Strategy Discussion Report C

The Chemical Engineer's Responsibility for Material and Energy Resources

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1. GENERAL REMARKS

In comparison to the exponential growth of energy consumption during the first half of this century, the second half has seen a much slower growth of consumption in the industrialized countries. However, the rising population and industrialization of the developing countries will require increasing energy resources in the future. The world energy consumption in 1960 was 147 EJ (Exa Joule = 10^{18} Joule) and the consumption is projected to be about 470 EJ in the year 2000. An estimate puts the number at about 800 EJ for the year 2050. Parallel to this trend, we have to keep in mind that the world population, currently at 5.2 billion, is expected to rise to 10 or even 14 billions by 2050.

There is a big disparity in energy consumption per person among various countries of the world. A person in Europe consumes about 5–10 times more energy than a person in Asia or Africa and the per capita energy demand in US and Canada is even higher than in Europe. The future population growth is expected to be mainly in Asian, African and South American countries which are today positioned at the low end of the energy consumption curve. Therefore, these countries will face a problem of satisfactorily meeting the rising demand. Recent developments seem to prove this trend. Between 1980 and 1989 the energy consumption in North America and in Western Europe has decreased by 10–15% while, during the same period, an increase of 13–20% was observed in South East Asia, USSR and China.

Today, the energy demand is met mainly by oil and coal but increasingly by natural gas. Renewable energy resources such as solar and wind energy make a negligibly small contribution to the energy supply. In the future, however, their share may increase. Contribution of hydro-power and its future potential in the world energy supply is often underestimated. The share of hydro-power in electric energy varies widely world-wide between 5% in FRG and 72% in South America. The usable potential of hydro-power is still very large, especially in Asia (5300 TWh), South America (3800 TWh), Africa (3100 TWh) and North America (3100 TWh). The hydro-power therefore offers a large potential energy resource and it may even serve as a source for producing hydrogen as an energy storage and carrier medium as proposed by a Canadian utility. Hydrogen can also serve as a raw material base for the chemical industry.

Renewable energy resources have the peculiarity of low energy density per unit area. The surface area requirement for a photovoltaic power station is in the order of 100,000 m^2/MW. For wind turbines, it is about 5,000 m^2/MW. In comparison, the figure for fossil powered power stations varies between 100–1000 m^2/MW depending on the size of the unit. The use of biomass requires 1,000,000 m^2/MW which is larger by a factor of 10 than for solar power stations.

This presents a problem of collecting and concentrating the energy before it can be distributed to the users. Therefore, the renewable energy resources are advisable in places where the population density is low. But, even in the developing countries, the trend is for increasing concentration of population in urban areas. It is estimated that, in the year 2030, fewer than 40% of the population will live in rural areas even in the developing countries. This makes the use of renewable energy resources more difficult.

From a technical and economical viewpoint nuclear energy offers a large potential. However, the fission processes have not found the necessary political and public acceptance thus far and the realization of fusion energy is too far in the future for an energy strategy for the next 50 years.

So, the remaining question is how much the primary energy can be saved by plants and processes with a higher energy efficiency and by more sophisticated use of energy in chemical engineering. Highly developed chemical processes have already reached a level of optimization from which a further reduction of energy consumption is difficult. During the last 30 years the energy usage for producing products of a certain value has been lowered by a factor of 2 in the industries of the industrialized nations. In many cases chemical processes are already near their thermodynamical minimum of energetic need.

For example, the net efficiency of a coal fired power station is in the range of 40–42% today. With an integrated coal gasification and combined gas/steam power cycle the efficiency can improve up to 45–48%. With pure natural gas as a fossil fuel a combined gas/steam cycle can go up to 55% efficiency. However, to justify the economic profitability of these high efficiency technologies, we will need to construct a large number of new power stations.

2. SESSION ISSUES

Essential facts resulting from oral presentations and discussions in various scientific/technical sessions are summarized below. Not all sessions contributed to the materials and energy resource aspects. Therefore, the facts quoted here are from the sessions in which specific and general ideas were developed for materials and energy strategy.

Session 3.1: Closed Cycle Production Strategy

The closed cycle production strategy represents the concept of "clean technology" in which environmental protection is directly integrated into industrial production. It also results in saving material and energy.

