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Data Reconciliation and Energy Audits for PTT Gas Separation Plant No.5 (GSP5)

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Nowadays, PTT Public Company Limited has six gas separation plants (GSP). These GSPs consume both fuel gases (using hot oil as heating media) and electricity for use in the process. This work is focused on GSP5. The energy audit or monitoring program will be applied to GSP5 to monitor and report energy usage in each area of GSP5 and identifies where energy is lost from the process. However measured data from energy audit may contain random and gross errors. Technique called “Data reconciliation with gross error detection” will be applied to reduce effect of error and improve accuracy of measured data. In this project the measured data from hot oil heat exchangers network of seventeen exchangers in GSP5 are reconciled simultaneously by using mass and energy balance as constraints. Constraints from energy balance were nonlinear equation and program General Algebraic Modeling System (GAMS) was used to solve nonlinear system. Data reconciliation, Gross error detection and gross error elimination used least-squares method, Global test and Measurement test respectively. The goal of this project is to develop the energy audit program and data reconciliation with gross error detection technique to improve the performance of GSP5. Program will monitor and report the energy usage and energy loss with more accuracy to improve energy usage in the plant.

1. Introduction

These GSPs process natural gas to methane (sale gas), ethane, propane, LPG and NGL (natural gasoline) and consume both fuel gases (using hot oil as heating media) and electricity for use in the process. The energy audit or monitoring program will be applied to GSP to monitor and report energy usage in each area of GSP and identifies where energy losses come from the process.

Data received from energy audit may contain some error which may decrease plant performance and profit. Errors in the measurement which cause measured values differ to true value can be classified into two types: random and gross errors. Random errors always present in the measurement can occur by many causes such as power supply fluctuation, network transmission and signal conversion noise, changes in ambient conditions. They cannot be completely removed and always presented in any measurement although the measurement is repeated with the same instrument and conditions. The effect from this type of error can be reduced by doing data reconciliation to adjust the data to reconciled data consistent with process constraints. Gross errors are caused by non-random events such as instrument malfunctioning, miscalibration, wear or corrosion of sensor, solid deposit. If the

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measurement is repeated with the same instrument and condition the contribution of a systematic gross error to the measured value will be the same. Before doing data reconciliation, measured data need to be contain no gross errors because they will make reconciled data deviate from the true value, therefore gross error detection and elimination technique were applied to remove gross error.
The goal of this research is to use the energy audit program and data reconciliation with gross error detection technique to improve the performance of GSP 5 by using energy audit program to monitor and report the data of energy usage and energy loss. The data reconciliation with gross error detection technique will be used to eliminate the errors and receive more accurate data for using in the improvement of energy usage in the plant.

2. Methodology

2.1 Collecting data from the PPT gas separation plant no.5

This task involves the collecting of heat exchanger data sheets, process control screen monitor data and economic data.

2.2 Developing energy auditing program

This program is created by Mr. Yuti Chaloeisamia and Dr. Nitipun Nivartvong for monitoring energy usage and define energy loss in GSP5. The main units for monitoring consist of: Inlet Gas Heater Unit, Acid gas Removal Unit 1 and 2 (AGRU), Hydrocarbon Dehydration Unit, Demethanizer Unit, Deethanizer Unit, Depropanizer Unit, Ethane Treatment Unit, Waste Heat Recovery Unit (WHRU)

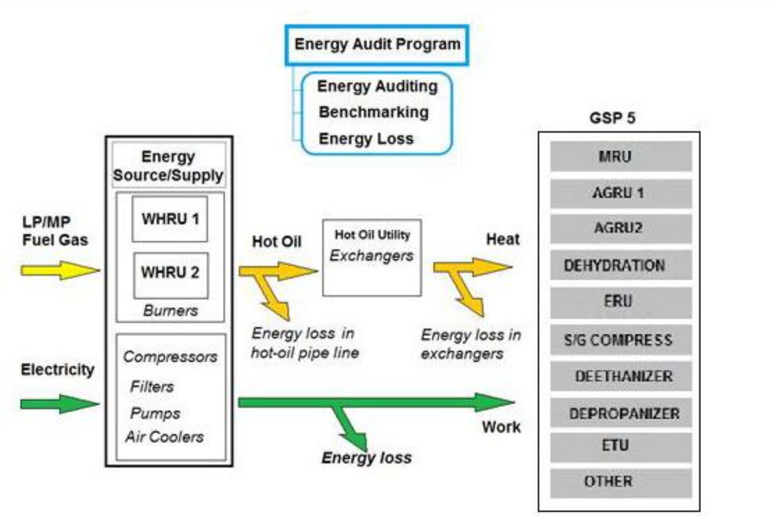

Figure 1: Scope of energy audit program

2.3 Developing data reconciliation and gross error detection model

2.3.1 Study of data reconciliation and gross error detection concept

Data reconciliation technique
Least-square method can be mathematically expressed as an optimization problem in this following form:

Objective function: $min \sum_{i=1}^{n} \left(\frac{y_i - \tilde{y}_i}{\sigma_i}\right)^2$ (1)

Subject to $F_k(\tilde{y}_i, u_j) = 0$ k = 1, ... , m (2)

Where y_i is the measured variable; $\tilde{y}_i$ is the reconciled estimate for variable I; u_j is the estimated of unmeasured variables; σ_i is the standard deviation of i measurement.

The objective function is to minimize the sum of the difference between measured value and reconciled value and the entire estimate reconciled, unmeasured value satisfy the constraint ($F_k(\tilde{y}_i, u_j)$). The standard deviation of i measurement can be estimated by Eq. 3.

$$\sigma_i = \frac{1}{n-1}[\sum_{i=1}^{N}(y_i - \bar{y})]^{1/2} \quad (3)$$

Gross error detection technique, Global test
Because objective function of data reconciliation by least-square method (Eq.1) is also a chi-squared probability distribution, with degree of freedom (v) that equal to degree of redundancy.
The global test for gross error detection states that,

$$\sum_{i=1}^{n}\left(\frac{y_i - \tilde{y}_i}{\sigma_i}\right)^2 < \chi^2_{(1-\alpha)}(\text{v}) \quad (4)$$

Where $\chi^2_{(1-\alpha)}$(v) is the upper limit value of the chi-square distribution where gross errors are not expected and α is the level of significance which is generally taken as α = 5 % if the objective function value is less than $\chi^2_{(1-\alpha)}$(v) then gross errors are not expected in the system. With α = 5 %, this means a 95 % confidence that gross errors are absent.

Gross error elimination technique, Measurement test
Measurement test is one of many gross error elimination techniques. This technique can detect and eliminate gross error by confidence interval (±2σ). The confidence interval can be calculated by using standard deviation (σ) of measurement adjustment (measured value – reconciled value).

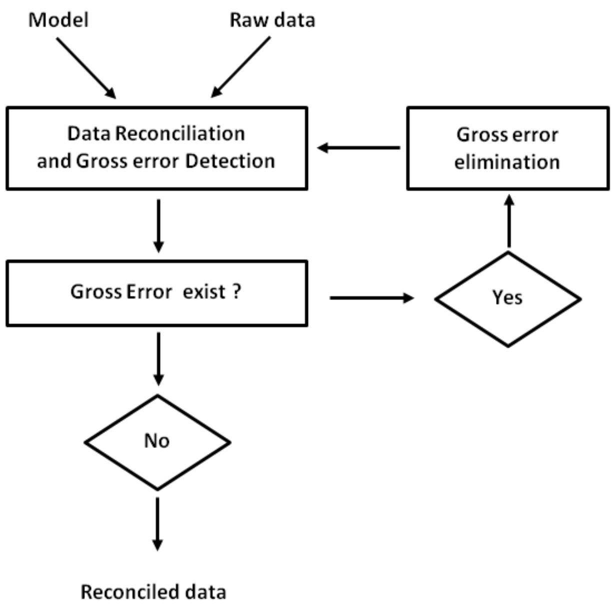

Figure 2: Flow chart of Gross error detection technique, Measurement test (Wikipedia, 2012)

The next steps are:

- Simulate the heat exchanger network by PRO II simulation software
- Simulate data with random errors based on PRO II heat exchanger network model
- Develop data reconciliation and gross error detection model using GAMS
- Compare the result from data reconciliation and gross error detection model with the simulation data from PRO II model.

2.4 Applying data reconciliation and gross error detection technique with process data
Before using data reconciliation and gross error detection technique process data have to be filtered by removing outliers. Outliers can be detected by box plot diagram created by Minitab Statistical Software.

Then program Microsoft FORTRAN PowerStation is used to remove outlier. After that data reconciliation and gross error detection technique are applied to validate process data.

