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# Performance Analysis of a New Nano Porous Ceramic Membrane Technology for Water Recovery (Extraction) from Boiler Flue Gases of a Combined Cycle Power Plant

***Abstract:*** Nowadays, due to scarcity of water resources, water recycling and extraction have been given more attention. Among sources of water is water vapor in combustion products. In this research, as an example, amount of water vapor in exhaust flue gases of Kashan combined cycle power plant unit was predicted in different seasons and conditions, which is a significant amount of 22.6 liters per second in winter season. Then, conventional systems of separation of gas streams, solid and liquid surface absorption, condensation cooling, cryogenic separation and membrane process were investigated for feasibility of extracting water from flue gases and were evaluated technically and economically. In this case, water quality parameters, energy saving, investment cost, operation cost and technology evolution were considered as evaluation parameters. result of comparison showed superiority of ceramic membrane system of porous nano filter. Assuming 40% extraction of water in flue gases, membrane system has a much lower investment cost than other systems and based on data of Kashan power plant, extraction of 9.32 liters of water per second can be expected.

***Keywords:*** Combined cycle, water extraction, gas turbine, power plant exhaust Flue gases, membrane system

## I. INTRODUCTION

With rapid increase in population and industrialization of human societies, lack of fresh water has become a global challenge [1]. Other factors such as industrial, agricultural and economic development and rapid changes in world's climate play an important role in aggravating challenge of water shortage around world. It should be noted that about 97% of earth's surface is covered by salt water in form of oceans and seas [2]. In near future, about 2-7 billion people worldwide will face challenge of fresh water shortage [3].

In industrial processes, need to recycle and reuse water in order to minimize need for fresh water is felt more than ever. Issues and problems caused by water supply for new and current industrial plants are important, because fresh water resources are limited and according to what was said, with prediction of water shortage crisis and statement that a significant percentage of world's population lives in water-scarce areas or will live without water, definitely one of big challenges ahead is provision of water for growing population and industry [1]. Many activities are being carried out to discover and access new sources of water, apart from existing ones, which include process of producing and releasing water vapor in combustion products of a fossil fuel as part of largest source of water, i.e. water vapor in atmosphere pointed out.

Considering combustion reaction equation of a fossil fuel (for example, methane) in an ideal combustion, we have:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (1)$$

For burning one mole of methane, two moles of water are produced and released into atmosphere as steam. If amount of combustion products is high, such as power plant boilers or gas turbines, amount of water produced will be significant. Now, if we can somehow extract this water from combustion products, a significant source of water will be created for use of power plant. Extracted water can be used for industrial use or can be prepared for drinking by purification. According to past researches, the most important methods of separation from gas streams include separation by absorbent liquids, separation by using absorbent solids, use of condensate and gas cooling,

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use of membranes. In recent years, a lot of research has been done in these fields for different gas streams for different separation methods, among which following can be mentioned:

In 2018, Beluco and colleagues used surface adsorption process with activated carbon to recover gasoline vapor. efficiency of their process was reported to be about 99%, but due to limitation of absorption capacity of adsorbent, process needed to continuously recover adsorbent after completing its absorption capacity. During 3 working weeks, amount of 47,000 liters of gasoline was recovered from 55,000 liters of evaporated gasoline (efficiency of about 85%) [4].

In 2020, in work of Tang et al., TiO2 and RGO were used as modifiers of MOF photocatalysts including ZIF-8, Uio-66 and Cu-BTC, and absorption capacity of normal compounds of hexane, methane, propane and methanol exceeded It was checked on them[5].

In 2019, in work of Petrusova and colleagues, polyamide composite membrane on Toray TM710D base was used to separate normal hexane vapor from nitrogen by reverse osmosis process[6].

In 2018, Dorosti and his colleagues tested effect of adding organic metal frameworks to Pebox membrane. They made Pebox/iron-benzene tricarboxylate Fe-BTC mixed network membranes and tested permeability of methane and carbon dioxide gases on membranes at a pressure of 3 bar and a temperature of 25 degrees Celsius[7].

Also, Farashi and colleagues made nanocomposite polymer membranes for gas separation in 2019, in which they added different percentages of aluminum oxide to Pebox and measured permeability of membranes at a temperature of 25 °C and different pressures for CO2 and CH4 gases. obtained results showed a better separation performance (CO2 permeability and CO2/CH4 selectivity)[8].

In another research, in 2020, Bernardo and his colleagues prepared a Pebox/polysorbate composite membrane and studied it. By loading 50% by weight of filler in polymer membrane, they were able to increase permeability of carbon dioxide from 66.5 barrer to 144 barrer for pure membrane[9].

In 2019, Dalane and Deng reviewed gas dewatering with membrane processes (process simulation and optimization). By introducing two thermopressurization units in series, compared to a design with one thermopressurization unit, TEG flow rate was reduced by 55%, membrane volume by 14.6% and energy demand by 37.8%. However, increasing number of regeneration steps increased complexity by introducing additional heaters[10].

In 2018, Kong et al. investigated modification of existing glycol technologies in gas dewatering to improve absorption properties and efficiency. This review briefly presented various processes and explained about their mechanisms, process flow chart, advantages, drawbacks and current status. Related works from 1991 to 2017 were collected and existing gaps were highlighted as recommendations for future works [11].

During a research, Shin et al. conducted a series of composite matrix membranes including Pebax-1657 as a polymer matrix, low molecular weight polyethylene glycol (PEG) derivatives as additives, and graphene oxide (GO) with different percentages as nanofillers, for separation of gases. prepared CO2/N2. Poly(ethylene glycol)-methyl ethyl acrylate (MEA-PEG) mixture with Pebax matrix significantly improved CO2 permeability without reducing CO2/N2 selectivity. results showed that Pebax/PEG-MEA alloy membrane containing 50% by weight of PEG-MEA showed a significant increase in CO2 permeability from 80 bar to 572 bar compared to pure membrane[12].

During a research conducted in 2021 by Kajabad and colleagues in order to separate carbon dioxide from nitrogen using corrected transfer membranes to improve membrane performance; They concluded that use of aniline with a weight ratio of 50% as a transfer agent increased permeability and selectivity at same time[13].

In 2019, Falkenberg and his colleagues, working on separation of gases from fermentation, proposed a hybrid process. Their purpose was to examine economy and performance of unit. In comparison, pressure swing surface adsorption unit achieved very high purity while having low recoveries. Membrane process had a relatively low cost and required high purity (it cannot provide very high purity)[14].

In 2018, Mozafari and his colleagues developed double-layer membranes with high carbon dioxide permeability, including a layer of polyether block amide (Pebax) coated as a CO2-friendly layer filled with MOF particles, on a porous base membrane made of polymethylpentene. (PMP), to achieve effective carbon dioxide/methane separation [15].

In 2018, Abedini and his colleagues investigated mesh membranes mixed with polymethylpentene polymer (PMP), by adding MOF particles, CuBTC to polymer mesh using a crosslinker in order to separate carbon dioxide gas and light gases. selectivity of carbon dioxide/methane and carbon dioxide/nitrogen increased after addition of HFBAA as a crosslinker to polymethylpentene (PMP) polymer network, but selectivity of carbon dioxide/hydrogen decreased [16].

In 2018, Isanejad and his colleagues investigated preparation of mixed network membranes based on polyether block amide (Pebax) and effects of silica filler loading on carbon dioxide/methane permeability and selectivity. They observed that in 15% by weight of filler modified with amine, permeability of carbon dioxide in membrane with silica filler and also ideal selectivity increased by 10% and 14%, respectively[17].

