Data reconciliation and optimal management of hydrogen networks of a petrol refinery

D. Sarabia*, S. Cristea*, E. Gómez*, G. Gutierrez*, C.A. Méndez, J.M. Sola***, C. de Prada***

**University of Valladolid, c/ Real de Burgos s/n, 47011 Valladolid, Spain (Tel: 34-983184647; e-mail: dsarabia@autom.uva.es).*
*** INTEC (UNL-CONICET), Güemes 3450, 3000 Santa Fe,Argentina (e-mail: cmendez@intec.unl.edu.ar)*
**** PETRONOR, Edificio Muñatones, San Martin, 5, 48550 Muskiz, Spain (e-mail: jmsola@repsol.com).*

Abstract: This paper describes the main problems associated to the management of hydrogen networks in petrol refineries and presents an approach to deal with them with the aim of operating the installation in the most profitable way. In particular, the problems of data reconciliation, economic optimization and interaction with the underlying basic control structure are reviewed. The paper provides also a proposal for the implementation of the system and illustrates the approach with results obtained using real data from an industrial site.

Keywords: Hydrogen networks, Process optimization, Data reconciliation, Control of networks.

1. INTRODUCTION

Hydrogen has become one of the main products in petrol refineries due to several factors, among them the new legislation about the reduction in the polluting compounds content (sulphur, nitrogen, aromatics, etc.), the need to convert heavy into light products to improve the economic balance of the refineries, and the installation of platformer plants, with the purpose of increasing the octane degree of the gasoline, as an alternative path to the use of lead compounds, operations that involve the use of large amounts of hydrogen.

As a result, hydrogen management plays a key role in the production of the different commercial oil fractions. Three different types of units are involved in a typical plant: dedicated hydrogen production units, hydrogen consuming units, and production units where hydrogen is the by-product of another process. All these kinds of units are interconnected through a hydrogen pipeline network.

Hydrogen is quite often produced on site from hydrocarbons in reformer ovens Control of these units, its temperature in particular, is not easy and MPC is frequently used to direct its operation. Demands of H_2 from the consumers change from time to time and constitute at the same time, a disturbance to reject with respect to the H_2 purity and a target to follow with regards to the mass flow. Adaptation to these demands plays an important role in order to operate with minimum losses while satisfying the orders from other units. The hydrogen production is fed at a given pressure and purity to the hydrogen pipeline network for distribution.

Most of the consumer plants have as a goal the desulphurization of different oil fractions and are named with the acronym HDS. They receive a mixture of hydrocarbons which react with H_2 at the appropriate temperatures and with the adequate catalysers in the HDS reactors. In order to secure the life of the catalysers, a given excess ratio hydrogen / hydrocarbons must be kept on the reactors. The surplus hydrogen from the reactors is separated and partially recycled, the excess being sent to the fuel-gas network. In the recovery of H_2, flash units can be employed as well as special membranes, which are used to separate high-purity H_2 from other gases.

The operation of the HDS is quite complex and its is affected by different disturbances, in particular the supply of hydrocarbons that may change in quantity as well as in composition according to the type of crude being processed and the global production aims. Important operating constraints are linked to the hydrogen / hydrocarbon ratio and to the operation of the compressors that maintain the hydrogen flows and inject it from the H_2 distribution network. This one should be able to provide the required amounts requested by the changing operation of the HDS along time.

There are a final set of plants, mainly platformers, which increase the octane index of the gasoline (catalytic reforming process) and generate hydrogen as result of these reactions. These plants generate a positive net flow of low purity hydrogen (between 75 % and 85 %) as a by-product, which is incorporated to the hydrogen pipeline network for use in other plants. Being a secondary product, there is no direct control of the H_2 production, so that it can be considered as a disturbance in flow and purity from the point of view of the network conditions.

All these types of plants are interconnected by several kilometres diverse pipes forming a distribution network with different purities, capacities and operating at several pressures. Fig. 1 displays the structure of one of such networks with three main hydrogen collectors, high purity manifold (C-H4), medium purity manifold (C-H3) and low purity manifold (C-BP). The boxes represent the different types of production (H3 and H4), consumer and net production units (P1 and P2). Production and net production units dump hydrogen to the collectors (C-H4, C-H3, C-P1N1 and C-P2N2), while the HDS are fed from the different sources according to the choice of the operators.

