Automatic control of volatile fatty acids in anaerobic digestion using a fuzzy logic based approach

As a project work for Course

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COURSE : INT246

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LOVELY PROFESSIONAL UNIVERSITY

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ABSTRACT:-

A control law based on fuzzy logic was developed and validated for an anaerobic wastewater treatment process. The controlled variable was the concentration of volatile fatty acids (VFA) in the reactor and the manipulated variable was the input flow rate. In order to use it as the input of the fuzzy sets, the controlled variable was treated using an algorithm of interpolation, extrapolation and filtering. The treatment of VFA values attempted to anticipate the behaviour of the variable and to avoid the inherent delay of the response, associated to the time constant of the system. Furthermore, the controlled variable derivative was used as a second input of the fuzzy sets to increase or decrease the speed of the control action. The control law was applied to a 0.948 m3 fixed-bed anaerobic reactor treating raw and diluted (1:2) industrial distillery vinasses. The validation was performed establishing different transient states between different set points in the range of 0.8 and 1.8 g VFA/l and different concentrations of the influent. The control law proved to be reliable supplying an adequate control action in terms of amplitude and velocity to achieve the desired set point for different types of perturbation and control purpose

ACKNOWLEDGEMENT:-

I would like to thank my mentor - pooja rana mam for her advice and inputs on this project. Many thanks to my friends and seniors as well, who spent countless hours to listen and provide feedbacks.

Table of Contents

INTRODUCTION:-

1.1 Context

This project has been done as part of my course for the CSE at Lovely Professional University . Supervised by POOJA RANA, I have ONE month to fulfill the requirements in order to succeed the module.

1.2 EXPLANATION

The anaerobic digestion is a complex process in which organic matter is converted into a mixture of methane and carbon dioxide. The overall conversion is carried out by a mixture of micro-organisms through several biochemical reactions in series and in parallel . It is generally proved that, in case of non particulate substrate or non-excessively complex organic matter, the limiting step is the conversion of volatile fatty acids (VFA) into methane. Hence, VFA are intermediates, which may accumulate provoking a decrease of reactor pH and the overall failure of the operation. The control of anaerobic digestion may attempt different goals, e.g. to maintain a constant concentration of organic matter at the output of the reactor, according to legislation; to optimise methane production for further energy exploitation; or to ensure a stable operation in case of systems treating high organic loading rates exposed to input concentration and/or flow rate variations. The control of VFA concentration within the reactor either directly or indirectly, is required in order to maintain the stability of the operation in variable-loaded reactors. This is the case of the majority of industrial plants. The most important drawback to fulfil VFA automatic control is the lack or the high cost of devices allowing its on-line measurement. To address this drawback some authors have developed and tested relatively inexpensive systems for the monitoring of, first, bicarbonate alkalinity capable of measuring VFA, as well as partial and total alkalinity based on a titrimetric method, supplying one measurement every half hour (3 minutes if required) and having proven its reliability over a five year period of daily use

TEAM MEMBERS:-

TEAM LEADER:-

SHAIK GAYAZUDDIN:-

Contributions:-

1. Coding
2. Datasets
3. Reports
4. Machine learning

LIBRARIES:-

Numpy:-

NumPy is a general-purpose array-processing package. It provides a high-performance multidimensional array object, and tools for working with these arrays.It is the fundamental package for scientific computing with Python.

As the whole project is based on whole complex stats ,we will use this fast calculations and provide results.

Matplotlip:-

Matplotlib tries to make easy things easy and hard things possible. We will generate plots, histograms, scatterplots, etc.,to make our project more appealing and easier to understand.

Scikit-learn:-

It is a Python library is associated with NumPy and SciPy. It is considered as one of the best libraries for working with complex data.

There are a lot of changes being made in this library. We will use it for cross-validation feature, providing the ability to use more than one metric. Lots of training methods like logistics regression will be used to provide some little improvements.

Proposed Modules:-

Machine Learning:-

Machine learning is a type of artificial intelligence (AI) that provides computers with the ability to learn without being explicitly programmed. Machine learning focuses on the development of Computer Programs that can change when exposed to new data.