3. Case study

The case study considers the data reconciliation and gross error detection technique for the heat exchanger by using the data from PTT GSP5

Constraints:

$$Q = \left| F_o \int_{T_{o,i}}^{T_{o,o}} C_{p,o} dT \right| \quad (5)$$

$$Q = \left| F_g \int_{T_{g,i}}^{T_{g,o}} C_{p,g} dT \right| \quad (6)$$

$$Q = UA \left[\left(T_{o,i} - T_{rg,o}\right) \times \left(T_{o,o} - T_{g,i}\right) \times \frac{(T_{o,i}-T_{g,o})+(T_{o,o}-T_{g,i})}{2} \right]^{1/3} \quad (7)$$

Noted: $C_{p,o} = 0.0036T + 1.8089$ (8)

$C_{p,g} = 0.002454T + 2.358406$ (9)

Eq. 5, 6 and 7 are heat duty of hot stream (hot oil), cold stream (regeneration gas) and heat exchanger respectively. In this case, there are eight process variables which are F_o (volumetric flow rate of hot oil), F_g (volumetric flow rate of gas), $T_{o,i}$ (inlet temperature of hot oil), $T_{o,o}$ (outlet temperature of hot oil), $T_{g,i}$ (inlet temperature of gas), $T_{g,o}$ (outlet temperature of gas), Q (heat duty of heat exchanger) and U (heat transfer coefficient of heat exchanger). In this case there are five degrees of freedom which means five of eight process variables must be measured to find the other variables but to perform data reconciliation in this case need at least six measured variable (Degree of Redundancy = 1).

Concept of data reconciliation is to minimize the difference between measured value and reconciled value.

Objective function: $$Min \left(\frac{F_o-\tilde{F}_o}{\sigma_{Fo}}\right)^2 + \left(\frac{F_g-\tilde{F}_g}{\sigma_{Fg}}\right)^2 + \left(\frac{T_{o,i}-\tilde{T}_{o,i}}{\sigma_{To,i}}\right)^2 + \left(\frac{T_{o,o}-\tilde{T}_{o,o}}{\sigma_{To,o}}\right)^2 + \left(\frac{T_{g,i}-\tilde{T}_{g,i}}{\sigma_{Tg,i}}\right)^2 + \left(\frac{T_{g,o}-\tilde{T}_{g,o}}{\sigma_{Tg,o}}\right)^2 \quad (10)$$

Before perform data reconciliation we have to remove outlier to get more accurate data by using box plot diagram. Box plot diagram will show the whisker extended from each end of the box. A point beyond whisker is called an outlier and will be removed by FORTRAN program.

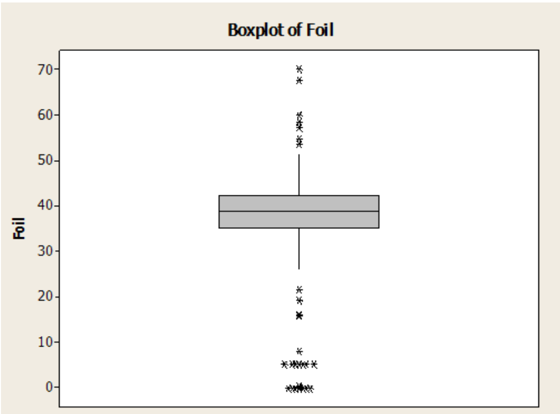

Figure 3: Box plot diagram of hot oil flow rate

4. Results and discussion

The energy audits program can monitor and report the energy usage of each area in the gas separation process. In addition it can define the energy loss, benchmarking and the efficiency of the equipments in the specify date and area. The interfaces of the program are shown in Figure 4.

