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Optimization of Sirri NGL heating steam generation and distribution system using a novel graphical targeting method and Low Pressure model

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Abstract

At the new Sirri NGL plant, steam was required to supply heat for process, especially in reboilers. Boiler feed water was fed from the Low Pressure (LP) Boiler Feed water Pumps to the LP Package Boilers to produce LP steam that will be distributed via a LP Steam Header system to the various users, and steam Condensate will be collected via a Steam Condensate Return header. The returning steam Condensate is partially flashed in the Condensate Storage Drum. At this NGL plant steam heat exchangers network layout is a pure parallel design which implies that each heat exchanger was directly connected to the boiler. The arrangement implies that by simply changing the layout of the network, needed steam flow rate for the system could be reduced without loss in required duty. In the targeting method such as the design of the network layout, phase changing of saturated steam to saturated liquid play a vital role. For the determination of network layout and the minimum steam flow rate, a graphical targeting method and mathematical model have been developed. Using designs and also targeting methods, a mathematical model was developed. Results show an approximately 7% reduction in steam consumption in the plant.

Key words: Steam distribution system; Heat exchanger network (HEN); Pinch technique; Graphical targeting; LP

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1. Introduction

Gas plants- because of their distinctive features- are economically complex systems. A unique characteristic in gas plants is that various gas streams belonging to other owners may be combined at the plant inlet and processed as a single group. During the process, the customer still retains their ownership in the same form. Another interesting characteristic is that for each process of the raw gas, there may be a separate contract with a different customer with unique terms and conditions. These contracts may be entirely different for each customer depending upon the age of the contract, the composition and amount of gas, plant recoveries, and the contractual preferences of the customer [1]. Regarding process, raw inlet gas can fall into one of the three following categories: it may originate from nearby gas fields, be a product of another type of process i.e. refinery off-gas, or collected as associated gas from oil fields. As a result, the composition and volume of each plant inlet stream may be drastically different. Upon process completion, the products are allocated to each inlet gas owner based upon the composition and amount of gas contributed minus the contractual plant processing fees. These fees are subject to any other contractual penalties for poor performance by either party [2]. The Neptune Cryogenic Gas Plant has two nominal 300 MMSCFD trains. The prime mover for each of the trains' residue gas re-compressor is a Solar Mars 100 gas turbine. The first train, which was commissioned in February of 2000, utilizes Ortloff's Gas Sub-cooled Process (GSP). The second Neptune train utilizes IPSI's patented Stripping Gas Process [3]. The plant receives a processing fee per the terms and conditions of the gas processing contracts with each inlet owner. The plant processing fee is usually determined in one of three ways: a fixed processing fee, a ‘keep- whole’ contract, or retention of a portion of the produced liquids. A fixed processing fee agreement pays the plant a flat fee based upon the volume of inlet gas. A ‘keep-whole’ contract allows the plant to remove liquids from the gas and pay the supply company based upon the BTU value of the fuel and shrinkage [4]. In addition to processing fees, the plant may gain income from compression, marketing, or pipeline transmission fees. The situation may be complicated further depending upon the terms for fuel allocation and shrinkage. Contractual penalties may also exist for low recovery, insufficient inlet gas flow, low plant inlet suction pressure, high field pressure, and high levels of impurities in the inlet or product, and lean inlet gas [5]. Steam is used in Sirri NGL plant for process streams that need to be heated and vaporized such as distillation towers and amine regeneration and also for low pressure flares and thermo compressor ejector in desalination unit. To save on energy costs, heat is initially exchanged between hot and cold process streams via heat exchangers, and then cooling water and Steam are used for the remaining process streams. Pinch Analysis is commonly used in maximizing process-process heat integration, thereby minimizing external utility requirements. Most industries worldwide have adopted Pinch Analysis as the most powerful tool in achieving a design with optimal usage of external utilities. Cooling towers, steam boilers and process-process heat exchangers all form part of a heat exchanger network (HEN). In the past minimization of the amount of the external steam needed in the system has been accomplished by optimizing the steam boiler, or optimizing each heat exchanger individually. However, in this work it is demonstrated that by optimizing the steam system as one entity instead of individual components, better results are obtained, as was proven Thokozani Majozi [6] and Cardona1 - Gutierrez [7] for heat exchanger network. The reduction of the steam flow rate also influences the capital cost of the steam boiler. When designing in the grass-root phase, reducing the steam flow rate results in the reduction of the capacity of the required steam boiler, thereby, directly reducing the capital costs of the HEN. For an existing HEN, reducing the steam flow rate (retrofit-design) debottlenecks the existing steam boiler, thereby, indirectly reducing the capital costs of the HEN in the case of future expansions.

