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Digital Twin for Pilot Plant for Water Treatment

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Abstract

The aim of the research project is to create a system that integrates live and virtual simulation in order to improve the efficiency and safety of heat exchangers and pipes within chemical industries thanks to an innovative biofilm and Limestone incrustations removal system. The solution presented has the purpose of solubilizing limescale and encrustations thanks to an integrated system that constantly monitors some system parameters and, thanks to the simulation, is able to adapt to the variations with fine-tuning machine learning algorithms in order to always operate optimally.

Keywords: Digital Twin, Water treatment, Piping , Limescale, Simulation

1. Introduction

To date, the industry uses large quantities of water for various processes. Due to the inadequacy or obsolete components of the systems, waste is numerous. Furthermore, the water naturally tends to form limestone and biofouling encrustations which amplify such waste also in terms of energy consumed due to an increase in the input power of the water due to the reduction of the diameters of the pipes. Limescale and biofouling in pipes are a crucial problem in industrial plants due to the reduction in flow efficiency. Due to these deposits, the useful section in the pipes is reduced with a consequent decrease in the flow rate (Andristos et al., 1997, Muryanto et al., 2014).

These problems generate high maintenance costs of the machinery and obviously a decrease in productivity and an increase in downtime during which faults must be solved or the systems must be cleaned of encrustations. For these reasons, it is necessary to find a method that is in able to permanently eliminate limescale and biofilm. The paper presents an innovative method of eliminating these components thanks to a mixture of inert gases of food purity.

This gas mixture obviously must find the right concentration in relation to the degree of Biofilm that occurs inside the pipe, the pressure and the flow, in order to release the optimum quantity of gas. The paper propose a digital twin capable of integrating the data deriving from the field with the virtual simulation in a feedback network that is able to optimize the input parameters thanks to the fine tuning of machine learning techniques.

The modern techniques of Modeling and Simulation, together with the new discipline called Strategic Engineering, will give the possibility to create simulation models to help future systems to reduce MTBF (mean time between failures) and to support their management and their service.

Figure 1, Digital Twin of the Pilot Plant including Virtual Human

Digital twins can obviously be scalable and interoperable in different contexts and on different platforms (Boxall & Saul, 2005; Bruzzone et al., 2012 & 2017; Augustine, 2020; Wei et al., 2022).

In fact, strategic engineering is based on the use of Artificial Intelligence, Data Analytics, Modeling & Simulation in closed loop with the data deriving from the field in order to optimize the processes studied.

2. State of the Art

The formation of limestone inside heat exchangers and pipes in plants leads over the years to a significant increase in capital and maintenance costs. Limestone is a solid deposit of salts (the major is Calcium and Magnesium) dissolved in water. In addition it is important to consider another important aspect on pipes and heat exchangers surfaces which is biofouling, biological deposits of microbes and extracellular products (Mattila-Sandholm & Wirtanen, 2009).

There are many different water treatments against Limestone and Biofilm, but in most of the cases they can be divided in two types: Chemical and Physical treatments. The most used physical treatment are filtration and softening. The first technique uses a membrane to capture the lime deposits while softening uses ion resins that blocks calcium and magnesium. Chemical treatment use chemical additives to reduce water hardness.

Anyway, all of these techniques do not eliminate all the deposits of limestone and Biofilm, and in most of the cases they reduce the value of the pH, increasing the corrosivity. There is also a new method that shows good against Limestone and Legionella that uses a mixture of inert gases of food purity (Bruzzone et al., 2021).

In order to improve this innovative technique the proposed paper focuses on the implementation of a digital twin integrated with a real pilot plant in order to optimize the injection of this gas through the use of Simulation and machine learning.

In facts, digital twins provides high fidelity models of real systems and they are used in many fields, also to support and simulate processes in industry (Bruzzone et al., 2012, 2019 & 2020); in figure 1 it is proposed the Digital Twin created for this application and dynamically integrated with data as well as with the real pilot plants.

3. Conceptual Model

The aim of the project is to develop a system that, thanks to simulation and machine learning integrated with the data deriving from the field, is able to optimize the concentration of an inert gas of food purity capable of solubilizing limestone and biofilm. The system operates on two simulations: the first is a live simulation capable of reproducing the consumption and problems of a given system through a pilot circuit.

The second one is a virtual simulation through the use of a digital twin that faithfully reproduces what happens in reality.

Through this last simulation it is possible to experiment with different configurations, analyze more data and test models quickly, create different scenarios and test the actual consequences of the actions taken to mitigate the problem of encrustations and biofouling on the virtual environment.

Through simulation it is possible to take real data and verify and validate the chosen models. An attempt was therefore made to integrate these two methods to exploit the benefits of both.

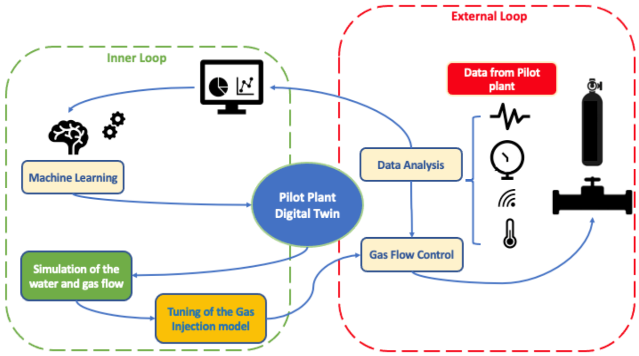

Figure 2, General Architecture

The whole system is simulated by an hybrid stochastic simulator that consider the performance of each elements based on uptodate sensor data collection.

