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Applications of Pinch Technology

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Abstract : Pinch Technology is a technique used to design a particular system in a process (or even overall plant) to minimize energy consumption. It has benefits in a huge range of plants and processes mainly in large industries but is used in smaller industries too. It is an important step in designing and development of the overall process which contributes to the process synthesis and optimization of already working plants. This paper reviews the use of Pinch Technology in various fields and can be studied by process engineers to get ideas for applying technology in the respective plants as required.
Keyword: Pinch Technology.

Introduction

Pinch Technology is a wider subdivision of process integration. It uses basic thermodynamic principles for constructing a design which will help in saving energy or optimize the process for maximum recovery of energy. Pinch technology is mainly used in major chemical manufacturing plants or oil refineries where heating or cooling of feed streams is required. Pinch analysis uses the hot streams to heat the cold streams and vice versa, thus saving the hot or the cold utility loads which obviously helps in energy and cost savings.

The idea of how Pinch Technology can be applied in the overall process design can be explained from the following diagram.

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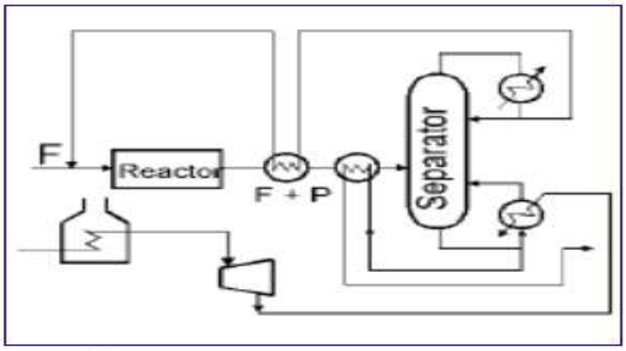

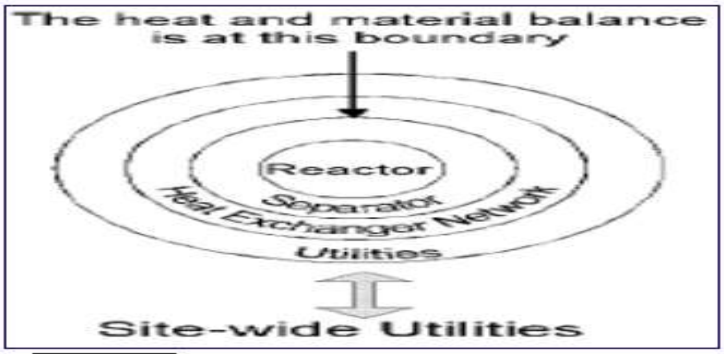

Figure 1 is a flow sheet for some standard process and figure 2 is the onion diagram of the process hierarchy representing the order in which the process optimization should be done. Firstly, the reactor which is also the "core" of the onion is designed. Once the feed, product, recycle concentrations and flow rates are obtained, the design of separators (the second layer of the onion) begins. Thus, the material balance and heat balance are established and the third layer i.e the heat exchanger network is then designed. The cold and hot streams which were not utilised in the heat exchanger network are optimized by the utility system which is the fourth layer.

Pinch Analysis involves

- Collection of heating and cooling stream data using heat and mass balances.
- Calculation of energy targets.
- Constructing the T-I diagram, hot and cold composite curves, and Grand Composite Curve.
- Finding the pinch point.
- Examining the opportunities for any process change.
- Designing a heat exchanger network according to the targets.
- Calculation of the energy and cost saved by performing Pinch Analysis.

But this paper is not about pinch technology. It's about the applications of pinch technology in various fields and sectors. Pinch analysis was initially used only in Petroleum industries its areas of application extended with people studying and applying pinch technology a lot more due to the recent advancements in technology. Pinch Technology is used in variety of industries ranging from base chemical production factories to paper and food industry. Pinch Technology is considered as one of the main process in plant design and every process engineer should have proper understanding of this to come up with new ideas of how the energy can be saved in any processing plant. Given below are some of the case studies of applications of Pinch Technology in various different fields.

