Optimization of Mass Exchanger Network Considering Piping Costs

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Abstract—
In the current synthesized mass exchanger network targeting methods, no one considered piping costs in total costs estimations. This optimization technique is based on Pinch technology with detailed cost estimation. In the pinch targeting method as mass separating agent costs increases, mass exchanger area decreases. Further, as the mass flow rates of utility streams increases piping size increases. It means by increasing mass separating agent costs, mass exchanger cost decreases, but piping costs will increase. In the present work a case study is taken from open literature to study the effect of piping cost consideration in total cost estimation for optimum mass exchanger network design. The result obtained shows that optimum network configuration changes after accounting piping cost. Further, it is also found that piping cost consideration also affects the optimum minimum allowable composition difference (ϵ) value.

Keywords *—Optimization of mass exchange network, total annualized cost, pinch technology, piping cost.*

I. INTRODUCTION

Mass exchanger networks (MENs) are combination of more than one mass exchange units. In Process Integration, Mass exchangers are defined as a direct contact mass transfer unit for transferring certain species from rich streams to lean streams. MEN are mostly used in chemical and allied industries for the specific purposes like: manufacturing of chemicals and food products, recovery of valuable materials, product finishing and purifications. MEN concepts firstly introduced by El-Halwagi and Manousiouthakis [5] in 1989. A MEN problem can be stated as follows ;

Given a number of rich streams (sources) (R_i) and a number of mass separating agents (MSA)s /(lean streams) (S_j). Rich streams are basically the industrial waste streams which can be disposed or forwarded for recycling/ reusing. But before disposing into the environment, it should be comply with environmental regulations. If rich streams are forwarded to process sink, it should be targeted to obtain desired composition. For these two purposes mass separating agents are used. Given also are the flow rate of each rich stream, Gi, its supply (inlet) composition, y_i^s , its target (outlet) composition, y_i^t , where i = 1,2,….. In addition, the supply and target compositions, x_j^S and, x_j^t, are given for each MSA where j = 1,2,….. The mass transfer equilibrium relations are also given for each MSA. The flow rate of MSA are unknown and is to be determined as a part of the synthesis task.

The MSAs can be classified in to two types, first type is process MSAs and second type is external MSAs. The process MSA already exists in the plant site and almost free of cost and can be used for the removal of the species at a low cost. The flow rate of each process MSA, Lj, that can be used for mass exchange is bounded by it availability in the plant and may not exceed a value of Lj. The external MSAs can be purchased from the market and their flow rates are to be determined by economic considerations. It is desired to synthesize a cost-effective network of mass exchangers that can preferentially transfer certain species from the rich streams to the MSAs. For synthesizing a MEN two approaches are used. First one is graphical approach and second one mathematical programming approach. These two approaches targets total annual cost of the MEN in which a tradeoff between mass separating agent costs and mass exchanger units costs are estimated.

The current targeting methods do not considered piping costs in TAC estimation of a MEN. But we know that, by increasing MSAs cost MEN operating costs increases, mass exchanger cost decreases and piping costs increases. It means by increasing MSAs costs, mass exchanger capital cost decreases and piping costs increases. Thus piping costs can affect the total capital cost of MEN i.e. (mass exchanger costs and piping costs).
In the Pinch technology, prior to design of the MEN, is necessary to specify a target point based on initially specified minimum allowable composition (MAC) ϵ value. The aim of the present study is to show the effect of piping cost consideration on optimum MEN design. For this purpose a Case Study is considered from open literature.