FUZZY LOGIC:

Fuzzy Logic (FL) is a method of reasoning that resembles human reasoning. The approach of FL imitates the way of decision making in humans that involves all intermediate possibilities between digital values YES and NO. The conventional logic block that a computer can understand takes precise input and produces a definite output as TRUE or FALSE, which is equivalent to human's YES or NO. The inventor of fuzzy logic, Lotfi Zadeh, observed that unlike computers, the human decision making includes a range of possibilities between YES and NO, such as −CERTAINLY YESPOSSIBLY YESCANNOT SAYPOSSIBLY NOCERTAINLY NOThe fuzzy logic works on the levels of possibilities of input to achieve the definite output.

For the purpose of controlling VFA, several approaches can be used, fuzzy logic being
Water Science and Technology Vol 48 No 6 pp 103–110 © IWA Publishing 2003
one among them. Zadeh introduced the theory of fuzzy sets in 1965 constituting an easy way to represent heuristic knowledge using linguistic labels implemented in linguistic rules. It presents the advantage of dealing with uncertainties and the non-requirement of complex mathematical relationships. The fuzzy inference process involves membership functions, fuzzy logic operators and knowledge rules. The membership functions allow the representation of a degree of membership to a fuzzy set, associated to a linguistic label, for a given input numerical value. The rules if-then introduce the expert knowledge in a computable wa been discussed in detail by several authors (Zimmermann, 1985; Li and Yen, 1995) and applied to anaerobic processes in some cases (Müller et al., 1997; Giraldo-Gómez and Duque, 1998; Estaben et al., 1997; Genovesi et al., 1999; Puñal et al., 2000; Murnleitner et al., 2002). In this work, a control law taking advantage of the theory of fuzzy sets has been built and implemented in an anaerobic digestion process treating raw industrial distillery vinasses. The concentration of VFA was set as the controlled variable and the input flow rate was the manipulated variable. The law was validated on-line under different influent concentrations and under different control requirements, e.g. VFA set points

Material and methods:

Anaerobic wastewater treatment plant
Raw and diluted (1:2) industrial wine distillery effluents were anaerobically treated in a 0.948 m3 fixed bed upflow reactor. The results presented in this work correspond to operation with diluted wastewater (1:2) except those corresponding to the validation of the control law against a sudden increase in influent COD concentration. In those cases, diluted wastewater alternated with raw wastewater was fed to the system.
The wastewater characterization is presented in Table 1. The detailed description of the anaerobic plant can be found elsewhere .
For this study, the interval between the titrimetric measurements was established at 30 minutes, as it was considered fast enough compared to the hydraulic residence time of the process (between 19 and 190 h) in order to obtain information about the operational state. The sensors are connected to an input/output device that allows the acquisition, treatment and storage of data on a PC using a modular software developed in our laboratory and freely available. The interval of reception and sending of information between the software and the process was fixed at 2 minutes, as it was considered a good solution to be fast enough for control and supervision purposes, however generating reasonable size data files. The COD was measured off-line (NF T 90-101) following the principle of oxidation of the organic matter in excess of potassium dichromate and acid media (H_2SO_4) at boiling temperatures. The excess of dichromate is titrated by a solution of ammonium-iron sulfate.

CONTROL LAW:

The chosen fuzzy methodology was the Mamdani's fuzzy inference method
In this method, the first and the second part of the fuzzy inference process
Typical characteristics of wine distillery wastewater

Component	Raw vinasses	Diluted vinasses (1:2)
Total COD (g/l)	26.40	13.20
Soluble COD (g/l)	23.60	11.80
Volatile Fatty Acids (g/l)	5.50	2.75
Total Suspended Solids (g/l)	3.70	1.85
Volatile Suspended Solids (g/l)	1.95	0.98
pH	5.20	5.2