To help the management of energy in a multi-period basis regarding a three/four level steam network, and to handle the annual budgeting planning, investment decisions, electricity contract optimization, shutdown maintenance scheduling and fuel/water balance problems in a petrochemical plant, a site model has been developed (Hirata et al., 2004). The energy consumption of countries is generally compared by establishing the ratio of per capita energy consumption to per capita gross domestic product (GDP); or, expressed otherwise, the total quantity of primary energy consumption from all sources, reported per capita and according to the level of economic activity. To avoid distorting the comparison, GDP figures are adjusted for Purchase Power Parity (PPP). Simply stated, the lower the energy intensity, the greater the energy efficiency.

The goal of gas plant economic optimization is to utilize all available plant information to determine the set of economically optimum operating conditions. Over time, the typical gas plant finds itself processing gas under such a wide variety of contracts and this makes it very hard, if not impossible, to recognize intuitively the economically optimum process conditions for the plant. The optimum is tangled further by the frequency of product price changes and variations in inlet stream flow rates. As a result, the economic optimum set of plant process conditions may be different for each gas supply company while the plant may have yet another optimum [9].

Problem statement

The problem addressed in this paper can be stated as follows, given:

a. The set of heat exchangers in Sirri NGL,
b. The fixed duties of each heat exchanger,
c. The hot temperature that in bottom of every tower is needed.
d. The limiting data for each heat exchanger, and
e. The minimum driving force ΔTmin for the overall network,

Determine the minimum amount of steam required to satisfy the heat exchanger network, as well as the steam utility network layout without compromising the minimum heat duty requirement.

2. Material and Methods

Saturated steam is used first to transfer the latent heat to cold process streams. The resulting saturated liquid is then further used to transfer heat to the remaining cold process streams, together with re-use of hot liquid from other units. The hot utility curve is constructed using the ΔTmin, after which, graphical targeting for the minimum steam flow rate is done. Fig. 1 shows the combination of the saturated steam, saturated liquid and hot utility composite curve on a Temperature vs. Duty diagram. The energy supplied by the saturated steam as well as the saturated liquid is given by Eq. (1)

$Q = m\,\lambda_v + mc_p\,\Delta T$ (1)

Where Q is the total energy supplied by the saturated steam and saturated liquid in kW

m is the water flowrate in kg/s

λ_v is the latent heat of vaporization of the saturated steam in kJ/kg

c_p is the specific heat capacity of the water in kJ/kg°C

ΔT is temperature difference in °C

After the steam target has been set, the heat exchanger network that meets the target is designed. As stated previously, saturated steam and saturated liquid are used as utilities in the HEN. Therefore, the diagram in Fig. 1 can be divided into four regions of interest as shown in Fig. 2. The composite curve divides the diagram into regions 1 and 2. Region 1 is a feasible region since all the utility streams within this region obey the thermal driving forces. Region 2, on the other hand, involves utility streams that violate the thermal driving forces and is, therefore, an infeasible region. The vertical dashed line separates the diagram into regions 3 and 4. In region 3, heat transfer takes place through sensible heat whereas in region 4 heat transfers involve latent heat, i.e. phase change. By exploiting the structure of Fig. 2, a HEN that meets the target steam requirement can be developed. In the region where only saturated steam is required, i.e. region 4, the layout will always be a parallel connection; therefore, one only needs to determine the layout of the rest of the heat exchangers for the saturated liquid region. In the saturated liquid region the layout can be parallel, series or both. The Temperature vs. Duty diagram gives a visual representation of the targeted solution. However, the diagram does not show the layout of the HEN in the saturated liquid region. A mathematical model is then used to obtain the HEN layout in the saturated liquid region. The mathematical model, which is a linear programming (LP) model, entails mass and energy balances as well as design constraints that should not be violated. A mathematical model can also be used to target for the minimum steam flow rate, as well as obtain a network layout for targeted value. The model developed for this, takes the form of a mixed integer linear programming (MILP) model. To prove the applicability of the developed methodology, an actual case study will be used.

