OPTIMIZING THE TRANSFER OF ENERGY IN A HEAT EXCHANGER MINIMIZING THE CORROSION PROBLEMS IN PIPES IN A HYDROELECTRIC POWER STATION USING DATA MINING AND SUPPORT VECTOR MACHINE

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OPTIMIZING THE TRANSFER OF ENERGY IN A HEAT EXCHANGER MINIMIZING THE CORROSION PROBLEMS IN PIPES IN A HYDROELECTRIC POWER STATION USING DATA MINING AND SUPPORT VECTOR MACHINE

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Abstract. This research is based on the operation tube heat exchangers, their use and problematic on hydroelectric power plants. It is based on the design heat exchanger tubes for industrial use, which took the parameters of operation, design, working fluids (air and water) and conditions to assemble a monitoring equipment at appropriate scale for the laboratory, with the necessary measurement instruments to analyze the behavior of heat energy transfer by means of thermocouples, the velocity of the air with a hot wire anemometer and the flow of water with a turbine flow meter, in pipes of different materials: copper, steel 1018 and stainless steel 316L, all in ideal conditions, and with this to found a comparative parameter with pipes of the same materials but under conditions of deterioration with the presence of forced oxidation and with the data mining and support vector machine can be minimized the corrosion problems in pipes.

Keywords: Data Mining, Support Vector Machine, Pattern Recognition and Decision Support System, heat exchangers.

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1 Introduction

The generating station of Angostura, in Venustiano Carranza, Chiapas, Mexico, has a hydroelectric plant with five generators of 180MW each, which has the capacity to generate 900MW of electricity. Due to its design, to maintain its operating temperature, an air recirculation system is used, in which cold air circulates through the poles of the rotor and the winding of the stator, then the hot air is extracted and made pass through tube heat exchangers (air-water), which are mounted in each of the stator windows to continue its cooling cycle Fig. 1.

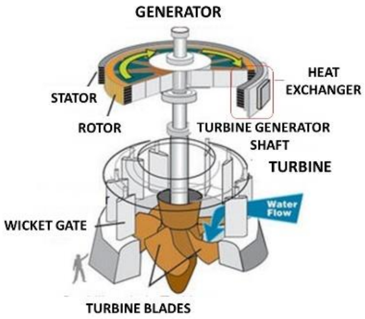


Fig. 1. Diagram of a Kaplan turbine and its cooling system
(Kaplan turbine). Recovered https://www.green-mechanic.com/2014/07/kaplan-turbine.html

Each generator has 24 heat exchangers, which perform the cooling of the air through the circulation water that passes through the pipe, in a cross-flow system where the working fluids do not mix. The water from the cooling system is taken from the Grijalva riverbed, it passes through the equipment and is poured back into it, not having a water recirculation [1] Fig. 2.

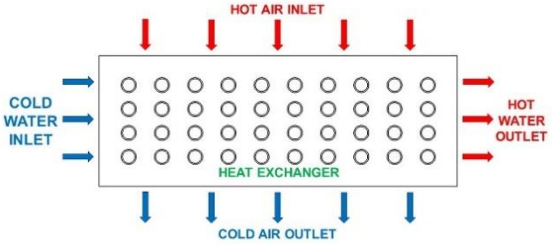


Fig. 2. Diagram of operation of the heat exchanger

The exchanger is composed of 200 tubes of 2m each of a 90/10 cupro-nickel alloy, plate-type aluminum fins and a large part of its A-36 steel structure. The water used in the cooling system, due to human settlement, pollution, waste, etc., is highly contaminated mainly by hydrogen sulfide, causing the heat exchangers and the materials that make it up to be susceptible to oxidation problems. erosion, incrustations and localized corrosion [2, 3] Fig. 3, having as a consequence in its most affected part pitting that cause leaks and consequently an increase in the temperature of the generator damaging the winding thereof.

