Optimal analysis for enhancement of thermo mechatronic processes

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ABSTRACT[1]

Thermodynamic processes are part of the road of a thermodynamic system, while it has an initial and final state of the thermal trajectory. Nevertheless, there are many intricate variables while the process goes from a transient to a steady state, in many contexts it causes imbalances in the final system, such as given losses in internal efficiencies of subsystems from the main system, furthermore the total losses in the system efficiency. Hence, in this work is proposed a procedure to optimize a general thermodynamic process which was evaluated in different applications that are part of primary manufacturing tasks like there are in Perú, even they can produce pollution or disturbances in nature conditions when it is not an optimal procedure to develop the thermodynamic process. This proposal procedure is based in mathematical modelling by correlation in theoretical analysis of the thermal system with analysis of experimental data through adaptive/predictive techniques, moreover, it was evaluated and suggested applications of new technologies as sensors/actuators based in nanostructures due to faster and robust characteristics as comparisons with traditional sensors/actuators. Finally, the results achieved were interpreted by standards norms that help to keep based comparisons to interchange with international community.

Keywords: thermo mechatronic process, optimization, sensor/actuator based on nanostructures.

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1. INTRODUCTION

There are plenty processes, in which the thermodynamic is quite important in order to study information of the process. Such as for example electricity production through steam achieved by a boiler, refrigeration system, compressor system and ventilation. Most of them need mathematic analysis, algorithms and experimental data evaluation according to get “Optimization”. However, there are situations during the process that need robust and faster sensors to capture information from variables that usually are considered as disturbances, but in this work is proposed a complementary analysis regarding perturbations. Therefore, in this research is analyzed a general optimal algorithm to evaluate thermo mechatronic processes, furthermore enhanced by sophisticated sensors/actuators based in nanostructures to join variables such as “vibration” owing to improve the best adaptive/predictive optimization for thermo mechatronic processes.

According to achieve successful optimization analysis, there were verified the achieved results by applying norms and standards of optimization processes.

2. OPTIMIZATION

Optimization is a methodology or mathematical procedure, in which is compared the requirement of a task with a measured or estimated variable, the best comparison is achieved when the error tends to be null. There are methods by simple statistical contexts, adaptive matrix, predictive values and complex neural models.

In this research are analyzed thermal processes in which the fluids are the main carrier of energy, hence, the “Diffusion equation”, proposed by the Eq. (1) gives information about the speed and flow of the fluid.

$$\frac{\partial f}{\partial t}+\mu\frac{\partial f}{\partial x}=D\frac{\partial f^2}{\partial x^2} \quad (1)$$

$$\frac{\partial(x,t)}{\partial t}+v(x)\frac{\partial c(x)}{\partial x}-d(x)\frac{\partial c(x)^{\alpha}}{\partial x^{\alpha}}=r(x,t) \quad (2)$$

By other side, Navier Stokes equation, has information of the speed and flow of the fluid too, however, this equation keeps more the theoretical approximation of the fluid behavior, therefore a mathematical model to achieve from experimental data analysis needs to have similarities with the polynomial model of Navier Stokes.[1]

$$\frac{\partial u_i}{\partial t}+\mu\frac{\partial u_i}{\partial x_j}+\frac{1}{\rho}\frac{\partial p_i}{\partial x_j}=\eta\Delta u_i \quad (3)$$

For this research, it was evaluated the performance of polynomial equations as described by general model inequation 1, for that P is the derivative $\frac{\partial^n}{\partial t^n}$,$y(t)$ is the variable output matrix, $u(t)$ is the variable input matrix, is the variable error matrix, "a" and "b" are the adaptive coefficients of the system.

$$P^n y(t)+\sum_{j=1}^{n} a_j P^{n-j} y(t)=\sum_{j=1}^{n} b_j P^{n-j} u(t)+e(t) \quad (4)$$

where solution error analysis "e(t)" is the discrete error, and "V" keeps the Fourier series coefficients.

$$e_n(m)=\sum_{k=m}^{n+m}\alpha(k,m,\theta_a)V(k) \quad (5)$$

Furthermore, α is the frequency parameter function in Eq(6).

$$\alpha(k,m,\theta_a)=C_{k-m}\sum_{j=0}^{n} a_j (jkw_o)^{n-j} \quad (6)$$

For which, the nonlinear model for error analysis is given by Eq. (7).

