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# A Novel Approach to Strategic Water Quality Management in Beverage Industry

In 2011 global beer production increased to 1.9 billion hectoliters [1]. With a current average consumption of 4 hl of fresh water for the production of 1 hl of sales beer in Germany [2], approximately 2.5–3.0 hl of waste water (WW) is produced. When using a water volume ratio > 4:1 [3, 4] the waste water volume is correspondingly higher.

The aim of the present research is the development of a production-integrated adaptive control for partial flows of process water in the CIP return (Cleaning In Place). Water flows in a brewery or in other foodstuff processes that are generated during the cleaning, rinsing or by means of so-called displacement water, are divided into partial flows according to their water quality. Intelligent water quality management (WQM), as discussed in this paper, is based on a fuzzy-logic control. The control unit, called in the following *water switch* aims to make a contribution to water savings in the brewing process (10–20 %, [5]). Aside from that a simultaneous increase in efficiency of the proven approach of the end-of-pipe system through concentrating organic loads is reached. It is shown, that the separation by means of fuzzy-logic and the treatment of a partial water stream through a filtration unit (membrane) is capable to produce permeate with reuse quality.

Descriptors: separation of process water streams, fuzzy-logic, *water switch*

## 1 Introduction

Fuzzy-logic has been used in the food industry (FI) for some decades and has become increasingly important. Due to rising demands on the quality and safety of food and beverages, various steps of the different production processes are controlled by means of the latest control technology. These advanced control systems include all computer-aided processes, whereas fuzzy-logic offers the advantage to control and evaluate the multi-variable actions in biological processes, which are frequently non-linear and which are difficult to mathematically represent [6].

Fuzzy-logic is, for example, used in the fermentation process of a brewery, in order to influence the subsequent quality of beer. In particular, temperature, pressure, the duration of the fermentation process, the yeast strain applied as well as yeast quantity influence the flavor of the beer. For the fermentation control system, which is called Ferment-Stop, temperature is selected as the first variable and present gravity (PG, actual extract content = dissolved sugar) is selected as the second parameter. The fermentation process itself is determined as the output parameter [7].

Another example of a fuzzy-control system can be found in the white wine fermentation process [8]. The temperature and the actual fermentation rate (measured by means of the sugar consumption)

are of interest and, therefore, serve as input variables. The cooling rate in the process is subject to these two input variables.

In addition to fermentation processes, fuzzy-systems can also be used for the control of filtration processes in the food industry, such as the cross-flow microfiltration of cane sugar products [9]. In a filtration process, a constant permeate flow is required. The flow rate is significantly influenced by the particles to be filtered. This can be compensated by increasing the trans-membrane pressure. For this purpose, two process variables are selected as input variables of the fuzzy-set: the difference between the set pressure and the measured trans-membrane pressure as well as the difference between the minimum required pressure, with which the process is just able to run, and the actual pressure.

Another wide area of application of fuzzy-logic can be found in the field of waste water cleaning and the evaluation of water qualities, to include waste water, river and ground water. The water quality depends on numerous parameters that make the control and supervision challenging due to their non-linear behavior. For the classification of different types of water, many parameters can be used for evaluation purposes according to the German Drinking Water Ordinance, such as the pH-value and electrical conductivity [10, 11, 12, 13, 14].

In the following table 1 an overview of further various fuzzy-systems in industry is shown.

In many other publications fuzzy-systems are used for water quality models of hydrological cycles, river systems, dissolved oxygen in a batch reactor or for the examination of a reactor inflow [16, 17, 18, 19, 20, 21, 22, 23, 24].

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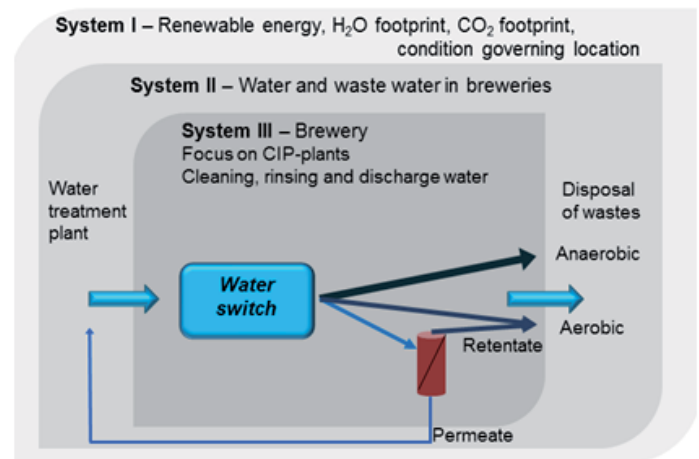
**Table 1** Overview about various fuzzy-systems in industry