2.1. Sirri NGL steam generation and distribution system and HEN

The utility data is given in Table 1. Saturated steam is provided at 162°C (6.2 bar) with a latent heat capacity of 2081.3 kJ/kg. The specific heat capacity of the resulting saturated liquid is 4.22 kJ/kg°C. The figure temperature vs. duty for Sirri NGL plant HEN shows the results of targeting using saturated steam, as well as saturated liquid. If only saturated steam was used as a hot utility, i.e., assuming a parallel design, the flow rate would be 39.3 t/h. However, by using the methodology described above, the flow rate needed is only 36.5 t/h, reducing the original flow rate by 7%. After targeting for the minimum flow rate, the network layout was obtained by using the LP model. Whether a heat exchanger should be allowed to split is a decision that rests with the designer, since a split increase the capital cost of the network according to the table 3. It should be noted however, that by not allowing a split to occur, the flow rate of the steam increases. The MILP model resulted in the same flow rate of 36.5 t/h, although a different network layout was obtained.

3. Results and Discussion

In the past minimization of the amount of the steam needed in Sirri NGL facilities has been accomplished by optimizing the boilers and heat exchanger individually. So in this work we demonstrated that by optimizing the steam system as one entity instead of individual components, better results were obtained. The reduction of the steam flow rate influences the capital cost of the steam boiler and for an existing HEN such as sirri NGL refinery, reducing the steam flow rate necks the existing steam boiler, thereby indirectly reducing the capital cost of the HEN in the case of future expansions. After the foregoing analysis and from the targeting, four regions were encountered, namely the feasible, infeasible, saturated steam and saturated liquid region. The heat exchanger layout in the saturated steam region will always be of parallel design and in the saturated liquid region can be parallel, series or both.Then we used an LP(linear program) model to determine the network layout of the saturated liquid region and an MILP(mixed integer linear program) model for targeting the minimum steam flow rate, as well as the network layout. By using this methodology the steam flow rate needed, reduced the original flow rate by 7%.

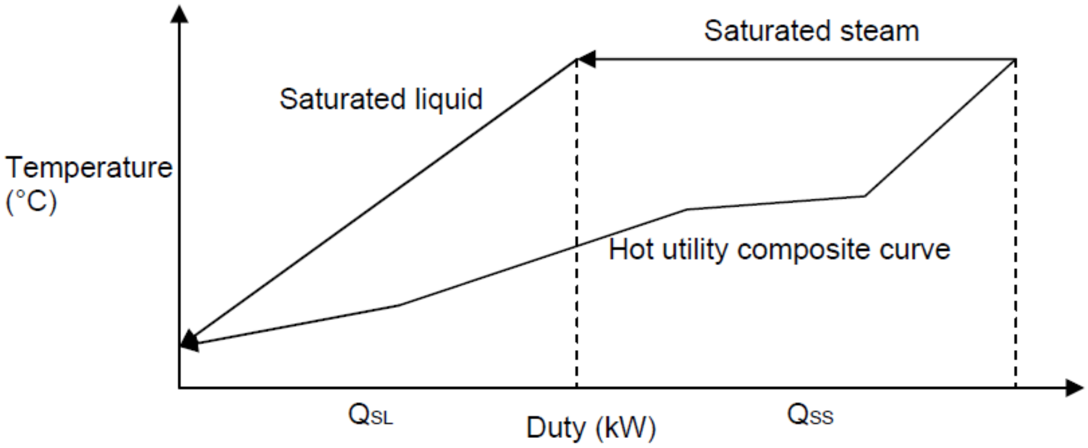

Figure 1. targeting using saturated steam as well as saturated liquid.