$$\sum_{j=0}^{n_1}\sum_{k=1}^{n_2} g_j(\theta)F_{jk}(u,y)P_{jk}(p)E_k(u,y)=0 \quad (7)$$

Therefore, the costing function is described by Eq. (8).

$$J(\theta)=\sum_{j=0}^{n_1}\sum_{k=0}^{n_1} r_{jk} g_j(\theta) g_j(\theta) \quad (8)$$

Also, according to get "parameters of the main model" it was achieved the derivation in Eq. (9).

$$\frac{\partial J}{\partial \theta}=(Y-\Gamma\theta)^T W^{-1}(Y-\Gamma\theta) \quad (9)$$

Where parameters are showed in equation Eq. (10), as dependence of the "adaptive" coefficients.

$$\theta=(\Gamma^T W^{-1}\Gamma)^{-1}\Gamma^T W^{-1} Y \quad (10)$$

Figure 1 shows the road "C_1" that represents the information achieved to get it through a thermodynamic road from "A to A^*", by other side, the road "C_2" shows that road as requirement, therefore the task from optimization is given because of finding the optimal road as requirement needs, such as depicted by curve "C_3"

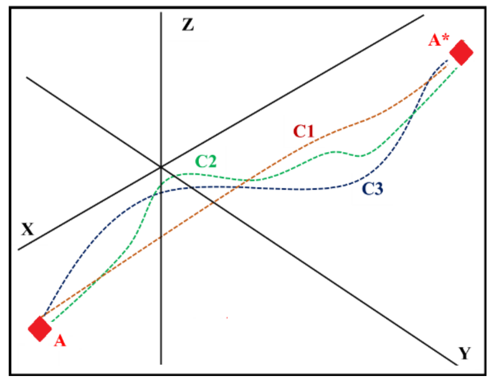

Figure 1. Optimal road depicted.

3. MODELING

By modulating functions techniques, it was possible to obtain the physical parameters as it was studied in the chapter above, therefore there were calculated solutions according to achieve the main physical variables such as pressure, volume and flow.

In figure 2 is depicted a setup for the fluid variables measurements, that was given by electromechanics sensors and sensors based in nanostructures.[2]

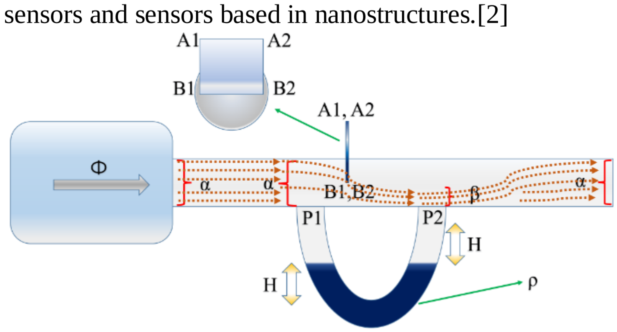

Figure 2. Scheme to show part of experimental setup

From Stokes, it is possible to reduce to Bernoulli model, therefore, by the scheme, and energy balance in Eq. (11)

$$\frac{1}{2}\rho v_1^2+p_1=\frac{1}{2}\rho v_2^2+p_2 \quad (11)$$

Therefore, it is obtained in Eq. (12):

$$\frac{1}{2}\rho(v_1^2 - v_2^2) = p_2 - p_1 \qquad (12)$$

Because of static pressure analysis, it is obtained in Eq. (13):

$$\Phi = A_1\left(\frac{2\Delta P}{\rho\left(1-\frac{A_1}{A_2}\right)^2}\right)^{\frac{1}{2}} \qquad (13)$$

From that, it is possible reduce to Eq. (14):

$$\Phi = A_1\left(\frac{-2\mathrm{gH}}{\left(1-\frac{A_1}{A_2}\right)^2}\right)^{\frac{1}{2}} \qquad (14)$$

Furthermore, by continuity equation in Eq (15):

$$v_2 = \frac{v_1 A_1}{A_2} \qquad (15)$$

Proposing the relation showed in Eq. (16):

$$A_2 = \frac{A_1}{2} \qquad (16)$$

Hence, the flow is presented in Eq. (17):

$$\Phi = A_1\sqrt{2g}\,H^{\frac{1}{2}} \qquad (17)$$

There were elaborated sensors based in AAO,[3] after electropolishing, anodization and deposited ferric oxide inside holes. Finally, through galvanization process, it was possible to fix cables by welding over corners of the sample according to get the transduction. There is explained two model equations for sensors, such as for figure 3, in which is represented heat transmission from focus to sensor.

