COMBINED HEAT AND POWER GENERATION

This is the third summary of papers presented at the Third International District Heating Conference in Warsaw, Poland, April 1976. Summaries I and II were published in our two previous issues. All are verbatim transcripts prepared by Poland, the host country.

IDHA Headquarters has copies of the referenced papers, which are written in the national languages of the authors; photocopy prices will be quoted upon request.

Development of Combined Generation of Electric and Heat Power

The centralised heat energy supply and the related combined economy in the period of low liquid fuel prices has developed mostly in eastern European countries, especially in socialist countries. It was both power coal and gas (USSR), as well as oil, that were used as fuel. In the early 1970's, even in Poland, where power coal is cheap, the construction of the peak load oil-fired water boilers has started.

In western European countries, cheap oil impeded development of the thermal-electric power stations.

The climatic conditions and political system as well as a rapid development, or in many cases building from the start the towns that had been totally destroyed during war operations, gave rise to an extremely rapid development in construction of the thermal-electric power stations in the Soviet Union and Poland. This has been well illustrated in the paper by Dr. Sokolow (USSR). Consumption of electric power in the Soviet Union doubles - as is the case in many other countries - every ten years, while consumption of heat power doubles every 15 years; and in 1975 it reached 1010 GJ, 85% of which accounts for town consumption. In 1974, one-third the power of the thermal-electric power stations consisted of the installed capacity of power stations working in the country, and it reached about
60 GW. The volume of energy supplied by these thermal-electric power stations reached $4.10^9$ GJ, that is to say, about 40% of the country's total power demand for low and medium-temperature heat power.

Over the past 15 years, the volume of heat generated by the combined economy has increased 4.6 times, whereas the volume of the thus generated electric power rose 7.4 times, due to the increase in the value of the heat-to-power combination factor from 175 to 279 kWh/Gcal.

So far, steam (53%) has been the leading heat carrying agent, although the share of water continues to increase, and rose from 27% in 1960 to 47% in 1975.

Plans envisage further increase in power of the thermal-electric power stations, where electric power and thermal power in big cities such as Moscow, Leningrad, Kiev, Minsk and Kharkov will reach the level of 1000-1500 MW and 3500-4500 MW (i.e., 3000-4000 Gcal/h), respectively.

The number of the newly built thermal-electric power stations in other countries rose at a slower pace in comparable cities and industrial plants (paper by Buki, Hungary). Severe winters and a long heating season, for example in Finland, gave rise to the development of thermal-electric power stations in major urban and industrial centres.

Utilisation of Peat Coal as a Fuel

A large increase in prices for liquid fuels, followed by the rise in coal prices, increased interest in the combined economy. The utilisation of other cheaper local fuels has been considered in place of expensive liquid fuels. In Finland attention has been recently focused on peat coal, while it has been a general tendency throughout the world to concentrate on nuclear energy, especially its utilisation for heat supplies to big urban agglomerations.

In Finland (paper by J. Sarkava), virtually all water power resources have been utilised. Wood has also been fully utilised, since industry processes an increasing amount of wood-waste. The only local fuel so far unutilised is peat coal, which has until now been used hardly at all, due to low prices for the imported fuels. Finland abounds in peat bogs, which cover almost one-third of its territory. According to the estimates, resources of the industrial peat coal amount to 1.9 milliard tons of oil. Total use of peat coal is likely to increase from 0.1 to 2.58 million tons of standard fuel unit (s.f.u. [1 s.f.u. ton = 7 Gcal]). The peat coal share in the fuel consumed in urban heating plants and in the thermal-electric power stations will reach 23% in 1985. In addition to the thermal-electric power station started in 1972 at Kuopio, the further construction has been envisaged of six thermal-electric power stations fired with peat coal, with the total electric power value of 325 MW and with heat power of 670 MW (575 Gcal/h). The above mentioned thermal-electric power stations will consume six million m$^3$ of peat coal yearly.

Peat coal has the mean heating value of 3.6 GJ/m$^3$, bulk density of 30-400 kg/m$^3$ (i.e., 9-12 GJ/ton = 2150-2870 kcal/kg). The content of sulphur is small (0.1-0.2% in relation to dry mass), and the moisture content is 45-50%. Peat coal is transported over distances of less than 100 km, the means of transportation being tipper trucks with trailers of 60-70 m$^3$ total load capacity, as well as railway cars of 150 m$^3$ capacity designed for transportation of shawings. Due to the dusting they are unloaded in a closed space.