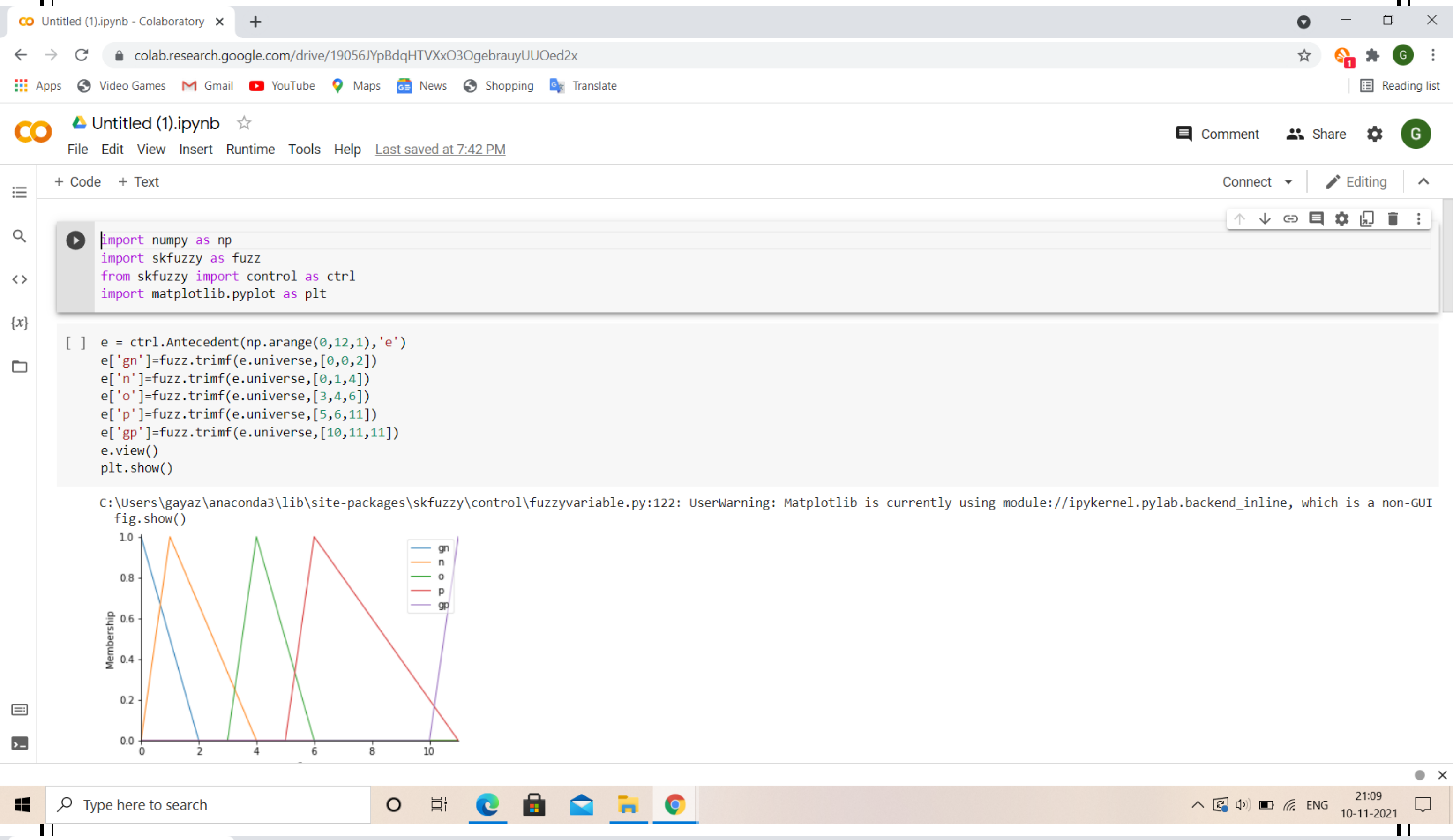
consist in the fuzzification of the inputs and application of fuzzy operators. Based on acquired knowledge of the process, a set of rules handling the regulation of the input flow rate in dependence on the concentration of VFA in the effluent of the reactor was set up. The controlled variable was the VFA concentration, the input flow rate being the manipulated variable. In order to detect and identify in a clearer way the variation of VFA concentration, another variable, the derivative of VFA concentration, was generated. This second variable represents the velocity of change of VFA concentration and was used as input of the set of rules, together with the VFA concentration itself. The output of the control law was the degree of modification required for the influent flow rate in order to lead the system to achieve the desired set point. The first step to build the control law was the translation of possible values of the different inputs and output variables into linguistic labels given by membership functions. The summary of rules implemented in the control law is presented the membership functions for the inputs and output of the first approach to the control law are presented. An important aspect to carry out the distribution of membership functions is the consideration of the time interval to apply the control action. At this point, two intervals were considered: 2 and 30 minutes; given by the fixed interval of exchange of information between the software and the process and by the interval of analysis of the titrimetric sensor, respectively. The membership functions present some differences in terms of amplitude considering the possibilities: (i) reaction every 30 minutes having the actual concentration of VFA at this moment and (ii) reaction every two minutes having the actual concentration of VFA every 30 minutes. This last possibility (case ii) requires a more careful treatment of signal since the action of the controller is performed based on a value of VFA, which is not the actual value each two minutes. This was the reason to choose this approach. This approach was considered the most interesting one as it comprises the understanding of signal evolution to be implemented into the control law structure and could be used as well as a basis for the other one. The extension to the case i) can be easily done by maintaining the distribution of membership functions for the actuation (dFin) and increasing the interval from [–0.5, 0.5] to [–10, 10] (data not shown).