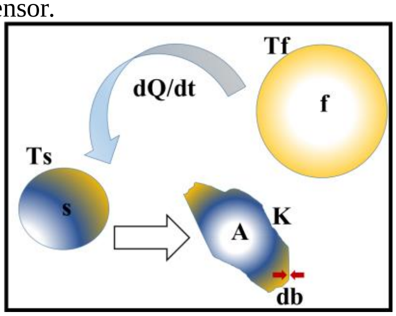

Figure 3. Heating transfer in temperature sensor scheme.

Therefore, the model can be explained by Eq. (18)

$$\Theta(t) = \Theta_f\left(1 - e^{-\frac{t}{RC}}\right) \qquad (18)$$

and by experimental analysis last equation can be proposed by its Laplace transformation in Eq. (19).

$$\frac{T^{\circ}}{U(S)} = \frac{K_p e^{LS}}{\tau S + 1} \qquad (19)$$

In second side, for a second order model, such as described in figure 4, in which, X0 means the displacement registered by the sensor and X1 means the real displacement.

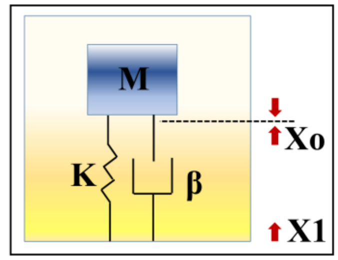

Figure 4. Displacement in position sensor scheme.

Therefore, the Eq. (20):

$$M\left(\frac{d^2X_1}{dt^2} - \frac{d^2X_0}{dt^2}\right) = KX_0 + \beta\frac{dX_0}{dt} \qquad (20)$$

and in Laplace domain, it is obtained the following model in Eq. (21).

$$MS^2X_1(S) = X_0(S)[K + \beta S + MS^2] \qquad (21)$$

Hence, Eq. (22) summarizes the parameters of the position sensor

$$\frac{X_0(S)}{S^2X_1(S)} = \frac{M}{K}\frac{\frac{K}{M}}{S^2 + \frac{\beta}{M}S + \frac{K}{M}} \qquad (22)$$

4. SENSOR DESIGN

In the following figure is showed part of the AAO samples elaborated by electrochemical process in researching laboratories of PUCP, in collaboration of TU Ilmenau. Sensors used for the experiments of this research are "thermocouples, manometers, rotameters". Nevertheless, according to achieve specific measurements such as correlation between vibration and sound, temperature in bigger area even though faster response and robustness, it was designed sensors based in nanostructures. The procedure was to elaborate nanoholes over aluminum by anodization techniques and after to deposit particles of Fe2O3 and specific points of galvanization [3], [4] according to get areas for welding of cables that receives the transduction from physical signal to electrical signal.

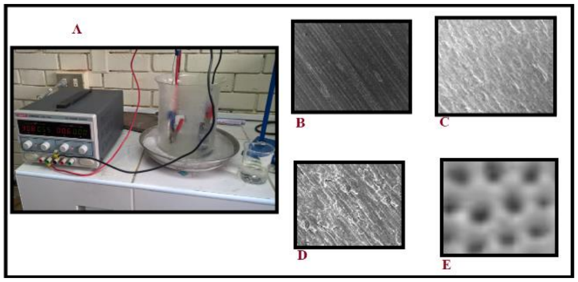

Figure 5. First order models for sensors design.

After the elaboration of the samples, there were analyzed many physical tests by statical and dynamical response for every proposal sensor, such as by the temperature, which is showed through the figure 6.

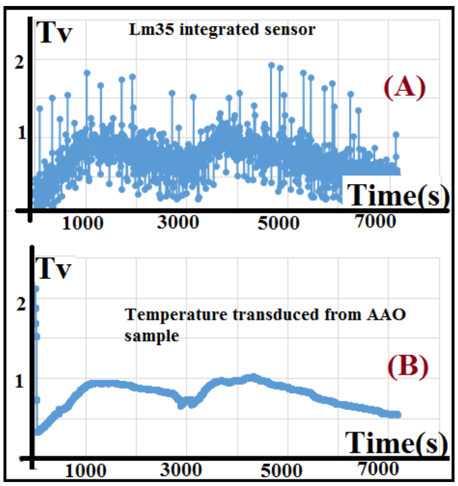

Figure 6. Temperature evaluation from sensor designed.