Author	Title of Research Work – Parameters
(Qin X.S., 2007)	An interval-parameter fuzzy nonlinear optimization model for stream water quality management under uncertainty [6]
	Input parameters BOD value, dissolved oxygen, volume of the discharged waste water, re-aeration rate desoxidation rate
	Output parameter Reduction efficiency of BOD concentration
(Samson M., 2010)	Assessing groundwater quality for potability using a fuzzy-logic and GIS – a case study of Tiruchirappalli City – India [14]
	Input parameters 16 different chemical, microbiological and physical parameters (such as the pH-value, water hardness, alkalinity, Escherichia Coli)
	Output parameters Four different quality levels 1. Undrinkable 2. Drinkable with caution 3. Drinkable 4. Highly drinkable
(Groß F., 2011)	Optical online measurement technique used for process control of the drying step during pasta production [15]
	Input parameters Moisture of pasta, colour etc.
	Output parameter Adapted drying profile of pasta
(Benoit J., 1994)	Water quality management with imprecise information – cross-flow microfiltration of cane sugar products [9]
	Input parameters Difference between the set pressure and the measured trans-membrane pressure. Difference between the minimum required pressure, with which the process is just able to run, and the actual pressure.
	Output parameter Adaption of pressure

This current research paper builds on a publication in Spring 2013 [5], which concludes that a separation of process water qualities, carried out in real time, is both rational and advisable in order to utilise existing water treatment measures, applied in the beverage industry in an optimal way and not, as has been the case, to collect and homogenize process and waste water of different qualities in an equalizing reservoir or to focus only on individual process water flows and their treatment.

Figure 1 represents the brewery and its surroundings, divided into three system boundaries. The current project deals with the system boundaries II and III. The water supply, waste water disposal ways and the core element *water switch*, which is implemented via a fuzzy-logic control, are shown.

As a tool, fuzzy-logic serves to separate water phases based on defined water quality parameters. The separation depends on the treatment option afterwards (filtration unit, aerobic or anaerobic unit). The water quality is divided into three different process water qualities which were defined on several chemical, physical and



**Fig. 1** Brewery scheme with its three system borders, its water supply and waste water disposal ways – the water switch separates the process water into three different water qualities, one is defined for anaerobic treatment, one for aerobic and one for membrane treatment with the aim of producing water with drinking water quality

organic parameters. A dilution of the organic waste water outside the brewery is avoided. This results in a better homogeneity of the waste water and an optimized process and energy efficiency, e.g. a higher yield of biogas and smaller bioreactor sizes.

In regard to the disposal way of anaerobic treatment it can basically be stated that the described approach in this paper is particularly for breweries that have the long-term goal of gaining independence from conventional energy resources and the intention to replace fossil fuels with green energy. Economic advantages are achieved by running or implementing a bioreactor together with a water quality management strategy. Either method, i.e. the filtration combined with aerobic treatment (municipal sewage plant) or the method suggested in this paper, are possible. In each case, the requirement of a mixing and equalization tank is recommended before any waste water is led into the municipal sewage system to avoid incurring extra financial costs.

The project focuses on the decentralized, production-integrated recycling procedure, the so called *water switch*, which divides the individual process water flows according to their measured water quality. The focus is on cleaning, rinsing and displacement waters with their partial flows, which are not, or only minimally loaded, e.g. with organics. These waters shall be reintegrated into the process via a filtration unit, with at least service water quality. Therefore, the utilization of this water quality for secondary applications without product contact is possible. A further alternative of returning the service water is to recycle it into the water treatment plant. To ensure the blending of the permeate of the filtration process (reuse water quality) with city or well water a minimum of water treatment is desirable e.g. via an activated carbon filter.

