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TARGETING HEAT RECOVERY AND REUSE IN INDUSTRIAL ZONE

Article Highlights

- Heat recovery and reuse of waste heat via indirect heat integration
- Increasing of energy efficiency and reducing consumption of fossil fuel
- Linear programming (LP) used for method formulation
- Industrial zone energy integration strategy

Abstract

In order to reduce the usage of fossil fuels in industrial sectors by meeting the requirements of production processes, new heat integration and heat recovery approaches are developed. The goal of this study is to develop an approach to increase energy efficiency of an industrial zone by recovering and reusing waste heat via indirect heat integration. Industrial zones usually consist of multiple independent plants, where each plant is supplied by an independent utility system, as a decentralized system. In this study, a new approach is developed to target minimum energy requirements where an industrial zone would be supplied by a centralized utility system instead of decentralized utility system. The approach assumes that all process plants in an industrial zone are linked through the central utility system. This method is formulated as a linear programming problem (LP). Moreover, the proposed method may be used for decision making related to energy integration strategy of an industrial zone. In addition, the proposed method was applied on a case study. The results revealed that saving of fossil fuel could be achieved.

Keywords: heat recovery, energy efficiency, heat integration, LP formulation.

Global industrial growth has triggered energy consumption levels by the industrial sectors [1]. Energy intensive processes rely on usage of fossil fuels to provide their energy requirements. Increased fossil fuel consumption leads to undesirable increase in greenhouse gas (GHG) emissions, causing climate changes [2]. There are two basic concepts to decrease the use of fossil fuels: replacing the fossil fuels with renewable energy or increasing the energy efficiency of the process [3]. In order to meet the industrial requirements while reducing emissions of GHG, the efficiency of production processes needs to be improved. Also, new technologies are developed to target process integration and process intensification [4]. Moreover, process inefficiencies cause substantial heat and energy loss to the environment. Bendig *et al*. classified energy loss as avoidable and unavoidable heat loss, and waste heat was defined as avoidable heat loss [5]. Heat recovery of waste heat is considered as a very promising strategy for enhancing the overall energy efficiency in a process [6]. Recovery and reuse of waste heat can be applied at the process level as well as at the plant level [7]. Recent studies applied waste heat recovery and reuse strategy on various levels - industries, industrial zones and continuous casting process [8-10]. In complex systems, which consist of multiple processing plants, each plant has its own independent operating and maintenance schedules, which sets difficulties and limitations during integration process. Also, an important factor to consider is the distance between a

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heat sink and a heat source, including heat loss due to transport.

Process level heat recovery is usually being referred to as a direct heat recovery, where heat recovery is performed between hot and cold process streams. This is not always achievable, due to many practical implementation issues such as: controllability, possibility of generating hazards, different operating scenarios, long distance between process streams, etc. Plant level heat recovery helps overcome the shortcomings of process level heat recovery and is often defined as indirect heat recovery. This type of integration is performed via intermediate fluids (such as steam, hot oil, flue gas, etc.), and provides advantages such as operational flexibility, controllability, as well as avoidance of hazards. However, comparing the two levels of heat recovery, during indirect heat recovery temperature driving forces are reduced, which often results in lower heat recovery and less energy saved [11]. Wang *et al.* considered both direct and indirect heat integration, as well as combination of both direct and indirect heat recovery involving the features of both giving more design options [12]. Recently, Miah *et al.* have maximized the heat recovery of diverse production lines by combining the direct and indirect heat exchange from zonal to factory level [13].