In the picture we can see also the outputs from the plants to fuel-gas network, where the excess hydrogen is sent to be consumed in furnaces. Part of this flow also comes from the pressure controllers of the collectors (i.e. from manifold C-BP on the left). In order to guarantee that enough hydrogen is available to the consumer units when need it, a surplus of it must be maintained in the collectors, the excess being released by the pressure controllers to the fuel-gas network.

Hydrogen networks have received attention in the literature from the point of view of its (re)design, but very few from the one of real-time operation and, as far as we know, no commercial software is available in the sector for this purpose. The most used method of analysis is the so-called hydrogen pinch to evaluate the scope for hydrogen savings, Alves (1999). On the other hand, Hallale and Liu (2001) developed an improved methodology for hydrogen network retrofit that considers pressure constraints as well as the existing compressors.

To improve the day-to-day operation of the whole hydrogen supply network, this paper presents an integrated optimization based framework to optimize the distribution of the available hydrogen from producers to consumer facilities, so as to take advantage of low purity hydrogen supplies by combining streams of different purity levels and flows and, at the same time, ensuring operational restrictions. This work is carried out within an industrial project in close collaboration with Petronor, an oil refining company belonging to the Repsol-YPF Group, Spain. The major aim of the project is to provide an effective and integrated decision support system for on-line, open-loop optimization and data reconciliation. The proposed optimization tool has been validated with real-world data provided by the Petronor refinery.

The paper is organized as follows: after the introduction, the main problems of the hydrogen network operation and a proposal for a decision support system (DSS) are described in section two. The formulation of the hydrogen network model is given in section three, then, data reconciliation and hydrogen optimal management problems are described in sections four and five respectively while results obtained using plant data are presented in section 6. The paper ends with some conclusions and a short bibliography.

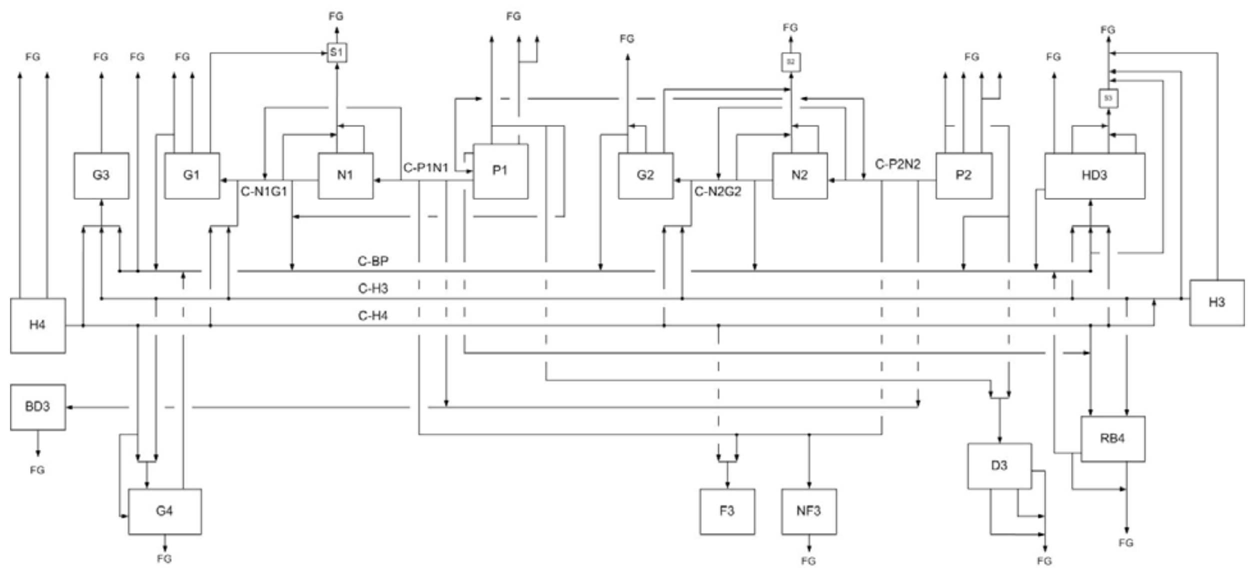

Fig. 1. A typical hydrogen network of a petrol refinery.

