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## Razvoj termoelektrarn na premog in varstvo okolja

### Development of Coal Fired Power Plants and Environmental Protection

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Prikazan je sedanji in prihodnji razvoj termoelektrarn na premog, kakršnega pričakujejo v tehnično razvitem svetu. Skrb za okolje vse bolj usmerja razvoj termoenergetike. Neprestano naraščajoč delež  $CO_2$  v ozračju, ki verjetno povzroča pojav »tople gred« z vsemi škodljivimi posledicami, zasluži vso pozornost. Predstavljeni so aktualni ukrepi za zmanjšanje emisije: posredni (izboljšanje izkoristka procesa) in neposredni ukrepi (izločanje). Možnost uporabe gorivnih celic je kratko opisana, čeprav je njihov razvoj še na začetku.

Present and future progress of power plants fired by coal expected by the industrially developed world is presented. The concern about the environment is more and more defining the direction of progress in power and energy engineering. The continuously increasing amount of  $CO_2$  in the atmosphere which probably causes the »greenhouse« effect with all its harmful consequences is especially worth mentioning. Realistic measures for the reduction of emissions are presented: Indirect measures (improvement of process efficiency) and direct measures (separation). The possibility of the use of fuel cells is briefly described although the development of these is still at the beginning.

#### 0 UVOD

Do sedaj odkrite svetovne zaloge fosilnih goriv, zemeljskega plina, surove nafte in premoga, napovedujejo, da bo delež premoga pri svetovnih potrebah po energiji moral ostati. Hkrati z željo, da bi ohranili dragocene zaloge zemeljskega plina in surove nafte, se moramo zavedati, da premog pri zgorevanju izredno obremenjuje okolje. In to ne le s »klasičnimi« onesnaževalniki, kakor so trdni delci letečega pepeла, žveplov dioksid  $SO_2$  in dušikovi oksidi  $NO_x$ , ki so dandanes tehnično obvladljivi, seveda za ustrezno ceno. Tudi pri »sodobnem« onesnaževalniku, ogljikovem dioksidu  $CO_2$ , ki najverjetneje povzroča segrevanje ozračja (»topla greda«), ima premog največji specifični emisijski količnik (črni premog 0,09 kg  $CO_2/MJ$ , rjavi premog oz. lignit, ki je za nas bolj zanimiv, pa celo 0,11 kg  $CO_2/MJ$ ). Nadaljnja raba ogromnih zalog premoga v svetu je torej v nasprotju s sklepi resolucije WEC kongresa v Toronto, ki zahteva zmanjšanje emisije ogljikovega dioksida  $CO_2$  za 25 odstotkov, in komisije ES, ki resno razmišlja o uvedbi posebnega davka na  $CO_2$ . Proizvodnja električne energije v termoelektrarnah ima znaten delež v celotni emisiji ogljikovega dioksida (okoli 28 odstotkov), od tega s premogom kurjene okoli 22 odstotkov.

Možnosti za zmanjševanje emisije ogljikovega dioksida v elektrarnah so:

- Jadrnska energija – vendar javno mnenje nasprotuje uporabi, razen v nekaterih deželah (Francija, Belgija).

#### 0 INTRODUCTION

Present data on known resources of fossil fuels, such as natural gas, oil and coal, suggest that coal will continue to play an important role in covering a part of the world's energy consumption. Although the use of natural gas and oil must be somehow retained, we have to be aware that coal combustion is a heavy burden for the environment. It emits »classic« pollutants such as solid flying ashes,  $SO_2$  and  $NO_x$ , which can, at a price, be technically removed from the exhaust gases. The amount of »modern« pollutant  $CO_2$  emitted by coal is the highest among fossil fuels (black coal 0.09 kg  $CO_2/MJ$ , brown coal even 0.11 kg  $CO_2/MJ$ ). Further intensive use of coal is in conflict with the Toronto WEC resolution, demanding the reduction of  $CO_2$  emission by 25 %. The EC commission is seriously considering the introduction of a special  $CO_2$  tax. Electricity production in power plants fired by fossil fuels accounts for a considerable proportion of the overall  $CO_2$  emission (about 28 %), coal fired about 22 %.

Possibilities for the reduction of  $CO_2$  emission in power plants are:

- Nuclear energy; it is opposed by public opinion, except for some countries (France, Belgium),

– Uporaba zemeljskega plina, specifična emisija je tu skoraj za 50 odstotkov manjša (0,0528 kg CO<sub>2</sub>/MJ). Eden izmed scenarijev energijske strategije, ki jo pripravlja Ministrstvo za gospodarske dejavnosti Slovenije [1], sloni na tem gorivu.

Zahodna Evropa napoveduje do leta 2010 gradnjo termoelektrarn v skupni moči 200 GW, v pretežni meri kot nadomestilo za sisteme, ki jim bo v tem obdobju potekla doba trajanja.

Porazdelitev teh elektrarn je naslednja:

- 4 % hidroelektrarne,
- 3 % kombinirana proizvodnja toplote in električne energije,
- 3 % izkorščanje ostankov (smeti, lesni odpadki),
- 10 % jedrska energija,
- 28 % zemeljski plin in
- 52 % premog.

V pričujočem pregledu nas zanima, kaj je mogoče storiti na področju zmanjševanja emisije ogljikovega dioksida pri termoelektrarnah na premog. Dva izmed treh scenarijev prihodnje strategije oskrbe Slovenije z energijo [1] slonita namreč na premogu, eden na domačem, drugi na uvoženem.

Pri kurjenju premoga razlikujemo dve vrsti ukrepov za zmanjšanje emisije ogljikovega dioksida:

- posredne, kjer je zmanjšanje emisije doseženo v pretežni meri z izboljšanjem izkoristka toplotnega procesa in
- neposredne, kjer iz uplinjenega premoga ali pa dimnih plinov izločimo del ogljikovega dioksida.

– Natural gas; specific emission is about 50 % lower (0.053 kg CO<sub>2</sub>/MJ). One of the energy scenarios envisaged by the Slovenian Ministry of Economic Affairs [1], is based on natural gas.

Western Europe plans to build power plants with an overall power of 200 GW by the year 2010, basically as a replacement for old systems.