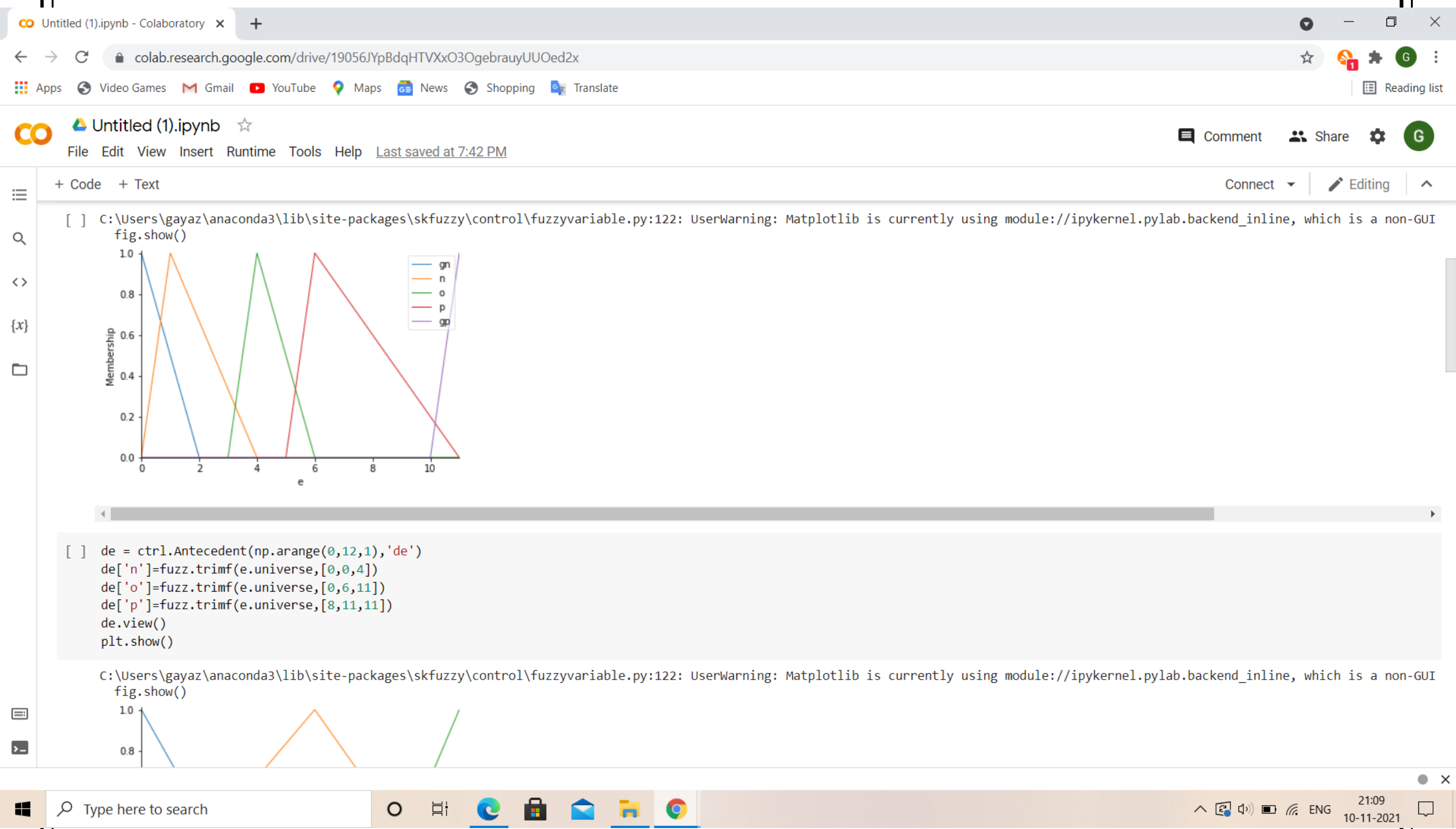
Summary of rules implemented in the control law. Input ε represents the VFA concentration minus the set point in g/l. Input dε is the derivative of ε and represents its variation with time in g/l min. Output dFin is the increment or decrease of the actual input flow rate in l/h

