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Air Pollution Monitoring Using Fuzzy Logic in Industries

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1. Introduction

In this chapter, an approach will be investigated by monitoring of industrial air pollutions by fuzzy logic. Monitoring by fuzzy logic means air pollutant risk will be evaluated on time in the specific industry and area. It will be able to identify which air pollutant has high risk and which industry is responsible for that, and also, which area is in the matter. In other word, it will evaluate air pollutant risk, related industry and related area on time. Therefore, it helps Air Pollution Control District (APCD) to identify high risk air pollutant, industry and area by numerical value.

Fuzzy logic is used in uncertainty environments so that expert's experiments can be converted into mathematical languages. On base of fuzzy logic is possible to maximize the utilization of design. In this chapter, it shows that, it used for monitoring of industrial pollutions as a case study of air pollution monitoring in iron and steel making industry and aluminum making industry.

Fuzzy logic has a real concept of natural actuation which everybody meets everyday. This logic seems to be natural phenomena in a real form. Fuzzy logic is used in uncertainty environments so that expert's experiments can be converted into mathematical languages. On the bases of fuzzy logic it is possible to maximize the utilization of decision making. It is possible to use it also for ranking of air pollutant risk, dangerous industries and high risk area by a continuous value between 0 and 1.

Fuzzy logic investigates the relative air pollutant. In order to accomplish this, fuzzy-logic approach defines a set for each property. For example, air pollutant has different criteria; industries produce different amount of air pollutant and also the mass of industry production differences in the specific area. Therefore, these matters have different membership degree in their sets. Using these sets and fuzzy logic rules, it can evaluate and compare different air pollutant risk for APCD decision making properly.

Fuzzy logic method was proposed because this method has not been used for air pollutant risk ranking. In the other word, fuzzy logic method shows the satisfactory value of air pollutant in a continuous value between 0 and 1.

In the first step, the parameters must be normalized. The second step is sets definition. These are 3 sets called air pollutant set, industry set and area set. In the final step, the air pollutant favorability degree in the specific industry at the relative area is determined; the industry favorability degree for the specific air pollutant production at the relative area is

determined and also the area favorability degree for the healthy environment in the specific industry at the relative air pollutant is determined.

Fuzzy logic explains the relativity of different features and defines a set for each feature and then determines the desirability of each variable to provide the involved feature on a scale of zero to one. This value, called the dependency degree of the involved variable in relation to the mentioned feature, will be evaluated.

Zero desirability degree means that the involved variable isn't provided at all for the related variable or the involved variable is not desirable for the correspondent feature at all; and desirability degree one implies that the target feature is completely provided for the involved variable or the involved variable is absolutely desirable for the related feature. A desirability degree of between zero and one means that the involved feature is partially provided for the target variable or the involved variable is partially desirable for the related feature.

There are different methods like AHP, Fuzzy Hierarchical TOPSIS and Fuzzy network TOPSIS for decision making. All these methods are heavily dependent on expert's opinion which does not have a scientific basis in general while fuzzy logic has a regulated pattern and is rarely influenced by expert's opinion [Astel A. 2007; Chen P.H. et al, 1998; Icaga Y., 2007; Mintz R. et al, 2005; Pokrovsky O.M. et al, 2002.; Sowlat M.H. et al, 2011]. The results of this research, in particular, are not influenced by expert's view.

After introducing fuzzy logic and comparing it to binary logic in this paper, its application in monitoring the pollutants of industries related to metallurgy in addition to a case study on monitoring the industrial pollutants, carbon dioxide, in iron and steel production industries, aluminum, zinc and lead production in some parts of the world have been stated.

2. Introduction to fuzzy logic

Fuzzy logic was first introduced by the originally Iranian professor, Mr. L. A. Zadeh, from the faculty of Electronics in the Berkeley University of America in 1965 through an article entitled "Fuzzy Sets" in Information and Control conference [Zadeh L. A., 1965].