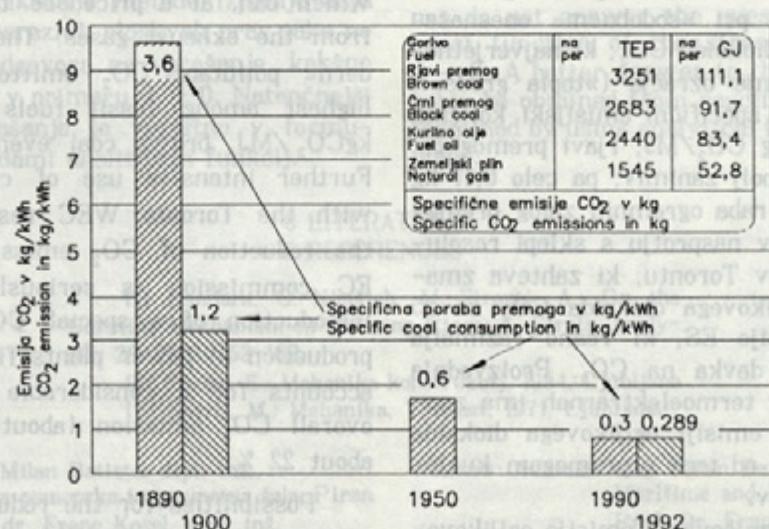
Distribution of the planned power plants is:

- 4 % hydro power plants,
- 3 % combined heat and power production,
- 3 % exploitation of waste (municipal solid waste, wood waste),
- 10 % nuclear power,
- 28 % natural gas,
- 52 % coal.

This paper is concerned with possibilities for the reduction of CO<sub>2</sub> emission by coal fired power plants. Two of three scenarios for future Slovenian energy supply [1] are based on coal, one on domestic and the other on imported coal.

There are two sorts of measures for reducing CO<sub>2</sub> emissions by power plants:

- indirect, where the reduction is caused by an improvement in the cycle efficiency and
- direct, where a part of the CO<sub>2</sub> is extracted from gasified coal or flue gases.



Sl. 1. Emisija ogljikovega dioksida (črni premog, najboljše vrednosti)

Fig. 1. Carbon dioxide emission (black coal of the best quality)

Tu je, energetsko gledano, posebej zanimiva prva skupina ukrepov. Slika 1 (po [2]) prikazuje, kako se je manjšala specifična poraba premoga za proizvodnjo 1 kW električne energije in tem tudi specifična emisija ogljikovega dioksida v zadnjih 100 letih. V preglednici na sliki so prikazane tudi specifične vrednosti emisije CO<sub>2</sub> na tono ekvivaletnega črnega premoga (TEP), oziroma na GJ.

## 1 IZBOLJŠANJE IZKORISTKA TOPLOTNEGA PROCESA

### 1.1 Osnovni parni proces

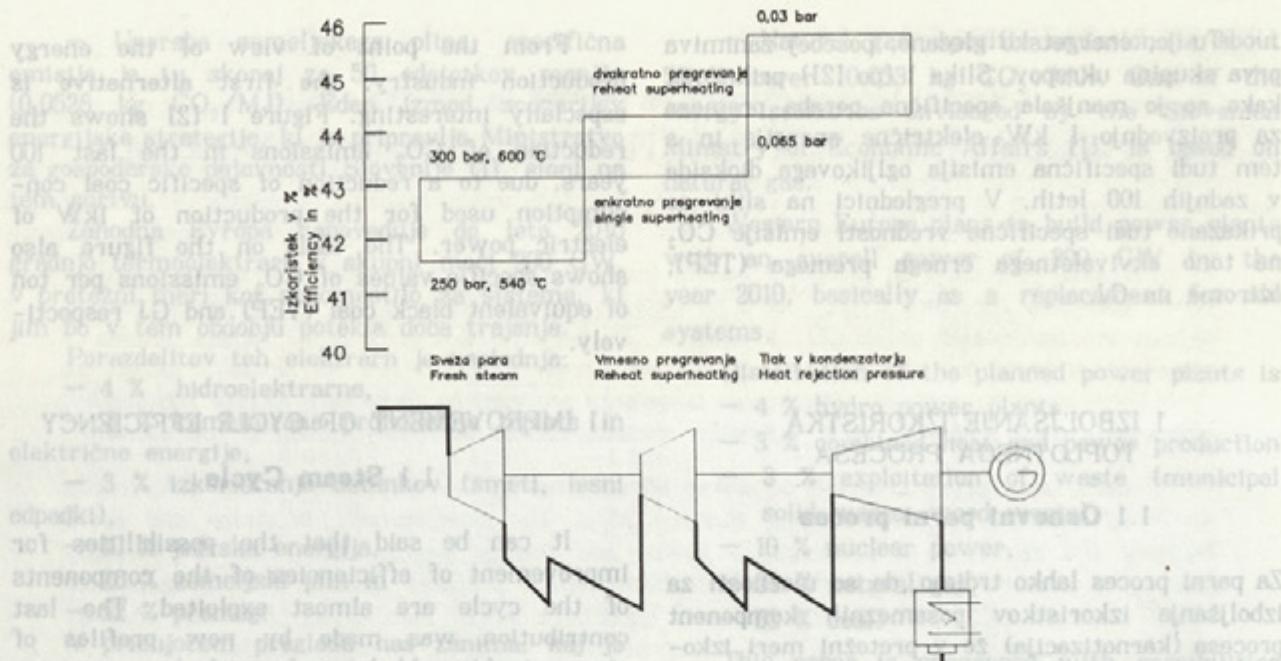
Za parni proces lahko trdimo, da so možnosti za izboljšanje izkoristkov posameznih komponent procesa (karnotizacija) že v pretežni meri izkorisčene. Zadnje izboljšanje so prispevali novi profili lopatic parnih turbin, dobljeni z računalniškim simuliranjem tridimenzionalnega pretoka pare. Tako lahko povečamo izkoristek krožnega procesa le še s povečanjem vstopnih parametrov sveže pare. Nadkritični parni procesi sicer niso popolna novost, saj so se prvi pojavili že pred dobrimi dvajsetimi leti. Slaba stran je bila izredno visoka cena zaradi uporabe avstenitnih jekel, ki so ob tem še premalo elastična, tako da so tak postroj lahko uporabljali le za osnovno obremenitev. V zadnjih letih so ameriški, nemški in japonski metallurgi izdelali feritno-martenzitna jekla, ki so uporabna do nadkritičnih parametrov (600 °C, 350 bar), s tendenco povišanja. To so jekla, ki vsebujejo ob 9 do 12 odstotkov kroma ter molibden in vanadij. Izkušnjam prvih že zgrajenih sodobnih termoelektrarn z nadkritičnimi parametri je bila posvečena posebna mednarodna konferenca v Koldingu na Danskem junija 1993. Izkušnje z nadkritičnimi parametri zbirajo hkrati v ZDA, Zahodni Evropi in na Japonskem, kjer so zgrajene tudi prve take termoelektrarne. V diagramu na sliki 2 (po SIEMENS-u) je prikazano mogoče izboljšanje izkoristka zaradi povečanja vstopnih parametrov, prehoda na dvojno vmesno pregrevanje pare in znižanja tlaka v kondenzatorju. Zadnji prispevek je mogoč le pri nizki temperaturi hladilne vode. Tako termoelektrarna v Aalborgu na Danskem, pri predvidenem izkoristku 47 odstotkov, uporablja hlajenje z morsko vodo s temperaturo 10 °C, ki jo črpa iz globine, kar za naše razmere ne pride v poštev. Za primerjavo: blok IV termoelektrarne Šoštanj, ki je bil zgrajen pred dobrimi dvajsetimi leti (1972), ima optimalen izkoristek pod 36 odstotkov.