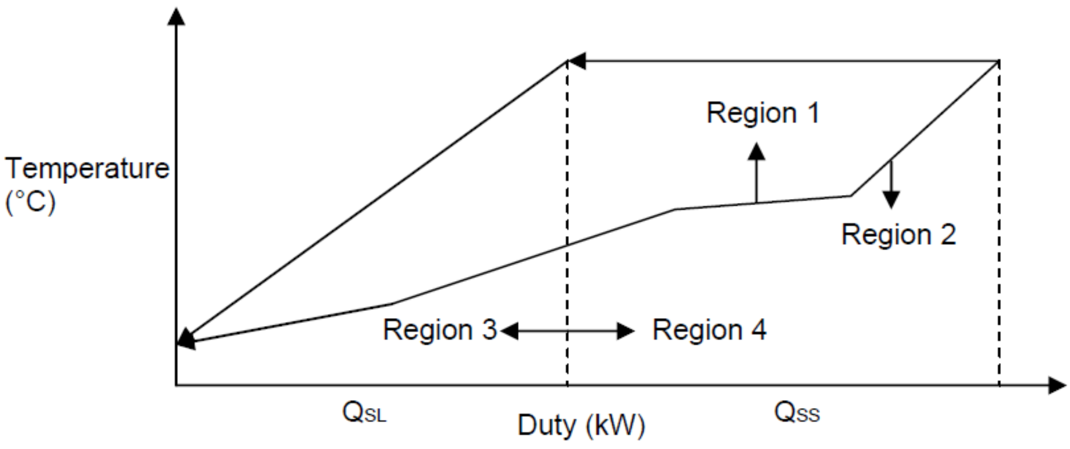

Figure 2. The four regions

Table 1: Utility data for the Sirri NGL [3]

Heat Exchanger	T_{supply}	T_{target}	Duty(KW)
1. Depentanizer	172	150.5	1218
2.Debutanizer	172	130.9	2859
3.Depropanizer	172	128	5313
4.Deethanizer	172	104	6626
5.Condensate Heater	172	110	3382
6.Amin Regenerator	139	120	7503
Total			**26901**

Table 2 : Initial calculations for estimating the minimum optimized rate of steam

Heat Exchanger	$Q = m\lambda_v + mc_p \Delta T$
Deethanizer	$Q = m(\lambda_v + c_p \Delta T)$ $m_1 \lambda_v = m_2 (\lambda_v + c_p \Delta T)$ $11337 \times 2081.3 = m_2 (2081.3 + (4.22 \times 68))$ $m_2 = 9963 \frac{kg}{hr}$
Depropanizer	$Q = m(\lambda_v + c_p \Delta T)$ $m_1 \lambda_v = m_2 (\lambda_v + c_p \Delta T)$ $8960 \times 2081.3 = m_2 (2081.3 + (4.22 \times 44))$ $m_2 = 8226 \frac{kg}{hr}$
Debutanizer	$Q = m(\lambda_v + c_p \Delta T)$ $m_1 \lambda_v = m_2 (\lambda_v + c_p \Delta T)$ $7490.6 \times 2081.3 = m_2 (2081.3 + (4.22 \times 41))$ $m_2 = 4423 \frac{kg}{hr}$
Depentanizar	$Q = m(\lambda_v + c_p \Delta T)$ $m_1 \lambda_v = m_2 (\lambda_v + c_p \Delta T)$ $2014 \times 2081.3 = m_2 (2081.3 + (4.22 \times 21.5))$ $m_2 = 1930 \frac{kg}{hr}$
Condensate heater	$Q = m(\lambda_v + c_p \Delta T)$ $m_1 \lambda_v = m_2 (\lambda_v + c_p \Delta T)$ $516.8 \times 2081.3 = m_2 (2081.3 + (4.22 \times 62))$ $m_2 = 459 \frac{kg}{hr}$

Table 3: The relationship of capital cost vs. steam flow rate

Unit	Type of cost function	Investment cost (s\year)
Large package boiler F: steam flowrate (t/h) P: pressure(MPa)	Nonliner Linear(9Mpa)	4954F0.77fp2 Fp2=1.3794-0.5438P+0.1879P2 495384+13861F
Heat recovery boiler Ffg: flue gas flowrate(t/h)	Nonliner liner	941Ffg0.75 6996+211.5Ffg
Steam turbine	Nonliner	$2237Wst^{0.41}$
Wst: power(KW)	Nonliner	$952Wgt^{0.76}$
Gas turbine Weg: power(KW)	Nonliner	$176Weg^{0.49}$
Deaerator F_b: BFW Flowrate(t/h)	Nonliner	$904F_b^{0.62}$

4. Conclusions

The following conclusions can be made from the foregoing analysis:

• From the targeting, four regions are encountered, namely the feasible, infeasible, saturated steam and saturated liquid region.

• The heat exchanger layout in the saturated steam region will always be of parallel design.

• The heat exchanger layout in the saturated liquid region can be parallel, series or both.

• An LP model can be used to determine the network layout of the saturated liquid region.

• An MILP model can be used for targeting the minimum steam flow rate, as well as the network layout.

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