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Process Integration of Cooling Water System: Thermodynamic Modelling & Experimental Validation for Energy and Water Conservation

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Combined pinch technology,
Cooling tower,
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Abstract

This paper deals with a technique for grass root design of cooling water system for wastewater minimization which incorporates the performances of the cooling towers involved. The study focuses mainly on cooling systems consisting of multiple cooling towers that supply a common set of heat exchangers. The heat exchanger network is synthesized using the mathematical optimization technique. In the present investigation, a prognosticated theoretical model of Recycled Cooling Water System (RCWS) is proposed accounting for interaction between cooling tower and heat-exchanger network. Regarding this model, an attempt was made for modern grass-root design method of RCWS based on combined pinch technology and mathematical programming in line with data available in public domain which may develop for minimum cost achievement. This technique may warrant upon and provide water and energy conservation, minimum cost and environmental impacts.

1. Introduction

Cooling tower are heat rejection devices used to transfer heat from hot water to the atmosphere air. In cooling tower water is made to trickle down drop by drop, or form a thin layer over flat surface so that it comes into direct contact with air moving upwards in opposite direction [1]. The heat transfer from the water to the air steam raises the air's temperature and its relative humidity to 100% and this air is discharged to the atmosphere. As a result of this some water is evaporated and is taken away from the bulk of water, which is thus cooled. Thus, evaporative cooling technique is used in the case of cooling towers. These systems also generate wastewater through the blow down mechanisms. Cooling towers fall into two main categories: Natural draft and Mechanical draft. Mechanical draft towers are available in the following airflow arrangements: Counter flow induced draft; counter flow forced draft. The efficiency of cooling tower depends on air and water flow rates and operating temperatures.

This paper presents the study of Process Integration of cooling water system (CWSs) and a theoretical model of Re-circulating cooling water systems (RCWSs). Process Integration of CWS's can be achieved either by interaction between the cooling towers and heat exchanger network unit or by using pinch analysis. The interaction between cooling towers and Heat Exchanger network (HEN) is explained by using Parallel configuration of cooling water network. RCWS's are by far the most common industrial waste process heat rejection systems to the environment. RCWS provides conservational opportunity for water and energy and pollution reduction relative to once-through systems because of water re-use possibility [2]. To RCWS design, the effect of any possible changes of the system components on the cooling performance should be predicted properly. Pinch technology is the most common design. This technology is based on targeting before design and exploits conceptual understanding.This document provides required guidelines for the authors to prepare their English papers in accordance with a standard identical format acceptable to this journal. The fulfillment of these instructions is mandatory for all contributors.

2. Parallel Configuration of Cooling Water Network

The interaction between heat exchanger and cooling tower is represented by using a parallel configuration of cooling water network design (Figure 1). In parallel configuration, fresh cooling water is supplied to individual heat-exchanger directly. The hot cooling water from the individual heat exchangers is returned to the cooling tower. Mixing water from individual heat-exchanger decreases inlet water temperature and increases inlet water flow rate of

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cooling tower. It is noted that high flow rate and low temperature of inlet cooling water leads to poor cooling performance because it decreases the driving force[3]. Furthermore, parallel arrangement, as the traditional design configuration cannot support when dealing with various processes. The best optimal design of the RCWS is based on providing water re-use opportunity & minimizes the energy consumption.

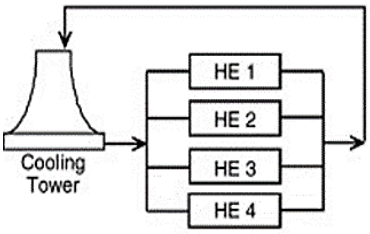

Figure 1. Schematic Diagram of Parallel configuration of cooling water network [5]

3. Pinch Technology

In the cooling tower heating all the cold streams with steam and cooling all the hot streams with water is waste of energy. So, it is to see as much as coupling between the hot and cold streams. To have the coupling between the streams and to minimize the energy consumption Pinch technology is used. In this technology, the data is represented as a function of heat load against temperature. This gives the two composite curves, one for hot stream and one for cold stream. Scope of heat recovery is identified from these Temperature – Enthalpy Plots (Figure 2). Pinch Technology is also used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point.