From the point of view of the energy production industry, the first alternative is especially interesting. Figure 1 [2] shows the reduction of CO<sub>2</sub> emissions in the last 100 years, due to a reduction of specific coal consumption used for the production of 1kW of electric power. The table on the figure also shows specific values of CO<sub>2</sub> emissions per ton of equivalent black coal (TEP) and GJ respectively.

## 1 IMPROVEMENT OF CYCLE EFFICIENCY

### 1.1 Steam Cycle

It can be said that the possibilities for improvement of efficiencies of the components of the cycle are almost exploited. The last contribution was made by new profiles of steam turbine blades, obtained by computer simulation of the three dimensional steam flow. Further improvement of the Rankine cycle efficiency can today be made only by higher temperatures and pressures of the steam entering the turbine. Supercritical Rankine cycles are not entirely new, since the first ones appeared almost 20 years ago. The disadvantage of these cycles is the very high price of the austenite steel, which is, in addition, not sufficiently elastic, so that such systems could run only at nominal load. In the last few years, American, German and Japanese metallurgists have developed new ferrite-martensite steel, which is nowadays used for supercritical parameters (600 °C, 350 bar). These materials contain molybdenum and vanadium, in addition to 9 to 12 % of chromium. A special international conference at Kolding, Denmark, held in June 1993, was devoted to the first experiences with supercritical power plants operation. These experiences have been collected simultaneously in USA, Western Europe and Japan, where the first supercritical power plants have been built. The diagram in Figure 2 (by SIEMENS) shows a possible improvement of thermal efficiency due to higher parameters of the fresh steam, double reheat and lower pressure heat rejection in a condenser. The latter is possible only when low temperature cooling water is available. The power plant in Aalborg, Denmark, with 47 % efficiency, uses sea water at 10 °C, pumped from the sea depths. For comparison: Unit IV, of Šoštanj power plant, built in 1972, has a best efficiency of just under 36 %.



SI. 2. Vpliv posameznih parametrov na izkoristek postroja  
Fig. 2. Influence of different parameters on system efficiency

## 1.2 Plinsko-parni proces z zemeljskim plinom oz. kapljevitim gorivom

Povečanje izkoristka toplotnega procesa je mogoče v prvi vrsti s povečanjem zgornje temperaturje procesa. Zato pomeni optimalno rešitev plinska turbina z vstopnimi temperaturami do  $1200^{\circ}\text{C}$ , s tendenco povisjanja. Pri takih vstopnih temperaturah in optimalnem kompresijskem razmerju je izstopna temperatura dimnih plinov med  $500^{\circ}\text{C}$  in  $600^{\circ}\text{C}$ , kar lahko izkoristimo v kotlu na odpadno toploto, ki daje paro parnemu procesu. Razmerje moči je  $2/3$  plinskega in  $1/3$  parnega procesa. Take sisteme imamo tudi pri nas, npr. v plinsko-parnih elektrarnah Brestanica (sl. 3) in Trbovlje, le da so bili tam izkoristki do 37 odstotkov, dandanes pa taki, seveda močnejši sistemi, dosegajo izkoristke do 55 odstotkov.

Slaba stran te kombinacije je le, da kurimo dragocen zemeljski plin in tekoča goriva. Zato v svetu pospešeno raziskujejo možnost zamenjave zemeljskega plina z uplinjenim premogom.

## 1.3 Plinsko-parne elektrarne na uplinjen premog

V Evropi poteka nekaj projektov, ki raziskujejo to področje. Najbolj znan je Kobra, ki načrtuje uplinjanje rjavega premoga in je za nas najbolj zanimiv. Na sliki 4 je shema takega procesa, ki je v osnovi podoben omenjenemu v prejšnjem poglavju, s približnim razmerjem moči plinskega in parnega procesa  $2/1$ . Razlika je le

