Numerical Analysis of Vapour Velocity in the Kettle Reboiler at Different Entrainment Ratio

Satish Pawar[a]
[a] **Senior Mechanical Engineer, Mechanical Engineering Department, Chicago Bridge & Iron Company**

Abstract

Kettle reboilers are perceived as an integral part of the refinery process. A proactive approach of mechanical optimization and monitoring is recommended to minimize the liquid carry over and maximize system reliability. Mechanical optimization requires an assessment of the reboilers design and operation to ensure proper entrainment ratio, correct location of inlet and outlet nozzles in reboilers, correct shell sizing, and impact of current system operation. Maintaining the liquid carry over in the reboilers and improving the kettle reboiler's performance.

Keywords: Design by analysis, Heat Transfer, Kettle Reboiler, Shell and Tube Heat Exchanger, Entrainment Ratio, Vapour Velocity.

I. INTRODUCTION

Kettle reboilers, also known as pool boilers, are often used for light hydro-carbons (propane, butane) [1]. These re-boilers handle process flow fluctuations and high heat fluxes well than other reboiler designs, but kettle reboilers have a greater tendency to foul on the process side.

Control of liquid carry over in a LN Rundown chiller (Kettle type reboiler) is a challenging problem in process industries due to its typical inverse response behaviour. Liquid carry over is a critical variable in the safe operation of a chiller. High drum level carryover into the header and exposing propane vapour compressors to damage. A LN Rundown chiller is used to cool the light naphtha. Here, the propane is two phase. The data for this work have been taken from an existing chiller and subsequently simulated using HTRI package. In this paper will discuss Kettle reboilers design, sizing and selection within a typical refinery and methods to maximize reliability through proper mechanical selection of the shell diameter, Nozzle location and entrainment ratio.

II. LITERATURE REVIEW

In Kettle reboiler figure-1 shows 100% PROPANE its liquid and vapour mixture. Vapour with entrained liquid flow over the weir in to the liquid take place and vapour flow overhead to the condenser. It was not possible under all conditions to remove all entrainment but give the sufficient time to disengage the vapour and liquid from the fluid. The LN Rundown chiller used is a kettle type reboiler, designed for 4.18 MMBTU/h duties with shell side and tube side pressures as 77.5 psig and 23.5 psig at 50°F and 113°F respectively. Liquid Naphtha is available at 113°F and has to be cooled to 86°F. The chiller is designed in such a way that liquid Naphtha will pass through tube side and 100% propane (50°F) will pass through shell side.
So, heat from tube side will transfer to shell side liquid propane to cause vaporizations (50°F). As a result traces of moisture and all condensable, such as, heavier hydrocarbons will get condensed and will go to separator for separation. To avoid liquid carry over will provide the sufficient travel time for disengagement.

Theory of Vapour-liquid disengagement

For kettle reboilers, the shell is oversized to cause disengagement of the liquid so that vapour alone is discharged from the overhead nozzle. In practice, it is probable that some entrainment always occurs. If dry vapour is really required, as in the case of a compressor feed, additional protection, such as mechanical mist eliminators, is needed. The basic relationship used in sizing separator drums is

$$Vv = Ke\ (\rho_l-\rho_v/\rho_v)^{0.5}$$

([4]Souders-Brown Equation)

The vapour velocity Vv above which a certain amount of entrainment is obtained, is a function of the entrainment coefficient Ke which usually ranges between 0.098 and 0.29 ft/s and is itself a function of the maximum amount of entrainment permitted and ratio of surface tension to density. An empirical relationship that has been used successfully in the past is

$$VL = 0.0645\rho_v(\sigma/\rho_l-\rho_v)^{0.5}$$

Where VL = vapour load, lb/s ft3 (vapour rate, lb/s, divided by volume of vapour space required to prevent entrainment, ft3), ρ_v = vapour density, lb/ft3, ρ_l = liquid density, lb/ft3, σ = surface tension, lbf/in