## 2 Materials and methods

### 2.1 Pilot plant

The process water (feed), conducted in the circuit via the membrane, is separated into retentate and permeate and reunited in the buffer tank. Depicted in figure 2 are the formation of the pilot

plant and the measurement devices which were placed before and after the ultra-filtration membrane and which were used to generate the expert knowledge for the fuzzy-system. The filter is a ceramic multi-channel membrane with following specifications: 10 nm pore size, typical clean water flux  $250 \text{ L m}^{-2} \text{ bar}^{-1} \text{ h}^{-1}$ , maximum trans-membrane pressure (TMP) 10 bar, 1750 channels, maximum temperature  $130 \text{ }^\circ\text{C}$ , pH-range 0–14, diameter 144 mm, length 864 mm. This membrane is chosen based on previous drinking water applications and the excellent results achieved even in areas the manufacturer suggested were problematic. The operating TMP of the experiments never exceeded 1 bar and experiments were carried out according to the permeate pressure value via the permeate flow, which was throttled as necessary. Membrane cleaning intervals were carried out regularly after each experiment to assure the reproducibility of the system and measurement techniques. But in prospective industrial applications of the *water switch*, no waste water quality is run over the membrane, which leads to an estimated service life of several weeks of the membrane without any cleaning, that has to be assured in further investigations and a demonstration plant.

For the monitoring of the process, conductivity sensors (inline), temperature sensors (inline), turbidity sensors (inline) and measuring devices for the pH-value (inline) are employed. The infrared sensor is used for the detection of dissolved sugar. A separate calibration via partial least square regression (PLS) is executed but not described in this paper.

The Fuzzy Logic Toolbox™ of the program Matlab® enables the creation of a fuzzy-logic system on the basis of simple, previously established logic rules.

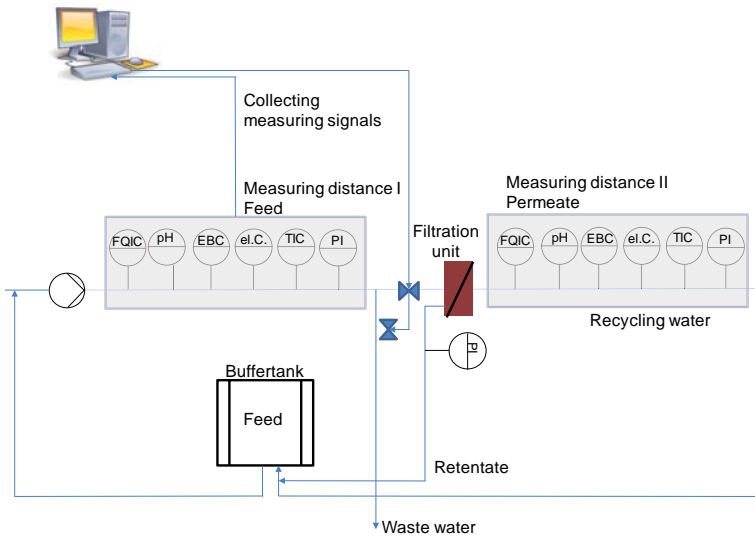


Fig. 2 Principle of the pilot plant

2.2 Data handling

After creation of the fuzzy-sets of the parameters pH-value, temperature, electrical conductivity, turbidity and sugar concentration with their membership functions on the basis of experiments, data analysis, comprehensive literature research and the application of further expert knowledge gained in tests [5], the created fuzzy-

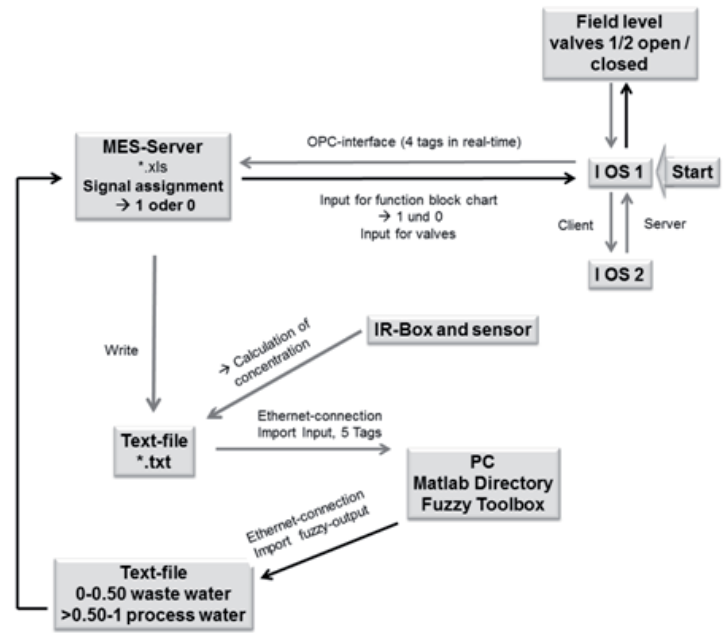


Fig. 3 Principle of data transfer (Abbreviations: OS – Operation Station, IR – Infrared, MES – Manufacturing Execution System)

system is linked with the pilot plant (basis PCS 7, Siemens) by means of the following data transfer – see figure 3.

