Design of 40 Klpd Absolute Alcohol Plant by MSDH Process

Mr.Mangesh D. Kulkarni[1], Prof. Mr. Rajendra Raut[2]
[1]*PG student, AISSMS College of Engineering, Pune*
[2]*Professor, AISSMS College of Engineering, Pune*

***Abstract*— Use of fuel ethanol as a blend in conventional fuel gaining much interest in now days. The cost for conversion of biomass to bio ethanol should lower than the current cost of conventional fuel. As distillation technique is not able to concentrate ethanol above its azeotropic point and molecular sieves can concentrate ethanol between 93-99.5% (w/w) so combination of distillation and adsorption technique is used. Hence using this technology design study of absolute alcohol plant has been done**

Comparative Analysis

As we see earlier distillation technique only able to produce 94% pure ethanol and adsorption technique able to produce 99% so basic purpose of this study is to design anhydrous ethanol plant which can be used in various sectors as in automobile, medical, beverage etc using combination of distillation and PSA (Pressure swing adsorption) technique named as MSDH process. Design intent consists of vaporizer column & molecular sieve beds with zeolite as a sieve. The simple tray distillation is need to be used at atmospheric pressure condition and after that these ethanol vapors need to be pass through molecular sieve bed by superheating them at 120-130°Cand time line for different cycles of adsorption technique is to be defined. While operation of MSB, one bed out of two is in operation i.e. adsorption phase while another one i.e. 2nd bed is in regeneration stage, after depressurization purged liquid is recycled to vaporizer again. This study will help to understand basic design of gas/vapor dehydration method, hygroscopic substance selection, molecular sieve bed sizing, and regeneration study for MSB. Current design of ethanol plant proposes formulas related to chemical process equipment design. For the future work, theoretical analysis of proposed 40LPD absolute alcohol plant with its simulation study is required to be done

***Index Terms*— Azeotropic, Adsorption, Distillation, Hygroscopic, Regeneration, Vaporizer**

I. INTRODUCTION

The manufacturing quantity of ethanol all over the world is increased because of increased demand of ethanol in various sectors of economy which help to increase GDP of country. Widely applications of ethanol are in the area of fuel, beverage and industrial. As per survey, approximately 74% of worlds total ethanol production; corresponds to fuel ethanol, 18% to beverages and 10% for industrial. It highlights the fact that major part of produced ethanol of the world's production used as fuel or additive for automobile sector. This helps to increase the life of conventional fuel reservoirs. Other benefits to this are, properties of ethanol like octane booster increased its use as fuel or additive to conventional fuel. Ethanol used as additive and it has less production cost as compared to MTBE. Addition of ethanol in diesel results in a decrease in cetane number, increases heating value, and kinematic viscosity of diesel fuel in automobile sector.

Other methods from design intentare, direct cooling, absorption, adsorption. In direct cooling, water vapour content of ethanol decreases with increased pressure/decreased temperature. Ethanol saturated with water may be partially dehydrated by direct cooling. The cooling process reduce the temperature to the lowest value which ethanol vapours will encounter at the desired pressure to prevent further condensation of water. After vaporization of ethanol in tray column, the vapours get condensed using condenser / sub-cooler and collected in collection vessel without passing through adsorption bed. In absorption technique, absorption carried out using liquid hygroscopic material to remove water vapour from the gas or ethanol water mixture mostlyethylene glycol or triethylene glycol used as hygroscopic liquid substance. In solid bed dehydration where solid hygroscopic material is used to separate water vapour from gas of ethanol hygroscopic material becomes saturated as moisture is adsorbed onto its surface. A good hygroscopic material should have the maximum surface area available to adsorption.

There are two types of adsorption process; physical and chemical. A good adsorbent should have properties like maximum surface area required for high capacity, good activity retention with time/use to be consider, high mass transfer rate, high mass transfer rate, easy and economic regeneration, it should have low resistance to gas flow so as to reduce pressure drop across bed, it should posses high mechanical strength, it should be non corrosive, non toxic, chemically inert.

