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Energy recovery and environmental concerns addressed through emergy–pinch analysis

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Abstract

Presented paper shows the power of emergy analysis and its ability for simultaneous consideration of different industrial resources, goods and services for the purposes of decision-making. Accompanied by the pinch concept, which by now tries to deal separately with each of the resources (energy, water, hydrogen, oxygen, etc.), the combined emergy–pinch analysis provides wide range of benefits boosted with extra inside and design guidelines improving the integration of processes and the ability to consider the 'past' and the 'future' of the resources (the effort of making them available and the effort of minimising their environmental impact). The paper presents the theoretical background of the emergy and pinch combination into general resources management technique and proves this concept on classical emergy and pinch examples accompanied with a combined resources management industrial problem considering the environmental impact of industrial activities.
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Keywords: Emergy; Pinch; Integration

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1. Introduction

The complexity of the real industrial environment calls for complex and systematic consideration of all (or at least many) industrial resources simultaneously. Any separate resources considerations in the decision-making and optimisation may compromise the overall effect of design and integration benefits on system's economy. The reflection of this practical goal is recently seen as a trend to develop pinch analysis for combined resources management and optimisation (heat and power, energy and water, heat and mass, oxygen and electrical energy, etc.). Traditionally the analysis of most economic systems is tied to energy-related methods. Unfortunately in many cases the resources management including various types of energy, materials, utilities, services and their optimisation as well as the account of their impact to the environment cannot be compared and totalled using these traditional methods. Despite this, there are number of successful attempts to highlight important sides of resources management and their design implications. Interesting examples are the pinch and the emergy concepts. Pinch concept was applied to number of industrial resources such as heat, water,

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hydrogen, oxygen, hardware, etc. Emergy was used to address the work of nature and that of humans combining environmental and economic values in a single universal index. The idea promoted in this paper represents an attempt to amalgamate the best features of these two methods for better assessment, evaluation, debottlenecking and decision-making in the area of resources utilisation in industrial operations.

2. The concept of amalgamation

The reflection of the practical goal of simultaneous resources management is recently seen as a trend to develop pinch analysis for combined resources management and optimisation (energy and water, announced by Savulescu et al. [1–3], energy and shaft work, heat and mass transfer, considered by Bagajevicz et al. [4], oxygen and electrical energy, suggested by Zhelev and Bhaw [5], etc.).

Another conceptual tool for analysis and environmental decision-making emerged in late eighties, known as emergy analysis, proposed by Odum [6]. It is again a thermodynamic method that evaluates complex resources, goods and services of a system using one criterion—the quantity of solar energy necessary to make them available. Yang et al. [7] have tailored emergy analysis for industrial systems.

Pinch analysis pioneered by Linnhoff [8], and extended by Klemeš [9,10] and emergy analysis are both developed as preliminary design tools. Both use similar principles plotting intensive against extensive parameter. Important feature of pinch analysis is the possibility to target maximum internal resources utilisation prior to design, while in emergy analysis a process can reduce its impact, reducing its emergy use, i.e. by means of less resources use (less emergy) or using resource with lower transformity, for example renewable that usually have lower transformity. In addition to this pinch concept includes the identification of the important system's constraint called pinch point. It plays an important role of:

(a) justifying the maximum resource reuse and
(b) guiding the design process to achieve this target.

Pinch concept deals with different resources on one by one basis (energy, water, oxygen, hydrogen, etc.). When applied to water management it succeeds to target the minimum fresh water demand, maximising wastewater contamination and minimising the effluent volume. Unfortunately it does not address the effort (cost) of water treatment, but presumes simply that less waste discharge corresponds to lower cost implications. Here comes the idea to utilise the power of emergy analysis firstly to unite different resources, such as fuel, chemicals, labour, finances, etc. under one denominator, and secondly to highlight the future of the generated waste. Introducing combined analysis requires a few words about the specific characteristics of each separate component.

3. Emergy analysis

The available solar energy used up directly or indirectly to make a service or product, defined as emergy by Odum [6], was applied by number of authors including Marchettini et al. [11] to compare inputs of different origin, such as human labour, trucks, energy, fuels, chemicals, utilities, plant cost, etc. Solar emergy is the solar energy directly or indirectly necessary to obtain a product or a flux of energy in a process; it is an extensive quantity and its unit is the solar emergy Joule [seJ]. To convert inputs and other kind of flows into the solar equivalent, it is necessary to know the solar transformity, which is the emergy necessary to obtain one unit of product. Unlike the emergy, transformity is an intensive quantity and usually measured in [seJ/J].