- **Distillation Unit and the Fluid Catalytic Cracking Unit**

Victoria TIMOTHY, UsmanAliyu EL-NAFATY, SaidatOlanipekunGIWA[3]analysed the results of energy integration of an **Atmospheric Distillation Unit and the Fluid Catalytic Cracking Unit** of Kaduna Refining and Petroleum Company using the HENSAD software. HENSAD (Heat Exchanger Network, Simulation and Design) allows engineers to systematically analyse industrial processes. In the atmospheric distillation unit, distillation of local crude into naphtha, gasoline, kerosene, diesel and bottom residue is carried out. Firstly, the present heating and cooling streams for the individual units were identified, and their data was entered in the HENSAD software. Then, the ΔT_{min} value along with the pinch point temperatures for both the units was calculated. Then the constant temperature intervals were obtained from shifted temperatures with the help of which, the cascade diagram and temperature interval diagram were constructed. The network design of heat exchanger for “above the pinch” and “below the pinch” were also constructed. After constructing the new heat exchanger networks, energy savings were calculated and an economic analysis was done. Based on this, it was proved that for the atmospheric distillation unit, the energy saved was 10011 kW and 6570 kW for the cold and hot utilities respectively. For the catalytic cracking unit, the energy saved was 64974.7 kW and 67750 kW respectively for the hot and cold duties. These are considerable amount of energy savings which yielded cost savings that could be further utilised for development of the company. Thus, the ADU and FCCU units were successfully optimized using the Pinch Technology and it was proved that the use of external utilities like energy, water etc. was minimized by using the present surplus utilities, thus helping in cost and energy savings.

- **Crude Preheat Train**

  Kemp, I. C. [2] in 1990 reported the was the first pinch study performed on a major operating plant. In the **Fractionation of Crude Oil** step, 25% increase in the throughput was to be achieved without increasing size of the current heater. So, the contractor’s design grid diagram was presented but the large air- cooled heat exchanger needed modification. So, a new model was presented where the ΔT_{min} value was reduced to 7°C. But this required 2 new heat exchangers and increase in total surface area which was proving to be costly. The reason as to why basic, contractor’s design and increased area design was not yielding the best results was found out by plotting grand composite curves and hence it was observed that pinch at shifted temperature was not sharp. So, a new MER network was designed using pinch. There were 5 hot streams and 1 cold stream. So, to manage the loads, 1 stream was to be evolved out. The MER design showed 10% energy saving over the existing plant and 25% over the contractor’s design. But, when UA analysis was done, the area required was found out to be very large. So, heat input the fired heater was increased by increasing the gap between composite curves. But still 2 problems remained i.e. the expensive modification of air cooler and the 4- way split. 1st one was solved by shifting load round the loops from air cooler to any of the water coolers. For solving the 2nd problem, the 5th branch was split and het was taken from top of the crude tower in a liquid “Pump around” due to which vapor flow was reduced in the topmost section. This required 1 more match but 1 less stream split. Therefore, this made the design correct near the pinch and identified multiple stream split making use of limited temperature driving forces. This design was later proved to be energy saving and was safer and cheaper.