Peat coal is burned in the pulverised fuel fired furnace, but due to the heterogeneous character of the supplied fuel, it is burned down by means of the boiler fuel oil. So far, oil has constituted up to 45% of the fuel; at present boilers are envisaged in which peat coal will supply 85% of heat and the rest (15%) is to be supplied by oil. A thermal-electric power station fired by peat coal is 34% more expensive than that fired by oil. Assuming the following prices for:
peat coal turns out to be more profitable in the case of a thermal-electric power station with the electric power of 60 MW and heat power of 115 MW, when the operation time exceeds 3000 h/annum. For the back-pressure operation of the plant, the operation time exceeds 4000 h/annum which makes the firing of peat coal still more economical.

Utilisation of Garbage in Power Industry

The rise in fuel prices has attracted attention to the profitability of utilisation of the various waste materials including town garbage (papers by Buki, Hungary and A. Neumann, Federal Republic of Germany); the more so as their current heating value of about 6.7 GJ/t (1600 kcal/kg) exhibits an increasing trend, since the fraction rises of the packaging in which paper and polyethylene have the heating value of about 17 GJ/t (4000 kcal/kg) and 46 GJ/t (11,000 kcal/kg), respectively. Although the cost of heat obtained in the process of garbage burning is higher than that obtained from oil burning, some part of this cost accounts for the disposal of garbage, which otherwise would have to be removed to distant dumping grounds. It should be borne in mind that with an increasing density of population, it is more and more difficult to localise a dumping ground in the close vicinity of towns. The same applies to the localisation of the incineration plant. Moreover, it should stand close to the town, to reduce both the cost of garbage transportation and of energy transmission. Besides, it should not be localised too close to residential quarters, as it is an annoying neighbour.

The garbage burning process is usually followed by the burning down with high energy fuel, mostly oil. Building costs of a heating plant with thermal power of 58 MW (50 Gcal/h) designed exclusively for garbage burning, are ten times higher than those of a heating plant fired with oil. When the fuel stuff consists of 30% oil and 70% garbage, the above mentioned difference is reduced to 450%.

Certain difficulties result from the fact that garbage supply is regular throughout the year, while the heat power requirement varies, according to the author A. Neumann, from 100% in the winter season to 5% during a hot summer. It may happen that there will be no demand for heat power, and garbage cannot be stored. In such a case, artificial cooling of water heated in the boiler should be envisaged.

It seems that in big cities, with their numerous consumption points operating all year round and with their high demand for hot water, such fluctuations reaching 10% of the maximum heat power demand may occur only exceptionally. If on the other hand, the thermal-electric power station incorporates a high-power incineration plant, the problem can be solved by the application of the extraction condensing or extraction quasi-condensing system.

Nevertheless, utilisation of garbage in the heating plant or in the thermal-electric power station permits saving a certain amount of fuel, although it involves high investment costs.

Nuclear Thermal-Electric Power Stations and Heating Plants

Utilisation of peat coal has a local importance, while garbage plays a supplementary role in meeting the town’s heat power requirements. On the other hand, the application of nuclear energy to the centralised heat generating system may be of the utmost importance (papers by Messrs. Andrzejewski and Troszkiewicz, Poland; M. Klail, Czechoslovakia; Kowylianskij, USSR;
and H. Kruger, FRG). The construction of both nuclear thermal-electric power stations and heating plants has been considered. Although, according to the paper by H. Kruger, the cost of the nuclear heating plant is about 60% of the cost of a thermal-electric power station of equivalent thermal power, still these are only approximate estimates. It has been rightly pointed out in the paper by Mr. Kowylianskij, that for the lack of the verified reactor arrangements designed for heating plants, any results of the economic analysis are likely to involve a considerable error margin.

The same reactors and steam generators which are constructed for nuclear power stations can be applied to the nuclear thermal-electric power stations. It is only the turbine, whose steam extractions serve for tapping steam for heating purposes, that is subject to modifications. It is a generally accepted rule that in any nuclear thermal-electric power stations, including the industrial ones, the extraction condensing turbines are installed in such a way that the thermal power of a reactor might be fully utilised in the periods of the diminished heat power load. With very low operating costs of nuclear energy, the generation of electric energy in the condensing type of operation is always profitable.

