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POSSIBILITIES OF NUCLEAR POWERED AGRO-INDUSTRIAL COMPLEXES FOR IRAN

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Abstract—Nuclear powered industrial and agro–industrial complexes are new concepts that can make major contributions to industrial, agriculatural and general economic advancement in Iran. The production of power, water and steam from a large nuclear power plant can provide cheap supplies for numerous industries such as petrochemical industries (including oil refineries), chemical fertilizers, caustic soda and chlorine production as well as the aluminium and steel industries. The state-of-art in the field is reviewed and the possibilities of creating agro–industrial complexes in Iran are discussed. The conditions of Iran are reviewed. Energy and water requirements are explained. The most economical methods of water desalination are reviewed. Conditions under which desalted water may be used for agriculture are explained. The type of nuclear power plants ordered for Iran are presented. Some of the environmental effects are discussed. Previous studies on the subject are also mentioned. Problems of implementation of such a program are briefly presented. A feasibility study of the subject for Iran is recommended.

1. INTRODUCTION

Nuclear powered industrial and agro-industrial complexes are new concepts that can make major contributions to the industrial, agricultural and general economic advancement of Iran. This kind of complex, as indicated in Fig. 1, might consist of a large nuclear power plant producing electricity, stream and desalted water (electricity, stream and water are fundamental to many industries). The production of these commodities at a low cost creates good prospects of establishing industries that make intensive use of such commodities and thus reduces their manufacturing costs.

While the high-temperature steam is used for production of electricity, the exhaust steam from the turbine may be used as the heat source for the production of fresh water. The steam may also be used in process industries such as petrochemical industries. Therefore, the production of power, water and steam from a large nuclear power plant can serve a host of

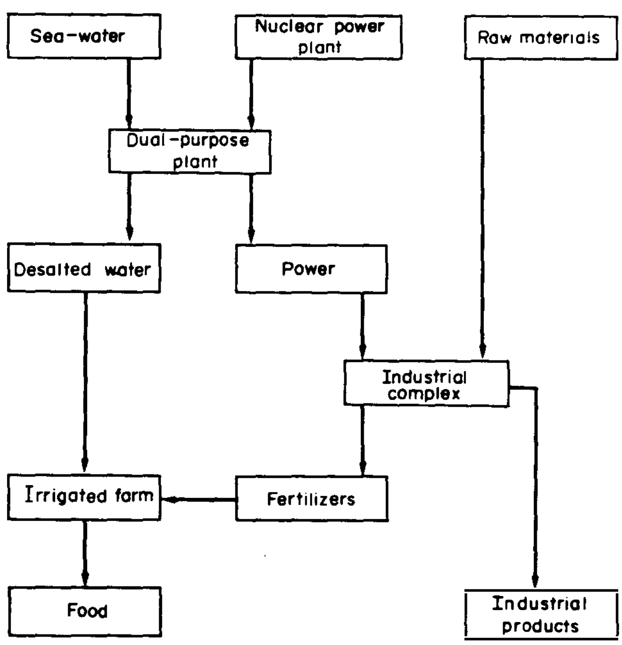

Fig. 1. The concepts of the agro-industrial complex.

industries such as petrochemical, including oil refineries, chemical fertilizers, caustic soda and chlorine, aluminium, magnesium and steel plants. Figures 2, 3 and 4 schematically show some of these processes. The low cost energy produced can be used in processes such as water electrolysis for the production of hydrogen required for ammonia, the electrothermic reduction of rock phosphate for phosphorous production and process steam for heating and cooling buildings.

Steam can be used to reform a light hydrocarbon such as natural gas to produce reducing gas composed of carbon monoxide and hydrogen (Figs. 5 and 6). The reaction is:

$$CH_4(\text{natural gas}) + H_2O(\text{steam}) + \text{heat} \rightarrow CO + 3H_2.$$

This reaction takes place at high temperature ($\approx 760°C$), utilizing the heat from a high-temperature gas-cooled reactor (HTGR). The hot carbon monoxide–hydrogen mixture produced by the reforming reaction will reduce iron oxide to sponge iron. The direct-reduced sponge iron can then be refined to steel in an electric furnace, for which the power would be produced from a portion of heat from HTGR. Therefore, the hydrocarbon is used only as the reducing agent and not for combustion to provide heat for the process; hence, it is conserved.

