Heat Integration in Sugar Plant "Case Study" Assalaya Sugar Factory, Sudan

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Abstract*: The main objective of this study is to reduce steam consumption in sugar plant, the reduce of steam consumption means reduce bagass consumption as fuel. The target of this process to divert this steam for generated electrical power shared with national net. The gain from this process is manufacturing sugar from cane with less cost depending on the by-product benefit and increase the profitability. Heat integration is a subdivision of a wider field of process integration, which is an efficient approach that allows industries to increase their profitability through reduction in energy, water and raw materials consumption, reduction in greenhouse gas (GHG) emissions and waste generation. Heat integration analysis principally the data which given and matches cold and hot process streams, then stream data extraction after determine temp approach (ΔTmin), when running of Heat Integration Net (HINT) technology software, generation of temp interval and cascade diagram ,Composite curve and construction of heat exchanger were appearing. The result of this study was, heat energy integration of Assalaia Sugar factory was carried out using pinch technology with HINT software. The minimum approach temperature of 20°C was used and the pinch point was found to be 120, 100°C for both hot and cold streams respectively. The hot utility requirements for the Company before (traditional) and after pinch analysis approach were found to be 1800 kW and the number of heat exchangers minimum 14 and installed are 3 and remaining is 12 heat exchangers. The important recommendation of this study was, the boiling of sugar in process house is under vacuum, that means in different of pressure and less temp of steam made boiling this process and maintain the sugar from the losses.

***Keywords*: Steam, Sugar, pinch technology, Heat Integration, Assalaya.**

1. Introduction

With large global demand for supplies, the industry in general has been increasingly looking for energy solutions that result in savings and sustainability. This is because energy consumption is by far the largest source of expenditure in the vast majority of industrial plants on the planet, and in some of them, there is no reliable energy integration, leading to more expenditure and more pollution from the burning of fuels to attend the specificity of the processes, often making the operation unfavourable to competitive markets. (Neves et al, 2023). Reduction of energy consumption and consequently decreasing of the environmental pollution has been gained a great attention in all energy sectors. Optimization of energy systems is one of the major promising solutions concerned by researchers. In this regard, many organizations with high energy consumption such as heavy industries, petrochemical industries, refineries, and power plants are decided to manage and reduce energy consumption as much as possible (Pradeep, 2015). Pinch technology presents a simple energy analysis and systematic methodology for industrial processes and the surrounding utility systems. The technique was first developed by two independent research groups and based on the applied thermodynamics concepts of (Noah and Aldo,2017). Pinch analysis techniques have been developed for a wide range of applications ranging from process plant thermal or water integration to financial and supply chain management, Pinch analysis was originally developed based on thermodynamic principles to identify optimal energy utilization strategies for process plants. The basic concept is to match available internal heat sources with the appropriate heat sinks to maximize energy recovery and thus minimize the need to make use of external heat sources such as purchased fuels. Analogies between heat and mass transfer led to the field of mass pinch analysis, which is concerned primarily with the efficient use of industrial solvents (Raymond and Dominic, 2007). Pinch technology presents a simple methodology for systematically analyzing Power Plant Processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. Pinch Analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. (Sunasara and Makadia, 2014). Pinch analysis was somewhat controversial in its early years. Its use of simple concepts rather than complex mathematical methods, and the energy savings and design improvements reported from early studies, caused some incredulity. Moreover, pinch analysis was commercialized early in its development when there was little knowhow from practical application, leading to several commercial failures. Divided options resulted. (Linnhoff et al, 2007). "Pinch Analysis" is often used to denote the application of the tools, algorithms and heuristics that are embedded in pinch technology.

The laws of thermodynamics provide the basis for determining the enthalpy changes and direction of heat flow and as such pinch analysis can be used to identify energy targets and heat exchanger network (HEN) capital cost targets for a process by recognizing the pinch point, the temperature at which the driving force for heat transfer is zero, and designing exchange networks based on the location of this point. The process streams that affect energy consumption are identified, quantified in terms of heat and mass flow and categorized in respect to their utility requirements as heating or cooling then combined in form of two composite curves, on a temperature-enthalpy diagram wherein the region for possible heat recovery and utility requirements can easily be identified. Grand composite curve analysis helps towards identifying opportunities for energy-efficient utility integration to satisfy the energy requirements (Dumbliauskaite et al, 2010). The Top-Down approach for analyzing the energy efficiency of industrial processes in the food industry uses Pinch Analysis to identify the possible heat recovery by heat exchange between the streams. The method shows that more than 80% of the energy consumption can be explained by describing only 20% of the units of a factory and thus the approach consists of the identification and characterization of the main Process Unit Operations whose streams are used in the pinch study (Muller, 2007). Assalaia sugar factory is one of the Sudanese sugar company under government sector, is located in latitude12° 13' &19° 1' N and 40° 37' &50° 32' E and located in white Nile state about 280km from south Khartoum, the total area is 41687 Feddan but actual area is 23000 Feddan. Capacity is 110,000 Ton /year sugar; started production in 1980 by England Company (F&S) the irrigation by pump from White Nile.