II. LITERATURE REVIEW

Adsorption is kind off complicated unit operation, compared with distillation, absorption, and extraction. Below step-by-step procedure for designing ordinary adsorbers, which consider basic pressure swing adsorbers and temperature swing adsorbers. Some of the methods mentioned below are semi-empirical, while remaining are on solutions of differential mass balance equations with no adjustable parameters. All the models encountered below require only a calculator to solve. The major constraint is that the basic properties required for simulation or design are not widely available, e.g., in handbooks or in property databases such as perry etc. Unfortunately, to solve the more features model, more flexible parameters are necessary, and the experimental data is necessary to evaluate them. With a relatively simple model and minimum figures we can evaluate and design required adsorber Calculations or solution for complex situation is to be considered in adsorbers, it required more mathematical models. These models can be fitted to parameters. In general practices, to merge with models would be desired to have a documented and user-friendly software package, a comprehensive database, and a fast Personal computer. Even with such tools, excess data may be required to “get exact” mass transfer rates, deviations from plug flow, heat transfers, and other related to operations, it may require long span of experimental effort.

Temperature get shift of about 20°C is a common situation in pressure swing adsorption (PSA). Air-drying system and oxygen-separation (from air) systems. A shift of that magnitude does affect air drying, but does not affect oxygen separation for small units, though the effect on large units is significant. So, it is not enough to assess the effect; one should also assess the impact on performance while accounting for collaborative effects.

Some normal properties of adsorbents are required in all adsorber design calculations. They never be assumed, but must be measured. In fact, vendor-supplied charts and tables are sometimes available, but there are low chances to be valid for design purposes. The necessary properties are; densities and void fractions, isotherms (or other equilibrium data), kinetics, and fixed bed dynamics. These factors are strongly involved in adsorber model. Not strictly a property, cost is also involved in every design factors. Frequently, rough values of density or a range of required properties are available from the vendor. Cost data are available as a function of quantity and required pre-treatment. Most vendors provide additional generic properties. If the potential sale is remarkable, they may even produce data. Otherwise, data for density, isotherms, and kinetics, might be found in books or monographs (e.g., Valenzuela and Myers, “Adsorption Equilibrium Data Handbook,” Dobbs and Cohen, “Carbon Isotherms for Toxic Organics.” Availability of sources, is rare to find the correct combination of adsorbent-adsorbate-temperature, range of data, pre-treatment conditions, etc. As a result, those resources may be considered risky. In Parallel, you might arrange to conduct the measurements. Finally, since the tests are sometimes tedious and require special apparatus, you might arrange to have tests conducted by an independent firm. They frequently offer unbiased evaluations of adsorbents from various vendors, skill in conducting and analyzing the tests.

Mass transfer kinetics is a term related to inter-particle mass transfer resistance. It is important because it controls the cycle time of a fixed bed adsorption process. Fast kinetics implies a sharp breakthrough curve, while slow kinetics leads to a distended breakthrough curve. The effect of a distended breakthrough curve can be overcome by adding adsorbent at the product end, or by increasing the cycle time (it reduces the throughput per unit of adsorbent). Both of these options increase the amount of adsorbent required. To optimize for slow diffusion, it is also possible to use small particles, but there is a measure loss due to increased pressure drop.

Diffusion between particle is done by an effective diffusivity,

Deff = DABCP/T

(Where DAB=Adsorbate diffusivity in the fluid, Cp = particle void fraction & T= Tortuosity)

PSA systems are designed as two or more identical, parallel beds that operate out-of- phase so that feed can be admitted to at least one of the beds continuously. Generic design decisions involve the cycle time, steps, flow directions, operating conditions (flow rates, pressures, etc.) and of course vessel dimensions. We will use the results of the simplest local equilibrium model to predict PSA performance. The advantage of this simple model is that few choices are necessary; the steps comprising the PSA cycle, operating conditions (feed composition,pressures,andstep-times),andevaluatethese.Fromthatpoint,themodelcan predictoverallperformanceintermsof:flowrates,productrecovery,byproductcomposition,and power requirements. Whichemployspressurizationbyproduct.SeveralothercyclesarediscussedbyRuthven Accordingly, the moles required for the feed, purified light product, and purge steps are: Respectively, where P_H/P_L (ratio of absolute pressure).

