Bakker A., Morton J.R., Berg G.M. (1994) Computerizing the Steps of Mixer Selection. Chemical Engineering, March 1994 (6 pages).

COMPUTERIZING THE STEPS OF MIXER SELECTION

Using knowledge-based software helps keep engineers from overlooking important process details

André Bakker, Jerry R. Morton, and Gary M. Berg
Chemineer Inc.

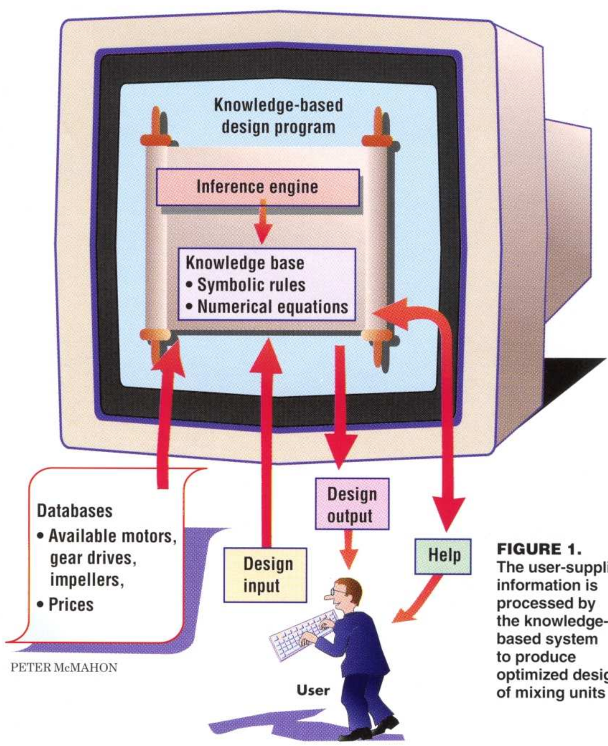
The human brain is no longer the sole repository nor the exclusive processor of knowledge. Computers are making headway as "reasoning machines" to help human apprentices as well as experts cope with the complex and growing bodies of knowledge in many fields of expertise.

For example, designing an agitator for a given application can be a challenging and time-consuming task. It requires thorough knowledge of both the process in question and the engineering details of a wide range of customizable or off-the-shelf mixing equipment. Lack of knowledge in any of these areas is likely to compromise the integrity of the design.

Today's computers offer the capability of storing an enormous amount of knowledge pertinent to the performance of a specialized task. When combined with their computing power routinely harnessed in process simulation, even their somewhat primitive reasoning ability can rival, and often surpass, a human's performance in speed, accuracy and consistency.

A human expert is someone who has extensive knowledge — a large memory of previously analyzed situations — that can be readily applied, often in some insightful and creative way, to solve a given problem. A mixing expert, for example, knows how to apply the established concepts and generally accepted engineering criteria to come up with an appropriate design for a mixer that suits a particular process situation. The human expert may also recommend what computations must be carried out — typically by a computer — to optimize the preliminary design.

Increasingly, however, computers are being used beyond the "number crunching" phase in equipment design and optimization. They can be programmed to apply the rules of reasoning — similar to those used by a human



PETER McMAHON

FIGURE 1. The user-supplied information is processed by the knowledge-based system to produce optimized designs of mixing units

Today's portable laptop computers permit prompt configuration of an agitator based on consultation with the operating personnel on the plant floor

expert — to the chunks of expert knowledge codified and stored for round-the-clock computer access (*CE*, April 1992, p. 5).

The authors and their co-workers have developed a knowledge-based system (KBS), called AgDesign, to design turbine agitators.* Currently, all their top-entry agitators are designed with AgDesign using customer-supplied specifications. In about one-tenth of the cases, however, it is necessary to have a human expert review the design because the user might have specified a non-standard impeller that requires some special in-house design. Nonetheless, about 90% of the designs are performed entirely with AgDesign.

*Several agitator vendors have developed similar software to help users select and specify the right mixing equipment.

There are significant benefits in having a KBS design a mixer because it never "forgets" the facts and figures codified in its knowledge base, nor does it fail to check for logical consistency. On the other hand, a human engineer can often overlook critical process details, and even forget to perform cross-checking procedures to ensure proper fits of the mechanical and electrical components of a designed system.