The main objective of this study is to reduce the steam consumption in Assalaya sugar factory to achieve steam consumption below 60 % cane by stopping the use of live steam as make up in process house and depend only on exhaust steam from alternative turbine and mills turbine, reduce of steam consumption means reduce bagass consumption as fuel.

2. Material and Methods

The procedure involves process streams specification, data extraction and use of HINT software to design or simulate energy process system. In streams specification, the process was divided into hot and cold streams. A hot stream is a stream that needs to be cold to satisfy the process need while cold stream is a stream that needs to be heated up to satisfy process need. In data extraction, the mass flow rate, specific heat capacity, input and output temperature and film heat transfer coefficient for each stream was extracted and finally the heat exchanger network simulation and design were carried out. The stream specification and out for cold and hot steams as presented in Table1.

Table 1

Presents the Operating data of assalaya sugar factory, White nile state, Sudan, which were used to Simulate and design the heat exchanger networks

stream	Stream type	Stream Specification	Flow kg/s	Heat capacity kj/kg.°C	Supply temp °C	Target temp °C	F*CP W/°C
1	Hot	Vapour 1	14.34	1.899	125	107	27.23
2	Hot	Vapour 2	14	1.895	107	85	28
3	Hot	Vapour 3	11.12	1.892	85	54	30
4	Hot	Juice from 2nd evap	30	1.890	120	106	27.25
5	Hot	Juice from3rd evap	24	1.88	106	84	28
6	Hot	Juice from 4th evap	18	2.8	84	55	31
7	Cold	juice from RJ.H1	72.5	3.74	30	65	27.5
8	Cold	Juice from R.J.H2	72.5	3.76	65	85	28
9	Cold	Juice from R.J.H3	72.5	3.77	85	103	28.5
10	Cold	Juice from pre evap	72.5	3.67	95	110	27.5
11	Cold	Juice from evap1	41.07	3.42	110	120	22.2

The following figure shows the steam consumption in Assalaya sugar factory through season 2016-2017.

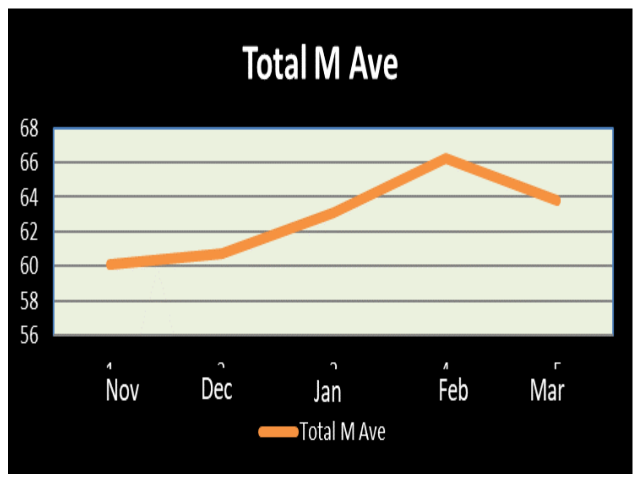

Fig. 1. Steam consumption %cane

3. Results and Discussion

Fig 2: represent the Hot and cold composite curve diagram of Assalaya sugar factory:

The upper curve is represents the hot streams composite curve while the lower curve represents the cold streams composite curve. The part of the hot stream the composite curve that extend beyond the start of the cold streams composite curve cannot be cooled by heat recovery. The point where the two curves are closest is the pinch point and the corresponding temperature is the pinch temperature. Therefore is minimum cold utility requirement (kW). The part of the cold streams. Therefore is the minimum hot utility requirement (1800 kW). The point the where two curves are closest is the pinch point and the corresponding temperature is the pinch temperature (128.5˚C).