The potential of renewable energies in closed cycle production was discussed in the session and the solar option was emphasized as fundamental for renewable energy. A technology mix including a bio-principle may be the best solution. Additionally, the strategy needs to be highly diversified to satisfy local conditions. In addition to the solar options (photovoltaic cells and solar towers), hydroelectricity and hydrogen as an energy reservoir could make a substantial contribution.

Session 3.2: Clean Chemical Plants

Clean chemical plants are interpreted as production places which have low effects on the environment. Environmental effects can result also from the energy consumption of the plant. A computer programme was presented in the session which can handle the connection between the technology, economy, energy and environment. Further, the programme allows strategies to be developed for chemical and related industries with respect to energy saving and environmental control measures. An example was given of substituting the feedstock lignites by natural gas and crude oil in different applications with special emphasis on the energy situation in the eastern part of Germany.

Session 3.7: Electro-Chemical Engineering for Future Transport Strategies

Newly developed fuel-cells can contribute to a more efficient use of energy resources. A new H_2/N_2 immobile fuel cell on an alkaline basis which is mainly used for space applications was presented. An advanced fuel cell with an electrical energy storage capability was reported.

The primary criteria of attractive fuel cells were described in a survey paper. Large potentials of Na/S, Li/Polymer and Li/Metal Sulfide systems were emphasized.

Session 4.1: Efficient Use of Energy in the Process Industries

This session and the contributions presented were specially devoted to raising questions and answers on possibilities of energy saving and alternative energy resources. Proposals were made for improving electricity efficiency in the process industries and for heat recovery techniques. New computer-aided methods can be useful for such endeavours. Along this line, it was recommended to develop new computer-integrated processing with data reconciliation and improved process simulators and production optimizers incorporating energy saving as one of its components. These tools are already highly developed and therefore further progress may be slower. Nevertheless, it is worthwhile to concentrate activities in the field.

Separation processes, especially distillation, generally consume a large amount of energy. An interesting project would be develop separation methods which are economical and, at the same time, energy-efficient. Some examples are: gas adsorption and membrane separation. Several research proposals for substituting distillation in separation of fluid mixtures were presented.

Process integration is highly developed in chemical engineering. It was proposed that we put more emphasis on a combined process integration which incorporates environmental and energy saving. This may also include reduction of CO_2 emission. An important component of the integrated process may be multi-functional reactors which can perform both chemical and transport processes. This will lower the cost of pumping and reduce heat losses. Such reactors may be within the capability of current equipment manufacturers but there is still a challenge to continue the progress and to invest in further research and development.

Special production lines were discussed. There is a strong need to to do more process research work on glass melting furnaces, cement kilns and baking ovens. Currently, the design and operation of such equipment is largely based on empirical models.

It is also worthwhile to think about improvements in existing and approved sub-components of chemical apparatus and plants with respect to energy saving. For example, the predominant use of structured packings during the recent years resulted in "revamping" of existing distillation columns by replacing their trays. We should look for the most cost effective solution with respect to cost and energy in these columns. In this regard, we have to discuss whether packings or trays should be favored. A priori cost and energy saving are not mutually exclusive. The equipment price should take into account the energy cost of manufacturing and the best economical selection needs to be determined based on the total cost.

How energy minimization may be achieved by following the principle of "minimum reflux" was extensively discussed. It was strongly recommended that the whole life cycle must be considered in such a discussion. For example, the energy cost of manufacturing structured packings which have a large number of theoretical trays per unit column height should be compared with the decrease in energy consumption resulting from the decreased volume reflux ratio.

Finally, a possibility of using solar energy in industrial chemical processes was discussed. There was general agreement that, although it has only a long-term prospect, research and development effort should be highly encouraged.

Session 4.2: Oil and Gas Industries

To a large extent, raw materials for organic chemistry are based on oil and gas. Therefore, for chemical engineering of the future, enhanced oil recovery and increased utilization of oil reservoirs will be important. Off-shore reservoirs will have to be explored to a greater extent. This implies that water will have to be injected to press out the oil. It was reported that the quality of injected water, such as salinity and pH of the permeating fluid, has been found to be the most important parameter controlling the process. Also, matrix acidification of carbonate formations improves the flow of injected fluids in oil reservoirs.