b) The principles of adsorption on molecular sieves are Simple. The porous crystalline structure and the maximum surface area provide a high electronic activity which gives molecular sieves their outstanding adsorption properties. “Contaminants” may affect on adsorption process in several ways: adsorption competition, degradation of the structure, partial blocking of the adsorbent bed, side reactions. The compounds involved and the causes are varied, but the consequences are always the same: poor performance of the beds ultimately leading to premature breakthrough, unacceptable pressure drop or adsorbent unloading difficulties

III. DESIGNCONSIDERATIONS

TABLE 1ADSORBER DESIGN CONSIDERATION

Sr No	Consideration	Clauses	Sub-Clauses
01	Basic Adsorbent Properties	Isotherm Data	Check for Hysteresis; Pre-treatment Condition; multi-component effects
		Mass Transfer Behaviour	Interface Character ;Dispersion; Film diffusion
		Particle Characteristics	Porosity; Pore size distribution; density; hydrophobicity, particle shape etc
02	Application Consideration	Operating Condition	Flow rate; Pressure/ Temperature; Cycle time etc
		Regeneration Technique	a)Thermal- steam/Hot fluid b)Chemical- Acid/Base/Solvent/Adsorbate recovery
		Energy Requirement	
		Adsorbent File	Attrition/Swelling/Aging/ Fouling
03	Equipment	Contact	a)Fixed- Axial/Radial flow; Pulsed/Fluidised Bed
		Geometry	No of bed; bed dimension; flow distribution; dead volumes
		Column Internals	Bed support/ Ballast etc
		Miscellaneous	Instrumentation; MOC; safety; operation; maintenance

A) Process Flow Diagram:-

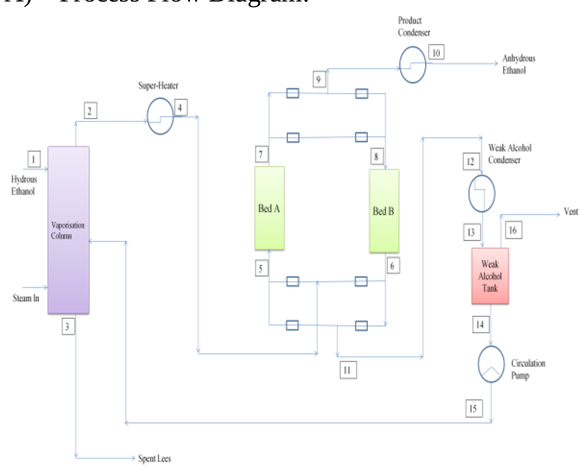

Figure 1.Dehydration of Alcohol by MSDH Process

B) Material & Energy Balance

1. Alcohol Column Material Balance

TABLE 2 MATERIAL BALANCE ANALYSIS

Column Feed Balance	31560	1315	-	-
Component	Kg/day	Kg/hr	Wt%	Cp(kj/kgk
Ethanol	29666	1236	94	0.50
Water	1893	78.90	6	1.01

Total	31560	1315	100	0.531
Column Overhead Balance	29666	1236	-	-
Ethanol	29073	1211	98	0.50
Water	593	24.7	2	1.01
Total	29666	1236	100	0.510
Column Bottom Balance	1893	78.90	-	-
Ethanol	593.33	24.72	2	0.50
Water	1300.2	54.18	98	1.01
Total	1893.6	78.90	100	1.0

2. Molecular Sieve Bed Material Balance

TABLE 3 MATERIAL BALANCE ANALYSIS

Molecular Sieve Bed In Balance	29666	1236.1	-	-
Component	Kg/day	Kg/hr	Wt%	Cp (kj/ kgk
Ethanol	29073.07	1211.38	98.0	0.5
Water	593	24	2	1.01
Total	29666	1236	100	
Molecular Sieve Bed Out Balance	29666	1236	-	-
Ethanol	29073	1211	99.50	0.50
Water	2.97	0.12	0.50	1.01
Total	29076	1211	100	
Water Adsorbed	590.36	24.59		

