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Benefits of an Energy Audit of a Large Integrated Fertilizer Complex

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Cet exposé décrit une méthodologie mise au point par ICI pour auditer l'usage de l'énergie dans une grande usine d'engrais et décrit un des nombreux exemples où la technique a été appliquée pour identifier le potentiel d'amélioration du rendement énergétique d'une grande usine d'ammoniac / urée en Inde. L'audit d'énergie a identifié des programmes avec des économies globales possibles de 12% sur la consommation totale spécifique d'énergie. Certains de ces programmes en sont maintenant à différents stades de mise en œuvre ou sont l'objet d'une étude détaillée prolongée.

INTRODUCTION

Pour la plupart des producteurs d'ammoniac et d'urée la contribution moyenne au coût de production est le coût de l'énergie, normalement sous la forme de gaz naturel. La production d'ammoniac dans une unité moderne comporte une série complexe de réactions chimiques dans des conditions difficiles et l'unité de mise au point du procédé est inévitablement très intégrée et coûteuse. Aussi le dessin d'une unité d'ammoniac implique un choix de configuration d'équipement et des conditions appropriées de traitement pour réaliser un équilibre convenable entre coût de capital et frais opératoires. Cet équilibre est réglé sur l'importance relative des coûts d'équipement, coûts de construction et coût de gaz et cela change selon la localisation d'un projet. L'équilibre approprié entre coûts opératoire et d'équipement a également changé au cours des 30 dernières années car il y a eu des changements significatifs dans les coûts du pétrole et du gaz. Donc, les unités plus anciennes n'ont souvent pas été conçues pour les coûts actuels plus élevés de l'énergie et il y a encore des possibilités significatives de modifications appropriées en vue d'améliorer le rendement énergétique. Le premier stade d'identification des opportunités d'amélioration dans les usines plus anciennes est une évaluation générale via un audit énergétique.

Synetix, section catalyseur d'ICI, a mis au point une aptitude à auditer le rendement énergétique de grandes unités d'ammoniac et d'urée, basée sur l'expérience directe des grandes unités de production appartenant à ICI et à travers l'exécution d'un certain nombre d'études pour nos clients. Le but principal de ces audits est d'améliorer le rendement énergétique des ces unités. Cette amélioration peut avoir un effet significatif sur la performance économique de l'unité à travers la réduction de frais variables. Il est aussi vraisemblable que le processus d'audit identifiera un certain nombre de sujets et de programmes ce qui, à côté de la réduction de consommation d'énergie, améliorera aussi production et fiabilité. L'implication d'une importante section de l'équipe opérationnelle dans le processus d'audit augmentera la prise de conscience de l'importance du rendement énergétique et entraînera une amélioration soutenue de la marche de l'usine.

Abstract

This paper describes a methodology developed by ICI to audit the energy usage in large complex process plants and describes one of the many examples where the technique has

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been applied to identify the potential for improving the energy efficiency of a large ammonia / urea factory in India. The Energy Audit identified schemes with potential total savings of 12% of the overall specific energy consumption. Some of these schemes are now under different stages of implementation or are the subject of further detailed study.

Introduction

For most ammonia and urea producers the largest contribution to the production cost is the cost of energy, normally in the form of natural gas. The production of ammonia in a modern plant involves a complex series of chemical reactions at difficult conditions and the process plant is inevitably highly integrated and expensive. The design of an ammonia plant therefore involves a careful choice of equipment configuration and appropriate processing conditions to achieve a suitable balance between capital cost and operating cost. This balance is adjusted depending on the emphasis between equipment costs, construction costs and gas costs and it changes depending on the location of a project. The appropriate balance between operating and equipment costs has also changed over the last 30 years as there have been significant changes in the cost of oil and gas. Hence older plants often have not been optimally designed for today's higher energy costs and there is significant scope for appropriate modifications to improve energy efficiency. The first stage in identifying opportunities for improvement in older plants is an overall assessment via an Energy Audit.

Synetix, the catalyst business of ICI, has developed a capability to audit the energy efficiency of large ammonia and fertilizer plants, based on the direct experience of ICI's own production plants and through the execution of a number of studies for our clients. The main purpose of such audits is to improve the energy efficiency of these plants. This improvement can have a significant effect on the economic performance of the plant through the reduction in variable costs. It is also likely that the audit process will identify a number of issues and schemes that, in addition to reducing energy consumption, will also improve plant output and reliability. Involvement of a large cross-section of the plant operating team in the audit process will raise awareness of the importance of energy efficiency and result in sustained improvement in plant operation.

Methodology

The purpose of an energy audit is to characterise the energy consumption of a large, complex process plant and identify opportunities to improve the energy efficiency.