The data of the parameters turbidity, electrical conductivity, temperature and the pH-value are retrieved from the field level (pilot plant) and transferred to a PC Matlab® Directory. Moreover, the IR evaluation box is separately connected to the process control system PCS 7 (MES-server) by means of an Ethernet cable. The values of the five parameters are then processed to the fuzzy-system. The output value of the fuzzy-system is returned to the MES-server. Depending on the size of the output value (< 0.50 or > 0.50), two valves are activated in the module programming Continuous Function Chart (CFC) of the Siemens software PCS 7 according the measured water quality.

2.3 Fuzzy-system

The fuzzy-output value, which indicates the choice of water treatment, is developed by a procedural method of the fuzzy-system that consists of different steps [25]

- Fuzzification of the input variables, water quality parameters, converting the numerical input value into a linguistic input value
- Application of the fuzzy-operators (*AND*, *OR*, *NOT*) by creating a rule-base with the possibility of adjusting the rule's weight with the goal to obtain linguistic output values for each rule
- Defuzzification of the linguistic output values through aggregation of all outputs into a single fuzzy-output value calculated by the centroid method

Each parameter is represented by a fuzzy-set, which consists of different membership functions. The membership functions range between 0 and 1. To illustrate the reaction of the fuzzy-system two exemplary rules of the developed rule base are shown in the following.

Rule a. represents a rule which dictates the direction of the water to the filtration unit.

a IF (Temperature [°C] is middle) AND (Conductivity[mS/cm] is < setpoint THEN water quality [-] is filtration

Rule b. combines the parameters pH-value, turbidity, conductivity and sugar concentration which leads to a discharge into waste water.

b IF (pH-value[-] is >setpoint) AND (Turbidity[EBC] is high) AND (Conductivity[mS/cm] is <setpoint AND (sugar[°Brix] is nosugar) THEN water quality [-] is waste water

The developed fuzzy-system consists of 91 rules that are based on the following mathematical operators AND, OR, NOT.

**Minimum – (AND) – Operator**  $\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x))$

**Maximum – (OR) – Operator**  $\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x))$

**Negation – (NOT) – Operator**  $\mu_{\bar{A}}(x) = 1 - \mu_A(x)$

The output water quality has three membership functions. In the following practical tests performed (see 3.1 and 3.2) an initial decision between waste water and the water to be treated by filtration is made. The waste water fraction municipal waste water (aerobic) treatment and bioreactor anaerobic) are viewed as one unit during practical testing. In the simulation (see 3.3), however, three water quality membership functions are considered. In figure 4 the parameters of the fuzzy-system with their different fuzzy-sets are shown.

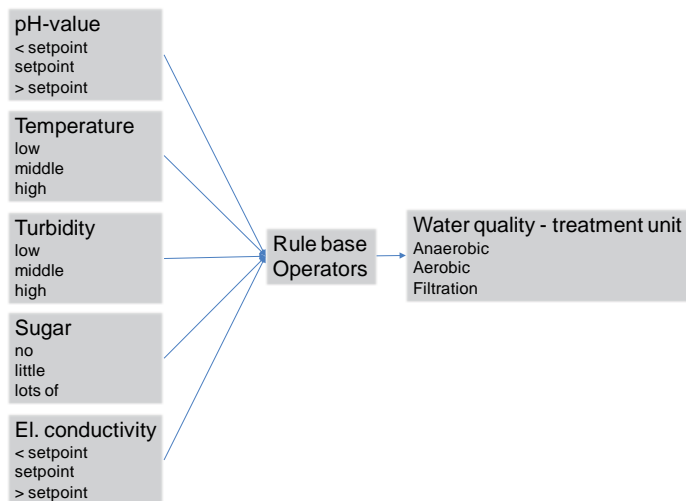


Fig. 4 Parameters with the selected fuzzy-sets

### 3 Results and discussion

#### 3.1 Experiments – basic testing

Testing with four parameters (= basic testing) is carried out to demonstrate that the fuzzy-based rules function with the four stan-