II. PIPING COST ESTIMATION

Till now many researchers have been developed different methods for mass integration and synthesis of MENs. However, they did not account piping network for the MENs. Moreover, Peters and

Timmerhaus [6] pointed out that piping is a major item in the cost of all the type of chemical process plants. These costs in a process plant can run as high as 80 % of the purchased equipment cost or 20 % of the fixed capital investment. It is a usage amount and should be included for the synthesis of MEN. Akbarnia et al.[7] considered piping network for the synthesis of heat exchanger network (HEN) and proposed a correlation for the estimation of piping costs for each stream passing through the heat exchanger. This correlation was formulated for accounting piping costs of HEN based on experimental data over a range of pipe diameter for piping associated to a single heat exchanger. To calculate the total piping cost for one stream, the calculated piping cost for one heat exchanger was multiplied by the number of heat exchanger units used for that stream. However it can be analyzed for practical cases that piping length and pipe size both will affect the piping costs, so piping length should also be considered in piping cost along with pipe diameter.

Thus, piping cost per unit length of different pipe diameter is calculated using following expression [6], which is given by a correlation as a function of the pipe diameter and piping length;

Piping cost (per m length) = $3.2 + 11.42\ D_p^2$ (1)

where, D_p pipe diameter in inches. The length of piping for a mass exchanger depends on the distance between two streams, which are exchanging mass in that exchanger. For all streams pipe diameter can be calculated as:

$$Dp = \sqrt{\frac{4Q}{\pi \rho_P u_P}}$$

Where Q is the flow rate of streams which is flowing into the pipe line. u_p and ρ_p are the velocity and density of the fluids which are flowing into the pipeline. For MSAs streams pipe size is dependent on the variation of **ε** as the mass flow rate changes by increasing or decreasing concentrations. Therefore, we have to calculate pipe size for the range of **ε** .The calculated pipe size shall be rounded to the nearest standard commercial pipe size such as 1/2, 3/4, 1, 1 1/2, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, . . . inches. These pipe sizes are valid for all ranges of **ε**.For avoiding the hammering problem, liquid phase streams velocity is assumed low enough. So the maximum allowable velocity for lean and rich streams is assumed equal to 1.1 and 15 (m/s) respectively [7].For annualizing piping cost it is also assumed that interest rate i = 10% and plant life n = 5 years. Material of construction of the pipelines is considered to be SS-304.

The piping lengths are estimated with the help of MEN designs. For simplicity piping distance in between the two units and storage tank to units are assumed 25 meters. Lean streams are flowing from the top of the column, so total piping length required for the lean streams are equal to the 25 plus height of the column.

A. Case Study

This case study is adopted from the article of [5]in which the problem involves the simultaneous removal of Hydrogen Sulfide from two gas streams; Sour coke oven gas (COG) (R_1) and Tail Gas (R_2). COG is a mixture of H_2, CH_4, CO, N_2, NH_3, CO_2, and H_2S.The removal is necessary because H_2S is corrosive and becomes the pollutant SO_2 when the gas is combusted. For this problem two MSAs are available: Aqueous Ammonia (S_1), which is a process MSA and chilled Methanol (S_2), which is an external MSA. Streams and cost data are given in Table 1,2& 3 respectively. The initial minimum composition difference,ϵ is specified as 0.0001.In this example, only the H_2S is the pollutant.

Table 1 Data for the Rich Stream

Rich Stream			
Stream	**G_i (kg/s)**	**Y_{ini}**	**Y_{outi}**
R1	0.9	0.07	0.0003
R2	0.1	0.051	0.0001

Table 2. Data for the Lean Streams

Stm	**L_j (Kg/s)**	**X_{inj}**	**X_{outj}**	**m_j**	**b_j**
S_1	2.3	0.0006	0.0310	1.45	0
S_2	∞	0.0002	0.0035	0.26	0

Table 3 Capital Cost Data

Installed costs (for1994)		
Sh	$\$20700D^{0.57}H$	
Tray	$\$250e^{0.66D}F_nN_r$	
	D column diameter (m)	
	H column height (m)	
	N_r:numberof real trays	
	F_n:traynumber factor:	
	N_r	F_n
	25	1

	20	1.05
	15	1.25
	10	1.50
	5	2.30
	1	3.0
Capital annualization factor	0.2	

B. Solution Methodology

The solution techniques used in the present work is the Pinch technology with the detailed cost estimation. The different steps, encountered during targeting and optimum designing of a MEN is presented in aFig.1.