We also have to look for alternatives to crude oil for the future. Oil sand is a potential alternative energy source. At present two commercial operations exist in Canada. The controlling factor in the process is the interfacial phenomena associated with separation of bitumen from the sand. Addition of alkali is an important step in bitumen separation and flotation. Further cracking of the bitumen produces crude oil. The utilization of oil sands can make an important contribution in North Africa, South America and USSR.

Improved economical and ecological use of energy may be achieved by improving the heavy oil processes. Examples such as cracking in a plasma spouted bed reactor and by thermal conversion were presented in the session.

Finally, the liquefaction of coal was discussed. The NEDOL process, recently developed in Japan to manufacture liquid fuel from Australian coal was reported. A pilot plant demonstrate an oil yield as high as 57%. In Germany, the Ministry for Research and Development supported construction and operation of pilot plants for coal liquefaction in the seventies. The technology is not necessarily new. During the World War II, coal liquefaction plants were operating on an industrial scale. The question was and still is an economical one. Compared to the current cost of crude oil, the cost of coal-derived oil is much too high.

A proposal for the liquefaction of biomass was also presented. According to this proposal the direct liquefaction of ligno-cellulosic material can serve as a new source of chemical feedstock and fuel. Experiences with liquefaction of dried poplar wood were reported. This was performed in a batch autoclave using methanol as hydrogen donor. It is well-known that oil from rape seeds may be a more convenient basis for liquid fuel.

Gas technology is another field for new material and energy conversion processes. Synthetic natural gas (SNG) will gain an increasing influence in energy supply. The base of SNG will be coal and, in some cases, biomass. Power plants of the future will be equipped with an integrated coal-gasification unit. A combination of gas turbine and steam turbine will produce electrical energy in the plants. The combined gas-steam-cycle guarantees higher thermal efficiencies and it will help in reducing CO_2 emission.

Session 4.4: Polymers and Advanced Materials

Chemical engineering aspects of polyethylene polymerization processes were reported. Efficient temperature control is very important in product quality and reproducibility and reducing the energy requirements in the subsequent separation processes. In addition, polymerization is an exothermic reaction. This, coupled with a large change of viscosity of the reactants in the course of reaction, makes the precise temperature control an engineering challenge. Use of multi-tubular reactors for polyethylene processes was proposed. Another approach is to use computer-aided process modelling. It was reported that the modelling approach was successfully used to identify the optimum operating conditions of a PE plant for producing PE with its MW and MW distribution within specification.

High strength high modulus polymers such as liquid crystal polymers have been developed for use in structural applications and to replace metals in transportation equipment. The weight reduction directly translates into significant energy saving during the lifetime of the transportation equipment. Performance of the polymers can be substantially improved by developing fundamental understanding of the relationship between mechanical properties and polymer molecular structure. We are now on the verge of an understanding of liquid crystal polymers. The need for research on a generic synthetic capability for deterministically prescribing polymer structures as against a statistical structure of conventional polymers was highlighted. The synthetic research may need to incorporate biological principles.

Session 6.1: Catalysis: An Interface Between Chemical Engineering and Chemistry

The importance of catalysis in materials and energy saving was highlighted in the session. With a catalytic process raw material consumption can be reduced. Catalysis also allows a process to proceed at a lower temperature resulting in lower energy consumption and cost. Better catalysts will therefore save fossil fuels in many processes, especially in refinery and coal conversion processes. A great future challenge for catalysis will be in natural gas processing. Transport of natural gas to user centers far from the production field is expensive and energy consuming. Processes to couple CH_4 to C-compounds are of great interest and catalysis can lower the energy consumption of the process.

Membrane catalysis is a promising option. New catalytic concepts were also introduced in the session.

Session 7.6: Food Process Engineering

Energy cost of food handling and processing is usually underestimated. There are a number of possibilities for reducing energy consumption in this industry. Optimization of process systems and improved logistics may be the first step.

Energy efficiency of mixing systems still needs significant improvement. This is particularly true for food processes but also generally true for chemical processes. A systematic method of selecting an agitation system for a given mixing task needs to be developed. Also, methods of measuring the efficacy of mixing must be improved. Improvement of mixing processes will greatly reduce the energy consumption in the food industries.