Fig. 3. Exchanger mirror with the presence of corrosion and incrustations

Support Vector Machine

Classifying data is a common task in machine learning. Suppose some given data points each be-long to one of two classes, and the goal is to decide which class a new data point will be in. In the case of support vector machines, a data point is viewed as a p-dimensional vector (a list of p numbers), and we want to know whether we can separate such points with a $(p - 1)$-dimensional hyperplane. This is called a linear classifier. There are many hyperplanes that might classify the data. One reasonable choice as the best hyperplane is the one that represents the largest separation, or margin, between the two classes [4] So, we choose the hyperplane so that the distance from it to the nearest data point on each side is maximized. If such a hyperplane exists, it is known as the maximum-margin hyperplane and the linear classifier it defines is known as a maximum mar-gin classifier; or equivalently, the perceptron of optimal stability.

2. Characterization of the problem.

Heat exchangers are devices designed to transfer heat energy from one medium to another medium. The energy is transferred from a hot fluid to a cold fluid in only one direction by conduction and convection and in some cases radiation as in the gases, transferring from the fluid with higher temperature to the fluid of lower temperature.

Condition T1<T2

There are different types of heat exchangers based on specific characteristics and take these parameters to implement the laboratory's heat transfer monitoring equipment, trying to match the conditions to the exchangers used in the industry.

2.1 Previous analysis.

To observe the heat exchange behavior of the heat exchangers used in the hydroelectric industry, the assembly of the monitoring equipment was implemented to observe this and more related phenomena. The heat exchanger Mesabi is taken as a basis, basis for its design. Based on the "Design and construction of a heat exchanger prototype with applications in hydroelectric power plants" [5], a preliminary analysis is performed with the necessary energy balance calculations, then the CAD design of its components. Which are composed of the part that intervenes in the distribution of the air flow as it is the pipe through which it passes and stabilizes until it incurs on electrical resistances where it absorbs the heat of them and later incise the hot air on the pipe of the exchanger until it passes through it, and finally exit [7] Fig. 4.

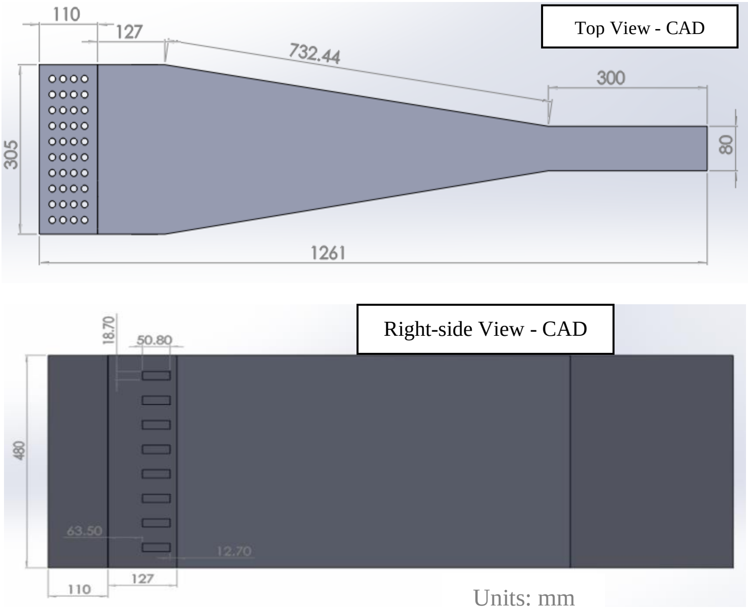


Fig. 4. Top and right-side view of the model in CAD

Later with the analysis carried out and evaluated in "Numerical simulation and construction of an experimental heat exchanger" [6], where the computer software MESHING-ICEM was used as the discretizing medium and the ANSYS Fluent for the simulation with the residual values converged, velocity vectors and temperature contours were monitored, creating different planes showing the desired current lines and contours [8], where it was inspected without significant turbulence in specific areas of the prototype, the uniform distribution of the air throughout the exchanger and the optimum temperature range at the required distances based on the original parameters.