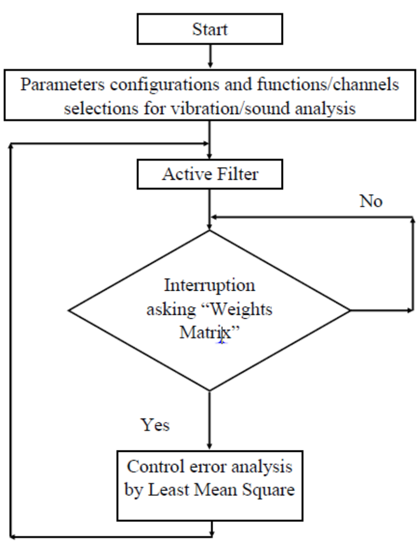

Figure 7. Algorithm scheme

5. REFRIGERATION SYSTEMS

A refrigeration system is composed by an evaporator, compressor, condenser and expansive valve. In Perú refrigeration systems are part important for industries. Nevertheless, it is necessary optimize their performance in order to get better energy uses. In figure 8 is showed a general refrigeration system that can enhance performance while variables as R12 can be changed.

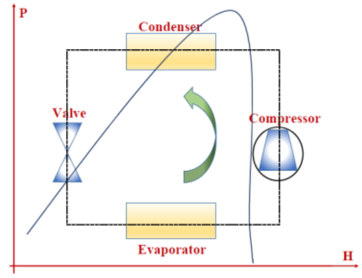

Figure 8. Refrigeration analysis

Theoretically, COP (performance) of cycle is given by Eq. (23)

$$COP_c = \frac{h_4 - h_1}{h_2 - h_1} \tag{23}$$

furthermore, the COP pf the system is explained by Eq. (24)

$$COP_p = \frac{\dot{W}_{ec}}{\dot{W}_t} \tag{24}$$

Nevertheless, by the proposal statistical model proposed, it can be selected the appropriated input/output variables according to optimize its trajectory, that means the desired trajectory and the optimal technique looks for an adaptative/predictive optimization to get the desired road as conditions over the input/output variables selected. However, the last model can be adjusted as the desired road "COP" for this context is required, it means while selecting input variables for the system "Model that depends as input variables We and Wc and output variable COP", so both input variables can be joined by "X" as it is described in Eq. (25)

$$X = \left(\dot{W}_e \dot{W}_t\right) \tag{25}$$

Therefore in Eq. (26),

$$COP_{eo} = X(X^T X)^{-1} X^T COP \tag{26}$$

Therefore, in the following figure 9 is showed the optimal COP as dependence of the temperature and power.

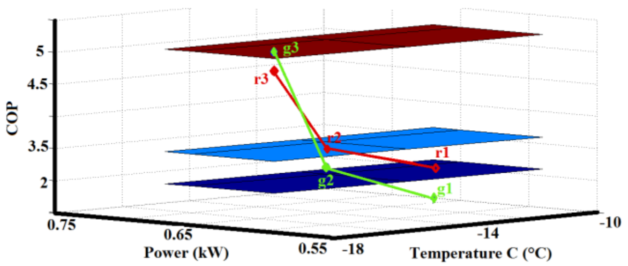

Figure 9. Refrigeration analysis

6. PSYCHOMETRIC SYSTEMS

It is expected to optimize humidification through thermal variable analysis. It is possible analyzing humidity sensor and comparing calculations. Peruvian market plenty used to dry vegetables and fruits in agriculture, in which air compressor is part of the internal stage of the drying process.

It showed in Eq. (27)

$$X = 0.622\frac{\phi P_s}{P - \phi P_s} \tag{27}$$

therefore, X is enhanced by "Optimal equations". Therefore, in figure 10

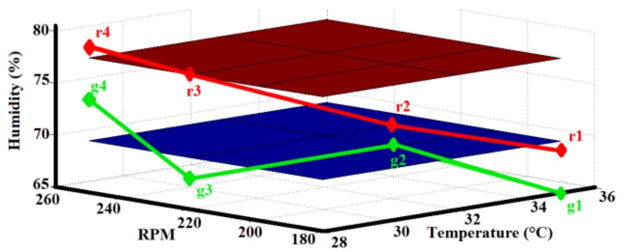

Figure 10. Optimization over psychometric system.