Session 8.3: Trends in Heat Exchange

Improvement of the operating performance of heat exchangers can lead to decreasing energy consumption. This is the case in all power plants and chemical processes in which the temperature difference between the primary and secondary sides needs to be ow. Further, we have to keep in mind that a large heat exchanger with poor heat transfer behavior wastes more energy than does a small heat exchanger.

Fouling is a severe problem in heat exchanger operation which is still poorly understood. More fundamental research is needed to understand fouling and incorporate the results into optimization of heat exchanger design.

Additional research efforts are also needed for improved design of heat exchangers in refrigerating systems and cryogenics. It is widely understood that cooling needs more heat than heating. There is a strong trend to replace refrigerants with new unhalogenated refrigerants. Thermodynamic and transport properties of these compounds are not yet well researched.

Session 10.1: Distillation

As previously mentioned, distillation uses a significant proportion of the energy consumed in chemical plants. A number of methods to reduce the energy consumption were proposed in the session.

Massive energy saving was obtained during the late decade by systematically lowering the reflux ratio in a distillation column. In some cases, very simple methods such as improving liquid distribution in a packed column can reduce the reflux ratio and lower the energy consumption.

Session 10.3: Supercritical Fluid Separations and Reactions

Supercritical absorption is well-known in the food industry, for example, in lowering the caffeine content of coffee. Application of the supercritical fluid separation to oil recovery and oil refining was proposed. This may have a large impact in energy saving. For example, a large reduction of energy demand can be expected in deasphalting of oil, compared to a subcritical separation method.

3. DISCUSSION IN THE AUDITORIUM

There was a very lively discussion on a number of issues in materials and energy technologies among the participants of the auditorium session. Written summaries of participants comments were forwarded to the session secretary and are reported here with a minimum of editing.

Professor V. Hornof brought to the attention of the audience the fact that, in considering energy strategies for the year 2000, it is useful to look back at the last century. After a few isolated achievements in the 19th century, the 20th century has become the century of information. The achievements in the information field have been incredible.

Similarly, as he further pointed out, we are seeing a few isolated achievements in the area of energy production now at the end of the 20th century. He believes that just as the 20th century belongs to communications the next century will belong to energy. New methods of energy generation including thermonuclear reaction and cold fusion, will be developed. They will provide us with abundant and clean energy which will render most of our current discussion irrelevant.

Mr. M. Suffern commented on the effects of environmental requirements (real and perceived) in our efficient use of material and energy resources. As an example, he mentioned that cement kilns were historically coal-fired, then oil-fired and now fired by natural gas. There may possibly be a need to revert to coal-firing. He mentioned also the possibility of incorporating recycled and "purified" waste solvents in the fuel for firing of the kilns. Finally, he gave a short remark on the difficulty of finding an acceptable location for a high temperature waste incinerator. Even in Australia there exists a shortage of economical locations.

Mr. B. O. Stroebel pointed out that he is not as pessimistic about coal liquefactions as in the secretary's report. As long as crude oil and natural gas are available at a low price, coal has little chance of producing liquid or gaseous products at a competitive price. However, large Fischer-Tropsch plants for coal gasification and synthesis in South Africa are operating with a conversion factor up to 40% and the direct coal liquefaction may reach a conversion factor of 60–65%. It should be attractive especially if one takes into account future pre-suppositions, which may include political or economical isolation, guarantees for the future and global economical conditions.

Dr. K. H. Funken commented that the solar power plant option may not be attractive for every location of the world. However, about ¾ of the world population lives in the sunbelt of the earth. There are enough locations suitable for solar power plants. The world's energy battle will probably be won or lost in those countries with dramatically increasing energy needs. The opportunities and obligations for industrialized countries are to develop and make available the required equipment.

The next generation of solar thermal power plants is being developed. The goal is to lower the electricity generation cost to make the technology competitive in places other than Southern California. About 80% of the today's solar power generation uses solar thermal power plants and the rest is in decentralized and centralized photovoltaic applications.

A new Implementing Agreement of IEA (International Energy Agency) is being formulated under the name of "Solar PACES".

Mr. P. Paschen said that what was missing was a survey on a hydrogen scenario. Hydrogen is a transportable form of electricity and, as a chemical engineer, one should think of the excellent heat transfer capacity of hydrogen and remember that hydrogen is also a reductant.