2. THE HYDROGEN NETWORK

2.1 Operational problems

Being a product heavily used and expensive to produce, optimizing the use of hydrogen is a clear target in any refinery. The problem can be formulated as of balancing the hydrogen that is being produced and consumed in the refinery and distribute it through the existing pipeline network in such a way that an economic target is optimized, while satisfying a set of operational constraints. Many aims appear as possible targets for the problem. For instance, minimizing the production of H_2, maximizing the use of lower cost hydrogen, minimizing the flow of H_2 to the fuel gas network, maximizing the use of low purity H_2, etc. the choice of one of them or a suitable combination being dependent of the particular situation of the refinery.

Several problems are related to the hydrogen management and optimization that are worth to mention, among them, the lack of reliable information about many streams and compositions and the large scale of the system that creates additional difficulties.

Regarding the first one, it is clear that reliable information of the network is required if we wish to perform optimal decisions. Part of the uncertainty comes from the measurement system, but mainly from unmeasured variables and from partial measurements. In particular, gas flows, which are the main variables of the process, are measured usually in terms of volumetric flows that require compensation in order to be converted to mass or normalized flows required for the models, based on mass balances. This compensation involves pressure, temperature and molecular weight of the streams. Nevertheless, the last one are quite often non available, partly because of the price and reliability of the instruments measuring hydrogen purity and partly because the purity of the flows do not reflect directly its composition. With other gases this would not be a problem, but hydrogen has a molecular weight of only two, so that a small change in the composition of the (unmeasured) impurities, for instance from methane to propane, can have a significant impact on the molecular weight of the stream and hence on its mass flow.

Consequently, improving the information about the hydrogen network implies then the need of a data reconciliation system able to correct the readings of the process transmitters and estimate the unknown variables Cronkwright (2007).

Regarding the large scale of the system, it imposes computational barriers for a global solution of the problem. Firstly, because the size of the problem, but also for the wide range of time scales involved. The problem is dynamic in nature, being one of its aspects the need to adapt the rhythm of production of hydrogen to its consumption in order to minimize losses to the fuel-gas network. It operates with the changes in global production at the time scale of hours-days, changes in the operation of the producer and consumer units at the time scale of minutes-hours and the fast dynamics of the pressures and gas flows in the order of seconds. Trying to find solutions involving all these elements at the same time would be unrealistic, but the division in time scales allows separating the decision problems in different layers, facilitating in this way the solution as a set of linked sub-problems. The separation can be considered also from a functional point of view: producer and consumer units can perform local optimizations of its functioning provided that they have predictions of its future loads, while the optimal distribution of these loads must be performed in the network, which operates with a much faster dynamics and can be considered static in relation to the slower producer and consumer units.

Finally, notice that the implementation of optimally computed targets for the units and the distribution network will require a control layer that takes into account its dynamics and associated constraints. Alternatively, a decision support system (DSS) could give recommendations to the operators of the control room about these targets, being them the ones in charge of the implementation using the existing plant controllers.

2.2 Proposed architecture

In view of the above mentioned problems, the following supervisory architecture, depicted in Fig. 2, is proposed. It consists of four stages: the first one, corresponding to data reconciliation, allows fitting periodically the network and units models to the state of the plant. The second stage uses simplified models of the consumer units to compute the future profile of the hydrogen consumption at the unit hydrogen entrance, required to treat the future loads. This profile can be locally optimized or taken as the one corresponding to the current operating policy. The third stage considers the whole distribution network and, using a model of it, computes the optimal production profile of each production unit as well as the optimal distribution that satisfies the consumer units needs. Notice that, formulated in this way this problem can be considered as a series of constraint programming problems. Finally, the last stage is performed either by local MPC controllers (model predictive controllers) that implement the required distribution of flows, or as a DSS that gives the recommendations to the operators.

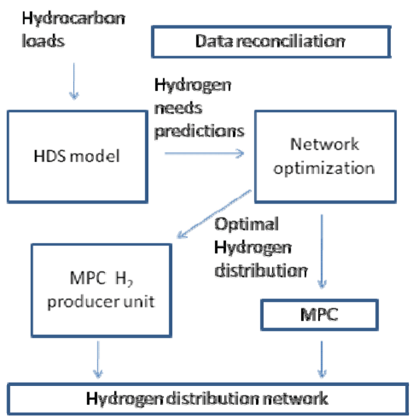

Fig. 2. A schematic of the proposed control and optimization system, with only one producer and one consumer unit.

In this paper, the reconciliation and optimization problems corresponding to the third stage are described assuming constant demands from the consumer units.