Another method is based on the production of hydrogen through the dissociation of water into hydrogen and oxygen. This can be done either through electrolysis of water or through a series of reactions requiring heat. As seen in Fig. 5, hydrogen from the electrolysis unit picks up enough heat (650°C) for the direct reduction of iron ore. The iron is then refined to steel in an electric furnace.

In an agro-industrial complex, consideration should be given to the production of fertilizer since the present and future food needs make intensive agriculture a necessity. From brine one can produce basic chemicals such as caustic soda, chlorine and soda ash. Other energy-intensive industries such as steel, aluminium and magnesium plants may also be considered for the complex. The chlorine can be used in plastic manufacturing since the most common plastics are chlorinated polymerization products of acetylene and polyethylene. The chlorine may also be used in adjacent petrochemical industries. Caustic soda, chlorine and hydrogen are co-products obtained by the electrolytic decomposition of brine. They are valuable base chemicals

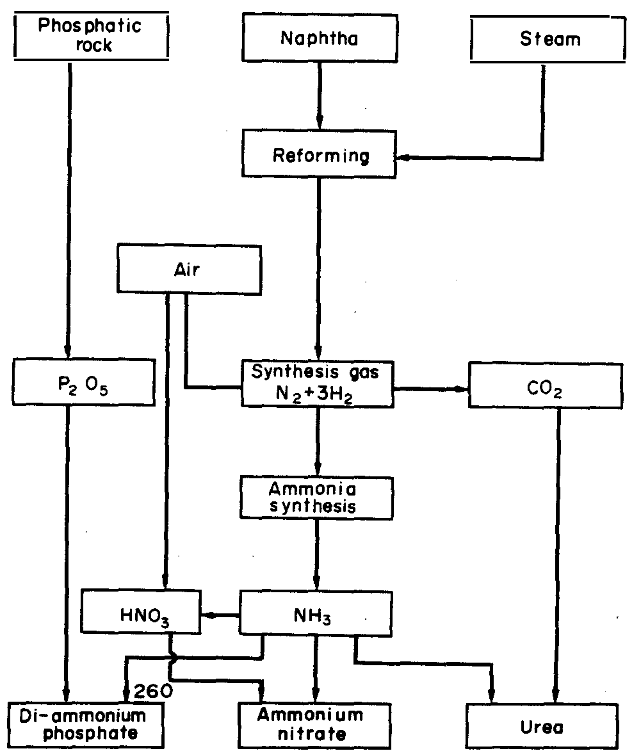

Fig. 2. Manufacture of fertilizers.