An interesting feature of emergy analysis is that it gives historical information about the resource or activity in question. The emergy in the particular moment of interest contains all emergies of stages changes occurring on the way to that stage. The emergy value associated with a product is the memory (the sum) of all energies that were used to produce it. In the case of solar emergy they are all the solar energies necessary to produce that product. Another great feature of emergy analysis is the ability of identification of critical processes/stages/units.

The first step of the practical process of emergy analysis includes the collection of information or calculation of transformities (ST, [seJ/unit]) of the chain of activities involved in the process of making a resource or service in question available for implementation. This is the most difficult part of the methodology because transformity databases even continuously updated by researchers and are rapidly growing are still not comprehensive. The next step involves the calculation of solar emergy (SE, [seJ/y]) followed by the calculation of solar emergy investment (SEI, [seJ/g]):

$$\mathrm{SE}\,[\mathrm{seJ/y}] = \mathrm{ST}\,[\mathrm{seJ/unit}] \times \mathrm{Amount}\,[\mathrm{units/y}], \tag{1}$$

$$\mathrm{SEI}\,[\mathrm{seJ/g}] = \mathrm{SE} \times \mathrm{Amount}[\mathrm{g/12y}]/12. \tag{2}$$

4. Pinch analysis

The principles of pinch were successfully implemented for analysis of different resources such as heat [12], water [13], hydrogen [14], oxygen, finances [15], hardware, etc. There were attempts of combining the typical pinch analysis Enthalpy–temperature consideration with other system characteristics for the purposes of combined resources management. Such is the case of combined pinch and Exergy analysis widely used for combined heat and power management and the introduction of Carnot factor to address the nonlinearity and the avoidable and inevitable exergy losses. We also reported attempts to use pinch concepts for combined heat and mass transfer processes accounting for energy gains/losses out of phase changes (condensation and evaporation) [16]. The reason for the attempt to combine different industrial resources in their consideration is obvious—better total efficiency and resources conservation. An expected question arises in this case—is there a way to address and analyse the vast majority of resources and goods, but what about the services, treatment and operations involving these resources? It is known from quite some time (less than a decade) that the emergy is providing resources for such combination.

5. Water pinch and emergy

Water pinch principles were announced in the early 1990s when it was realised that the resources of fresh water and their preservation are to be one of the biggest challenges of 21st century. Introduced by El-Halwagy and Manousiouthakis [17] and further developed by Wang and Smith [18]. Water pinch principles have established a standard for drawing the limits for water reuse in industries and setting pre-design targets of minimum fresh water demand, an important feature for addressing alternative solutions of design changes and production expansion. One important feature of Water pinch, inherited from the classical pinch analysis, is that this method apart from the preliminary targets setting gives design guidelines, an important advantage comparing it to emergy analysis. Water pinch deals with them mainly considering streams' contamination level, what in the general case is not enough. It is more than obvious that different contaminations and concentration levels would need different efforts of water treatment depending on the nature of contamination, composition, chemical bounds, etc., not only concentration levels and limits. Here comes the accent on the emergy analysis. The ability to assess the history and the effort associated with the solar equivalent of treatment stages would give opportunity to assess the feasibility of water reuse at "any price". Similarly, the assessment of different utilities considers the "cost" of fuels and addresses the origin of fuels together with their past and future implications.

The confidence to use transformity as an analogue to the temperature in thermal-pinch analysis or concentration in water pinch targeting comes from the fact that the transformity is an intensive unit and measures the quality of energy. More precisely, a higher transfomity means that a certain product or flow requires more emergy per unit of energy. The emergy of the wastewater may be determined from the knowledge of the concentration and nature of the emission, and the transformity of the relevant ecological services (water treatment process).

6. Combined emergy–pinch analysis

The combined analysis would apply to the preliminary, conceptual design stage. The idea is to apply both methods simultaneously benefiting from the historical consideration of the emergy analysis, the process improvement guidance supported by pinch analysis and the maximum utilisation of internal resources and minimum waste, highlighted again by emergy analysis. The intention is even to go further into amalgamation of both concepts through construction of a new emergy composite curve (ECC) in analogy with the pinch composite curves. The ECC benefits from the plot of solar transformity against the solar emergy and matching to the composite the total emergy investment (TEI) supply line restricted by the ECC at the point of pinch. The analysis based on ECC benefits from both emergy and pinch features.