In 2018, Huang et al. fabricated stable highly hydrophobic membranes for long-term CO2 adsorption in membrane contactors. To make membranes, zinc oxide nanoparticles were placed on outer surface of glass fibers. produced membrane coating was then modified with FAS17 and then PVDF-HFP polymer was coated on membrane [18].

In 2018, Peng et al. investigated effect of different non-solvents on structure of PVDF membranes for CO2 absorption in membrane contacts. non-solvents of lithium chloride and phosphoric acid and their mixture with a ratio of 0-8% in polymer solution and their effect on membrane structure were investigated. By increasing non-solvent concentration in polymer solution, a spongy structure was obtained and membranes showed smaller pore sizes. By adding 8% phosphoric acid to polymer solution, highest absorption flux was obtained for PVDF hollow fiber membranes[19].

In a review, Ren et al discussed completed and ongoing research on membrane separation of water in flue gas and summarized advantages and challenges of current membrane-based technologies in recovering water resources [20].

Alabid and Dinka investigated technical and cost aspects of using two-stage polymer membranes in a coal-fired power plant with a capacity of 330 MW. In their study, membrane absorption process of CO2 after combustion was investigated using CHEMCAD software with several parameters and with an expander to reduce total cost. simulation showed promising results regarding reduction of energy consumption and cost after using an expander for high absorption rates (more than 90%) and CO2 concentration more than 95% [21].

Sinagh et al. conducted a comprehensive review of progress and challenges related to membrane separation for gas separation. This review detailed effect of separation parameters, including feed composition, flow rate, temperature, and pressure, on separation efficiency. This paper also refers to recent advances and developments in membrane-based O2 and N2 separation performance and showed progress in this field[22].

Kamio et al reviewed recent developments in organic and inorganic materials for high-performance CO2 separation membranes from molecular design to engineering perspectives. mechanisms of CO2 separation and effects of membrane material properties on permeability of CO2 to other light gases are discussed, and recent developments on inorganic and glassy polymer membranes with intrinsic microporous structures, rubbery polymer membranes, and gel-based membranes are discussed. They investigated ionic liquid. Finally, they suggested future research challenges and perspectives for commercialization of CO2 absorption and separation process using high-performance materials[23].

A comprehensive review of membrane gas separation module modeling and membrane gas separation process simulators was conducted by Conceicao et al. They proposed a list of membrane-module modeling for modeling and developing new gas separation membranes [24].

According to articles, although much emphasis has been placed on eliminating or reducing CO2 emissions from factories that use fossil fuels, little attention has been paid to capturing water vapor during combustion. main goal of this article is to extract water from exhaust flue gases of Kashan power plant taking into account desert geographical location of region. In this study, gas separation technologies that are suitable for water recycling are identified according to studies and surveys. Then, suitable methods for water recycling are studied from a technical and economic point of view, and best method is selected according to technical and economic criteria.

In this article, parameters of water quality, energy saving, investment cost, operating cost and technology evolution are used as decision indicators for prioritizing water vapor separation method.

## II.CALCULATION OF AMOUNT OF WATER VAPOR IN EXHAUST FLUE GASES OF CHIMNEY

In this part, flue gases parameters of power plant chimney have been calculated according to analysis of natural gas fuel, which is used as main fuel in this power plant. Next, amount of water vapor in chimney of this gas power plant with natural gas fuel is determined.

Despite many advantages that gas turbines have, changes in environmental conditions such as temperature, pressure and humidity have a great effect on their performance. Since they are air-sucking machines, their performance changes with any factor that affects air density or its mass flow at compressor inlet. Therefore, mass flow rate of air changes with change of environmental conditions, so amount of flue gases produced will also vary.

Flue gases moisture comes from three sources: fuel moisture, water vapor resulting from fuel hydrogen oxidation, and water vapor transported to combustion chamber through combustion air and excess air, so amount of water vapor in flue gases is variable.

According to fuel analysis provided by fuel laboratory, moisture in fuel has not been declared and reason for that is its small amount. Accordingly, fuel humidity does not play a role in calculating amount of water vapor in flue gases. Water vapor obtained from two other sources depends on amount of fuel and air used for combustion reaction and cooling air. Therefore, according to changes and environmental weather conditions compared to reference state, compressor flow rate and required fuel ratio changes according to fuel-air ratio, and these changes have their effect in chemical reaction equation governing combustion process. It shows fuel.

In this project, we have determined weather conditions in form of average temperatures in each month and average relative humidity in each month for a period of 10 years, which information is given in Table (1) and Figure (1).

**Table 1.** weather conditions of Kashan

| Average relative humidity (%) | Average temperature (C) | Month |
|---|---|---|
| 49 | 15.1 | April |
| 34 | 19.1 | May |
| 21 | 26.4 | June |
| 21 | 28.2 | July |
| 24 | 27.5 | August |
| 19 | 23.6 | September |
| 27 | 20.7 | October |
| 43 | 12.7 | November |
| 44 | 8.8 | December |
| 56 | 0.7 | January |
| 54 | 4.7 | February |
| 48 | 10.2 | March |

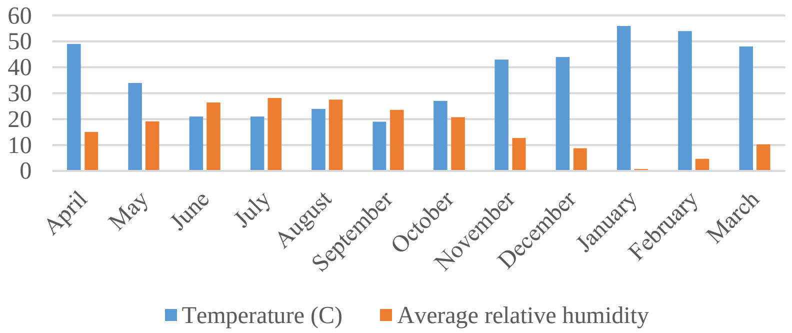

**Fig.1.** Average temperature and relative humidity of different months of year in Kashan city

According to presented diagram, temperature difference during a year for different months is large, and in order to show effect of temperature on amount of water vapor in produced Flue gases of a gas turbine, two average temperatures of cold and warm season were selected and based on this information and ratio It will be compared to conditions of reference state.

### ISO conditions

The environmental conditions for this state are defined from ISO state in table (2). Based on available documents, technical information of unit is given in table (3)[25].