Also, it is a general opinion that the existing reactors might be economically applied to big urban agglomerations, where thermal power consumption is maintained at the level of 1700 MW. It is expected, however, that the increase in fuel prices will lower the limit of profitability to 700-800 MW and, under special circumstances, even to 100-300 MW.

The existing projects permit a controlled fission of radioactive substances to be accomplished within the range being much lower than that allowed by the relevant regulations. Safety devices and tight housing construction ensure proper protection of the environment from radiation, even in the case of the heaviest possible breakdown. The probability of irradiation of population is extremely small. Attempts to move nuclear thermal-electric power stations close to the limits of the agglomeration, which is desirable due to the reduction in the costs of the transmission of heat energy, are fraught with difficulties of psychological nature; that is to say, the inhabitants' fear referred to as the Hiroshima complex. The localisation of the nuclear power station far from the town limits may reduce the building costs, owing to alleviation of certain safety requirements, but it raises the costs of transmission of heat energy. According to current opinions, the nuclear thermal-electric power station should be situated within the distance of 30-40 km from the town at most (paper by H. Kruger). In the case of leaks in the steam generator, radioactive substances get from the reactor cooling system into the working system. To prevent radioactive substances from entering the district heating network, three circulations have been designed, namely: (1) radioactive circulation for reactor cooling (2) working system consisting of the steam generator, turbine, condenser and generator (3) thermal, water or steam network circulation supplied with heat from turbine extraction by means of the diaphragm heat exchanger.

Nuclear thermal-electric power station economics depend not only on the assumed investment costs, as well as fuel prices, but also on the assumed method of distribution of costs related to the generation of electric and thermal energy. Nevertheless, the profitability of nuclear thermal-electric power stations is unquestionable for stations of big thermal power of the order of 1200 MW. According to some authors, it is the heating plants that are more economical in the case of smaller thermal power stations.

Some French publications include the conceptions of nuclear heating plant designs beginning from a thermal power level of the order of 30 MW, while the Finnish papers presented at the Paris Conference in April 1975 proved that nuclear heating plants of thermal power of 100 MW were profitable.

The method presented in the paper by Messrs. Andrzej-
jewski and Troszkiewicz deals with the calculation of the costs of thermal energy generated in the nuclear thermal-electric power station. The method has been based on the assumption, that the above mentioned costs of thermal energy are charged with the costs resulting from receiving the thermal energy from a nuclear thermal-electric power station working in the electro-energetic system. This applies to the nuclear thermal-electric power station, which up to the moment of applying the heating load, operated at full load as the condensing power station. Heat energy output results in the decrease in electric power put into the system. The method is distinguished in that the fixed costs of heat generation depend on the investment costs of the nuclear thermal power station only to a small extent, while the operating costs are wholly independent of the nuclear fuel costs. Under this calculation procedure, heat generation costs are very low, since the advantage of the combined economy is shared by thermal energy generation.

The paper by M. Klail deals with four variants of the inclusion of the nuclear thermal-electric power station into the district heating system. According to the first variant, total heat power is being utilised for heating purposes, whereas the minimum steam flowing to the condenser remains under the maximum thermal load. According to the output steam parameters, electric power then ranges from 40-75% of the condensing operation power, while heat power demand from the nuclear thermal-electric power station is met totally. If, however, peak-level demand for heat power is to be met by conventional sources of heat power, it leads to smaller losses of electric power. The combination factor is less than 1.0, which corresponds to the system presented in the paper by Mr. Kowylianski. Variant No. 3 concerns such a type of cooperation between the nuclear thermal-electric power station and the conventional heat power sources, in which they would take over thermal power generation during the electric peak-load interval. Thus, the nuclear power station operates at its normal condensing output. Variant No. 4 can be treated as an extension of the above mentioned system in which the thermal-electric power station cooperates with heat accumulators. Unfortunately, the author quotes no quantitative data.

Heat Systems in the Thermal-Electric Power Stations

Development of centralised heat power generation was followed by the typification of both the particular designs and the entire systems of the thermal power stations and thermal-electric power stations.