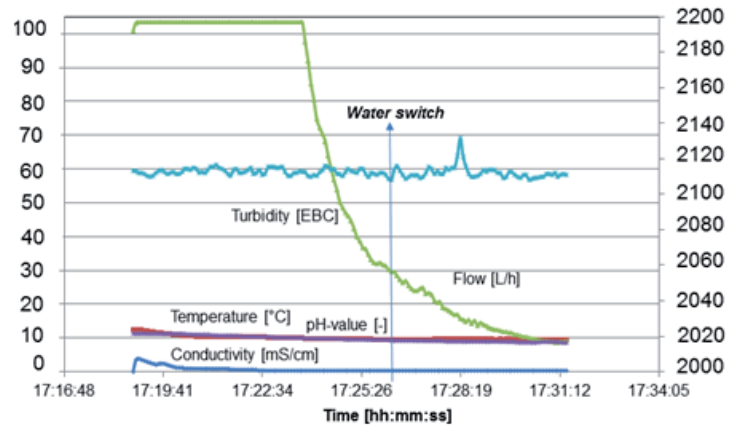


Diagram 1 Course of testing with the four standard parameters in breweries carried out in a pilot brewery (primary axis – conductivity, temperature, turbidity, pH-value, secondary axis – flow). Testing period approx. 4 min. from switching point

standard parameters in a brewery (pH-value, temperature, electrical conductivity, turbidity) and already enable a very good separation. These parameter are defined as standard due to their regular occurrence in breweries. The course of basic testing can be found in diagram 1. Conductivity, temperature, pH-value, turbidity are plotted on the primary axis; volume flow on the secondary axis.

The vertical arrow in the diagram signals the point in time of switching. According to the point in time, table 2 shows the switching values of the *water switch* and the fuzzy-output signal 0.5640.

Table 2 Parameter values while switching to water quality to be filtrated (> 0.50) of the fuzzy-system and value of the respective fuzzy-output

Parameter	Parameter values while switching	Fuzzy-output while valve switching
pH-value [-]	9.34	0.5640
Conductivity [µS/cm]	220.00	
Trubidity [EBC]	31.30	
Temperature [°C]	~10.00	

The parameter turbidity is still higher as the fuzzy-system reacts on basis of the pre-defined membership functions. Except the turbidity, the other values are in the range of the values of the Drinking Water Ordinance. Turbidity due to particles can be treated via the filtration unit. Therefore, this water quality is defined as water quality – filtration unit.

The four parameters concerning the feed and permeate composition were additionally examined under laboratory conditions in accordance to the methods described, see table 3. Three further parameters (sediment, visual, and odor) were also assessed. The column process water represents the results of the composition of feed in the beginning of the testing; the column membrane permeate shows the values of permeate sample after the filtration unit. The limit values of the Drinking Water Ordinance 2001 are also given.

The samples of the feed and the permeate are visualized in figure 5. On the left hand side the turbid feed (process water) is presented, on the right hand side the clear permeate (after activation

of the *water switch* and after passing the filtration unit). Additionally, the sample, which was collected before the membrane, is shown to demonstrate the allowed higher turbidity value that is based on the fuzzy-set of the parameter turbidity.

It is evident that the parameters pH-value, electrical conductivity, turbidity and oxidizability have fallen – the pH-value from 11.58 to 8.57, electrical conductivity from 1.20 mS/cm to 0.40 mS/cm, turbidity from ~40.00 EBC to 0.10 EBC and oxidizability from 28.00 mg/L to 6.20 mg/L (exceeded by only 1.60 mg/L). The latter narrowly fails the limit values of the Drinking Water Ordinance 2001. Descriptions of the samples (light yellow, slightly turbid) mentioned in table 3 can be found in figure 5. However, it is easy to see that the middle sample is slightly turbid but the permeate is not. This result is accurate as the pre-defined fuzzy-system allows an increased turbidity which can easily be removed by the treatment measures of the membrane.

**Table 3 Results of basic testing of the water qualities (feed composition = process water, permeate = membrane permeate); Mix of process water/feed consists of fresh water with caustic solution and dry yeast for level of turbidity**

Parameter	Method	Process water	Membrane permeate	Limit value	Dimension
Visual	Visual	Little yellow and turbid	Colourless, nearly clear		[-]
Odor	DEV B ½	Negative	Little strange		[-]
Precipitate	Visuell	Little beige	Negative		[-]
pH-value at 20 °C	DIN 38404 C5	11.58	8.57	6.5-9.5	[-]
Conductivity at 25 °C	DIN EN 27888 C 8	1200.0	400.0	2790.0	µS/cm
Turbidity	DIN EN ISO 7027 C 2	159.00	0.39	1.0	NTU
Oxidizability	DIN EN ISO 8467 H5	39.75	0.10	[-]	EBC
		28.00	6.20	5.0	mg/L