Moreover, a KBS can pool the knowledge of not just one, but multiple experts in pertinent fields of expertise. And it is relatively easy, in principle at least, to transfer the contents from one knowledge base to another if they are designed to be "portable." Humans, on the other hand, require a slow process of human communication and learning to share the knowledge. Most process engineers often cannot afford the time to become a mixing expert, but today's dedicated KBSs allow every process engineer to design a cost-effective agitation system.

Designing an agitator typically takes a human expert about two to three hours. Even if the human expert has ready access to the pertinent data on standardized designs, it takes on average 1.5 h to specify an agitator. Working with a KBS on mixer design, such as AgDesign, the same person can design an agitator in less than 10 min. Apart from the time savings, the KBS usually comes up with a design that is better-optimized and less-expensive than that selected by a human expert.

A recent study [*1*] has shown that the U.S. chemical process industries (CPI) lose between one and ten billion dollars annually because of process inefficiencies due to poor agitation. Clearly, there are two strategies that can be employed to reduce these huge losses. The first is to improve existing design procedures by performing more fundamental research in mixing.

The second strategy is to make better use of the wealth of knowledge that already exists. Given the increasing use of design KBS software, the economic impact of these systems is expected to equal, or even exceed, that of mixing research alone.

MAKEUP OF THE KNOWLEDGE BASE

Sample symbolic rules

1. IF (the application is solids suspension) THEN (needed: solids density)
2. IF (the application is solids suspension) THEN (needed: settling velocity)
3. IF (impeller speed > 80% shaft critical speed) THEN (incorrect design)
4. IF (the impeller is a radial-disc turbine) THEN (NOT (suited for solids suspension))
5. IF (the impeller is a high-efficiency impeller) THEN (suited for solids suspension)

Sample numerical rules

1. Power draw, $P = Po\rho N^3 D^5$
2. Torque on impeller, $T = P/(2\pi N)$

FIGURE 2. A KBS may require hundreds or even thousands of rules and equations before it can be considered fully functional

Compensating for human frailty

Humans are rather slow and prone to error in performing lengthy analysis on the logical implications of all the "facts" recalled from long- and short-term memories [*2*], or acquired from such external sources as handbooks and journals. Much disciplined thinking is often necessary to detect contradictory information of technical subtlety. Humans are also not efficient in conducting ex-