**Table 2.** Different environmental conditions

| relative humidity (%) | Pressure (kpa) | temperature (C) | environmental conditions |
|---|---|---|---|
| 60 | 101.325 | 15 | ISO |
| 6.26 | 82.285 | 32.5 | Summer |
| 33.1 | 82.914 | 7.98 | Winter |

**Table 3.** Technical information in different environmental conditions

| Winter | Summer | ISO | environmental conditions |
|---|---|---|---|
| 419.45 | 371.80 | 510 | Compressor air flow rate (kg/s) |
| 8.62 | 7.18 | 9.2 | Fuel flow rate (kg/s) |
| 135.60 | 112.99 | 144.68 | Theoretical air flow rate (kg/s) |
| 209.40 | 228.97 | 252.42 | Excess air percentage (%) |

Now, if we write equation of chemical reaction governing process by considering required fuel (ISO conditions and at base load) and assuming no decomposition of N2, result will be as table (4).

$$\begin{aligned}
&0.4299CH_4 + 0.02583C_2H_6 \\
&+0.0098C_3H_8 + 0.00191C_4H_{10} \\
&+0.0025C_4H_{10} + 0.00067C_5H_{12} \\
&+0.00052C_5H_{12} + 0.00051C_6H_{14} \\
&+0.00057C_7H_{16} + 0.0128N_2 \\
&+0.0066CO_2 + 1.0488(O_2 + 3.76N_2) \\
&\rightarrow 0.5417CO_2 + 1.014H_2O \\
&+9.9865N_2 + 2.6473O_2
\end{aligned} \tag{2}$$

**Table 4.** exhaust Flue gases compositions in ISO conditions

| **Component** | **kmol** | **kg** | **%Mass** | **%kmol** |
|---|---|---|---|---|
| $CO_2$ | 0.542 | 23.83 | 5.86 | 3.82 |
| $H_2O$ | 1.014 | 18.25 | 4.49 | 7.15 |
| $N_2$ | 9.987 | 279.62 | 68.80 | 70.33 |
| $O_2$ | 2.647 | 84.71 | 20.84 | 18.66 |

### Environmental conditions of summer season

The environmental conditions for this state are defined from summer state in table (2). Based on performed performance tests, information and performance data for environmental conditions are given in table (3).

Now, if we write equation of chemical reaction governing process by considering required fuel (environmental conditions in summer and at base load) and assuming no decomposition of N2, result will be as shown in table (5).

$$\begin{aligned}
&0.3358CH_4 + 0.02018C_2H_6 \\
&+0.00768C_3H_8 + 0.001497C_4H_{10} \\
&+0.00194C_4H_{10} + 0.000526C_5H_{12} \\
&+0.00041C_5H_{12} + 0.0004C_6H_{14} \\
&+0.00044C_7H_{16} + 0.010028N_2 \\
&+0.00513CO_2 + 0.81906(O_2 + 3.76N_2) \\
&\rightarrow 0.42309CO_2 + 0.79193H_2O \\
&+7.074595N_2 + 1.875430_2
\end{aligned} \tag{3}$$

**Table 5.** exhaust Flue gases compositions in summer environmental conditions

| Component | kmol | kg | %Mass | %kmol |
|---|---|---|---|---|
| $CO_2$ | 0.42 | 18.62 | 6.4 | 4.16 |
| $H_2O$ | 0.79 | 14.26 | 4.9 | 7.79 |
| $N_2$ | 7.08 | 198.09 | 68.1 | 69.6 |
| $O_2$ | 1.88 | 60.01 | 20.6 | 18.45 |

### 2.3 Environmental conditions of winter season

The environmental conditions for this state of winter are defined in table (2). Based on performed performance tests, information and performance data for environmental conditions are given in table(3).

Now, if we write equation of chemical reaction governing process, considering required fuel (environmental conditions of winter and at base load) and assuming no decomposition of N2, result will be as shown in table (6).

$$\begin{aligned}
&0.40291CH_4 + 0.02421C_2H_6 \\
&+0.00921C_3H_8 + 0.00179C_4H_{10} \\
&+0.00233C_4H_{10} + 0.00063C_5H_{12} \\
&+0.00049C_5H_{12} + 0.00048C_6H_{14} \\
&+0.00053C_7H_{16} + 0.01203N_2 \\
&+0.00616CO_2 + 0.98287(O_2 + 3.76N_2) \\
&\rightarrow 0.50771CO_2 + 0.95031H_2O \\
&+7.76375N_2 + 2.05813O_2
\end{aligned} \tag{4}$$

**Table 6.** exhaust Flue gases compositions in winter environmental conditions

| Component | kmol | kg | %Mass | %kmol |
|---|---|---|---|---|
| $CO_2$ | 0.508 | 22.34 | 6.92 | 4.5 |
| $H_2O$ | 0.95 | 17.11 | 5.3 | 8.42 |
| $N_2$ | 7.764 | 217.36 | 67.37 | 68.83 |
| $O_2$ | 2.058 | 65.86 | 20.41 | 18.24 |

Therefore, as predicted, weight percentage of water vapor in exhaust Flue gases of power plant varies in different environmental conditions, and result is presented in table (7).

**Table 7.** weight percent of water vapor in different selected conditions

| | | |
|---|---|---|
| Water vapor ($H_2O$) | Selective conditions | Wt.% |
| | ISO | 4.49 |
| | Summer environmental | 4.9 |
| | Winter environmental | 5.3 |

The amount of flue gases output from chimney is defined as sum of air flow rate of compressor and fuel flow rate. By using weight percentages in above tables and also calculating mass flow rate of turbine exhaust flue gases from above equation, amount of water vapor in flue gases can be obtained in each of three conditions of ISO, summer and winter according to table below.

**Table 8.** Amount of water vapor in Flue gases

| | | | | |
|---|---|---|---|---|
| Turbine exhaust mass flow | environmental conditions | kg/s | Water vapor ($H_2O$) | kg/s |
| | ISO conditions | 519.2 | | 23.31 |
| | Summer environmental conditions | 378.98 | | 18.57 |
| | Winter environmental conditions | 428.07 | | 22.69 |

Using information provided in above table, graph of amount of water vapor in Flue gases is according to figure (2).

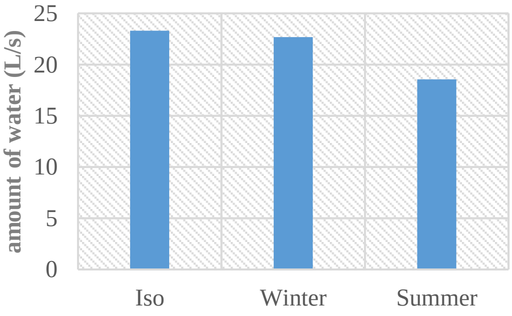

**Fig.2.** Amount of water vapor in Flue gases

According to information in table (8) and also figure (2) in worst temperature condition of Kashan power plant, amount of water vapor in Flue gases of one gas unit of Kashan power plant is about 18.5 L/s and a total of 2 gas units is 37 L/s, which is based on approximate amount of 3 L/s daily water consumption of power plant units and taking into account 1 L/s for repairs and recharging of systems is expected with mentioned technology and extraction of 20% of these vapors in addition to supplying water consumption required by industrial units. power plant, it is possible to provide a part of water needed by public sectors and green spaces in power plant, which will definitely reduce need for water consumption from other sources if extraction rate increases.

### Technologies for extracting water from soot

Various methods for extracting water from gases have been introduced and researched, which are divided into following four main categories depending on their type:

1. Solid and liquid surface absorption

2. Condensation cooling

3. Cryogenic separation

4. Membrane process

The comparison of discussed technologies is given in table (9) and it shows possible use, possibility of use on a large scale, water purity, safety and environmental risks and conclusion of need for more studies.

**Table 9.** preliminary comparison of proposed technologies to recover water from Flue gases of a fossil fuel power plant

| | Liquid surface absorption | Surface absorption of solids | Cryogenic separation | Condensation cooling | Membrane technology |
|---|---|---|---|---|---|
| Application to extract water from Flue gases | Yes | No | No | Yes | Yes |
| Possibility of large scale application | Yes | No | Yes | Yes | Yes |
| water purity | Suitable for feeding boiler water | Suitable for feeding boiler water | it is not clear | Suitable for compensating cooling tower water, not for feeding boiler water | it is not clear |
| Safety and having environmental aspects | Probably not need further investigation | Probably not need further investigation | Yes | No | Yes |
| Read more | Yes | No | No | Yes | Yes |

By using information in above table, three methods of liquid surface absorption, condensation cooling and membrane technology (type of gas separation and evaporative seepage) are recognized as appropriate in initial review and comparison and are introduced as methods of extracting water from Flue gases. next sections will be investigated further.

