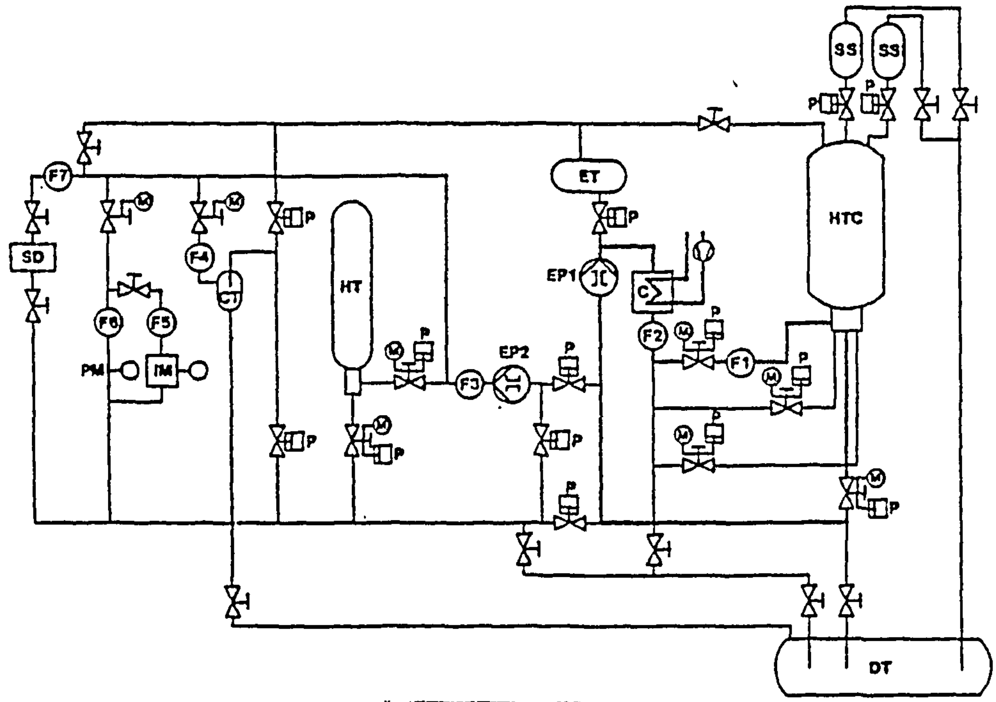

FIG. 4: Simplified Flow Scheme of the Potassium High Temperature Loop "HT 3"

Schéma simplifié du boucle de potassium à haute temperature "HT 3"

CT	Cold Trap	Piège froid
DT	Dump Tank	Reservoir de vidange
EP	Electromagnetic Pump	Pompe éléctromagnetique
ET	Expansion Tank	Récipient d'expansion
F	Flowmeter	Débitmètre
HT	Hot Trap	Piège chaude
HTC	High Temperature Container	Cuve à haute temperature
IM	In Line Monitor	Monitor continue
M	Motor Drive	Commande éléctrique
P	Pressurized Air Drive	Commande à air pressurée
PM	Plugging Meter	Indicateur de plugging
SD	Sampling Device	Prise d'échantillons
SS	Safety System	Appareillage de sécurité

Uncertainties existed in the judgement of pool fires resulting from great leaks at high temperatures. Test series were carried out with the unexpected result that potassium pool fires could be handled more easily than sodium fires.

The experimental program for the near future will be the demonstration of component and material compatibility in liquid potassium at the maximum operating temperature of a topping cycle, that is 87o-89o°C. Additional experiments will cover problems of boiling instabilities and corrosion in a recirculation boiling circuit.

Concluding Remarks

- It is a necessity for all countries to conserve energy and to diversify into alternative sources of energy. In case of electricity production in thermal power stations an increase of conversion efficiency can conserve primary energy and reduce all kinds of environmental pollution.
- Power plants with a high thermal efficiency are more complicated than conventional systems. Operation experience with "high efficiency combined cycles" using gas turbines as topping cycles has demonstrated excellent reliability and high conservation capability.
- Because of the use of a Brayton cycle in a combined cycle a further significant increase in conversion efficiency cannot be expected. A Rankine cycle with an evaporating working fluid will give a better conversion efficiency between the same working temperatures.
- With potassium as the working fluid the necessary vapour qualities can be generated in a temperature range below 9oo°C where existing constructional materials can be used. For the best Carnotization of the thermodynamic process between heat input temperature and ambient conditions, three vapour processes have to be put on top of each other, a water, a diphenyl and a potassium cycle, which together give the Treble Rankine Cycle Process.
- A great amount of experience has been accumulated in the field of alkali metal technology resulting from the Fast Breeder Reactor Development and from activities in the US space program. From these results there is good evidence that construction of a potassium topping cycle can be undertaken successfully with existing materials and today's technology.
- An international program for the realization of a TRC has been started under the auspices of the IEA. Presently an engineering study is under way which will include technical solutions with main dimensions and a cost estimate for a 6oo MW_{el} coal fired power station.
- Essential experimental work for the development of components and the demonstration of material behaviour in high temperature potassium systems is being conducted in the Austrian Research Center Seibersdorf.

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