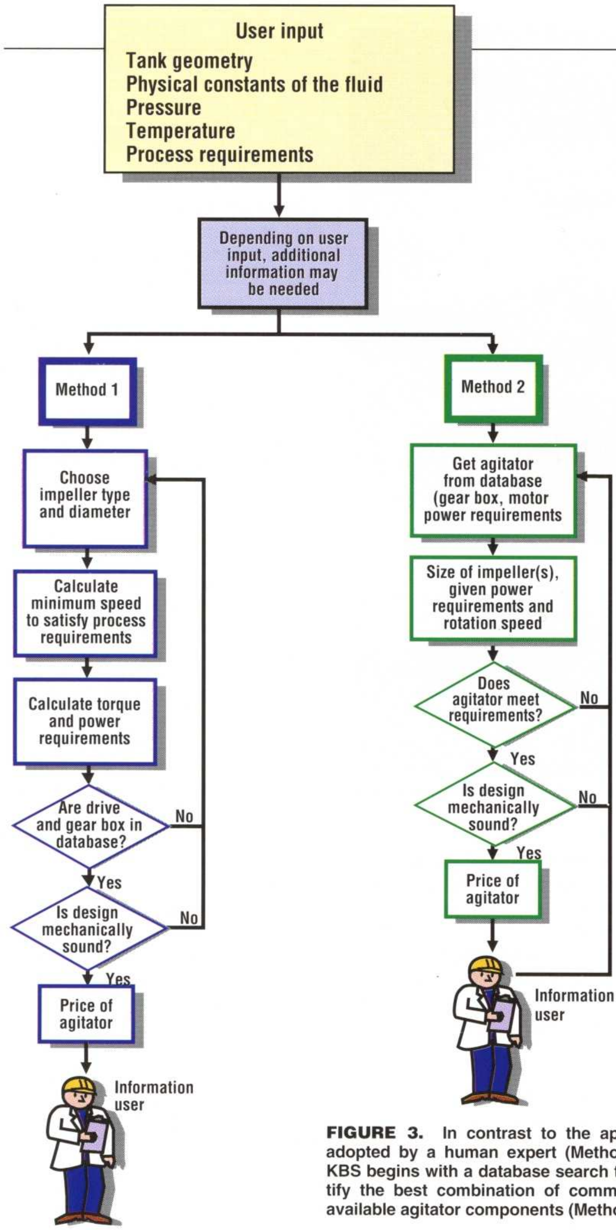


FIGURE 3. In contrast to the approach adopted by a human expert (Method 1), a KBS begins with a database search to identify the best combination of commercially available agitator components (Method 2)

tensive searches for alternatives, especially when much backtracking from dead ends is necessary. Consequently, a human designer is usually forced to design the impeller first, and then select the closest commercially available agitator system. This method, however, does not necessarily result in the most cost-effective solution.

In contrast, a computer starts with a scan of its knowledge base covering all the commercially available agitators to determine which ones meet the process requirements as well as the mechanical design criteria. This approach almost guarantees the most cost-effective solution. Also, technical drawings generated by a drawing software and flow-pattern analyses via computational fluid dynamic models are additional features that make it easier for an engineer to quickly evaluate alternative designs.

A previous article in this series on mixing technology (*CE*, January, pp. 94–100) presents modern flow-analysis techniques, such as computational fluid dynamics, laser-Doppler and particle-image velocimetry. When integrated with a KBS, these tools provide fresh insights that can be readily incorporated into a new design.

Forthcoming articles will focus on design guidelines and procedures for blending, solids suspension and gas dispersion. These are based on well-tested knowledge of mixing phenomena, and can be structured to develop KBSs for designing suitable agitators for most CPI processes.

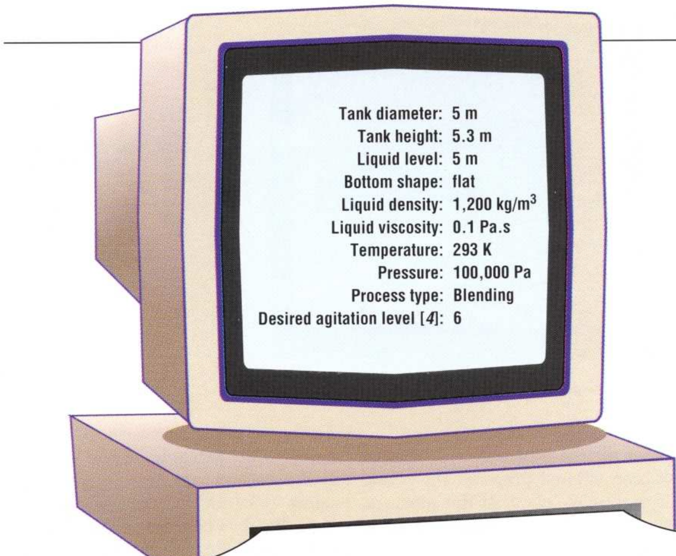
However, often there is not just one agitator design that gives the desired process performance. For example, a standard pitched-blade impeller may give the same blend time as a high-efficiency impeller but at the expense of a larger torque and greater power draw. This results in larger capital investment and operating costs.

On the other hand, high-efficiency impellers often operate at slightly higher speeds than their pitched-blade counterparts. If the process in question requires a long shaft, then the shaft diameter must be much larger (to handle the associated dynamic load), and thus the design may incur additional capital costs, compared with a similar pitched-blade design.

Another complicating factor is that one cannot specify arbitrary values of design parameters, such as speed and power requirements for a motor. For economic reasons, agitators are usually assembled from standard parts. Gear boxes, electric motors, shafts, seals and flanges are available only in sizes of discrete and incremental steps.

These restrictions make it difficult and laborious to design an agitator that not only satisfies the process requirements but is also mechanically sound and cost-effective. However, this maze of design constraints and engineering standards can be formally organized into a KBS.