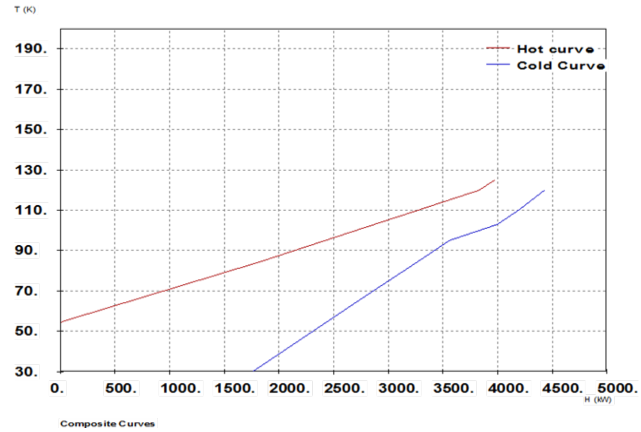

Fig. 2. Composite curve

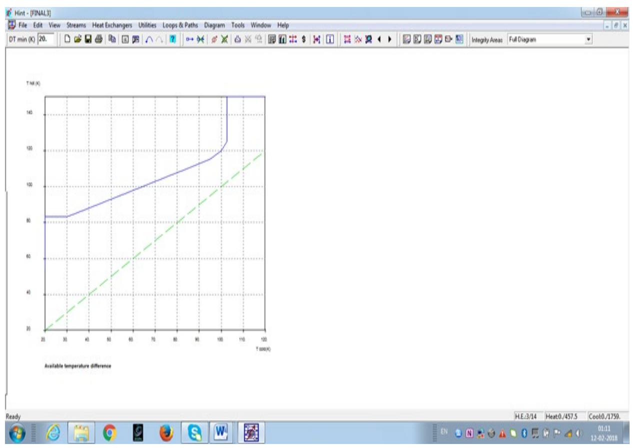

Fig. 3. Shows the different temperature between hot and cold stream

Table 2
Stream table

Stream Description	Type	Heat Type	T1	T2	H mcp
1 H1	Hot	Sensible 125	107	-504	28
2 H2	Hot	Sensible107	85	-627	28.5
3 H3	Hot	Sensible 85	54	-930	30
4 H4	Hot	Sensible 120	106	-395.5	28.25
5 H5	Hot	Sensible 106	84	-616	28
6 H6	Hot	Sensible 84	55	-899	31
7 H7	Cold	Sensible 30	65	962.5	27.5
8 H7	Cold	Sensible 65	85	560	28
9 H8	Cold	Sensible 85	103	495	27.5
10 H10	Cold	Sensible 95	110	412.5	27.5
11 H11	Cold	Sensible 110	120	240	24

The above table can be use to introduce the thermal properties of these stream and called stream table this table is table data which interred in to the system including the following:

-stream hot and cold
-Description of the stream e.g. .juice vapours ….etc.
-type of stream hot or cold
-T_s: supply temperature (T1)
-T_t : target temperature (T2)
-MC_{Pc}: mass multiply by specific heat (kw/k)
-H: new result after finished all streams and press ok.

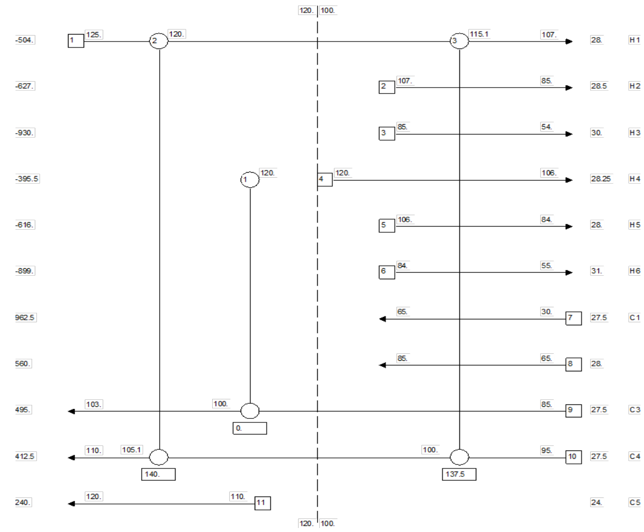

Fig. 4. Grid diagram

The cascade diagram of Assalaya Sugar factory shows the minimum driving force of 10°C between the hot and cold streams were used. The graph showing the temperature intervals for hot and cold streams were established. The left side is for the hot streams while the right side is for the cold streams. 15 intervals were used, which means there are 15 points from possibilities of heat transfer within the system.