C. Result and Discussion

Fig.2 represents super targeting results of total costs with the variations of ϵ values with and without considering piping costs in TAC estimation of MEN. This graph shows, that new optimum ϵ obtained after considering piping costs in TAC. The obtained new optimumϵvalueis0.0003,while0.00025is the targeted optimum ϵ value without considering piping costs in TAC estimation. Fig.3representstheactualMENdesignwhich is drawn on the basis of targeted minimum number of units without considering piping costs in TAC estimation of the MEN. For this case study minimum number of targeted units required to obtain the desired compositions are four units by following targeting method [4]. But this actual MEN design gives poor driving force above the pinch point. Actual network design increases the number of trays by 41.4 % to the targeted number of trays. The annualized capital cost of this MEN design is $647371 at 0.0001 ϵ, which is 21.47 % above than that targeted capital cost. To improve the network design we can add one more unit in a network.Fig.4 shows an improved MEN design with a TAC of $410323, which is only 1.37 % above the targeted TAC. This design is acceptable based on the minimum TAC of MEN. In fact, for this design the total number of trays required is 63, which is 10 % below the target. Before considering piping costs in TAC estimation optimum MEN obtained by preferring improved network design instead of actual network design. After accounting piping costs the optimum network design becomes Actual network design instead of improved network design on the basis of minimum TAC of the MEN. This is happened due to the fact that in improved network design one more mass exchanger unit is required from the targeted units. The TAC obtained after including piping costs for improved network is more, due to this one more unit. By detailed cost estimation the piping costs required for the improved network is approximately ±31% more as compared to the piping costs required for actual network design for this Case study. Fig.5 shows the effect of piping costs consideration on preferred network design to obtain the optimum MEN. From this Fig.5 it is clearly shows that at every minimum allowable concentration (MAC) difference value before piping cost consideration improved network design gives the minimum TAC for the desired output. But after including piping cost in TAC preferred network design becomes actual network design and optimum MEN obtained at 0.0003 ϵ value. Fig 6 shows that piping cost noticeably decreased with the increased value of ϵ. This is happened due to the fact that as ϵ value increases the lean stream phase concentration in the rich stream phase decreases. It shows that the low rich stream phase concentrations are preferable to assure maximum mass transfer rates. One way to keep low rich stream phase concentration is to use high rich stream mass/molar flow rate but in this problem rich streams are gaseous streams, which are assumed to remain constant [4]. So to achieve maximum mass transfer rates mass/molar flow rate of lean streams can be reduced. As mass flow rate decreases piping size decreases and consequently the piping cost decreases. The % contribution of piping cost in TAC contributes around 8 to 12% in TAC for taken Example.