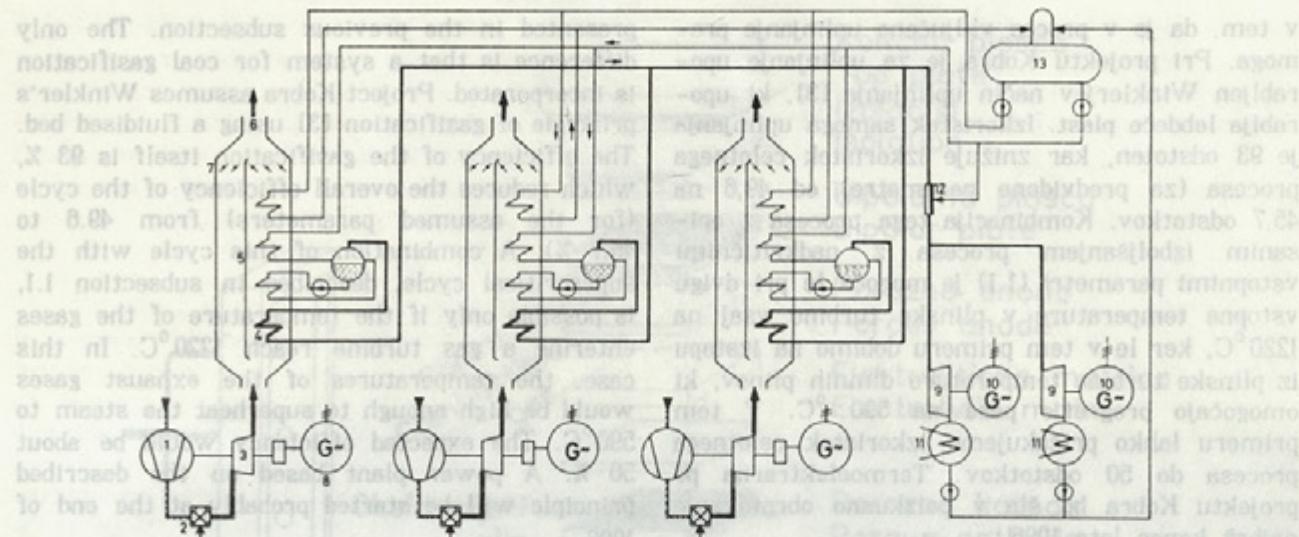
## 1.2 Combined Gas-Steam Power Cycle Fired by Natural Gas or Liquid Fuel

The improvement of the cycle efficiency is primarily due to a higher temperature of the heat addition. A gas turbine with an inlet temperature of  $1200^{\circ}\text{C}$  and higher is therefore an optimal solution. Applying such an inlet temperature and corresponding pressure results in an exhaust gases temperature of  $500$  to  $600^{\circ}\text{C}$ , which can be utilized in a waste heat boiler (utilizer), providing heat for a bottoming Rankine cycle. Such systems also exist in Slovenia, in Brestanica (Figure 3) and Trbovlje [5] power plants, where the achieved overall efficiencies are about 37 %. Nowadays modern and more powerful combined gas-steam power plants reach efficiencies up to 55 %.

The disadvantage of such combined systems is the consumption of valuable natural gas and liquid fuels. The possibility of replacing natural gas by gasified coal is therefore being intensively studied.

## 1.3 Combined Gas-Steam Power Cycle Fired by Gasified Coal

A few projects running in Europe are dealing with this theme. Kobra, planning the gasification of brown coal, is well-known and the most interesting for Slovenia. Figure 4 shows the scheme of such a process, with an approximate power ratio of the gas and steam cycle of  $2/1$ , which is basically similar to that

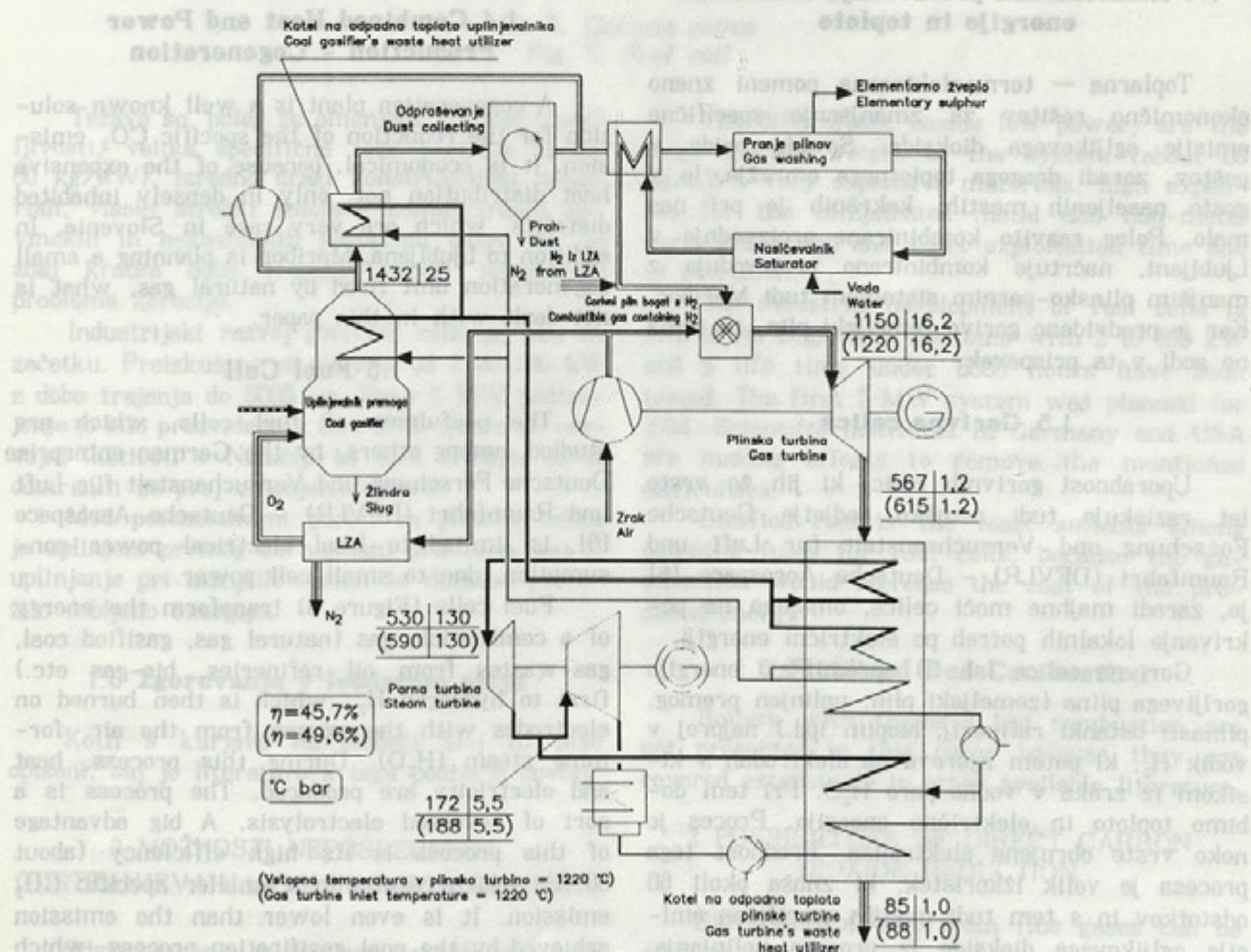


Sl. 3. Shema plinsko-parne elektrarne Brestanica

1 - kompresor, 2 - gorilnik, 3 - plinska turbina, 4 - buben, 5 - dimni kanal, 6 - dimnik, 7 - lopute, 8 - generator, 9 - parna turbina, 10 - kondenzator, 11 - rezervoar napajalne vode, 12 - hlajenje pare