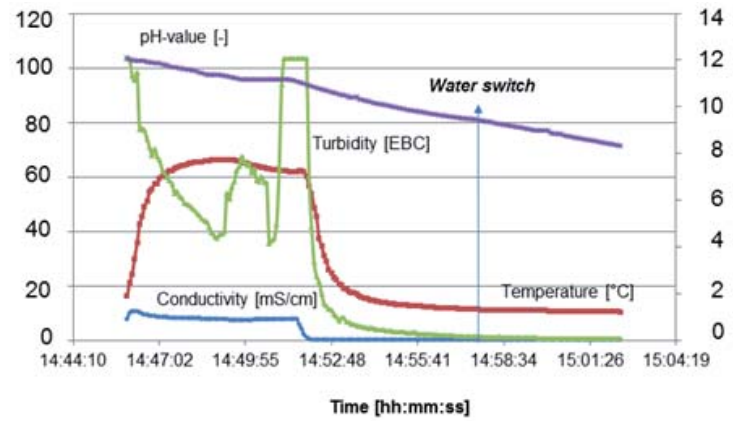


**Fig. 5 Water samples from left to right – Feed sample, sample after the water switch and before the membrane, permeate sample after the membrane**

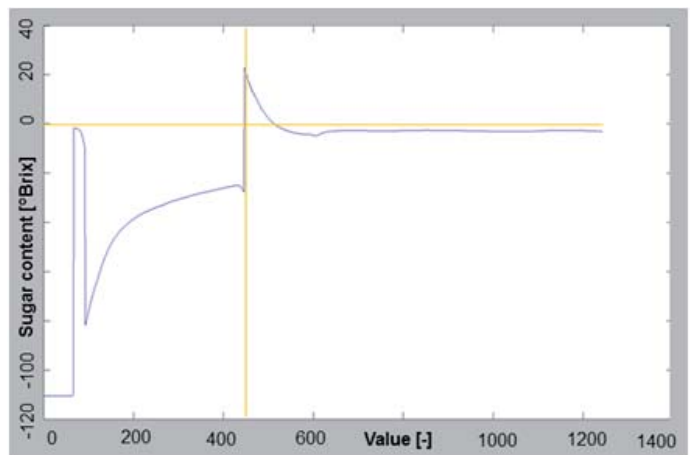
### 3.2 Experiments – testing with IR-sensor

After basic testing with four parameters a further test result is shown in diagram 2 including the infrared (IR) sensor for measuring the sugar concentration. Temperature, conductivity and turbidity are plotted on the primary axis; the pH-value is plotted on the secondary axis.

Aside from the four basic parameters, diagram 3 shows the course of value of the parameter sugar, measured via the IR-sensor. The



**Diagram 2 Course of testing with four parameters carried out in a pilot brewery (primary axis – conductivity, temperature, turbidity, secondary axis – pH-value). Testing period approx. 4 min**



**Diagram 3 Range of values of sugar content (°Brix) of the IR-sensor, the horizontal and vertical line symbolizes the start of testing and the zero line**

graph describes an initially fluctuating course of values which stabilizes at a measuring value of 400 and a constant value is calculated. The fluctuation is probably due to the high temperature of the feed as the calibration model was created at 20 °C.

The course (diagram 2) shows the rinsing of the feed to the defined fuzzy-limit values, see arrow marking. It becomes clear during testing that the pH-value remains in the system for a long period of time; longer than the particles that cause turbidity or the salt that influences conductivity in the initial values. The pH-sensor is therefore indispensable to the fuzzy-system as the parameter conductivity cannot be safely determined within the system in regard as to whether the pH-value is acidic, neutral or alkaline. Turbidity and temperature have a similar decay behavior.

When a fuzzy-output signal value of 0.5063 has been reached the *water switch* changes from waste water to filtration unit. The value is rounded up by the valve control in the PCS 7-system to 0.51. All switching parameters are shown in table 4.

The water samples concerning the feed and permeate composition were again examined under laboratory conditions, see table 5. Three further parameters (sediment, visual, and odor) were again assessed. The column process water represents the results of the composition of feed in the beginning of the testing; the column membrane permeate shows the values of permeate sample after

**Table 4** Parameter values while switching to water quality to be filtrated (>0.50) of the fuzzy-system and value of respective fuzzy-output

Parameter	Parameter values while switching	Fuzzy-output while valve switching
pH-value [-]	9.48	0.5063
El. Conductivity [ $\mu\text{S}/\text{cm}$ ]	220.00	(rounded 0.51)
Turbidity [EBC]	1.32	
Turbidity [NTU]	5.28	
Temperature [ $^{\circ}\text{C}$ ]	11.20	
Sugar content [ $^{\circ}\text{Brix}$ ]	-0.0	

the filtration unit. The limit values of the Drinking Water Ordinance 2001 are also given. The process water values all exceed the drinking water quality limits. During rinsing the *water switch*, based on logical rules and pre-defined values, is activated. According to the defined fuzzy-system, the permeate reaches then water with drinking water quality in all investigated parameters.

