OPTIMAL analysis

Massimiliano Di Febo, Paganini Pasquale, and Gaetano Esposito, IPC, Italy, discuss the optimisation of centrifugal compressor performance analysis.

Centrifugal compressors are a vital component within process plants. They are often one of the most important assets within these plants and have a critical impact on capital investment due to the impact they have on plant production during temporary unavailability for maintenance, as well as repair costs.

Consequences of compressor failures can be dramatic as repair processes can be long and costs for the supply of spare parts and overall repair process may be high. Hence,



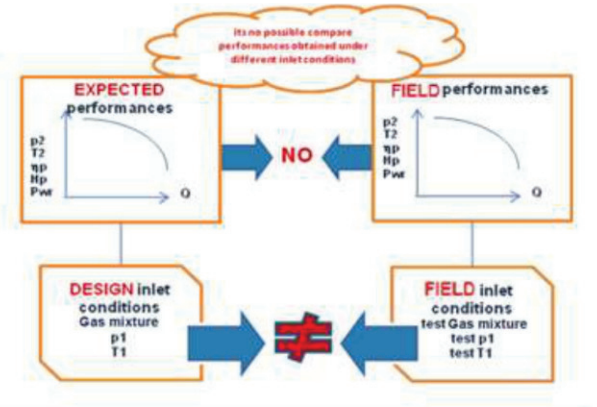


Figure 1. : Compressor performances can be compared when obtained with the same inlet conditions.

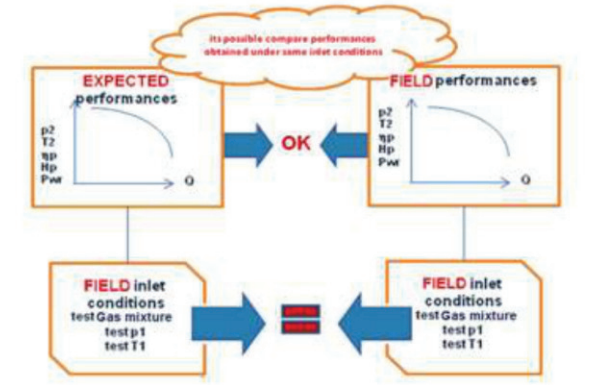


Figure 2. Design performances, adjusted to actual (field/test) performances can be used as reference for measured performance evaluation.

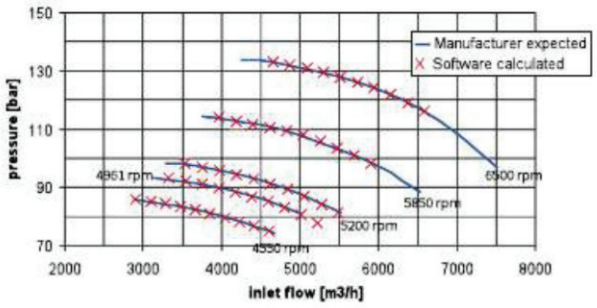


Figure 3. Centrifugal compressor design performances comparison to calculated performances (discharge pressure).

one of the biggest challenges for plant management is maximising the productivity of these assets, implementing the best strategies to achieve maximisation of machine availability and reducing downtimes. In this context, it is evident that the capability to detect early indicators of eventual malfunctioning is extremely useful in minimising overall operational costs due to the above mentioned causes.

One of the main problems for the analysis of centrifugal compressors' operational performance is that this performance is usually graphically represented in terms of discharge pressures, temperatures, polytropic heads, efficiencies and absorbed power, related to the design inlet conditions, e.g. gas mix composition, inlet pressure and temperature. However, actual performance is related to actual field inlet gas conditions that often deviate from design conditions. In this situation the comparison of field measurements to expected values becomes complicated because the expected performances need to be adjusted to the actual field conditions.

The main purpose of this article is to present a method and tools for the evaluation and comparison of centrifugal compressor field performances. A case study will be presented, in which this method has been applied.

The execution of the method that is to be elaborated is complex, and requires the availability of calculation algorithms able to predict both machine behaviour and thermodynamic gas properties under different operating conditions. In contrast, current practice relies on simplified theories. These simplified theories are often completely neglected at plant/machine level, causing a lack of analytical support for evaluation of machine health and consequently a lack of support for maintenance decision making.

Furthermore, these theories become progressively more approximate when approaching the high pressure range. Introduced errors inhibit the ability to make accurate predictions about more severe applications. In these cases more rigorous calculations and adequate computational tools are in fact necessary to implement the most modern thermodynamic theories and machine models without limiting approximations.