3. Overall Material Balance

TABLE 4 MATERIAL BALANCE ANALYSIS

Abs Alcohol plant Capacity	kl/Day	40
	Kg/day	31560
	Kg/hr	1315
Raw feed strength	%	94
Ethanol qty in solution	Kg/day	29666
	Kg/hr	1236
Water in Solution	Kg/day	1894
	Kg/hr	79
Dehydration strength	%	98
Alcohol Strength	Kg/day	29073
	Kg/hr	1211
Balance water O/P	%	2
Water removed	Kg/day	593
	Kg/hr	24

C) EQUIPMENT DESIGN SPECIFICATION

TABLE 5

1. DEHYDRATION COLUMN PARAMETERS AND DESIGN FIGURES

PERTICULARS	UOM	TOP	BOTTO M
Vapor			
Top Pressure	Kg/cm2A	1.5	1.90
Top Temperature	°C	85	110
Molecular Weight	kg/kmol	45	18
Density	Kg/m3	2.2	1.05
Vapour Flow	kg/hr	1418	1437.46
Liquid			
Density	Kg/m3	789	1000
Liquid Flow	kg/hr	182	62.29
Vapour Load		0.330	0.43s
Flood Capacity Factor		0.31	0.31
Vapour Capacity Factor		0.26	0.26
Tower ID	mm	1067	1067
Flow path length	Inch	22.32	22.32
Tower Area	Ft2	9.62	9.62
Weir Length	Mm	906	906
L/D		0.85	0.85
Active Area	ft2	6.19	6.19
% Flooding	%	20.38	28.40

2. DEHYDRATION COLUMN CONDENSER LOAD

TABLE 6 DEHYDRATION COLUMN ENERGY BALANCE

PERTICULARS	UOM	Value
FEED		
Flow	Kg/hr	1315
Temperature	Deg C	65
Sensible Heat	Kcal/Kg C	0.53
Enthalpy	Kcal/hr	45353
OVERHEAD		
Flow	Kg/hr	1236
Temperature	Deg C	85
Sensible Heat	Kcal/Kg C	0.51
Enthalpy	Kcal/hr	53606
BOTTOMS		
Flow	Kg/hr	79
Temperature	Deg C	110
Specific Heat	Kcal/Kg C	1.01
Enthalpy	Kcal/hr	8677
Steam to Re-boiler	Kg/hr	2500
Steam Enthlpy	Kcal/kg	503
Enthalpy (Hs)	Kcal/hr	1256859
Condenser Load	Kcal/hr	1239929
Avg Latent heat	Kcal/kg	874
Total Vapour Condensed	Kg/hr	1418
Reflux Ratio		0.147

TABLE 7 CONDENSER WATER REQUIREMENTS

3. HEAT EXCHANGER DESIGN FIGURES

TABLE 8

a) SUPERHEATER (HEAT EXCHANGER)

DESCRIPTION	UOM	VALUE	
		Tube	Shell
Feed Supply Temperature	Deg C	30	110
Feed return Temperature	Deg C	50	50
Feed Viscosity	Cp	1.09	00
Density	Kg/m3	789	
Heat Capacity	Kcal/kgk	2.56	0.38
Thermal Conductivity	Kcal/hr/m/k	0.14	0.03
Feed Material Flow	Kg/hr	5128.48	1227
Total heat Load	Kcal/hr	262578	26257
LMTD	Deg C		36.40
Correction Factor			0.94
Corrected LMTD	Deg C		34.22
U Overall	w/m2K		120
No of Tubes	No's		341
Shell Diameter	Mm		740
Area Required	M2		58.16

TABLE 9

b) PRODUCT CONDENSER (HEAT EXCHANGER)

DESCRIPTION	UOM	VALUE	
		Tube	Shell
Feed Supply Temperature	Deg C	30	80
Feed return Temperature	Deg C	37	50
Feed Viscosity	Cp	1	
Density	Kg/m3	1000	
Heat Capacity	Kcal/kgk	1	0.38
Thermal Conductivity	Kcal/hr/m/k	0.53	0.14
Feed Material Flow	Kg/hr	37037	
Total heat Load	Kcal/hr	259261	
LMTD	Deg C		30.04
Correction Factor			0.94
Corrected LMTD	Deg C		28.24
U Overall	w/m2K		827.13
No of Tubes	No's		59
Shell Diameter	Mm		350
Area Required	M2		24.87