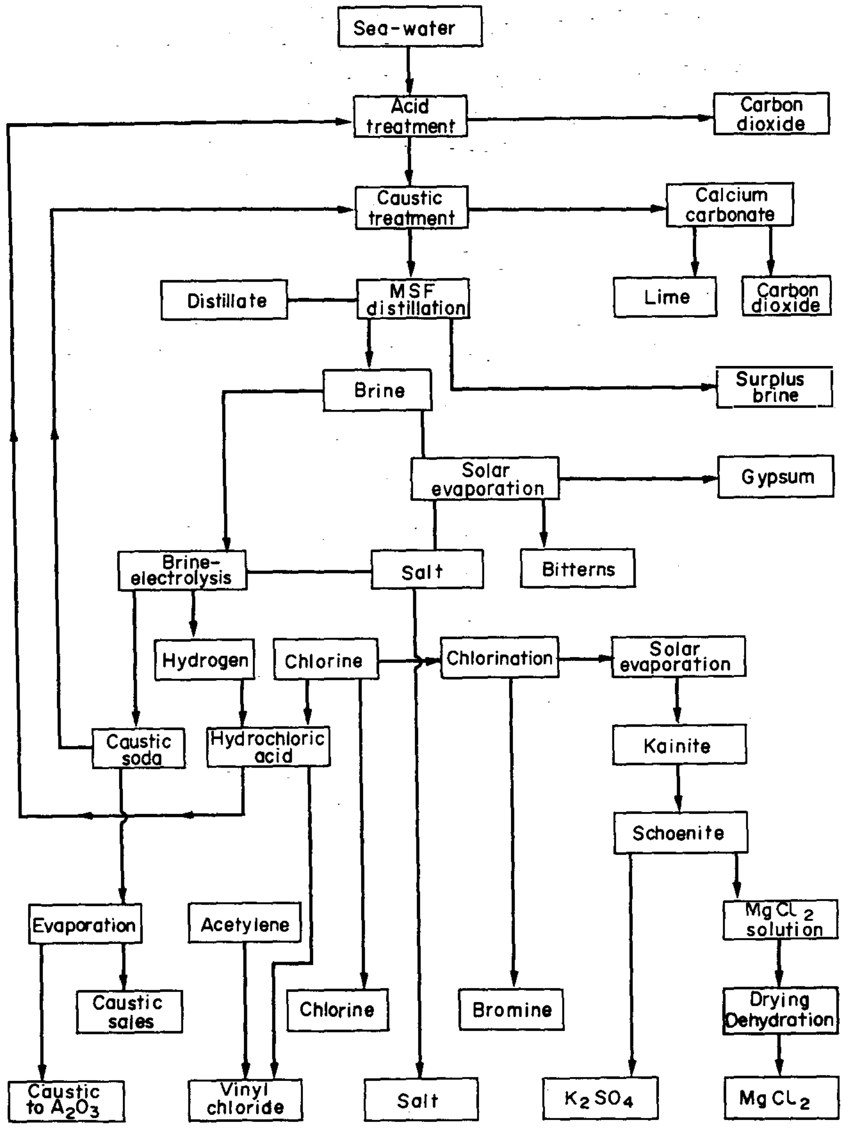

Fig. 3. Manufacture of caustic soda and marine chemicals.

and are used in the manufacture of a wide range of secondary chemical products. Aluminium is a power intensive industry and a large part of its production cost is the cost of the power it consumes. Low cost power is required to make aluminium production competitive. Therefore, an aluminium plant may be a suitable part of an agro-industrial complex.

The desalting of sea or brackish water offers a promising means of partly meeting future fresh water needs. The cost of desalted water is at least several times the cost of normal irrigation water. For this reason it seems very unlikely that in the near future the cost of desalted water will become low enough to permit its use in irrigation, based on the present irrigation technology. But using advanced irrigation methods such as subsoil irrigation technique, the use of desalinated water for agriculture could be made economical. However, we must realize that shortage of water is due to rapid economic and population growth. In many places, one cannot put a price on water and it may be considered priceless.

2. IRAN

Iran is a mountainous country that extends between 25 and 40° north latitude and is, therefore, entirely in the temperate belt of the northern hemisphere. Seen geographically, it occupies the major portion of the Iranian plateau.

Iran has a total area of 1.65 million square kilometres, about 10,000 km^2 of which have been

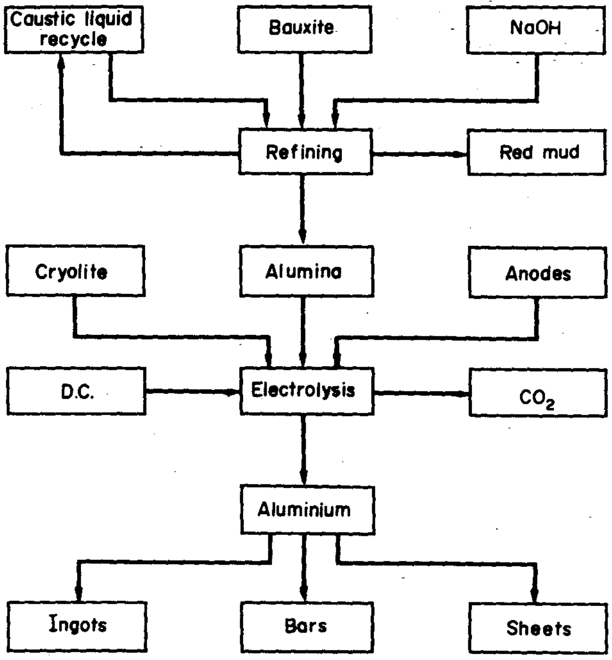

Fig. 4. Manufacture of aluminium.