In order to execute this advanced machine performance analysis, the IPC research lab has developed a dedicated software tool based on the most recent gas theories and centrifugal machine models.

Cmap is a Windows based software tool for PC, designed to perform simple and easy centrifugal compressor performance evaluations. The software also allows some additional tasks useful to compare centrifugal compressor expected/design performances with field data measured ones.

Method

In order to compare performances obtained under different inlet conditions it is necessary to adjust and align performances to the same reference inlet conditions.

When attempting to evaluate performance by comparison between field measured parameters and expected parameters, the trick is to remember that one of the two performances needs to be manipulated and adjusted to the inlet conditions of the second one. In brief, inlet conditions need to be homogenous (Figure 1).

Process Insight:

Ideal Stage or Mass Transfer... Which Model Should Be Used?

The design and optimization of separation processes is carried out using process simulators, which utilize various calculation approaches. Two techniques that are widely used for modeling distillation are the ideal stage model and the mass transfer model.

IDEAL STAGE MODELS

The ideal stage model requires a minimum amount of data—only equilibrium relationships and enthalpy data for the heat balance. The assumptions of the ideal stage approach are: 1) that the vapor and liquid are both perfectly mixed so that the vapor and liquid leaving a stage are at the same composition as the material on the stage and 2) that thermodynamic equilibrium is obtained on each stage. The equilibrium assumption also means liquid and vapor leaving a stage are at the same temperature. Ideal stage models can also account for non-ideal column performance through the use of reaction kinetics as is done for amine sweetening columns.

Obviously, the main disadvantage of the ideal stage approach is just that—the use of ideal stages to model real trays or packing depths. However, for most processes encountered in gas processing and other industries, the overall efficiencies are well established for proper operating conditions of the column. For systems that are unavailable, similar systems often exist to allow for efficiency estimation. If not, the mass transfer approach is available as an option.

MASS TRANSFER MODELS

For the end user, the notable feature made available via the mass transfer approach is the ability to model a column with the actual number of trays in the unit or the actual depth of packing. However, there are still several assumptions that are made in this approach that can have a significant impact on results. Two that are worth mentioning include the mixing model for trayed columns and the discretization of the packing depth for packed towers.

Application of the mass transfer model to random or structured packing requires the column height to be discretized into vertical segments or stages. For trayed columns, various mixing models can be used for the liquid and vapor phases. The most basic assumption is that of complete mixing in both the liquid and vapor phases. However, the concentration gradients that develop on a tray can significantly impact the predictions made by this model since this gradient is the driving force for mass transfer. As the column diameter becomes larger, the perfectly mixed flow model is less applicable.

For modeling both liquid phase chemical reaction and mass transfer, the use of the enhancement factor technique may be considered. The enhancement factor describes the increased rate of absorption due to the effect of a chemical reaction. The material balance requires kinetic rate expressions for all chemical reactions occurring in the system. As with equations for a non-reacting system, an appropriate model for interface behavior must be used.

Mass transfer models require data necessary to calculate interphase mass and heat transfer coefficients and interfacial area based on correlations of the following transport and thermal properties: diffusivities, viscosities, densities, heat capacities, thermal conductivities, etc. Furthermore, mass transfer models require detailed information on the column internals. For trays, this includes information such as weir heights and fraction active area. For packing, this includes surface area per unit volume and void fraction.

If the simulator allows the user to select from various alternatives for these parameters, knowing the correct selection may be problematic. Further, the prediction of multicomponent mass transfer coefficients is of questionable accuracy. These facts prompt the recommendation that columns modeled with the mass transfer approach be checked against an ideal stage model with an expected efficiency until sufficient experience with the particular application is achieved.

CONCLUSIONS

When performed properly, both the ideal stage and mass transfer approach as implemented in ProMax 4.0 can calculate accurate results for a variety of separation processes with and without reactions. The ideal stage approach can be used initially to determine appropriate equipment sizes and operating conditions. More detailed studies can be performed using the ideal stage approach, the mass transfer approach, or both. Although significant operating experience provides reasonable efficiency estimates for most processes, the empiricism in scaling up from ideal to real stages or ideal stages to real bed lengths can be a disadvantage when accurate overall efficiencies or HETP's are unavailable.

The mass transfer approach requires more equipment design details and does not make use of overall efficiencies or HETP's. More detailed composition and temperature profiles are produced by this method at the expense of longer calculation time. The mass transfer approach may appear more predictive in nature, but is not necessarily more accurate. It relies on more parameters that must be estimated, as both require thermodynamic data to model equilibrium—for the tray composition in the ideal stage approach and for the interface composition in the mass transfer approach. Many of these mass transfer parameters are of limited accuracy but also may be of limited sensitivity in some systems. Both techniques are useful tools in process simulation.