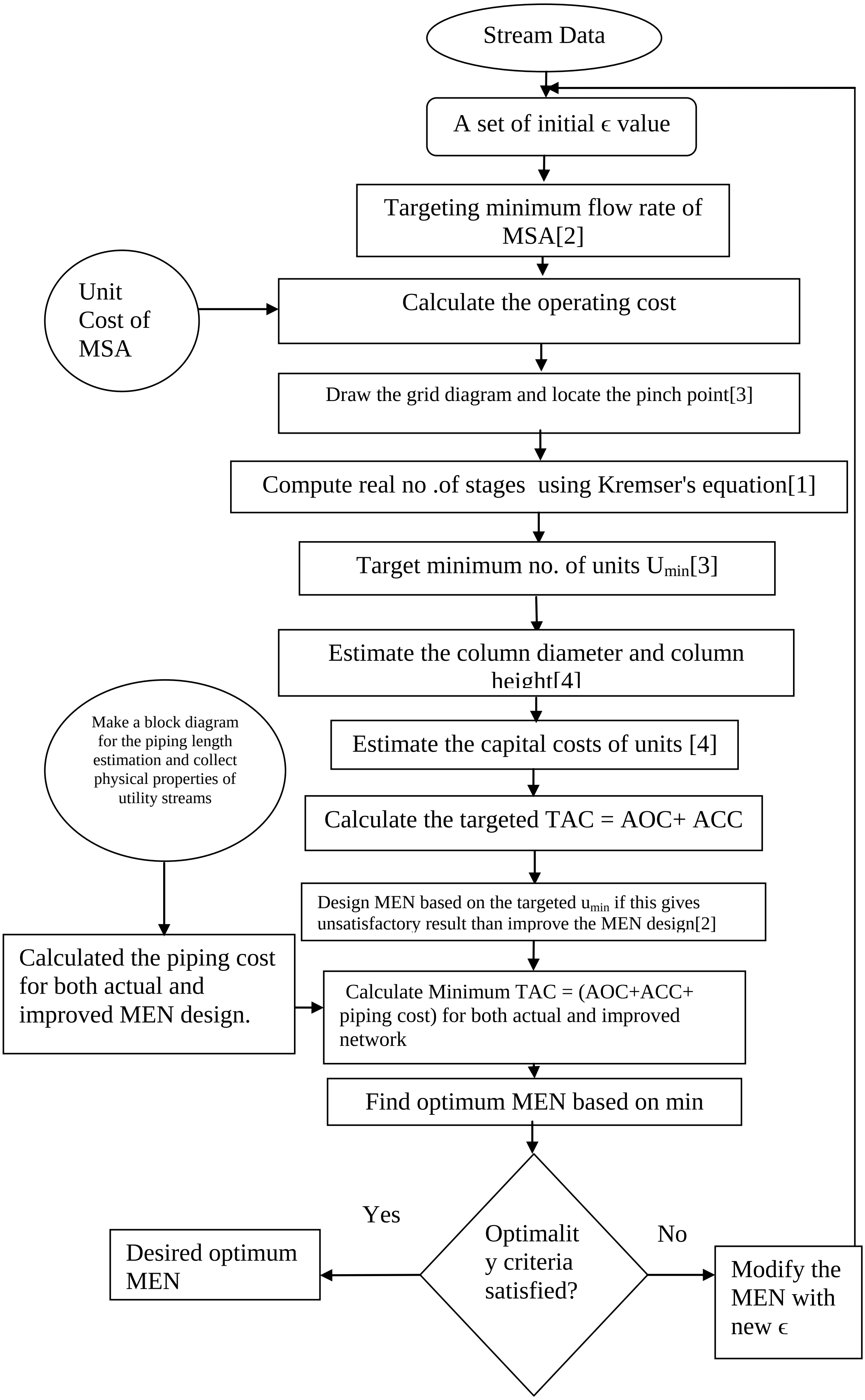

Fig.1: Flowchart of Present Workprocedure

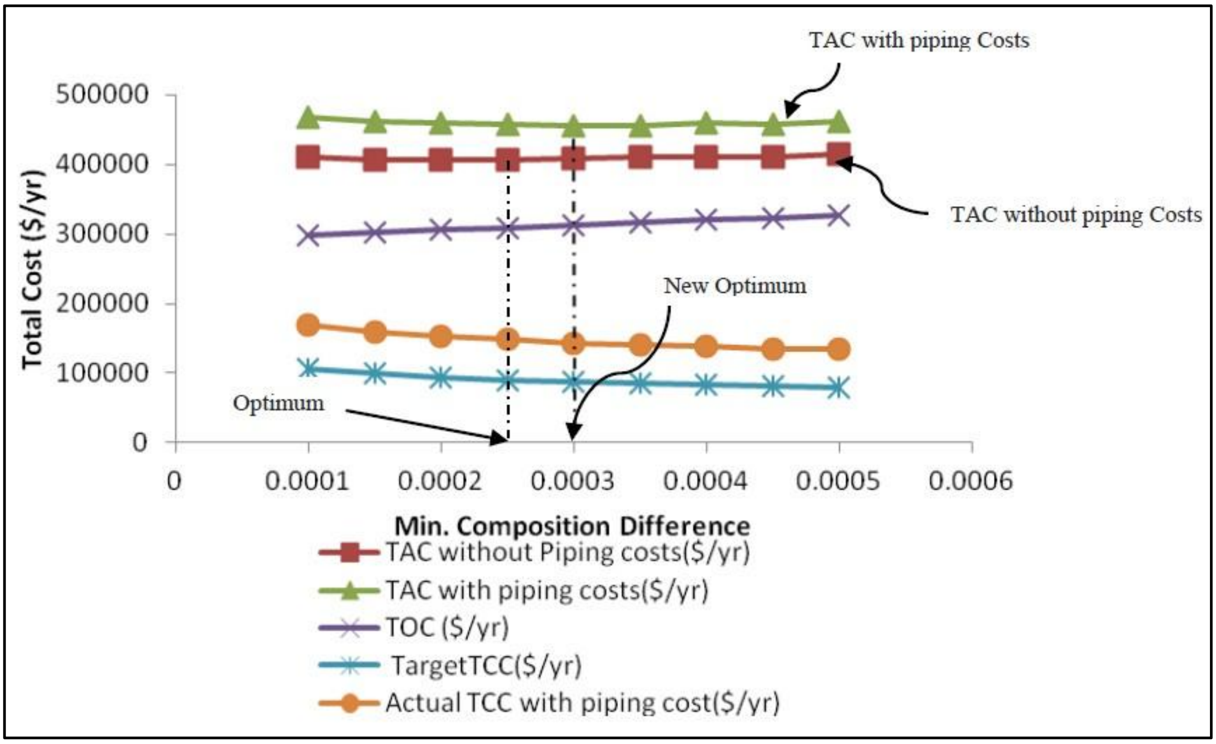