- **Naphtha Production Unit**

  Ali Manizadeh, Ashkan Entezari and Rouhollah Ahmadi [4] reported their study of the **Energy Optimization of A Naphtha Production Unit** by applying pinch technology. They used the Energy Pinch technique to subject the given system to Maximum Energy Recovery (MER) design where the hot and cold utilities’ size in a process is minimized by the internal energy streams. They identified the opportunity for a better heat exchanger network for decreasing the energy consumption. The present unit was then retrofitted in 3 stages. In its first stage, the design aimed to obtain the maximum possible heat exchanger recovery. Here, the GCC of the MER design was constructed and it was found out that that the thermal energy recovery was increased in the MER design. But, the duty of heat exchangers also increased with the energy recovery. So, the 2nd stage aimed at relaxing or eliminating a few exchangers or utilities to reduce the investment cost. Since, the design of 2 separate heat exchanger networks for above the pinch and below the pinch design were adding up to the increasing investment cost, the exchanger with a lower thermal load in the loop was removed. This led to a little increase in the heating and cooling duties but reduced the investment cost. So, the 3rd and last stage focused on finding the perfect balance between optimum energy and also economic retrofit system. The external loads were provided using natural gas and electricity for heating and air coolers respectively. Thus, the naphtha production unit was presented with a new design. This design was not the optimum design for energy recovery but it was the best possible design for increasing the economical profits and reducing the operational costs.

- **Industrial Ethylbenzene Plant (Retrofit Case)**

Sung-Geun Yoon, Jeongseok Lee and Sunwon Park[5] studied and retrofitted a heat exchanger network for an **Ethylbenzene Plant** using pinch analysis for energy saving because in petrochemical industry, energy saving is the most important issue along with cost and regulations. The entry and exit temperatures and the heat duties were collected first, and the hot and cold streams were then identified. The heat exchange area and quantity of heat exchange was estimated using the temperature data. Next step was to check the gap between ideal and current energy consumption because retrofitting is not possible if the gap isn't satisfactory enough. Composite curve was plotted for analyzing this gap between ideal and current HEN (Heat Exchanger Network). The cold and hot composite curves were located in the most adjacent position to discover the amount of energy recovery. $\Delta T_{min}$was 10°C and the pinch point was 100°C. Since, to achieve minimum energy consumption, the heating utility must be higher than the pinch point, HEN improvement was carried out because the heat source was below the pinch point. In designing the new HEN, heat source and heat sink streams were defined. 1 new heat exchanger was added for heat recovery and therefore, the use of LP steam and cooling water was reduced. The additional heat duties of the reboilers were later reduced by raising the column feed temperature. After analyzing the streams by the ASPEN Plus software, it was found out that the gap between 2 curves was narrowed in the retrofit HEN, but the pinch point was the same. Although the retrofit design had different operating conditions than the base case, more heat was recovered using this design. Economically, this design was able to achieve savings worth $0.61 million per year. So, the heat exchange between top vapor stream going to the condenser and the feed stream containing benzene reduced the energy cost for benzene preheating, reboiler preheating and condenser cooling.

- **Evaporator/Dryer Plant**

Ian C Kemp in his book "Pinch Analysis and Process Integration"[2] reported another application of the Pinch Technology in an **Evaporator Plant**. This was carried out in a **Food Processing Factory**. The 1st stage processing comprised old and inefficient batch equipment. So, it was decided to rebuild the front end of process and an energy utilization study was performed for efficiency improvements and possible process change. The evaporator in the process uses flash tanks in 3 stages driven by flash vapor, steam ejector, utility steam, respectively. After that, the dryer carries product through 7 different temperature zones from 30-60°C whose heat input is via 6 steam radiators. Therefore, the steam data of hot and cold streams was extracted. The direct steam injection, flash tanks, mixing streams, condensates were also considered for process change analysis. ΔTmin was found out and the heat recovery was 1171 kW. On plotting the GCC, pinches were localized and the temperature driving forces were extremely high. The sharp pinch suggested that heat pumping could give further energy savings. But, only 347 kW could be pumped which required 40°C rise in temperature. So, this situation was improved by using a pocket and using a 2-stage heat pumping strategy. For increase in the savings, a mechanical compressor was used instead of ejector. Flash steam 2 and its condensate was used to heat the process water, hence replacing the utility steam. A part of flash steam 1 was used to heat flash steam 3. But, the MER network for this design showed a small ΔT_{min} violation. So, a higher load was to be carried to rectify the rule and therefore the plate frame type heat exchanger's area was increased by adding more plates. Also, the H.E area between the Stage 3 flash heater and the feed heater was increased. The vacuum system capacity was then increased due to increase in size of the piping system. The revamped layout of the modified plant was utilized, and this design helped to achieve 47% savings and yielding a profit of □ 85,000 per year. This study also proved that pinch analysis could yield results on smaller scale too and not only the big plants in bulk chemical industries.