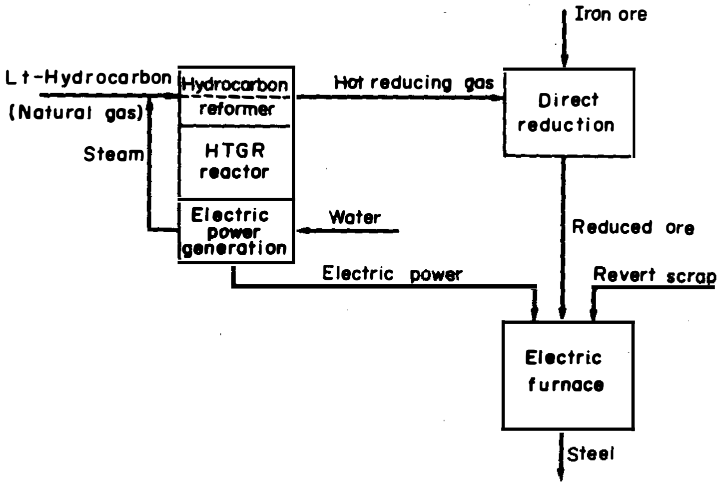

Fig. 5. HTGR-hydrocarbon reforming for direct reduction.

irrigated and cultivated. The country can roughly be divided into three areas: 1/3 consists of mountains, 1/3 of deserts and 1/3 of forest and woodlands. The Caspian littoral with its forests and heavy rainfall contrasts sharply with the barren, salty stretches of desert, while the snow covered mountains make a contrast to the palm groves on the Persian Gulf.

The southern coastal plains of Iran, that widen considerably in Khuzistan at the head of the Persian Gulf, are hot with high relative humidity throughout the year. Maximum temperature in Khuzistan exceeds 55°C almost every year. From the southwestern area of the coast to the southeast the maximum temperature and rainfall decrease and moisture increases. Eighty six per cent humidity and an air temperature of 38°C are common observations along the Oman coast. In these southern coastal plains, the minimum temperature nevel falls below freezing. Summers are long and hot and winters are mild and short. Although atmospheric humidity is high, the amount of annual precipitation is very low and, as a result, most of the coastal belt is basically as arid as the dry interior.

Iran, with a present population of 32 million, has a growth rate of 3.2% (attempts are being made to reduce this to 2.7%). Shortage of water in cities, expecially on the southern coastal

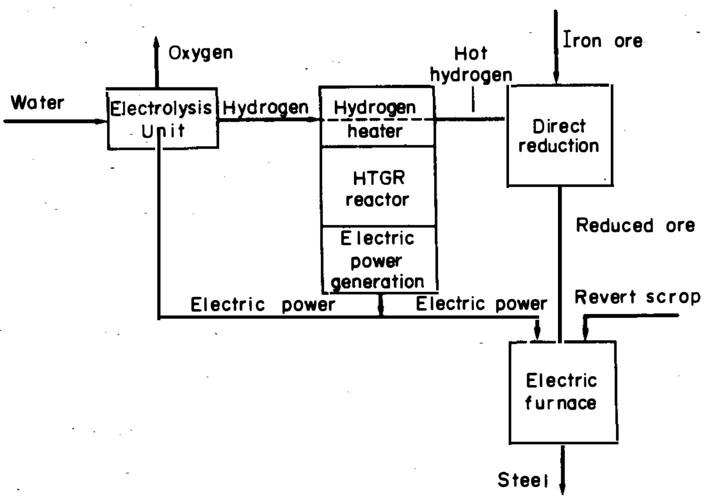

Fig. 6. Combination of hydrogen from water electrolysis and HTGR for direct reduction.

area, is the biggest problem. For example, it is believed that water will have to be rationed in Tehran when its present population of nearly 4 million reaches the 5.5 million level.

The annual precipitation for the country as a whole averages from 300 to 350 mm. The range varies from less than 10 mm in desert to more than 2000 mm in the southwestern corner of the Caspian Sea. On average, some 500 cubic kilometres of water are obtained from annual precipitation. Of this, 60% evaporates and 15% sinks into the ground, leaving only 25% or 125 km^3 to flow on the surface.

3. WATER DEMANDS

Three quarters of the human body is made up of water indicating the importance of water in our life. Large amounts of water are needed by agriculture and industry. Depending on the climate, about 500–3000 m^3 of water is normally required per ton of dry matter produced, excluding the various water losses involved in irrigation. For example, for wheat a skilled farmer may obtain a yield of 3.5 t/ha needing 5700 m^3 of water, thus producing an efficiency of water use of 630 gm^3 of water; it takes 30 m^3 of water to produce 1 kg of beef and 760 m^3 to grow 1 t of alfalfa; it takes 900 m^3 of water to make 1 t of acetate, 2500 m^3 to make 1 t of synthetic fuel from coal. Even simple household uses require more water than most people realize.

