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COMPUTER AIDED PROCESS EQUIPMENT DESIGN FROM EQUIPMENT PARTS

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Abstract
Process equipment are usually made by assembling them from parts. The idea of this paper is to speed up the equipment design using the history of different designs, and using lists of equipment parts to make a set of mechanically sound designs. A possible set of equipment designs is combined based on the information of the parts lists. This methodology utilizes two basic advantages of computers: *large memory capacity* for storing knowledge from old design cases, and *calculation efficiency* for combining different equipment combinations.
This type of an idea can be implemented as a case-based reasoning system where the case-base consists of the well documented old designs. The retrieval is done by distance functions, but the adaptation is implemented using combinatorial calculus. At first, the specification of the design problem at hand is compared to the old cases in the case-base. Process and mechanical parameter values from the nearest cases of the design problem specification as well as part of the input data are then used to identify suitable design combinations. However, the parameter values of the cases should be first adapted for the design problem. It can be done by using the scale-up or scale-down parameters to the corresponding problem. The equipment lists on the other hand are defined as different groups which describe physical parts, like motors, gears, shafts, etc. In the proposed system an equipment is pre-defined so that there should be parts from certain groups in order to create a combination. The combinations of the equipment parts are updated as the lists of parts are changed. In the proposed design system all the mechanically sound combinations are at first created. The combinations are the proposals for the solution of the process design problem.
A software tool has been constructed for this kind of idea. The proposed idea can be especially useful for the equipment manufacturers in process industries. Design offices can as well utilize the proposed idea if equipment manufacturers provide them with necessary data from their equipment parts. An example of the proposed computerized tool has been implemented for the design of top-entering fluid mixers.

Keywords: Case-based reasoning, combinations, design, equipment, process.

Introduction

The aim of this work is to present a possible method to introduce a detailed process equipment design by computer. The core of this method is based on case-based reasoning (CBR) and on the computation of combinations.

CBR has been applied in some form to process equipment design earlier by Kraslawski et al. (1995), Goel and Stroulia (1996), Virkki-Hatakka et al. (1997), and by Koiranen et al. (1998). Work by Goel and Stroulia is directed mainly to diagnosing fixes in preliminary design. Others have attempted to find tools for solving the design process itself. The research has been stressed on finding useful adaptation techniques, which is one of the major research topics in CBR. However, the shortcomings have been in applying CBR up to the level of detailed design.

The clear benefit of adding detailed design is that the consistent design will be ensured. While the design is on the preliminary level, values of design parameters do not necessarily meet the real equipment, especially in case of design from equipment parts.

In this paper a robust procedure for selecting a process equipment from its parts to design real equipment is presented.

General program structure

The developed program includes the basic parts of CBR applications, namely the problem description, case-base, retrieval part, the adaptation part, and normal database functions like storing of cases etc. The general structure of the proposed CBR application is presented in Figure 1.

The case-base contains old design cases which are retrieved based on the minimization of the distance functions, as described e.g. by Virkki-Hatakka et al. (1997). Old design cases consist of process and design parameters, and of equipment part lists.

As the nearest case is retrieved it can be adapted for the problem at hand. One way to make the adaptation in process design is to use the process design equations. The data of the described problem and design data from the retrieved case can be used as inputs of design equations. As a result, a set of design parameter values are created. In the final stage, the adaptation of possible equipment combinations is made. It means to find a suitable set of equipment constructed from its parts by using the adapted design parameter values.

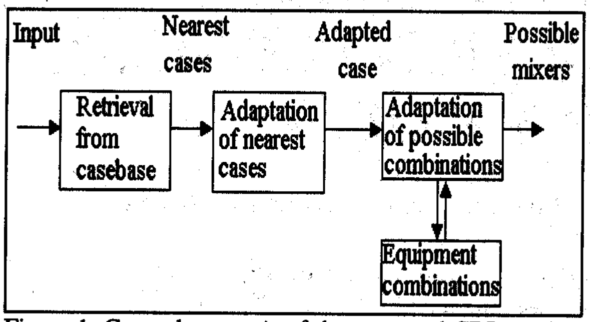

Figure 1. General structure of the proposed CBR application.

Combination strategy
The possible set of the process equipment can be made by combining items from different lists of equipment parts. From the manufacturer point of view the systematization of equipment parts should be done. The systematization means to determine the attributes (e.g. sizes) of equipment parts which are manufactured. It will for its part speed up the time from the equipment design to equipment delivery.
The combination of equipment from its part lists can be calculated from:

$$Y = X_1 \times X_2 \times X_3 \times \ldots \times X_N \tag{1}$$

where X Vector consisting of equipment part list
Y Matrix consisting of equipment combined from its parts

The combinations are calculated in advance, and also when the equipment lists are updated.

