

Fuzzy set implementation for controlling and evaluation of factors affecting multiple-effect distillers

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Abstract

Multiple-effect (ME) distillation was the first process used to desalt a significant amount of seawater. This process takes place in a series of effects (stages) and uses the principle of reducing the ambient pressure in the various stages in order of their arrangement. In this work, a fuzzy logic is used to evaluate the factors affecting the ME distillers. The fuzzy logic detection was performed to assess three rules; i.e., “Increase”, “Decrease”, or “No Change” in distillation system in Jordan. We considered the factors that affect the detection of yield. There are many factors affect the ME distillers include: top brine temperature (TBT), concentration factor (CF), seawater temperature (T_{sw}), seawater pH (pH_{sw}), seawater salinity (S_{sw}), scale formation (SF), and CO_2 release. The various characteristics for the case study was synthesized and converted into relative weights w.r.t. fuzzy set method. The fuzzy set analysis for the case study reveals increase as confirmed by the experimental data. The application of the fuzzy set methodology offers reasonable prediction and assessment for detecting yield in distillation system in Jordan.

Keywords: Fuzzy control; Option-factors-fuzzy decision; Multiple-effect distillation; Distillation system

1. Introduction

Multiple-effect (ME) distillation was the first process used to desalt a significant amount of seawater. This process takes place in a series of effects (stages) and uses the principle of reducing the ambient pressure in the various stages in

order of their arrangement. This causes the feed water to boil in a series of stages without supplying additional heat. Vapor generated in the first stage gives up heat to the second stage for evaporation and is condensed inside the tubes. This continues for several stages. The seawater is either sprayed, or otherwise distributed onto the surface of horizontal tubes in a thin film to promote rapid boiling and evaporation. The condensate

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from the boiler steam is recycled to the boiler for reuse. The larger the number of stages, the less heat that is required as heat sources. There are many factors affect the ME distillers include: top brine temperature (TBT), concentration factor (CF), seawater temperature (T_{sw}), seawater pH (pH_{sw}), seawater salinity (S_{sw}), scale formation (SF), and CO_2 release.

Scale formation and CO_2 release have mutual effect on each others and this strongly depends on temperature, pH as well as on the concentrations of HCO_3^- , CO_3^{2-} , Ca^{2+} , and Mg^{2+} ions. Al-Rawajfeh et al. [1–4] have modeled the CO_2 desorption rates in ME distillers. Recently, Al-Rawajfeh [5] has developed this model to simulate the simultaneous desorption of CO_2 with the deposition of $CaCO_3$ and investigate their mutual effect.

This paper presents a fuzzy control method which is used to estimate the load of different essential factors (i.e. designs, climate and operational parameters on the productivity) affecting the performance of ME distiller productivity. The fuzzy control is widely accepted as a technology offering an alternative way to tackle complex problems. It is able to deal with nonlinear problems, and can perform predictions and generalisation at high speed. It has been used in diverse applications in control, power systems (Mamlook et al. [6]), and manufacturing. It was tested by Mamlook et al. [7] for the field of solar systems implementation, and water leakage predictions (Mamlook et al. [8]). More detail on fuzzy logic theory and applications are outlined in (Mamlook et al. [6–12], Zadeh [13–14]).

2. Proposed methodology

The fuzzy method presented here was presented in [8] for detecting leakage in water distribution systems in Jordan, also to detect the yield of solar distillation systems in Jordan [12], and is used here to detect the yield in ME distillation systems in Jordan.

Synthetic evaluation is an important application of the fuzzy transform used in developing the extension principle. The term synthetic is used here to connote the process of evaluation whereby several individual elements and components of an evaluation are synthesized into an aggregate form: the whole is a synthesis of the parts. The key here is that the various elements can be non-numeric, and the process of fuzzy synthesis is naturally accommodated using synthesis evaluation. An evaluation of an object, especially an ill-defined one, is often ambiguous and vague. Since a numerical evaluation is often too unacceptable, too complex, and too ephemera (transient), the evaluation is usually described in natural language terms.