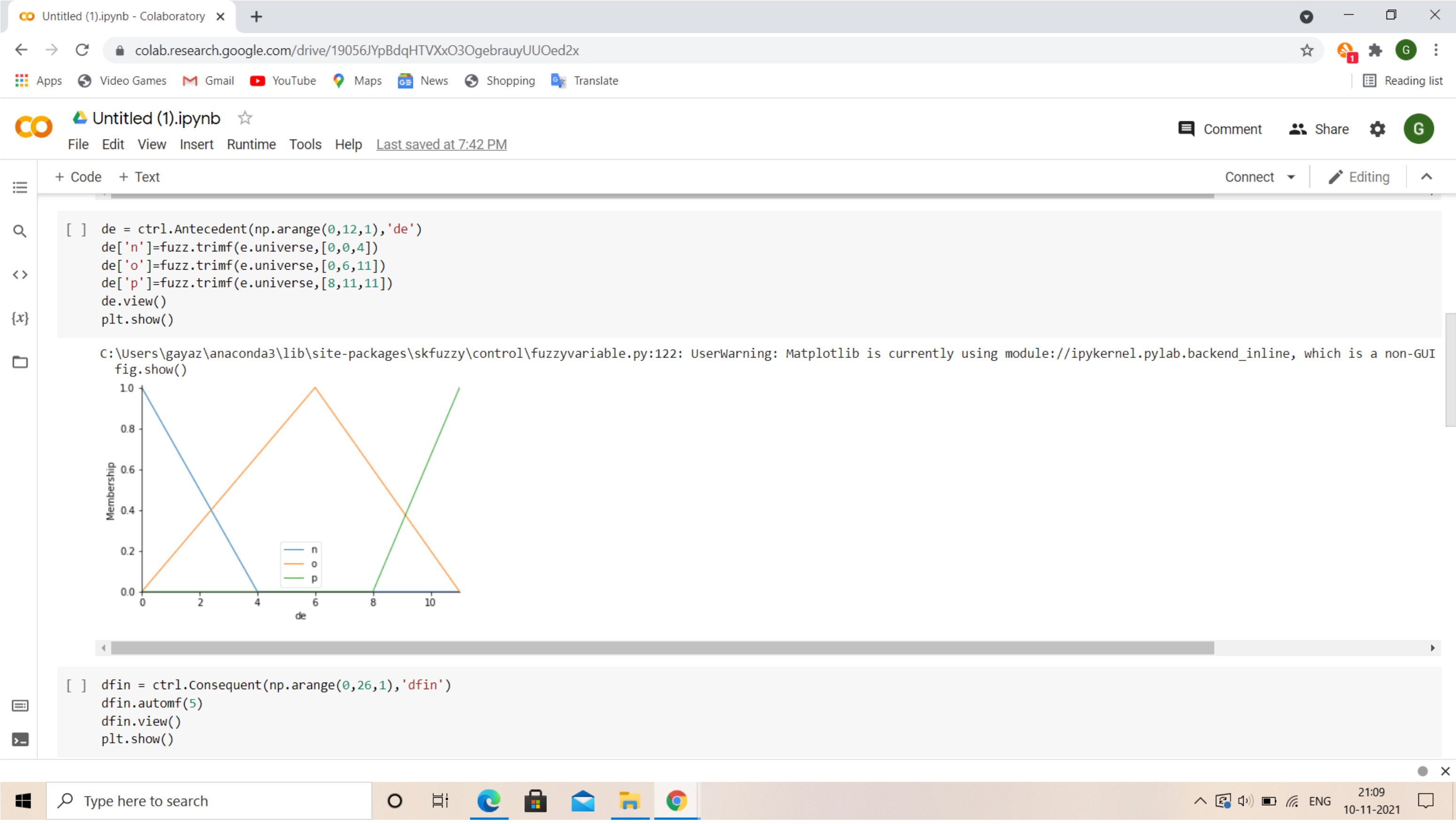
		Input ε					
		gp	p	0	n	gn	
	n	gn	n	p	gp	gp	
Input dε	0	gn	n	0	p	gp	Output dFin
	p	gn	gn	n	p	gp	

