INTEGRATION OF FIRED HEATERS INTO TOTAL SITE

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ABSTRACT

Total site integration across many process plants can result in substantial energy conservation. Indirect integration through an intermediate fluid to transfer heat from one process to the other is widely practiced. A simple methodology is proposed in this paper to establish maximum potential of indirect integration among multiple plants and establishes a site grand composite curve. The site grand composite curve represents the total utility requirement at any temperature after achieving maximum integration between different processes through intermediate fluid. However, the choice of intermediate fluid influences the overall site grand composite curve. Energy integration of fired heaters into the overall site depends on the site grand composite curve. A procedure is developed to target the number of fired heater, minimum fuel requirement, and appropriate air-preheat temperature. Effects of intermediate fluid flow rate on energy integration of fired heaters are also discussed.

Key words: Total site, Process Integration, Fired Heater, Site grand composite curve, Intermediate fluid

NOMENCLATURE

C	Heat capacity as defined after equation (1) [kJkg^{-1}K^{-1}]
c	Specific heat capacity [kJkg^{-1}K^{-1}]
E	Excess air fraction over stoichiometry
F	Net calorific value [kJkg^{-1}]
GCC	Grand composite curve
HU	Hot utility [kW]
H	Heat duty [kW]
M	Mass flow rate [kgs^{-1}]
S	Stoichiometric air fuel ratio
SGCC	Site grand composite curve
T	Temperature [K]

Greek letters

α	Setting losses fraction
Δ	Difference

Subscripts

a	Air
adl	Additional
E	Non assisted
eff	effective
F	Assisted
f	Fuel
g	Flue gas
gout	Condition at exit of convection section
i	Intermediate
min	minimum
n	Actual condition
p	pinch
s	Stack
0	Ambient

1. INTRODUCTION

The concept of total site was introduced to describe a set of processes serviced by and linked through a central utility system [1]. The total site integration of independent processes or plants can lead to more energy saving opportunities. Processes with different pinch locations offer potential for site integration. In the total site integration of processes direct integration offers the maximum energy benefits whereas it may involve complex networking, less flexibility and economic constraints [2]. However, indirect integration with intermediate utilities (such as steam, hot oil etc.), transferring heat from one process to another offers greater advantages on flexibility and process control with associated energy penalty (compared with direct integration).

Procedures based on pinch analysis have been utilized to establish total site energy integration potential. Morton and Linnhoff [3] identified that the overlap between different grand composite curves (GCC) is a measure of site

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integration potential. Ahmad and Hui [4] identified the energy conservation potential between different areas of integrity. Dhole and Linnhoff [1] introduced the site source and site sink profiles to target steam generation and utilization between processes. After removal of pockets from the individual GCCs, the site source and the site sink profiles are constructed. Based on the total site profiles, cogeneration potential, overall fuel requirement, and emission targets can be set [1]. Hui and Ahmad [5] developed a procedure to target the cost optimum heat integration between different processes. A methodology for simultaneous optimization of production processes and total site utility systems was proposed [6] to reduce energy demands and emissions of the plant. Mathematical programming techniques were also used to solve total site integration [7].

Significant amount of heat integration may be realizable through heat transfer between the pinch locations of the two processes. In certain cases to achieve the maximum possible energy integration, it is required to transfer heat, known as assisted heat transfer, outside the pinch regions [2]. If the pockets are removed, the amount of heat transfer between pinches of the two processes is H_E (Figure 1). Figure 2 shows the importance of assisted heat transfer to achieve maximum heat integration. With assisted heat transfer above pinch (H_F), heat integration potential may be improved to $H_E + H_F$ (Figure 2). A mathematical programming method has been developed to identify maximum energy integration potential across multiple plants [8-10].

A simple methodology is proposed in this paper to establish maximum potential of indirect integration among multiple plants. This methodology employs the tools of pinch analysis and establishes a site grand composite curve (SGCC). SGCC represents the total utility requirement at any temperature after achieving maximum integration between different processes through intermediate fluid.

Process furnaces, also known as fired heaters, supply heat to process streams at elevated temperature directly by burning fuel. Fired heaters are both energy and capital intensive. Prediction of performance and proper integration of a fired heater is necessary for the overall optimization of the entire plant. An analytical procedure for the fired heater integration was presented by Varghese and Bandyopadhyay [11].

