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ROLE OF THE HEAT-EXCHANGERS IN THE FACTOR 4 ENERGY POLICY

Peter Novak
Faculty of Mechanical Engineering
University of Ljubljana
Aškerčeva 6
Ljubljana, 1000
Slovenia

ABSTRACT

The fact that the concentration of carbon dioxide is increasing steadily forces us to reconsider the ways in which we exploit fossil fuels. Current carbon dioxide emissions should be reduced by factor two. In case we don't take any actions to reduce emissions now, they will double in the future, due to the increase of energy use from the growing Earth's population. Therefore, we will have to deal with an emission reduction factor of four, merely to stabilize the Earth's climate.

It is possible to reduce primary energy needs for 50 - 75% by introducing sustainable energy system and by increasing efficiency at energy conversion and use. Heat exchangers will play an important role in this respect. In this paper some ideas are presented about how to attain the desired reduction of energy use while at the same time preserving the current level of living comfort and transportation using high efficiency heat exchangers.

FACTOR 4 PHILOSOPHY – CARBON DIOXIDE EMISSIONS

Today's emissions of carbon dioxide are close to <??> mio ton/year. Along with the increase in population, the energy needed to satisfy its needs increases as well. The estimate of experts for climate changes is that we should reduce current emissions of carbon dioxide by factor two until 2050 if we want the Earth's atmosphere to stabilize. Otherwise, if no changes are performed regarding the way of providing energy to the consumers, carbon dioxide emissions will double over next fifty years.

We are confronted with a problem of how to reduce current carbon dioxide emissions by factor four given the estimated increases in population size and energy needs as shown in Fig. 1.

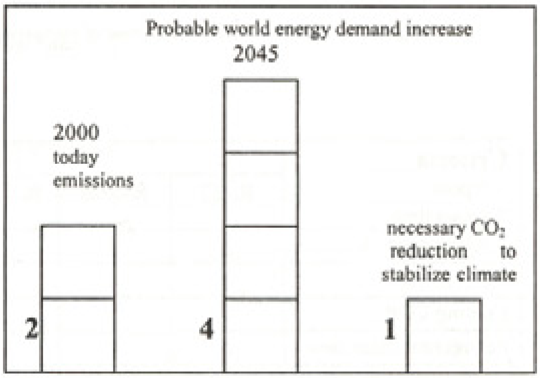

Fig. 1: Factor 4 Philosophy – carbon dioxide emissions

Sustainable Energy System

In order to close the gap between carbon dioxide emissions and energy needed, we have to switch from the current extensive energy system paradigm to a paradigm that will be sustainable and aligned with the capacity of our environment. Doing so, it is important to note the distinction between the options that are in this respect available to developed industrial countries and those that are available to developing countries. With regards to economic and technical capabilities it would be necessary to reduce the consumption of primary fuels by 50 – 75% in developed industrial countries while at the same time take control over the primary energy needs growth rate in the developing countries so that increase in carbon dioxide emissions would not exceed twice the current level over the next fifty years. Since the current fossil fuel consumption ratio between the developed industrial countries and the developing countries equals approximately 4:1 such a reduction of fossil fuel consumption in the developed industrial countries would change this ratio to 2:1 in favor of the developing countries. However, the population size ratio between developed industrial countries and developing countries is still 5:1 in favor of the developing countries, which means that in spite of the reduction, consumption of fossil fuels per capita in developed industrial countries would still be two and a half times of the consumption in the developing countries. Of course, the structures of the energy consumption in developed industrial countries and developing countries will differ.

If we accept the philosophy "More for less", decide to combine the renewable energy sources with fossil fuels and accept the efficiency with sufficiency paradigm, then it is possible to avoid the crisis to which the consumer society is currently heading.

HOW CAN WE REACH THE GOAL?

The way and the opportunities to reach the goal are similar for the developed industrial countries and the developing countries. For both types of countries it is of great importance to increase efficiency at energy transformation by introducing new processes and more efficient heat exchangers.

Speaking of introduction of new processes we especially refer to the complementary production of heat and electricity (CHP) and fast introduction of fuel cells.