First of all we develop a pilot plant circuit in order to simulate the water consumption of a system, with 200 people with a pro capite consumption of 200 liters of water per day. Then we created the digital twin of the circuit. The DT reproduces the system through nodes and arcs. Each node corresponds to the input of water or gas, boilers and tanks, while the arcs represent the pipes. The generator fluid dynamics model is schematized through Bernoulli equations and the control of the number of Raynolds generated in an arc according to the parameters set.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \sum L$$

$$L_f = f \frac{L}{D_H} \frac{v^2}{2g}$$

$$\Delta P_k = f \frac{L}{D} \frac{\rho V_{ort}^2}{2}$$

$$Re = \frac{VD\rho}{\mu}$$

Re = Reynolds number

V = fluid speed

μ = dynamic viscosity

ρ = density

D = diameter

Z= height

P= pressure

f= friction factor

$\sum L$=pressure loss

L= pipe length

In addition, we have different monitoring sensors, two pressure sensors, two flow rate sensors, temperature sensors, conductivity sensors and a Biofilm sensor.

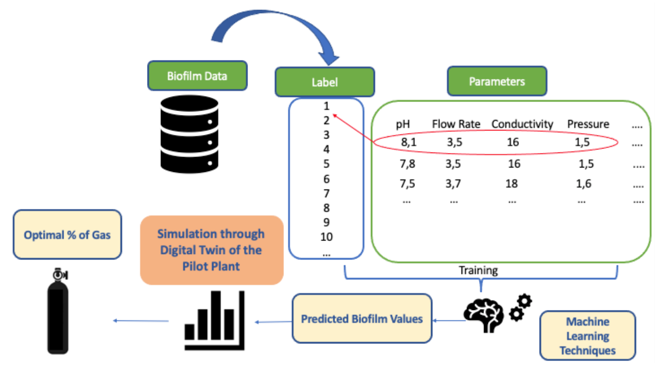

Figure 3, Internal Loop

The system is based on two nested regulation loops, one more internal and one more external. The external one takes the optimum gas percentage data obtained by the internal loop and through the gas cylinder pressure, water pressure and water flow data it adjusts the gas leakage based on the fluctuations of these values in order to keep the percentage of injected gas constant.

The internal loop, on the other hand, is based on past and present data of pressure, flow, water temperature, water conductivity, biofilm level, through machine learning techniques finds the optimal percentage of gas to minimize the biofilm value. The output of machine learning systems becomes the input for new simulations in the digital twin in order to find the best percentage of gas injection.

4. Implementation

The system is based on two loops based on live simulation and virtual simulation which collaborate with each other through data exchange and analysis in order to obtain an optimal gas release value to solubilize the limestone.

The implementation was carried out in C# integrating the code for intelligent data analytics in Python within a 3D virtual framewor able to operate on multiple platforms (e.g. laptop, smartphones, cave) based on M2SG paradigm (Modeling, interoperable Simulation and Serious Games) that further extend the intuitiveness as well as the usability of the simulation models.

.First of all, a scale pilot circuit was built for the external loop through which it is possible to first collect the data through the sensors and then test the models chosen for verification and validation.

The external loop uses a plc (programmable logic controller) which, through a circuit of feedback sensors (water pressure, gas pressure and water flow rate), is able to keep gas leaking from the cylinder constant by adjusting its scope.

The purpose of the internal loop, on the other hand, is to provide an optimal percentage value of gas that is able to minimize the value of the biofilm. The biofilm sensor measures the conductivity of the bacterial patina that forms on it as a result of the deposit upon the passage of water.

Obviously being a biological process, it takes many hours to stabilize. For this reason we proceeded with a data collection in different experimental conditions, varying pressure, temperature, flow, pH and percentage of gas introduced to verify the variations in amplitude over time of the biofilm curve.

In this phase of the project, the data collection was completed and various machine learning algorithms are being implemented, capable of capturing the behavior of the biofilm as the other parameters vary in order to understand and predict the variation and adjust the percentage accordingly. of gas. The first step is related to data analysis in order to process data filtering, eliminate noise or outliers, etc. At this point, we have divided the biofilm values into different classes according to the expert opinion since the modifications of some units are irrelevant. at this point, thanks to machine learning, we can build a model that shows us, thanks to the historical series and the constant injection of data from the field, in which class the value of the biofilm will fall in a certain period of time. The data obtained are thus inserted into the digital twin of the pilot various combinations of gas percentage through a Monte Carlo simulation in order to obtain the optimal gas release mechanism. The whole process of the internal cycle is explained in Fig. 2.

5. Conclusions

This paper proposes the creation o a digital twin during the experimentation on a Pilot Plant and to adopt MS2G paradigm as well as the innovative approach based on Strategic Engineering in order to guarantee solubilization of limestone and biofilm. The use of a mixture of inert gases that showed vary promising performances against bacterial populations and limestone in pipes, is optimized through the use of Simulation and machine learning in order to tuning the injection of gas respect to the data collected from the field. Limescale deposits as well as biofouling and bacterial population like Legionella, represent a big problem for water pipes and heat exchangers in many fields, from industry to ship, reducing their functioning and increasing the cost. The approach proposed in this paper is under development by the authors that are currently fitting the models on past data in order to fine tune the whole process.

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