The Pinch analysis (PA) method introduced by Linnhoff *et al.* is one of the most commonly used methods that can estimate possible heat recovery within an individual process [14]. PA methods are based on thermodynamic principles to determine maximum heat recovery potential, and hence can be used to construct efficient designs for heat exchanger network (HEX) [15-20]. The main disadvantage of this method is that it does not allow options for forbidden or preferred matches between process streams. Moreover, the total site analysis (TSA) method has been introduced to improve heat recovery within a given plant [21]. TSA applies energy integration between multiple processes to enable maximum indirect heat recovery potential. Processes within a plant are considered to be supplied by a common utility system, which provides the required heat and power. Dhole and Linnhoff introduced TSA to establish targets for heat recovery by integrating processes and optimizing the quantity of utility used in plants [21]. Practical implementation of TSA as an energy conservation concept has been improved in previous studies [22-24]. Chew *et al.* pointed out that TSA methods should be extended to design, operability, reliability/ /availability, maintenance, regulatory policy, as well as economics of utility systems [25]. Further studies investigated total site heat integration considering pressure drops and utilizing the TS Heat Integration profiles for assessing the process modifications to decrease capital costs [26,27]. Improvement of TSA method has been investigated by Varbanov *et al.*, who implemented a modification to enable the use of different minimum temperature differences [28]. New graphical approaches are proposed to present better clarity for the quantitative interaction between the process and utility system targets [29]. TSA methods mainly rely on graphical techniques that cannot provide precise estimations [3,28,30]. Moreover, steam superheating considerations are overlooked, often causing heat recovery potential to be overestimated [31]. Mathematical programming techniques have been developed to overcome the aforementioned drawbacks TSA in identifying optimal HEXs designs. Papoulias and Grossman proposed a mathematical programing technique that identifies an option for forbidden matches, whereas Becker and Marachel developed a mathematical programming model by adding an option for intermediate heat transfer units [32,33]. Liew *et al*. developed an extended methodology TS Heat Integration in a steam system that considers the water sensible heat (boiler feed water preheating and steam superheating during steam generation) using a systematic numerical tool [34]. Several reviews of relevant publications on heat exchange synthesis and process integration have been published [35,36]. Recent studies have introduced an optimal design approach and multi-objective optimization methods of cogeneration systems based on exergo-economic and exergo-environmental parameters [37,38].

The goal of this study is to develop an approach to maximize energy efficiency of an industrial zone through waste heat recovery and reuse, *via* indirect heat integration. Previous work done by Stijepovic and Linke proposed a method targeting maximal waste heat recovery and reuse across decentralized utility system [9]. This method is based on a study of an industrial zone consisting of independent plants operating multiple processes. It is considered that each plant is served by an independent utility system and each plant has been optimized for energy efficiency. In this study, a new approach is developed to target minimum energy requirements in an industrial zone supplied by a centralized utility system instead of decentralized utility system. To reveal potential waste heat streams, the concept of exergy was used, a method described by Stijepovic and Linke [9]. The transshipment model is adopted to estimate maximal heat recovery from recognized waste heat streams. The study is based on targeting maximum waste heat recovery potentials in a centralized utility system prior to the design of optimal network. Furthermore, the proposed approach may assist in the decision making process regarding the retrofitting strategy for utility system configuration in an industrial zone. For example, it can reveal whether introducing a centralized utility system between multiple plants is justified.

Problem definition

A plant usually comprises several processes, where a common utility system provides overall heat for all processes. In this study, an industrial zone consists of multiple independent plants and it is considered that all plants are served by one centralized utility system, which provides required heat and energy for all plants, instead of each plant having a separate utility system. Both initial and target temperatures, heat capacities and heat loads are specified for each hot and cold process stream. Centralized utility system uses fossil fuel to generate very high pressure steam (VHP), where thermodynamic state is reduced to required utilities pressures and temperatures by let-down stations. Depending on the requirements of the process, different types of high pressure (HP), medium pressure (MP), and low pressure (LP) utilities are generated. Heat demands for required utilities define the overall consumption of fossil fuel.

Generally speaking, two types of process streams exist: 1) hot process streams have to be cooled down to a specified temperature, and 2) cold process streams have to be heated to a specified temperature. Hot process streams are cooled down using cold process streams. Similarly, cold process streams are heated up using hot process streams. Any hot or cold process steams which are unable to reach their specified temperature solely via heat exchange must be cooled down or heated up additionally by using external cold or hot utilities, respectively. Any excess heat that is released to cold utilities may then be used to provide heat for another plant within the industrial zone. Therefore, excess heat can be used to generate utilities, which can then be used as a heat source in another plant within the industrial zone [31].

Process streams that eject excess heat into cold utilities can be identified as a potential heat source, as shown in Figure 1. Cold utilities mainly use air or cooling water to cool down a hot process stream. Heat released to cold utilities is considered waste heat (Figure 1a), which can later be used as a heat source to generate utilities subsequently referred to as “recoverable utility” (Figure 1b). The role of introduced recoverable utilities in heat integration is to transfer heat from a process where excess heat is identified to a process with heat deficit. The generated recoverable utility replaces required hot utilities, either totally or partially, leading to decrease in overall industrial zone heat demands set prior to heat integration.

Figure 2 illustrates a utility system with indirect heat integration between processes within an industrial zone. The utility system generates VHP steam that is converted by let-down stations to hot utilities HP steam, MP steam, and LP steam. Recoverable utilities are generated using excess heat from hot process streams and are directed to hot utility steam headers, where they are linked with the specified steam from let-down station. This leads to decrease in demands of generating VHP as well as the usage of fossil fuels.

