ABSTRACT
In-line mixing problems affected by controlled variables such as conductivity, pH, viscosity, composition and density, are appropriate candidates to be solved using Computed Multi-Variable (CMV) control techniques. For this type of linear control problems, the aim is to compute the proportions of input product flow rates yielding a final product, thus satisfying as much physical properties as manipulated input flow rates exists. Linear model based approximation implemented on the basis of computational tools associated to the proposed control strategies (FCC and EFC), conforms the core of the contribution.

KEYWORDS: In-line mixing, Computed variable control, Functional approximation, Feedforward neural networks, Conjugate gradient algorithm

1. INTRODUCTION
One interesting extension of conventional control was the idea of controlling the variables that are of real interest by computing its values from other measurements (Luyben William L. 1990). Traditionally, some mixing problems were solved successfully by means of conventional computational methods and means. With the help of modern computational methods, much more complex types of computed variables can now be calculated. Several variables of a process can be measured and all the other variables can be calculated from a rigorous model of the process or from virtual sensors based on soft-computing techniques. For instance, the nearness of flooding in distillation columns can be calculated from heat input, feed flow rate, and temperature and pressure data. Another application is the calculation of product purities in a distillation column from measurements of several tray temperatures and flow rates by the use of mass and energy balances, physical property data, and vapour-liquid equilibrium information. The use of available and sophisticated computational methods made these rigorous estimators feasible. It opens up a number of interesting possibilities in the control field, without limitations in applying such powerful methods even with the scarcity of engineers who understand both control and chemical engineering processes well enough to apply them effectively.

A typical class of mixing problems involve linear models, such the problem of thermal mixing, where the problem is to control the temperature of an output flow from a tank by proportioning the input flow into the tank, or the problem of concentration mixing where two fluids of different concentrations are mixed to produce a desired concentration by varying the input flow rate [1]. In both cases, the material-balance and energy-balance equations are the basis of process modelling.

Some other mixing problems are not linear such those problems involving temperature, pressure, viscosity, conductivity, pH [2] composition, etc. For instance, the liquids used in hydraulic systems generally exhibit large changes in viscosity with relatively small changes in temperature.

1.1. Continuous Mixing Control Problem
Since agitated vessels are expensive, simple devices such as in-line mixers are often considered for composition control systems. Properly applied, these devices are effective, but careful attention to the following design criteria is required: reagent delivery hysteresis, loop gain, and neutralization stage interaction [3]. An in-line mixer can be a dynamic mixer such as a centrifugal pump or a baffled section of pipe called a static mixer as shown in figure 1. The static mixer provides radial mixing but little backmixing. It can be considered to be a plug flow
process dominated by dead time. Disturbances and noise pass through the mixer unattenuated. With such a mixer, the best controller response to fast disturbance and noise is no response at all, because any corrective action will arrive too late and will create yet another disturbance. The advantages of in-line mixers are its small dead time, loop period, and recovery time. Conventionally, control structures based in the combination of feedback, feedforwarded, cascade and ratio control are used.

\[ D = \frac{L \cdot A}{q} \]  

so that, the inherent time lag is \( e^{DS} \)

This work describes proposed control strategies for a continuous in-line mixer/reactor designed to optimise the fast chemical reactions required in many of today’s chemical processes. It allows development and manufacture of nanomaterials in a process controlled to the molecular level of mixing. In most conventional chemical reactors, inadequate mixing and mass-transfer rates limit the value and performance of a fast chemical reaction. As a result, product yields are low, and unwanted by-products are produced.

Two main reasons are the aim of this analysis: Avoid the effect of time lags on feedback control, which suppose an important disturbance on mixing control loop, and simplify mentioned conventional control structures. In order to achieve such topics, model based computing variable control methods are proposed. Two open loop control strategies are presented:

Computed variable Feedforward-Cascade Control (FCC).- Consists in compute the manipulated variables as function of the desired controlled variables and input process variables.

Computed variable Estimated feedback Control (EFC).- Consists in compute the process variables as function of manipulated variables and process characteristics.

2. COMPUTED VARIABLE FCC
In order to show the control strategy based in the computed variable feedforward-cascade method, a process consisting in mixing a fluid at different flows and temperatures to achieve a desired temperature and flow as process variable output is described. The basic and necessary equipment to implement an in-line mixer is shown in figure 2.