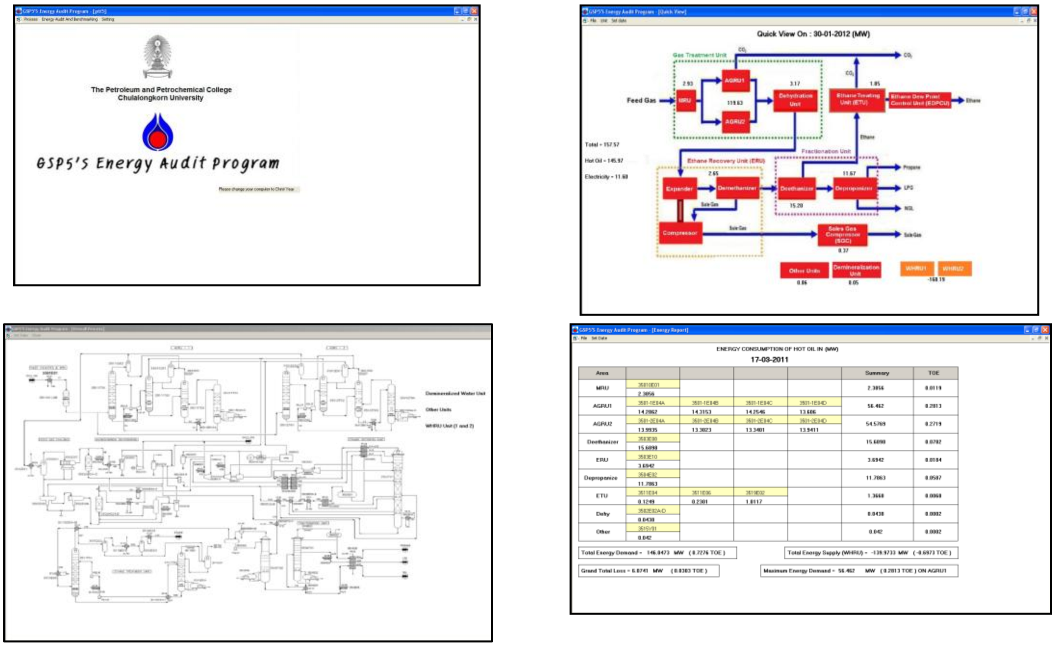

Figure 4: Interfaces of the energy audits program

In data reconciliation part, GAMS program is used to perform data reconciliation and gross error detection by minimizing the objective function (Eq. 10) to makes the reconciled value of flow rate and temperature suitable to process constraints as shown in Table 1. The result from GAMS shows that value of objective function (17.185) is larger than chi-square distribution ($\chi^2_{(1-0.05)}(1)$ = 3.841). From the global test technique shows that some gross error is presence in these measurements so measurement test technique is required to eliminate gross error. If gross error didn't remove before perform data reconciliation so the reconciled data were deviate from simulated data as shown in Table 1.

Table 1: Reconciled measured variables, relative error of variable

Variable	Symbol	Average Measured Value	Reconciled Value	Relative Error
Hot oil flow rate (m^3/h)	F_o	39.264	51.373	23.57 %
Gas flow rate (m^3/h)	F_g	18,962.12	16,588.889	14.31 %
Hot oil inlet temperature (°C)	$T_{o,i}$	260.908	261.117	0.08 %
Hot oil outlet temperature (°C)	$T_{o,o}$	212.240	201.224	5.47 %
Gas inlet temperature (°C)	$T_{g,i}$	44.757	45.266	1.12 %
Gas outlet temperature (°C)	$T_{g,o}$	229.002	222.358	2.99 %
Heat duty (kW)	Q	-	1618.946	-
Heat transfer coefficient (kW/m^2°C)	U	-	56.954	-

From Table 2 flow of hot oil (F_o), gas (F_g), and outlet temperature of hot oil ($T_{o,o}$) have magnitude of measurement adjustment larger than 2σ. Among these the measurement adjustment of gas flow rate (F_g) has the largest magnitude and can be identified to contain a gross error because of the largest magnitude it can make other streams deviate from true value that make magnitude of measurement adjustment larger than 2σ. Therefore the next reconcile will perform without using the flow rate of regeneration gas but DOR = 0 so data reconciliation cannot perform. The values are shown in Table 3.

Table 2: Measurement adjustment and standard deviation

Variable	Symbol	Measurement Adjustment	2σ
Hot oil flow rate (m^3/h)	F_o	-12.109	9.335
Gas flow rate (m^3/h)	F_{rg}	2373.230	2348.410
Hot oil inlet temperature (°C)	$T_{o,i}$	-0.209	1.331
Hot oil outlet temperature (°C)	$T_{o,o}$	11.015	9.816
Gas inlet temperature (°C)	$T_{g,i}$	-0.509	3.614
Gas outlet temperature (°C)	$T_{g,o}$	6.644	12.229

.*Table 3: Measured variables and unmeasured variables*

Variable	Symbol	Average Measured Value	Calculated Value
Hot oil flow rate (m^3/h)	F_o	39.264	39.624
Gas flow rate (m^3/h)	F_{rg}	-	9949.427
Hot oil inlet temperature (°C)	$T_{o,i}$	260.908	260.908
Hot oil outlet temperature (°C)	$T_{o,o}$	212.240	212.240
Gas inlet temperature (°C)	$T_{rg,i}$	44.757	44.757
Gas outlet temperature (°C)	$T_{rg,o}$	229.002	229.002
Heat duty (kW)	Q	-	1013.038
Heat transfer coefficient (kW/m^2°C)	U	-	36.841

5. Conclusion

The energy audits program developed in this work can monitor and report the energy usage of each area in the gas separation process. In addition it can define the energy loss, benchmarking and the efficiency of the equipments. Data reconciliation and gross error detection technique can be used to reduce effect of random error and can detected and eliminate gross error to receive reconciled data which consistent to process constraint.

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