Application example
The proposed method is applied in the design of top-entering fluid mixers to accomplish blending of miscible liquids, Figure 2. Fluid mixer equipment is supposed to consist of the following parts: power unit, shaft, and impellers. The electric motor, gear box, and bearings are included in the power unit. The equipment part lists are :

- 87 Power units: 1.5-45 kW, 58-171 rpm
- 47 Cylindrical shafts: 30-200 mm diameter
- 27 Impellers: 300-3000 mm dia., two different geometries producing axial flow

The number of possible combinations is 110403 based on the items of equipment part lists. However, in this application example all of the items in the parts lists do not fit mechanically together.

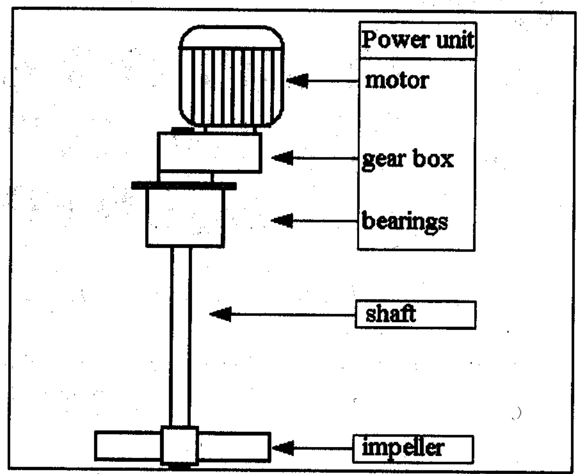

Figure 2. Basic structure of top-entering fluid mixer.

Therefore, constraint rules have been included in order to assure the consistency among the equipment parts.

- Power unit and shaft are connected together with a flange, and therefore the flange sizes should be same with them.
- The inner diameter of the impeller hub should be greater than the shaft outside diameter.
- It has not been allowed to use more than two impellers of the same size and same type on the shaft in this application example.

Thus, the number of mechanically sound mixer equipment is 3872.
The information flow diagram of the application is introduced in Figure 3. User defines the mixing problem by giving the necessary input data for determining the blending process:

- Fluid volume
- Average bulk velocity in the tank by Bowen (1985)
- Fluid viscosity and density
- Tank dimensions

There are 20 different cases in the case-base which represents blending of miscible liquids. The fluid volumes range from 5 to 100 m^3, fluid viscosities range from 1 to 1000 mPas, average bulk velocities range from 0.03 to 0.15 m/s. Based on the input information the nearest cases are retrieved from the case-base. In this application it has been allowed to select the case to be adapted among the five nearest cases.
Before the adaptation tank dimensions should be defined, or the geometrical tank aspect ratios (Z/H, Z/T) of the retrieved case could be used. Baffle dimensions are adapted based on the fluid viscosity (Casto (1972)), or based on the geometrical aspect ratio (B_w/T, B_s/T). The number of impellers is derived from the case. Impeller clearance can be designed from the retrieved case using the geometrical ratios (C_i/T). The impeller diameter is selected as the closest available from the list of impellers based on the D/T ratio derived from the case.

For the mixing power calculations adapted tank and impeller dimensions, flow number and Newton number are used. The values for average bulk velocity and the number of impellers are derived from the case. The input values for the fluid density and the fluid viscosity are used. Based on this data mixing power, net power and impeller speed are calculated. The effect of baffles is also taken into account in mixing power calculations. Mechanical calculations by Ramsey et al. (1976) are based on adapted impeller diameter and weight, calculated mixing power and impeller speed, adapted impeller clearance and adapted tank height.

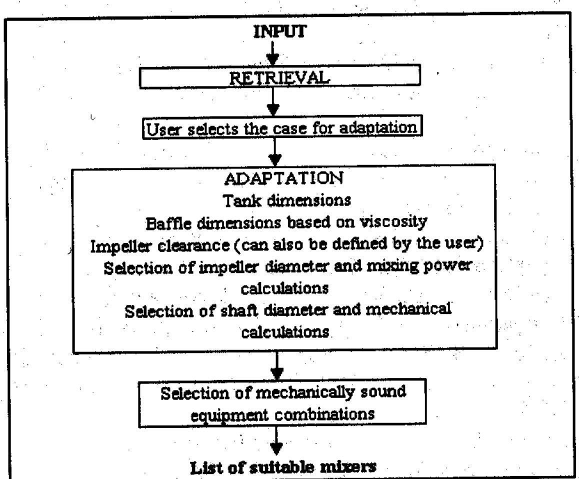

Figure 3. Information flow diagram for the fluid mixer design using CBR.