Model formulation

The proposed model is depicted in the heat cascade diagram in Figure 3. Hot streams represent heat sources, and recoverable utilities represent heat sinks during heat exchange which is carried out in temperature intervals *k*. Temperature intervals account for the thermodynamic constrains that control heat transfer in order to guarantee feasible heat transfer conditions in each interval. This has been ensured by partitioning the entire temperature range into small temperature intervals, which are defined by initial and final temperature of present streams. The entire range of temperature values is set in decreasing order in the cascade diagram. There are *k* temperature intervals for *k*+1 values of temperature, each represented by a separate block of heat exchange between sources (hot process streams) and sinks

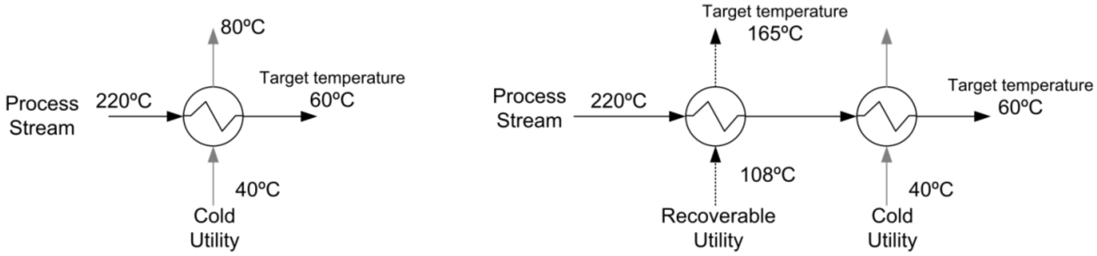

Figure 1. a) Hot process stream cooled by cold utility; b) hot process stream generating recoverable utility.

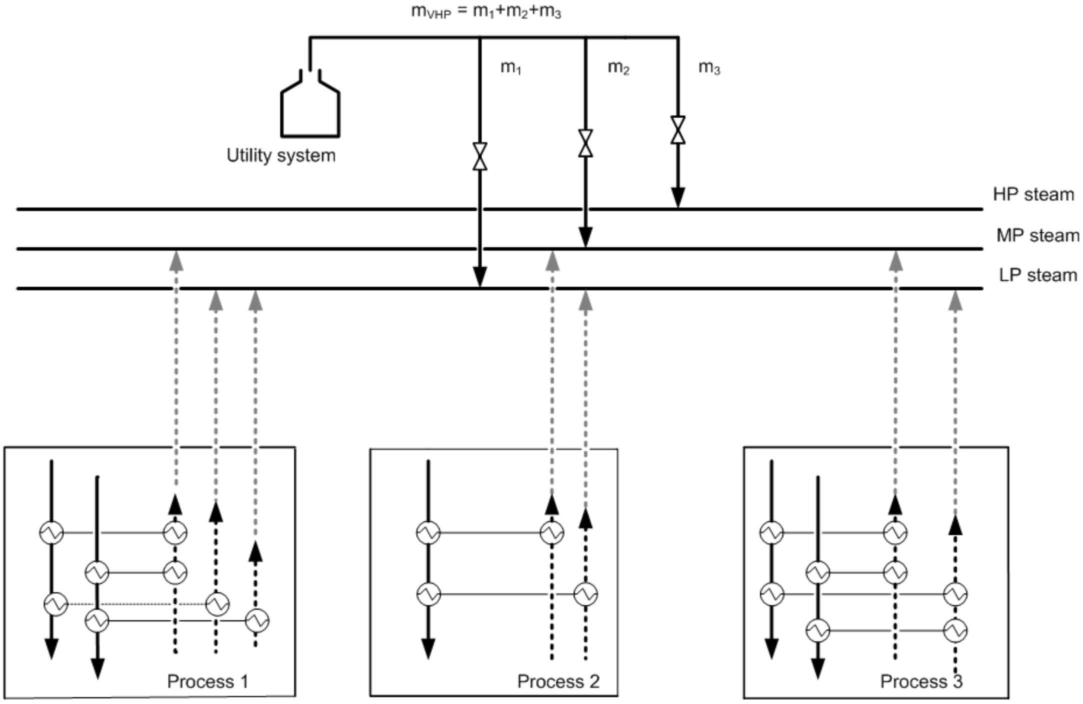

Figure 2. Utility system with indirect heat integration.

