Marginal Cost Analysis in Process Decision Making

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Abstract

The marginal cost of an extra tonne of production is generally significantly different from the average cost of production. It can be much higher or lower depending on circumstances and, importantly, more production may not always mean more profit. Analysis of marginal costs can highlight and address what are effectively economic decision points in plant operations, capital projects and plant design. This analysis is also important with regard to equipment condition and availability and can be used to guide the allocation of maintenance resources to minimize production costs. Marginal cost analysis is based on a comprehensive process model of the plant combined with a cost model. A well-tuned plant model will give accurate information about the relative differences in raw materials and energy (RME) between different designs, plant configurations or operating targets. The model RME utilizations for different scenarios are input to the cost model that includes detailed fixed and variable operating costs. Comparison of scenarios with a base case will give accurate marginal cost information. Scenarios may be very detailed and include variations in individual equipment performance and availability that can be used to build an equipment sensitivity matrix for big data analytics. This method of analysis gives a true measure of the bottom line impact of any process change which can be used to select appropriate technologies and allocate limited resources to minimize production cost within real constraints. It is a proven tool in refinery management and in mature plants has allowed for continual production increase and cost reduction without major capital expenditure.

Keywords: Process simulation, cost analysis, resource allocation, marginal cost.

1. Introduction

An alumina refinery is in many ways a marvel of process engineering - a typical plant has hundreds of unit operations, thousands of pieces of equipment, many kilometers of pipes, wiring and conveyers, a big plant may have in the order of a billion liters of Bayer liquor and over 50,000 tonnes of solids inventory in the active circuit. These large complex operations produce a single product which has to meet a strict range of chemical and physical specifications and they need to be competitive in a global commodities market.

There is a strong incentive to reduce manufacturing costs and increase output. This can be done with large capital projects and brownfield expansions. It can also be done with small projects and the optimization of operating parameters, controls strategies and allocation of maintenance resources. Making smart choices of how to allocate limited resources over time will reduce costs and increase output with little or no capital expenditure. Many small improvements can add up to give significant benefits and there are a number of plants around the world that have done just that. The trick is to identify, justify and prioritize the improvements.

The effects of small process changes are generally not directly measurable in a plant and require a detailed process model in order to evaluate their effects. The relative benefits also need to be evaluated using *marginal* production costs rather than average production costs. Marginal cost is often very different than the average cost and this can strongly skew the potential benefits when comparing projects.

The Wikipedia definition for marginal cost is: "*In economics, marginal cost is the change in the opportunity cost that arises when the quantity produced is incremented by one unit, that is, it is the cost of producing one more unit of a good*." In a refinery the question is "how much did the extra tonnes cost to make" and in general, the answer is "a lot different than the average cost". The focus of this paper is on quantifying the effect of small changes on a process and using that information to optimize plant operations.

2. Measurement

One characteristic of the Bayer process is that the liquor continuously circulates around the process. There are also many inner recirculation loops within the big outer loop. The consequence of this is that any change anywhere in the process will affect everything else everywhere in the process. The changes may be in ways that are not necessarily expected and may be counter intuitive. This means that in order to evaluate the effect of some change on a process you need to be able to look at what happens across the entire process and for small changes, you need to be able to accurately model small differences in RME use across the plant and add them up to get the real net change.

The measurement of process changes in a plant is not straight forward. A refinery is a harsh environment for instrumentation and the size of the equipment and the magnitude of the flows make accurate measurements difficult. It is easy to accurately measure a 1 kL/h flow – it is hard to accurately measure a 1,000 kL/h flow. In addition, it is not always clear when to measure. There are a range of time scales between cause and effect. It takes something in the order of days for the liquor to complete a full trip around the circuit, it takes about a day for solids to pass through precipitation and most are recirculated again, charge pump to blow off tank is an hour or two, transit through the heat interchange department (HID) is in the order of minutes and recirculating flows can transfer the effects of process changes to other parts of the process more quickly. For example, if there was a sudden change in test tank caustic, digestion would see this change much sooner than the back end of precipitation. Aside from any intentional process changes, there are continual changes in a process due to equipment condition, variation in bauxite quality, lag times in normal plant controls, equipment swaps, etc.

Plant data tends to be noisy enough so that is difficult to see the effect of minor process changes.
In a plant making 5 000 t/d of alumina, a difference of 25 t/d cannot be readily measured. This might be discernible in long term data, but not on a daily basis. If you measured 25 t/d difference in production (which in this case is 0.5 %) you cannot know whether that is measurement error in the weight belt, material coming out of precipitation tank inventory, a change in charge pump flow from 5 days ago, a slight drift in charge control instrumentation, a small change in evaporation rate 3 days ago or the optimization of some control parameters to make the plant run more efficiently. An important point here is that 25 t/d extra production – for whatever reason – is worth in the order of $1 M USD per year in bottom line profit.

Maintenance resources are always limited and there is a constant need to prioritize those resources for both planned and unplanned maintenance. Safety and plant integrity should always be at the top of the list, but beyond that some maintenance jobs have a larger return than others in terms of production rates or cost. Some of these changes might be noticed in an operating plant if they were long term but not in the short term. For example, permanently removing a precipitation tank from service would have a measurable impact, but if a tank comes out of for example, a boiler off and steam restrictions, an evaporation unit off, different quality bauxite, etc. The same process model and cost model can be used for all of these situations. The different base cases can be stored as scenarios and reloaded as needed. The calculations can be made as deviation from plan and this can be done on a weekly basis to provide support for short term planning.

The simulation model with its reports, calculations and collection of base cases should be maintained and improved on an ongoing basis. This requires adequate allocation of human resources, procedures and standards for the modeling program and regular use of the model. A key point is that an investment in building and maintaining a good quality plant model together with best practices and procedures for using the model, can provide a bottom line benefit for a range of applications in operating a refinery. With a commitment to the ongoing use of modeling at a refinery, there can be significant ROI with benefits for production, quality, reducing costs and understanding of process plant operational relationships. Golubev [1] and Franco [2] give some good examples of modeling use in process optimization.

7. Conclusions

Plant data in an operating refinery is noisy and instrumentation often lacks the accuracy necessary to sensibly analyze the effects of small changes to a process. This makes it difficult to use plant data for making decisions to improve production and/or reduce costs. However, with the "digital twin" of a good plant model, analysis is readily available to make and prioritize decisions that have the most effect on the bottom line for an operating refinery.

This paper focuses on marginal cost analysis for RME to improve operational profitability, but the same simulation model and technique can be used for justifying and prioritizing small capital cost projects for process equipment changes or improvements. A further example of use for this technique is in evaluating alternate or improved process control strategies and/or operator procedures.

These techniques can be taken further through automation of running a large number of scenarios for producing significantly large data sets and then using novel data analytics and reporting (visualization) software to gain insights into refinery operations and optimization. A possible future progression, now possible with emerging technology, is to use model simulation data together with plant data in a range of interesting AI applications.

8. References

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