Description of the monitoring equipment based on the design and behavior of the fluids in the simulations, the monitoring equipment is implemented integrating the heat exchanger with the necessary instrumentation for its operation and analysis of the fluids involved [9, 10]. A fan was installed to supply the forced air to the interior of the duct, and by means of a Dwyer anemometer the air speed is monitored at different heights and determined distance. By means of an Autonyms temperature controller, the temperature of the electrical resistances that will heat the air passing through them is controlled. A water circulation system is installed with two water tanks, one upper and one lower, through which the tanks and tubing of the exchanger are passed. To monitor the volumetric flow, a turbine flowmeter is installed at the entrance of the exchanger. To monitor the temperatures of the entire system, 32 thermocouples type T (Cu-Constantan) were installed, and by means of a National Instruments data acquisition and the Lab view interface, the values are acquired Fig. 5.

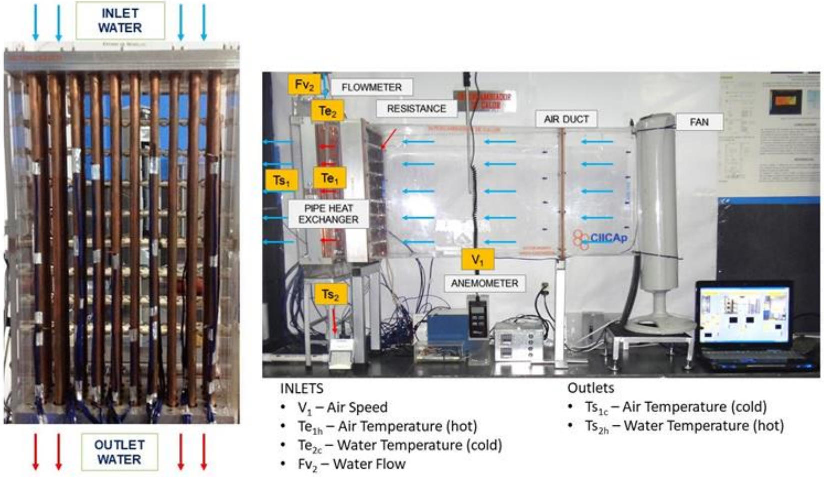


Fig. 5. Views of instrumented monitoring equipment

3. Proposal Methodology

3.1 Test Parameters

Operating parameters for the design were taken Table 1, primarily the values of the fluids that intervene in the system as their temperatures and operating pressures established by the manufacturer [11]. The parameters of the pipe-line were taken into account, such as its diameter, its length, the number of pipes, their arrangement and their distribution Table 2. The dimensions of the casing and its component parts were determined based on the dimensions of the pipe and the size of the desired prototype to handle in the laboratory based on CAD design Table 3.

Table 1. Design parameters

	Heat Flow Air 1	Cold Flow Water 2
Inlet Temperature	43.2°C	27.3°C
Outlet Temperature	30.3°C	28.6°C
Inlet Pressure	3.86 kg/cm^2	3.86 kg/cm^2
Outlet Pressure	3.09 kg/cm^2	3.09 kg/cm^2
Volumetric Flow	-	24 l/min

Table 2. Pipe

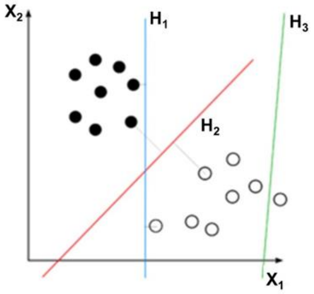
		Value
Outside Diameter	Do=	0.0127m
Inside Diameter	Di=	0.0107m
no. Pipes	n=	40 pipes
Lenght Pipes	l=	0.517m

Table 3. P

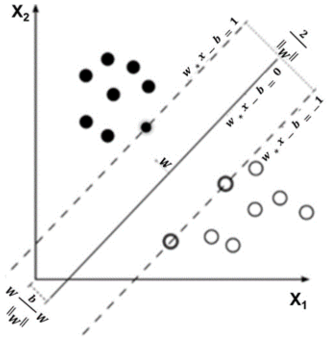
Detail / Abbrevation		Valor (m)
Width	A_{IN}	0.3
Depth	P_{IN}	0.1