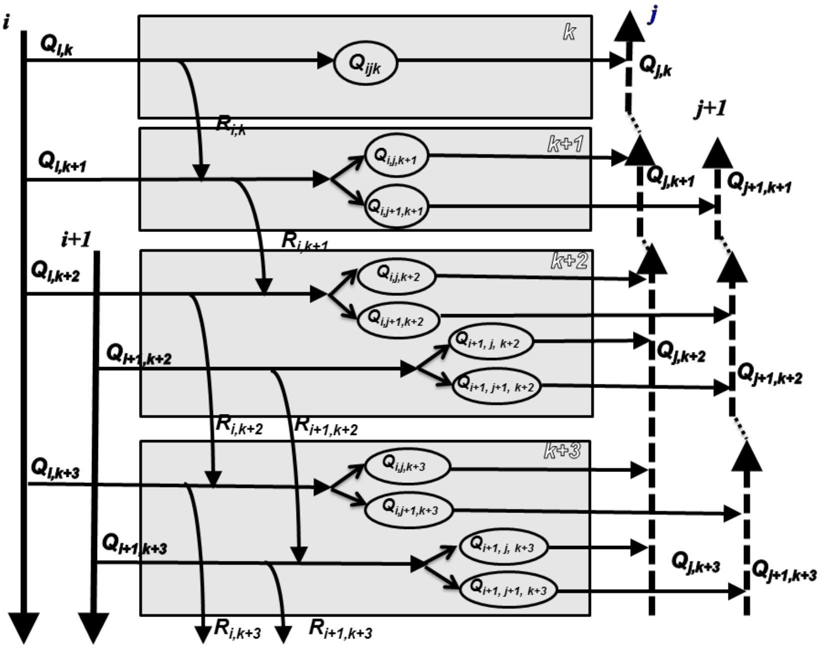

Figure 3. Heat cascade diagram.

(recoverable utilities). Index sets, parameters and variables that are required by the problem are defined in the nomenclature.

Each hot process stream with an excess heat content at temperature interval, *k*, $Q_{i,k}$, can exchange heat content with any recoverable utility, *j*, that is present in that particular temperature interval, *k*. The transferred heat from hot process stream *i* to recoverable utility *j* in temperature interval *k* is represented by $Q_{i,j,k}$. Part of the heat content of hot process stream that has not been exchanged in the temperature interval *k*, is transferred to the next, lower temperature interval, *k+1*, as a heat residual, $R_{i,k}$ (Figure 3).

The proposed approach is defined as follows:

$$\min OF = m^{\text{VHP}} \tag{1}$$

Set to constrains:

$$R_{i,k} - R_{i,k-1} + \sum_{j=1}^{J} Q_{i,j,k} = Q_{i,k}^{H}\ ,\ i \in Hk, k \in TI \tag{2}$$

$$\sum_{i=1}^{I} Q_{i,j,k} = Q_{j,k}^{C}\ ,\ j \in Ck, k \in TI \tag{3}$$

$$m_{\text{req}} - m_j \geq 0\ , \text{req} \in RHU, j \in Ck \tag{4}$$

$$m^{VHP} = \sum_{req=1}^{REQ} m_{req} - \sum_{j=1}^{J} m_j \tag{5}$$

$$R_{i,k},\quad Q_{i,j,k},\quad m_j \quad \geq \quad 0 \tag{6}$$

$$R_{i,0} = 0 \tag{7}$$

The defined objective function (OF) minimizes the mass flow rate of generated VHP steam, m^{VHP}, defined by Eq. (1). The heat balance for one temperature interval, *k,* is described in Figure 4.

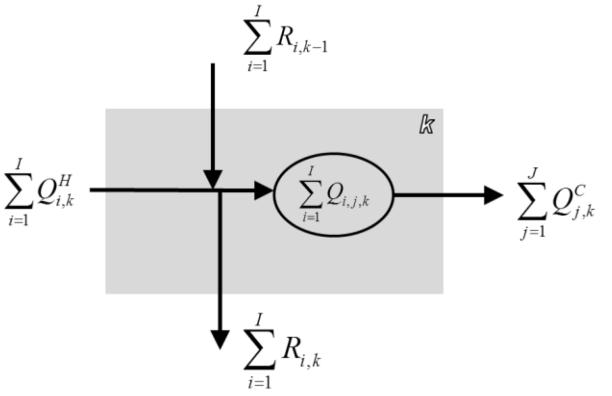

Figure 4. Heat flows during one temperature interval.