Energy integration of fired heaters into the overall site depends on the SGCC. In this paper, a methodology is also proposed to target the number of fired heaters, minimum fuel requirement and appropriate air-preheat temperature. The choice of intermediate fluids influences the overall SGCC and its effect on energy integration of fired heaters are also discussed. Proposed methodologies are demonstrated through an example.

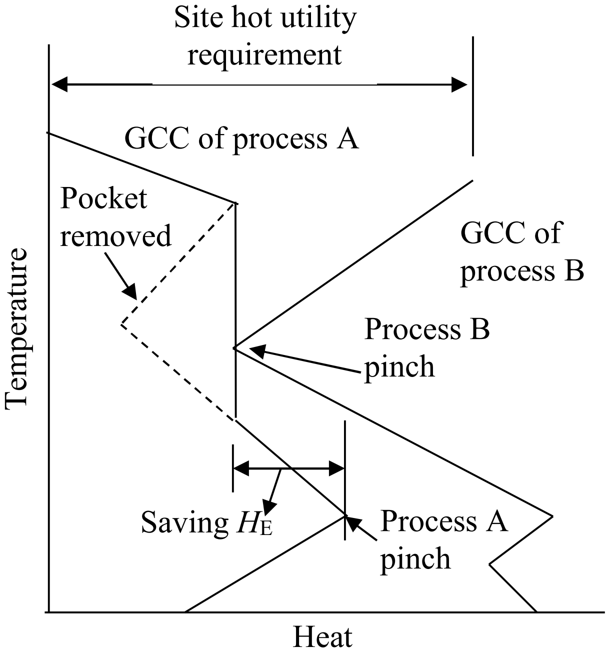

Figure. 1. Site integration of two processes without assisted heat transfer.

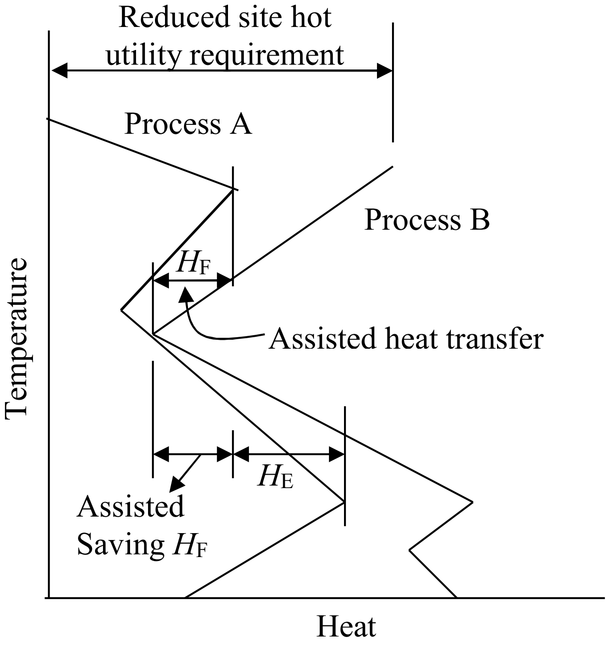

Figure.2. Site integration with assisted heat transfer.

2. FIRED HEATER TARGETS

Fired heater supplies the required hot utility. Process streams enter into the fired heater convection section after completing possible process to process heat recovery. Streams flows from the convection section to the radiation section and leaves the fired heater after picking up the required amount of heat duty. Schematic of a fired heater is shown in Figure 3.

