CLOSED LOOP OPTIMIZATION UPDATE

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Closed Loop Optimization Update – We Are a Step Closer to Fulfilling the Dream

Closed loop economic optimization of refineries and chemical units has been a dream in our industry for over four decades. There have been at least three waves of attack on this problem, but Optimization has resisted the onslaught and remained a dream. Having witnessed a number of unsuccessful on-line optimization projects, I wrote several papers (1, 2, 5, 6, 8, 10), suggesting that closed loop optimization needs certain technological breakthroughs to be viable. However recently there have been some refreshing new developments and this editorial is written to tone down the negative language and express hope that while there are still many difficulties, we are now a step closer to fulfilling the dream.

Starting around 1990, and until about a year ago closed loop optimization has taken the following format.

- A linear multi-variable predictive controller (MVPC), handling the advanced control part of the application: pushing the plant against constraints while keeping product qualities at targets. The practice has usually employed large MVPC's, often only one to handle the complete plant.
- Statistical regression models for inferring product qualities, serving the MVPC's as virtual analyzers. Both traditional regression and neural network techniques have been employed.
- A steady state rigorous simulation model, searching for optimal plant settings, and downloading those settings as MVPC targets.
- The steady state model requires steady state input data, and most applications wait several hours between each process change to ensure steady state.

Implementation of this technology has been largely unsuccessful, and while orchestras of papers (for example 3, 4, 7, 12) have trumpeted closed loop optimization, reality on the ground was that these applications were labor intensive, difficult to develop and easy to fall apart. In my publications I offered a number of reasons for why the technology did not work.

1. Lack of procedures for estimating intermediate product prices. A unit cannot be optimized in isolation unless its product economics are known.
2. Inability to define unit feed makes it impossible to predict product qualities. Even the best rigorous simulation would be useless unless feed characteristics are known.
3. Infrequent optimization runs are incompatible with the operational desire to change constraints and targets in small steps. Designing the applications to wait for a “steady state” set of data is strange, because MVPC's are able to forecast the eventual resting values of all process and manipulated variables, but that is the way most applications have been configured.
4. Effective optimization requires detailed accurate models and complex simulations. That presents a problem of first - developing high accuracy models with hundreds of thousands equations, and second – keeping track of those models and maintaining them in a working environment.

5. Linear MVPC technology has a hard time with real life nonlinear units. Practitioners of this technology have dealt with this problem by de-tuning the controllers, and that is perhaps OK for holding the unit at steady state. However on-line optimization requires moving the unit smoothly along constraints from one steady state to another, while controlling product qualities al targets. A de-tuned MVPC cannot be both quick and precise at the same time.
6. This de-tuning problem is exacerbated by size. Large MVPC's are exponentially more difficult to tune than medium size ones, and this author has not seen a single large MVPC that performed well dynamically.
7. Linear MVPC's are usually equipped with a linear optimizer (whose task is not to optimize but to prioritize constraints). Coordination between the rigorous optimizer and the linear MVPC optimizer is awkward.
8. Statistical regression inference models, which ignore chemical engineering principles, need frequent re-calibration, and altogether too much laboratory support to perform well. Again here, when the unit is kept at steady state for long times – the models could be biased based on laboratory results, but in a dynamically unsteady constraint control and optimization environment, reliable quality prediction is crucial.
9. Shortage of people. In the current environment of "streamlining", plants are badly short of engineers, and have no hope of maintaining but the simplest of applications.

The next interesting development was a kind of optimization application called "Composite LP". Many practical workers (for example 9) in the field have shelved their desire to optimize the plant via a steady state rigorous simulation, and moved to solve a more manageable problem. The composite LP application typically contains several MVPC's, each looking at a very local set of constraints. The LP coordinates how a plant wide constraint would be handled among the different MVPC controllers. For example, a constraint on distillation equipment can be relieved by:

- Reducing feed,
- Changing yield pattern or plant severity,
- Changing feed composition (if possible),
- Relaxing product specifications (often possible when the product is not final),
- And possibly other mechanisms, depending on the specific situation.

Economically speaking, this technology is not a proper optimization technique because it relies on approximate linear models, rather that rigorous ones. Also, most MVPC's are already equipped with LP's and on the face of it all that has been achieved is an extension of the LP to cover several MVPC's. However this development has brought about important changes, which later permitted nonlinear rigorous optimization.

- Practitioners of composite LP technology did away with the steady state wait, designing the optimizer to input future steady state data predicted by the MVPC's. The optimizer can now run every minute, moving the unit in small steps. As stated above, this prediction of steady state inputs does not necessitate composite LP, but somehow this change came about as a part of composite LP applications.
- While LP formulation often oversimplifies the models, it permitted the later application of successive LP, which is a good method of solving nonlinear problems, especially when small steps toward the optimal solution are called for.

- Control engineers can now work with reasonable size MVPC's and still maintain global view of the plant. Smaller MVPC size would permit better controls underneath the optimizer (11).