As suggested earlier by Zhelev et al. [19] the amalgamation between emergy and pinch concepts can lead to number of benefits. To apply pinch concept one needs to construct the ECC and draw the targeting emergy investment supply line. The streams, being utility or process streams, are defined in emergy units and in the way that can support emergy composite construction. Each stream is represented in a specific way. There is a portion of information (transformity) describing the past emergy investment, the ‘‘history’’ of the stream; a second portion, showing the ‘‘market’’ potential of the stream in terms of usability, as it is the heat (temperature) potential for a thermal stream or the concentration limits, if it is a water stream; the final, third portion of information is associated with the stream’s future—it is linked to the future of the stream and its further usability (regenerative reuse). In the case of thermal-pinch analysis, the hot and cold streams will have different sign of this component of final emergy investment. The required emergy investment to heat the cold streams will possess different sign compared to the available emergy, allowing at this level of analysis to relax particular constraints such as $\Delta T_{\min}$ that can lead to minimisation of the usage of expensive hot utility.

As it is mentioned by Yang et al. [7] the emergy analysis seldom addresses industrial systems and do not consider the impact of wastes—that third portion of information we impose to the stream definition. Important issue is the possibility in the third portion (stage) of any resource stream to consider waste reuse option (partial positive emergy) associated with it and another portion that is to be lost when disposed to the environment. The same authors considered waste treatment (regeneration) and reuse in the emergy indexes used for emergy analysis. The emergy loss is considered through the investment in waste treatment. At the same time, this treatment may not only recover ecologically acceptable level of the resource, but also raise its potential for regenerative reuse.

Applying the pinch analogy, the projection of any stream-representing vector on X-axis shows the solar emergy, the projection on Y-axis gives the solar transformity. The solar transformity is a quality characteristic. The slope (reverse of the slope) of the line represents the amount/flowrate, quantity of the resource. It should be noted that the solar emergy has a relative (not absolute) value, so the allocation of the line representing a resource would be not fixed in horizontal plane.

In the general case of emergy analysis similar to classical pinch analysis the processes ‘‘overlap’’ in the horizontal plane (temperature range, concentration range, (here) transformities range). The emergy loads, or investments, for different processes are characterised by relative values. Then their graphical representation can be freely shifted left and right in their ST/SE plot (Fig. 1).

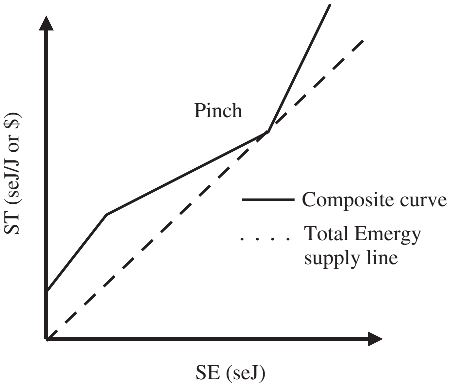

Fig. 1. Composite curve.

6.1. Targeting

The TEI would be targeted drawing the line touching the composite and accounting for its slope. The greater the slope of TEI line, the smaller the rate of TEI. This means the supply of combined resource and corresponding costs associated with it will be minimised lifting the emergy supply line to its maximum. The limit is manifested by the touching point between the supply line and the composite curve, the point known as pinch. Measuring the allocation of the emergy supply line and its slope can help to compare alternative design or operation options. In other words, transformity is accepted as a parameter involving quality and plotted against the emergy investment, which allows targeting of TEI and determination of maximum total transformity needed to run the process.

6.2. Design guidelines

Yang et al. [7] stated that the treatment and reuse of wastes is the key to the evaluation of systems sustainability. The emergy loss is considered through the investment of waste treatment, but at the same time, this treatment may not only recover ecological acceptable level of the resource, but also raise its potential for renovated usage. Such emergy-driven guidelines can help design and redesign decision-making.

The pinch concept is also giving unequivocal guidelines helping to design a system fulfilling earlier defined targets. The design guidelines are suggested by one of the main pinch design tools, namely the pinch Grid diagram. The emergy composites (ST/SE plot, Fig. 1) will identify potential processes to be modified before fixing temperatures and flowrate of streams. The design issue of combined emergy–pinch analysis is of special interest. A single emergy composite is drawn for all streams and an emergy investment supply line is matched accordingly. Such an analysis would show the targets in terms of emergy investment.

An interesting point for further discussion is how to consider processes generating energy, water, power and other resources. An account should be made for the original definition of emergy of a product or a flow as memory of all emergies necessary to make them available. It should be noted that emergy cannot be generated.