Fig. 3. Scheme of gas-steam power plant Brestanica

1 - compressor, 2 - burner, 3 - gas turbine, 4 - boiler drum, 5 - flue gases duct, 6 - chimney, 7 - shutters, 8 - generator, 9 - steam turbine, 10 - condenser, 11 - feedwater tank, 12 - steam temperature control



Sl. 4. Shema plinsko-parne elektrarne z vplinjanjem premoga v lebdeči plasti

Fig. 4. Scheme of gas-steam power plant with fluidized bed coal gasification

v tem, da je v proces vključeno uplinjanje premoga. Pri projektu Kobra je za uplinjanje uporabljen Winklerjev način uplinjanja [3], ki uporablja lebdečo plast. Izkoristek samega uplinjanja je 93 odstoten, kar znižuje izkoristek celotnega procesa (za predvidene parametre) od 49,6 na 45,7 odstotkov. Kombinacija tega procesa z oplasnim izboljšanjem procesa z nadkritičnimi vstopnimi parametri (1.1) je mogoča le pri dvigu vstopne temperature v plinsko turbino vsaj na  $1220^{\circ}\text{C}$ , ker le v tem primeru dobimo na izstopu iz plinske turbine temperature dlimnih plinov, ki omogočajo pregretje pare na  $590^{\circ}\text{C}$ . V tem primeru lahko pričakujemo izkoristek celotnega procesa do 50 odstotkov. Termoelektrarna po projektu Kobra bo šla v polzusno obratovanje najbrž konec leta 1996.

Podobne raziskave [7] potekajo v ZDA, Hollandiji in na Japonskem, prelzkusne elektrarne pa gradijo v Buggenumm-u v Hollandiji, v Puerto-llanu v Španiji ter že omenjeni Kobra objekt v Kölnu (Nemčija) v TE Goldenberg.

#### **1.4 Kombinirana proizvodnja električne energije in toplotne**

Toplarna – termoelektrarna pomeni znano ekonomično rešitev za zmanjšanje specifične emisije ogljikovega dioksida. Seveda pride v poštev, zaradi dragega toplotnega omrežja, le v gosto naseljenih mestih, kakršnih je pri nas malo. Poleg razvite kombinirane proizvodnje v Ljubljani, načrtuje kombinirano proizvodnjo z manjšim plinsko-parnim sistemom tudi Maribor. Ker je predvideno gorivo zemeljski plin, ta tema ne sodi v ta prispevek.

#### **1.5 Gorivna celica**

Uporabnost gorivnih celic, ki jih že vrsto let raziskuje tudi nemško podjetje Deutsche Forschung und Versuchsanstalt fur Luft und Raumfahrt (DFVLR) – Deutsche Aerospace [8] je, zaradi majhne moči celice, omejena na pokrivanje lokalnih potreb po električni energiji.

Gorivne celice (sl. 5) spremiščajo energijo gorljivega plina (zemeljski plin, uplinjen premog, plinasti ostanki rafinerij, bioplín ipd.) najprej v vodik  $\text{H}_2$ , ki potem zgoreva na elektrodah s kisikom iz zraka v vodno paro  $\text{H}_2\text{O}$ . Pri tem dobimo toplotno in električno energijo. Proses je neke vrste obrnjena elektroliza. Prednost tega procesa je velik izkoristek, ki znaša okoli 60 odstotkov in s tem tudi manjša specifična emisija ogljikovega dioksida iz procesa uplinjanja, ki je še za tretjino manjša od tiste pri zemeljskem plinu.

presented in the previous subsection. The only difference is that a system for coal gasification is incorporated. Project Kobra assumes Winkler's principle of gasification [3] using a fluidised bed. The efficiency of the gasification itself is 93 %, which reduces the overall efficiency of the cycle (for the assumed parameters) from 49.6 to 45.7 %. A combination of this cycle with the supercritical cycle, described in subsection 1.1, is possible only if the temperature of the gases entering a gas turbine reach  $1220^{\circ}\text{C}$ . In this case, the temperatures of the exhaust gases would be high enough to superheat the steam to  $590^{\circ}\text{C}$ . The expected efficiency would be about 50 %. A power plant based on the described principle will be started probably at the end of 1996.

Similar studies [7] are in progress in the USA, Holland and in Japan, and experimental power plants are being built in Buggenumm (Holland), Puerto-llan (Spain) and in Cologne (Germany) in the already mentioned Kobra project Goldenberg power Plant.