American industrialists and scientists accepted his logic as a merely theoretical viewpoint and ignored its applicable aspects. With the arrival of this logic into the East (especially Japan), this logic was used as an applicable method to analyze processes. Since Prf. Asgharzade was a professor of electronics, the applications of this logic in electricity and electronics sciences were first taken into account but it is now used in all technical and engineering sciences [Ghafari A. et al., 1998].

We can simply say that fuzzy logic is the new view of science towards the universe. In fact, processes are analyzed as they truly are, not the way we want them to be, but how can we use them? Everything should be formulized in technical and engineering sciences; otherwise, its application will be limited and does not have a scientific basis. After all, the problem is how fuzzy logic can be formulized?

The function that yields the accuracy or inaccuracy of propositions in fuzzy logic is called the membership function. The defined membership function should be compatible with the nature of process; otherwise, the fuzzy inference will be erroneous. It is thus necessary to identify the process completely before defining the membership function.

How does fuzzy infer these figures then? There are different rules to infer fuzzy. One of the most famous ones is the fuzzy maximum-minimum rule (fuzzy peak-trough). It should be noted that the inference rule has to be compatible with the nature of process. Having

sampled inferences (especially at limit quantities) and compared them with reality (real quantities), we can make sure of the correctness of selecting the fuzzy inference rule.

The minimum rule is used when a connector i.e. the conjunction 'and' is used. In this rule, the minimum value of propositions is accepted as an inference; in other words, if there are some propositions valued a, b, c, d, ..., the minimum rule infers the minimum of these values [Ameri R., 2003; Taheri S. M., 1999].

$$Fuzzy\ Minimum\ Rule = min\ (a, b, c, d, \dots) \qquad (1)$$

The maximum rule is used when a separator i.e. the conjunction 'but' is used. In this rule, the maximum value of propositions is accepted as an inference; in other words, if there are some propositions valued a, b, c, d, …, the maximum rule infers the maximum of these values [Ameri R., 2003; Taheri S. M., 1999].

$$Fuzzy\ Maximum\ Rule = max\ (a, b, c, d, \dots) \qquad (2)$$

3. Comparison between binary logic and fuzzy logic

Einstein says "where classic mathematics rules are realized, they are not reliable and where they are reliable, they cannot denote reality." Einstein's description is an imagination of the inefficiency of classical logic rules in mathematics. In natural conditions, indeed, the world of zero and one, correct and incorrect, good and bad is an abstract and imaginative world. A given subject is rarely 100 percent correct or incorrect and good or bad.

Using fuzzy logic, the precision of results increases and errors decrease. For instance, using the limited elements method, surface residual stresses resulting from grinding with an average error of 12.3 percent are predictable; however, the error level of calculation decreases to 0.037 percent by using this logic [Ali Y.M. and Zhang L.C., 1997].

We are familiar with the term 'fallacy' in binary logic. Its famous example is that if the proposition 'the fire is on the ship' is a true proposition and if the phrase 'the ship is on the water' is true too, the proposition 'the fire is on the water' should be true as well. Fire and water are two opposite things in reality and cannot be together; hence, the above conclusion is incorrect. It is obvious that the final conclusion is wrong because the value of these propositions is correct or incorrect in our view and there is no an intermediate state and also we have not considered the opposite natures of water and fire [Ghafari A. et al., 1998].

Fuzzy logic deals with this process as it is. It means that it gives a value between zero and one for the accuracy of the proposition 'the fire is on the ship'. Value one is given when fire has covered a ship completely and value zero is given when there is no fire on the ship. Generally, the degree of the accuracy of this proposition is defined according to the fraction of fire on the ship. There is a similar view for the proposition 'ship on water' i.e. a fraction of ship touching water is regarded as the degree of the accuracy of the proposition (the ship is on the water). Consequently, when the ship is completely sunk, this proposition is true with a value of one, but when the ship does not touch water at all, this proposition is true with a value of zero.