For both kettle and horizontal thermo siphon reboilers, steps should be taken to assure adequate longitudinal flow distribution. Above a certain length-to-bundle diameter ratio, the number of liquid and vapour nozzles should be increased [3]. As a rule of thumb, the number of pairs of nozzles (liquid and vapour) is given by
$NN = L / 5D_b$

Where NN = number of pairs (inlet plus outlet) of boiling-side nozzles for horizontal thermo siphon, L = length of tube bundle, ft, D_b = tube bundle diameter of circle tangent to outer tubes, ft

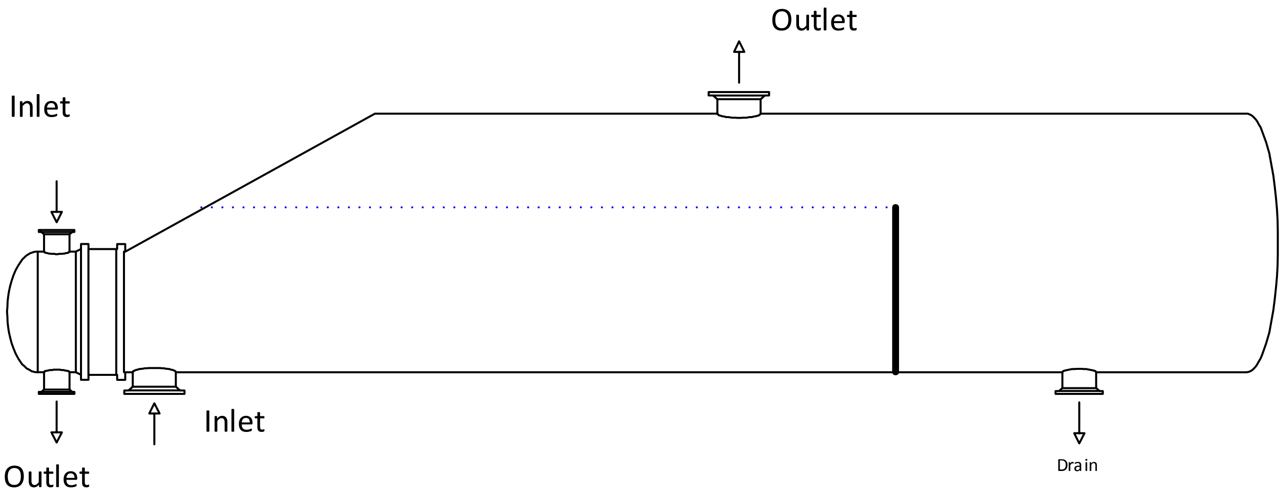


Figure-1 Schematic Representation of Kettle Reboiler

III. CALCULATION DATA.

Fluid Allocation	**SHELL SIDE**				**TUBE SIDE**	
Fluid	**100% Propane**		**100% Propane**		**Light naphtha**	**Light naphtha**
Property	In		Out		In	Out
	Liquid	Vapor	Liquid	Vapor	Liquid	Liquid
Total Fluid entering, lb/hr	37360				291657	
Fluid entering, lb/hr	26790	10570		37360	291657	291657
Density, lb/ft3	32.1	0.86		0.86	38.8	39.8
VISCOSITY, cP	0.115	0.008		0.008	0.214	0.246
Thermal Conductivity, Btu/hr.ft2. °F /in	0.719	0.118		0.118	0.708	0.738
SPECIFIC HEAT, Btu/lb°F	0.631	0.420		0.420	0.547	0.526
TEMPERATURE, °F	50		50		113	86
OPERATING PRESSURE, psig	77.5		77.5		23.5	18.5
Fouling Resistant, °F.h.ft^2/Btu	0.001				0.001	

IV. NUMERICAL MODELING

The thermal design of chiller has been performed using a commercial program called HTRI Suite 6.0, which allows thermal analysis of chiller.

The experimental data consisted of pressure, temperature, actual gas flow and the gas and liquid compositions, density and viscosity and the amount of liquid collected/carried over and sizing values were obtained from the numerical analyses software Heat Transfer Research Institute (HTRI).