#### **1.4 Combined Heat and Power Production – Cogeneration**

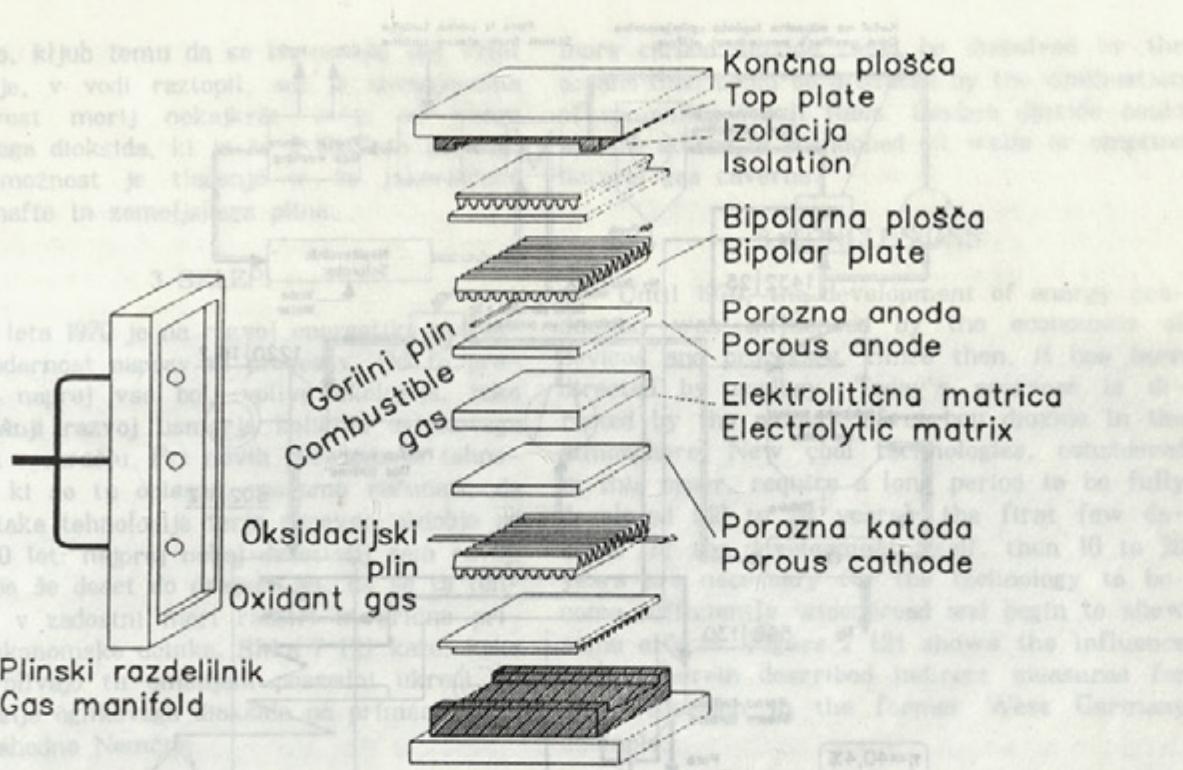
A cogeneration plant is a well known solution for the reduction of the specific  $\text{CO}_2$  emission. It is economical, because of the expensive heat distribution net, only in densely inhabited districts, which are very rare in Slovenia. In addition to Ljubljana, Maribor is planning a small cogeneration unit fired by natural gas, what is not dealt with in this paper.

#### **1.5 Fuel Cell**

The usefulness of fuel cells, which are studied, among others, by the German enterprise Deutsche Forschung und Versuchsanstalt für Luft und Raumfahrt (DFVLR) – Deutsche Aerospace [8], is limited to local electrical power consumption, due to small cell power.

Fuel cells (Figure 5) transform the energy of a combustible gas (natural gas, gasified coal, gas-wastes from oil refineries, bio-gas etc.) first to hydrogen  $\text{H}_2$ , which is then burned on electrodes with the oxygen from the air, forming steam ( $\text{H}_2\text{O}$ ). During this process, heat and electricity are produced. The process is a sort of reversed electrolysis. A big advantage of this process is its high efficiency (about 60 %), which results in a smaller specific  $\text{CO}_2$  emission. It is even lower than the emission achieved by the coal gasification process, which is still only 75 % of that achieved by natural gas combustion.

da se bo, kljub temu da se v ozračju zadrži samo 10 do 20 % ogljikovega dioksida, mogoče izkoristiti zmogljivosti morja nekajkrat. Druga možnost je tudi uporaba vrtive nafte in zemeljskega plina.



Sl. 5. Gorilna celica

Fig. 5. Fuel cell

Težave so, poleg že omenjene majhne zmogljivosti, velika specifična teža postroja (pribl. 60 kg/kW), izredno dragi konstrukcijski materiali, visoki stroški izdelave komplikiranih kovinskih in nekovinskih sestavnih delov ter za zdaj kratka doba trajanja zaradi nerešenega problema korozije.

Industrijski razvoj gorilnih celic je še na začetku. Preizkušeni so sistemi od 2 do 100 kW z dobo trajanja do 6000 ur. Prvo 2 MW postrojenje je bilo predvideno v letu 1995. Danes se razvojni inštituti v Nemčiji in ZDA trudijo, da bi odstranili že prej omenjene težave.

Med potencialnimi gorivi za plinske celice je uplinjeni premog še najmanj primeren, saj bi uplinjanje pri manjših enotah še dodatno podražilo dobljeno energijo.

### 1.6 Zgorrevanje v lebdečem sloju

Kotli s kurjavo na lebdeči sloj tu niso opisani, saj je literature s tega področja dovolj.

The difficulties, beside low power, are the large specific weight of the system (about 60 kg/kW), very expensive materials, high expenses for the complicated metal and non-metal parts production and short exploitation time due to corrosion.

The industrial development of fuel cells is still at its beginning. Systems with 2 to 100 kW and a life time under 6000 hours have been tested. The first 2 MW system was planned for 1994. Scientific Institutes in Germany and USA are making efforts to remove the mentioned difficulties.

Gasified coal is the least suitable among potential fuels for fuel cells, because the gasification would increase the cost of the produced energy.

