CAPD – Computer-Aided Plant Design

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Abstract

The layout of chemical plants has to take into consideration boundary conditions and requirements of many different engineering fields. In order to assist the design engineer at an early stage during the extended basic engineering, a system for computer aided plant design has been developed. It contains modules for •extended equipment models including equipment related piping and areas for maintenance, •estimation of the steel structure, •layout modelling by rule based algorithms and force directed placement as well as •pipe routing.

At last the quality of the plant layout is evaluated in order to indicate how the design can be improved. The application of the design methods have been proven by industrial projects.

1 Introduction

One major task of chemical industries is the need for shorter „time to market". This calls for improvements in process and plant design, as well as for economic work flows. A general approach to solve these tasks is computer aided engineering. Nevertheless experience and heuristic rules are necessary to make correct decisions. Compared to other traditional computer applications in chemical engineering plant layout is still in its infancy and offers very interesting potentials for improvements.

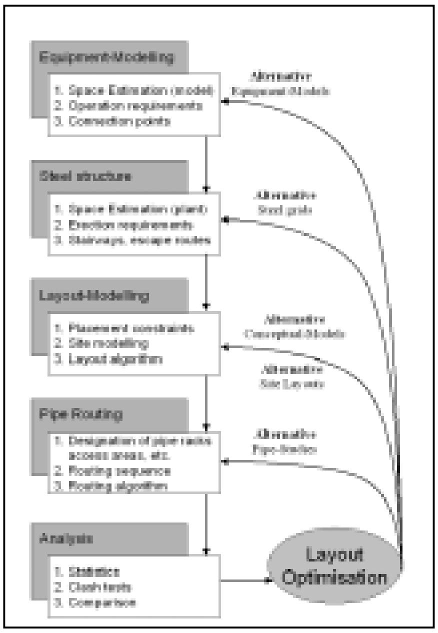

Fig. 1: Structure of the system

The aim of plant layout is to find an optimal arrangement of all process equipment in a chemical plant. In today's practice, this is done by experienced engineers, and usually the resulting concept is based on realised plants or already developed projects. Instead of plastic models, three-dimensional visualisation software tools are increasingly used. As a major disadvantage, these tools do not offer any systematic approach to plant layout, and neither knowledge can be preserved nor algorithms can be used to generate alternative placements.

Several commercial products fight for their share of the market. They are namely AutoPLANT by Rebis Inc. (Rebis 2001), CADISON R/5 by CADISON (Aarich 2001)

and ACPlant-Designer by AC Plant Consult (Meier-Rössl 2001). These applications offer powerful graphic tools and/or consistent database models for smooth project planning from beginning to end. But the engineer gets no support by knowledge databases of previous projects or experiences from other engineers.
K. Möller of the University of Applied Sciences, Frankfurt (Möller 2001) is conscious of this need and is on his way to incorporate a plausibility and logic consistency check for the Vögtlin Cadison Software GmbH.
M. C. Georgiadis presents a mathematical approach based on MILP-solvers. The results have been proven to be useful for plants of up to 20 equipment units in rectangular shape basing on a unified grid size (Georgiadis 1999).
At Dortmund University a new strategy is developed to create a modular computer-based system (Fig 1). It supports the concerned engineer and conducts him step by step to a conceptual 3D plant layout.

2 Computer-aided Plant Design (CAPD)

The CAPD system which will be described here focuses on the extended basic engineering. Even though the graphical representation of the results may look like the detailed engineering plant design it has to be kept in mind that the aim is to optimise the plant layout. Therefore final specification data of the equipment as well as pipes given by pipe classes are not taken into account at this time. The main modules of the CAPD system are described in the following.

2.1 AUTO-EQM

For layout optimisation it is necessary to reduce the complexity of the given problem. One possibility to do this is the definition of extended equipment models. In the following task the equipment has to be placed within a building or steel structure and their position has to be optimised. Therefore the envelopment for such extended models has to include all elements which are associated to the equipment. The AUTO-EQM module estimates the space requirements for the equipment itself including the space for piping which is located closely to it and the needed space for local access. The result of this estimation are simple geometric elements like boxes and cylinders. These equipment models include specific spatial elements for the pipe router to distinguish between those areas where piping is preferred or not allowed. Finally optional connection points for the process piping are generated.
For standard equipment like pumps, heat exchangers, vessels, columns or stirred reactors detailed models have been developed. They configure the individual equipment depending on their special requirements. In case of tubular heat exchangers the user can choose for instance a special TEMA-type. The equipment related piping may include a control valve and will be designed for a certain nominal diameter. Fig. 2 shows an