Each temperature interval *k* has two inputs, heat content from all hot stream ($\sum_{i=1}^{I} Q_{i,k}^{H}$ *),* and residual heat from the previous temperature interval ($\sum_{i=1}^{I} R_{i,k-1}$). Moreover, each temperature interval has two outputs: heat transferred to recoverable utility *(*$\sum_{j=1}^{J} Q_{j,k}^{C}$), and surplus heat, known as heat residual ($\sum_{i=1}^{I} R_{i,k}$, Eq. (2)) [39].

During heat transfer, each recoverable utility undergoes a phase change. As a result, each recoverable utility has a different heat capacity value throughout the temperature range. The heat transferred to recoverable utility, $Q_{j,k}$, depends on the heat capacity at that particular temperature interval (Figure 3). Heat demands of recoverable utility, $Q_{j,k}$, is equivalent to the sum of the transferred heat from hot streams, $\sum_{i=1}^{I} Q_{i,j,k}$, to particular recoverable utility, *j*, which is defined as one of the constrains in Eq. (3).

After generating recoverable utilities, *j*, (mass flow rate, m_j), they are set to replace the specific required hot utility either totally or partially, *req* (mass flow rate, m_{req}) (Figure 2). Therefore, mass flow rate of recoverable utility, m_j must be less than or equal to the mass flow rate of corresponding required utilities, m_{req}. This condition is set as one of constrains, and it is defined by Eq. (4). All required hot utilities, *req*, are supplied by VHP steam, which is generated in common utility system using fossil fuels. Hence, generated recoverable utilities, *j*, replace the required hot utilities, *req* and consequently reduce demands for generated VHP steam, m^{VHP}, in common utility (Eq. (5)).

Known parameters are set of heat sources, $Q_{i,k}^{H}$, $i \in Hk$, at each temperature interval and the mass flow of each required hot utility, m_{req}:

$$Q_{i,k}^{H} = C_{p,i}(\theta_k - \theta_{k-1})\ ,\ i \in Hk, k \in TI \tag{8}$$

$$m_{req} = Q_{req} / (\Delta H_{vap,req}(\theta_{sat,req}) + \\ + c_{pG,req}(\theta_{uh,req} - \theta_{sat,req})),\ req \in RHU \tag{9}$$

Optimized variables are mass flow rates of recoverable utilities, m_j, $j \in Ck$, which define the heat content, $Q_{j,k}^{C}$, represented in Eq. (10):

$$Q_{j,k}^{C} = m_j c_{p\,j,k}(\theta_k - \theta_{k-1})\ ,\ j \in Ck, k \in TI \tag{10}$$

As aforementioned, recoverable utilities undergo a phase change during the heat transfer therefore phase state and specific heat capacity depends on the specified temperature interval. This is represented in Eq. (11) by three options for each of the phase state: liquid phase (*L*), vaporization (*VAP*) and superheated state (*SS*):

$$c_{p\,j,k} \begin{Bmatrix} c_{p\,j,k}^{L}, & T^{in} \leq \theta_k < T^{sat} \\ c_{p\,j,k}^{VAP}, & T^{sat} \leq \theta_k \leq T^{sat} + 1 \\ c_{p\,j,k}^{SS}, & T^{sat} + 1 < \theta_k \leq T^{out} \end{Bmatrix} \tag{11}$$

$$j \in Ck, k \in TI$$

where

$$c_{p\,j,k} = \Delta H_{vap\,j} / \Delta \mathrm{T}\ ,\ \Delta T = 1K \tag{12}$$

During the vaporization, saturation temperature, T^{sat}, is constant, but in this model formulation it is approximated that the vaporization is happening throughout 1 K. The values are obtained from the standard thermodynamic tables [40]. Each specific heat capacity value, c_p, is calculated as an average value of the two values: at the initial and final temperature of the phase state.

Case study

The proposed model has been applied to an industrial case study [9]. An industrial zone consists of four independent petrochemical plants, where each plant consists of one or more processes. Each plant is served by an independent utility system and each plant has been optimized for energy efficiency. The methodology to develop optimal heat recovery in decentralized system is presented in previous study [9]. In this study, the industrial zone is considered to be served by one centralized utility system, which provides required heat for all processes, instead of each plant having independent utility system.

The fossil fuel used in the utility system is natural gas. Combustion of natural gas generates VHP steam, which is expanded by a let-down station to lower pressure and temperature: HP, MP or LP steams, in order to satisfy the requirements set by processes in each plant.

Data acquisition

For required optimization, three sets of data are necessary. The first set of data represents hot process streams and excess heat that can be reused. The hot streams are defined by the Stijepovic and Linke method using the concept of exergy is applied [9]. There are seven hot process streams that are recognized as potential heat sources and their properties are summarized in Table 1.