Fig.2-Comparison Between the TACofMEN with and Without Piping Costs

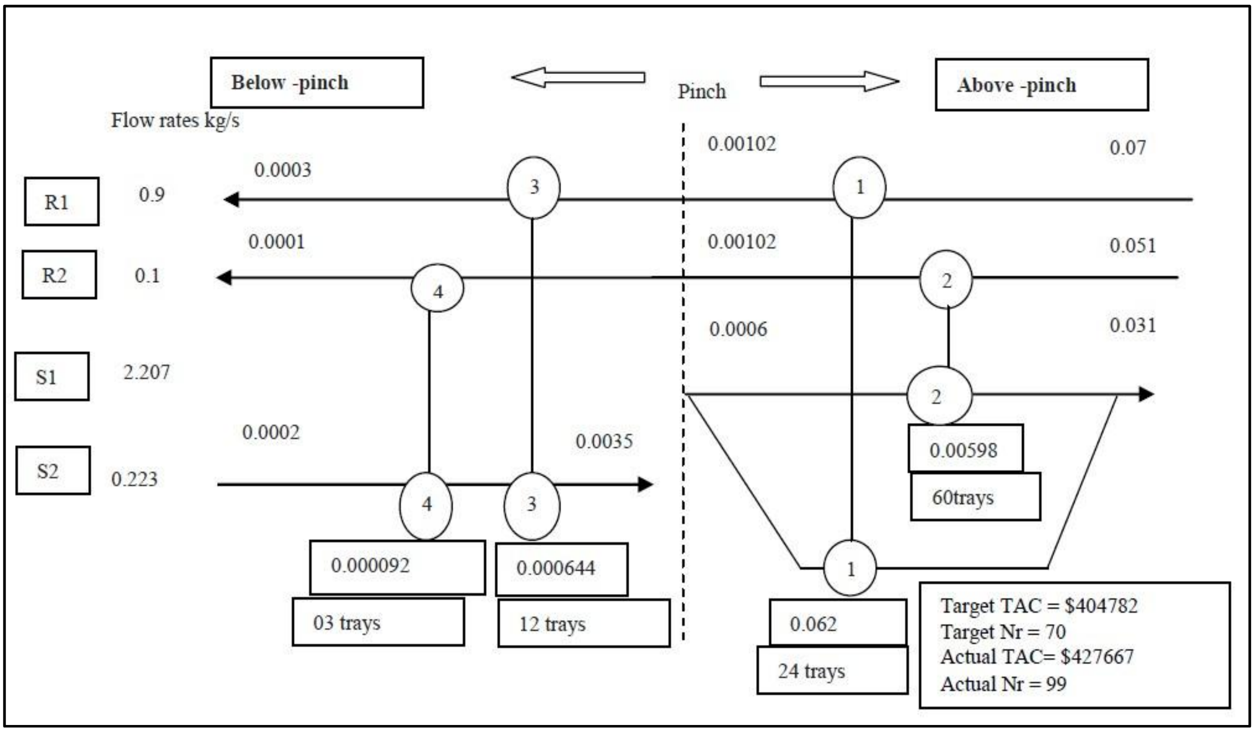

Fig.3 Actual Networkdesignat Specifiedϵ = 0.0001