- **Organic Chemicals Manufacturing Site**

Clayton[2] reported the application of Pinch Technology in an **Organic Chemicals Manufacturing Site** in 1988. But, over here, the formation of heat and mass balance and the methods of stream data extraction were not discussed. The site concerned had 3 separate major plots :- Tar Acid Formation (TAR), Crude Oil Distillation(COD), Effluent treatment Plant (ETP), all with different pinch temperatures. The heat recovery was difficult to achieve. For example:- TAF plant contained many distillation columns but because of heat sensitivity, high viscosity, shifting temperature and pressure could not necessarily allow heat transfer sufficiently. So, when the stream data set for entire site combined, grand composite curves were plotted, it showed much larger saving. But, the TAF and ETP plants were 1/4 mile apart. Therefore, the piping would have been uneconomic. But, since the heat demand for ETP was due to low pressure steam, the steam could be raised from condensers of TAF plant and piped using the existing site steam mains. Therefore, the distillation columns acted as supplementary boiler-house. Also, if the ETP plant was shut down, the steam raised on TAF plant could be used for other low-pressure needs. If all the processes were combined, 29% savings were achieved and if only TAF and ETP plants were linked, 33% savings was obtained. Thus, pinch technology and GCC helped in identifying the zonal targeting method and total site analysis.

- **Multiple Effect Evaporators In Sugar Process Production**

Meilyn González Cortés, Harry Verelst and Erenio González Suárez[6] performed the energy integration of **Multiple Effect Evaporators In Sugar Process Production**. They reported that the energy consumption of evaporator subsystem is reduced when multiple-effect evaporators (MEE) are used along with the remaining processes. The process heating and the evaporator subsystem was to be retrofitted for improving the heat recovery. A Sugar Plant Simulation was carried out in ASPEN PLUS software. The evaporator step in the subsystem which generated vapor and condensates was configured using process integration due to which, the possibilities to increase the sugar output without any costly investments in the utility system could increase. The cold and hot currents analysed in the ASPEN PLUS software were directly introduced to the ASPEN PINCH software where the energy integration was carried out. The data were evaluated at different ΔT_{min} and the GCC were constructed. Minimum Utility Requirements were obtained which was lesser than the initial requirements. So, it was proved that there was an excess exhausted vapor consumption which could be easily replaced by the utility currents. Thus, process simulation and integration helped to select the most suitable configuration of Multiple effect evaporator for the best possible energy savings.

- **Energy Integrated Distillation Column Sequence**

MunawarZamanShahruddina, Ahmad NafaisRahimi, Muhammad AfiqZubir, Muhammad Fakhrul Islam Zahranb, KamarulAsri Ibrahim, and MohdKamaruddinAbdHamid[7] published their study on **Energy Integrated Distillation Column Sequence** by driving force and pinch analysis method. Distillation finds its applications widely in the chemical and the petrochemical process. The driving force method was used to determine the best possible distillation sequence for minimum energy consumption. The process involved five alkane components and about 14 distillation column sequences were possible and therefore simulated using the ASPEN HYSISV9 software. After extracting the required data based on simulations, the sequential algorithms were constructed. The most effective sequence was determined using the heating, cooling and total loads and calculating the total energy consumption for each after which the grid diagram was constructed based on the best possible sequence. The grid diagram was then analysed and the total energy requirement was re calculated and thus, the energy savings were calculated. Thus, Pinch analysis when combined with the driving force method also showed a lot of energy savings.