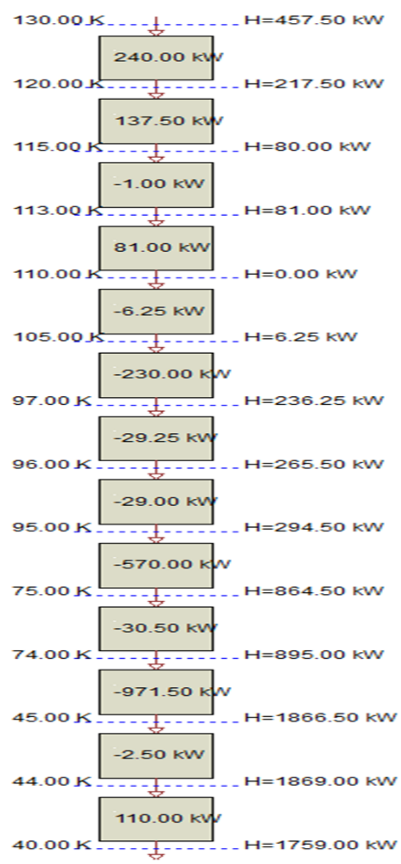

Fig. 5. Cascade

The streams with arrow pointed downward are hot streams, which mean they have to be cooled to satisfy the process need. The streams with arrow pointed upward are cold streams; they have to be heated up to satisfy the process need.

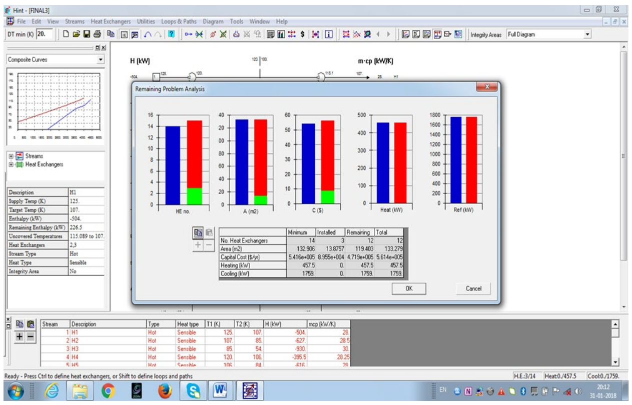

Fig. 6. Remaining problem

If we are looking to the columns in the above figure, there was more cooling than heating. The minimum number of H.E is 14but installed was3remaining was 12that means heat transferred in boiling house by the different of pressure (under vacuum). The minimum area was 132.906m,but installed was 13.8757m and remaining was 119.403m and total was133.27

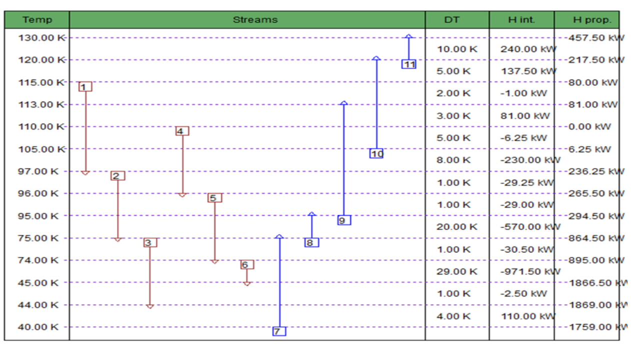

Fig. 7. Interval diagram

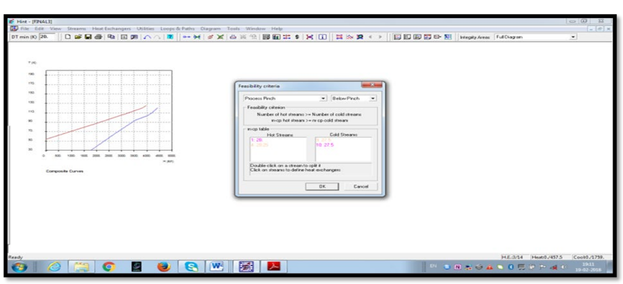

Fig. 8. Feasibility

The graph showing the temperature intervals for hot and cold streams were established. The left side is for the hot streams while the right side is for the cold streams. 11 intervals were used, which means there are 11 points from with possibilities of heat transfer within the system. The streams with arrow pointed downward are hot streams, which mean they have to be cooled to satisfy the process need. The streams with arrow pointed upward are cold streams; they have to be heated up to satisfy the process need. And temperatures of the output cold streams. The temperatures were from any hot streams were transferred to any of arranged in descending order. In each interval, heat the cold streams in the interval.