7. COMPRESSOR SYSTEMS

To optimize compression through polytropic coefficient optimization. Vibration sensors over compressors.
It is known in Eq. (28)

$$P_1V_1^n = P_2V_2^n \tag{28}$$

Furthermore in Eq. (29)

$$PV = RT \tag{29}$$

That results in Eq. (30)

$$\frac{T_1}{T_2} = (\frac{V_2}{V_1})^{n-1} \tag{30}$$

also in Eq. (31)

$$\frac{T_1}{T_2} = (\frac{P_2}{P_1})^{\frac{n-1}{n}} \tag{31}$$

through first thermodynamic law over compressor

$$\frac{dQ}{dt} = \frac{dm}{dt}(h_2 - h_1) - \frac{dm_r}{dt}\int_{p_1}^{p_2} vdp \tag{32}$$

by theory it is possible to analyze that vibration troubles in compressors can be seen in displacement troubles, and thermo dynamically by heating losses therefore by vibration sensors based in nanostructures and AMB it can be improved.

It is suggested to correctly fix the sensors over working area in order to avoid losses. Therefore, as dependence of correlation between input and output variables, it is proposed the Eq. (33).

$$ne = X\hat{\beta} \tag{33}$$

for which "X" stores every input array of variables, while "n" is known as the polytropic coefficient achieved through calculation of input variables. Nevertheless, it is expected the estimated "n_e". Therefore $\hat{\beta}$ is given by Eq. (34).

$$\hat{\beta} = (X^TX)^{-1}X^Tn \tag{34}$$

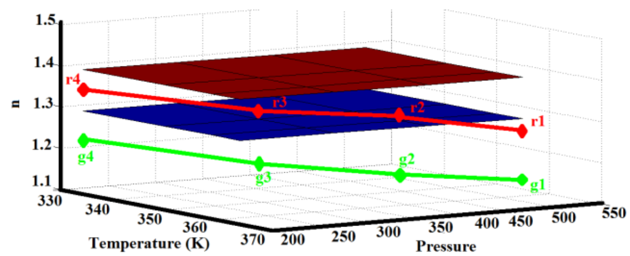

Figure 11. Optimization of the polytropic coefficient

8. RANKINE CYCLE THERMAL PLANT

A Ranking cycle is plenty used to achieve mechanical energy through heat, for this task, water steam is the most used fluid, even though it tends to be changed by organic fluids nowadays. Advantages from this thermodynamic cycle are based widely due to it is available, cheap, moreover, much heat produced. Nevertheless, disadvantages are caused owing to low pressure achieved, that is the reason why this cycle get down efficiency too. In order to evaluate the methodology to optimize thermodynamic processes, in this subsection is studied and analyzed parameters to increase efficiency of this cycle, eve trough it can be working by water steam as main fluid yet. Rankine cycle is applied in Perú in thermal plants such as in internal process of energy production as consequence of steam utilization.

According to analyze the optimization model of this research, it was necessary to identify its problematic, that is caused because of no coordination of internal variables while boiler receives cold water to reduce temperature in maximal load and pressure level. Therefore, schematic is depicted in figure 12, in which are showed internal variable and from that is possible to understand dependence from internal variable with main input/output variable to get increasing in its efficiency. Hence, for this application, it was selected fuel as input variable "F_c", power generator as output variable "W_t", however this system is composed by many variables, which as the way these are organized, it can be possible to find the optimal solution. For instance, the internal variables are given by "Pressures, Temperatures, flows" measured when water steam (fluid) goes through the boiler "B_l" after to increase its pressure and temperature, even in order to improve final efficiency the system needs the superheater "S_h", furthermore, under increased pressure the turbine can generate power "W_t", moreover the flow (steam water) after to be the main transporter give power from the system, needs to be closed the cycle. That is the reason why it is looked for achieving condensed from the condenser "C", moreover the vacuum pump "V_p" the heat exchanger "H_e".