6.3. Bottlenecks identification

The identification of bottlenecks is of great concern in all methods of analysis and evaluation. The pinch method does it through one of its graphical tools, the Grid diagram. It shows the cross-pinch energy transfer, which, if in place, leads to cost penalties. The emergy analysis identifies the critical processes through the value of the emergy investment. Combining emergy with pinch concept, we are able to identify more precisely the combined influence of critical processes through allocation of constrained processes (these touching the TEI supply line (Fig. 1) and limiting the degree of its slope). The pinch type of targeting contributes the analysis through several important evaluation parameters:

(1) The ultimate minimum emergy supply to run the entire process at any time (the slope of the TEI line). This is the flow of resources, services and work necessary to run the entire system.
(2) The TEI for the entire process for the entire period.
(3) The maximum transformity (the ‘‘amplitude’’ of transformity, giving the total ‘‘power’’ of resources to run the process—another criteria to compare alternatives, identifying process requiring resources of highest quality)—the horizontal projection of the right end point of the emergy investment supply line.
(4) Limiting stages/resources (restricting the emergy investment supply line to increase its slope). This one gives indication about processes and resources whose utilisation is to be intensified in order to improve the efficiency of the entire process.
(5) Pinch point allocation. There is some substantial difference in the possibilities for improvement (minimisation) of the total emergy supply for pinch points allocations characterised with lower transformity compared to those with high transformity. The explanation of this statement is based on the following: Because the emergy investment supply line starts from point zero and the composite curve in the general case does not start from same ‘‘zero’’ point, smaller improvements in process intensification (slopes) of processes with low transformity requirements would have bigger effect on the total emergy

supply than processes with high transformity (changes in constrained pinch point at the lower end of the supply line will cause bigger change of the slope of this line than pinch points allocated in the upper end of this line) (see Fig. 1).

7. Practical implementation

To build understanding and experience in the implementation of described methodology we decided to focus on three types of problems: (a) to apply emergy analysis for a typical thermal-pinch problem, (b) to apply pinch analysis to a typical emergy problem, (c) to apply combined emergy-pinch analysis for a new type of multiple resources management case.

7.1. Applying emergy analysis to a typical pinch problem

The application of emergy analysis to a typical pinch problem faces some difficulties. The data necessary to pursue an emergy analysis are different from that of pinch analysis and often not readily available. Presented problem is taken from the book Smith [20]. A simplified flowsheet is shown in Fig. 2.

The flowsheet of the pinch-guided design is shown in Fig. 3. Let us try to exercise emergy analysis on designed system. Emergy considers the history of a resource, i.e. the solar energy used to make it available. To differentiate two streams according to their emergy value, one needs to consider their history and the type of treatment imposed to supply them. Therefore, the characterisation of a stream requires calculation of the emergy applied to the stream (cold or hot utility) and the heat exchangers used to bring it to the required final temperature. In order to facilitate the application of emergy analysis on typical pinch analysis problems we consider monetary values, in spite of mass or energy value, we transform it in emergy units with the help of "transformity of money" [6]. Different from the energy, emergy characteristic is not a conservative function and a stream does not lose emergy exchanging heat with another stream.

As it can be seen in Fig. 3, Feed 1 passes through three heat exchangers, Feed 2 passes through two heat exchangers and a steam heater, Product 2 passes through two heat exchangers and Product 1 through three heat exchangers and one cooler. The emergy investment was calculated for each stream separately. The way it is done for stream No. 1 (Feed 1, Fig. 3) is shown in Table 1. The emergy of a utility depends on the type of it and the effort of making it available, while the emergy of a heat exchanger depends on the heat transfer area. For example, the emergy investment of Stream 1 (Table 1) is a sum of emergies of the three heat exchangers involved in its heating. Table 2 summarises the emergy investment for all participating streams following the same way of calculation explained for Stream 1.

This approach allows the identification of the stream with the highest emergy investment. The stream with the highest emergy value passes through more treatments (heat exchangers or utility heaters/coolers).

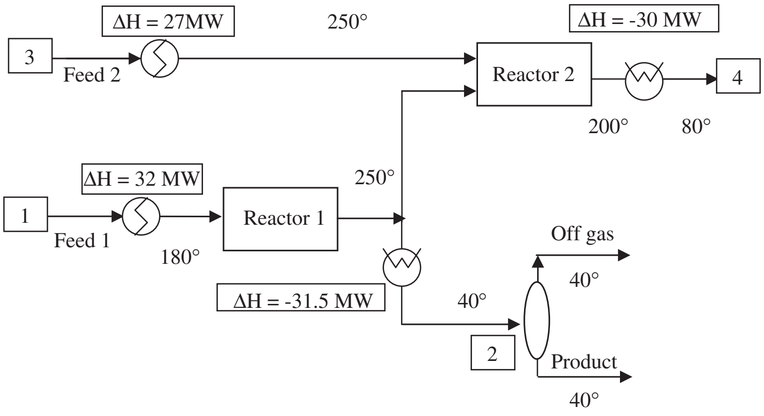

Fig. 2. A four-stream heat integration problem [11].

