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Conclusions and Future Perspectives

Exergy losses are mainly due to irreversibilities in chemical reactions, mixing different temperature, composition streams. The overall exergy efficiency of the inorganic industry is 29% and organic industry is 35%. Equipments dealing with separation and heat transfer in chemical industries are having lower exergy efficiency. Overall sectorial efficiency is low due to the combination of efficiencies of all plants. Exergy methods can help to improve economic evaluations and environmental assessments. Many design related applications of exergy analysis are helpful to evaluate, compare, and improve the process (Nimkar and Mewada, 2014). Exergy analysis shows poly generation systems for the production of energy and chemicals is promising in the future.

7.1 Nitric Acid Process

The nitric acid plant is a net exporter of energy. Ammonia oxidation is a major source of energy. Plants energy efficiency is 31% and exergy efficiency is 20.83%. Heat energy discarded through cooling tower water is 67.86% of the total energy. Reaction irreversibility is a major cause of exergy loss. The exergy efficiency of the plant can be increased by reducing exergy losses. It is concluded that by reducing the inlet air temperature in the compressor, exergy efficiency of the plant can be increased by 2.44%. Using heat given by cooler condenser in organic Rankine cycle power plant, exergy efficiency can be increased by 14.58%. Additional available energy of 254.26 MJ/t from both measures will increase exergy efficiency of the nitric acid plant from 20.83 % to 24.65% (Mewada and Nimkar, 2015). Apart from these benefits, reduction of CO$_2$ emission is an added advantage. Above savings can reduce 57.56 kg of CO$_2$ per ton of acid (100%). Carbon credits will help to reduce expenditure required for the above improvements.
7.2 Ethylene Oxide/Ethylene Glycol Process

The present study for ethylene oxide and ethylene glycol production provides an insight into the relation between catalyst selectivity, exergy loss, capital cost and production cost for EO/EG process. There is no fixed trend of EO-EG prices and even shutdown of one plant may cause variation of prices in that region. To get maximum profit in such situations exergoeconomical analysis is useful. This methodology can be extended to other processes where catalyst selectivity plays an important role in the production. Exergy analysis pinpoints the true losses in the process and exergoeconomic analysis shows the relation between exergy destruction and capital cost. Exergy efficiency of the process is higher (74.59%) at SR and lower (73.29%) at ER. Highest exergy destruction is observed in EO reactor (46%) at SR and (47.53%) at ER followed by EG reactor (11.8%) at SR and (10.70%) at ER. Exergy efficiency of the new process is same as that of the conventional process at the start run but improves at the end run. Capital cost saving is the added advantage of the new process. Ethylene recovery from purge gas will improve exergy efficiency of entire plant up to 5.17%. The temperature in the reactor, increase in the volume of gas and price of ethylene are the limiting factor to decide ER selectivity of the catalyst. Statistical data for thermodynamic loss rate to capital cost ratio values shows that relative spread in Mean value (R) for different devices are large when it is based on energy and small when it is based on exergy. The relation between thermodynamic loss rate, ethylene cost, steam cost and income generated will be helpful to maximize profit at different selectivity values. Different types of a catalyst like high selectivity catalyst, high activity catalyst, hybrid catalyst are used for the production of EO. Our proposed method can be helpful to select end run selectivity of a catalyst based on $EGR_{ex}$ values which is the ratio of exergy destruction to income generated.

7.3 Thermally Coupled Reactor

In thermally coupled reactors exothermic and endothermic reactions are taking place in the same reactor. Such reactors utilize heat generated by exothermic reaction to carry out the endothermic reaction. Use of this reactor will reduce the number of equipment for the production of methanol and hydrogen, results saving in capital cost. Exergy analysis of
various thermally coupled reactors was carried out. In thermally coupled reactors for methanol production, thermally coupled reactor (TCR-C6H12) and membrane coupled reactor (MCR) are the best reactors on the basis of exergy analysis. Equilibrium conversion can be enhanced by keeping lower output temperature. Simultaneous production of hydrogen with methanol is great economical advantage. Though hydrogen production capacity cannot be matched as per steam methane reformer (SMR), it can be advantageous to use produced hydrogen as make up quantity.

7.4 Overall Conclusions

Based on the work carried out, overall conclusions are drawn as follow,

- Exergy analysis is an important tool to identify places of major exergy losses within the process.
- Technically feasible solutions to reduce exergy losses and economic analysis to implement such solutions can be linked with exergy analysis.
- Exergy analysis will be very helpful for selection of better process, catalyst and equipment for the process.

7.5 Recommendations and Further Work

Chemical industries are operating above the practical minimum energy requirement. There is ample scope to improve energy efficiency of the processes. Exergy is used as a tool for this analysis since last few decades. Its use in the industry is limited due to lack of practical applicability. If more chemical processes are analyzed and practical suggestions are provided, it will become a usable tool in chemical industries. For the improvement of present work following suggestions are recommended

- Comparison of mono high pressure and dual pressure plants based on exergy analysis will give the best plant for operation. These plants can be also compared on the basis of exergy and economics. A major part of heat energy is given to turbo-compressor in this process. Optimum conditions of turbo-compressor can be found out based on exergy analysis.
- In the present study of EO/EG process, high activity catalyst is used. This plant can be also analyzed by using high selectivity and hybrid catalyst. Time value of
money can be used for calculation of $EGR_{ex}$. EO reactor can be analyzed by implementing measures required for reduction in exergy loss. The capital investment required for a revamping of the reactor should be considered as a part of economic assessment.

- Exergy analysis of thermally coupled reactor shows improvement in energy use and hydrogen production. Exergoeconomic analysis can be used to find out economic aspects.

As a future work different endothermic processes can be analyzed. Change in exergy efficiency of the highly exothermic process to moderate exothermic process and highly endothermic processes to moderate endothermic process can be observed. It would be valuable to investigate an indicator or parameter which will be helpful to categorize these processes based on exergy and economics.
It is also recommended to study various solid oxide fuel cells on the basis of exergy for the simultaneous production of nitric acid and electricity.