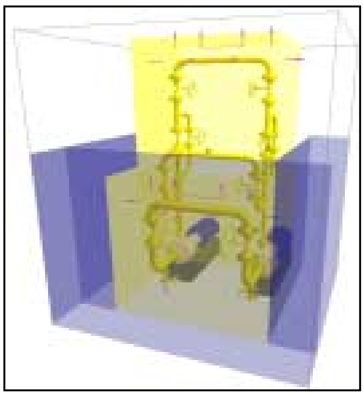

Fig. 2: Extended model for centrifugal pumps

example for a centrifugal pump. Vertical piping has been chosen for these twin pumps. In principle the CAPD system has to place all equipment of a plant. Therefore different black box models are available to configure the overall space for special equipment.

2.2 AUTO-STEEL

The size of the steel structure depends on the area which is needed for the equipment, stair cases, walk ways etc. in each floor. As these data are not available at the beginning of the layout, a first estimate is made for the ground floor area based on those equipment which have to be placed at ground floor and statistical data from existing plants. Then the user has to decide upon the grid size and the number of floors of the structure. This leads to a rectangular structure, wherein the equipment can be placed without any spatial constraints. After the first placement of the equipment the structure has to be reduced to its necessary and economic extend and the placement has to be repeated if necessary.

2.3 AUTO-PLACER

In order to be able to place all equipment within a given steel structure and to optimise their position to each other as well as to given connection points at battery limits, all demands, requirements and constraints concerning the layout have to be known. Input data for the AUTO-PLACER module are extracted from the equipment list, pipe list and the PI-diagram. Additional data have already been generated by the modules AUTO-EQM and AUTO-STEEL .

At first the AUTO-PLACER uses a set of general rules to derive the placement requirements for each item of equipment. These rules are related to different types of equipment as well as to process needs. They may also be completed or modified by the user in case of special project conditions. The general rules have been worked out by extensive discussions with experts from industries and are stored within the data base of the CAPD-system. The requirements generated by these rules specify absolute as well as relative constraints for the placement of the equipment. These constraints are also weighted by the predefined fuzzy-like attributes „must“; „shall“ and „should“ (Table 1).

Tab. 1: Equipment item: P-1301

General Rules	Placement requiremts.	Placement algorithms
If equipment is a pump transportation device is needed	-	-
If transportation device is needed equipment must be on ground floor	P1301 must be on ground floor	5, m_P-1301, m_Floor-0
If transportation device is needed equipment must be near walkway	P1301 must be near walkway	5, m_P-1301, m_Way-01
If pump is linked to column pump shall be near column	P1301 shall be near column	3, m_P-1301, m_T-1320
If equipment needs maintenance equipment shall be near walkway	P1301 shall be near walkway	3, m_P-1301, m_Way-01

The placement requirements for certain equipment may be redundant and also in conflict with others. In case of redundant requirements the constraints with the highest

weight will be selected and the remaining requirements are deleted. Conflicting requirements have to be handled by the placement routine. For automatic placement of equipment the fuzzy requirements are transformed into placement algorithms. The integer values which replace the fuzzy weighting have been evaluated by experience. The following example illustrates the procedure.
Fig. 3 shows an example of the layout calculations. The simulated annealing routine places the overall equipment models (Leuders 2002). These are transformed into the individual equipment models including the equipment related piping.

Fig. 3: Layout model represented by overall boxes and detailed equipment models

2.4 AUTO-ROUTER

The common task of pipe routing systems is the estimation of the detailed collision free pipe design. The user gets data for the first material take off and may also check the model for further improvements. In addition to a routing routine which prevents any collisions with obstacles, other routers can be used to analyse the quality of the layout. The simplest estimation is the Manhattan Distance which calculates the orthogonal distance between two nozzles or a nozzle and pipe. Another router which has been developed is the Manhattan Router. It also neglects obstacles but in contrast to the Manhattan Distance it takes into account the vectorial orientations of the nozzles, follows pipe racks and inserts bends of given radii (Fig. 4).