The opposite natures of water and fire are occult in fuzzy logic. Given what was said so far, if the fire has covered 30 percent of the ship, the proposition 'the fire is on the ship' is true with a value of 0.3. Also, if 20 percent of the ship is touching water, the proposition 'the ship is on water' is true with a value of 0.2. According to the fuzzy minimum rule, the proposition 'the fire is on the water' is then true with the least value of the propositions which is 0.2 percent.

$$\text{Min } (0.3, 0.2) = 0.2$$

Notice that the defined membership functions are compatible with the nature of processes. In the above example, if water covers all the ship which means that the ship is sunk, the proposition 'the ship is on the water' would be true with a value of one. But certainly there would be no fire on the ship in this case since water and fire are opposites. The proposition 'the fire is on the ship' is then true with a value of zero and, therefore, the proposition 'the fire is on the water' is true with the least values which is zero.

$$\text{Min } (1, 0) = 0$$

4. Monitoring of industrial pollutants

Monitoring of pollutants can be studied in three sets. The first set is the type of the metallurgical process that provokes pollution, so set M, the set of metallurgical processes {iron and steel production, aluminum production, copper production, zinc production, … } is defined as relation 3. The second set is an area that provokes pollution; so a set of areas is formed like relation 4. Set A, is a set of areas definable all over the universe. For example, the set of world factories {Khuzestan Steel, Isfahan Iron Melt, …, Bohler,… , Myhanaite, …} or the set of world states or provinces {Mazandaran, Gilan, …, Florida, Texas, …} or the set of world countries {Iran, Japan, …}. Also, the set of areas can be defined in a country e.g. the set of factories in Iran {Khuzestan Steel, Isfahan Iron Melt, …} or the set of provinces in Iran {Mazandaran, Gilan, …}. More general the selected area (the whole world) and more detailed its divisions or the members of the set (factories) are, more detailed the monitoring will be. Due to the insufficiency of data on the area set in this research, the set of countries was taken into account. The third set is the type of pollutant that led to the formation of set P, the set of pollutants {carbon dioxide, carbon monoxide, sulfur dioxide, lead, nitrogen oxides, evaporative organic compounds, arsenic, lead and copper in water, …} according to equation number 5. Set M can have m members, set A can include a members and set P can have p members.

$$M = \{i \in N, i \in [1, m], m_i\} = \{m_i\} \tag{3}$$

$$A = \{j \in N, j \in [1, a], a_{i,j}\} = \{a_{i,j}\} \tag{4}$$

$$P = \{k \in N, k \in [1, p], P_{i,j,k}\} = \{P_{i,j,k}\} \tag{5}$$

m_i is the process i we want to study. $a_{i,j}$ is the process i in area j which will be studied and $P_{i,j,k}$ is the amount of pollutant k in process i that is in area j. It should be noted that the amount of pollutant is normalized i.e. $P_{i,j,k,Normalized}$ amount of pollutant is produced in area j for each unit of product of process i. Hence, equation 6 is used to calculate $P_{i,j,k,Normalized}$.

$$P_{i,j,k,Normalized} = \frac{\text{total k pollution in the } a_{i,j}}{\text{total mass production of} a_{i,j}} \tag{6}$$

4.1 Safety degree determination

The goal is to determine the biocompatibility or safety degree of process i in producing pollutant k in area j. Therefore, a new set named C is formed which means biocompatible

processes in producing different pollutants in different areas. Each member in this set belongs to set C at a certain degree. This degree indicates the degree of biocompatibility or safety of a certain process in producing a certain pollutant in a certain area i.e. $C_{i,j,k}$. Equation 7 which is called the membership function of the members of the set C, i.e. $C_{i,j,k}$, is used to calculate $C_{i,j,k}$.

$$C = \{C_{i,j,k}\}$$

$$\text{If } C_{i,j,k} > 0 \text{ then } C_{i,j,k} = \left(\frac{\text{Min}\{P_{i,j,k,\text{Normalized}}\}}{P_{i,j,k,\text{Normalized}}} \times \left(1 - \frac{G_{k,j}}{G_{k,\text{critical}}}\right)\right) \quad \text{Else} \quad C_{i,j,k} = 0 \quad (7)$$

$G_{k,j}$ is the amount of pollutant k in area j and $G_{k,\text{critical}}$ is the critical amount of pollutant k that is reported by the Air Pollution Control District (APCD) and there is thus a fixed and certain amount for each pollutant. $G_{k,j}$ is equal in equilibrium conditions in all over the world; however, this amount is different in real conditions for different areas.