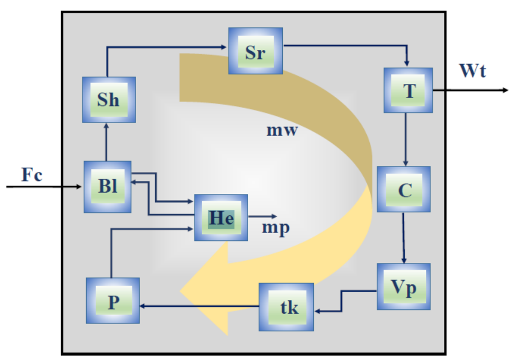

Figure 12. Optimization

There are many equations theoretical analysis for relation of every internal stage, however by optimal analysis it is possible to obtain optimal estimations such as described by Eq. (35).

$$\hat{\eta} = X(X^T X)^{-1} X^T \eta \quad (35)$$

The optimal analysis result is depicted in figure 13. There is better to choose as response signal the reference signal, however in context that it is not enough to achieve an optimal estimation, in that situation it could be possible to introduce the reference signal under specific analysis according to get action over the variables "X".

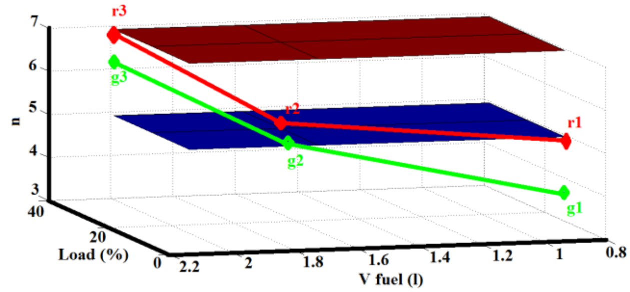

Figure 13. Schematic block diagram.

Surface above was analyzed efficiency as dependence of combustion consumed. However, even trying theoretical analysis optimal curves need many requirements and solutions. By other side, how to choose the variable to optimize, has consequence of the input selected variables. Such as for example for tests of this task "it was selected as input variable load and combustion consumed", but it can be selected another variables "around turbine" and improved its own performance like through vibration and finally it is achieved a better performance...Like enhanced by sensors based in nanostructures.

9. VENTILATOR

Ventilators are plenty used to transport fluids such as air. As dependence of its geometrical characteristics: "axis angle and blades numbers" their efficiency can change.

Efficiency is dependence of Eq. (36).

$$\eta_t = \frac{\rho \phi g}{\dot{W}} \quad (36)$$

Because of the process matrix "X" is composed by the "Power" and flow "ϕ", and the efficiency "η" as reference variable, therefore the optimal estimated efficiency is given by Eq. (37)

$$\hat{\eta} = X(X^T X)^{-1} X^T \eta \quad (37)$$

Nevertheless, by the polynomial model proposed in this research, it can be possible to compare both model as requirements are needed. The airflow is measured by a flow sensor based in nanostructure of AAO, the differential pressure is correlated with flow signal from a sensor calibration. The fast response from the airflow sensor transduces the signal to an electrical equivalent, the robust transduction is achieved because of the electrical resistance as equivalent, this parameter is obtained as a consequence of electromagnetic effect in the airflow sensor designed.

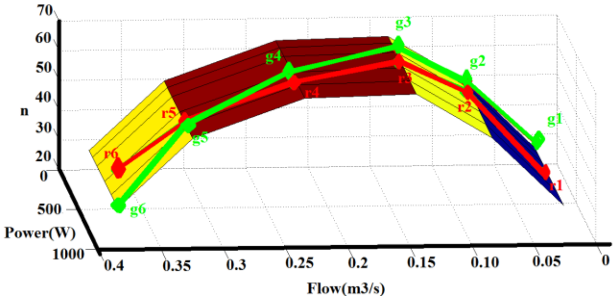

Figure 14. Refrigeration analysis.

10. LOSSES IN PIPES, HOSES AND FITTINGS

When fluids cross inside pipes, it is lost energy as pressure changes in the flow, that can be explained because of friction. The mathematical explanation can be given through generalization of "Bernoulli equations" [2] as a consequence of analysis from equations 1 and 2.