3. THE NLP MATHEMATICAL MODEL

All nodes in the complete hydrogen network are modelled by mass balances in terms of purity, flow and molecular weight for every stream, considering also a mixture of ideal gases. For example, a node consisting in one input stream F_1 and two output streams F_2 and F_3 with hydrogen purities X_1, X_2 and X_3 and molecular weights MW_1, MW_2 and MW_3 respectively is described by,

$$\begin{aligned} F_1 &= F_2 + F_3 \\ F_1 X_1 &= F_2 X_2 + F_3 X_3 \\ F_1 MW_1 &= F_2 MW_2 + F_3 MW_3 \end{aligned} \tag{1}$$

On the other hand, the molecular weight of every stream is calculated from the hydrogen purity X, hydrogen molecular weight and molecular weights of all impurities MW^{imp} according to:

$$MW_i = (2X_i + MW_i^{imp}(100 - X_i))/100 \qquad i = 1,2,3 \tag{2}$$

Volumetric flows F_i (Nm^3/h) in (1) are measured at standard temperature (0ºC) and pressure (1 Atm) conditions and purities are measured in percentage of volume.

In the particular industrial case considered, the nonlinear model consists of 142 equations like (1) and (2) and 263 variables, 137 of them are flows, 42 are purities, 42 are molecular weights of the streams and 42 are molecular weights of impurities of every stream. From a mathematical point of view it is necessary to define 121 boundary variables and the remaining 142 are considered explicit variables. On the other hand, there are 138 measured data from the process, so, 121 are assigned to boundary variables and the remaining 17 are redundant (explicit variables but with a measured data available).

4. DATA RECONCILIATION PROBLEM

The data reconciliation problem can be formulated as to compute the decision variables $F_{i,dec}$, $X_{i,dec}$ and $MW_{i,dec}^{imp}$ (flows, purities and molecular weights of impurities that minimize the function J (3) given by the sum of the squares of the deviations between the (compensated) measured data ($F_{i,med}, X_{i,med}, F_{i,med}^{red}, X_{i,med}^{red}$) and the calculated variables ($F_{i,dec}, X_{i,dec}, F_{i,exp}^{red}, X_{i,exp}^{red}$), while satisfying the nonlinear model (4), and the ranges on the explicit and decision variables (5), (6).

$$\begin{aligned}\min_{\{F_{i,dec}, X_{i,dec}, MW_{i,dec}^{imp}\}} J = & \sum_{i=1}^{89} \frac{w_i}{\sigma_i^2}\left(F_{i,dec}/Fc_i - F_{i,med}\right)^2 \\ & + \sum_{i=1}^{16} \frac{w_i}{\sigma_i^2}\left(X_{i,dec} - X_{i,med}\right)^2 \\ & + \sum_{i=1}^{15} \frac{w_i}{\sigma_i^2}\left(F_{i,exp}^{red}/Fc_i^{red} - F_{i,med}^{red}\right)^2 \\ & + \sum_{i=1}^{2} \frac{w_i}{\sigma_i^2}\left(X_{i,\exp}^{red} - X_{i,med}^{red}\right)^2\end{aligned} \tag{3}$$

Subject to:

$$\begin{aligned} F_{i,exp} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,33 \\ F_{i,exp}^{red} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,15 \\ X_{i,exp} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,24 \\ X_{i,exp}^{red} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,2 \\ MW_{i,exp} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,42 \\ MW_{i,\exp}^{imp} &= g(F_{j,dec}, X_{k,dec}, MW_{l,dec}^{imp}) & i &= 1,...,26 \end{aligned} \tag{4}$$

$$\begin{aligned} 0 \le F_{i,exp} &\le F_{max} & i &= 1,...,33 \\ F_{i,\min}^{red} \le F_{i,exp}^{red} &\le F_{i,\max}^{red} & i &= 1,...,15 \\ 0 \le X_{i,exp} &\le 100 & i &= 1,...,24 \\ X_{i,\min}^{red} \le X_{i,exp}^{red} &\le X_{i,\max}^{red} & i &= 1,...,2 \end{aligned} \tag{5}$$

$$\begin{aligned} F_{i,\min} \le F_{i,dec} &\le F_{i,\max} & i &= 1,...,89 \\ X_{i,med} \le X_{i,dec} &\le X_{i,med} & i &= 1,...,16 \\ MW_{i,\min}^{imp} \le MW_{i,dec}^{imp} &\le MW_{i,\max}^{imp} & i &= 1,...,16 \end{aligned} \tag{6}$$

The stationary model of the hydrogen network is represented by (4), where explicit variables $F_{i,exp}$, $X_{i,exp}$, $MW_{i,\exp}$, $MW_{i,exp}^{imp}$, $F_{i,exp}^{red}$ and $X_{i,exp}^{red}$ are calculated solving the model $g(\bullet)$ with values of the boundary variables $F_{i,dec}$, $X_{i,dec}$ and $MW_{i,dec}^{imp}$ respectively.