### 1.6 Fluidised Bed Combustion

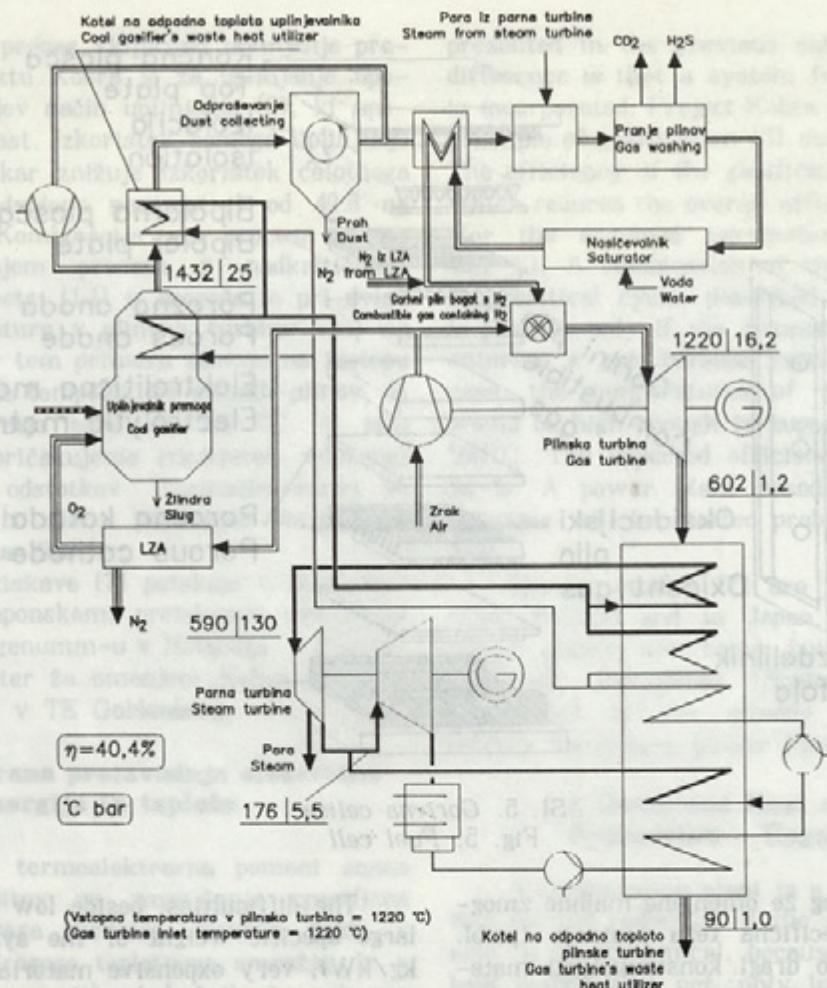
Boilers with fluidised bed combustion are not presented in this paper because they are covered extensively in other available literature.

## 2 POSSIBILITIES OF DIRECT CARBON DIOXIDE REDUCTION

Extraction of CO<sub>2</sub> from flue gases can be done in various ways. The most promising is extraction from the gas produced in the pressurized gasification device. It can also be removed

### 2 MOŽNOSTI NEPOSREDNEGA ODSTRANJEVANJA OGLJKOVEGA DIOKSIDA

Odstranjevanje ogljikovega dioksida iz dimnih plinov je mogoče na več načinov. Največ obeta odstranjevanje v tlacični uplinjevalni napravi.



SI. 6. Shema plinsko-parne elektrarne z vplinjanjem premoga in zmanjšanjem  $\text{CO}_2$  v dimnih plinih

Fig. 6. Scheme of gas-steam power plant with coal gasification and  $\text{CO}_2$  reduction from flue gases

Uporabljajo tudi fizikalno pranje ali membranski postopek. Na sliki 6 je prikazana shema plinsko-parnega postrojenja z integriranim uplinjanjem premoga na podlagi lebdeče plasti (glej 1.3) in delnim izločanjem ogljikovega dioksida [6]. Količina tako izločenega dioksida, največkrat v tekočem stanju, je odvisna od izbranega postopka. Izločevalna zmogljivost take naprave v plinsko-parni TE v Lubboku (Texas) je 1000 t/dan.

Seveda zahteva tako izločanje ogljikovega dioksida tudi precej energije. Predvidevamo, da se bo zaradi tega izkoristek poslabšal za približno 6 odstotkov, to je od 46,4 na 40,4 odstotke. Skupaj torej uplinjanje premoga in izločanje ogljikovega dioksida zahtevata dobro petino priboljene energije.

Poseben problem je deponiranje produktov takega sistema. Utekočinjen ali pa sublimiran ogljikov dioksid bi lahko uskladiščili na dnu morij, saj je težji od vode. Tu lahko računamo,

by »washing« or »filtering« through a membrane. Figure 6 shows a scheme of a gas-steam power plant with integrated coal gasification, based on a fluidised bed (see subsection 1.3) and partial removal of carbon dioxide [4]. The amount of the extracted dioxide, most often in the liquid phase, depends on the chosen procedure. The extraction capacity of a facility in a gas-steam power plant in Lubbock (Texas), is 1000 t/day.

Any dioxide extraction needs energy. The overall efficiency will be reduced by about 6 %, from 46,4 to 40,4 %. The coal gasification and carbon dioxide extraction consume about 20 % of the produced energy.

Storing products of such a system is a special problem. Liquefied  $\text{CO}_2$  could be stored on the sea bottom (its specific weight is higher than water's). A smaller part would then return to the atmosphere but the majority would be dissolved by the sea water. Several times

da se bo, kljub temu da se bo manjši del vrnil v ozračje, v vodi raztopil, saj je shranjevalna zmogljivost morja nekajkrat večja od vsega ogljikovega dioksida, ki je še v fosilnih gorivih. Druga možnost je tlačenje v že izkorisčene vrtine nafte in zemeljskega plina.