Lo and behold, at the last NPRA Computer Conference we finally heard a paper (13), which describes application of successive composite LP on an ethylene plant. This system applies rigorous plant models, but only for calculating partial derivatives and updating LP matrices to current working points. Composite LP and MVPC's do the rest, driving the plant in small steps toward the optimum. The process repeats once per minute, continually nudging the plant to better operation. Once partial derivatives are available, as an added bonus, the system also updates MVPC's gains on the fly, eliminating the need to de-tune the controls. The double existence of two optimizers – one ate the MVPC level and another at the rigorous optimizer level is also gone. The composite successive LP is the only optimizer.

I have counted above a list of nine sticky issues, which made the closed loop optimization problem seem insurmountable in the past. It is of interest to re-assess what issues have been addressed by the successive LP approach, versus what is still a problem. Below are the issues that have not yet been solved and are still a hindrance to the successful implementation of closed loop optimization.

1. Lack of procedures for estimating intermediate product prices. Perhaps successive composite LP technology can use larger set-ups and group together several units. The work described at the NPRA conference took an ethylene plant as one unit with known product economics. But eventually for a more general situation, unit optimizers must be supplied with marginal product economics for the unit. This, if you will, is a scheduling issue, which has also been an unfulfilled dream, but that is a subject for another editorial.
2. Estimating unit feed properties is still a problem. Partial derivative, matrix gains and LP coefficients are all functions of feed properties, and no model can give reliable results if the unit feed is unknown. Some authors (for example 12) have employed a complex laboratory and book keeping system for monitoring and forecasting FCC feed properties. But we are of the opinion that such an approach is of limited use, and the only solution that could work seamlessly for closed loop optimization would involve automatic feed detection, either by on-stream analyzers or inferential formulae.
3. Effective optimization is still limited by availability of good models. We have not made an attempt to evaluate models applied in the specific case, though a general discussion of modeling problems specific to ethylene manufacturing is discussed by the author elsewhere (10).
4. Accurate, first principle inference models are still a problem. The economic drive usually calls for increasing throughput while maintaining product yields and qualities at targets. Throughput increases accompanied by yield reduction or off specification products does not necessarily make money. We sometimes can use analyzers in lieu of inference, but the slow analyzer response makes it difficult to apply even constraint control, let alone optimization.

5. Shortage of people is still a huge problem. Managers who would like to bask in the glory of closed loop optimization should understand that it is incompatible with "streamlining".

To summarize, while there are still very significant issues, their number has dropped in half, and some objectionable practices have been eliminated. Is closed loop optimization nowadays possible? Perhaps at some sites it could be, depending on specific site configuration and ability to address the still very sticky five dilemmas stated above. What I wanted to do here is not to encourage people to rush and implement five million dollars optimization projects, but to simply say that we have made progress with a problem that in the past seemed insurmountable.

Literature cited

1. Friedman, Y. Z., "Avoid Advanced Control Project Mistakes", Hydrocarbon Processing, October 1992.
2. Friedman, Y. Z., "What's wrong with closed loop optimization?" Hydrocarbon Processing, October 1995.
3. Pedersen, C. C., Mudt, D. R., Bailey, J. K., and Ayala J. S., "Closed Loop Real Time Optimization of a Hydrocracker Complex", NPRA Computer Conference, November 1995.
4. Hardin, M. B., Sharum, R., Joshi, A., and Jones J. D., "Rigorous Crude Unit Optimization", NPRA Computer Conference, November 1995.
5. Friedman, Y. Z., "Advanced Process Control – It takes effort to make it Work", a guest editorial note, Hydrocarbon Processing, February 1997.
6. Friedman, Y. Z., "Advanced Control --What Works, What Doesn't, Where's the Money", Presented at AIChE Houston Chapter Meeting, February 1997.
7. Kossman, W., Besl, H., Crowe T. J., and Karacotsios M., "Closing the Loop: Innovations for Naphtha Complex Optimization", NPRA Computer Conference, November 1997.
8. Friedman, Y. Z., "More about closed loop optimization" A guest editorial, Hydrocarbon Processing Journal, August 1998.
9. Jakhete, R., Rager, W., Hoffman, D. W., Online Implementation of Composite LP Optimizes FCCU/GPU Complex", Hydrocarbon Processing Journal, February 1999.
10. Friedman, Y. Z., "Advanced Control of Ethylene Plants, What Works, What Doesn't and Why", paper presented at the Ethylene Producers' Committee, March 1999, later published in Hydrocarbon Asia, Jul/Aug 99.
11. Korchinsky, W. J., Hoffman, T. W., Hoffman, D. W., "Tips for Control Engineers", Hydrocarbon Processing Journal, September 1998.
12. Georgiou, A., Krambeck, F. J., Cheng T. C., Hene, C., and Frederickson, M., "Closed Loop Real Time Optimization Reaps Economic and Operations Benefits for FCC – Alky Complex", NPRA Computer Conference, November 1999.
13. Nath, N., Alzein, Z., Pouwer, R., Lesieur, M., "On-line Dynamic Optimization of an Ethylene Plant Using Profit Optimizer", NPRA Computer Conference, November 1999.