In the German Democratic Republic (paper by Mr. Dressler), the boilers assembly with the steaming capacity of 25, 40 and 64 tons/h makes it possible to establish 11 variants of heating plant operation, with the vapourity ranging from 75-320 tons/h of steam. The thermal-electric power station was designed to include typical systems consisting of the extraction back-pressure turbine sets of electric power of 60 MW, with the inlet parameters of 132 bar, 535 °C, and the boilers with the steaming capacity of 320 tons/h. These units are expected to be fundamental for thermal-electric power stations established until 1990. It is assumed that, in order to assure the reliability of supply, the power of the biggest unit should not exceed one-third the power value of the entire thermal-electric power station. From October to April, that is to say, during the highest electric power load, total electric power should be at the disposal of the thermal-electric power station. Outside this season only one-third of the real electric power is needed, one-third is on stand-by (cold stand-by), and one-third under repair.

Thermal power demand of 220-350 MW has been assumed to be the lowest limit for the establishing of the combined heat and power generation economy.

In Finland (paper by Mr. Helmlund), thermal-electric power stations employing back-pressure turbines have been constructed for high heat consumption units, the
optimum combination factor being 0.5-0.6. The rest of the heat is supplied by top-load boiler houses. The above mentioned peak-load and basic-load boiler houses supply the heating network with over 70% of the heat power demand in the cases when it is not worthwhile to establish the combined heat and power generation economy. These boiler houses are, with few exceptions (power peat coal, shavings), oil fired.

Large stationary boilers with thermal power of the order of 20 MW operate within the water temperature range of 180/140 °C, and are incorporated in the heating network system having parameters of 120/70 °C by means of heat exchangers. High water temperature inside protects the boilers from sulphur corrosion. The steam section of the water boilers provides soot blowers, deaerating heaters and oil heaters with saturated steam. Well kept boilers have the efficiency of 0.85-0.9. A boiler house usually includes from two to four boilers.

The installing of big boilers prior to the full scale development of the system is as uneconomical as heat energy transmission by means of long pipelines. These losses can be eliminated, thanks to small mobile boilers which operate until the thermal power demand reaches the level justifying the establishment of a stationary heating plant. Thermal power of such boilers ranges from 0.7-8 MW. The weight of the largest element does not exceed 25 tons, its width being less than 3746 mm. The entire equipment of the heating plant is assembled in a housing made of a corrugated sheet, and it operates under full automatic control; it does not involve any staff. In the case of breakdown, the alarm signal was previously transmitted to the staffed control station by telephone lines; recently, it has been transmitted by a short-wave transmitter. Mobile boilers have no purification of flue gases. They are equipped with a short chimney stack about 20 m long. The chimneys in the stationary heating plants are 80 m long on the average, and are equipped with multicyclones. If the manufacturer of the burner guarantees that the maximum content of the solid substances in flue gases will be less than 100 mg/m³, then dust collectors are not installed.

In recent years, the requirements of the human environment protection imposed an obligation to keep the noise level below 45 dB in the direct neighbourhood of an apartment building.

With the widespread use of boiler fuel oil, it is obvious that gas turbines have also been used in district heating systems. In the years 1971-72, when plans were made for the development of the heating plant in the town of Lappeenranta situated in the southeast of Finland, close to the Soviet border, it appeared that natural gas could be recovered for firing boilers. Projects were made at that time to erect a thermal-electric power station operating in a steam-gas system (paper by P. Ahvenainen, Finland). At that time in Finland, there already operated three thermal-electric power stations employing gas turbines. In these thermal-electric power stations, the heat content of the outlet flue gases was used for generation of steam for technological purposes, or for producing hot water for heating purposes.