4. WATER DESALINATION

Fresh water represents only 3% of the total water reserves in the world and about 75% of that is immobilized as ice, while most of the remaining 25% is in lakes, rivers and underground reservoirs. The dissolved solids affect the taste and usefulness of water. According to thier salt content natural waters are classified as (1) good potable water with no more than 500 ppm total dissolved solid (t.d.s.), (2) slightly salty water with up to 1000 ppm t.d.s. acceptable as potable, (3) salty water with 1000–2000 ppm t.d.s. which is still used in some arid areas for drinking and household purposes, (4) brackish water with 2000–10,000 ppm t.d.s., (5) salt water with over 10,000 ppm t.d.s. and (6) sea water with salinity of about 35,000 ppm t.d.s.

Over the next 20 or 30 years it seem likely that the desalting of sea water will prove one of the most important factors in the economic development of the world as a whole. Distillation, as one of the most common methods of desalination, is defined as a process in which a portion of water is first evaporated and subsequently condensed.

The most common systems of distillation proposed and used industrially are the multi-stage flash (MSF) and the vertical tube evaporation system (VTE). A brief description of each of the mentioned systems are given below.

In multi-stage flash distillation, the heated brine is introduced in open channel flow into a chamber under reduced pressure. Some of the water vaporizes (flashes) immediately and is condensted on tubes cooled by sea water feed flowing toward the steam-heated heat input section. Several chambers (or stages) are at progressively reduced pressures form the plant. The sea water feed increases in temperature as it passes through the condenser tubes, in the opposite direction to the flashing flow, towards the heat input section. The condensed steam is collected on trays below the condensers and is pumped out of the plant as product water.

The distinguishing feature of vertical tube evaporation is that steam which forms in one effect condenses as product water in the next lower effect. Evaporation occurs as hot sea water flows downward inside vertical tube bundles surrounded by steam. The sea water boils on the inside surface of each tube and the steam generated passes to the next lower pressure effect, heating the incoming feed and condensing on the outside of the tube bundles, forming product. Hot brine which remains after vaporization of some of the brine in one effect is pumped to the top of the next effect, where it flows downward again on the inside surface of vertical tubes. In some instances, an MSF pre-heater is used in conjunction with a vertical tube evaporator to pre-heat the sea water.

A desalination plant processes about 6–10 times as much water as is made into product. Most of the water is heated to about 5–8°C above the sea temperature and the salt concentration is twice that of the sea water. The ejected sea water may contain more copper ions than raw sea water due to corrosion of Cu–Ni tubes which has adverse effect on the sea life in the vicinity of the plant. The use of titanium tubes will solve the problem if it could be economically justified.

There were 812 land based deslination plants in the world (as of 1972) producing one million cubic metres of water per day. Ninety six per cent of these plants are in the Middle East producing half a million cubic metres per day of desalted water. About 93% of water produced by desalination is by distillation.

The combination of large nuclear power reactors with water desalination plants can most economically be utilized because the higher the temperature and pressure of steam used in a turbine, the lower the cost of electricity produced. For distillation, on the other hand, steam at low temperature and pressure is needed and the greater part of input heat is the latent heat of steam. Therefore, the power production and desalination systems may be advantageously combined. For example, to produce 300 MWt of electricity and 570,00 m^3/day of water separately, one needs about 2600 MWt of energy, but to produce the same amount of electricity and water in a dual purpose plant one needs only about 1850 MWt of energy, a saving of about 40% in energy consumption. A 1000 MWt nuclear power reactor when employed in a dual purpose plant for producing both power and water will produce 700 MWe of electricity and about 1,300,000 m^3/day of desalted water.

The conventional means of combining a power station and a desalting plant is to let the high pressure steam flow through the back-pressure turbine, and the total exhaust steam flow to the brine heater. This method is suitable for a high water-to-power ratio requirement but the system is rather inflexible. In order to make the water-to-power ratio more flexible, one may use extraction turbines, a combination of a back-pressure turbine with by-pass steam, or a combination of a back-pressure turbine with a fully condensing turbine.