3.2 Linear SVM.

Given some training data D a set of n points of the form D $D = \{(x_i, y_i) | x_i \in R^P, y_i \in \{-1, 1\}\}_{i=1}^{n}$ y_i x_i x_i $y_i = 1$ $y_i = -1$ x, where the y_i is either 1 or −1, indicating the class to which the point x_i belongs [12]. Each x_i is a p-dimensional real vector. We want to find the maximum-margin hyperplane that divides the points having $y_i = 1$ from those having $y_i = -1$. Any hyperplane can be written as the set of points x satisfying.



Graph. 1. H_3 (green) doesn't separate the two classes. H_1 (blue) does, with a small margin and H_2 (red) with the maximum margin



Graph. 2. Maximum-margin hyperplane and margins for an SVM trained with samples from two classes. Samples on the margin are called the support vectors

$w \cdot x - b = 0$, where · denotes the dot product and w the normal vector to the hyperplane. The parameter $\frac{b}{\|w\|}$ determines the offset of the hyperplane from the origin along the normal vector w.

We want to choose the w and b to maximize the margin, or distance between the parallel hyperplanes that are as far apart as possible while still separating the data. These hyperplanes can be described by the equations $w \cdot x - b = 1$ and $w \cdot x - b = -1$.

Note that if the training data are linearly separable, we can select the two hyperplanes of the margin in a way that there are no points between them and then try to maximize their distance. By using geometry, we find the distance between these two hyperplanes is $\frac{2}{\|w\|}$, so we want to minimize $\|w\|$. As we also have to prevent data points from falling into the margin, we add the following constraint: for each i either $w \cdot x_i - b \geq 1$ for x_i of the first class or $w \cdot x_i - b \leq 1$ for x_i of the second.

This can be rewritten as:

$$y_i \left(w \cdot x_1 - b \right) \geq 1, \text{ for all } 1 \leq i \leq n \tag{1}$$

We can put this together to get the optimization problem:

Minimize (in w, b) $\|w\|$ subject to (for any $i = 1, \ldots, n$) $y_i \left(w \cdot x_i - b \right) \geq 1$.

Primal form

The optimization problem presented in the preceding section is difficult to solve because it depends on $\|w\|$, the norm of w, which involves a square root. Fortunately, it is possible to alter the equation by substituting w with $\frac{1}{2}\|w\|^2$ (the factor of $1/2$ being used for mathematical convenience) without changing the solution (the minimum of the original and the modified equation have the same w and b). This is a quadratic programming optimization problem. More clearly:

Minimize (in w, b) $\frac{1}{2}\|w\|^2$ subject to (for any $i = 1, \ldots, n$) $y_i \left(w \cdot x_i - b \right) \geq 1$.

By introducing Lagrange multipliers α, the previous constrained problem can be expressed as $\min_{w,b} \max_{\alpha \geq 0} \left\{ \frac{1}{2}\|w\|^2 - \sum_{i=1}^{n} \alpha_i \left[y_i \left(w \cdot x_i - b \right) - 1 \right] \right\}$ that is we look for a saddle point. In doing so all the points which can be separated as $y_i \left(w \cdot x_i - b \right) - 1 > 0$ do not matter since we must set the corresponding α_i to zero.

This problem can now be solved by standard quadratic programming techniques and programs. The "stationary" Karush–Kuhn–Tucker condition implies that the solution can be expressed as a linear combination of the training vectors $w = \sum_{i=1}^{n} \alpha_i y_i x_i$.