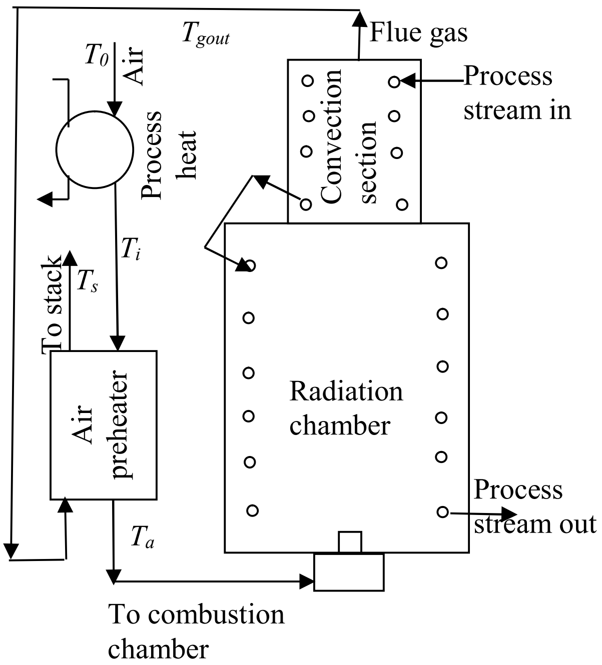

Figure 3. Schematic of a fired heater.

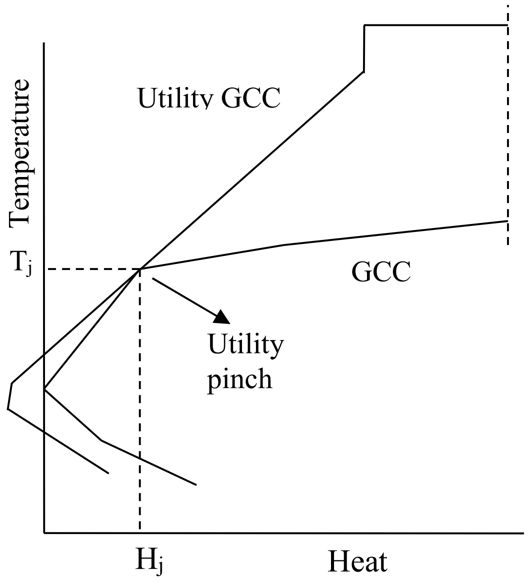

Figure 4. Fired heater integration with the process.

Procedure for targeting and energy integration of fired heater is reviewed briefly [11]. The process GCC is matched against the utility grand composite curve consisting flue gas and air preheating as shown in Figure 4. Two zone model for fired heater is employed here. Ambient air is initially heated to an intermediate temperature T_i using process heat and then it is further heated to a final temperature of T_a.

Flue gas leaves the fired heater convection section after supplying the required heat at T_{gout} and leaves to the stack at temperature T_s after preheating the combustion air. Combining the energy balance for the air preheater, process hot utility requirement, and the concept of the adiabatic flame temperature, mass flow rate of the fuel can be expressed as

$$M_f = \frac{HU}{F_{eff} - C_g(T_s - T_0) + C_a(T_i - T_0)} \tag{1}$$

where $C_a = c_a S(1+E)$, $C_g = c_g[1+S(1+E)]$ and $F_{eff} = (1-\alpha)F$.

Based on the utility pinch, intermediate air preheat temperature may be calculated as

$$\begin{aligned} T_i = {} & \frac{HUC_g[C_gT_s - C_a\Delta T_{ga}]}{HUC_aC_g - H_jC_a\Delta C} \\ & - \frac{\Delta CC_g(HUT_{jn} + H_jT_s)}{HUC_aC_g - H_jC_a\Delta C} \\ & + \frac{\Delta CH_j(F_{eff} + T_0\Delta C)}{HUC_aC_g - H_jC_a\Delta C} \end{aligned} \tag{2}$$

where

$$T_{jn} = T_j + \Delta T/2 + \Delta T_{adl}, \quad \Delta T_{ga} = T_{gout} - T_a \tag{3}$$

Since the utility pinch point is not known a priori, the intermediate air preheat temperature is calculated for all possible vertices on the process GCC. The minimum of all the calculated temperatures, defines the actual utility pinch (H_P, T_P) as well as the maximum possible intermediate air preheat temperature, T_i. From the energy balance of the utility pinch, the final air preheat temperature may be expressed as

$$T_a = T_i + \frac{C_g(T_{p,n} - T_s)}{C_a} - \frac{H_p}{M_fC_a} \tag{4}$$

It may be noted that as the process pinch temperature increases, the intermediate air preheat temperature decreases and thereby increases the fuel requirement (or decrease in heater efficiency). Similar methodology for targeting fired heater for the total site may be applied on a SGCC, which is defined in the next section.