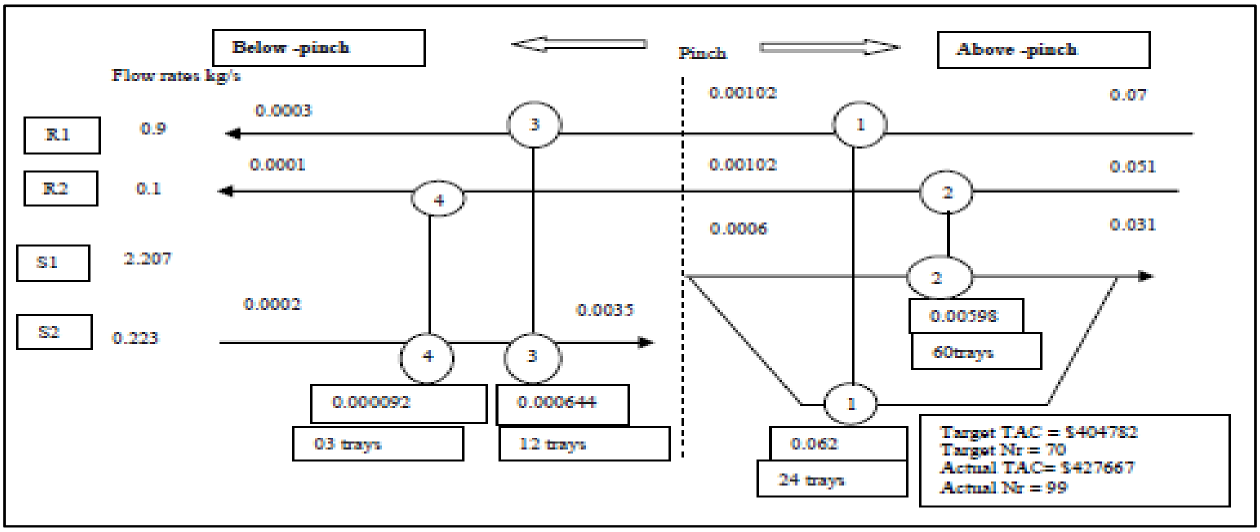

Fig.4-Improved Network Design at Initially Specified Value of ϵ =0.0001.