Fortunately, the established design procedures are highly structured and lend themselves to computerization. Also, modern software-development tools makes it possible to integrate databases, process-design rules and mechanical-design rules, with the con-



KBS OUTPUT BASED ON USER INPUT

Options	Gear box	Power requirement, hp	Impeller speed, rpm	Ratio of impeller to tank diameter	Impeller style	Initial capital cost	Five-year cost
1	5	15	56	0.40	HE-3	1.00	1.55
2	5	10	37	0.48	HE-3	1.02	1.17
3	5	15	45	0.46	HE-3	1.05	1.56
4	5	20	68	0.38	HE-3	1.05	1.95
5	5	7.5	30	0.54	HE-3	1.07	1.00
6	5	10	30	0.57	HE-3	1.09	1.20
7	5	30	100	0.32	HE-3	1.14	2.75
8	6	30	56	0.34	P-4	1.15	2.75
9	6	20	37	0.39	P-4	1.20	2.01
10	7	25	37	0.41	P-4	1.70	2.59
11	7	30	45	0.38	P-4	1.72	2.98

FIGURE 4. After the user keys in the necessary information about associated process characteristics, the KBS comes up with several options of mixer designs

stantly updated knowledge and experience of human experts.

Mining the knowledge field

One can select from a variety of available methods to automate the entire design process or portions thereof. Spreadsheets and other numerical-algorithm-based programs are used for relatively simple computations, such as calculating power draw, blend time, mass-transfer rate, and the impeller speed needed to simply sustain the suspension of solids, known as "just suspended speed." Developing such programs is fairly easy. In return, one achieves significant time savings by speeding up the calculation part of the design.

However, the designer still has to verify that the process requirements are satisfied, and that the agitator is mechanically sound and optimized for low capital or operating costs. What's more, the user has to rely on outputs from several of these programs, and manually key in the outputs from one program as inputs for another.

A different and more-advanced approach is to develop an integrated, specialized knowledge-based design system (Figure 1). The core of the program is its knowledge base, which contains symbolic rules and numerical equations. The system can be linked to external databases that contain highly organized lists of available agitator components and impeller types. The user provides the system with facts and data about the specific process for which the mixer is being designed, through a user-friendly interface.

The symbolic rules contain the knowledge of a human expert in a highly structured form that can be programmed into a computer. The rules are often formulated in the conventional if-then format (Figure 2), in which if certain premises are true then a conclusion follows.

The symbolic rules contain all the requirements that must be met by an agitator design to be mechanically sound as well as satisfy the process constraints (Figure 2). Some of the rules lead directly to conclusions about the agitator. For example, Rule 4 states that a radial turbine is not suitable for solids suspension.

Other rules require a numerical calculation to evaluate the premise. Rule 3, for example, requires the calculation of the critical speed of the shaft. When a numerical calculation is necessary, the corresponding "numerical rules" must be evaluated.

Numerical rules, such as correlations for power draw, can be easily programmed in a spreadsheet. However, spreadsheets are not suitable for programming large, complicated sets of symbolic rules. Under some circumstances, one can get by using a hybrid of a computer-human KBS in which the human expert mentally evaluates the large sets of symbolic rules while the spreadsheet program performs the necessary numerical calculations.

One method of creating a full-fledged design KBS is to use available software-development tools, known as expert-system shells. Such shells allow the input of the symbolic rules in an arbitrary sequence. When using the KBS, a so-called inference engine, which is a part of the shell, determines which rules have to be evaluated and in what order, during execution of the program.

Such shells, however, tend to be inefficient in handling highly elaborate numerical calculations. Therefore, it is often convenient to develop a dedicated KBS using a conventional programming language, such as Pascal or C. Also recommended are languages, such as Prolog, that are specifically designed to make KBS development easier [3].

AgDesign has been developed using

C++, which combines some of the advantageous features of the expert-system shells (efficient evaluation of the symbolic design rules) with the convenience of the spreadsheet approach (efficient numerical calculations). The software took about five worker-years to develop, which included the efforts of collecting, structuring and coding the knowledge base as well as its testing. The fully functional system contains about 100,000 lines of C++ code, and requires 4 MB of random-access memory to run. Such a system can be run on today's laptop computers, allowing engineers to carry it with them and design agitation systems on site based on consultation with plant personnel.