The widespread use of renewable energy resources is a matter of course. World's resources of hydro, wind and biomass energy are still far from being well exploited. This is, however, a subject to change, since exploitation of those energy resources is becoming more and more economical. The growth of electrical energy production based on wind energy in Europe from a few hundreds of kW to 4000 MW in 1999 is just a single example which confirms the above statement. A similar growth can be expected in the area of biomass energy exploitation which can serve as a base for CHP but will be mainly used for the production of methanol. Exploitation of hydro energy resources should pursue several goals. Construction of dams and water storage reservoirs is supposed to be multi-purpose: apart from productions of electricity, such constructions can also serve to protect against flooding, to foster agriculture (irrigation of land), to ease crossing of rivers etc.

The goal can be reached with the introduction of a **new energy system** whose backbone will consist of the three fundamental energy carriers: electricity (obtained from fossil fuels and renewable energy sources), methane (as natural gas and by synthesis) and methanol, oxidized and hence liquid methane, which will be used to solve the problem of accumulation of solar energy (Fig. 2).

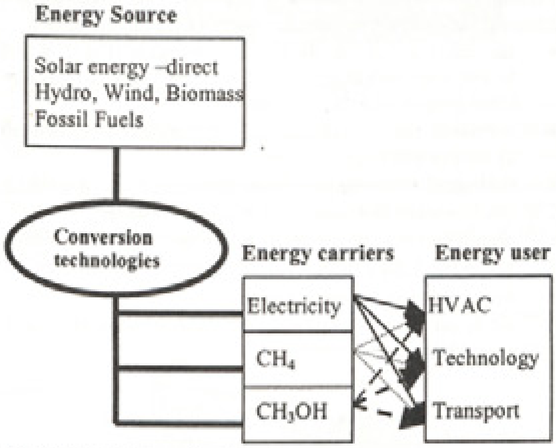

Fig. 2: New Energy System

Methane and methanol are the two fuels that have the biggest number of hydrogen atoms per an atom of carbon, which means that the use of these two fuels yields the minimal emission of carbon dioxide. Besides that, all technologies needed to implement their extraction; transport and use are well known. It is possible that the natural gas, which is one of the major energy carriers today, will be in the future replaced with the synthetic methane obtained from the solar hydrogen and the biomass accumulated on Earth. The same holds for the methanol.

The next important step in achieving the goal is to separate energy supply and energy services. To satisfy the needs of the population it is necessary to move from selling of energy towards selling of energy services. Typical energy needs of an average person today are for example a warm residence, warm water, an air-conditioned office and a suitable form of transportation from home to work. All of those services can be implemented using various amounts and types of primary energy.

Altogether, it is important to perform a transition from the consumer society to the society with sustainable development and all other activities in accordance with the environment capacity. The transition from the consumer society towards new, let's call it sustainable society, will have a significant impact on the production processes. More than half of the production today is targeted towards the products that have no direct influence on the quality of life. Therefore, if we are able to cancel the production of such products we can save a large amount of energy and material. Also, the recycling of steel, aluminum, copper and some types of plastics can already significantly reduce energy waste of consumer societies.

The swift development of information technologies will have a substantial influence on the location of workplaces, required mobility and consequently on the primary energy use. Internet, intershop, video conferencing, possibility to work and study from home using new information technologies are indisputably some of the elements that are leading us towards energy more efficient society.

OPTIONS AVAILABLE UNTIL 2050

It will be a great success if we will manage to stop the growth of fossil fuel consumption until 2050. The "zero growth" topic is becoming more and more topical. Is it feasible?

Analysis of the possibilities in the three major sectors of energy use:

- transforming of primary energy to electricity,
- production sector,
- residential sector

leads to the conclusion that reaching the zero growth until 2050 is possible. So, which are the important strategic elements and suppositions?

For the transformation of fossil fuel energy to electricity, the Rankin-cycle is currently used. This process has a transformation efficiency of 4o% - 45%, using the new, state of the art devices. The current equipment efficiency, used to transform energy of fossil fuel to electricity is normal lower than 40%. Great irreversibilities at heat exchange are the main cause for low efficiency.