Table 1. Data for hot process streams

Stream number	Plant number	T_{in} / °C	T_{out} / °C	ΔH / kW
1	1	230	60	30000
2	1	200	55	20000
3	1	55	40	10000
4	2	200	60	20000
5	3	330	60	25000
6	3	300	70	20000
7	4	180	60	12000

The second set of data represents required utility usage in each plant. The third set of data represents properties for recoverable utilities, which are generated in common utility *via* heat exchange with hot process streams. For each of the nine required utilities, nine recoverable utilities are introduced in the system. The second and third set of data are summarized in Table 2. All represented utilities only use steam at different levels.

The approach assumes that all process plants in an industrial zone are linked through the central utility system. Hot process streams (Table 1) generate recoverable utilities (Table 2) in a common utility. They are then transported to a specific plant to replace the specified required utilities either totally or partially (Table 2).

In order for recoverable utility to replace the required utility, conditions like temperature and pressure must match. Pressure of recoverable utility must be the same as the pressure of required utility and the target temperature, *i.e.*, outlet temperature, of recoverable utility must match the temperature of required utility header. In order for heat transfer to be feasible the minimum allowable temperature difference, ΔT_{min}, must be introduced for recoverable utilities: 30 °C for HP and MP steams, and 15 °C for LP steams.

For illustration purposes, the data used are imaginary but comparable to data observed in existing production plants.

RESULTS AND DISCUSSION

Equations (1)-(12) form linear problem that is solved using LINGO software [41]. The objective function is to minimize VHP steam generated in the centralized utility system through waste heat recovery and reuse *via* indirect heat integration. Variables that are optimized are mass flow rates of recoverable utilities.

Table 2. Data for required utilities

Str. No.	Plant No.	Required utilities				Recoverable utilities		
		T_{in} / °C	T_{out} / °C (T_{sat})	Heat required, kW	Mass flow rate, kg/s	T_{sat} / °C	T_{in} / °C	T_{out} / °C
1	1	280	240	23000	12.09	240	108	280
2	1	240	200	29000	14.14	200	108	240
3	2	320	240	20000	9.88	240	108	320
4	2	250	220	39000	20.02	220	108	250
5	2	200	170	21000	9.89	170	108	200
6	2	150	120	28000	12.37	120	108	150
7	4	220	190	19000	9.23	190	108	220
8	4	150	130	25000	11.27	130	108	150
9	4	120	108	23000	10.18	108	108	120

Figure 5 represents indirect heat integration for this case study. As the depicted utility system burns natural gas, it generates VHP steam, which is reduced to required HP steam, MP steam and LP steam. Recoverable utilities are generated through heat exchange from hot process streams, as it is shown in Figure 5. Generated recoverable utilities obtained by optimization are four utilities with lowest saturated temperatures: utilities 5, 6, 8 and 9. Recoverable utilities are directed to steam headers, where they are linked to the corresponding required utilities. The replacement of required utilities decreases demands of total VHP steam generated in utility system, as well as decreases consumption of natural gas.

The obtained results of optimized variables, mass flow rate of recoverable utilities, m_j, are presented in the Table 3. Results of the optimization show that all generated recoverable utilities are low