- **Steel Plant**

Kazuo Matsuda[8] published his study on the application of Pinch Analysis in a **Steel Plant**. Steel plant utilizes a huge amount of energy. For total energy saving potential identification, pinch technology is to be used for total site analysis. Most of the processes in steel plant were operated under atmospheric pressure. Therefore, the concept of heat exchangers for recovery wasn't recognized. So, a procedure for retrieval of the heat exchanger data is important to analyse how the data is utilised in each process system. The study was done on a large steel plant which had the annual production capacity of 80,000,000-ton crude steel. CDQ (Coke Dry Quench) was the most effective recovery system with a CDQ chamber and boiler. N_2 in the 1st heat exchanger (CDQ chamber) appeared as utility fluid but operating condition was of process fluid, so it was decided to use the data of 2nd heat exchanger (CDQ boiler). 5 utility conditions were used for heaters which were 2 pressure levels, 1 steam condensate, 2 types of flue gas and 3 utility conditions were used for the coolers. Presently, the heater's duty was almost twice as large as that of coolers. Therefore, the heat recovered was only 50% of the heat consumed. The unrecovered heat was due to a large gap between composite curve for heaters and coolers. Then, the targeting case for energy savings was obtained by changing the utility conditions by replacing old streams and generating new streams. Intermediate pressure steam (IPS) was now used for FG-H instead of FG-L due to which FG-H did not heat the steel but sent the heat to the adjacent thermal power plant for power generation. Also, on cooling side, VHPS gen was used. Therefore, maximum heat recovery was thus obtained. This approach was able to identify large energy saving potential.

- **Heat Pumps**

H. Becker, F. Maréchal and A. Vuillermoz[9] stated that it is required to install a **Heat Pump** to optimize processes due to high fuel cost. In heat pump, the waste heat of the process is enhanced by electrical power, thus producing higher quality of heat. The produced energy is later used in the process to lower the fuel requirement and thereby causing a reduction in CO_2 emission. A systematic analysis with pinch and exergy techniques was studied in detail. The author stated a research experiment that analyzed integration of heat pump in a process using a computer program that systematically allows one to change the temperature level of individual stream involved in the heat pump. The analysis of process composite curves helped to identify proper heat pump types and temperature levels. The author also depicted the work of a researcher who presented a mathematical formula in the integration of heat pumps which evaluated the hot and cold utility cost. When the temperature levels of heat pump cycle were known, the saving potential was estimated. Since, the heat pumps were used in process utilizing water, a combined water and energy analysis was made. The temperature-enthalpy profile of heat transfer requirement and quality-flow rate profile of water usage was defined. The effluent stream contained a lot of renewable heat and were cooled to an ambient temperature. Thus, the maximum energy recovery possible was calculated. 25% of water was saved in the process. Then, the utility stream was analyzed and defined. The pinch point was located around 59°C and according to pinch analysis, heat pump would be integrated to escalate the heat from 52°C-82°C.

- **Industrial ORC Integration**

Donald Olsen, YasminaAbdelouadouda, Peter Liemb and Beat Wellig[10] stated that the most effective technique related to process design optimization to improve energy efficiency is process integration. The in-process heat recovery (HR) is central for increasing energy efficiency. The core of analysis was to set the optimum connections between different heating and cooling streams and the requirements for the entire system which give the maximum heat recovery at minimum cost. Organic Rankine Cycle (ORCs) are generally used in the industries for obtaining electricity by using heat which would otherwise be rejected to the environment. For proper and optimal ORC integration, the in-process Heat Recovery must be accurately assessed so that ORC integration should make use of only the waste and surplus heat. Its design was obtained graphically by plotting the Grand Composite Curve and obtaining the $\Delta T_{min}$and the pinch point. Therefore, the temperature and heat flow of the evaporator and condenser were obtained directly from the graph. The waste heat below the pinch point was used to produce electrical energy. The overall cold utility (CU) requirement after ORC integration is equal to the CU minus the electrical power generated which benefits the ORC as the cold utility requirement is thus reduced. Therefore, it was concluded that pinch technology is a convenient method for performing and applying ORC analysis in industries.