TABLE 10

c) WEAK ALCOHOL CONDENSER (HEAT EXCHANGER)

DESCRIPTION	UOM	VALUE	
		Tube	Shell
Feed Supply Temperature	Deg C	32	50
Feed Return Temperature	Deg C	37	35
Feed Viscosity	Cp	1	
Density	Kg/m3	1000	
Heat Capacity	Kcal/kgk	1	1.78
Thermal Conductivity	Kcal/hr/m/k	0.53	0.33
Feed Material Flow	Kg/hr	2670	500
Total heat Load	Kcal/hr	13350	13350
LMTD	Deg C		6.81
Correction Factor			0.85
Corrected LMTD	Deg C		5.29
U Overall	w/m2K		100.55
No of Tubes	No's		120
Shell Diameter	Mm		410
Area Required	M2		15.00

TABLE 11

d) PRODUCT SUB- COOLER (HEAT EXCHANGER)

DESCRIPTION	UOM	VALUE	
		Tube	Shell
Feed Supply Temperature	Deg C	32	50
Feed Return Temperature	Deg C	37	35
Feed Viscosity	Cp	1	1.09
Density	Kg/m3	1000	
Heat Capacity	Kcal/kgk	1	2.56
Thermal Conductivity	Kcal/hr/m/k	0.53	0.17
Feed Material Flow	Kg/hr	9304	1212
Total heat Load	Kcal/hr	46522	46522
LMTD	Deg C		6.81
Correction Factor			0.85
Corrected LMTD	Deg C		5.79
U Overall	w/m2K		100.55
No of Tubes	No's		418
Shell Diameter	Mm		785
Area Required	M2		90.91

TABLE 12

e) MOLECULAR SIEVE BED DESIGN SPECIFICATION

DESCRIPTION	UOM	VALUE
Design Temperature	Deg C	260
Operating Temperature	Deg C	140
Design pressure	Kg/cm2 (a)	2.4/fv
Operating pressure	Kg/cm2 (a)	2
Fluid Density	kg/m3	800
Volume	m3	4.5
Insulation Thickness	mm	50
Shell diameter	mm	1750
Shell Length	mm	2100
Shell MOC		SS304
Type of sieve		Zeolite
Pore Diameter	Angstroms (A)	4
Composition		$Na_2OAl_2O_32SiO_29/2H_2O$
Sieve Quantity	kg	2700
Water Absorbing capacity	%w/w	21-22
Bulk Density	kg/m3	600

IV. BRIEF OPERATING PROCESS

As per process flow diagram, min 93 to 95% ethanol is heated in heat exchanger unit either by product vapours (Heat recovery technology) or by using heating media, after that it is fed to distillation column to remove impurities and enrich ethanol up to 98% followed by super heater where alcohol vapours get superheated. This 98% alcohol vapours from column are get fed to molecular sieve bed from top for the adsorption process where zeolite sieves are used as adsorbent detail specification for column, heat exchanger, sieve bed are tabulated in the above section.

Adsorption cycles are get completed as in the form of pressurisation---purging---depressurisation, purged material is again processed in the form of weak alcohol in the system.

IV. COST ANALYSIS

The capital costs of the columns and adsorption beds are affected seriously by reflux ratios recycle flow rates, and entrainer usages in the distillation cases. Additionally these parameters affect directly the heat duties of the process and the quality of the final ethanol product. Total estimated cost of the project considering storage tanks, heat exchangers, molecular sieve bed, distillation column, etc (Equipment as per block diagram), then piping work, instrumentation and electrical work, civil work is approximately going to 274.5 lacs say 275 lacs including miscellaneous expenses. Material of construction for all equipment and piping is considered as SS304 after confirmation of its compatibility with chemical

V. APPLICATIONS

There are wide applications of absolute alcohol as in the field of Medicinal use, as these are used to disinfect the skin before surgery etc. Absolute alcohol can be used as antidote or antiseptic for medicinal use and can be used as a solvent as its molecular structure allows for the dissolving of both polar, hydrophilic and nonpolar, hydrophobic compound. As ethanol has lower boiling point, it is easy to remove from solution that is used to dissolve other chemicals, etc

Major application of this anhydrous ethanol is as fuel, Ethanol can be used as engine fuel, rocket fuel, fuel cell, as in the blending format with conventional fuel type.