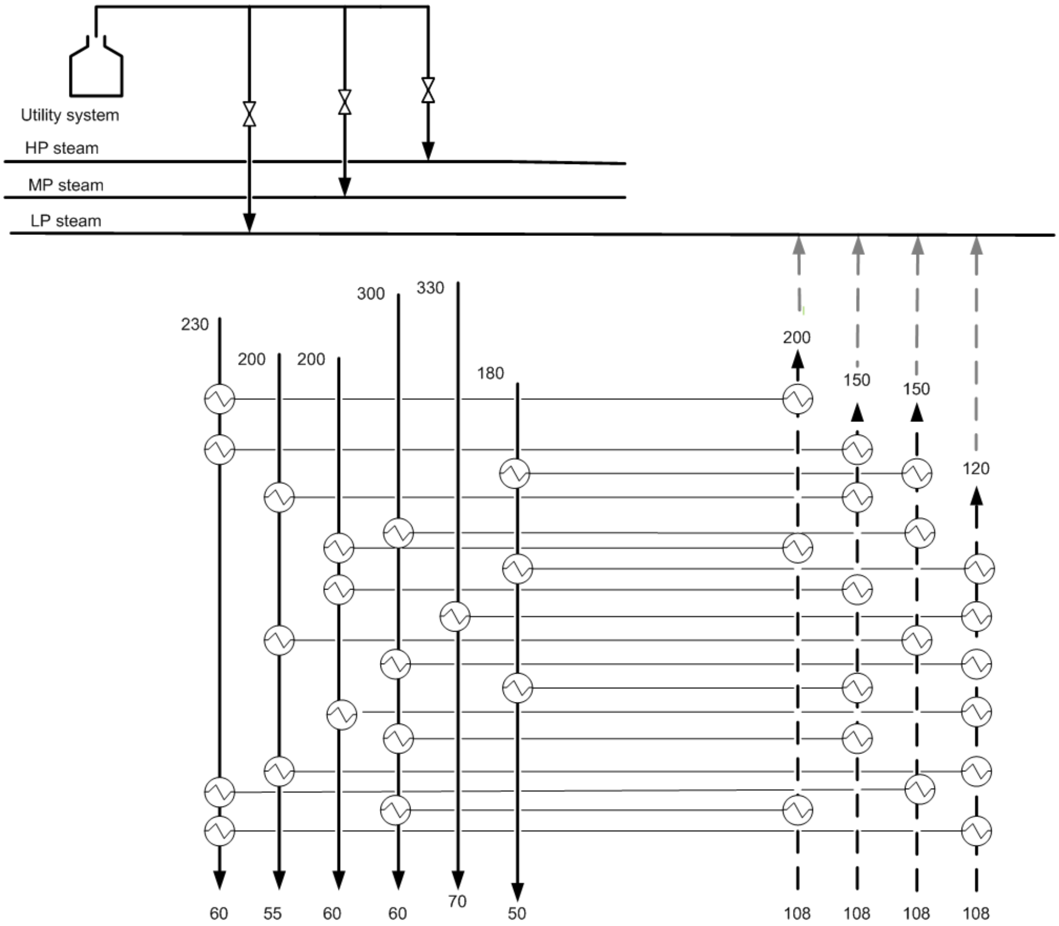

Figure 5. Case study system with indirect heat integration.

Table 3. Comparing mass flow rates of required utilities before and after heat integration

Utility	T_{sat} / °C	T_{out} / °C	Mass flow rate of recoverable utility, m_j / kg s^{-1}	Mass flow rate of required utility before heat integration, kg/s	Mass flow rate of required utility after heat integration, kg/s
1	240	280	0	12.09	12.09
2	200	240	0	14.14	14.14
3	240	320	0	9.88	9.88
4	220	250	0	20.02	20.02
5	170	200	1.16	9.89	8.73
6	120	150	12.37	12.37	0
7	190	220	0	9.23	9.23
8	130	150	11.27	11.27	0
9	108	120	10.18	10.18	0
Total	-	-	34.98	109.07	74.09

grade utilities: utilities 5, 6, 8 and 9. Three out of four generated utilities are totally generated with targeted mass flow rate. These results are expected, since the objective function is set to minimize the quantity of used VHP steam as heat resource.

Additionally, in Table 3 are represented data for the mass flow rates of required utilities before heat integration and after heat integration. The mass flow rate of each required utility after heat integration represents difference between mass flow rate of required utility before heat integration and mass flow rate of corresponding recoverable utility, which is set to replace required utility. The requested total mass flow rate by required utilities before the heat integration is 109.07 kg/s. After the heat integration, total mass flow rate is reduced to 74.09 kg/s, which is 32.07% less than before the integration. Therefore, demands for generating VHP steam in utility system is reduced by 32.07%.

Heat determined by required utilities supplied by the utility system, before and after heat integration is presented in Table 4. As it can be observed, the optimization results show that 78.463 kW heat can be recovered *via* heat integration, which represents 34.56% of heat supplied by steam from centralized utility system.

Table 4. Comparing data of required utilities before and after heat integration, heat, kW

Utility No.	Heat required before the heat integration	Heat required after the heat integration	Heat recovered via heat integration
5	21000	18536	2464
6	28000	0	28000
8	25000	0	25000
9	23000	0	23000

Less demands for generating VHP steam, after the heat integration, leads to less demands for combustion of natural gas in the centralized utility system. The consumed natural gas is compared before and after heat integration in order to evaluate the amount of natural gas that can be saved through heat integration in this case study. Natural gas consumption is defined by next equation:

$$m_{\mathrm{VHP}}(c_{pL}(\theta_{j,sat}-\theta_{j,in})+\Delta H_{\mathrm{VAP}}+ \\ +c_{pG}(\theta_{j,out}-\theta_{sat}))=m_{\mathrm{ng}}LHV_{\mathrm{ng}} \qquad (13)$$

where m_{VHP} is total mass flow rate of VHP steam that is generated from burning natural gas (kg s^{-1}), m_{ng} mass of natural gas (kg s^{-1}), and LHV is low heat value for natural gas (kJ kg^{-1}). Comparing the amount of natural gas consumed before (7.89 kg s^{-1}) and after heat integration (5.36 kg s^{-1}), the saved amount of natural gas during the heat integration is 2.53 kg s^{-1}.