gp: great positive; p: positive; 0: no variation; n: negative; gn: great negative

SCREENSHOTS:-







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Connect Editing
[ ] de = ctrl.Antecedent(np.arange(0,12,1),'de')
de['n']=fuzz.trimf(e.universe,[0,0,4])
de['o']=fuzz.trimf(e.universe,[0,6,11])
de['p']=fuzz.trimf(e.universe,[8,11,11])
de.view()
plt.show()
C:\Users\gayaz\anaconda3\lib\site-packages\skfuzzy\control\fuzzyvariable.py:122: UserWarning: Matplotlib is currently using module://ipykernel.pylab.backend_inline, which is a non-GUI
fig.show()
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de
[ ] dfin = ctrl.Consequent(np.arange(0,26,1),'dfin')
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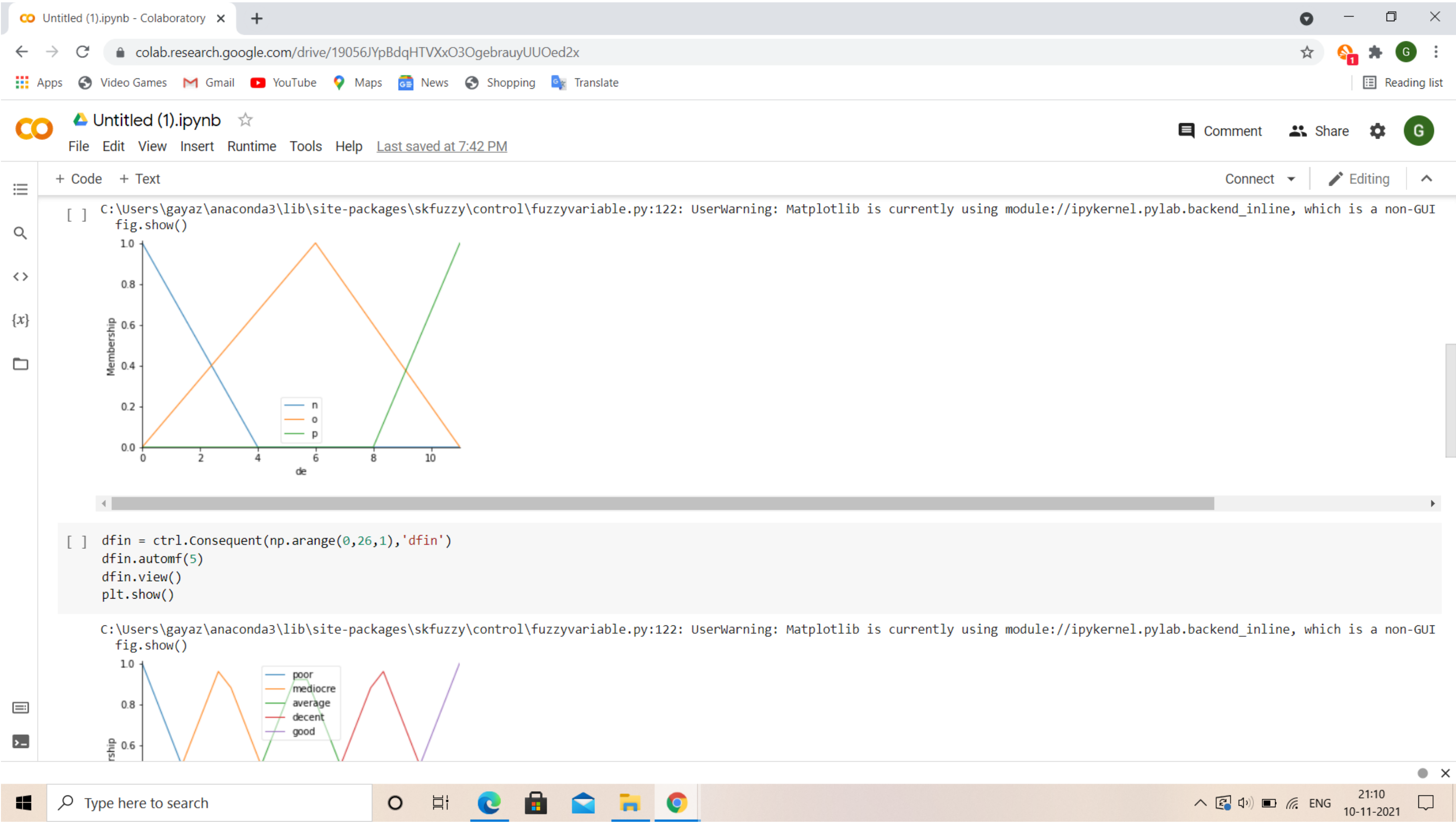

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[ ] C:\Users\gayaz\anaconda3\lib\site-packages\skfuzzy\control\fuzzyvariable.py:122: UserWarning: Matplotlib is currently using module://ipykernel.pylab.backend_inline, which is a non-GUI