The values derived from the input, selected case and adaptation calculations are combined as a report. Based on this report the possible mixer combinations are selected. The required properties for each combination are:

- the same impeller type as in the report
- equal impeller diameter as in the report
- shaft diameter is not less than the minimum shaft diameter in the report
- max. impeller speed must be higher than required
- max. power must be greater than the power required

Based on these criteria, all possible equipment combinations are listed. The program has been implemented on MS-Excel v. 5.0c spreadsheet program, and Visual Basic (VBA) Macro Language has been used. A working example of the application is presented in Tables 1-4.

Table 1. Input data describing the mixing problem. Parametric weight (0-1) describes its importance in retrieval.

Quantity	Value	Parametric weight
Fluid volume, m^3	10	0.1
Average bulk velocity, m/s	0.1	1.0
Viscosity, mPas	2	0.8
Density, kg/m^3	1100	0.6

Table 2. Retrieved case from the case-base.

INPUT DATA	VALUE
Fluid volume, m^3	150
Fluid viscosity, mPas	20
Fluid density, kg/m^3	1000
Average bulk velocity, m/s	0.09
OUTPUT DATA	
Impeller	
Type, -	HE
Diameter, mm	1700
Speed, rpm	70
Newton number, -	0.9
Flow number, -	0.38
Mixing power, kW	19.9
Net power (mech. losses incl.), kW	23.4
Number of impellers	1
Distance from bottom, mm	2220
Shaft diameter, mm	95
Cylindrical tank	
Diameter, mm	5350
Height, mm	7490
Liquid height, mm	6740
Bottom type, -	Flat
Tank top, -	Flat
Baffles	3
Width, mm	445
Setout, mm	75

Table 3. Adapted case.

INPUT DATA	VALUE
Fluid volume, m^3	10
Fluid viscosity, mPas	2
Fluid density, kg/m^3	1100
Average bulk velocity, m/s	0.09
OUTPUT DATA	
Impeller	
Type, -	HE
Diameter, mm	800
Speed, rpm	119.5
Newton number, -	0.9
Flow number, -	0.38
Mixing power, kW	2.5
Net power (mechanic losses incl.), kW	2.9
Number of impellers	1
Distance from bottom, mm	890
Shaft diameter, mm	55
Cylindrical tank	
Diameter, mm	2150
Height, mm	3010
Liquid height, mm	2700
Bottom type, -	Flat
Tank top, -	Flat
Baffles	3
Width, mm	180
Setout, mm	30

Table 4. List of possible fluid mixers. Abbreviations: PU=power unit type, P_m=max. power, n_m=max. impeller speed, Ud=flange size of power unit, SD=shaft diameter, Sd=flange size of shaft, IT=impeller type, ID=impeller diameter, Id=Inner diameter of impeller hub.

U	P_m kW	n_m rpm	Ud	SD mm	Sd	IT	ID	Id
E	15	131	215	60	215	HE	800	70
F	3	133	170	60	170	HE	800	70
F	5.5	171	170	60	170	HE	800	70
F	15	131	215	60	215	HE	800	70
J	3	133	170	60	170	HE	800	70
J	5.5	171	170	60	170	HE	800	70
J	15	131	215	60	215	HE	800	70
L	5.5	171	170	60	170	HE	800	70
L	15	131	215	60	215	HE	800	70

Conclusions

A computerized method for a detailed design of process equipment has been presented. The core of this method is based on CBR and on the computation of combinations.

The case-base consists of earlier designs which are retrieved based on the similarity of the new problem. The most similar case is then adapted to fit the new problem from the process design viewpoint by using application specific design equations. The list of mechanically sound process equipment combined from its parts should be created to get into the detailed design of the equipment. Finally the parameters of the adapted case are compared to the parameters of mechanically sound process equipment in order to get the list of equipment which are suitable both mechanically and from the process design viewpoint.

The method has been applied for the design of fluid mixers from its parts. The biggest effort in constructing such applications is inevitably in the adaptation part, and therefore the use of different methods other than design equations should be considered. In some test cases it had been found that the list of suitable fluid mixers became very large and therefore the following improvements should be considered. The list of suitable mixers could be ranked according to the parameters of the adapted case using similar distance functions which are used in the retrieval phase. Another way is to add more constraints as the list of suitable mixers is created.

This type of program can be especially useful among the equipment manufacturers in process industries because of the time-savings. The routine work of manually finding mechanically sound parts from the equipment lists can be avoided. Additionally, the designed cases can be easily applied by case-based techniques. Also, the robustness of design is increased as the equipment is tested both mechanically and from the process design viewpoint in the same program framework. However, a systematization of equipment parts would be needed before starting to use this type of computerized tools.

Notation

B_s = Baffle setout
B_w = Baffle width
C_i = Impeller clearance from tank bottom
D = Impeller diameter
T = Tank diameter
X = Vector consisting of equipment part list
Y = Matrix consisting of equipment combined from its parts
Z = Liquid height

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