Applying combined production of heat/cold and electricity (CHP) it is possible to raise efficiency up to 90%. According to (1) this would enable boosting the world production of electricity from 2 PWh/year in 1995 to 4.6 PWh/year in 2050. The share of the CHP in the whole production would be 32% in the OECD countries and 22% in the developing countries. Use of renewable energy sources in this process could reach the 35% share. As a consequence, this would practically result in halving the carbon dioxide emissions in electricity production.

As already mentioned, the progress in the development of technologies for the exploitation of the renewable energy sources has given way for their more widespread use. If there will be no obstacles due to the removal of market trade restrictions for electricity obtained from fossil fuel and nuclear power plants, we can expect 7 – 8 PWh/year of electricity from the sun and wind energy sources in 2050. Using biomass energy, 3 – 4 PWh/year could be produced taking into account the fact that only the **annual increase** of biomass can be used for that purpose. The same amount could be produced by exploiting hydro and geothermal energy. Altogether, renewable energy sources could contribute 15 – 16 PWh/year to the world energy balance in 2050. This estimate does not take into the account the ideas such as "solar hydrogen from Sahara" and others.

In the production sector it is necessary to introduce widespread recycling and dematerialization of production processes. Transition from the consumer society towards the sustainable society will cause structural changes inside and between the production sectors. The service sector will increase in size substantially. The introduction of organic agriculture, will enable the energy use to remain practically constant in this sector. However, with respect to the population growth, we can expect the actual growth of end energy use for 40% at the same (or lower) rate of use of fossil fuels in this sector.

The residential sector is the one with the strongest influence on the quality of life. A great deal of the Earth's population today doesn't have a decent shelter.

Construction of the energy efficient buildings (with 14 – 28 Wh/m^2 DD) is supposed to be the goal. Share of the passive architecture buildings is supposed to exceed 20%. Using currently known solutions, it is possible to reduce the amount of energy needed for a normal functioning of a household for 20 – 80%. The reduction of energy needed for cooking from 440 kWh (OECD countries) and 1730 kWh (developing countries) to the 300 kWh per month in average, will have an important impact on the quality of life, since this is currently a major problem for a large part of population of Africa, India and even China. The **research of the heat exchange at cooking** and search for its improvements may not compete well with research of the heat transfer in a rocket motor or a nuclear reactor regarding its prestige, but it is of high importance to at least 4 billion inhabitants of this planet.

Similar is the situation with the energy needed for the preparation of warm water (in countries where they can afford it). In OECD countries it is possible to reduce the consumption from 1300 kWh/cap to 800 kWh/cap, while increasing it in the developing countries from 200 kWh/cap to 240 kWh/cap per month. Similar as average energy needed for cooking, average energy needed for the preparation of warm water would then be 330 kWh/cap per month. Of course, preparation of warm water heavily depends on the geographic location and the availability of water resources.

Table 1 (Wiessekar 1998) shows technically feasible reductions of energy consumption for household gadgets and Table 2 shows the same for the construction of buildings.

Appliance	1995	2050
Lighting	1040	400
Clothes Dryer	780	250
Refrigerator	710	140
Freezer	650	200
Stand-by	200	10
Dish Washer, Washing Machine *without hot water (56 or 113 kWh/a)	160*	70*
TV, Audio, PC etc.	140	100

Table 1. Specific Electricity Consumption of Electrical Appliances in OECD in kWh/a

Traditional	160 kW/m^2
1985 code	90 kW/m^2
1993 code (D)	65 kW/m^2
Passive solar	12 kW/m^2
Trisolar - special design	5 kW/m^2

Table 2. Annual Heat Demand of Apartment Houses

Is it possible to attain such reductions and how?

It is possible to reduce energy needed for heating of buildings for a factor of 20 (Table 2) using better heat isolation, better glazing of windows, using the heat coming from the Sun, heat pumps, ground coupled heat pumps, pre-heating of air in the ground and recuperation of waste heat. All listed are known technologies, however, their use depends on the regulations and economic stimulation of users in a particular country (carbon dioxide tax?).