3. SITE GRAND COMPOSITE CURVE (SGCC)

3.1. Shifting Process GCCs

The slope of the individual process GCC segments represents surplus heat (source) or heat demand (sink) within a temperature interval. In indirect integration, intermediate fluid receives heat from source of a process and transfers it to sink of another process. To achieve feasible heat transfer through an intermediate fluid, a double temperature difference (ΔT_{min}) is required between the source and the sink. To incorporate this requirement of double approach temperature, process GCC segments are shifted as per the following scheme. Segments representing the heat sink (segments with positive slope) needed to be shifted up by 1/2 ΔT_{min} and segments representing a heat source (segments with negative slope) be brought down by 1/2 ΔT_{min} (Figure 5). These shifted segments may intersect each other. This implies that it is not advisable to carry out any indirect integration of these overlapping segments, as they don't have enough driving force to accommodate double approach temperature. It is better to utilize these segments for intra-process heat recovery. For integration across processes these overlapping regions are to be removed (Figure 5).

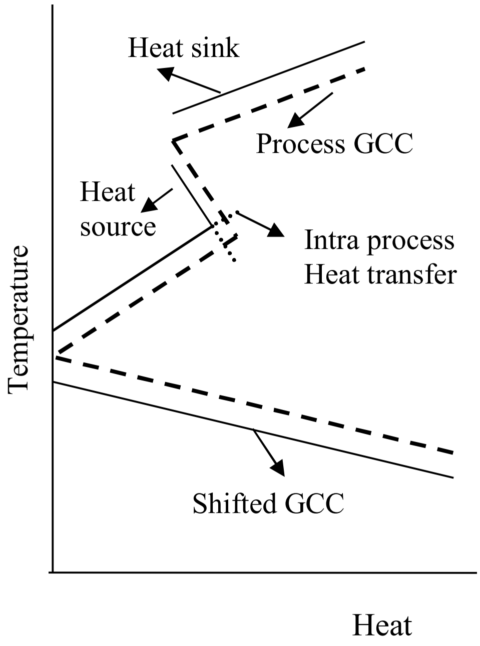

Figure. 5. Shifting GCC for indirect integration.

Modified process GCCs may be used for indirect integration. For two processes, a methodology similar to one shown in Figure 2 may be applied. However, for multiple processes, it is better to generate a site level integration approach.

3.2. Site GCC

Every segment of a modified GCC may be considered either as hot or a cold pseudo stream. Through problem table algorithm [12, 13], a site level GCC or SGCC may be generated. Since the required temperature driving force is incorporated in modified GCCs, SGCC should be generated without any extra ΔT. SGCC becomes the plot of heat surplus/deficit, incorporating maximum indirect heat transfer, against the actual utility temperature. SGCC represents the total site heat utility profile after maximum indirect integration with possible assisted heat transfer. At any temperature level it represents the utility requirement at the actual utility temperature. This information provides the opportunity to target multiple utility levels for the indirect site integration.

Example 1

The data for two process GCCs are given in Table 1. Without integration, a total of 278.8 kW of hot utility is required for this example. The two process GCC are shifted for a ΔT_{min} of 20K as discussed in section 3.1. SGCC for this example is shown in Figure 6. SGCC for this problem suggests that a total of 256.5 kW of hot utility is required if he processes are integrated indirectly. Thus, a reduction of 22.3 kW of hot utility is possible through indirect integration. SGCC hold a pinch at 470 K (the site pinch).

Table1. Site data for example 1

Process -1		Process-2	
Temperature (K)	Heat (kW)	Temperature (K)	Heat (kW)
760	144.8	610	134
640	24.9	540	64
610	0	460	0
290	54.9	290	34

3.3. Intermediate fluid for heat integration

The intermediate fluid, used in indirect integration of processes, carries heat from the source of one process to the sink of another process. The intermediate fluid becomes a cold utility to the source process streams and act as a hot utility to the sink process streams. Interaction of the intermediate fluid with the processes changes the nature of individual process GCCs and thus, shape of the SGCC also changes accordingly. The intermediate fluid heat capacity and temperature has to be within a permissible range. Numerical values of heat capacity and temperature span have to be within the region of the overlapping of the shifted GCCs in temperature-heat duty diagram. The effect of the intermediate fluid properties on the site GCC is illustrated with the example 1. Depending on the conditions of the intermediate fluid chosen, the fired heater targets based on site GCC may change significantly.