Thus, all processes are scaled continuously between 0 and 1 relatively according to the pollutants they produce and in relation to the area which is located in. As the scale 0 for the member $C_{i,j,k}$, i.e. the process i located in area j, is not biocompatible or safe at all in producing pollutant k, while scale one for member $C_{i,j,k}$, i.e. process i located in area j, is completely biocompatible or safe in producing pollutant k and a scale between 0 and 1 for member $C_{i,j,k}$, i.e. process i located in area j, is partially biocompatible or safe in producing pollutant k.

The worst conditions are considered in this research; therefore, the minimum fuzzy logic rule is used. The most dangerous process i in producing pollutant k in area j is the process that has the least biocompatibility or safety in producing pollutant k in area j. As a result, $C_{i,j,k,\text{critical}}$ is obtained from the fuzzy minimum rule like equation 8.

$$C_{i,j,k,\text{critical}} = \text{Min}\{C_{i,j,k}\} \quad (8)$$

Perhaps, it seems that monitoring of pollutants only through the set of processes is confusing. For instance, areas having advanced technologies have higher degrees of biocompatibility or safety because the normalized amount of the pollutant is low; but the total amount of the production of process at a unit of time may be so high that it practically includes a major part of the pollutant production. It is noteworthy that if the amount of the product in areas with advanced technologies reduces, with which technology would the shortage caused by the reduction in production be produced? If the involved technology is not as advanced as the intended technology, the amount of the pollutant will increase more than the past in equilibrium conditions. Hence, the total product production amount variable in an area will be placed in the second statement of equation 7 over time.

4.2 A case study on monitoring pollutants in industries

In this case study four industries including one, iron and steel production industry; second, aluminum production industry; third, zinc production industry and fourth, lead production industry were studied. It means that set M has four members (i=4). In addition, the set of countries was studied as the set of areas that included 4 members (j=4), a country in the Middle East, one in far east, one in Europe and one in America continent.

4.2.1 Monitoring pollutants in iron and steel production industry

The main pollutants in iron and steel making industries are carbon dioxide in the air, lead in the earth and sewage, nickel in the earth, cadmium in sewage and sulfur in water [Vahdat S.A. and Tohidi N., 2009]. Due to the shortage of data, the air pollutant, carbon dioxide, was only studied. It means that there is only one member (k=1) in the set of pollutants related to iron and steel production industries.

4.2.2 Monitoring pollutants in aluminium production industry

The main pollutants in aluminum production industry are carbon dioxide in the air, methane hexafluoride, methane tetra fluoride in the state of gaseous and dust, sulfur dioxide, nitrogen dioxide and mercury [International Aluminum Association, 2005]. Due to the shortage of data, the air pollutant, carbon dioxide, was only studied. It means that the set of pollutants related to aluminum production industry has only one member (k=1).

4.2.3 Monitoring pollutants in zinc production industry

The main pollutants of zinc production industry include carbon dioxide in the air, sulfur compounds and nitrogen oxides [Siegmund et al, 2010]. Due to the shortage of data, the air pollutant, carbon dioxide, was only studied. It means that the set of pollutants related to zinc production industry has only one member (k=1).

4.2.4 Monitoring pollutants in lead production industry

The main pollutants of lead production industry include carbon dioxide in the air, lead in the water and air, sulfur compounds and nitrogen oxides (International Lead Association, 2005; Siegmund et al, 2010). Due to the shortage of data, the air pollutant, carbon dioxide, was only studied. It means that there is only one member (k=1) in the set of pollutants related to lead production industry.

As the data related to the amount of pollutant in each area were not available, their amounts in different areas were considered to be the same and equal to its maximum amount in the world, i.e. 360 PPM. It means that its effect on the degree of safety was ignored.