Developing the rules has been the most time-consuming part of the project, taking up about 70% of the total. It turns out that the expert knowledge is not always easily available because the expertise is spread out among different people throughout an organization. Also, the human experts may need to be coached on how to explicitly articulate individual ideas. Translation of the massively linked network of concepts from the experts' minds into coherent language is a difficult skill that can be improved only through practice.

Climbing the steps

It is best to adopt a step-by-step approach (Figure 3) in using a design KBS, such as AgDesign. First, the user inputs the information describing the mixing tank, the physical properties of the process fluids, the expected temperature and the pressure in the tank. The information about pressure is required to evaluate forces on the tank walls, bearings and seals. The temperature is needed to determine the maximum allowable stresses on the shaft and impeller blades, and to select suitable materials for the seals.

Next, the user enters the process requirements. This might include a desired mixing time for blending applications, or a required mass-transfer rate for gas-liquid applications. Depending on the type of the process in question and the associated requirements, the program asks the user for more information, such as the gas flowrate (for gas-liquid mixing) or the solids properties and concentration (for solids-suspension applications).

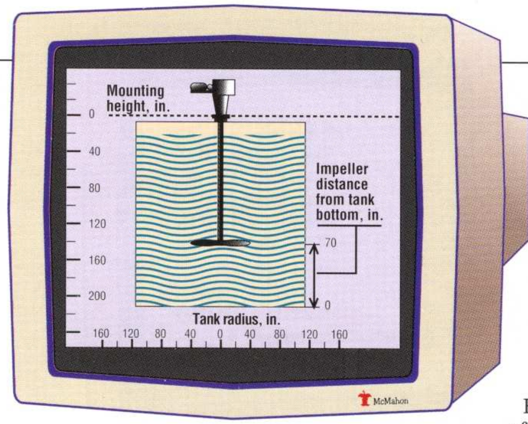


FIGURE 5. A full-fledged KBS can generate a tank sketch to help users identify any obvious mismatch of agitator parts

After all the requested information has been entered properly, the actual design can take place. At this juncture, however, the KBS can follow either of the two design methods available.

The first method, which a human expert would use, is to design an impeller system that meets the process requirements, and calculate the power draw and torque. Subsequently, the KBS searches its database with available gear boxes, drives, shafts and impellers to determine if the selected agitator can actually be built. An advantage of this method is that it is fast.

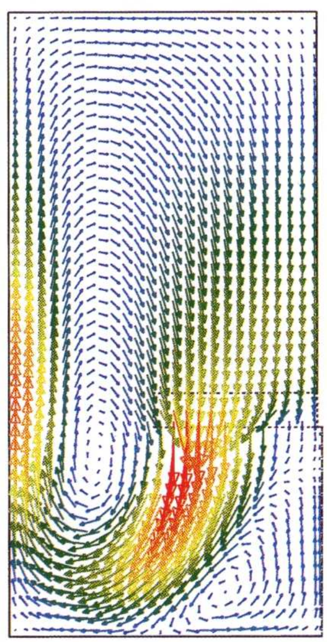


FIGURE 6. A computational fluid dynamic analysis provides the finer details of flow patterns in a mixing unit

However, impellers of the calculated diameter, speed and power draw are not likely to be available off the shelf. In that case, one may have to pay a premium price for the non-standard design. Yet it is possible that a commercially available unit could do the job just as well because there is usually more than one impeller design that can give the desired process result.

The second design method overcomes these problems. Here, the design KBS first scans the list of commercially available agitators, gear boxes and motors. Then, for each agitator, it calculates what impeller diameter is needed to load the motor.

Once the impeller system is designed, the KBS verifies if the agitator satisfies the process requirements. If it does, this design is added to the list of possible alternatives. After processing every available agitator selection, the KBS checks them for mechanical soundness to ensure that the impeller speed is below the first critical frequency of the shaft, and the mechanical stresses are below the maximum allowable limits. For those agitators that satisfy the process requirements and are mechanically sound, several additional analyses can be made.