The lower and upper limits of the decision variables associated to flows and purities come from the range of their corresponding instruments. But the limits for molecular weights of impurities are obtained through historical data of laboratory analysis in the associated streams, because there are not measured online. Finally, all terms in the cost function (3) have been normalized by means of the variance (σ_i^2) of data measured and can also be weighted by w_i (from 0 to 1) which indicates the level of importance of the corresponding instrument. The problem is a NLP (nonlinear programming) one that consists of 121 decision variables, 142 nonlinear equations (network model), 148 nonlinear constraints (74 lower limits and 74 upper limits of explicit variables) and 121 linear inequalities (lower and upper limits of decision variables).

There is another issue associated to flow measurements which must be taken into account: Most flowmeters in the refinery are orifice plates and they provide volumetric flows at standard conditions considering a specific pressure, temperature and molecular weight of design. However, these values change during the operation, being necessary compensate the corresponding measured flow. The compensated flow is given by,

$$F_{i,compensate} = F_{i,med} Fc_i \Rightarrow F_{i,med} = F_{i,compensate} / Fc_i \tag{7}$$

where $F_{i,med}$ is the measured flow and Fc_i is the factor of compensation defined for each orifice plate,

$$Fc_i = \sqrt{\frac{T_{i,dis} + 273}{(P_{i,dis} + 1) MW_{i,dis}}} \sqrt{\frac{(P_{i,op} + 1) MW_{i,op}}{T_{i,op} + 273}} \tag{8}$$

$P_{i,dis}$, $T_{i,dis}$ and $MW_{i,dis}$ are the design values for pressure, temperature and molecular weight of the stream (in kg/cm^2, ºC and g/mol respectively) and “op” are the operating values. Then, pressures and temperatures are also measured data from the process, and the molecular weight of every stream is a variable of the model, which is calculated through the model (4) or equation (2) in the small example.

So, the compensation factor Fc_i is a function of the hydrogen purity and molecular weight of each stream and indirectly a function of molecular weight of impurities for every stream and has been included in cost function (3). In this way, the reconciliation of mass and volume is made simultaneously in a rigorous manner.

5. OPTIMAL MANAGEMENT PROBLEM

According to the policy depicted in Fig.2, the main goal in this step is to distribute the hydrogen in the network and recirculate most of the excess of hydrogen from consumer units into the low purity manifold (C-BP), minimizing the hydrogen production from units H3 and H4 and all flows to the fuel gas manifold, while satisfying predefined hydrocarbon production targets, actual topological restrictions (10) as well as the exact demand in flow and purity of the hydrogen makeup flowing from the different sources to each consumer unit. The cost function *Jc* is shown bellow and the 11 flows to be minimized are shown in Table 2.

$$\min_{\{F_{i,dec},Pu_{i,dec}\}} Jc = \sum_{i=1}^{11} w_i F_i \tag{9}$$

Subject to:

$$\begin{aligned} F_{i,exp} &= g(F_{j,dec}, X_{k,dec}) & i &= 1,...,33 \\ F^{red}_{i,exp} &= g(F_{j,dec}, X_{k,dec}) & i &= 1,...,15 \\ X_{i,exp} &= g(F_{j,dec}, X_{k,dec}) & i &= 1,...,24 \\ X^{red}_{i,exp} &= g(F_{j,dec}, X_{k,dec}) & i &= 1,...,2 \end{aligned} \tag{10}$$

$$\begin{aligned} F_{i,\min} \le F_{i,exp} &\le F_{i,max} & i &= 1,...,33 \\ F^{red}_{i,\min} \le F^{red}_{i,exp} &\le F^{red}_{i,\max} & i &= 1,...,15 \\ X_{i,\min} \le X_{i,exp} &\le X_{i.\max} & i &= 1,...,24 \\ X^{red}_{i,\min} \le X^{red}_{i,exp} &\le X^{red}_{i,\max} & i &= 1,...,2 \end{aligned} \tag{11}$$

$$\begin{aligned} F_{i,\min} \le F_{i,dec} &\le F_{i,\max} & i &= 1,...,89 \\ X_{i,\min} \le X_{i,dec} &\le X_{i,\max} & i &= 1,...,16 \end{aligned} \tag{12}$$