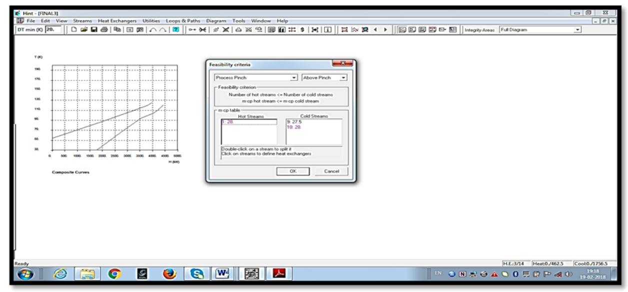

Fig. 9. Feasibility

The feasibility criteria forms for the streams above the pinch temperature (right) and bellow the pinch temperature (left). The upper section displays the feasibility criteria on each side. The lower section displays the mC_p tables. Streams that are connected with a pinch heat exchanger are marked in the same colour in the mCp tables. Heat exchanger design started from feasibility and showing in fig 8 &9.

a) Bellow pinch the number of hot stream number of cold stream and mC_p hot stream $\geq mC_p$ cold stream.
b) Above pinch the number of hot stream $\leq$ number of cold stream and mC_p hot stream $\leq mC_p$ cold stream.

4. Conclusion and Recommendations

A. *Conclusion*

Energy integration of Assaalia sugar factory was carried out using 20 as ΔT min. The temperature interval; Cascade and composite curve diagrams were constructed using the data obtained from operating of Assalia sugar factory. The hot utility requirement, cold utility requirement and pinch point were obtained. The hot utility requirement, cold utility requirement and pinch point were found to be 110 kW, 1750 kW and 110°C, respectively from the temperature interval, cascade and composite curve diagrams, and the number of heat exchanger is minimum is 14 and installed is 3 and remaining 12. From this study and after application of heat integration, I observed there was more cooling in comparison of heating. The heating of juice use 2[nd] and 1[st] vapors in different in pressure by vacuum, also juice in evaporator and pan all this under vacuum as the boiling in temp less than 100°C all these should be considered when applying of HINT.

B. *Recommendations*

1. Mills should operate with optimum conditions to produce exhaust 70% to 80%.
2. Live stem which DE superheated should stop.
3. Stop any leaking of steam or vapor lines.
4. Isolate any line carry steam or vapor to reduce radiation losses.

5. Isolate any line carry juice syrup, magma, and molasses.
6. Routine practice to use 7 Kg steam for molasses tank and molasses conditioners. Conditioned molasses temperature – 80^{o}C to use 160-180^{o}C steam to achieve 80^{o}C temperature is not advisable.
7. The routine practice to use 7kg/cm steam pan washing before start of new strike.7kg/cm steam should replace by exhaust steam 120^{o}C to achieve 90^{o}C
8. The boiling of juice and sugar under vacuum in process, this can be considered in application of HINT.

References

[1] B. Linnhoff, D.W. Townsend, D. Boland, G.F. Hewitt, B.E.A. Thomas, A.R. Guy and R.H. Marsland, 2007, Pinch Analysis and Process Integration A User Guide on Process Integration for the Efficient Use of Energy Second edition Ian C Kemp.

[2] Dumbliauskaite, M., Becker, H. and Maréchal, F. (2010) Utility Optimization in a Brewery Process Based on Energy Integration Methodology. Proceedings of ECOS, 91-98.

[3] Noah Tibasiima, Aldo Okullo, 2017, Energy Targeting for a Brewing Process Using Pinch Analysis, Energy and Power Engineering, Scientific Research publishing, ISSN Online: 1947-3818 ISSN Print: 1949-243X.

[4] Muller, D. (2007) Web-Based Tools for Energy Management in Large Companies Applied to Food Industry. PhD Dissertation, EPFL-STI, Industrial Energy System Laboratory, Lausanne

[5] Raymond R. Tana,[a,*], Dominic C.Y. Foo[b], 2007, Pinch analysis approach to carbon-constrained energy sector planning, ELSVIER, Science Direct ,Energy 32 , pp1422–1429.

[6] S. R. D., Neves, Y. P. C. D., Santana Silva, O. D. A. D. (2023). Energy Optimization Study In an Ethanol Production Unit Using Pinch Technology. J Electrical Electron Eng, 2(2), 187-195.

[7] S. R. Sunasara[1] , J. J. Makadia [2] *, 2014, Pinch Analysis for Power Plant: A Novel Approach for Increase in Efficiency, International Journal of Engineering Research& Technology(IJERT). Vol.7 Issue:6.

[8] T.S.G.V. Pradeep Varma,2015, Design and analysis of a cogeneration plant using heat recovery of a cement factory Case Stud. Therm. Eng., 5), pp. 24-31