**Table 5** Results of testing with five parameters, including IR-sensor. Feed composition = process water, permeate = membrane permeate; Mix of process water / feed consists of a temperature level approx. 65  $^{\circ}\text{C}$ , dry yeast (turbidity) + caustic solution (pH-value) + salt tablets (conductivity)

Parameter	Method	Process water	Membrane permeate	Limit value	Dimension
Visual	Visual	Little yellow and turbid	colourless, nearly clear		[-]
Odor	DEV B ½	Little strange	Nearly odorless		[-]
Precipitate	Visual	beige	Negative		[-]
pH-value at 20 $^{\circ}\text{C}$	DIN 38404 C5	12.76	9.26	6.5-9.5	[-]
Conductivity at 25 $^{\circ}\text{C}$	DIN EN 27888 C 8	8500.0	410.0	2790.0	$\mu\text{S}/\text{cm}$
Turbidity	DIN EN ISO 7027 C 2	190.00	0.42	1.0	NTU
		47.50	0.11		EBC
Oxidizability	DIN EN ISO 8467 H5	34.0	1.5	5.0	mg/l

The samples of the feed and the permeate are again additionally visualized in figure 6. On the left hand side the turbid feed (process water) is presented, on the right hand side the clear permeate (after activation of the *water switch* and after passing the filtration unit). Additionally, the sample, which was collected before the membrane, is shown.



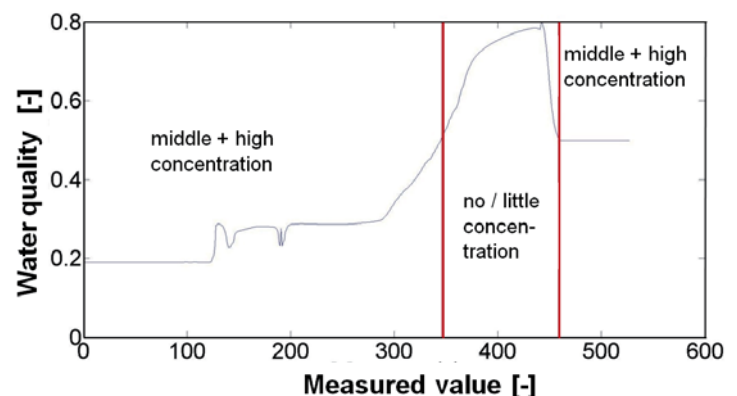
**Fig. 6** Water samples from left to right – Feed sample, sample after activation of the water switch and before the membrane, permeate sample after filtration unit

### 3.3 Simulation

In addition to practical testing with two membership functions of the water quality parameter a simulated comparison of the fuzzy-system, based on a defined data set, using three and two membership functions in the output water quality, is carried out. For this purpose, sugar concentration ( $^{\circ}\text{Brix}$ ) is converted into a COD-value. The conversion from  $^{\circ}\text{Brix}$  to COD-value is based on the reaction equation (Application of maltose to carbon dioxide and water, oxygen demand of 112.24 g for 100 g Maltose)  $C_{12}H_{22}O_{11} + 12 O_2 \rightarrow 12 CO_2 + 11 H_2O$  [26]. In the following, the expression concentration relates in this case to the grade of waste water.

The previous two membership functions during practical testing of the output water quality (filtration and waste water) are extended by one further membership function aerobic (middle) concentration. To enable differentiation, the output water quality is classified in the figures into hardly any/little concentration with a COD-value of 0–100 mg/l (process water for filtration); in middle concentration with a COD-value of 100–1000 mg/l (process water of aerobic environment / municipal sewage plant) and in high concentration with a COD-value higher than 1000 mg/l (anaerobic bioreactor / biogas production). The fuzzy-sets of the other input parameters via membership functions remain identical.