### Technical analysis of water extraction technologies from Flue gases

According to information in table (9) of previous section, three technologies of surface liquid absorption, condensation cooling and membrane technology will be further investigated in order to remove water from power plant Flue gases. At this stage, important and basic issues that play a role in feasibility assessment are tried to be investigated, therefore, in order to evaluate and compare technical aspects of water recycling technologies, following steps should be taken:

- Growth and evolution of technology
- Efficiency and efficiency
- Matters related to operation and safety and environmental issues
- Calculation of amount of energy consumed by each of water extraction systems from Flue gases
- Miscellaneous items

According to effect of local conditions (wet or dry weather conditions), only qualitative ranking according to table (10) can be done.

**Table 10.** quality criteria for extracting water from Flue gases

| | dehydrating liquid | Condensation cooling | Membranes |
|---|---|---|---|
| Water quality | 2 | 3 | 1 |
| Energy saving | 3 | 1 | 2 |
| Evolution of technology | 1 | 2 | 3 |

**Water quality:** It is thought that in membrane process technology, quality of water obtained is acceptable and equal to boiler feed water quality without need for further purification. water quality of a dewatering liquid can also be a very good quality, it depends on performance of drip catcher in separator column. water obtained from cooling method of Flue gases condensation, especially coal combustion, will be contaminated with acids such as HF - HCL - HNO3 - H2SO4 (depending on type of use of water obtained from this method, further purification will be necessary).

**Energy consumption:** main purpose of condensing cooling process is to recover energy from Flue gases. Depending on type and design of heat exchangers and characteristics of power plant, net electrical efficiency can be improved by 0.4 to 1.8 percentage points according to maximum reported amount. In event that absorption liquid technology requires input energy. Most of energy required for dewatering liquid processes is input heat required by heaters to separate enriched liquid. For this purpose, turbine steam must be used, so steam is pulled out of turbine. In case of membrane technology, main energy input is electricity required for vacuum pumps. Depending on type and design of heat exchanger and characteristics of power plant, net electrical efficiency can be reduced by 0.1 to 1.1 percent.

**Growth and development of technology:** technology of dewatering liquid (scrubbers) is an advanced technology and has been used in Flue gases purification for desulfurization (sulphur dioxide absorption in a suspension system, lime or limestone) on a large scale. Absorption of water vapor from Flue gases flow is a new but possible application, although not so big problems are expected. Choosing construction materials to prevent corrosion problems requires special attention. Membrane technology for water recovery from coal combustion or artificial Flue gases has been tested only on a small scale. This technology is considered least developed. Complete planning should be done in near future.

Dewatering of Flue gases through scrubbing with a concentrated aqueous salt solution with low water activity (such as LiBr, LiCl, LiNO3, CaCl2) or glycol (such as MEG, DEG, TEG) has been tested and tested in power plants on a pilot scale. But it is not used commercially. This technology is used on a large scale for extracting water from air (air conditioning systems) and optimizing natural gas. One of disadvantages of glycol-based systems is atmospheric waste caused by Flue gases, while salt solution-based systems are highly corrosive and erosive. Their advantage is production of relatively pure water, but energy demand for preheating and cooling stages is high.

Cooling fumes below water dew point in condensing converter technology with aim of water recovery is not commercially practical. All measures taken in this field are focused on increasing efficiency and effectiveness of power plant. main weakness of this technology is condensation of acids (sulfuric acid, nitric acid, hydrochloric acid, hydrofluoric acid) in Flue gases. Therefore, it is necessary for heat exchangers used to be insulated and either made entirely of plastic (such as G-FLON fluoroplastic) or of corrosion-resistant alloys such as titanium, although they are expensive to manufacture. water produced will be contaminated and require further treatment.

**Economic analysis and cost estimation of water extraction technologies from Flue gases**

One of common methods of economic analysis and comparison of investment projects is calculation of equivalent current value of each project, which will be done using this method of economic analysis.

**Annual initial costs:**

In order to obtain costs that are paid once in a while, following relationship is used with current value of money [26]:

$$C_{acap} = C_{cap} \cdot ap\left(i, R_{proj}\right) \tag{5}$$

In above relationship, $C_{acap}$, $C_{cap}$ and $R_{proj}$ are equal to annual initial cost, initial costs and number of years of system life, respectively.

i: is real interest rate obtained from following relationship.

$$i = \frac{f_f - i'}{f_f + 1} \tag{6}$$

$i'$ and $f_f$ are equal to nominal interest rate and inflation rate, respectively.

CRF is capital return factor and is calculated as follows.

$$CRF\left(i, R_{proj}\right) = \frac{i(1+i)^{R_{proj}}}{(1+i)^{R_{proj}} - r} \tag{7}$$

In above relationship $R_{proj}$ is number of years of system life.

**Annual replacement costs:**

The annual replacement costs are equal to replacement costs of each of system parts during life of system, minus value of each of them at end of their life. Using following relationship, annual replacement costs of each of system parts can be obtained.

$$\begin{aligned} &C_{arep} = C_{rep} \cdot f_{rep} \cdot ep\left(i, R_{comp}\right) \\ &-S.\,SFF\left(i, R_{proj}\right) \end{aligned} \tag{8}$$

In above relation, $C_{arep}$, $C_{rep}$, $R_{proj}$ and $R_{comp}$ are respectively equal to annual replacement costs, replacement costs, number of years of life of a system and number of years of life of each of desired parts.

Since it is possible that number of years of life of a system is different from number of years of life of each of parts of system, from coefficient $f_{rep}$ as ratio of coefficient of return of capital during life of system to coefficient of return of capital in period of replacement costs of each of parts system is used throughout system's lifetime and is obtained from following relationship:

$$f_{rep} = \begin{cases} \dfrac{CRF\left(i, R_{proj}\right)}{CRF\left(i, R_{rep}\right)} & \text{ow if } R_{rep} > 0 \\ 0 & \text{if } R_{rpp} = 0 \end{cases} \tag{9}$$

In above relationship, $R_{rep}$ is equal to period of replacement costs, which is calculated from following relationship:

$$R_{rep} = R_{comp}\, INT\left(\frac{R_{proj}}{R_{canp}}\right) \tag{10}$$

S in equation (8) is equal to recycling value of each part of system at end of its life, which is calculated using following equation:

$$S = C_{rep} \cdot \frac{R_{rem}}{R_{comp}} \tag{11}$$

where $R_{rem}$ is equal to remaining life of each of system parts at end of system life, which is calculated from equation (12):

$$R_{rem} = R_{comp} - \left(R_{proj} - R_{rep}\right) \tag{12}$$

SFF(i,N) in relation (8) is consumption factor that distributes amount of future value of each part of system into equal payments according to interest rate (i) during N periods and is calculated using following relation.

$$SFF(i,N) = \frac{i}{(1+i)^N - 1} \tag{13}$$

$SFF(i, R_{comp})$, $C_{rep}$ in relation (8) is future value of replacement cost of each of system parts according to interest rate (i) during lifetime of each of them ($R_{comp}$) It distributes equally. Also, $S.SFF(i, R_{proj})$ also distributes future recovery value (S) of each part of system according to interest rate (i) in system time ($R_{proj}$) into equal payments.