It was the Mertaniemi thermal-electric power station operating in the steam-gas system that was designed for the town of Lappeenranta. Outlet flue gases exhausted from two gas turbines with the power of 37 MW each, have the temperature of 485 °C under full load. These flue gases are directed to two steam boilers. The boilers produce 60 tons of steam/h without the employment of the process of burning down. When the burning down process is employed, the steaming capacity reaches 125 tons/h, the pressure and temperature of the superheated steam being 92 bar and 450-535 °C respectively. Steam drives the extraction condensing turbine with the power of 76 MW. With the condensing type of operation and with the total power of more than 100 MW, the efficiency of the system exceeds 0.4. Thermal and electric power level can be controlled by means of the relevant operation of one or two gas turbines, as well as by putting on additional burners installed between the gas turbine and the boiler. Since the thermal-electric
power station will be put into service in 1976, no ex-
periences have been acquired so far. Increase in li-
quid fuel prices does not seem to favour the appli-
cation of gas turbines as the source of basic thermal
power in the thermal-electric power stations.
It should be stressed, however, that heat accumu-
ators have been rarely applied in district heating sys-
tems so far. Banks of heat accumulators with the capa-
city of 400 Gcal (465 MWh) and with the heat power of
70 Gcal/h (80 MW [paper by H. Hunig, German Demo-
cratic Republic]) have been employed in the heating system of
the city of Karl-Marx-Stadt. Heat power accumulated in
such accumulators is generated during the nightly low
power demand, and then is consumed during the peak-heat
power demand. This prevents erecting of the peak-load
boiler house. For the heating network of Karl-Marx-
Stadt city, any investment expenditures for the banks
of heat accumulators are 20% lower than the outlays for
the equivalent oil fired peak-load boiler station.
Besides, the operation of these accumulators does not
require any staff, the maintenance costs being lower.
Heat accumulators contribute to the improvement of the
combined heat and power generation economy of the ther-
mal-electric power station, since they extend its opera-
tion by about 500 h/annum. The accumulator bank with
the heat capacity of 400 Gcal consists of 36 tanks with
the cubic capacity of 165 m³ each. A tank has the dia-
meter of 3.5 m and length of 19.6 m; it weighs 40 tons.
Satisfactory experiences acquired during its operation
courage the establishment of a heat accumulator with
the heat capacity of 600-1000 Gcal in the further develop-
ment of the district heating network. The application
of the concept of heat power accumulation in the systems
incorporating thermal-electric power stations is dealt
with in the paper by M. Klail.

Turbines in District Heating Systems

An increasing number of thermal-electric power sta-
tions was followed by the development of standard tur-
bines and standard heating systems. The bigger and more
varied the heating systems, as for example the systems
working in the Soviet Union, the greater the variety of
turbines and heating systems applied (paper by W. Wodic-
zew, USSR). The turbines made in serial production and
designed at present in the Soviet Union have power rang-
ing from 6-250 MW. Their steam parameters range from
34.5 bar and 435 C to 265 bar and 560 C; their tempera-
ture of interstage reheating being up to 565 C. There
are both back-pressure and extraction back-pressure tur-
bines, as well as extraction condensing turbines
designed for supplying feedwater heaters with steam, or
for direct supplying heating steam networks.

The T-type turbines are the extraction condensing
turbines. The most popular turbine of the T-100/120-130
type is designed for inlet parameters of 127 bar and
565 C. In the pure condensing operation the turbine's
power is 110 MW, while in the part-load heating opera-
tion its power can reach 120 MW. The two extractions
supplying the district heating system have a controlled
pressure, namely 0.5-2.0 and 0.6-2.5 bar. The turbine
can operate in the system with the poor cacuum; i.e.,
when the condenser operates within the feedwater circu-
lation. The pressure inside the condenser may then
reach 0.5 bar. The turbine of the T-250/300-240 type is
currently the largest one from the series being built in
the Soviet Union. The electric power of the turbine -
when working within the super critical range of para-
metres, with the district heating load of 384 MW - is
250 MW, while in the pure condensing type of operation
its electric power amounts to 300 MW.

In addition to the above mentioned turbines, the
P-type turbines are constructed in the version of
smaller output power starting from 40 MW. The PT-type
turbines, being also the extraction condensing turbines,
have, apart from the extractions serving for feedwater
heating, an additional extraction for tapping steam for
 technological purposes. Their pressure is controlled in
quite a wide range. According to the type of turbine,
the pressure of technological steam may range from 5-10
to 12-21 bar, the power of the turbine ranging from 12-165 MW. The inlet parameters for the turbines of small power are low, namely, 34.4 bar and 435°C; for the biggest power turbines these parameters are 127 bar and 565°C.

To supply the industrial plants of stable steam consumption with technological steam, the back-pressure turbines of the R-type have been employed. The turbines are constructed in a wide range of power, that is to say from 6-100 MW, their inlet parameters being from 34.4 bar and 435°C to 127 bar and 565°C.