Only a few α_i will be greater than zero. The corresponding x_i are exactly the support vectors, which lie on the margin and satisfy $y_i \left(w \cdot x_i - b \right) = 1$. From this one can derive that the support vectors also satisfy $w \cdot x_i - b = 1/y_i = y_i \Leftrightarrow b = w \cdot x_i - y_i$

which allows one to define the offset b. In practice, it is more robust to average over all NSV support vectors:

$$b = \frac{1}{N_{SV}} \sum_{i=1}^{N_{SV}} \left(w \cdot x_i - y_i \right) \tag{2}$$

Dual form

Writing the classification rule in its unconstrained dual form reveals that the maximum margin hyperplane and therefore the classification task is only a function of the support vectors, the training data that lie on the margin.

Using the fact that $\|w\|^2 = w \cdot w$ and substituting $w = \sum_{i=1}^{n} \alpha_i y_i x_i$, one can show that the dual of the SVM reduces to the following optimization problem:

Maximize (in α_i)

$$\widetilde{L}(\alpha) = \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i,j} \alpha_i \alpha_j y_i y_j x_i^T x_j = \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i,j} \alpha_i \alpha_j y_i y_j k(x_i, x_j) \tag{3}$$

subject to (for any $i = 1,\dots,n$) $\alpha_i \geq 0$, and to the constraint from the minimization in $b = \sum_{i=1}^{n} \alpha_i y_i = 0$

Here the kernel is defined by $k(x_i, x_j) = x_i \cdot x_j$. w can be computed thanks to the α terms:

$$w = \sum_{i} \alpha_i y_i x_i$$

Biased and unbiased hyperplanes

For simplicity reasons, sometimes it is required that the hyperplane pass through the origin of the coordinate system. Such hyperplanes are called unbiased, whereas general hyperplanes not necessarily passing through the origin are called biased. An unbiased hyperplane can be enforced by setting $b = 0$ in the primal optimization problem. The corresponding dual is identical to the dual given above without the equality constraint $\sum_{i=1}^{n} \alpha_i y_i = 0$

4. Experimentation

4.1 Tubing in Different Conditions.

By means of the opening of the valves, various positions are defined, and their flows measured until the ones with the greatest variation are defined, thus obtaining nine flow variations.

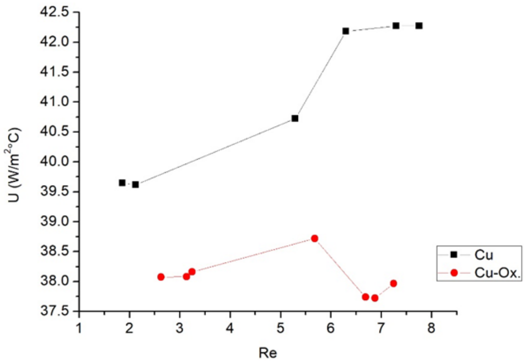
With the experimental tests, the parameters of the instrumented work fluids are obtained for each test, in order to perform an analysis of the behavior of each pipeline.

For the pipeline, its characteristics and dimensions are taken into account and its properties and thermal conductivity.

The experimental tests are carried out by varying the flows gradually and the behavior of the air velocity is obtained, as well as its different temperatures and the volumetric flow in each one of them.

The data of the global coefficient of heat transfer against the Reynolds number is plotted to observe how the amount of heat that can be transferred by the temperature difference changes as a function of the change in the movement of the cold fluid with its linear trend line for copper pipe under normal conditions. The behavior was characterized with the materials susceptible to wear and deterioration by oxidation previously submitted to a forced corrosion [13].

The data of the Global Heat Transfer Coefficient against the Reynolds number are plotted for copper pipe under normal conditions and the comparison with oxidation [14] Graph 3.