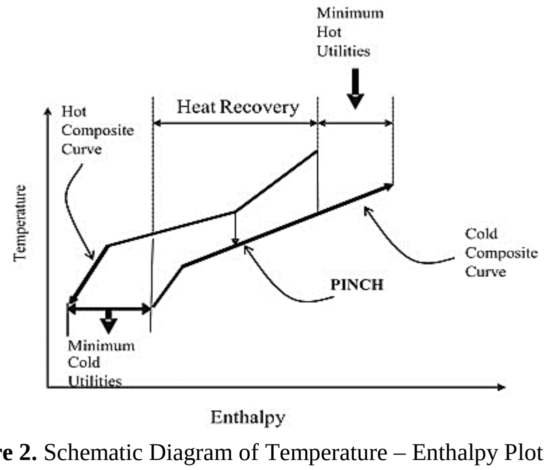

Figure 2. Schematic Diagram of Temperature – Enthalpy Plot in Pinch Technology

Steps of Pinch Technology:

1. Identification of hot, cold & utility streams in the process.
2. Thermal data extraction for process & utility streams
3. Selection of initial DTmin value.
4. Construction of composite curves (Temperature – Enthalpy Plots).
5. Estimation of minimum energy cost targets.
6. Estimation of Heat exchanger network capital cost targets.
7. Estimation of optimum DTmin value.
8. Estimation of practical targets for Heat exchanger network design.
9. Design of heat exchanger network.

So, from this Temperature – Enthalpy Plot the region of overlap between the two composite curves is the amount of heat that can be recovered. When we increase the DTmin value, the cold curve shifts towards the right hand side. This decreases the overlap between the curves. So, the heat recovered from the heat exchanger network also reduces and load on the utilities increases.

Total cost variation with respect to DTmin and water flow rate is shown in the Figure 3 & 4. The DTmin is fixed by the economic trade-off between the operating costs and capital costs because as the DTmin value increases, the load on the utilities increase but the area of the heat exchanger network decreases. When the load increases, the operating costs increases & when the area of heat exchanger network decreases, the capital cost decreases.

As we have discussed earlier that, if the DTmin value decreases, then the capital cost increases and energy cost decreases. An optimum DTmin value is selected where the total cost is low. From the graph between water flow rate and cost (Figure 3&4), we can conclude that as the water flow rate increases, operating cost increases and capital cost decreases. Thus an optimum flow rate is selected where the total cost is low.

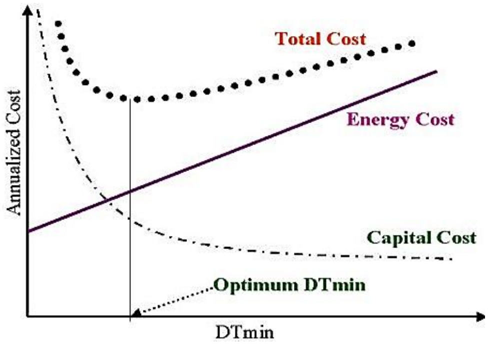

Figure 3. Total cost variation with respect to DT_{min} [5]

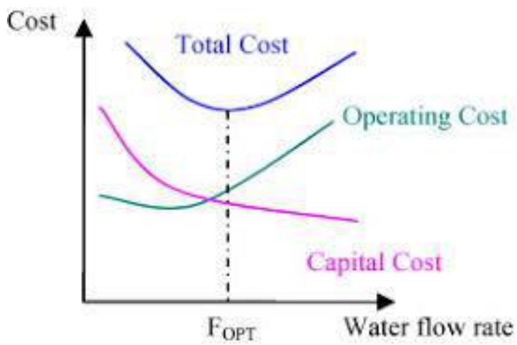

Figure 4. Total cost variation with respect to water flow rate [5]

4. Mathematical Programming

The major achievement of the mathematical programming approach is that it replaces the multi-step iterative pinch design method and enables the design of multicomponent mass exchange networks as well. The cooling water system consists of cooling towers and heat exchanger network [4]. Therefore the mathematical model for designing cooling system entails the heat exchanger network model and the cooling tower model.

The Advanced Pinch Design (APD) is based on a superior algorithm derived from combination of pinch analysis and mathematical programming. The optimum cooling water system through Advanced Pinch Design (APD) method is carried out in three stages.

- The first step is to define the feasible region from the cooling composite curve taking into consideration the system constraints.
- The second step is to explore the feasible region to target the cooling water supply line.
- The final stage is to design the cooling water network for target conditions with pinch migration concept through water main synthesis method.

An experiment have been carried out by M.H. Panjeshahi (2009) on advanced pinch technology. The minimum cost is obtained from the presented grass-root design procedure [5]. He took an example of a cooling water system which has 4 heat exchangers & using cooling water as cooling medium for hot process streams. The optimization results of the experiment using various design methods are given in the Table 1. The conclusions from the optimization results indicate that the optimum water supply flow rate is 108.51t/h. The cooling water enters the tower with temperature of 49◦C and leaves the tower with temperature of 25.2◦C. The optimization results show that the operational cost including fan cost, pumping cost, make-up water cost, water chemical and blow-down treatment cost is 44.07k$/year and capital cost for cooling tower is 8.03k$/year which makes total cost of 52.10k$/year achievable. The results are presented in the Table 2.

5. Results and Discussion

The wet parameters of the discharge samples are collected from a typical process plant. The samples are analysed and the results are tabulated in Table 3. From these results we can conclude that the chloride content of the samples are higher when compared with normal standards of the process plant. Conventional design of RCWS is often carried out in parallel configuration. This loses opportunity for water re-use. However, re-use of cooling water between different cooling duties enables cooling water networks to be designed with series arrangements. This allows better cooling tower performance and increased cooling tower capacity.