- **Waste Management Using Pinch Analysis**

Wai Shin Hoa, Sie Ting Tana, HaslendaHashima, JengShiun Lima and Chew Tin Leeb[11] brought up a new method for modifying the ways of **Waste Management Using Pinch Analysis**. They studied the WAMPA method (WAste Management Pinch Analysis) which aims to identify the waste management techniques based on landfill reduction target and the carbon emission target. Carbon Emission Pinch Analysis (CEPA) method already was in existence which addressed the carbon emission constraint issues. WAMPA makes use of the CEPA method which requires user to set a new target. Firstly, a supply curve (Waste Processing Capacity Curve) is constructed which represents waste treatment, processing and disposal capacity. Then, the targets are set for the reduction of waste to landfill and carbon emission reduction. These targets are calculated using the Pinch Analysis method. New curve is then plotted based on the new targets. The supply curve is grouped under 3 categories according to carbon emission from landfill, WTE(waste to energy) and no emission strategies. Thus, the effect of increasing and decreasing allocation for various categories was later presented. Due to this, WAMPA was able to identify the capacity of each group of strategy and the effect of changing the targets set for each group.

- **Hospital Site**

A. Herrera, J. Islas and A. Arriola[12] studied the application of pinch technology in a **Hospital Complex** of

IMSS. Here diesel was using 75% of its overall energy consumption. So, it was important to optimize the thermal energy savings in the complex. Pinch analysis showed the identification of the maximum thermal energy recovery, best possible heat exchanger network and minimal thermal utilities requirement. Firstly, the process diagram and thermodynamic data of hospital complex was obtained. Then, the hot and cold screams were identified followed by plotting the hot and cold composite curves. When the graph of required thermal services against ΔTmin was plotted, a threshold case was opted between the temperature range 0-22°C. So, to resolve this case, an analytic method was used to find by iteration. The modified temperature data was obtained and the ΔTmin value was 22°C. According to this, a heat exchanger network was designed. 4 heat exchangers were to be placed. 2 in the boundary zone, 1 in the machinery, 1 in condensation tank area. The energy targets were found out; the thermal system did not need any cooling utilities only heating utilities were required. The minimum heat load necessary to transfer from hitting utilities to hospital complex was found out to be 388.64 kW. The grand composite curve was then plotted which told the yearly savings to be 12.26 TJ. This could save 2,46,000liters of diesel and 100000 USD yearly savings. Also, the analysis of GCC showed that 60% of thermal power demand could be satisfied through solar collectors, heat pumps etc. Finally, GCC suggested that use of these technologies could be a source of major energy and economic reduction.

- **Pulp And Paper Mill**

ElinSvensson and Simon Harvey [13] reported their study in which they proposed retrofit designs in a partly integrated **Pulp And Paper Mill** industry. Successful implementation of bio refinery concepts requires maximised heat integration and can lead to increased and diversified revenues as well as reduced global carbon dioxide emissions. Integration of bio refinery operations within a pulp and paper plant is a typical application of heat cascading where heat for one plant is supplied by excess heat from another. A chemical market pulp mill with optimised energy consumption could achieve a surplus of energy which is further used to produce electricity and enables decreased firing of bark fuel in the mill's power boiler. The study in consideration was reported was performed at BillerudKarlsborg mill. Multiple heat exchangers were used to supply heating and cooling to the mill process streams. After finding out the pinch temperature and $\Delta T_{min}$and plotting the composite curve and the grand composite curve, it was observed that the heat which was currently used for warm water production from raw water, could be released by making use of hot streams which are below the condensers' temperature i.e. the outgoing air from the pulp dryer and the hot effluents from evaporation plant. But this design had several pinch violations because it was heated below the pinch. So, to fix this, 2 retrofit suggestions were presented. Retrofit 1 involved straight forward changes whereas retrofit 2 was more extensive. Retrofit 1 mainly focused on saving steam as much as possible without interfering with hot and warm water system. It suggested that the existing hot streams should replace the low-pressure stream for energy savings of around 4%. Similar concept was used in the retrofit design 2, but the number of cold utilities replaced by the number of hot utilities was more which resulted in larger savings than design 1. It was possible to save approximately twice as much steam as in retrofit 1. The changes were made in hot and warm water system by adding heat exchanger networks. The proposed retrofit designs assured that steam savings led to a reduced use of bark in the power boiler with more energy savings and lesser pinch violations.

