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Automated targeting technique for indirect inter-plant hydrogen integration

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Abstract The increase of hydrogen demand has been one of the focal point recently. Indirect inter-plant hydrogen integration (IPHI) is a new issue for reducing hydrogen consumption and hydrogen discharge, in which hydrogen networks for different plants are integrated indirectly through centralized partitioning regeneration unit where hydrogen is regenerated for further reuse/recycle. This work is an extension of the automated targeting technique that was developed for single hydrogen network and the automated targeting that was developed for inter-plant water integration. The concentration cascade model has been developed to optimize hydrogen networks through partitioning regeneration unit such as pressure swing adsorption (PSA) or membrane separation. Two case studies from literature are studied to illustrate the applicability of the proposed model.

1. Introduction

Hydrogen management is getting essential in refineries and petrochemical complexes, since refineries face an increasing challenge of meeting the growing demand for clean fuels. Along with the legislation for environment protection higher gasoline and diesel quality specifications have been implemented to reduce pollutants from automotive exhausts. Oil refineries consume hydrogen in large amounts during the past decade to remove sulfur and nitrogen compounds and produce lighter fuel with high quality, since crude oil gets heavier and contains more sulfur and nitrogen. Thus the hydrogen supply in many refineries is becoming a critical problem [1,2]. Hydrogen resources are units that either consume or produce hydrogen. Management of these two resources leads to lower consumption of hydrogen and improves refinery profitability [3,4]. The production sources of hydrogen in refining are catalytic reformers, hydrogen plants, ethylene plants and hydrogen import. Where the most common hydrogen consumption units are hydrocracker and hydrotreaters. The hydrogen demands of hydrogen consumers vary with the changes of operational load mostly and raw material [5–7]. As the demand for hydrogen grows, the management and optimization of hydrogen system in refinery is becoming increasingly important [8]. Development process integration has been proven as a promising approach in maximizing potential resource conservation [9]. The hydrogen network integration optimizes the hydrogen network with all the hydrogen demands and hydrogen supplies. Consequently it can significantly increase the reuse of the process hydrogen and minimize the hydrogen utility consumption. The management of hydrogen network

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Nomenclature

Abbreviations

AF	annualization factor
A_{MEM}	membrane area, m^2
AWH	annual working hours
A	fractional interest rate per year
CCR	continuous catalytic reformer unit
CNHT	cracked naphtha hydrotreater unit
D	length of the cross-plant pipeline, m
DHT	diesel hydrotreater unit
$F_{cp,k}$	feed flowrate to the regenerator from network, k
$F_{FH,k}^{FIPHI}$	fresh inter-plant hydrogen integration for network, k
$F_{DH,k}^{FIPHI}$	inter-plant hydrogen discharge flowrate from network, k
$F_{i,k}^{EXP}$	flowrate exported from source i in network k to the regenerator
$F_{SKj,k}$	flowrate of sink j for network k
$F_{SRj,k}$	flowrate of source i for network k
$g_{cp,k}$	top product of the regenerator to network k
GPU	cm^3(STD) * 10^{-6}/cm^2 s cmHg
HCU	hydrocracker unit
I	is a source in hydrogen networks
IPHI	inter-plant hydrogen integration
I_{pipe}	capital cost of pipeline, US$
I_{psa}	capital cost of pressure swing adsorption, US$
$I_{regenerator}$	capital cost of regenerator, US$
ISO	isomerization unit
J	is a sink in hydrogen network
JHT	jet fuel hydrotreater unit
L	number of years
LB_{cp}	lower bound of the cross-plant pipeline flowrate
$L_{cp,k}$	bottom product of the regenerator for network k
Lg_{H_2}	permeability of hydrogen component through membrane
LP	linear programing
M	index for concentration levels
MMSCFd	million standard cubic feet per day
$N_{INDIR,k}$	binary variable indicates the existence of a cross-plant pipeline from the top product of the regenerator to all sinks of network, k.
MINLP	mixed-integer nonlinear programing
MP	mega Pascal
NLP	nonlinear programing
P	maximum pressure of the pipeline in MPa
P_n^{feed}	inlet feed pressure to the regenerator
$P_n^{product}$	top product pressure of the regenerator
PSA	pressure swing adsorption unit
SK	sink
SR	source
TAC	total annual cost measured by US$
UB_{cp}	upper bound of the cross-plant pipeline flowrate
US$	American dollar
$W_{cost,k}$	unit cost of fresh hydrogen for network, k
$X_{INDIR,k}$	binary variable indicates the existence of a cross-plant pipeline from all sources of network k to the regenerator
Y_F	inlet impurity concentration to the regenerator
$y_{H_2 in\ feed}$	hydrogen concentration in the feed of the regenerator
$y_{H_2 in\ product}$	hydrogen concentration in the top product of the regenerator
Y_i	impurity concentration of source I
Y_p	impurity concentration of the top product of the regenerator
Y_r	impurity concentration of the bottom product of the regenerator
Y_r^{min}	the minimum concentration of all sources in the participating networks when they are regenerated individually
Y_r^{max}	the maximum concentration of all sources in the participating networks when they are regenerated individually
$Z_{INDIR,k}$	binary variable indicate the existence of a cross-plant pipeline from the bottom product of the regenerator to all sinks of network k
$\delta_{m,k}$	net material flowrate from level m for network k
$\varepsilon_{m,k}$	residue of impurity load from concentration level m for network k
α_L	hydrogen recovery

involves two alternatives: reuse and regeneration [10]. For the two alternatives, many researchers focused on the optimization of hydrogen network by graphical or mathematical methods. For graphical optimization, Towler et al. [1] presented a value composite curve method to analyze the hydrogen network. Alves and Towler [2] presented the purity profiles and hydrogen surplus profiles to calculate the minimum fresh hydrogen consumption. Zhao et al. [11] proposed a simple graphical method for determining fresh hydrogen demand at any concentration. El Halwagi et al. [12] presented a rigorous graphical targeting technique to obtain the minimum fresh hydrogen utility. Agrawal and Shenoy [13] proposed a unified conceptual approach for water and hydrogen network. Zhao et al. [14] improved an iterative targeting method considering multiple impurities for hydrogen network.

For mathematical optimization, Liu and Zhang [15] introduced a detailed model of regeneration units by selecting an optimum regeneration unit. Foo et al. [16] presented an algebraic algorithmic method based on concentration intervals. Ng et al. [17,18] introduced the automated targeting technique based on pinch calculation for resource conservation problems for hydrogen reuse and hydrogen regeneration system. Lou et al. [19], presented an improved graphical targeting approach (pinch sliding approach) for water and hydrogen networks with different types of regenerator. The minimum flowrates of utility and regenerator feed are targeted by integrating the triangle rule and the optimal condition theorem. Zhou et al. [20], introduced a systematic modeling methodology for both the economic efficiency and environmental performance of hydrogen network. The economic efficiency is based on the