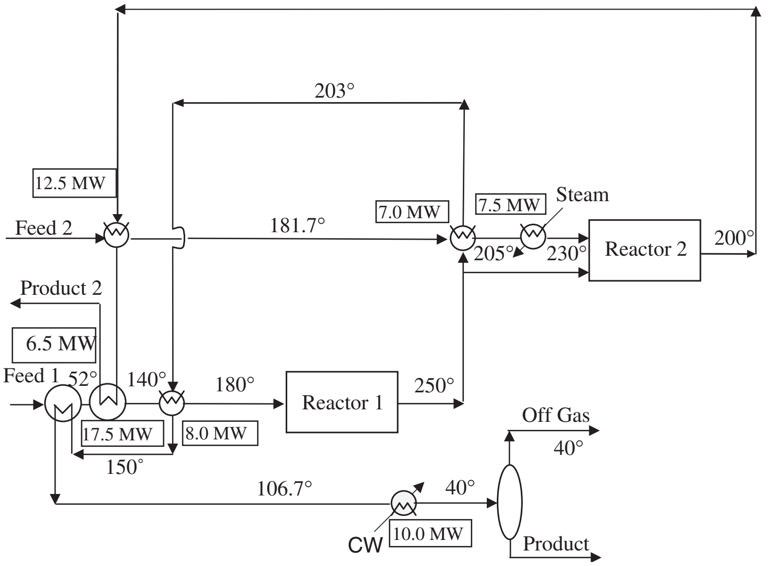

Fig. 3. Maximum heat recovery as suggested by pinch analysis.

Table 1
Emergy characterisation of Stream 1

Stream 1			
Item	Cost ($)	Transformity (seJ/$)	Energy (seJ)
Heat exchanger 6.5 MW	1.34 E+05	1.75 E+12	4.35 E+17
Heat exchanger 17.5 MW	1.52 E+06	1.75 E+12	2.65 E+18
Heat exchanger 8.0 MW	7.18 E+05	1.75 E+12	1.26 E+18
Total emergy			4.14 E+18

Table 2
Emergy investment of separate streams

Stream	Emergy investment (seJ)	Emergy investment per mw (seJ/mw)
Stream 1	4.14E+18	1.29E+17
Stream 2	6.31E+18	2.00E+17
Stream 3	5.13E+18	1.90E+17
Stream 4	4.71E+18	1.57E+17

7.2. Processing impact

As it can be seen in Fig. 2 Stream 2 is generated from Stream 1 and Stream 4 is generated from Stream 3. So, to calculate the emergy of Stream 2 (the product of the reactor), one has to sum the emergy of Stream 1 and the emergy associated with exchangers of 7 and 10 MW and the emergy of the cooling utility. The emergies of heat exchangers of 6.5 and 8.0 MW are not included because they were considered when the emergy of the Stream 1 was calculated (Table 3).

7.3. Cost and utilities

Another emergy impact can be seen in the utilities management. Considering more efficient utilities can lower the TEI. The choice of utility according to the emergy investment may not coincide with the cost of it.

In order to clarify the potential of emergy analysis in respect to cost analysis we have compared two alternatives of fuel used for generation of a hot utility such as steam. The two fuels considered were methane and diesel. The analysis takes into account the heat necessary to produce steam from these two fuels and assumes the fuel cost is almost similar or higher for methane. Changing the fuel has no impact on pinch analysis because the energy supplied by the steam makes no difference how it was produced. The results from emergy analysis and cost analysis are shown in Table 4.

As it can be seen from Table 4, emergy analysis can differentiate between alternative ways of utility generation. The process based on methane has lower emergy investment as methane has lower transformity. From emergy analysis standpoint methane has lower impact on the environment. If the steam required was generated through combustion of wood, the emergy investment would be even lower. Similar considerations can be applied to cold utilities. Analysing different processes of utility generation one can identify the process with the lowest emergy investment.

The conclusion from the emergy analysis of the heat exchanger network is that emergy analysis can help in finding the best option of streams' treatment and optimise the entire system according to new, more comprehensive criteria, the emergy investment, compared to the usual one, the maximum energy recovery.