The methodology developed by ICI involves a structured approach which combines a study of the hard issues such as plant process conditions and computer modelling of modifications with the softer issues that includes understanding the operating philosophy, actual practices and perceived constraints.

The implementation of a fully detailed Energy Audit involves a significant amount of time and effort and so it is usual to proceed through a series of structured stages. These stages identify the potential for improvement with minimal expenditure and provide a series of points at which decisions can be made to proceed with further study, depending on the potential savings that have been identified. A staged approach to an Energy Audit would normally include the following steps.

Stage 1 – Preliminary Benchmarking

This provides a quick initial assessment of the potential for improving energy consumption. This is done by answering some basic questions about plant performance, modification history and utility consumption. Comparison with industry standards gives a broad indication of the scope for improving the energy consumption of the unit.

Stage 2 – Exploratory Audit

This involves more complete understanding of the plant operation, including the determination of the heat and material balance for the plant. This Audit, which is normally undertaken by an experienced senior consultant, will identify a number of simple changes that are likely to give a quick improvement in plant performance. It will also identify a number of other areas that are likely to need further study.

Stage 3 – In-depth Energy Audit

The third stage of the Energy Audit process involves a more detailed assessment of the plant operation and the scope for improvement. An in-depth audit comprises:

- Data collection
- Base case modelling
- On-site discussions
- Development and evaluation of relevant modifications
- Review and reporting

Data collection – this is a necessary first step to understand the operation of the process units. The data collection will include information about the plant design and modifications, a complete snapshot of operating conditions in order to establish a plant simulation model, and historic data to show changes in performance over time.

Base case modelling – a computer simulation is used to reconcile the plant operating data and produce a consistent description of baseline plant performance. The model can then be used to evaluate potential changes to operating conditions or plant equipment. Establishing the appropriate level of detail in the model involves careful judgement so the model is sufficiently comprehensive to assess the impact of design changes without being so detailed that it requires an excessive amount of time to prepare the model.

On-site discussions – these discussions will validate the computer model of the plant and allow discussion of operating philosophy and perceived plant constraints. These discussions are normally developed into a series of “brain-storming” sessions with a wide cross-section of people from the operating team. These sessions will raise a number of pertinent ideas and suggestions to improve plant efficiency, reliability and output.

Development and evaluation of ideas – this involves evaluation of the plant performance to identify scope for improving energy usage and assessing the ideas from the brainstorming sessions. The opportunities for improvement may be identified using many techniques, including formal analysis tools to examine energy flows and “pinch” points and experience from ICI’s background as a developer and licensor of ammonia process technology.

Review and reporting – this concludes the Energy Audit by presenting the findings and recommendations to the client. This will include a number of suggestions for immediate implementation together with ideas that may require further study and evaluation.

Case Study

ICI has applied the Energy Audit process to a large number of production plants, both within the ICI group and for external clients. These studies have included different types of processes and have also been conducted for highly integrated factories as well as stand alone facilities. One of the recent Energy Audits was conducted for a large urea producer in India and this audit will be described in more detail to illustrate the technique.

Chambal Fertilisers and Chemicals Limited (CFCL) operate an ammonia plant and a urea plant, together with the associated utility systems at Gadepan in Northern India. The site began production at the end of 1993. The ammonia plant has an original design capacity of 1350 MT/day and the urea plant has twin units of a nominal design capacity of 1174 MT/day feeding a common prill tower. The site is self-sufficient in steam and power and is provided with 2 auxiliary boilers raising high pressure steam and 2 gas turbine units co-generating medium pressure steam and electrical power.

A View of the Chambal Fertilizer Factory at Gadepan, showing the Urea Plant in the Foreground

CFCL wanted to assess the energy efficiency of the whole production site at Gadepan with the intention of reducing the specific energy consumption of urea production.

The Energy Audit was conducted by ICI using assistance from Simon India Ltd, our local Indian partner. The Audit followed the methodology described above. The 5 stages of the Auditing process were conducted over a period of about 6 months.

December 1998 – Initial site visit to collect information and operating data

January 1999 –	Process modelling and data reconciliation
January 1999 –	Site visit to review modelling and generate ideas from the plant operating team
April 1999 –	Site visit to present preliminary findings and resolve outstanding issues
May 1999 –	Site visit to focus on urea process issues
July 1999 –	Final site visit to present the project report and closeout the Audit.