To formalize the fuzzy synthesis evaluation, let F be a universe of factors and P be a universe of evaluations, so

$$F = \{F_1, F_2, \dots, F_N\} \text{ and } P = \{P_1, P_2, \dots, P_M\}$$

Let $R = \{r_{ij}\}$ be a fuzzy relation as in Table 1, where $i = 1, 2, \dots, N$ and $j = 1, 2, \dots, M$. Suppose we introduce a specific ME distillation system into the evaluation process on which the expert engineer has given a set of “weights” (w_i) for each of 7 factors as listed below:

- Top brain temperature (TBT)
- Concentration factor (CF)
- Seawater pH (pH_{sw})
- Seawater salinity (S_{sw})
- Seawater temperature (T_{sw})
- Scale formation (SF) or $CaCO_3$ precipitation
- CO_2 release

Table 1
Sample matrix for fuzzy pairwise relation

	P_1	P_2	...	P_M
F_1	r_{11}	r_{12}		r_{1M}
F_2	r_{21}	r_{22}		r_{2M}
...
F_N	r_{N1}	r_{N2}		r_{NM}

Table 2
Matrix for fuzzy ME distillation system pairwise relation

Parameter	Increase	Decrease	NC (no change)	Engineering experts weight for each parameter
Top brine temperature (TBT)	0.8	0.1	0.1	0.8
Concentration factor (CF)	0.7	0.2	0.1	0.4
Seawater temperature (T _{sw})	0.2	0.6	0.2	0.4
pH _{sw}	0.2	0.7	0.1	0.5
Seawater salinity (S _{sw})	0.6	0.2	0.2	0.7
CO ₂ release	0.8	0.1	0.1	0.6

The quantification of the above parameters is shown in Table 2. We ensure for convention that the sum of weights is unity. Each of these weights is actually a membership value for each of the factors, F_i in {Top brain temperature (TBT), Concentration factor (CF), pH_{sw}, seawater salinity (S_{sw}), seawater temperature (T_{sw}), and CO₂ release}, and they can be arranged in a fuzzy vector, W . So we have

$$W = \{w_1, w_2, \dots, w_N\} \text{ where } \sum_{i=1}^N W_i = 1 \quad (1)$$

The process of determining a value for a specific ME distillation system distribution is equivalent to the process of determining a membership value for the ME distillation system in each of the evaluation categories, P_j in

- Increase (I)
- Decrease (D)
- No Change (NC)

This process is implemented through the composition option,

$$E = W O R \quad (2)$$

where R is a fuzzy relation as in Table 1, W is a set of weights as in Eq. (1), O is the max–min composition operation, and E is a fuzzy vector containing the membership values for the ME distillation system in each of the P_j in {increase, decrease, and no change} evaluation categories.

If the evaluation expert engineering team applies a factor of 0.8 for TBT, 0.4 for CF, 0.4 for T_{sw}, 0.5 for pH_{sw}, and 0.7 for S_{sw}, and 0.6 for CO₂ release which together form the factor, W , then the composition,

$$E = W O R = \text{MAX}\{e1, e2, e3\} \\ = \text{MAX}\{0.8, 0.5, 0.2\}$$

where $e1$, $e2$, and $e3$ are the membership values in the categories Increase (I), Decrease (D), and No Change (NC) respectively. And

$$e1 = \text{MAX}\{\text{MIN}(0.8,0.8), \text{MIN}(0.4,0.7), \\ \text{MIN}(0.4,0.2), \text{MIN}(0.5,0.2), \text{MIN}(0.7,0.6), \\ \text{MIN}(0.6,0.8)\}, \\ e2 = \text{MAX}\{\text{MIN}(0.8,0.1), \text{MIN}(0.4,0.2), \\ \text{MIN}(0.4,0.6), \text{MIN}(0.5,0.7), \text{MIN}(0.7,0.2), \\ \text{MIN}(0.6,0.1)\}, \\ e3 = \text{MAX}\{\text{MIN}(0.8,0.1), \text{MIN}(0.4,0.1), \\ \text{MIN}(0.4,0.2), \text{MIN}(0.5,0.1), \text{MIN}(0.7,0.2), \\ \text{MIN}(0.6,0.1)\}$$

result in an evaluation vector that has its highest membership in the category “Increase”.