7.4. Emergy problem

The second problem extends the case study presented by Yang et al. [7] and applies pinch analysis adding extra information about the streams involved (Fig. 4). It forms a typical four-stream, threshold problem (stream data given in Table 5).

Two alternative strategies concerning the utilisation of the side-products are considered. The first one presented in Fig. 4 shows direct release of the slag and the CO, H_2 gas as effluents, when the second one (Fig. 5) explores further utilisation of them. The emergy analysis takes into consideration the operations of preparation of raw materials as shown in Fig. 6 and demonstrates that by reclaiming wastes one can improve effectiveness and reduce the environment impact of the entire operation.

Table 3
Emergy of the streams 1–2 and 3–4

Stream	Emergy investment (seJ)	Emergy investement per MW (seJ/MW)
Stream 1 initial	4.14E+18	1.29E+17
Stream 2 product	8.97E+18	2.85E+17
Stream 3 initial	5.13E+18	1.90E+17
Stream 4 product	7.78E+18	2.59E+17

Table 4
Considering alternative fuels

Stream 3	Cost analysis ($)	Emergy investment (seJ)
Heat exchanger 12.5 MW	1.18E+06	2.06E+18
Heat exchanger 7 MW	2.87E+05	5.02E+17
Steam from methane	2.64E+04	8.56E+18
Steam from diesel	2.64E+04	
Heat exchanger 7.5 MW	3.43E+05	6.00E+17
Total (methane)	1.83E+06	1.17E+19
Total (diesel)	1.83E+06	1.46E+19

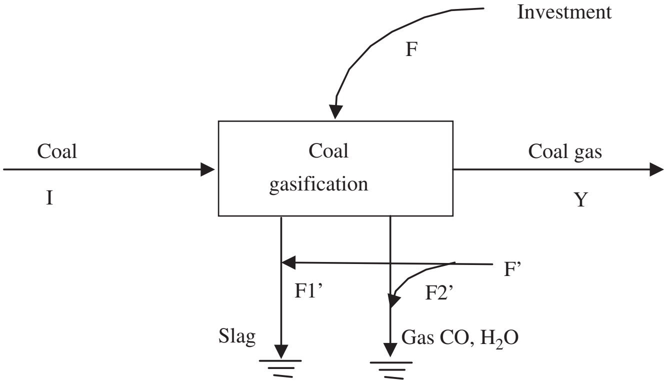

Fig. 4. Realise gases after treatment.

Table 5
Stream—data

Stream	Description	Type	T_s (°C)	T_t (°C)	F_m (t/a)	H (kW)
1	Water	Cold	18	140	447552	7281.54
2	Coal slurry	Cold	20	150	372960	4199.78
3	Coal gas	Hot	700	70	17400	−382.36
4	Pipeline gas	Hot	700	70	691224	−43324.79
5	Slag	Hot	600	200	111888	−1868.58

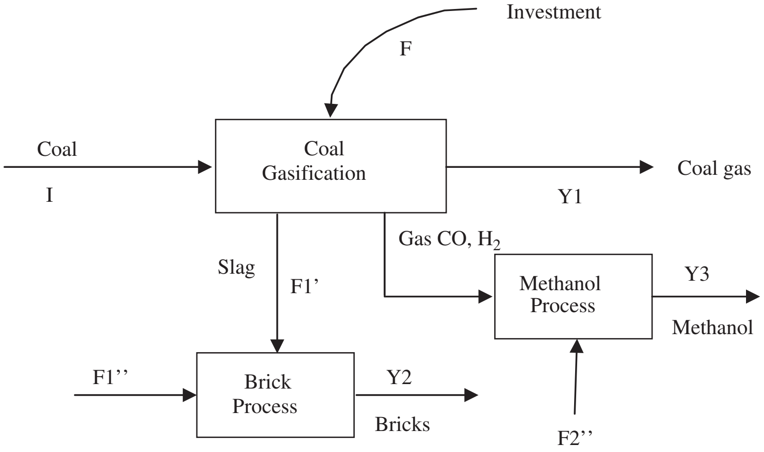

Fig. 5. Reclaim gases for new products.

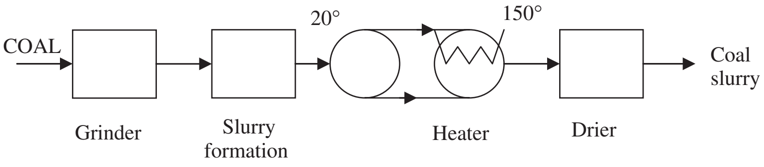

Fig. 6. Pre-treatment of raw material.