**Operation and maintenance costs:**

These costs are equal to costs of repair and maintenance of system parts. For example, they include costs of repairs, consumables, fuel, electricity, salary and operator costs, etc. on an annual basis.

After obtaining mentioned costs, two final parameters of economic analysis method are as follows:

**Total Net Present Value:($)**

To get total net present value of a system during its lifetime, we must first calculate total annual costs of system parts from following equation:

$$TAC = TAICC + TARC + TO\&M \tag{14}$$

where TAC, TAICC, TARC and TO&M are respectively equal to total annual costs, total initial costs annually, total total annual replacement costs and total total repair and maintenance costs related to system parts during one year. to be After obtaining sum of all annual costs, total net present value of desired system can be calculated using equation (15):

$$C_{NPC} = \frac{TAC}{CRF(i, R_{proj})} \tag{15}$$

$CRF(i, R_{proj})$ factor is capital return factor, as stated earlier, and is used here to obtain current value.

**Economic review of present work**

In this part, we will discuss economic analysis and comparison between extraction systems. First of all, it is necessary to calculate applied incomes and expenses after installing system. Therefore, we will continue to calculate these incomes and expenses according to prices of water, electricity and gas:

The price of electricity is considered 0.01$ per kilowatt hour [37]. price of each cubic meter of purified water is 1.31$ [27]. price of 100 grams of calcium chloride is 10.31$ [38]. price of gas is 0.015$ per cubic meter[39].

**Economic evaluation of dryer**

Investment costs: by Full Kadahl and colleagues in 2006, implementation cost is estimated at 5,800,000$ [28]. In order to update mentioned rate to current year, using information of interest rate and inflation of United States [40] and [41] and equation provided, result is as follows:

$$\mathrm{F} = \frac{(\mathrm{E} \times (1+\mathrm{i})^{\mathrm{n}})}{(1+\mathrm{f_f})^{\mathrm{n}}} \tag{16}$$

where F, E, i, $f_f$ and n are respectively equal to current value of money, previous value of money, interest rate, inflation rate and number of years to be calculated.

Average: i=6%

Average: $f_f = 2\%$

Number of years (from 2007 to 2024): n=18

$$F = \frac{5800000 \times (1+6\%)^{18}}{(1+2\%)^{8}} \tag{17}$$

$$= 16555167 \cong 16600000\$$$

So, amount of initial cost is considered to be 16,600,000$.

Referring to statistics of Central Bank of Iran, value of two items $\mathrm{f_f}$ and i is as follows:

$$\begin{gathered} f_f = 31\% \\ i' = 24\% \end{gathered} \tag{18}$$

Using equations (6) and (7) respectively, we have:

$$i = \frac{(31\% - 24\%)}{(31\% + 1)} = 0.0534 = 5.34\% \tag{19}$$

$$\begin{aligned} &CRF\ (5.34\%, 20) = \frac{5.34\%(1 + 5.34\%)^{20}}{(1 + 5.34\%)^{20} - 0} \\ &= 0.08257 \end{aligned} \tag{20}$$

The initial annual cost according to equation (5) is as follows:

$$\begin{aligned} &C_{acap} \ = 16600000 \times 0.08257 \\ &= 1370662\ \$/\ year \end{aligned} \tag{21}$$

Based on cost of repairs and maintenance of Kashan combined cycle power plant units, we assume that annual cost of repairs and maintenance of mentioned system is 4% of initial investment cost of system. Therefore, this cost is calculated with mentioned default.

$$\begin{gathered} C_{O\&M} = 16600000\$ \times 4\% \\ = 664000\$/\ year \end{gathered} \tag{22}$$

The cost of electricity consumption of mentioned system is equal to 701 kilowatts. Therefore, annual cost of electricity consumption is as follows:

$$\begin{gathered} C_{ellec} = 701kW \times 24 \times 365 \times \frac{0.01\$}{kWh} \\ = 61407.6\$/year \end{gathered} \tag{23}$$

Referring to Fukdahl's report, amount of dryer consumption is 13.6 kg/h, therefore, taking into account amount of dryer wastage during cycle of revival, repairs and also end of life, charge amount of 30 kg of dryer is considered annually:

$$\begin{matrix} 100\text{gr} & 10.31\$ \\ 30\text{kg} & \text{X} \end{matrix} \Rightarrow$$

$$X = C_{mat} = 3093 \frac{\$}{year} \tag{24}$$

Now, sum total of annual expenses using equation (14) is as follows:

$$TAC = 1370662 + 664000 + 61407.6$$
$$+3093 = 2099162.6\$/\,year \tag{25}$$

So total net value is obtained according to equation (15):

$$C_{NPC} = \frac{2099162.6}{0.08257} = 25422824.3\$ \tag{26}$$

**Economic evaluation of condensing converter**

The only record found is related to a 30 MW fluoroplastic heat exchanger replacing steam air preheater. cost of this project is equal to 4700000€ (in 2004)[29]. In order to update mentioned cost to current year, it should be done as before.

$$i = 5.6\% \tag{27}$$

$$f_f = 2.16\% \tag{28}$$

$$n = 20 \tag{29}$$

$$F = \frac{4700000 * (1 + 5.6\%)^{20}}{(1 + 2.16\%)^{20}} = 9115000€ \tag{30}$$

The modified cost in same way regarding Euro and based on price level of 2024 should be changed to 9115000€. Anyway, this project is special and dimensions of work are related to a 30 megawatt project. As a result, in order to convert and compare it with mentioned project, we multiply mentioned cost by 2.5 times and then consider final amount as initial cost of calculations. With euro to dollar conversion rate, we have:

$$C_{cap} = 9115000 \times 2.5 \times 1.218$$
$$= 27755175 \cong 28000000\$ \tag{31}$$

The initial annual cost according to equation (5) is as follows:

$$\mathrm{C_{acap}} = 28000000 \times 0.08257$$
$$= 2311960\$/\,\mathrm{year} \tag{32}$$

The annual cost of repairs and maintenance is assumed to be 3% of initial investment cost by referring to history [29]:

$$C_{O\&M} = 28000000\$ \times 3\%$$
$$= 840000\$/\,year \tag{33}$$

**Energy costs:** Energy is not consumed.

**The cost of auxiliary materials:** annual cost of auxiliary materials is same as cost of water treatment extracted from condensing converter according to Levy's report [30]. Therefore, cost of purifying and producing very pure water (demin) by reverse osmosis (RO) or ion exchange technology (IX) with estimation of production cost per cubic meter is about 2.4 dollars and Levy report that efficiency of water extraction is 70%. It can be Now, if we apply default amount of 40% water extraction in Flue gases flow for price comparison, according to information obtained in previous case, annual amount of water produced is 189,216 cubic meters per year, so cost is calculated as follows:

$$\begin{gathered} C_{mat} = 189216 \times \frac{2.4\$}{m^3} \\ = 454118.4\$/year \end{gathered} \tag{34}$$

Now, total annual expenses using equation (14) are as follows:

$$\begin{gathered} TAC = 2311960 + 840000 \\ +454118.4 = 3606078.4\$/year \end{gathered} \tag{35}$$

In this way, total net present value of desired system is obtained from equation (15).