The fuzzy logic detection was performed to assess three rules; i.e., “Increase”, “Decrease”, or “No Change” in ME distillation system in Jordan. We considered the factors that affect the detection of yield (Fig. 1). Fig. 1 is based on actual data obtained from field measurements for ME distillation in Amman City. Our objective is to

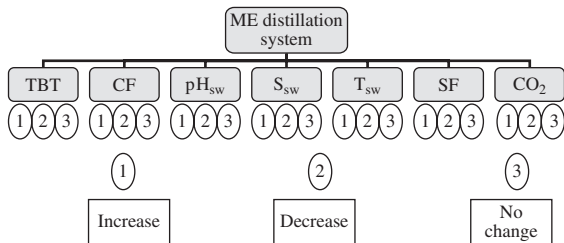


Fig. 1. Yield detection fuzzy system structure.

make the decision of detecting yield of the ME distillation systems in Jordan.

The fuzzy logic decision maker method described above was used to compare ME distillation system production options ($p_1 =$ increase; $p_2 =$ decrease; $p_3 =$ no change) in Jordan to detect yield in ME distillation system. Many factors affect this decision. They include $F_1 =$ top brine temperature (TBT), $F_2 =$ concentration factor (CF), $F_3 =$ seawater pH (pH_{sw}), $F_4 =$ seawater salinity (S_{sw}), $F_5 =$ seawater temperature (T_{sw}), $F_6 =$ scale formation (SF) or $CaCO_3$ precipitation, and $F_7 = CO_2$ release (Fig. 1).

3. MED process configuration

MED works on the principle of inducing seawater evaporation and vapour condensation inside a series of cells (effects). A variety of multiple-effect process configurations has been installed.

The most common process configuration is shown in Fig. 2.

Multi-effect distillation (MED) is one of the main and oldest thermal desalination methods. But since 1960 Multi-stage Flash (MSF) process dominated the desalination market. Recent developments in MED technology have again brought it to the point of competing technically and economically with MSF process. MED has a number of distinguished features, in particular, lower primary energy consumption [15], higher gain output ratio [16], lower heat transfer area [15]. MED process is less susceptible to corrosion and scaling than MSF process [17].

4. Results and discussion

4.1. CO₂ release

Table 3 shows the effect of top brine temperature (TBT), concentration factor (CF), seawater pH (pH_{sw}) and seawater salinity (S_{sw}) on the release of CO_2 in a reference ME distiller [3]. The release rates of CO_2 decrease from the first to the last stage. CO_2 release increases with increasing top brine temperature and seawater salinity and decreasing concentration factor and pH of the seawater. Relating the desorption rates to the feed water flow rates, the specific CO_2 desorption increases with the concentration factor. The

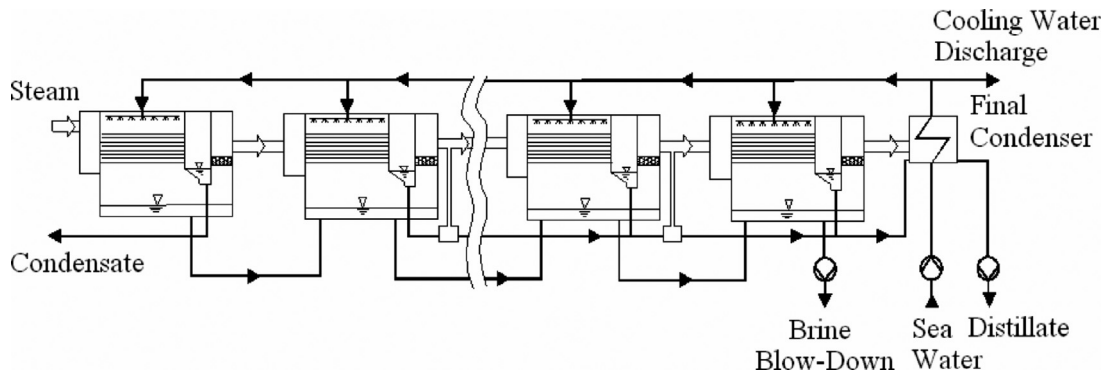


Fig. 2. Process configuration of the MED process [1–5].