Graph. 3. Copper pipe behavior under normal conditions and forced oxidation

In order to obtain the most efficient arrangement of components, we developed a cluster for storing the data of each of the representative individuals for each component. The narrative guide is made with the purpose of distributing an optimal form for each the evaluated components. The main experiment consisted in implementing components with our hybrid algorithm, with 500 issues and 200 époques. The stop condition is reached after 50 iterations. The vector of weights employed for the fitness function is Wi= [0.6,0.7,0.8,0.5,0.6,0.9,0.8, 0.7,0.6, 0.9,0.5,0.8,0.7], which respectively represents the importance of each component. Then, the hybrid algorithm will select the specific value of each component based on the attribute's similarity. Each attribute is represented by a discrete value from 0 to 7, where 0 means absence and 7 the highest value of the attribute. The experiment design consists of an orthogonal array test with interactions amongst variables components; these variables are studied within a location range (1 to 400) specific to a coordinates x and y. The orthogonal array is L-N (2**7), in other words, 7 times the N executions. The value of N is defined by the combination of the 7 possible values of the variables, also the values in the location range. In Table 4 we list some possible scenarios as the result of combining the values of the attributes. The results permit us to analyze the effect of all the possible combinations of values.

Table 3. The orthogonal array test

V_1	Te_1	Ts_1	fv_2	Te_2	Ts_2	D_{ext}	L	N	K_{cooper}
Air Speed	Air Inlet Temp.	Air Outlet Temp.	Water Flow	Water Inlet Temp.	Water Outlet Temp.	External Diameter	Pipe Length	Pipe Numbers	Conductivity
4	1	2	2	3	5	3	5	2	2
3	1	2	2	3	3	4	4	7	4
2	1	3	2	4	1	2	2	5	5
5	1	3	2	5	4	5	5	4	3

The use of the orthogonal array test facilitates the reorganization of the different attributes. Also, the array aids to specify the best possibilities to adequate correct solutions for each component. Different attributes were used to identify the real possibilities of improving a component set in a particular environment, and to specify the correlations with others.

5. Conclusions

1. Conclusions

With the construction of a scale monitoring equipment, the behavior of the heat exchangers used in the hydroelectric plants can be carried out, under different conditions, but controlled variables cannot be maintained in their entirety, since they have fluctuations due to the system of air intake by a fan for air and valves for the passage of water that counts. Despite this, it was possible to standardize the behavior of the operating conditions for the copper pipe that is taken as a point of comparison for the different materials used.

The transfer of heat energy in copper test pipes under ideal operating conditions was evaluated, obtaining a decrease in the hot air inlet temperature (± 58.8 °C) of 19.4 °C min. at 26.6 °C max., with a maximum heat transfer coefficient of 42.2 $W/_{m^2 {}^\circ C}$ and a calculated effectiveness of 50.9%.

The transfer of heat energy in copper test pipes under conditions of forced oxidation was evaluated, obtaining a decrease in the hot air inlet temperature (± 59.5 °C) of 16.0 °C min. at 29.3 °C max., with a maximum heat transfer coefficient of 38.1$W/_{m^2 {}^\circ C}$.

Data processing was carried out through tools such as data mining and support vector machines to find related patterns within them, allowing the creation of models or abstract representations of reality, obtaining a classification form for the training data and see in which class a new data will be by means of a linear classifier. This algorithm repeats the process of multiple evaluations according to different combinations of optimal values until reaching the necessary qualifiers of the series and obtaining the most efficient arrangement of the components, which is observed in the orthogonal matrix in its last evaluation, than the air velocity , the water inlet temperature, the external diameter and the length of the pipe and the air outlet temperature a value of 5, where 0 means absence and 7 the highest value of the attribute, denoting that these variables are the ones that most they influence the test and therefore more important for the evaluation.

5.1Future Research

To obtain experimental data without so much noise by means of controlled variables, it is recommended to implement a forced air intake system that does not have losses or energy losses by use, besides maintaining the flow in a laminar or transitory regime. Baffles can be added in the air duct to help its linearization; studies can be simulated to achieve it. Improve the control system for the temperature of the resistances to heat the air without so much fluctuation, changing the controller for one with a shorter range of variation. Improve the control of the passage of water, by means of the change of the valves of globe by electro valves and thus be able to maintain the same flow if it is required to have variations and to have the veracity of it with a flow meter with less uncertainty. The number of thermocouples in the critical study areas could be increased to increase the temperature mapping for the flow of hot air and inside the pipeline to know how the transfer is behaving along it, and not only at the entrance and exit.

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