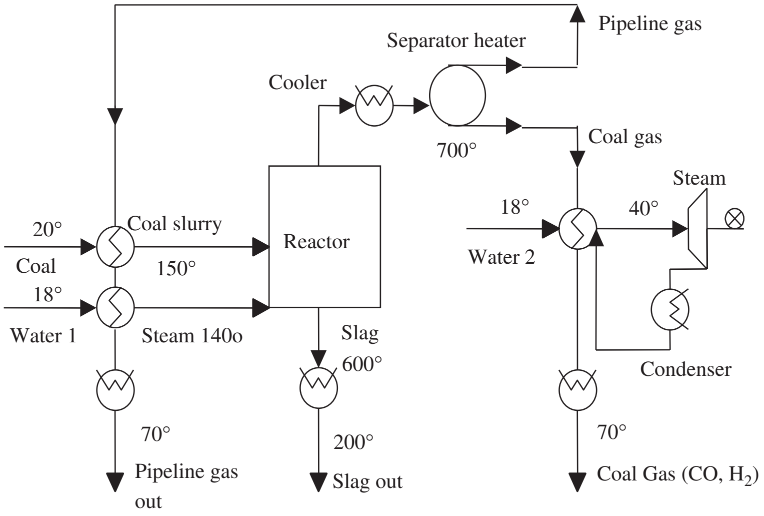

Fig. 7. Product release after treatment and energy recovery suggested by pinch analysis.

Next, pinch analysis was applied for both strategies taking care of maximum energy recovery and the design of corresponding heat exchanger network.

Design changes imposed by pinch analysis suggest a heat exchanger network synthesised to recover maximum of energy (Fig. 7). Accepting the energy waste concept we can see maximum of the residual value of the waste that can be recovered and returned back to the system supported by the decision of additional co-generation option. The suggested changes are similar as a concept to the so-called "end of pipe treatment" of waste. The application of pinch analysis helps in this case to maximise the energy recovery and minimise the negative environmental impact.

7.5. Combined pinch– emergy problem

In the second case, a strategy of "reclaiming for new products", as opposite to the previous one "release the gases after treatment", focuses on best options to generate new products, restructuring the input and the output streams. Emergy analysis has been applied guiding the design to make efficient use of the non-renewable resources and to assess the best option for utilisation of products obtained in the coal gasification process. The slag is converted to bricks, thanks to the exhaustive brick manufacturing process (extrusion, drying, baking), and the coal gas (CO, H_2) is used for producing methanol with the help of a catalytic reactor followed by methanol separation from water. Part of the pipeline gas (CH_4, CO_2) is recycled to obtain heat enough for baking of manufactured bricks.

So, the process has been changed, introducing new streams, some of them are methanol, water–methanol mixture, flue gas from the furnace, air required for combustion, bricks, water, etc. Again it is necessary to characterise all the streams through their temperatures, specific heats and flowrates for calculating their enthalpies (Table 6). Consequently, using pinch guidelines the new heat exchanger network was designed. The results are shown in Fig. 8.

In addition to the advantages of the waste reclaim opportunity for new products, compared to the design with simple release of gasification products, pinch analysis shows the maximum energy utilisation option that enriches the picture and gives design guidelines related to energy recovery optimisation.

The problem under consideration is a typical thermal-pinch problem including three hot and two cold streams. Two of the streams possess quite similar heat availability and thermodynamic properties. The application of emergy analysis to the problem shows that there are two important improvements suggested by the emergy concept: the first one is the additional inside in the selection of the most appropriate (match) heating or cooling partner. When the heat capacities are nearly similar the choice falls on the stream with lower emergy investment for environmentally friendly removal from the system. The second aspect is related

Table 6
Streams involved in the process of products' reclaiming

Stream	Description	Type	T_s (°C)	T_t (°C)	F_m (t/a)	H (kW)
1	Coal slurry	Cold	20	150	372960	4199.78
2	Water 1	Cold	18	140	447552	7281.54
3	Water + methanol	Cold	35	64.7	16530	53.84
4	Water 2	Cold	21	99.99	334372.08	3422.11
5	Brick entering drying	Cold	21	355	111457.36	983.71
6	Air	Cold	20	760	244518.75	6254.05
7	Pipeline gas	Hot	700	70	691224	−43324.79
8	Methanol	Hot	64.7	30	8000	−26.63
9	Slag	Hot	600	200	111888	−1868.58
10	Brick exiting furnace	Hot	900	40	111457.36	−2532.91
11	Flue gas	Hot	600	140	244518.75	−3031.68
12	Methanol mixture exiting reactor	Hot	275	40	17400	−113.45