5. ENERGY REQUIREMENTS

The theoretical energy requirement for sea water desalination amounts to about 0.75 kWh/m^3 of product water. In this idealized process, the distillate and brine would leave the system at the same temperature as the raw sea water and the brine would leave the system at the same salinity as the sea water. Under practical conditions, the minimum energy requirement for the desalting process is about 3.5 kWh/m^3. The usual figures achieved under realistic operating conditions are much higher and in the order of 280 kWh/m^3.

If the single effect distillation device is heated with saturated steam, roughly 1 kg of distillate will be produced per kg of steam consumed. However, if the heat recuperation is utilized, theoretically, an additional kg of distillate water would be obtained in each consecutive stage for the same kg of steam initially introduced into the first stage. The maximum performance ratio (defined as the ratio of the mass of distillate to the mass of vapor used) achieved in distillation plants is about 12, which amounts to 19 m^3/MWht. Since a distillation plant takes its heat input entirely from the reject heat from a turbine in the range of 90–120°C, a plant efficiency of about 33% yields a basic water: power ratio of order of 38 m^3/MWhe.

6. NUCLEAR POWER

The world energy demand is rapidly growing. This demand is the consequence of two factors, namely the ever increasing world population and the increase in per capita energy consumption caused by affluency. The energy consumption in the world has increased about 2.7 times (i.e. 5.1% per year during the 19 years between 1950 and 1970). For Iran this has been much larger and will grow at a still higher rate. The demand for electrical energy of Iran by 1994 is estimated to be 73,000 MWe of which 23,000 MWe will be supplied by nuclear power plants. Iran is rich in fossil fuels and the country is rapidly becoming industrialized with the determination of making the best use of its oil resources in the petrochemical industries. The estimated natural resources of the country include about 70 billion barrels of oil, 214 trillion cubic feet of gas and 4.5 billion tons of coal.

To satisfy the country's growing need for energy, the government has decided to develop a nuclear power program to utilize nuclear energy. The first few reactions are intended to be of the pressurized water reactor (PWR) type. In these reactors, ordinary water, under pressures and temperatures of up to 326°C is used both as coolant to transport the heat released in fission of uranium-235 and as moderator to slow down the fast neutrons initially produced in fission. The pressurized water nuclear power plant is so called because the primary water flowing through the reactor is pressurized to 160 bar so that its boiling point is well above 326°C. Fuel rods for this reactor consists of uranium dioxide enriched to about 3% in uranium-235, hermetically sealed in tubes of zirconium alloy. This zirconium tubing constitutes the first barrier against escape of the highly radioactive fission products which form in the fuel as the end product of the nuclear reaction.

Assemblies of these zirconium-clad fuel rods are mounted in a heavy-walled steel pressure vessel and are surrounded by the pressurized flowing water, which enters at a temperature of approx 390°C and leaves at approx 326°C. The water has the effect of slowing down neutrons produced in fission, thus increasing their probability of reacting with uranium-235 to such an extent that the uranium fuel constitutes a critical mass capable of sustaining a nuclear fission chain reaction. To hold the chain reaction at a steady rate, a variable amount of neutron-absorbing boron is used in the reactor, partly as boric acid dissolved in water.

Pressurized water is pumped through the reactor by the circulating pump, past the pressurizer which holds the pressure constant and through the steam generator. The heat is transferred from the primary pressurized water at 326°C and 160 bar to the secondary water, boiling at a lower pressure of around 68 bar to make steam at around 285°C. The steam flows through a turbine dirving an electric generator and then passes to the condenser where it is condensed at sub-atmospheric pressure. The condensate is returned to the steam generator by the condensate pump.

In the condenser, hear from the condensing strem is transferred through cooling coils to cooling water at a pressure above atmospheric, which leaves the condenser at a temperature typically 10°C warmer than the incoming water. In some plants this cooling water is drawn from natural sources, such as the ocean; in others it is recirculated through cooling towers.

Steam which flows through the turbine could be extracted at various points in an extraction turbine or could be taken fully from a back-pressure turbine after certain expansion of steam to supply a desalination plant in an agro-industrial complex.