Data Reconciliation

Analysis of the raw data from the plant generally showed good agreement between the various instrumentation and analyses, with the exception of the ammonia synthesis loop. There was a significant inconsistency between the production rate, gas analysis exit the converter and reactor temperatures. This data could, however, be reconciled by assuming a leak of 4% in the internal heat exchanger in the converter. Such leaks are relatively common in ammonia converters of this type and it seemed likely that this is the cause for the apparent data anomalies. In a subsequent plant shutdown the leakage was confirmed and attended to. This is an example of how analysis of the data can be used to infer valuable information about equipment condition that can be used for further inspection or maintenance planning.

Ammonia Plant Efficiency

The single largest contribution to the cost of fertilizer production is the energy efficiency of the ammonia plant. The initial data collection exercise was used to generate a material and energy balance for the ammonia plant and characterise the overall unit efficiency. The overall energy consumption for the ammonia plant is significantly lower than the design figure, thus indicating both that the plant is well operated and that there is some margin in the design basis.

The breakdown of this energy consumption is indicated in the table below. The intrinsic energy content of the product ammonia is 24 GJ/MT and hence the difference between this and the actual energy consumption indicates the energy used in the process. Such processing energy is represented primarily by losses associated from the 3 main compressor turbines, unrecovered process heat and flue gas heat.

Table 1 – Summary of Energy Flows

Product Ammonia	71.9 %
Unrecovered Process Heat	10.5 %
Air Compressor Turbine	7.8 %
SynGas Compressor Turbine	5.7 %
Flue Gas	2.4 %
Refrigeration Compressor Turbine	1.8 %
Miscellaneous	0.6 %
Overall	**100.0 %**

Opportunities for Improvement

After establishing the base case material balance an optimisation and sensitivity study was conducted to identify any adjustments in major process variables that would lead to an efficiency improvement. This exercise identified a number of variables such as the steam ratio to the primary reformer and the exit temperature from the primary reformer that were some distance from the design values and also were away from the most appropriate values for minimum energy consumption. The variable optimisation allowed some quick adjustments to be made with no cost implications that had an immediate benefit on plant operation.

Table 1 demonstrates that the largest part of the energy loss from the ammonia plant is associated with the main machines in the plant. As the performance of the major machines is critical to the overall energy performance, the operation of the machines was reviewed in some more detail. In particular the achieved efficiency of each turbine and compressor stage was assessed to identify areas where the performance may have fallen below expected levels. This identified some specific compression stages where efficiency was unusually low.

Brainstorming

Review meetings were held with groups of the plant operating team to discuss operating practices and generate suggestions for modifications and improvements. These sessions generated more than 100 ideas for consideration. As part of the evaluation process, the ideas they were prioritised using a scoring system that roughly considered cost, value generated and implementability. Although the main focus of this exercise was to improve energy consumption, ideas were also generated that addressed plant output and reliability.

Audit Recommendations

The recommendations of the Energy Audit were classified into 3 main areas:

> **Process optimisation** – these involve negligible expense and can be implemented immediately.
>
> **Minimal Cost** – these are likely to involve some small maintenance expense or minor projects.
>
> **Capital Projects** – opportunities for Capital Projects aimed at efficiency improvement are identified. The evaluation of such potential projects is the subject of further study.

The overall savings identified by all of the recommended schemes was equivalent to 4 GJ/Te in ammonia plant energy consumption, or 12% of the site energy costs.

Process Optimisation

The Energy Audit for CFCL identified 30 schemes in this category. Some examples of these schemes are given below:

Correct the natural gas feed flowmeter – As part of the plant modelling exercise the raw plant measurements are reconciled in a consistent material and energy balance. This process identifies those measurements that are likely to be incorrect, either because of an instrument error or need for instrument re-calibration. In the Chambal study it was found that the main natural gas flowmeter was reading high by approximately 4-5%. Identification of this error and subsequent instrument re-calibration allowed the operating team to better understand the actual operation of the plant.

Change calculation of steam ratio – CFCL had used the total carbon content of the natural gas stream as a basis for calculating the necessary steam flow to achieve a set point of steam / carbon ratio. In such a calculation it is inappropriate to include the portion of carbon that is in the form of CO_2 and only the carbon in the form of hydrocarbons should be included. The CO_2 content at CFCL is around 5% and so this change makes a significant difference to the steam addition. The change is equivalent to saving 10 MT/hr of medium pressure steam and is worth 0.02 GJ/MT or $20,000 per year.

Reduce steam / carbon ratio from 3.65 to 3.3 – the target set point used by CFCL for the steam / carbon ratio to the primary reformer was 3.65. This is significantly higher than seen on many modern ammonia plants. The process model and optimisation of the main process variables indicated that the optimum steam ratio was close to 3.3. A reduction in the steam ratio would lead to a significant reduction in fuel load in the primary reformer and an improvement in the plant steam balance. Such a reduction also gives a lower pressure drop in the front-end of the plant, thus leading to a potential increase in plant rate as well as a reduction in the energy consumption.