$$\mathrm{C_{NPC}} = \frac{3606078.4}{0.08257} = 43672985.3\$ \tag{36}$$

**Economic evaluation of membrane technology**

The lifetime of system is 20 years, but lifetime of membrane module is considered to be 7 years. lifespan of membrane module is reasonable between 5 and 10 years [31]. Considering that price of membrane module is per square meter of surface area of membrane, surface area of desired project should be calculated first. According to dimensions of Flue gases duct, i.e. space at end of HRSG (the distance between CPH and steam chimney), cross-sectional area of Flue gases is 106m^2. According to technical information of module and referring to [32], price of each membrane module is $230/m^2 in 2013, and price of modules in a membrane system is approximately 32% of total system price, so price of modules of mentioned project And also membrane system is estimated considering installation cost. As a result, initial cost of mentioned system is as follows:

$$317187.5\$ \tag{37}$$

In order to update mentioned cost to current year, it should be done as before.

$$i = 5.6\% \tag{38}$$

$$f_f = 2.16\% \tag{39}$$

$$n = 10 \tag{40}$$

$$F = \frac{317187.5 * (1 + 5.6\%)^{10}}{(1 + 2.16\%)^{10}} = 441719.3\$ \tag{41}$$

The initial annual cost according to equation (5) is as follows:

$$\begin{gathered} C_{acap} = 441719.3 \times 0.08257 \\ = 37472.7\$/ \, year \end{gathered} \tag{42}$$

The annual cost of repairs and maintenance with a default of 3% of initial investment cost is equal to:

$$441719.3\$ \times 3\% = 13251.6\$/\,year \quad (43)$$

The cost of electricity consumption of mentioned system is only to extent of needing a small pump to circulate water in membranes. Since required vacuum is very detailed and flow rate is low, then a 20 kW electric pump should be used for stated requirement. Therefore, annual electricity consumption cost of mentioned system is as follows:

$$20kW \times 24 \times 365 \times 0.01\$/kWh = 1752\$/\,year \quad (44)$$

Annual replacement costs for membrane module with an estimated life of 7 years are equal to:

$$SFF\ (5.34\%, 7) = \frac{5.34\%}{(1+5.34\%)^{7} - 1} = 0.12 \quad (45)$$

$$SFF(5.34\%, 20) = \frac{5.34\%}{(1+5.34\%)^{20} - 0} = 0.02917 \quad (46)$$

$$R_{rep} = 7 \times INT\left(\frac{20}{7}\right) = 21 \quad (47)$$

$$R_{rem} = 7 - (21 - 20) = 6 \quad (48)$$

$$S = 230000 \times \frac{6}{7} = 197142.86 \quad (49)$$

$$CRF\ (5.34\%, 21) = \frac{5.34\%(1+5.34\%)^{21}}{(1+5.34\%)^{21} - 1} = 0.08035 \quad (50)$$

$$f_{rep} = \frac{0.08257}{0.08035} = 1.0276 \quad (51)$$

$$C_{arep} = 230000 \times 1.0276 \times 0.12 - 230000 \times 1.0276 \times 0.7 = 22611.1\$/\text{ year} \quad (52)$$

Now, sum total of annual expenses using equation (14) is as follows:

$$TAC = 37472.7 + 13251.6 + 1752 + 22611.1 = 75087.4\$ \quad (53)$$

So total net value is obtained according to equation (15):

$$C_{NPC} = \frac{75087.4\$}{0.08257} = 909378.7\$ \quad (54)$$

In Folkdahl's report, water extraction is between 22 and 62%, in Levy's report, water extraction is up to 70%, and in Wang's report, water extraction is between 40 and 55%. result of economic analysis is according to table (11).

**Table 11.** financial comparison between water extraction technologies

| Total Net Present Value | Water extraction methods |
|---|---|
| 12500188.9$ | Dryer |
| 49265757.5 | Condensing converter |

| | |
|---|---|
| 2024780.2$ | Membrane technology |

At time of using different methods, present value of options that have same lifetime, if all options have same capacity and same service, so that their annual income is same, then option that has lowest present value of cost should be selected. In calculations and economic analysis, drop factor in output of gas turbine, which causes a decrease in efficiency of gas unit and a decrease in production power of unit, has not been calculated due to having relatively equal conditions between all three options. Because in case of two condensing and membrane converter systems, this loss is almost same, but in case of dryer system, loss created at exit of gas turbine by installing spray nozzles and due to direct contact with absorbent solution will be less. On other hand, due to heat recovery during process of extracting water using condensation and membrane TMC method, efficiency of boiler increases by about 5 to 7%, and this increase in efficiency increases production power of cycle. Therefore, in this case, conditions of all three options are assumed to be fixed. Based on information in table (11), financial comparison chart between water extraction methods is according to figure (3).

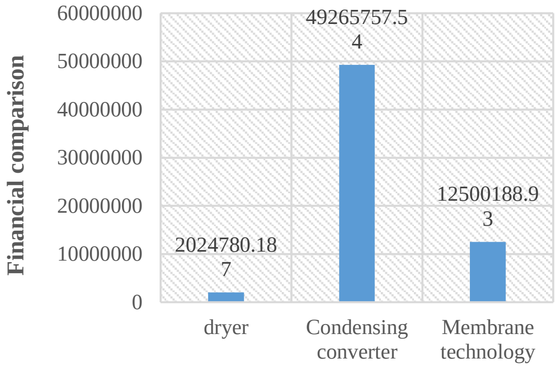

**Fig.3.** Financial comparison between water extraction methods

So, as it is clear, in present work, membrane technology is chosen with a huge difference compared to other methods.

### Effect of using selected technology on gas turbine and recovery boiler

By conducting an economic analysis between conventional water extraction technologies, general result is presented in table (12).

**Table 12.** technical and economic comparison between technologies

| | dehydrating liquid | Condensation cooling | Hydrophilic porous type nano membrane |
|---|---|---|---|
| water quality | 2 | 3 | 1 |
| Energy saving | 3 | 1 | 2 |
| Investment cost | 2 | 3 | 1 |
| Operation cost | 2 | 1 | 1 |
| Evolution of technology | 1 | 2 | 3 |

According to information presented in table (12), superiority of nano porous ceramic membrane system compared to other two systems is clear. Although, by studying details presented in previous sections, existence of this difference and distance between them becomes more clear. Therefore, this system is selected.

### Design of nano porous ceramic membrane and how to implement it in system

Due to existence of 7-8 percent of water vapor volume in Flue gases stream of a gas-burning combined cycle power plant and on other hand, limitation of pressure drop at output of a gas turbine, it is necessary to select appropriate membrane to obtain an acceptable percentage of water. Due to placement of this type of membrane directly in path of Flue gases flow, there is a limitation in material of membrane, configuration of module as well as function of membrane. As a result, it is necessary to have chemical, thermal and especially mechanical stability. On other hand, because membrane system is placed directly in Flue gases flow, it is necessary that membrane system is defined as a system with a small pressure drop so that process of Flue gases flow transmission inside chimney is not disturbed. Also, create lowest pressure drop at gas turbine outlet.

In order to achieve above goals, nano porous ceramic membranes should be made into modules and placed inside a rack designed for this purpose. place of installation of this rack is considered at end of boiler and in empty space of about three meters between CPH and chimney of steam turbine.

The modules in question are TMCs that can recover heat flows of moisture loss and with that sensible heat and a large amount of latent heat resulting from natural gas combustion process, which are based on this (Figure 4) [33].

**Fig.4.** TMC module made of garolite [34].

A TMC module is made of several hundreds of thin nanoporous ceramic membrane tubes. distance between pipes allows Flue gases to flow through them with a favorable pressure drop. Therefore, number of tubes used in a module is of particular importance. cold feed water flows through these thin tubes, and there is a flow of moisture-filled Flue gases transversely from end to end of tube (Figure (5)). Waste heat and pure water are recovered in cold water stream, while other gas compounds in exhaust Flue gases stream are prevented from passing through membrane.