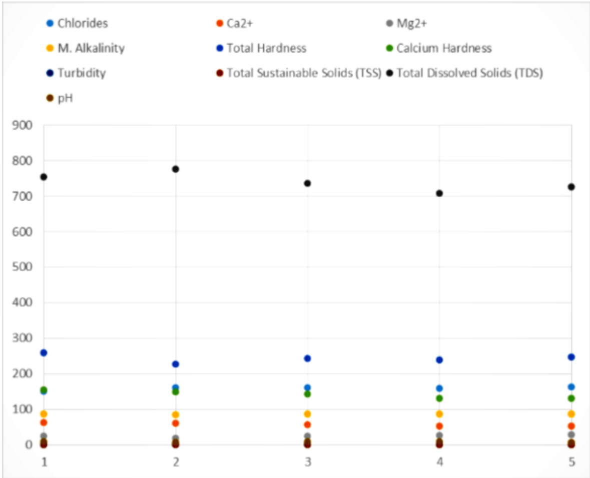

Figure 5. Trend Analysis of results of tested parameters of cooling tower discharge samples

From Figure 5 we can conclude that the pH of the samples is within the standard limits for the prescribed cooling water original manufacturer specification. For maintain the pH values H2SO4 dosing may be carried out. The chloride content in the discharge samples of the cooling tower is beyond the standard limits due to higher values of incoming water. If the chloride content decreases below the standard limits that leads to the increase in microbiological content in the water. Necessary action must be taken in order to avoid the problem. The free residual chlorine (FRC) in the discharge sample is below the prescribed value. Total Dissolved Solids (TDS), Total Suspended Solids (TSS), M. Alkalinity, Calcium Hardness & Total Hardness of the discharge sample of cooling tower are within the standard limits.

Table 1. Optimization results using various design methods [5]

Design Method	$T_{hot,in}$ (ºC)	$T_{cold,out}$ (ºC)	C_p (kW/ºC)	F (t/h)	Efficiency (%)
Convectional	40.46	30	286.67	246.89	41
APD	49	25.2	126	108.51	70

Table 2. Cost Comparison of various design methods [5]

Design Method	Operation Cost (k$/year)	Capital Cost (k$/year)	Total Cost (k$/year)
Convectional	65.90	6.54	72.44
APD	44.07	8.03	52.10

Table 3. Variation of different parameters of a simulated design water system

S. No	WET PARAMETER	SAMPLE 1	SAMPLE 2	SAPMLE 3	SAMPLE 4	SAMPLE 5
01	pH	7.8	7.59	7.91	7.89	7.69
02	Total Dissolved Solids (TDS)	753.6	775.6	735.5	709.1	726.9
03	Total Sustainable Solids (TSS)	0.001	0.001	0.0095	0.001	0.001
04	Turbidity	1.2	1.2	1.0	1.1	1.1
05	Free Residual Chlorine (FRC)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
06	Calcium Hardness	156	150	144	130	130
07	Total Hardness	260	228	244	240	248
08	P. Alkalinity	NIL	NIL	NIL	NIL	NIL
09	M. Alkalinity	87	85	86	87	86
10	**Chlorides**	**152**	**161.652**	**161.148**	**158.44**	**162.5028**
11	Ca^{2+}	62.556	60.15	57.744	52.13	52.13
12	Mg^{2+}	25.272	18.954	24.3	26.73	28.674

8. Conclusions

Cooling water tower develop increased TDS through the evaporative cooling process. While chlorides are a component of the overall TDS value, typically calcium accounts for the majority of this value. Cooling water conductivity is generally controlled with a conductivity controller that activates a blow down valve to maintain a present range of conductivity. This controlled range provides optimal efficiency, and reduces the amount of chemistry added to control scale, corrosion and bio fouling. Deionized water or Reverse osmosis of water is effective to remove the scale forming potential of the makeup water to a cooling tower. From antifouling point of view, chlorine dioxide concentration of 0.2 mg/L would give better results than 0.5 mg/L of chlorine. Therefore even systems regarded as under good control with conventional microbiological control programs are still susceptible to corrosion from microbiological activity. Most cooling water systems benefit from lower corrosion rates with the use of chlorine dioxide; hence, its unique properties make it the ideal microbiological control chemistry.

The new technique for grass root design will minimize the amount of waste water disposing in cooling water system. Energy saving is a major issue in sustainable development. Analysis of the whole process leads to much more efficient solutions for saving energy (process – process heat recovery) than just by optimizing the heat exchangers. Pinch Analysis can set optimum targets for energy saving from enthalpy – temperature profiles and detailed design of heat exchangers. On the basis of the present analysis energy conservation and cost effectiveness is achieved.

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