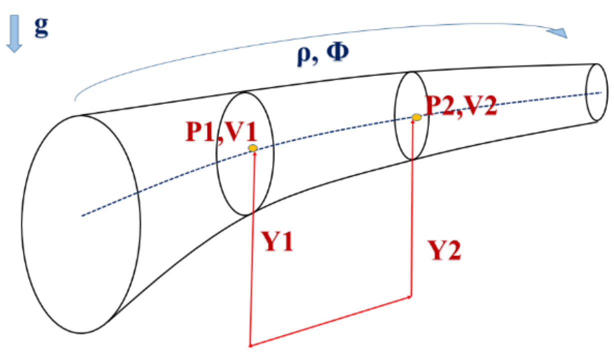

Figure 15. Fluid scheme inside a pipe.

By Eq. (38) it is represented "Bernoulli" model, in that "P_1 and P_2" are the pressure over stages "1 and 2", "g" is the gravity accelerate, "Z" is the level change, "ρ" is the density of the flow, "V_1 and V_2" is the flow around the stages "1 and 2".

$$P_1 + \rho g Y_1 + \frac{1}{2}\rho V_1^2 = P_2 + \rho + \rho g Y_2 + \frac{1}{2}\rho V_2^2 \qquad (38)$$

Therefore losses because of pressure is given by Eq. (39).

$$\Delta P_{2-3} = \left[\xi\left(\frac{L_1 + L_2 + L_3}{D}\right) + 2K\right]\frac{8\rho\dot{V}}{\pi^2 D^4} \qquad (39)$$

Because of the process matrix "X" is composed by the "RPM" and flow "ϕ", and the discharge coefficient "C_d" as reference variable, therefore the optimal estimated discharge coefficient is given by Eq. (40)

$$\hat{C}_d = X(X^T X)^{-1} X^T C_d \qquad (40)$$

In which, the flow f as part of the process matrix variable is measured by a sensor prototype based in nanostructures

of which, the flow f as part of the process matrix variable is measured by a sensor prototype based in nanostructures of AAO, that obtained correlation with the pressure differential of the fluid analyzed by equation 39. This measurement was obtained from surface area along 2 places of the pipe trajectory of the fluid. The nanostructures let to obtain a faster answer of the flow and robust measurement. Nevertheless, by equation 39 and equation 40 there were obtained optimal parameters to get the optimal geometric characteristics of pipes or the optimal pressure losses.

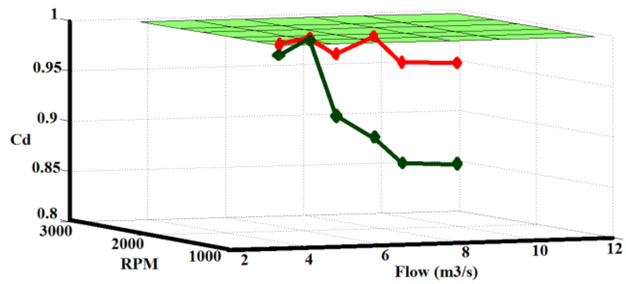

Figure 16. Optimization of pipes losses.

11. CONCLUSIONS

It was accomplished, in this research, a procedure to enhance the optimization of the efficiency for thermodynamic processes. The procedure is based through the correlation between mathematical models, theoretical models and users requirements, which was evaluated by norms and standards.
Furthermore, it was achieved enhancement in the performance of the optimization studied over the thermodynamic processes described in this research, due to new sensors based in nanostructures as part of the main optimization algorithm. The effect was given owing to the sensors designed proportionate faster response and robustness adjusted to requirements of the system, by coefficients that connect their geometrical and material characteristics over the mathematical model of the thermodynamic process.

12. FUTURE WORK

As it was proposed in paragraphs above, it is suggested to extend this research by "control tasks experiments" according to evaluate the applications of the performance achieved through the optimal/adaptive/predictive models in thermodynamic processes. Moreover, it is expected to enhance better more the efficiency by the applications of controlled techniques of vibrations that are disturbances for the operational work, this enhancement can be achieved by "Active Magnetic Bearing" (AMB) over the main connector of the source of movement transmitter: "Its shaft", with the rotating machine needed to get changes in states of the thermal process.

13. ACKNOWLEDGMENT

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It is dedicated special gratitude to Hugo Medina because of his teachings in "Science Physics" for many generations of engineers, he did and makes that "Physics laws" could be so easy necessities to get understanding of nature and current life, such as for this research, with a very good base of nature laws, it was possible to obtain a fundamental to correlate advanced mathematics for the formalism that engineering applications always need.

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