The nuclear thermal-electric power stations are designed to include the sets of the TK and PTK-50 types with the power of 500 MW. The pressure of the saturated steam is about 60 bar.

In the German Democratic Republic, the plans for 1981-1990 envisage the basic equipment of the thermal-electric power station to consist of a power set comprising the boiler, with the steaming capacity of 320 tons/h and the extraction back-pressure turbine with the power of 60 MW, and the steam parameters of 132 bar and 535°C (paper by H.J. Dressler, GDR). The turbine can be constructed in the version with extractions for feedwater heating, as well as with extractions for steam network supply (the pressure of the extracted steam is 6 bar and 10-12.5 bar).

For large municipal thermal-electric power stations in Poland, several types of turbines have been designed. Their inlet pressure is 127 bar and their temperature of superheating is 535°C (papers by J. Ragan and J. Stepien, Poland). First, production of the sets having the above mentioned parameters for the extraction back-pressure turbine with the power of 52 MW was begun. With the increase in the heating power of the thermal-electric power station, larger turbines with the electric power of about 100 MW have been constructed. At the same time in order to reduce the dependence of the electric power output on heat demand, the back-pressure turbine has been provided with an additional cooler situated in the place where feedwater enters the first heater. Thanks to this arrangement, the turbine in the quasi-condensing type of operation can develop the power of 113 MW. For cases in which the turbine is to run for longer periods (in summer) in the condensing type of operation, another type of extraction condensing turbine with interstage reheating has been designed, to be established in the heating plant. Further development of district heating systems provides for the construction of heating plant turbines of the electric power of about 200 MW.

Similarly, for the purposes of development of the thermal-electric power stations in Budapest, the extraction back-pressure turbine sets are applied. Their power is 50 MW and 100 MW with the parameters of 100 bar/540°C and 135 bar/540°C respectively (paper by Mr. Buki, Hungary). For the largest thermal-electric power stations, there have been installed extraction condensing turbines with the power of 215 MW, which are a modified version of the condensing type of turbine used in Hungary. The steam parameters of those turbines are 162 bar and 540°C with the temperature of interstage reheating up to 540°C. In the condensing type of operation the power of the turbine set equals 213.9 MW. With the application of the heating load of 277 MW (water is heated from 44.1 to 77.3°C) the power falls to 180 MW. When the district heating load is 340 MW, i.e., when the water is heated from 71.4 to 112.3°C, the power falls to 166.9 MW. A cooperation between the newly built thermal-electric power stations and the existing thermal-electric power stations and heating plants is envisaged.

General Problems Connected with the Centralised Generation of Thermal Energy

Out of a number of general problems connected with generation of thermal energy in thermal-electric power stations and heating plants, one may mention the method of optimisation of the parameters of the heating medium (paper by A. Neumann), and the conception to establish...
a national board for power engineering (paper by H. R. Cater, Great Britain), which is not to be confused with the electric power industry. The author's assumption is that under current circumstances, from the viewpoint of the power industry, it is a waste of fuel to use it for generation of low-temperature heat energy. The author presents, therefore, the conception of the district heating network which would cover the whole territory of the country. It should be pointed out here that such projects have been worked out for the Federal Republic of Germany, which has been mentioned in the paper by H. Kruger. The establishment of such a network, which would collect all of the "waste" heat and distribute it among the consumers, will depend first of all on the density of energy consumption. It goes without saying that such a concept first originated in the FRG. However, such a network is extremely expensive, and its profitability depends on a number of factors, including the above mentioned density of heat power demand, service period, fuel prices and rate of interest.

Conclusion

Although the authors of these papers approach the problem in different ways, still we may draw some general conclusions. First, there is a clear tendency to develop centralised heat supplies from the heating plants (also referred to as boiler houses) or from the thermal-electric power stations. Considerable increase in fuel prices makes us use local fuel resources, such as brown coal, peat coal, hard coal and garbage collected in towns, as well as to increasingly utilise nuclear power for these purposes.

In thermal-electric power stations, basic demand for thermal energy is met by the extractions of the extraction condensing or extraction back-pressure turbines. Peak-load power demand is met by the peak-load boilers, usually fired with oil. Against a background of these general trends there develops a great variety of detailed projects resulting from local climate, fuel resources, economic possibilities and tradition.