fig.show()
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[ ] dfin = ctrl.Consequent(np.arange(0,26,1),'dfin')
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poor
mediocre
average
decent
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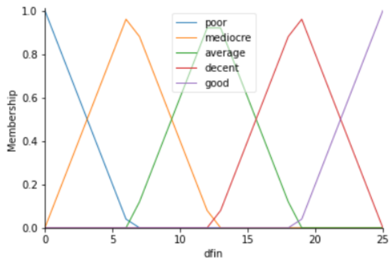
```
dfin = ctrl.Consequent(np.arange(0,26,1),'dfin')
dfin.automf(5)
dfin.view()
plt.show()
```

```
C:\Users\gayaz\anaconda3\lib\site-packages\skfuzzy\control\fuzzyvariable.py:122: UserWarning: Matplotlib is currently using module://ipykernel.pylab.backend_inline, which is a non-GUI
  fig.show()
```




```
rule1=ctrl.Rule(e['gp'] & de['n'], dfin['poor'])
rule2=ctrl.Rule(e['gp'] & de['o'], dfin['poor'])
rule3=ctrl.Rule(e['gp'] & de['p'], dfin['poor'])
rule4=ctrl.Rule(e['p'] & de['n'], dfin['mediocre'])
rule5=ctrl.Rule(e['p'] & de['o'], dfin['mediocre'])
rule6=ctrl.Rule(e['p'] & de['p'], dfin['poor'])
```