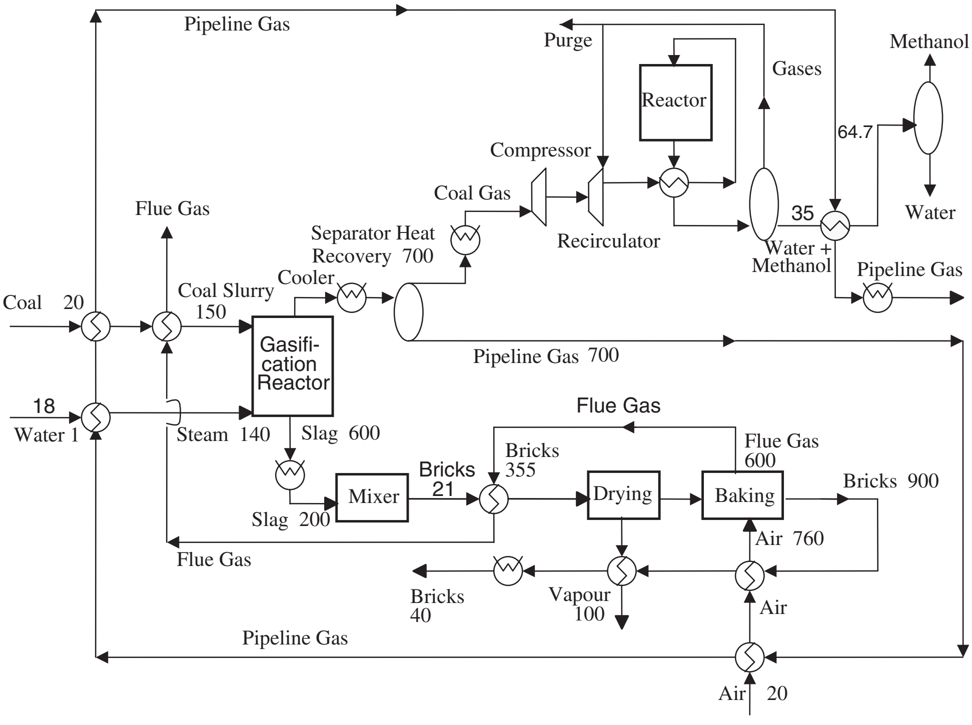

Fig. 8. Reclaiming products and heat integration suggested by pinch analysis.

to the management of utilities, where the emergy analysis introduces additional inside related to the history of utility acquisition. Finally, the third problem was taken from the Water pinch arsenal. There the regenerative reuse and disposal of waste characterised with the least residue emergy is to be considered. Here the sustainability considerations have to be further extended and the application of combined concept for simultaneous water and energy management is to be shown on appropriate case study.

8. Conclusions

The combination of the two approaches (emergy and pinch) gives the following advantages: helps to analyse/assess/evaluate variety of non-monied and monied resources, services, commodities, processes and activities aiming comparison of alternatives through collective criteria; targets the theoretical maximum/minimum of total resources and activities to design and operate an industrial process; helps decision-making and comparison of alternatives prior to any design step; introduces optimising principle through the pinch concept and incorporates the ability to quantify the environment's role in absorbing and processing pollutions through the emergy concept.

The strongest side of emergy analysis is the ability to consider the "history" of resources as well as the "future" of them expressed in terms of the residue value of the waste and its potential for reuse after possible partial or full regeneration. The power of pinch is in current "value" and real potential of resources for immediate and most appropriate use.

An interesting phenomenon is to be mentioned: the supply line in the composite presentation is actually the energy supply line. This closes the loop started by the idea of merging pinch analysis with emergy and brings it again to the analysis of one single resource.

Shortly, presented approach combines energy efficiency and the environmental impact of selected process. The environmental impact of a process can be reduced only by reducing its emergy usage. This is possible through reducing the quantity of raw material (less emergy) or using product with lower transformity, for example using renewable resource that has lower transformity.

Combined approach enables the consideration of nature of raw materials and products and suggests ways to minimise the disruption of the environment when taking these resources from it and releasing them back. It considers the cost (efficiency implication) and (the most important) the beneficial design changes imposed by both emergy and pinch analysis. The combination shows the bottlenecks, but restricted by now only to energy aspects in the process. Currently we are working towards the consideration of water, hydrogen, oxygen and other resources.

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