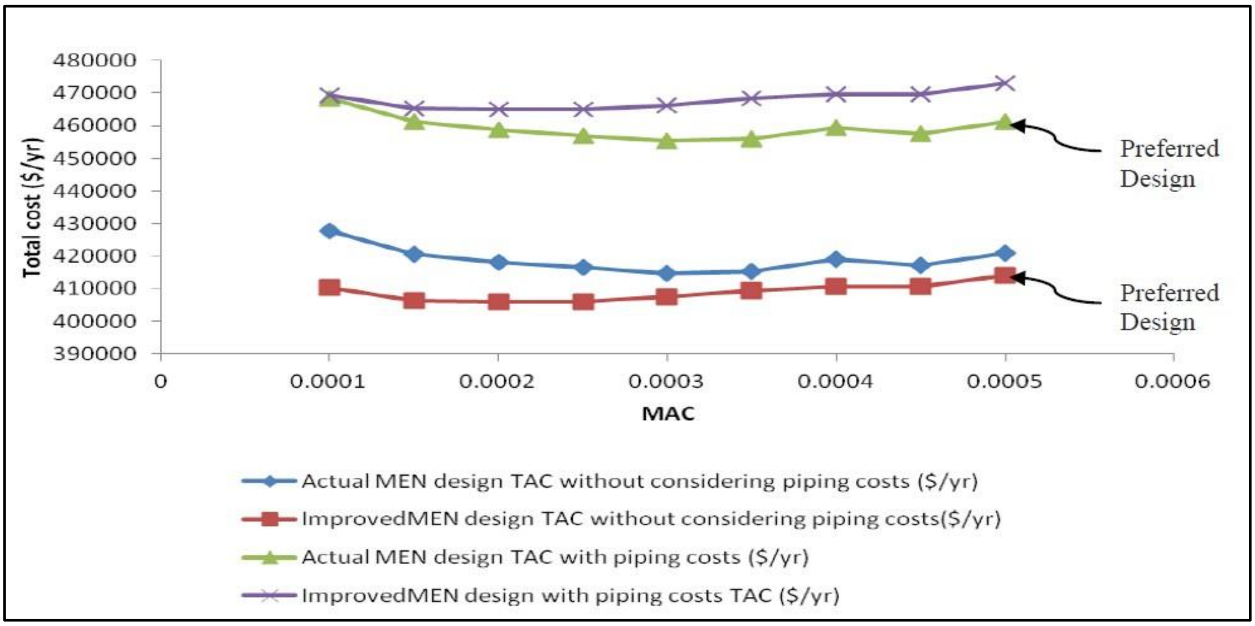

Fig.5-Comparison of the Results Found After and Before Considering Piping Cost in TAC Estimation on Preferred MEN Design.

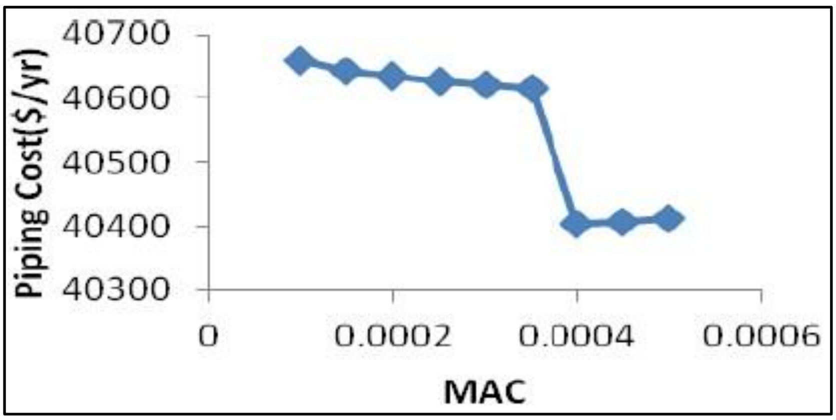

Fig.6-Piping Cost Variation With the Range of ϵ for the Taken Case Study.