Preparation of warm water can be made more efficient by using heat pumps, solar energy, isolation of pipelines and recuperation of heat. Applying those technologies can result in a factor 4 reduction of carbon dioxide emissions.

Development in the technologies related to household appliances will in general cause them to be more efficient, to last longer and to consume only half as much energy as before (new TVs and PCs with LCD displays, economical light bulbs, efficient washing and dish-washing machines, dryers etc.).

THE ROLE OF THE HEAT EXCHANGERS IN THE FACTOR 4 ENERGY POLICY

Factor 4 energy policy is not feasible without development of new, more efficient heat exchangers. They should be twice as efficient and at least twice cheaper than the currently existing. Achieving this, it will be possible to build transformers for energy of all types that will be environmentally and economically acceptable. The general criteria for the design and manufacturing of new heat exchangers are the following:

- recyclability,
- compactness,
- lightness,
- reliability,
- high heat-transfer rate,
- manufactured from environmentally friendly materials.

Technological evolution over past decade was characterised by different innovations of variable magnitude leading to:

- increased use of flat plate heat exchangers (Fig. 3, 4 and 5) and heat exchangers with flat tubes instead of circular tubes (Fig. 6, 7, and 8),
- increased use of light alloys and stainless steel instead of copper and copper alloys,
- increased heat transfer from 30% to 50% in boiling, condensation and heat recuperation processes,
- significant reductions of the boundary layer thickness,
- lower mass flow rates,
- lower or similar pressure drop,
- air to air or gas to gas heat exchangers with efficiency over 90% (Fig. 3).

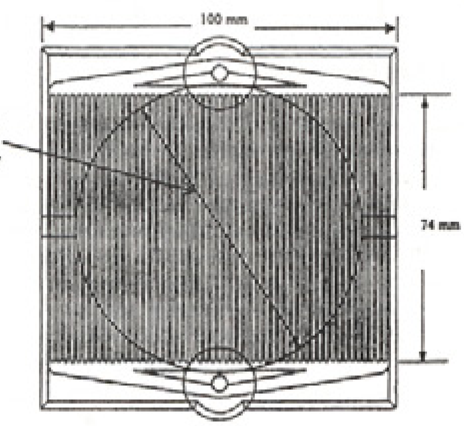

Fig. 3: Flat plate liquid/liquid heat exchanger

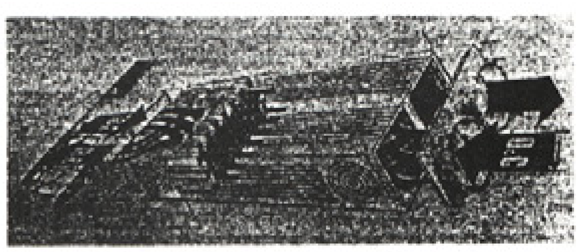

Fig. 4: Air to air counterflow heat exchanger, with efficiency over 90%

Innovations also yielded changes in the production of heat exchangers. The production departed from mechanical manufacturing of heat exchanger of type pipe/fin to brazing and similar processes (Fig. 6).

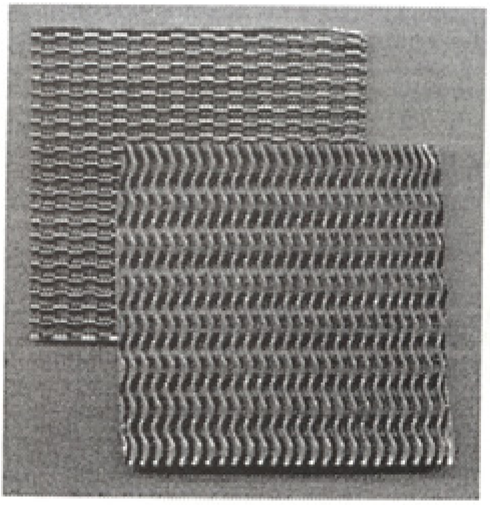

Fig. 5: Corrugated plate heat exchanger

The use of louvered fins made from the infinite ribbon by rolling (Fig. 7) has increased. The introduction of micro-channels (0.2 x 0.5 mm) in heat exchangers (Fig. 3) demanded new technologies for their manufacturing (e.g. photolythic processes) and resulted in a significant reduction of the heat exchanger size.