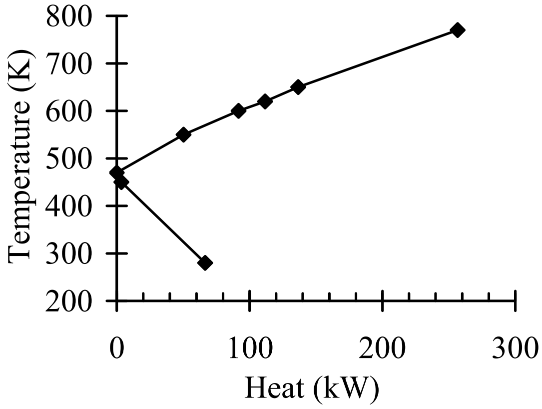

Figure. 6. SGCC for example 1.

GCCs of both the processes are placed together (or matched against each other) to highlight the heat transfer region (Figure 7). GCCs touch each other at the site pinch (470 K). For inter process heat transfer, an intermediate fluid may be utilized. Since the site pinch is at 470 K, intermediate fluid has the lowest temperature of 470 K. Other terminal temperature for the intermediate fluid may be varied by varying its mass flow rate. Other terminal temperature may be varied between 497.9K (minimum possible) and 600K (maximum temperature possible). As the terminal temperature of the intermediate fluid changes, the shape of the SGCC changes significantly (Figure 8). It should be noted that the variation of mass flow rate of the intermediate fluid changes only the shape of SGCC and not its duty. This is expected as SGCC represents heat demand/ supply after maximum indirect heat integration. Change in shape of SGCC, however, influence on site level fuel requirement, as described in the following sections.

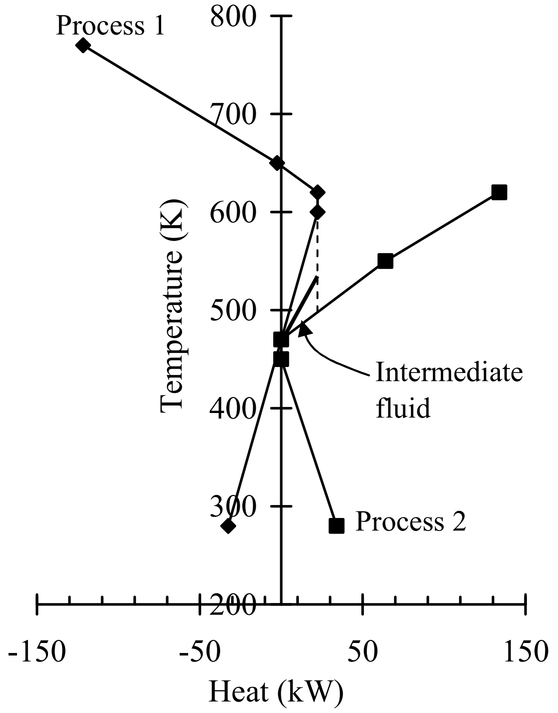

Figure. 7. Shifted GCCs of both the processes are matched against each other.

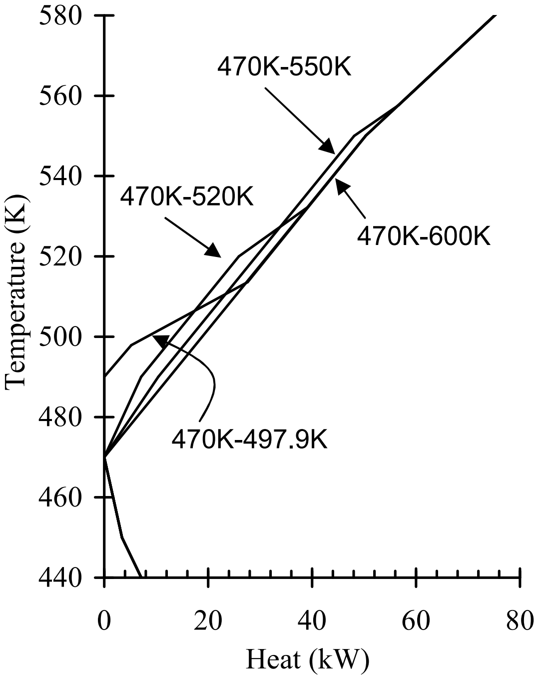

Figure. 8. Effect of intermediate fluid flowrate on SGCC for example 1.