Its hows that the low rich stream phase concentrations are preferable to assure maximum mass transfer rates. One way to keep low rich stream phase concentration is to use high rich stream mass/molar flow rate but in this problem rich streams are gaseous streams, which are assumed to remain constant [4]. So to achieve maximum mass transfer rates mass/molar flow rate of lean streams can be reduced. As mass flow rate decreases piping size decreases and consequently the piping cost decreases. The% contribution of piping cost in TAC contributes around 8to12% in TAC for taken Example.

For comparison the final result obtained in present work with and without considering piping costs in TAC of a MEN are compared with the published work as shown in Table4 for the same case study. From this Table4 it can be seen that no one considered piping costs for the optimization of MEN. The values of specified and optimized by other researchers are presented in the third column of the table. The optimum TAC obtained in the present work before considering piping costs is $406060 per year whichis1.2% below the TAC obtained by Hallale [2] at specified value. After including piping costs in TAC the optimum MEN is obtained at(0.0003) which is17% above the optimized value given by Hallale [4].At0.0003 the TAC obtained in present work is smallest than the other results which are presented in column 7 ofTable4.

III.CONCLUSION

The optimization procedure study in present Work is cost effective. It is obvious that the optimization of values is highly important to synthesize a MEN and piping cost consideration improves the global optimum point of value. The piping cost consideration improves the accuracy of total annual cost of mass exchanger network. The piping costs are a fraction of total costs, typically not of the same order of magnitude as the major equipment. These costs become more important when piping dominates most of the equipment, such as water distribution networks. Hence piping cost is an important factor and must be considered in the design of MEN.

REFERENCES

[1] N.Hallale, D.Fraser,Capital costtargets formass exchangenetworks Aspecialcase:Waterminimisation, ChemicalEngineeringScience53(1998)293-313.

[2] N.Hallale,D.Fraser,Supertargeting forMass ExchangeNetworks: PartI:Targeting andDesign Techniques, Chemical Engineering Research and Design78(2000)202-207.

[3] N.Hallale,D.Fraser,Capitalandtotalcosttargets formass exchange networks: Part1:Simple capital cost models, Computers & Chemical Engineering23(2000) 1661-1679.

[4] N.Hallale, D.Fraser, Capital and total cost targets formass exchange networks: Part2: Detailed capital cost models, Computers & Chemical Engineering23 (2000)1681-1699.

[5] M.M.El-Halwagi, V.Manousiouthakis, Synthesis of mass exchange networks, AIChE Journal 35 (1989) 1233-1244.

[6] M.S.Peters, K.D.Timmerhaus, R.E.West,K. Timmerhaus, R.West, Plant designand economics for chemical engineers, McGraw-Hill NewYork 1968.

[7] M.Akbarnia, M.Amidpour, A.Shadaram,A new approach in pinch technology considering piping costs in total cost targeting for heat exchanger network, chemical engineering research and design 87 (2009) 357-365.

[8] PapalexandriK.P.,Pistikopoulos, E.N.,&Floudas, C.A.,Mass exchange networks for waste minimisation: a simultaneous approach, *Trans IChemE*., 72 (1994) 279-294.

Table4-Comparison of Results of Present Work with that of Published Work (Casestudy-1)

Author	Process used	(ε)	Nr	TAC×10^4 ($/yr)	Piping cost ($/yr)	TAC ($/yr)
El-Halwagi [5]et al.,	Pinch Analysis specified,ϵ	0.0001	50	52.604	--	--
Papalexan dri et al.[8]	MINLP	0.0001	8	91.800	--	--
Hallale et al.,[2]	Super-target method	0.00031	25	42.706	--	--
Hallale and Fraser [4]	Detailed capital costing models, specified,ϵ	0.0001	63	41.085	--	--
Present work	Pinch technology with Detailed capital costing , specified,ϵ	0.0001	63	41.032	47186	463602
Present work	Pinch technology with Detailed capital costing , without pipingcost, Optimized ,ϵ	0.00025	51	40.606	32552	450554
Present work	Pinch technology with Detailed capital costing ,after including pipingcost	0.0003	73	40.752	32544	447343