$M = \{i \in N, i \in [1, 2, 3, 4]\}$ = {Iron and steel production, aluminum production, zinc production, lead production}

$A = \{j \in N, j \in [1,2,3,4],$ a country in America continent, a country in Europe, a country in the Middle East, one in the Far East }

$P = \{k \in N, k \in [1]\}$ = {carbon dioxide}

So, according to the equations (3) to (6) and presented data in the tables (1) and (2), we have:

$P_{1,1,1,Normalized}$= Carbon dioxide in iron and steel production industry in the Middle East country =2.5

$P_{1,2,1,Normalized}$=Carbon dioxide in iron and steel production industry in the Far East country =3.1

$P_{1,3,1,Normalized}$= Carbon dioxide in iron and steel production industry in the Western Europe country =1.5

$P_{2,4,1,Normalized}$= Carbon dioxide in aluminum production industry in an American country =3.4

$P_{3,4,1,Normalized}$= Carbon dioxide in zinc production industry in an American country =0.19

$P_{4,4,1,Normalized}$= Carbon dioxide in lead production industry in an American country =0.26

Description	Average of carbon dioxide production in ton for the production of one ton product $P_{i,j,k,Normalized}$	Current amount of carbon dioxide in the area
Iron and steel industry in the Middle East country	2.5	
Iron and steel industry in the Far East country	3.1	
Iron and steel industry in the Europe country	1.5	
Aluminum industry in a country in Europe	1.6	360 PPM
Aluminum industry in a country in America	3.4	
Zinc industry in a country in America continent	0.19	
Lead industry in a country in America continent	0.26	

Table 1. The amount of pollutant in ton for the production of one ton of product for monitoring pollutants in industry in 2005 [America Environmental Protection Agency, 2005; International Aluminum Association, 2005; International Lead Association, 2005; Geir, 2005; Siegmund et al, 2010].

Description	Allowed amount in PPM
carbon dioxide $G_{1,critical}$	300

Table 2. The allowed amount of air pollutant in PPM in 2005 [America Air Pollution Control San Diego, 2005; Geir, 2005].

Having inserted the above figures in equation seven, we have:

$$C_{1,1,1} = \frac{0.19}{2.5} \times \left(1 - \frac{360}{300}\right) = -0.01520 < 0 \implies C_{1,1,1} = 0$$

$$C_{1,2,1} = \frac{0.19}{3.1} \times \left(1 - \frac{360}{300}\right) = -0.01226 < 0 \implies C_{1,2,1} = 0$$

$$C_{1,3,1} = \frac{0.19}{1.5} \times \left(1 - \frac{360}{300}\right) = -0.02533 < 0 \implies C_{1,3,1} = 0$$

$$C_{2,4,1} = \frac{0.19}{3.4} \times \left(1 - \frac{360}{300}\right) = -0.01118 < 0 \implies C_{2,4,1} = 0$$

$$C_{3,4,1} = \frac{0.19}{0.19} \times \left(1 - \frac{360}{300}\right) = -0.20000 < 0 \implies C_{3,4,1} = 0$$

$$C_{4,4,1} = \frac{0.19}{0.26} \times \left(1 - \frac{360}{300}\right) = -0.06333 < 0 \implies C_{4,4,1} = 0$$

According to equation 8 we have:

$$C = \{0,0,0,0,0,0\} = 0$$

$$\implies C_{1,1,1} = C_{1,2,1} = C_{1,3,1} = C_{2,4,1} = C_{3,4,1} = C_{4,4,1} = 0$$

In fact, the maximum amount of carbon dioxide in the world is higher than the allowed amount. Therefore, producing carbon dioxide pollutant even at a very small amount is practically dangerous. It means that the desirability degree of all industries in all areas of the world is zero for the production of carbon dioxide pollutant which means that it is not desirable at all.