7. DISCUSSIONS AND RECOMMENDATION

The agro-industrial concept is an integrated complex in which the large-scale production of energy is effectively combined with the consuming industries at a single site or contiguous area. Such a complex would enable the prduction of power at lower real costs than otherwise might be achievable, because of the large scales involved and the reduction or elimination of transmission and distribution costs. Small plants cannot participate in the economic benfits of nuclear dual- or multi-purpose operation since the thermodynamic gains do not appear unless most of the steam produced reaches the distillation and other plants. One can use a back-pressure turbine or an extraction turbine or the combination of the two in the system. The back-pressure turbine for large amounts of water and the extraction turbine for small amounts of water is most suitable. To minimize the problems of the plants of the first type, it seems advisable to use on the extraction turbine and produce less desalted water, avoiding any possible reactor instability. The price of steam from a back-pressure turbine is the same as from the extraction turbine. A desalination plant may be used as a flywheel in the system to take up the load variation of the nuclear power plant in the complex, producing and storing desalted water at higher load factor during low power consumption periods.

The multi-stage flash system (MSF) is the most widely used method for large desalination. There exist contradictory opinions on the merits of the vertical tube effect system (VTE) over MSF system. Therefore, VTE system may not be advisable for the first plant. The largest MSF unit presently built is about 23,000 m^3/day but it is believed that the units of about 40,000 m^3/day can be built without much difficulty.

The safe method for building a large desalination plant is to make a combination of many smaller units which have been well tried rater than embarking on the development of a new large unit.

The data and operational experiences which will be obtained from the conventional MSF desalination plant planned to be built in Bushire, will be essential in order to embark on a large multi-purpose nuclear power plant, because the fluctuation in sea water temperature and other ambient conditions affect the power, steam production and demand. Also information on corrosion and scale formation under local conditions needs to be collected. As the salt content increases during progressive evaporation, the critical point may be reached at which the solubility limit is exceeded and scale formation begins. Corrosion must also be prevented. The sea water must, therefore, be adequately treated beforehand. The main constituents of scale deposits are calcium carbonate, magnesium hydroxide and calcium suphates.

Today, sea water distillation plants of 4000–40,000 m^3/day are producing fresh water for costs ranging from 25 cents to $1.50 per cubic metre.

Desalted water at the present time is not economical for use in agriculture except if used for special crops using advanced irrigation techniques.

Switching from sprinkler irrigation to the techniques of subsoil or trickle irrigation can potentially double the water utilization efficiency for many crops. Environmental control can provide higher yield grains. For example, greenhouse tests have shown that rice yeild is almost doubled when the level of carbon dioxide is increased from 320 ppm to 400 ppm. With several on site by-product sources of carbon dioxide available in an agro-industrial complex, sizeable yield increases might also be achieved in the field.

Considering an agro-industrial complex on the coast of the Caspian Sea, it should be possible to make use of some of the nuclear power plant's surplus heat to increase the temperature of a limited area of the sea by only a few degrees, so that the tourists can swim in the Caspian Sea all the year round, thus adding an important attraction to the area. Of course in the implementation of such a project all the economical, ecological and hazards to population aspects of the project must be carefully studied and evaluated.

In the world there are still no large nuclear powered desalting plants although one is nearing completion on the shores of the Caspian Sea in the Soviet Union. There have been many studies done on the concept of industrial and agro-industrial complexes and dual purpose nuclear power plants, but due to financial or political difficulties they have not been implemented. To mention a few, there is the Israel study, the Bolsa Island study, the Mexico project, the Diablo Canyon project, the Middle East study, the Puerto Rico Energy Center study and the Indian study.

A national long-range development program, leading to the demonstration of large-scale nuclear desalting, should be formulated now and must be implemented as soon as possible if our future critical water shortages are to be averted.

The successful implementation of an agro-industrial complex involves large capital investment, specialized technologies, proper coordination among the different units of the complex, very high utilization factors for the various units and large storage and transportation problems which may pose great challenges.

A study clearly demonstrate now nuclear energy can serve as a catalyst for the rapid development of this country. What is acutely needed at the present is an appreciation of political decision-making levels in understanding the ultimate economic worth of such a scheme, calling for a quick response in ordering a feasibility study on a nuclear powered agro-industrial complex for Iran in order that our independently growing industries may come together in a complex gaining the full benefits of economy. I hope that the results of such a study lead us to be the implementer of the world's first agro-industrial complex, thus turning the dream of the concept into a reality.

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