V. RESULTS OF THE ANALYSES.

A summary of the calculated data at different entrainment ratio and the results are summarized below

Title	Vapour Velocity at Different Entrainment Ratio				
Entrainment Ratio (lb Liquid/lb Vapour)	0.5 (Figure-2)	0.05 (Figure-3)	0.01 (Figure-4)	0.005 (Figure-5)	0.001 (Figure-6)
Kettle Diameter (inch)	34 (Figure-2)	37.3 (Figure-3)	40.7 (Figure-4)	42.9 (Figure-5)	49.7 (Figure-6)
Min. Kettle Diameter (inch)	33.6	33.6	33.6	33.6	33.6
Max. Kettle Diameter (inch)	69.7	69.8	69.8	69.8	69.8
Outer Tube Limit (inch)	23.2	23.3	23.3	23.3	23.3
Liquid Level (inch)	28.6	28.6	28.6	28.6	28.6
Allowable Vapour Velocity (ft/s)	2.1	1.42	1	0.84	0.56
Calculated Vapour Velocity (ft/s)	2.11	1.41	1	0.84	0.56
Horizontal Vapour Velocity (ft/s)	8.71	4.51	2.69	2.06	1.11
Vertical Vapour Velocity (ft/s)	0.51	0.44	0.37	0.34	0.28
TEMA Shell Type	BKU	BKU	BKU	BKU	BKU
Shell ID (inch)	24	24	24	24	24
Number of Shell	Series 1 Parallel 1	Series 1 Parallel 1	Series 1 Parallel 1	Series 1 Parallel 1	Series 1 Parallel 1
Number of Passes	Shell 1 Tube 2	Shell 1 Tube 2	Shell 1 Tube 2	Shell 1 Tube 2	Shell 1 Tube 2
Shell Orientation (deg.)	0	0	0	0	0

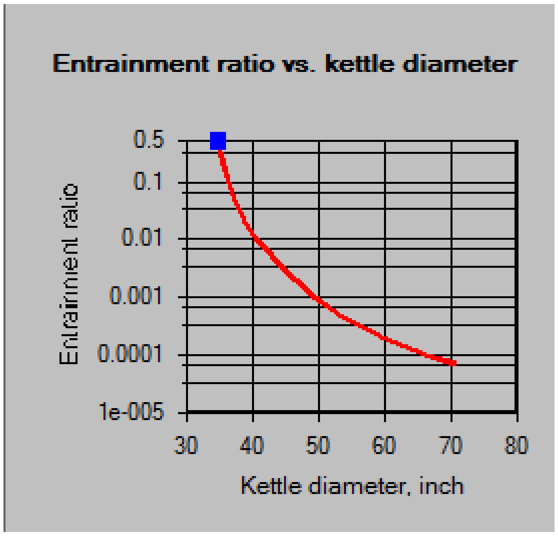
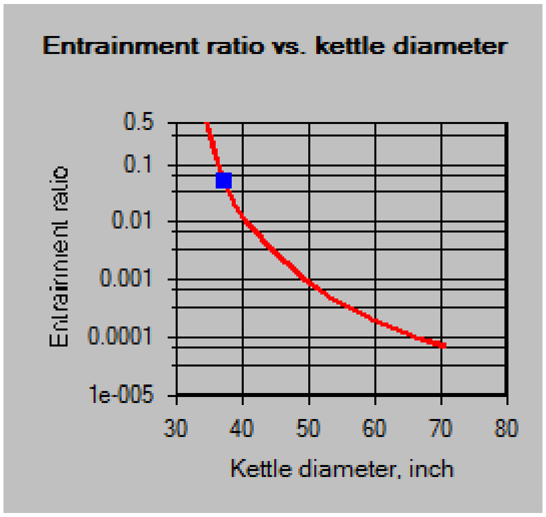