For example, a tank sketch can be generated to show the position of the impeller or impellers in the tank, as well as the maximum and minimum liquid levels. All wetted parts (shaft, impeller blades and so on) can be checked to make sure that they fit through the manholes, and therefore, can be mounted in the tank.

For the designs that satisfy all these demands, an additional analysis with the aid of computational fluid dynamics (CFD) simulation software can be made. This shows the flow pattern in the tank. Such flow-pattern plots can be used to examine if there are any stagnant or "dead" zones, and to determine the optimum position for inlet-feed pipes and drains. CFD analyses can also be made for solids-suspension and gas-dispersion processes, with such specialized CFD codes as Ghost! (*CE*, January, pp. 94–100).

The operating, maintenance and capital costs of the available agitators can then be calculated. At this point, upon evaluating budgetary parameters and process needs, the user is in a position to make a well-informed decision on the best agitator design for the application.

KBS in action

What follows is an example of how KBS software, such as AgDesign, performs the design of a blending tank. The dialogues between AgDesign and the user are summarized in Figure 4. The actual formats of the input and output may look slightly different, containing additional information.

First, AgDesign asks the user for some basic information about the tank. Then it asks for information on the process type under consideration.

For blending, the program asks for the desired level of agitation [*4*]. For solids suspension or gas dispersion, the KBS might ask for additional parameters on these processes.

Once all the necessary information is entered, AgDesign scans the databases of available agitators, designs a correct impeller system for each, checks to see if a particular agitator satisfies the process requirements, and performs mechanical and other checks.

A typical database might contain 300 to 400 agitators. Processing the data on a fast personal computer takes only a few seconds. It turns out that for this blending problem there are 11 alternatives that meet all the process and mechanical requirements (Figure 4). The KBS lists them all in the order of increasing capital costs. Also shown are the gear-box size, the power requirement for the motor, the impeller style, and several other variables.

In this example, the total five-year cost, including capital and electricity but excluding maintenance, has been calculated. Both the capital and five-year costs are listed, relative to the cheapest selection.

When low initial capital investment is important, one chooses Selection 1. When the longterm cost is the most important consideration, one specifies Selection 5. Note that over a five-year period, the cheapest agitator system with a standard pitched-blade impeller (P4, Selection 9) is more than twice as expensive as the cheapest high-efficiency impeller system (HE-3, Selection 5).

Once the agitator is chosen, AgDesign generates a tank sketch (Figure 5), which shows the impeller or impellers, the shaft and the liquid level. It can also use another KBS, called AgDraw (which is part of a larger design KBS that includes AgDesign), to automatically generate technical drawings of the various agitator parts. These drawings are then used in manufacturing the whole unit.

With a dedicated KBS on CFD, such as AgFlow (already developed by the authors), one can transfer the data to a CFD program to automatically carry out flow-pattern calculations and generate a three-color graphical output (Figure 6) with just a few keystrokes. The application of the fresh insights obtained from such detailed simulation is limited only by the user's imagination. ■

Edited by Gulam Samdani

References

1. Mixing 3A Workshop on Industrial Mixing Needs, University of Maryland, March 22–23, 1989.
2. Kurzweil, R., "The Age of Intelligent Machines," The MIT Press, Cambridge, 1990.
3. Quantrille, T. E., and Liu, Y. A., "Artificial Intelligence in Chemical Engineering," Academic Press, New York, 1991.
4. Hicks, R. W., and others, How to Design Agitators for Desired Process Response, *Chemical Engineering*, pp. 102–110, April 26, 1976.

The authors

André Bakker was an author of a previous article (January, pp. 94–100). His biography appeared at the end of that article.

Jerry R. Morton is manager of management information systems at Chemineer Inc. He has been with the company for 28 years, and has held previous positions as process engineer, applications engineer, and senior development engineer in R&D. Responsible for Chemineer systems for the past 18 years, he has made major contributions in the development of design procedures. He holds bachelor's and master's degrees in chemical engineering from Ohio State University.

Gary M. Berg is principal application programmer at Chemineer Inc. He has been with the company since 1977, specializing in the development of engineering programs. He received his B.S. degrees in mathematics and chemistry from Ohio Wesleyan University, and a master's degree in computer science from Purdue University.