To avoid the destruction of the anaerobic environment of the pH-value and temperature dependent bacterial strains, waste water with an extremely high pH-value is conducted in the area of middle concentration. High turbidity is classified into the category high concentration. Those with smaller or middle/average turbidity can be filtered via the membrane and can therefore be used in the water quality hardly any/little concentration. Classification by means of sugar concentration is carried out as in the previous section however taking into account the use of the converted COD-value. High values for conductivity enable a middle concentration, high temperatures lead to higher concentration or otherwise to hardly any/little concentrated process water. The three defined limit values of the output water quality are divided into three equal ranges for high concentration (anaerobic), for middle concentration (aerobic) and low concentration (filtration).



**Fig. 7** Simulation with two membership functions in the output signal water quality (no/little concentration – filtration unit, middle + high concentration – anaerobic unit)

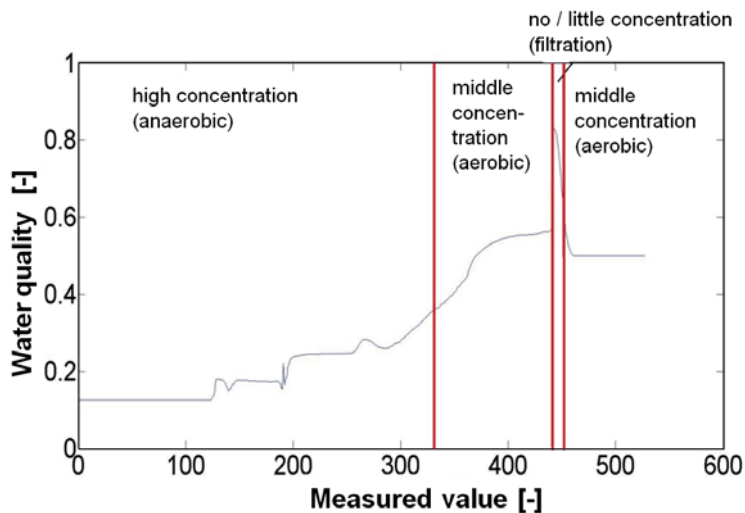


Fig. 8 Simulation with three membership functions in the output signal water quality (no / little concentration – filtration unit, middle concentration – aerobic unit, high concentration – anaerobic unit)

Both fuzzy-systems (two or three membership functions in the output water quality) are examined and compared using a pre-defined dataset, see figures 7 and 8.

In a comparison between the two simulations (two and three membership functions in the output), it becomes evident in figures 7 and 8, that a transition area middle concentration has developed in conjunction with the number of membership functions in the output.

Results show that the output water quality with three membership functions is classified into three different areas with the same test data. The area of water quality hardly any/little concentration with the output of three membership functions is considerably narrower in comparison to the areas of water quality hardly any/little concentration with two membership functions.

The middle concentration in figure 8 (on the right), was previously to be found in the middle/higher concentration in figure 7. As predicted, considerably less water is allocated to the area of high concentration, which was before middle/high concentration. The fact that the area of hardly any/little concentration is relatively small compared to the other two sections derives mostly from the given limit values of pH 6.5 und 9.5.

#### 4 Conclusion / Summary

This paper presents a developed fuzzy-system which leads to a separation of different water qualities. On the one hand, practical testing with two membership functions in the output water quality – treatment, on the other hand, two simulations comparing the output with two membership functions to the output with three membership functions, was carried out.

Fundamentally it can be stated that the detection and separation of water qualities is feasible. Aside from minimal deviations in the results of the permeate samples in basic testing (oxidizability failed by 1.6 mg/l) they were within the area of drinkable water which is a precondition for the reuse of water in the food and beverage industry.

To assure microbiological safety of the reuse water quality and in regard to water supply an additional application of an ultra-filtration membrane (pore size 10 nm) to the utilized sensors for the *water switch* was used.

The influence of the retentate of the filtration process on the biological degradation in the anaerobic basin and the concentrating of waste water for the anaerobic section is estimated as non-problematic due to the logical rules of the *water switch*. Interfering substances, e.g. cleaning solutions are conducted to the mixing and equalization basin first.

The separation of the process water flow within the brewery results in a smaller design of the final treatment systems enabling the saving of costs when building new plants. In each case it is possible to examine the reduction of rinsing and cleaning cycles, but it may not always be desired, for reasons of microbiological safety. The possibility to reuse the process water after having passed the filtration unit results in the consequence that longer rinsing and cleaning cycles are not relevant with regard to the waste water costs. Moreover, the separation of the water flows lead to a longer service life of the membrane due to the reduced loading of the process water. Generally, it is possible to adapt further and/or other measurement techniques to the *water switch* that makes the *water switch* to an universal tool for the optimisation of process water treatment.

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