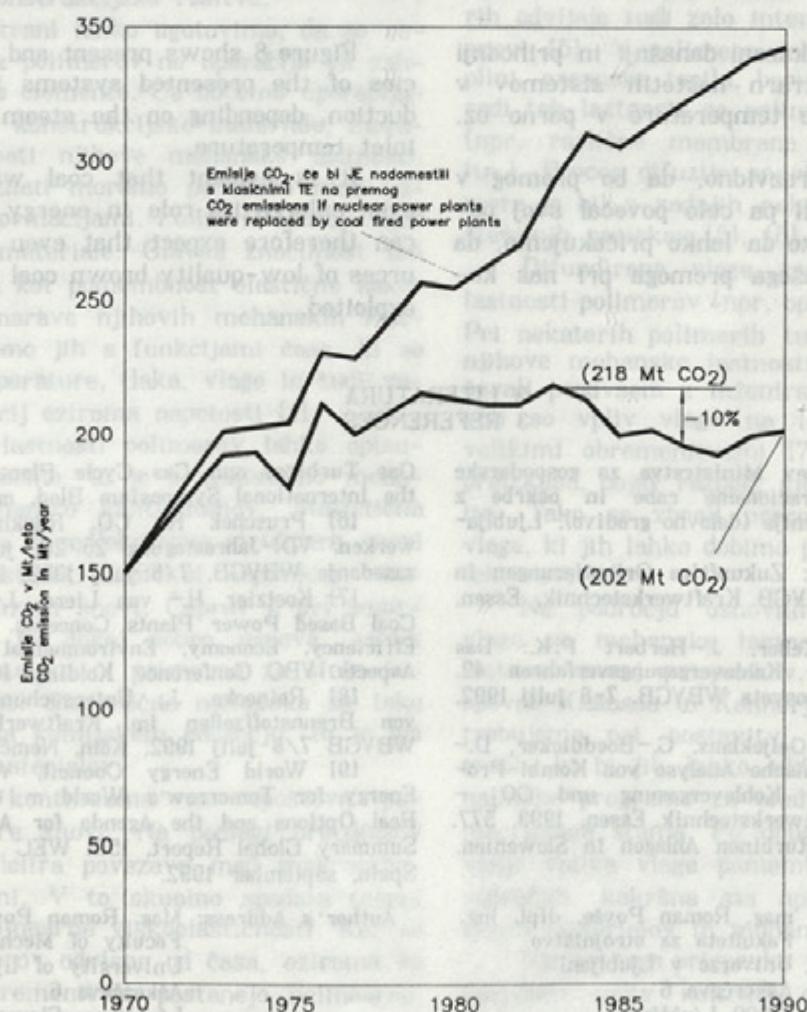
### 3 SKLEPI

Do leta 1970 je na razvoj energetike vplivala gospodarnost naprav in procesov. Od te prelomnice naprej vse bolj vpliva ekologija, tako da današnji razvoj usmerja količina ogljikovega dioksida v ozračju. Pri novih premogovih tehnologijah, ki so tu opisane, moramo računati, da razvoj take tehnologije terja časovno obdobje od 40 do 50 let: najprej nekaj desetletij sam ravoj, potem pa še deset do dvajset let, da se ta tehnologija v zadostni meri razširi in prične prinašati ekonomske učinke. Slika 7 [2] kaže, kako lahko vplivajo tu omenjeni posredni ukrepi na zmanjšanje ogljikovega dioksida na primeru nekdanje Zahodne Nemčije.

more carbon dioxide could be dissolved by the oceans than could be produced by the combustion of remaining fossil fuels. Carbon dioxide could also be stored in abandoned oil wells or emptied natural gas caverns.

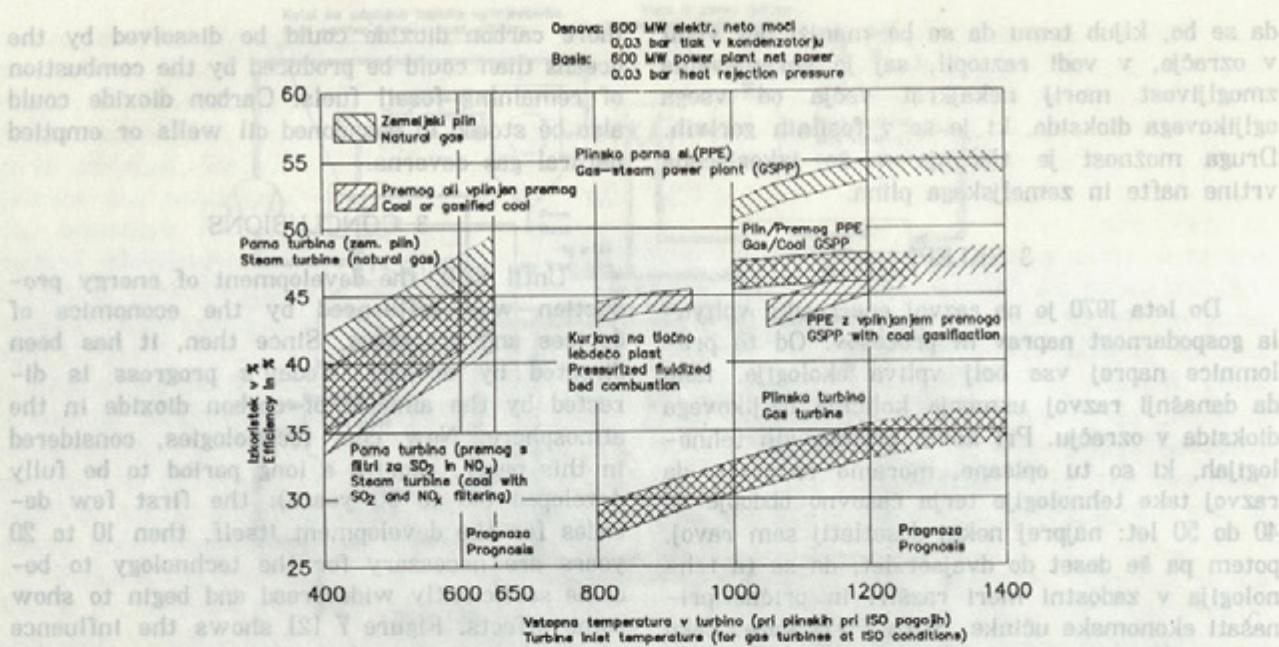
### 3 CONCLUSIONS

Until 1970, the development of energy production was influenced by the economics of devices and processes. Since then, it has been directed by ecology. Today's progress is directed by the amount of carbon dioxide in the atmosphere. New coal technologies, considered in this paper, require a long period to be fully developed (40 to 50 years): the first few decades for the development itself, then 10 to 20 years are necessary for the technology to become sufficiently widespread and begin to show some effects. Figure 7 [2] shows the influence of the herein described indirect measures for CO<sub>2</sub> reduction in the former West Germany example.



Sl. 7. Emisije CO<sub>2</sub> iz TE v nekdanji Zahodni Nemčiji

Fig. 7. CO<sub>2</sub> emissions from power plants in former West Germany



Sl. 8. Izkoristek elektrarn razreda 600 MW

Fig. 8. Efficiencies of power plants of 600 MW class

Na sliki 8 so prikazani današnji in prihodnji izkoristki termoelektrarn naštetih sistemov v odvisnosti od vstopne temperature v parno oz. plinsko turbino.

Iz sestavka je razvidno, da bo premog v prihodnosti obdržal ali pa celo povečal svoj pomem v energetiki, tako da lahko pričakujemo, da bodo zaloge tudi slabšega premoga pri nas koristno porabljeni.

Figure 8 shows present and future efficiencies of the presented systems for power production, depending on the steam or gas turbine inlet temperature.

It is evident that coal will preserve or even enlarge its role in energy production. We can therefore expect that even our own resources of low-quality brown coal will be usefully exploited.

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