For more information about this study, see the full article at ***www.bre.com/support/technical-articles.aspx.***



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In order to proceed to performance evaluation, IPC applied this method in the following steps:

- Expected performances related to design inlet conditions have been adjusted to field suction conditions.
- Field performances are compared to adjusted expected performances.

At this point it is possible to proceed with the comparison.

Software

In order to use Cmap, the starting point is the availability of a compressor performance map, the relevant gas mix composition and thermodynamic conditions (pressure and temperature). Having this input data available, the software will perform all complex calculations fully and produce expected compressor performance details.

The input process offers a number of alternative methods of entry. The most common method is to enter performance curves expressed in terms of delivery pressure versus inlet flow rate, and delivery temperature versus inlet flow rate. Data input processes can also be executed in a digital way, picking up graphical data directly from pdf or jpeg files.

Cmap is structured to allow analysts and engineers to build their own machinery database and maintain the records of all executed calculations.

Case study

The compressor under study was mapped for two different inlet conditions of pressure and temperature:

Design condition 1 (D1)

Pressure: 40.2 bar.
Temperature: 50 °C.

Design condition 2 (D2)

Pressure: 53.2 bar.
Temperature: 37.8 °C.

Starting from the curves of the D1 condition, the expected performance curves in the D2 were calculated using the Cmap software. The obtained curves, D2calc, were then compared to the D2 curves available as input.

Figure 3 compares the D2calc with the D2 performance curves. The curves almost overlap: the maximum error calculated is less than 0.2% (polytropic work at maximum speed). Measured errors have been considered tolerable for the purpose of the evaluation of compressor field performance.

This case study confirms the capability of the proposed method to predict compressor performances aligned with design ones. An important application of these proposed methods is on surge protection systems and for diagnostic purposes.

Actual centrifugal compressor protection systems being reliant on simplified algorithms that use suction thermodynamic parameters, the protection action is rigidly linked to design suction parameters and remains valid only for the design specified gas mix. Therefore, these systems provide a limited surge protection valid in a small operating range around the design conditions. The compressor protection is not correctly active when inlet conditions move to off design values, especially when approaching high pressure range.

Conclusion

The methods proposed and described in this article can allow operators to:

- Predict the performances of a centrifugal compressor under varying thermodynamic conditions of the inlet gas. The prediction of compressor performances is accurate even at high pressures, where the ideal gas theory commonly used introduces considerable errors.
- Analyse the performance of the compressor during operation and compare them with those expected (provided by the manufacturer).
- Implement advanced protection from surge, overcoming limits of the current technology.
- Having useful indications of the health of the compressor (diagnostics) based on the capability to analyse the performances and efficiency of the machine in a simple and immediate way.
- Support decisions and planning of predictive maintenance and activities.

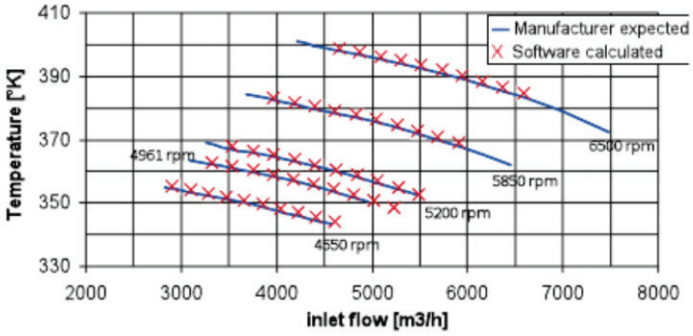


Figure 4. Centrifugal compressor design performances comparison to calculated performances (discharge temperature).

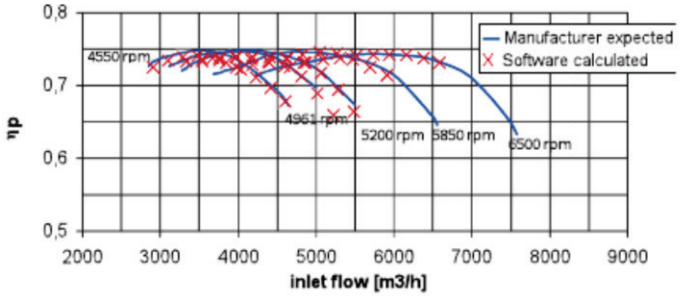


Figure 5. Centrifugal compressor design performances comparison to calculated performances (polytropic efficiency).