This problem assumes that the dynamics of the network is faster than the one of the production and consumer ones, distributing in a better way the hydrogen available in the refinery. This is possible because in several units the excess hydrogen in the reactions can be sent to fuel gas manifold or recirculated to the low purity manifold (C-BP). Moreover, medium purity manifold (C-H3), low purity manifold (C-BP), manifold from unit N1 to G1 (C-N1G1) and manifold from unit N2 to G2 (C-N2G2) can send hydrogen to fuel gas if there is an overpressure, that is, if the hydrogen in these manifolds is not consumed/used in other units. Table 1. lists the decision variables of the problem: hydrogen production flow in units H4 and H3 (H4.F and H3.F) and all flows to fuel gas manifold which we want to minimize.

Notice that the model of the hydrogen network represented in (10), and used to solve the optimal management problem only includes flows and purities. The molecular weight of every stream, and the molecular weight of impurities are considered constant because all flows measured come from the solution of reconciliation problem previously solved. Equations (11) and (12) are the lower and upper limits of all flows and purities. In many cases these upper and lower limits are equal, forcing to maintain the exact flow and purity of hydrogen makeup in each consumer unit and forcing to maintain the exact excess of hydrogen and its purity from units as the current ones, letting unmodified in this way the internal operation of the HDS. For example, in unit G2 the decision variables are the inflow from manifold C-H4 (C-H4_G2.F), the inflow from manifold C-H3 (C-H3_G2.F) and the inflow from manifold C-N2G2 (C-N2G2_G2.F), imposing the constraints on the total inflow and purity to the unit. Others decision variables are the outflow from G2 to fuel gas (G2_FG.F) and from G2 to low purity manifold (G2_C-BP.F) being their sum fixed by the operation of the unit.

6. RESULTS AND DISCUSSION

The approach presented before has been tested with sets of real operation data of the refinery. Here we present some of them in a certain normalized scale. They corresponds to the average of two hours of operation and the corresponding standard deviation of the measured variables in this period. First, the data reconciliation methodology has been applied and then, the optimal management problem has been solved with all data reconciled. In both cases, the CPU time necessary to solve the optimization problem is lower than 3 minutes in a Intel Corel Duo with 2.13 GHz. Notice that all flows presented here have been scaled between 0 and 100 Nm^3/h and the purities of H_2 are in percentage (%).

6.1 Data reconciliation

The optimization problem (3) has been solved with a set of weights w_i equal to 1 for all terms in cost function (3), that is, we suppose that all measured data has the same accuracy. Fig. 3 shows the standard deviation times between the reconciled data (the solution) and measured data. Notice that, measured flows are not compensated but the solution flows are compensated in pressure, temperature and molecular weight, so, to compare both quantities the flows have been de-compensated. The solution of NLP problem provide a coherent close balance of hydrogen in all hydrogen network, 108 reconciled measures have a difference lower than 4 sigmas. These differences can be due to a bad flowmeter calibration or other causes. In order to eliminate its effect, the data reconciliation is repeated, this time with a weight w_i equal to zero in the potentially faulty variables, and the new reconciled data are used in the following step, while an order is given to recalibrate the defective instruments.

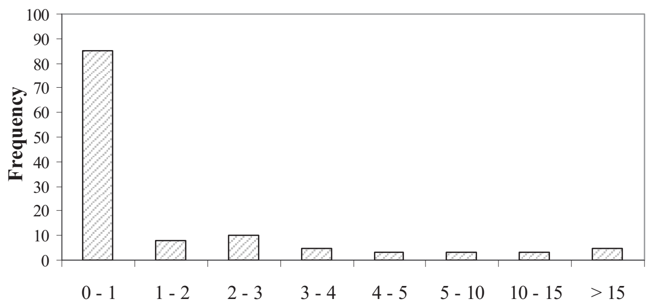

Fig. 3. Difference between reconciliated and measured data in number of standard deviations.