4. FIRED HEATER INTEGRATED TO TOTAL SITE

Fired heater targets for the total site shall be set based on the integration approach as described below.

4.1 Non integrated processes

The plants hot utility requirements are met through individual fired heaters and the total heat load is the sum of the individual hot utility requirement of the plants. The fired heater for the process with low pinch point possesses high efficiency with respect to the fired heater integrated to the process with high pinch point. This is because the fired heaters with low process pinch recover more heat by effective utilization of air preheat from heat below the pinch. The total fuel requirement will be the sum of the two processes and this will be the maximum requirement compared to other cases.

4.2 Direct integrated processes

In this case the streams of both plants are combined and integrated; this is the most efficient method of integration. The total heat utility requirement shall be the minimum as this method ensure the maximum inter-process heat recovery. The combined pinch of both the processes may be found graphically by inserting the low pinch plant GCC into the high pinch plant GCC [9]. For the fired heater integration the combined GCC is matched against the utility GCC and the targets are set.

4.3 Indirect integration of processes

The site target is set using the shifted GCC and the site GCC is generated. The SGCC is used to set the site level fired heater target. The fuel requirement would be higher than the direct integrated site. Depending upon the intermediate fluid parameters chosen the utility pinch formed between the utility GCC and SGCC may result different fired heater targets.

Selection of intermediate fluid

The changes in the site GCC with the intermediate fluid parameters change the fired heater integration parameters. As discussed earlier the site GCC takes different shapes (Figure 9) within the process to process heat exchange zone.

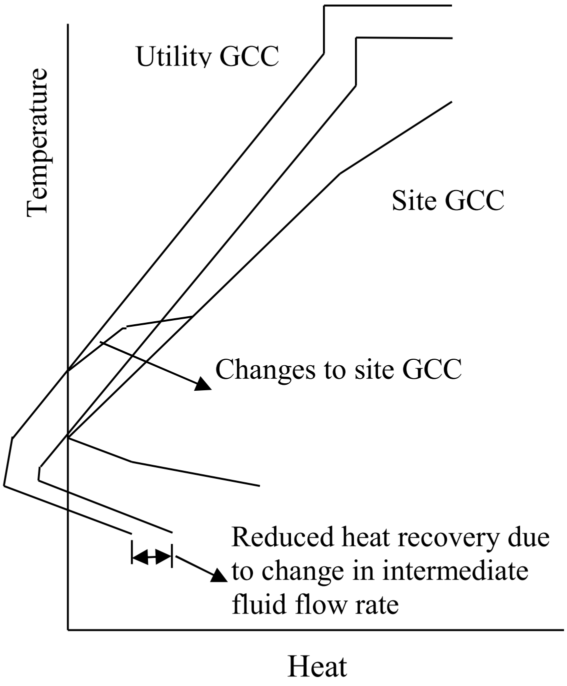

Figure. 9. SGCC integrated with fired heater for different intermediate fluid conditions.

The conditions chosen for the intermediate fluid may cause the fired heater flue gas line to form a utility pinch above the site pinch and this may reduce the process heat recovery below the pinch. This increases the fuel requirement and thus, reducing the fired heater efficiency. This highlights the importance to choose the intermediate fluid heat capacity and temperature range appropriately.

5. TARGETING FIRED HEATER NUMBER

The procedure starts from the terminal point of the SGCC and a stream line is drawn at the terminal point with slope corresponding to the largest heat capacity of the cold stream present at the terminal point. If this line intersects the site GCC above the site pinch, another stream with second largest heat capacity is chosen and the composite line is drawn. The same procedure is continued till the composite line lies entirely above the site GCC. It has also to be ensured that the composite line should be able to absorb the total heat requirement of the process. More number of streams may be added to ensure that the composite line intersects the temperature axis at or above the process pinch (Figure 10). Minimum number of streams required to form a composite line that lies entirely above the process GCC and intersects the temperature axis at or above the site pinch represents the minimum number of fired heater required to meet the site hot utility requirement. The site fired heater number may result in a reduction of the total fired heater number requirement otherwise targeted individually.