Table 3

The effect of top brine temperature (TBT), concentration factor (CF), seawater pH (pH_{sw}) and seawater salinity (S_{sw}) on the release of CO_2 in a reference ME distiller

Stage	TBT	CF	pH_{sw}	S_{sw}
	65°C	1.4	8.0	40 g/kg
1	18.88	18.41	20.80	17.68
2	17.25	16.82	19.16	16.17
3	15.89	15.45	17.72	14.86
4	14.62	14.22	16.42	13.68
5	13.41	13.03	15.17	12.55

Table 4

The effect of top brine temperature (TBT), concentration factor (CF), seawater pH (pH_{sw}) and seawater salinity (S_{sw}) on the deposition of CaCO_3 in a reference ME distiller

Stage	TBT	CF	pH_{sw}	S_{sw}
	65°C	1.4	7.9	40 g/kg
1	130.15	127.30	130.62	122.05
2	122.96	120.09	122.65	115.00
3	116.34	113.28	115.12	108.35
4	109.77	106.74	107.88	101.96
5	103.12	100.12	100.57	95.52

Table 5

Our factors in (%) for each experimental work (case study)

Parameter	Experimental results (case study)	Increase	Decrease	NC (no change)
Top brine temperature (TBT)	60%	0.8	0.1	0.1
Concentration factor (CF)	15%	0.7	0.2	0.1
Seawater temperature (T_{sw})	10%	0.2	0.6	0.2
pH_{sw}	25%	0.2	0.7	0.1
Seawater salinity (S_{sw})	45%	0.7	0.2	0.1
Scale formation (SF) or CaCO_3 precipitation	55%	0.8	0.1	0.1
CO_2 release	50%	0.8	0.1	0.1

total CO_2 release (sum of the CO_2 release in the stages) increases from about 14 g CO_2 per ton of feed water at a top brine temperature of 60°C to about 18.2 g/t at 70°C. Between 14 and 18% of the total inorganic carbon in the feed water is released as CO_2 .

4.2. CaCO_3 deposition

Table 4 shows the effect of top brine temperature (TBT), concentration factor (CF), seawater pH (pH_{sw}) and seawater salinity (S_{sw}) on the deposition of CaCO_3 in a reference ME distiller [5]. The amount of CO_2 desorbed decreases from 36.4 g/ton feed water in the first stage to 32.5 g/ton in the last stage. The specific CaCO_3 deposition decreases from 127.3 g/ton feed water in the first stage to 100.1 g/ton in the last stage. The amount of CO_2 desorbed decreases from the first stage to the last stage and found to be higher of about 49–59% from the desorption rates calculated assuming negligible scale formation. CaCO_3 deposition rates decreases from the first stage to the last stage. CaCO_3 deposition rates increase with increasing top brine temperature, salinity and concentration factor and decrease with increasing pH values of the seawater.

Our factors in (%) for each experimental work (Table 5) applies a factor of 0.6 for TBT, 0.15 for CF, 0.1 for T_{sw} , 0.25 for pH_{sw} , 0.45 for S_{sw} , 0.55 for SF and 0.5 for CO_2 release, which

together form the factor, W , then the composition, Eq. (2):

$E = W O R = \text{MAX}\{0.60, 0.25, 0.1\}$ results in an evaluation vector that has its highest membership in the category “Increase”.

5. Conclusion

One of the advantages of the fuzzy logic decision maker for ME distiller production (FLDMMED) method presented here is that it used minimum and maximum operations, which are easier and faster than that are used by other methods. Also FLDMMED method used fuzzy sets that enabled us to condense large amount of data into smaller set of variable rules.

The detection of yield of the ME distillation systems are virtual importance. This research proposed a methodology for the detection of yield of the ME distillation systems in Jordan.

The fuzzy sets enabled us to condense large amount of data, collected to detect yield in the ME distillation systems in Jordan, into a smaller set of variable rules.

The various characteristics for the case study was synthesized and converted into relative weights w.r.t. fuzzy set method. Table 5 illustrates the basic readings and calculations for detecting yield. Based on Table 5, detecting yield was estimated to be 60%. Based on our proposed methodology it was revealed that there is close correlation between the actual and predicted values of detecting yield. The actual and predicted values for the case study were 65 and 60% respectively. The fuzzy set analysis for the case study reveal increase as confirmed by the experimental data in Table 5. The application of the fuzzy set methodology offers reasonable prediction and assessment for detecting yield in ME distillation system in Jordan.

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