6.2 Optimal management of hydrogen network

The optimization problem (9) has been solved with the set of reconciled data obtained before. Results of the optimization are given in Table 1 besides their initial values(reconciled data): the cost function *Jc* and individual values of each term in this cost function. The cost function has been reduced from 100 Nm^3/h to 81.76 Nm^3/h. The optimal solution obtained reduces the total flow produced in units H4 and H3, from 73.22 Nm^3/h to 64.10 Nm^3/h and decrease the flow sent to fuel gas, from 24.98 Nm^3/h to 16.76 Nm^3/h, that is, the results show the possibility to reuse the hydrogen available in the refinery in a better way: i) without modifying the operation of each consumer unit ii) without increasing the production of hydrogen and iii) without increasing the purity of hydrogen produced. The minimum and maximum production of hydrogen allowed in unit H4 is 27.84 Nm^3/h and 62.77 Nm^3/h respectively and 15.57 Nm^3/h and 34.53 Nm^3/h for unit H3. Notice that the flow production of unit H3 (H3.F) has been reduced to the minimum production allowed, 15.57 Nm^3/h.

Table 1. Solution of the hydrogen optimal management problem

Flows (F_i)	Units	Data reconciled	Optimal solution
H4.F	Nm^3/h	50.76	48.53
H3.F	Nm^3/h	22.46	15.57
G1_FG.F	Nm^3/h	0.00	0.00
G2_FG.F	Nm^3/h	2.42	10.11
P1_FG.F	Nm^3/h	2.64	0.00
P2_FG.F	Nm^3/h	5.75	0.00
C-BP_FG.F	Nm^3/h	0.26	0.29
C-BP_FG2.F	Nm^3/h	12.72	6.36
C-N1G1_S1.F	Nm^3/h	0.08	0.00
C-N2G2_S2.F	Nm^3/h	1.72	0.89
C-H3_FG.F	Nm^3/h	1.20	0.00
Sum of all flows (*Jc*)	Nm^3/h	100.00	81.76
Economical cost (*Je*)	€/h	100.00	66.50

It is interesting to evaluate the economical cost of this solution *Je*. To do this, we are going to use the economical criteria used in the refinery. That is, the economical cost *Je* is the total hydrogen sent to fuel gas manifold times the total cost of hydrogen production minus the price of hydrogen as fuel,

$$Je = F_{H2-FG}\left(Cost_{ProductionH2} - Price_{combustibleH2}\right) \quad (13)$$

On the other hand, the total cost of hydrogen production is calculated by means,

$$Cost_{ProductionH2} = \frac{Cost_{H2inH4}H4.F + Cost_{H2inH3}H3.F}{H4.F + H3.F} \quad (14)$$

where H4.F and H3.F are the flow production in H4 and H3 respectively, the cost of hydrogen production in unit H4 is $Cost_{H2inH4}$ = 77.0€/KNm^3, in unit H3 is $Cost_{H2inH3}$ = 88.1€/KNm^3 and the price of hydrogen used as combustible in the fuel gas manifold is $Price_{combustibleH2}$=6.55 €/KNm^3. These are scaled values and they are related to pure hydrogen (100 % of purity). Table 1. shows the economical cost before hydrogen optimal management *Je* = 100.00 €/h and for the optimal solution *Je* = 66.5 €/h, so, it is possible a economical reduction of 33.5 %. Of course, this solution is not directly applicable to the refinery mainly due to the pressure constraints in hydrogen network. At present, further research is conducted to include the dynamical constraints imposed by the lower network control layer on the network optimization.

6. CONCLUSIONS

An approach has been presented to optimally manage complex hydrogen networks of refinery operations. The data reconciliation and optimal hydrogen distribution steps have been described with more detail using a NLP based optimization. The proposed method is able to systematically reduce utility cost by increasing hydrogen recovery in consumer units and reducing production cost in the alternative hydrogen suppliers. This paper is mainly focused on the treatment of hydrogen mass balances. Future work is aiming at extending the model to actual compression costs and other operational constraints as well as the use of alternative separation units (membranes) to recycle higher-purity off-gas to consumer units. In particular, including membranes in the model, convert it in a hybrid process, because membranes are formed by discrete package which can be turn on or turn off. Other improvements are related to the gross errors detection must be added to the DSS to enhance the quality and coherence of the reconciled data as well as better detect instrumentation malfunctions in the refinery.

ACKNOWLEDGMENTS

The valuable collaboration of Repsol-YPF and the Petronor refinery is gratefully acknowledged. The authors are also thankful for financial support received from project DPI2006-13593 of the Spanish CICYT and project GR. 085/2008 of JCyL.

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