CONCLUSION

A method for waste heat recovery and reuse via heat integration is developed in order to increase energy efficiency and decrease the use of fossil fuels. Industrial zones usually consist of multiple independent plants, where each plant is supplied by an independent utility system, as a decentralized system. In this study, a method is applied to target minimum energy requirements where an industrial zone is supplied by a centralized utility system instead of decentralized utility system. The proposed method is based on linear programming problem (LP). It was tested out on a case study and the results indicate that fossil fuel savings are achieved, and energy efficiency of an industrial zone is increased by recovering and reusing waste heat *via* indirect heat integration. This approach can be used in the decision making process in retrofitting strategy for utility system configuration in an industrial zone.

Acknowledgments

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Nomenclature

Indices

i - hot stream
j - recoverable utility
k - temperature interval
req - required hot utility
pc - phase change of recoverable utility

Sets

Hk = {*i* | hot stream *i* supplies heat at interval *k*, *i* = = 1,…,*I*}
Ck = {*j* | recoverable utility *j* demands heat at interval *k*, *j* = 1,…,*J*}
TI = {*k* | temperature interval, *k* = 1,…,*K*}
RHU = {*req* | required hot utility, *req* = 1,…,*REQ*}

Parameters

$Q^{H}_{i,k}$ - heat content of hot stream i at temperature interval k, kW

Q_{req} - heat content of required hot utilities req, kW

m_{req} - mass flow rate for required utility, kgs^{-1}

$C_{p,i}$ - heat capacity flowrate of the hot process streams, i, kJ K^{-1}

$c_{pG,req}$ - specific heat capacity of the gas phase, G, for required utility, req, kJkg^{-1} K^{-1}

$\Delta H_{vap,req}$ - latent heat of vaporization for required utility stream, req, kJ kg^{-1}

$\theta_{uh,req}$, $\theta_{sat,req}$ - temperature of utility header and saturation temperature of required utility, K

Variables

m_j - mass flow rate for recoverable utility, kg s^{-1}

$Q^{C}_{j,k}$ - heat content demanded by recoverable utility j at temperature interval k, kW

$Q_{i,j,k}$ - heat exchanged between hot stream i and recoverable utility j at temperature interval k, kW

$R_{i,k}$ - heat residual of hot stream i at temperature interval k, kW

θ_k , θ_{k-1} - inlet and outlet temperatures of the each temperature interval, k, K

$c_{p,j,k,}$ - specific heat capacity of recoverable utility j, kJ kg^{-1} K^{-1}

m^{VHP} - mass flow rate of generated VHP steam, kg s^{-1}

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NAUČNI RAD

REKUPERACIJA TOPLOTE U INDUSTRIJSKOJ ZONI

Sa ciljem da se smanji upotreba fosilnih goriva u industrijksim sektorima, a da zahtevi procesa proizvodnje budu zadovoljeni, razvijaju se novi pristupi toplotne integracije i rekuperacije toplote. Cilj ove studije je razvijanje pristupa koji će omogućiti povećanje energetske efikasnosti u industrijskim zonama rekeperacijom otpadne toplote putem indirektne integracije. Uobičajeno je da se industrijska zona sastoji od više nezavisnih postrojenja, kao decentralizovani sistem, gde je svako postrojenje obezbeđen nezavisinim sistemom pomoćnih fluida. U ovoj studiji, razvijen je novi pristup, gde se minimalizuju energetski zahtevi i gde se industrijska zona obezbeđuje centralizovanim sistemom pomoćnih fluida, umesto decentralizovanog sistema. Ovaj pristup pretpostavlja da su sva procesna postrojenja u industrijskoj zoni povezana kroz centralizovani sistem pomoćnih fluida. Predloženi metod je formulisan kao problem linearnog programiranja (LP). Pored toga, ovaj postupak može se koristiti tokom odlučivanja o strategiji energetske integracije industrijskih zona. Štaviše, predloženi metod je primenjen na studiju slučaja. Rezultati pokazuju da je moguće ostvarenje uštede fosilnih goriva.

Ključne reči: rekuperacija toplote, energetska efikasnost, toplotna integracija, LP programiranje.