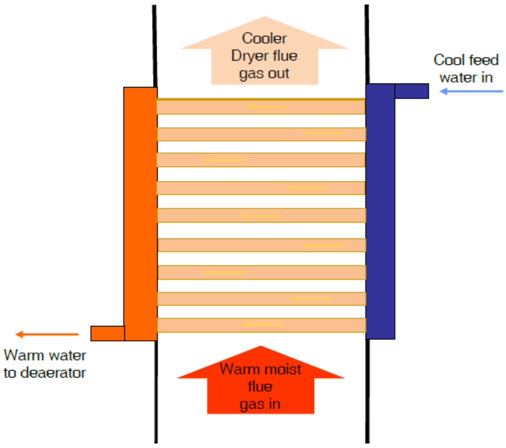

**Fig.5.** Design of TMC module with water flow inside pipe [42].

The TMC system for a power plant is designed in two stages. Therefore, based on [33], schematic design and general diagram of integration of TMC water recycling device in boiler of combined cycle power plant and steam turbine cycle are presented according to Figure (6). Two water flows in system, one of turbine steam condensate and other of condenser cooling water can be used. In addition to low temperature of cooling water, presence of a driving force for water flow in TMC is important. Accordingly, input water of first stage of TMC is through condensed vapors from condenser side, and output water along with recycled water vapor and resulting latent heat will go to deaerator for use as boiler compensation water. water entering second stage of TMC will be a part of condenser cooling water flow. water coming out of this stage joins cooling water flow together with recycled and added water from Flue gases flow.

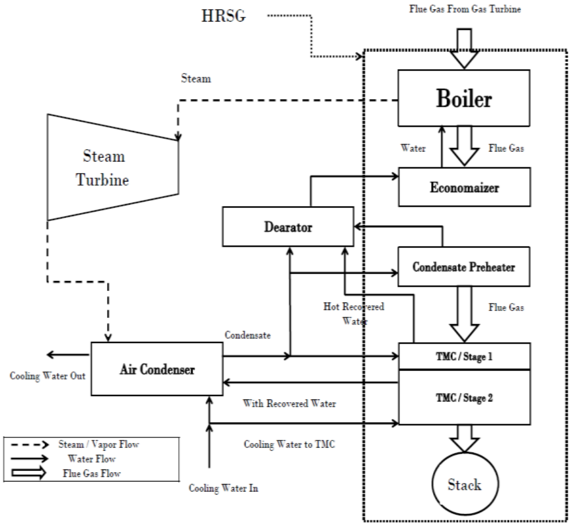

**Fig.6.** Water and heat recovery from power plant exhaust Flue gases using two-stage TMC

A schematic of mechanism of TMC technology is given in figure (7).

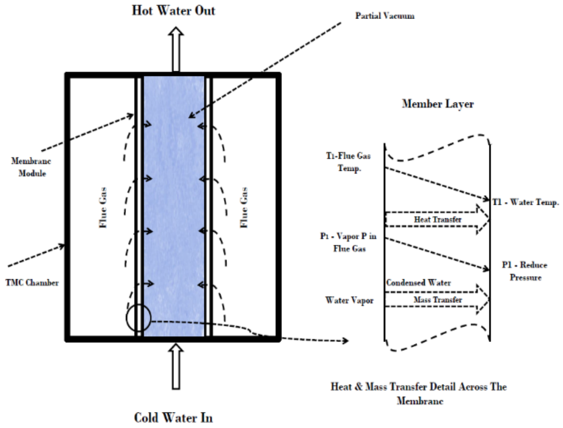

**Fig.7.** Schematic of TMC working mechanism

The choice of module configuration and also order of modules should be based on economic considerations and with correct engineering parameters used to achieve it, which include: creating greatest connection between Flue gases and membrane, possibility of extracting maximum amount of water from Flue gases, ease of cleaning. , ease of repair and maintenance, ease of operation, compactness of system, scale and possibility of replacement. To obtain geometry of module, dimensions of pipes (cross-sectional area and length) as well as their number are desired factors: pressure drop, water extraction rate, dew point, available space and flow size, based on which requested type of module can be ordered.

According to dimensions of duct, i.e. space between CPH and chimney with a depth of 2.3 meters in direction of Flue gases, this place has been found suitable for installing system. So, using information of membrane module, arrangement of membranes will be done and amount of loss and its effect on gas turbine will be calculated. example of module and its structure is according to figure (8).

**Fig.8.** An example of a long TMC module designed and built for use in power plant boilers [33].

Based on selected module, proposed structure and layout is according to Figure (9).

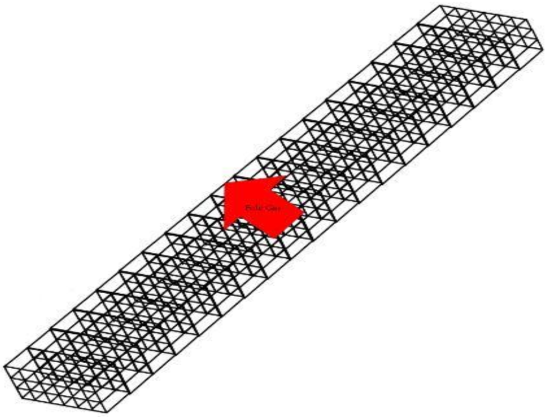

**Fig.9.** Design and arrangement of TMC modules in duct of Kashan combined cycle power plant

As mentioned, a two-stage TMC thermal power plant has been considered in order to extract water and heat from Flue gases flow. first stage can recover maximum amount of heat and only amount of compensation water for boiler, but second stage can recover maximum amount of water. Accordingly, in schematic presented in above figure, based on pilot plan, three rows of membranes are used in proposed structure plan. With this explanation, Flue gases passing through first stage, whose temperature has dropped and its humidity level has also decreased, enters second stage, and as long as relative humidity in Flue gases stream is high, second stage will be successful in recovering a large part of water. So first and second stages have opposite reactions to each other. That is, lower temperature of first stage cooler, lower water transfer rate in second stage and higher in first stage. same is true for Dubai. In general, TMC system performance is improved by reducing average inlet temperature and increasing flow rate.

### Calculating amount of water that can be extracted from membrane module system

The formation of droplets and condensation of water vapor outside membrane tubes of water extraction system causes a decrease in efficiency and effectiveness of system. Therefore, it is necessary to examine its occurrence and non-occurrence with conditions of plan. Using gas turbine manufacturer's information in ISO conditions:

$$\begin{aligned} &P_{4,C} = 1.0475bar \\ &\Delta P_{B,S} = 26.1mbar \\ &P_{P,1} = \left(P_{4,C}-, P_{B,S}\right) \end{aligned} \tag{55}$$

$P_{4,C}$, $\Delta P_{B,S}$, $P_{P,1}$ are respectively output pressure of turbine in combined cycle, HRSG pressure drop after CPH and before steam exhaust and input pressure of combustion products to water extraction system.

$$P_{P,1} = 1.0475 - 0.0261 = 1.0214 bar \tag{56}$$

According to 4.4 millibar drop of water extraction system, $P_{P,2}$ pressure of combustion products after extraction system is obtained as follows:

$$\begin{aligned} P_{P,2} &= 1.0214 - 0.0044 \\ &= 1.017\ bar\ = 101.7 kPa \end{aligned} \tag{57}$$