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```
rule1=ctrl.Rule(e['gp'] & de['n'], dfin['poor'])
rule2=ctrl.Rule(e['gp'] & de['o'], dfin['poor'])
rule3=ctrl.Rule(e['gp'] & de['p'], dfin['poor'])
rule4=ctrl.Rule(e['p'] & de['n'], dfin['mediocre'])
rule5=ctrl.Rule(e['p'] & de['o'], dfin['mediocre'])
rule6=ctrl.Rule(e['p'] & de['p'], dfin['poor'])
rule7=ctrl.Rule(e['o'] & de['n'], dfin['decent'])
rule8=ctrl.Rule(e['o'] & de['o'], dfin['average'])
rule9=ctrl.Rule(e['o'] & de['p'], dfin['mediocre'])
rule10=ctrl.Rule(e['n'] & de['n'], dfin['good'])
rule11=ctrl.Rule(e['n'] & de['o'], dfin['decent'])
rule12=ctrl.Rule(e['n'] & de['p'], dfin['decent'])
rule13=ctrl.Rule(e['gn'] & de['n'], dfin['good'])
rule14=ctrl.Rule(e['gn'] & de['o'], dfin['good'])
rule15=ctrl.Rule(e['gn'] & de['p'], dfin['good'])
rule=[rule1,rule2,rule3,rule4,rule5,rule6,rule7,rule8,rule9,rule10,rule11,rule12,rule13,rule14,rule15]
```

```
x=ctrl.ControlSystem(rule)
y=ctrl.ControlSystemSimulation(x)
```

```
y.input['e']=7
y.input['de']=8
y.compute()
print(y.output['dfin'])
```

```
6.273719165085389
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```
x=ctrl.ControlSystem(rule)
y=ctrl.ControlSystemSimulation(x)
```

```
y.input['e']=7
y.input['de']=8
y.compute()
print(y.output['dfin'])
```

```
6.273719165085389
```

```
dfin.view(sim=y)
plt.show()
```

```
C:\Users\gayaz\anaconda3\lib\site-packages\skfuzzy\control\fuzzyvariable.py:122: UserWarning: Matplotlib is currently using module://ipykernel.pylab.backend_inline, which is a non-GUI
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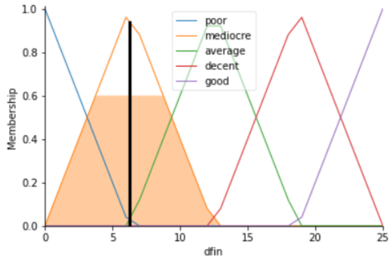

conclusion:

A control law based on fuzzy logic features was developed and validated for an anaerobic wastewater treatment process treating wine distillery wastewater. The controlled variable was the concentration of Volatile Fatty Acids (VFA) in the anaerobic reactor and the manipulated variable was the input flow rate. The validation was performed establishing different transient states between different set points in the range of 0.8 and 1.8 g VFA/l. This approach was tested as well for managing disturbances in COD influent concentrations (usually unknown by operators or by the control law), which represent the usual situation, associated to the variations in process production in real plants. The sensitivity of the control law was optimised by interpolation, extrapolation and filtration procedures in order to avoid the undesired effects due to signal noise, without loosing sensitivity to detect disturbances in the process. The control law proved then to be reliable, supplying an adequate control action in terms of amplitude and velocity to achieve the desired set point as well as to manage a sudden change in influent COD concentration. It is important to note that one of the main advantages of this approach is the simplicity in terms of variables used as well as of development and implementation, which may be comparable to a simple controller, but supplying a more satisfying performance.

refernces:

To conduct this project the following tools have been used :

● Jupyter notebook and spyder

● Numpy (Library) : http://www.numpy.org/
https://www.researchgate.net/publication/8990043_Automatic_control_of_volatile_fatty_acids_in_anaerobic_digestion_using_a_fuzzy_logic_based_approach