Increase the primary reformer exit temperature – the plant operating strategy, for various downstream considerations, had deviated from the original design and the standard practice was to operate the primary reformer with an exit temperature of only 750^{o}C. An increase in this temperature would lead to a substantially lower methane slip and increased hydrogen production, giving both an increase in production and improved energy consumption. An increase in reformer exit temperature was therefore recommended, after first overcoming concerns about reformer tube temperatures and checking that changes in tube temperature would not have a significant effect on tube life. Overall the recommended changes to the primary reformer conditions were estimated to reduce the plant costs by $ 300,000 per year and lower the energy consumption by 0.3 GJ/MT

Lower the quantities of catalyst in critical reactors - The CFCL ammonia plant has a conventional design with High Temperature Shift and Low Temperature Shift reactors. By using the latest generation catalysts from Synetix, performance equivalent to the plant design conditions can be achieved with substantially lower catalyst volumes, thus reducing pressure drop and also saving catalyst costs.

Increase C-2 reflux in the urea plant – An increase in the reflux flow to the C-2 distillation tower will lead to lowering of water content in the recycle stream to the urea reactor, so giving enhanced efficiency in the reactor and lower specific energy consumption.

Optimise reactants feed composition – Data from the urea plants showed them to be operating with an ammonia/ CO_2 ratio of 3.2, which is lower than the optimum value. Adjusting this ratio to the optimum value would save approximately 5 MT/hr of MP steam.

Minimal Cost Items

In the CFCL example study most of the Minimal Cost Items were associated with machine performance. A number of specific machine stages were identified as having lower than optimal achieved efficiency. These are summarised in the table below, which shows the difference between the achieved and design efficiency for some of the key duties.

Table 2 – Machine Efficiencies

Machine	Stage	Efficiency drop
Syn Gas Compressor	2 3	4 % 3 %
Air Compressor	3	12 %
CO2 Compressor	2	4 %

Improved maintenance practices or minor machine modifications are likely to significantly improve the efficiency of the critical stages identified above.

Capital Projects

Several opportunities for capital projects were identified for the CFCL example audit. These potential projects are typical of those identified.

Ammonia synthesis loop heat recovery - The amount of heat recovery from the ammonia synthesis loop was less than normally applied on a modern ammonia plant. There is scope for an additional heat exchanger at the exit of the ammonia converter to recover heat to boiler water heating. In addition to improving the heat recovery this would also lower the temperature into the converter, lower the average catalyst temperatures and lead to an increased conversion per pass. This is being actively considered by CFCL prior to implementation.

Low pressure loop – the design ammonia synthesis pressure in the studied plant was 220 kg/cm^2. This is substantially higher than for modern low energy designs and there is scope for substantial power saving by retrofitting a low pressure synthesis loop. Such a power saving would result in a significant saving of medium pressure steam, as well as potentially removing the machine as a limit to plant throughput. This would be a major revamp scheme and so detailed further study is necessary.

HP absorption – an energy saving scheme was identified that uses high pressure water scrubbing to remove ammonia from the loop purge gas before it passes to the hydrogen recovery unit. This scheme would replace the current system which is based on refrigeration, saving approximately 500kW of power. This is being considered for further detailing prior to implementation.

Cooling of synthesis gas at the suction of the main compressor – the suction and interstages of the main compressor are cooled by cooling water. A scheme has been developed to lower the temperature from these coolers by using a refrigeration system. This is a relatively standard retrofit option for ammonia plants. This scheme is currently being considered in more detail prior to implementation.

Install ammonia pre-heater – preheating the ammonia prior of the urea reactor can be done using heat which is currently rejected to cooling water. As well as recovering more heat this will lead to an improved temperature profile in the reactor.

Install new carbamate pre-heater – overhead vapour from the distillation tower could be used to preheat high pressure carbamate solution. Such a scheme would reduce the plant cooling water requirement and improve energy consumption.

Install urea solution pre-concentrator – This is another example of improved heat integration of the urea plant where a hot stream that would otherwise be cooled with cooling water is used to preheat another stream that would otherwise be heated with steam.

Conclusion

ICI has developed a successful Energy Audit methodology that has been applied to a number of large chemical processing plants, including ammonia and fertiliser plants. The methodology has been proven and validated though application to a large number of ICI's own plants, as well as being used for our clients.

A recent example of the application of this methodology to a relatively new ammonia plant identified a significant number of ideas for improvement. The total improvement from all the specific schemes identified was over 12%. The schemes have been classified and prioritised to allow quick modifications to be implemented immediately and larger schemes to be studied in more detail.