Figure-2



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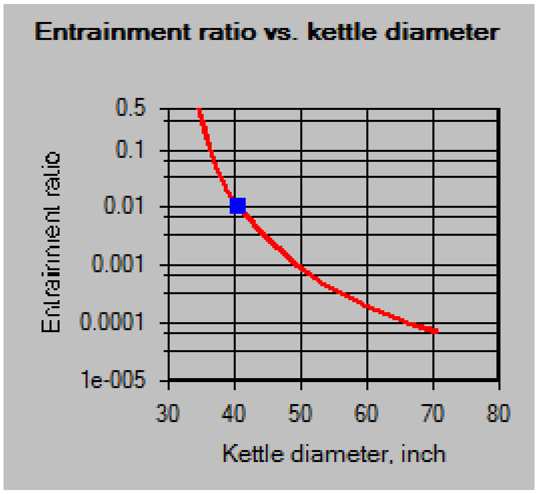

Figure-4

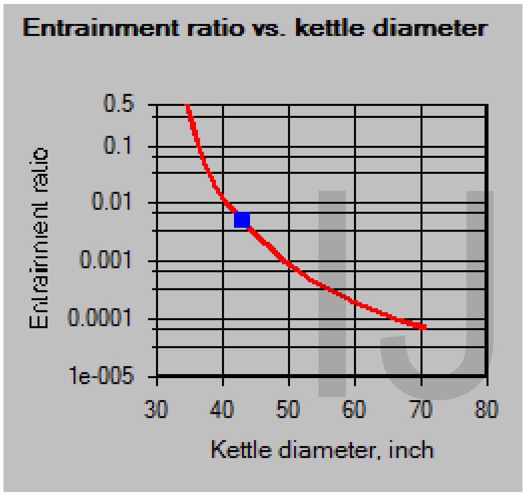

Figure-5

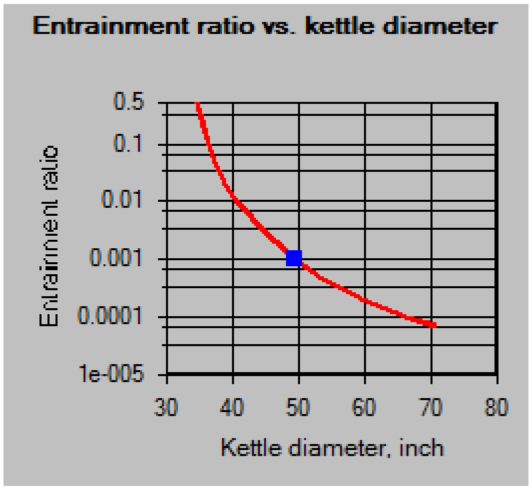

Figure-6

VI. CONCLUSION

The numerical analysis of kettle reboiler is presented. It's based on the different disengaging space and velocities at various entrainment ratios.

The developed model is comparing the entrainment ratios and velocities, which also indicates a reliable prediction of shell internal diameter, since the disengaging space on the reboiler is determined by the entrainment ratio. In addition, numerical result shows expected a minimum velocity that has to be reducing liquid droplets being carried out of the unit. Also the gap between the bundle diameter and kettle diameter is not less than 12 in [2]. Regarding these finding it should be emphasised that the space should be above the liquid boiling surface to the top centreline of the reboiler shell is adequate for disengagement of vapour. When vacuum operations are involved, the height should be greater than 12 in. Vapour outlet nozzle velocities must be selected to be low to essentially eliminate entrainment. The liquid boiling surface should not be greater than 2 in. above the top horizontal tube, and in order to reduce entrainment, it is often advisable to leave one or two horizontal rows of tubes exposed [2] , i.e., above the liquid. This will tend to ensure that the liquid mist/droplets are vaporized and thereby reduce entrainment. As a guide to the relationship between tube bundle diameter and kettle shell diameter, the following can be helpful. Also, often the tube bundle is not completely circular; that is, the upper portions of circular tubes are omitted to leave a flat or horizontal tube row at the top of the bundle, at which level the liquid is often set [2]. To size the kettle shell the distance from the centreline of the uppermost tube in a horizontal bundle to the top of the shell should not be less than 40% of the kettle shell diameter [2].

References

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