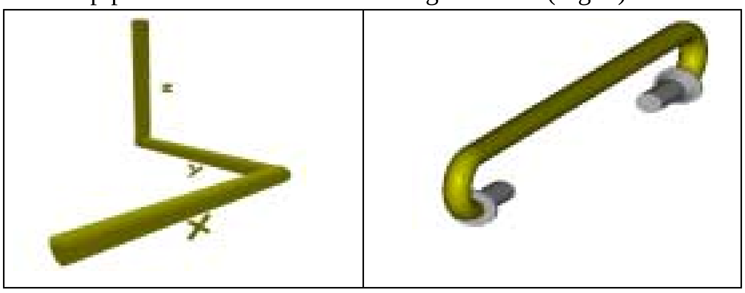

Fig. 4: Manhattan Distance and Manhattan Routing

Two different algorithms for detailed pipe routing can be chosen. The grid router based on the Lee algorithm first divides the routing volume which is enclosed by the two

connection points into equally sized cubes. These cubes are rated by different numerical values according to the classification of their position which may be preferred, optional or forbidden for piping. Beginning at the starting point the wave-like search advances from one cube to the next. During each step penalties are set according to the summarised pre-set numerical values and the element of the pipe which is necessary, e.g. changing the direction means higher penalties.
The vector router searches the optimal pipe route by sending vectors in orthogonal directions until an obstacle or the plant boundary is reached. The optimal route is found by an evaluation of penalties according to the length and the changes in direction, too (Nipper 2000).

2.5 AUTO-EVALUATION

After layout modelling and pipe routing it has to be checked how the layout design can be improved. Later on, the material take off will be estimated in order to compare layout models which have been worked out under different constraints. A further indicator for the quality of a design is the number of placement requirements which are fulfilled by a certain design.
Indications for improvements of the layout design are given by the calculated ratio of the equivalent Manhattan Routing length and the Manhattan Distance. If the ratio is considerably higher than one, the position of the equipment connected by this route should be adjusted in order to reduce the number of bends and the equivalent pipe length.
The second indicator is the ratio of a collision free routing and the Manhattan Routing length for a single pipe. Here, a ratio higher than one indicates that the pipe route has to make a deviation because of an obstacle like an equipment or the steel structure. So the user may check how to improve the layout.
A third indicator for the evaluation of the pipe design is the ratio of a pipe route which prevents collisions with other pipes and the route of the single pipe which neglects other pipes. In this case the designer gets information how to improve the pipe design e.g. by changing equipment nozzles or starting the pipe design with the most expensive pipes.
The AUTO-EVALUATION can also supply a documentation about the requirements which have caused the position of a certain equipment. For industries this is of interest as it makes the reasons for the layout more comprehensible

3. Example Project

A well known German engineering company has provided the University of Dortmund with the basic data of a plant design of their own built plant to perform a test on the developed software. The according plant's purpose is the separation of pyrolysis gasoline. It has a capacity of about 200.000 tons per year and includes 97 pieces of equipment. Basic flowcharts, the from-to-list, equipment lists as well as technical equipment specifications were used as project input data.
Applying the general placing rules of the knowledge database resulted in a catalogue of 415 placement requirements. The algorithm was able to find positions for all models while fulfilling most of the requirements. Of all the must-criteria, 95% were obeyed, 86% of the shall-criteria and 74% should-criteria.

In order to evaluate the quality of the routing system, the as-built layout of the plant has been copied. The routing algorithm revealed a 7% accuracy within the total material take off of the original plant. Figure 5 shows a part of the 3D Model as it is designed with CAPD.

Fig.5: 3D-Model in Open GL

4. Conclusion

Contrasting to the work of Georgiadis, this program utilises the simulated annealing algorithm and no MILP-solver. Therefore it is not necessary to divide the equipment in uniform squares and to provide a suitable grid of possible locations. The main problem of UAD (uniform area division) is that a very fine grid demands high computational power and a coarse grid results in suboptimal solutions because it is less able to represent the actual shape of the equipment. The simulated annealing algorithm used in our case is able to represent all rectangular shapes in millimetre-resolution and allow any position on each floor by the millimetre, too.

The approach of Georgiadis for layout optimisation is based on specific cost data only. He considers transportation cost, cost of piping, floor construction and land cost which have to be provided by the user. The pressure loss caused by pipe friction is usually only 30% of the total pressure loss and therefore it is difficult to determine the exact transportation cost. He then tries to minimise the costs with no regard to any other influence in a good plant layout. In Our approach the knowledge and experience of former designs and layout practice is included by building a database of rules.

Comparisons with industrial projects have proven that the CAPD-system offers reliable methods for computer aided plant design. It is easy to generate different alternatives for the layout of a certain plant. For further practical use the rules and requirements for the layout should be adjusted and the standard equipment model may be completed by company standards.

5. Acknowledgement

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