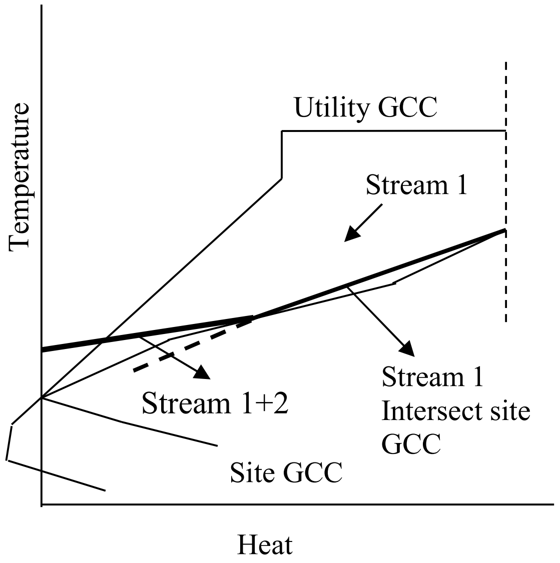

Figure 10. Targeting number of fired heaters.

Example 2

The process data given in example 1 is used illustrate the effect of intermediate fluid parameters on the integration of fired heater into the site. It is assumed that the fuel is having a net heating value of 41000 kJ/kg. The stoichiometric air-fuel ratio is further assumed to be 15 and minimum excess air recommended is 10%. The ambient is at 300 K. Average specific heat of air and flue gas are assumed be 1.005 kJ/kg-K and 1.148 kJ/kg-K, respectively. The limiting dew point temperature of the flue gas is 433 K. The setting loss is assumed to be 2% (α = 0.02). An additional temperature potential□□ ΔT_{adl} of 40K between the flue gas and process streams is assumed. The temperature potential between air-preheat and flue gas outlet is assumed to be 50 K. The site hot utility requirement considering indirect integration using an intermediate fluid is 256.6 kW. Intermediate fluid is transferring 22.3 kW of heat from process 1 to process 2. The temperature range permissible to the intermediate fluid is between 497.9K– 600K, with 470K holding the common point.. The upper range of 470-600 K give an efficiency of 94.2%, however if the intermediate fluid is chosen between 470-497.9 the fired heater efficiency drops to 94%. This shows the importance of the intermediate fluid property selection.

Table 2: Effect of intermediate fluid conditions on fired heater efficiency.

Intermediate fluid	Fuel (kg/hr)	Fired heater efficiency %
470-600	23.92	94.2
470-550	23.92	94.2
470-497.9	23.94	94.0

6. CONCLUSIONS

Total site integration of processes provides additional energy saving opportunities across processes. Processes with different pinches offer the potential for site integration. The indirect method of integration using an intermediate fluid is the preferred integration method. For indirect integration, with appropriate shifting of the process GCC the site level utility targets and a site GCC could be generated. The properties of the intermediate fluid used to transfer heat from the source process to the sink process affect the site GCC profile.

Processes with high pinch has a low efficient fired heater where as the process with low pinch has a high efficient fired heater Nonintegrated plants with fired heater have the maximum total fuel requirements and direct integration with fired heater gives the minimum possible fuel requirement. The efficiency of fired heater integrated indirectly into the process lies in between the direct integration and non integrated processes. The changes to the site GCC profile with the intermediate fluid properties in certain cases may increase the fired heater fuel requirement. It is recommended that the intermediate fluid properties are to be chosen such that the fired heater is not forming a utility pinch with the modified site GCC with the intermediate fluid. The minimum number of fired heater could be targeted for a site using the site GCC.

Use of steam as an intermediate fluid is a very popular choice. Steam can also help in integrating the site utility system. As steam is a point utility (as only the latent heat is utilized), it may not be possible to integrate processes to the fullest extend. Effect of steam as an intermediate fluid on total site integration is currently pursued.

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