Actually, it is not possible to stop producing the mentioned products; steel, aluminum, zinc and lead because human's dependence on these products is currently inevitable. As a result, we can investigate which industry in which area in the production of carbon dioxide has a smaller role. Equation seven will thus change as follows for this particular case.

$$\text{If } C_{i,j,k} > 0 \text{ then } C_{i,j,k} = \left(\frac{\text{Min}\{P_{i,j,k,\text{Normalized}}\}}{P_{i,j,k,\text{Normalized}}}\right) \text{ else } C_{i,j,k} = 0$$

By replacing the data, we have:

$$C_{1,1,1} = \frac{0.19}{2.5} = 0.07600$$

$$C_{1,2,1} = \frac{0.19}{3.1} = 0.06129$$

$$C_{1,3,1} = \frac{0.19}{1.5} = 0.12667$$

$$C_{2,4,1} = \frac{0.19}{3.4} = 0.05589$$

$$C_{3,4,1} = \frac{0.19}{0.19} = 1.00000$$

$$C_{4,4,1} = \frac{0.19}{0.26} = 0.73077$$

According to equation 8:

$$C_{i,j,k,\text{critical}} = \text{Min}\{0.07600, 0.06129, 0.12667, 0.05589, 1, 0.73077\} = 0.05589$$

$$\Rightarrow C_{2,4,1} = 0.05589$$

5. Discussion and conclusion

At present, the amount of carbon dioxide in the world is higher than the allowed amount. Therefore, producing carbon dioxide pollutant even at a very small amount is practically dangerous. So, the safety degree of all industries in all over the world for producing carbon dioxide is zero i.e. it is not desirable at all. But, it is not possible to stop producing steel and aluminum, because at present human's dependence on these products is inevitable. As a result, we can investigate which industry in which area is in safer conditions of producing carbon dioxide pollutant.

In the set of aluminum, copper, zinc and steel industries and in the areas set, a country in the Middle East, a country in the Far East, a country in the Western Europe and a country in the America continent, Aluminum production industry located in a country in America has

the most critical conditions in producing air pollutant, carbon dioxide, with a safety degree of 0.05589. Hence, further focus should be done on controlling carbon dioxide pollutant in aluminum industry in a country in America. Thus, other areas and industries that are not safe in producing carbon dioxide, according to their significance are:

- $C_{1,2,1}$ i.e. iron and steel production industry in a country in the Far East with a safety degree of 0.06129
- $C_{1,1,1}$ i.e. iron and steel production industry in a country in the Middle East with a safety degree of 0.07600
- $C_{1,3,1}$ i.e. iron and steel production industry in a country in the Western Europe with a safety degree of 0.12667
- $C_{4,4,1}$ i.e. lead production industry in a country in the America continent with a safety degree of 0.73077
- $C_{3,4,1}$ i.e. zinc production industry in a country in the America continent with a safety degree of 1

6. Suggestions

Due to the insufficient data in this research, a limited number of industries and countries as well as a limited number of pollutants were only studied. Increasing the number of the members of the set of pollutants, industries and areas, monitoring will be carried out in a wider range and will close to the real conditions.

7. Acknowledgement

We would like to appreciate Pr. Naser Towhidi's valuable and scientific directions.

8. Variables list

$P_{i,j,k,Normalized}$, the amount of pollutant k that is produced for each unit of product of process i in area j.

$G_{k,j}$, the amount of pollutant k in area j

$G_{k,critical}$, the critical amount of pollutant k that is normalized.

$C_{i,j,k}$, the safety degree of process i in producing pollutant k in area j.

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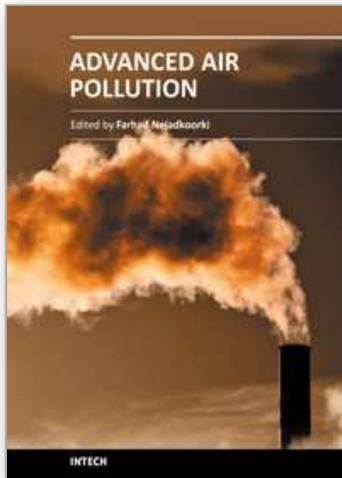
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