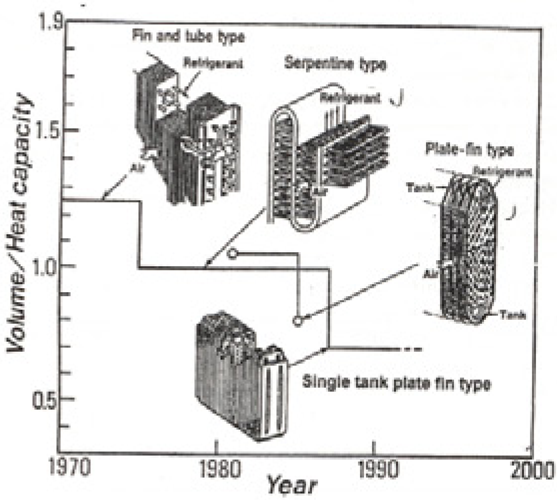

Fig. 6: Improvement of heat exchanger efficiency trough the time

The material consumption during manufacturing has become insignificant. Plastic materials are being introduced for heat exchangers that work at lower temperatures.

It is only a matter of time, when we will be able to say: "We have built the Factor 4 heat exchanger, now it's up to designers to use it in the devices and systems that will help implementing the Factor 4 energy policy.".

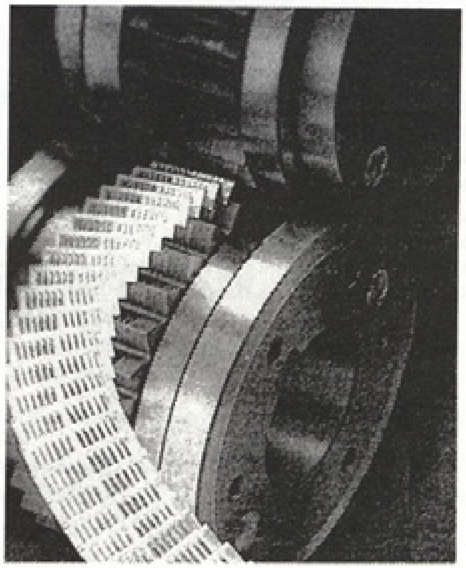

Fig. 7: Production of louvered fins

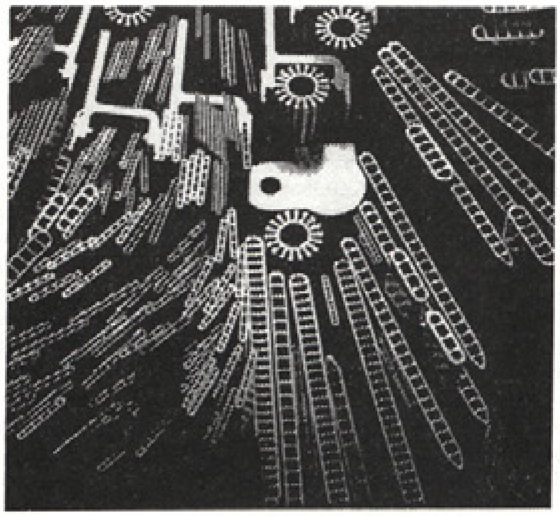

Fig. 8: Variety of flat pipe for new type of heat exchanger

CONCLUSION

Factor 4 Energy Policy is a new direction to the solution of the greenhouse effect, caused by intensive use of fossil fuels. It is viable if the efficiency of the heat transfer can be doubled without large increase of pressure drop and heat exchanger price. That is why the solution to the greenhouse effect lies in the hands of the researcher of heat and mass transfer in the broadest sense. They are the ones that let the ghost out of the Aladdin's lamp with the introduction of the combustion processes and so they are now responsible to tame it. The three magic words that will put the ghost back into the lamp are: the heat exchanger.

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