- **Ventilation System**

VioletaMisevičiūtė, VioletaMotuzienė and KęstutisValančius[14]analysed the opportunities of the analysis of process integration in a **Ventilation System**. Heating, ventilation and air conditioning (HVAC) systems of buildings consumes 40% of energy and much of it is wasted. Ventilation systems use heat exchangers as one of their main energy saving measures. The data for Air Handling Unit of a ventilation system was extracted. Then, the thermal utilities were identified and ΔT_{min}value was found out after constructing the composite and grand composite curve. A HEN was then designed where a few changes were proposed. The outdoor air temperature which changes seasonally is the cause of heat shortage. This could be fixed by additional heating equipment. The design for the same was given. Also, an additional flowing heat transfer fluid could be used from the heat supply network. The new HEN uses waste energy which leads to reduced energy demand. Also, a significant decrease in energy costs after integration was caused because of the poor combined capacity regulation of both temperature and flow rate applied in the actual system. In this way, it was inferred that the utilization of process integration (pinch method) to integrate the process in building engineering systems can provide more efficient solution for complex planning of such system in terms of energy and exergy.

- **Wastewater Minimization in Process Industry**

R. P. Singh, K.K. Srivastava and S.P. Singh[15] analyzed another case study on application of pinch technology to **Minimize the Wastewater In Process Industry**. Before treating the wastewater, it was important to reduce its generation as it automatically reduces the treatment cost and load on fresh water supply. In industries, generally the process material is contacted with fresh water to reduce its contaminant level due to which, the water gets contaminated and wastewater is generated. The methodology for process wastewater minimization involved the reuse of wastewater. The process requirement specifies the inlet and outlet concentration of contaminants in process stream, mass of the contaminants transferred and the water flow rate. To maximize water reuse, the inlet concentration must be high according to which the maximum outlet concentration is also specified. This profile of maximum inlet and outlet concentration is called the limiting water profile. Then, a limiting composite curve was constructed. The water supply line was then matched against this limiting composite curve. A pinch in the design is created at the points where the limiting water profile comes in contact with the supply line. To minimize the water flow rate using the limiting composite curve, 2 different approaches were used. The first one involved using **maximum driving forces**. Here, the limiting composite curve was divided into 3 vertical mass load intervals and the network grid diagram was designed along with the flowsheet. To remove the additional complexities, loops were identified and then broken. The 2nd approach involved **minimizing the number of water sources** which included methods of bypassing and mixing. Here, concentration intervals were used instead of the mass load intervals. The limiting composite curve was followed and the driving forces in individual matches were minimized. The excess water was bypassed to get mixed later. The resultant network was then plotted. Thus, the wastewater treatment cost was minimized and the load on fresh water supply was reduced. The wastewater was thus optimized.

Conclusions

These case studies of Pinch Technology help a process engineer to analyze the working of the plant or process they are working on and to find the possible opportunities for the application of Pinch Technology in the working plant or process. In every case, application of pinch technology has contributed to significant energy savings. Energy savings obviously led to financial savings in some or the other form like reduction of investment cost or reduction of the equipment required thus reducing the equipment cost etc. Identification of the opportunities to save energy or heat is a very important step in any industry. Therefore, every process engineer must have knowledge of Pinch Technology and analyzing case studies generates ideas for adaption of pinch and the required changes in the plant which is to be modified.

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