For every kilomol of fuel burned, according to composition of Flue gases in ISO conditions, 28.85 kilomols of combustion products are formed. Due to 2.06 kilomoles of H2O, dew point temperature of combustion products is higher than 106.4 degrees Celsius at P_(P,1) pressure. Now, if we use water extraction system with a drop of 4.4 millibars, it is necessary to obtain minimum permissible amount of Flue gases temperature reduction in reduced pressure. Using following equation, this maximum Flue gases temperature is calculated as follows [35].

$$\frac{N_v}{N_{prod.}} = \frac{P_v}{P_{prod.}} \cdot = \frac{P_v}{P_{P,2}} \tag{58}$$

If $N_w$ kmol of H2O liquefies, then $2.06 - N_w$ kmol of water vapor will remain in combustion products. number of moles of combustion products in gas phase will also decrease $28.85 - N_w$. by Considering ideal gas law for combustion gases in mentioned state, then $N_w$ is obtained as follows.

$$\frac{(2.06 - N_w)}{(28.85 - N_w)} = \frac{(12.349 kPa)}{(101.7 kPa)} \tag{59}$$

$$P_v \times N_w - N_w = 28.85 \times P_v - 289 \tag{60}$$

After solving, maximum pressure of saturated vapor is about 7.5 kPa in order to avoid formation of drops due to condensation, corresponding temperature of which is 40.29 degrees Celsius. Now, if temperature falls below mentioned temperature, i.e. below dew point, then mixture is saturated. For this reason, partial pressure of vapor is same as saturation pressure at temperature of mixture.

Allowed inlet water that does not cause drop formation and condensation of water vapor in extraction system, must be higher than obtained temperature. According to temperature of 45 degrees Celsius of water entering water extraction system, which is related to condensed water of condenser output, as a result, formation of drops due to condensation does not occur in system. According to temperature of incoming water and by providing required flow of cooling water, temperature of combustion products can be expected to decrease by 50 degrees Celsius, which does not cause any problems regarding dew point of products and there is enough temperature gap. It is important to mention that outlet temperature of chimney is economic 40 to 55 degrees Celsius [36].

In pilot project with 10.9% water vapor mass percentage of Flue gases, water transfer efficiency of 40 to 55% has been mentioned by performing field tests in total of two stages of TMC. Considering use of same membrane in mentioned project but in different dimensions, it can be expected that extraction efficiency will remain in same conditions. It is important to note that in pilot project, difference between temperature of Flue gases and inlet cooling water is much lower than similar conditions, based on data of power plant. Using information in table (8) and considering minimum efficiency, amount of water that can be extracted is as described in following table.

**Table 13.** amount of water that can be extracted from Flue gases with conditions of proposed system

| Water vapor (H2O) | | kg/s | Water recovery | kg/s |
|---|---|---|---|---|
| | ISO conditions | 23.31 | | 9.32 |
| | Summer environmental conditions | 18.57 | | 7.43 |
| | Winter environmental conditions | 22.69 | | 9.08 |

Using information obtained in above table, which is related to a power plant unit, graph related to amount of water that can be extracted in different conditions is as shown in Figure (9).

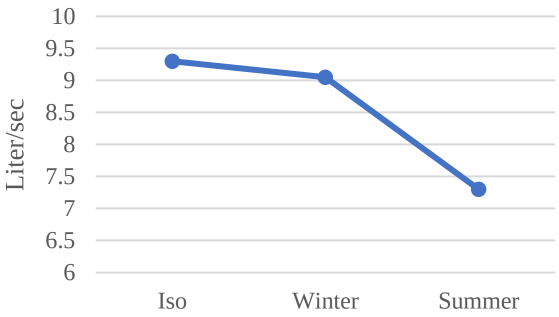

**Fig.10.** amount of water vapor that can be extracted from Flue gases flow

Since correct design of TMC has an effect on amount of water transfer, from information mentioned in Mr. Wang's article about conducting a pilot project in a 550 MW coal-fired power plant, during search, it was found that in addition to conducting a pilot project with a branch of Flue gases output of said power plant, design of membrane module has been done according to characteristics of that power plant in scale of Flue gases duct sizes and other data collection. modules used in terms of dimensions (length: 120 cm, width: 62 cm and width: 45 cm) are much larger than pilot design module, and this increase in size, in addition to reducing amount of structure connections and holders, reduces pressure drop. Also, due to reduction of frame and frame, it will be around membrane, which will be very effective considering actual dimensions and cross-sectional area. drop of aforementioned modules below one inch of water column and increase in water temperature after passing through TMC has been announced as 20 to 50 degrees Celsius, which depends on amount of discharge and temperature of incoming water, and indicates feasibility of mentioned plan.

## III.CONCLUSION

The main goal of this article is to extract water from exhaust flue gases of Kashan power station taking into account desert geographical location of region and lack of water in dry areas. As first step for feasibility study, amount of water in flue gases was investigated, and it was found that amount of water vapor in flue gases flow is enough to make power plant unnecessary from other available water sources, even in hottest seasons of year. According to geographical conditions and different seasons of Kashan, amount of water in exhaust flue gases of Kashan power plant for ISO, summer and winter conditions was 23.31, 18.57 and 22.69 liters/second, respectively. Then, different gas separation methods were introduced and researched, among which three liquid surface absorption technologies, condensation cooling and membrane technology to extract water from flue gases were identified. Then these three technologies were compared in terms of water quality, energy saving, investment cost, operation cost and technology evolution. By examining research history and recorded practical results and their technical and economic comparison with each other, their ability to extract water from flue gases was obtained in order of priority in form of hydrophilic nano-porous membrane system, dewatering liquid system and condensation cooling system.

In order to choose best water extraction system, in addition to its technical ability, cost-effectiveness is also very important. Therefore, in this project, in addition to technical comparison of mentioned systems, their comparison was also done with regard to initial costs, installation, repairs and maintenance, using results of economic and technical analysis of best system to extract water from flue gases of porous nano membrane system. Known as water-loving. By comparing results of economic analysis, current cost of dryer technologies, density converter and membrane technology is equal to 25422824.3, 43472985.3 and 909378.7 dollars, respectively, and cost of membrane technology is lowest value.

With technical feasibility study, it is possible to use introduced membrane system, and according to minimum efficiency of 40%, amount of water extraction in worst temperature conditions in Kashan is 7.43 liters of water per second, which is a total of 2 gas unit is responsible for consumption of power plant.

**List of signs and abbreviations**

| | |
|---|---|
| C | Cost ($/year) |
| CRF | capital return factor (-) |
| E | Previous value of money ($) |
| f | Inflation (-) |
| F | Current value of money ($) |
| i | real interest rate (-) |
| $i'$ | nominal interest rate (-) |
| n | number of years (-) |
| N | number of moles (-) |
| P | pressure (bar) |
| $\Delta P$ | pressure drop (bar) |
| R | number of years |
| $S$ | Recycled Value ($) |
| SFF | Consumer funds factor (-) |
| TAC | Total annual expenses ($) |
| TAICC | Annual initial costs ($) |
| TARC | Annual replacement costs ($) |
| TO&M | Annual maintenance and repair costs ($) |
| | |
| | |
| 4, C | Combined cycle turbine output |
| acap | Annual initial investment |
| arep | Annual compensation |
| B, S | After CPH and before steam exhaust |
| cap | investment |
| comp | piece |
| NPC | net present value |
| P, 1 | Input of combustion products to water extraction system |
| prod | Combustion products |
| proj | System |
| rem | left over |
| rep | exchange |
| v | Steam |
| w | Liquid H2O |
| | |

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