Anhydrous ethanol has lower freezing point (-114.4 deg C) and lower toxicity, ethanol is used in laboratories as in the form of dry ice or coolant to keep vessels at temperature below freezing point of water.

VI. RESULT AND DISCUSSION

This paper is presented on the work done for the project of design of anhydrous ethanol manufacturing unit having 40 klpd capacity using hybrid technologies of distillation process and molecular sieve dehydration technique. The design approach of ethanol manufacturing unit is empirical hence to perform theoretical analysis strong experimental results are required which is not a part of this project so here is not presented thus theoretical design is carried out only.

VII. CONCLUSION

As a result, we are able to meet our objective i.e. design of Absolute alcohol plant using MSDH technique with study of its applications and costing. As part of capital expenditure total cost with current market price is, approximately, 275 lacs for 40 KLPD production of Absolute alcohol plant. Zeolite Molecular sieves with 4Ȧ pore diameter has to be selected for adsorption purpose, which are able to adsorb 20-21% w/w water, required quantity of this type of molecular sieves are about 2700kg. Selected composition of zeolite is $Na_2OAl_2O_32SiO_29/2H_2O$ Produced alcohol has wide market as in the form of Fuel, medicinal, solvent

VIII. ACKNOWLEDGMENT

I would like to express my deep sense of gratitude and honor towards my respected project guide Prof. R.S. Raut, Chemical Engineering department, AISSMS College of Engineering, Pune for his unending, inspiring and all dimensional guidance and encouragement to complete this work.

I am thankful to Dr. P. N. Dange Head of Chemical Engineering Department and all those colleagues of AISSMS COE, Pune who helped me in all respects to

fulfill the work with effectiveness for helping me for my project work.
I also express my sincere thanks to Dr. D. S. Bormane, Principal of AISSMS COE, Pune for his encouragement to complete this project.

REFERENCES

[1] Karl Kolmetz, Ayuzaki Lestari, “Mole sieve dehydration Design and Troubleshooting”, Handbook of Process Equipment Design, Rev.1 Sept 2015.
[2] Kent S Knaebel, “A how to guide a adsorberdesign”, Adsorption research inc, Volume – 1, Issue – May 2015.
[3] Ronghong Lin, AustingLadshaw, Yue Nan, Jiuxu Liu, “Isotherms for water adsorption on Molecular sieve 3A: influence of cation composition”, Department of biomedical and chemical Engineering, Syracuse university, Issue 2, August – 2014.
[4] Zabaluev, Y. V. “Management of radionuclides from reprocessing plant gaseous effluents”. IAEA Bulletin. 1979, 21(1), 23-31
[5] Filss, P. “Sampling and counting triturated water vapor from radioactive off-gas streams by adsorption of silica gel”. Radiochemical Radioanal Lett.1973, 15(3), 213-223
[6] Nakashima, M.; Tachikawa, E. “Removal of triturated water vapor by molecular sieves 5A and 13X, silica-gel and activated alumina”. J NuclSci Technol. 1982, 19, 571-577
[7] Leung, P. C. W.; Kunz, K. B.; Seff, K. “Crystal structures of hydrated and dehydrated potassium-exchanged zeolite” A. J. Phys. Chem. 1975, 79, 2157-2162
[8] AlexandreTerrigeol; “Molecular Sieves contaminants: Effects, Consequences, Mitigation” May-2012
[9] R.J. Bombardieri, T.Elizondo, “Extending molecular sieve life depends on understanding how liquid form”, Oil & Gas Journal, May 19, 2008, p.55-63.
[10] R.R. Eguren,”Molecular Sieves operational challenges”, 62nd Laurance Reid Gas Conditioning Conference, Norman, Oklahoma, February 2012.