The following notation is used in the process of figure 2:

- \( Q_e \) = Energy flow rate in the output
- \( q \) = mass flow rate in the output measured by the sensor FT3
- \( T \) = temperature in the output measured by TT3
- \( C_e \) = specific heat of the fluid
- \( T_1 \) = temperature at the input pipe of fluid 1 measured by sensor TT1
- \( T_2 \) = temperature at the input pipe of fluid 2 measured by sensor TT2
- \( q_1 \) = mass flow rate of fluid 1 measured by FT1
- \( q_2 \) = mass flow rate of fluid 1 measured by FT2

![Diagram](image)

Fig. 2. In-line mixer and control equipment

### 2.1. Process modelling

**Energy balance:**

\[
q_1 C_e T_1 + q_2 C_e T_2 = (q_1 + q_2) C_e T
\]

**Material balance:**

\[
q = q_1 + q_2
\]

The aim in computed variable FCC, is to compute the manipulated variables as function of the desired controlled variables. So that, starting from process model (4) and (5) a matrix based model is achieved as

\[
\begin{bmatrix}
q_1 \\
q_2
\end{bmatrix}
= \begin{bmatrix}
T_1 & T_2 \\
1 & 1
\end{bmatrix}
= qT
\]

(4)

from which, the manipulated variables are computed yielding

\[
\begin{bmatrix}
q_{1(SP)} \\
q_{2(SP)}
\end{bmatrix}
= \begin{bmatrix}
T_1 & T_2 \\
1 & 1
\end{bmatrix}^{-1}
\begin{bmatrix}
qT \\
q
\end{bmatrix}
\]

(5)

where \( q_{1(SP)} \) and \( q_{2(SP)} \) are the setpoint or desired values of manipulated variables. Such open loop strategy is shown in figure 3.
3. COMPUTED VARIABLE EFC.

The aim of computed variable EFC, is to compute the process variables as function of manipulated variables and its characteristics. Starting from eq. (6) yields

\[
\begin{bmatrix}
q_{1(\text{SP})} \\
q_{2(\text{SP})}
\end{bmatrix} = \begin{bmatrix}
T_1 & T_2 \\
1 & 1
\end{bmatrix}^{-1} \begin{bmatrix}
q_D \\
T_D
\end{bmatrix}
\]

where \( q_{\text{EST}} \) and \( T_{\text{EST}} \) are the estimated process variables. The control structure is shown in figure 4.

\[
\begin{bmatrix}
q_{\text{EST}} & T_{\text{EST}} \\
T_{\text{EST}}
\end{bmatrix} = \begin{bmatrix}
T_1 & T_2 \\
1 & 1
\end{bmatrix} \begin{bmatrix}
q_1 \\
q_2
\end{bmatrix}
\]

(6)

Fig. 4. Strategy for computed variable EFC of an in-line mixer.
4. APPLICATION ON AN IN-LINE MIXER

This application deals with the task of supplying the necessary fuel oil (F.O) to a Diesel engine to get the required power in terms of engine speed (rps). In order to supply a demanded fuel flow rate at a required temperature, two fuel lines at different temperatures and flows provide the required amount of fuel at the proper temperature by means of an in-line mixer controlled on the basis of proposed control strategies. So that, Eq. (5) and (6) solves the problem of mixing control, which is represented in figure 5. This figure shows the structure of a feedback control loop where the forward loop supports the in-line mixer controller, based on the two alternative algorithms: the FCC and the EFC strategies.

4.1. Structure of the engine speed controller

The operating curves for an engine indicate that the output shaft speed $\omega$ is a nonlinear function of both the fuel flow rate $Q$ and the load torque $T_{\text{load}}$. Nevertheless, the fuel flow rate demand $Q_D$, is determined by the required engine speed using a PID control loop, where the in-line mixer control module is embedded in series with the PID feedback controller. Thus, the block diagram of the engine speed control loop is shown in figure 5. The forward path contains the in-line mixer FCC or EFC controller.

![Fig. 5. Engine speed feedback control associated to a nonlinear multivariable feedforward-cascade controller: the in-line mixer controller.]

4.2. In-line mixer simulation

In order to inspect the performance of the proposed control strategies on the In-line mixer, that means, given the known variable values $Q_D$, $T_D$, $T_1$, $T_2$, achieve $q_1$ and $q_2$ by applying FCC and EFC strategies, a simulation block diagram has been constructed which is shown in figure 5.

5. CONCLUDING REMARKS

In this work, some contributions to improve the procedures to solve linear in-line mixing problems have been presented. These contributions are based on two computed multi-variable control strategies:

- Computed multi-variable control using the developed FCC strategy
- Computed multi-variable control using the developed EFC strategy

In both cases, linear solutions were presented.

With regard to results, the value of viscosity achieved by the In-line mixer, is into the range of acceptable expected results, and some other simulation results not shown in this work, are into acceptable limits. Extensive simulation tests on EFC strategy yields the same results as FCC, which is shown.

With regard to performance, rapid response, precision, robustness under changes (disturbances) of input variables, are the main topics.
It can be pointed out as an important advantage that for the sake of the lack of a conventional mixing tank, and the lack of feedback measuring devices due to proposed strategies, minimum time delay on the mixing process control is achieved.

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7. REFERENCES