A KNOWLEDGE BASED APPLICATION TO ENHANCE FIRED HEATER DESIGN

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Abstract: This paper describes meaningful issues related to the development of a Knowledge Based (KB) application to automatically configure fired heater for a chemical plant. It concerns a typical example of product technical configuration. The paper discusses differences between commercial and technical configuration and motivates potentialities of KBE approach in the domain of chemical plant design. In the developed application, the automation of the configuration process is based on two different models: the first one for the plant components, while the second for the design process. This choice has been done because the design of a fired heater, such as many other products, requires the execution of specific design tasks and in parallel the definition of the product architecture. In detail, the product architecture is represented by a tree structure while the configuration process by a list of activities with possible iterations. The paper describes the product and process formalization as well as the most relevant aspects of the implementation activity. The KB application demonstrates how the use of simple data structures can help to solve complex technical problems.

Key words: Design Automation, Knowledge-based Engineering, Product configuration, Fire Heater, Product and process knowledge.

1- Introduction

The term "product configuration" means different activities that can be oriented to marketing or to product development. The first case refers to the commercial configuration while the second case to engineering or technical configuration. Typical examples of commercial product configuration are those proposed via WEB by automotive companies. The potential customer can choose a car model and customize it selecting technical variants (e.g., gasoline, diesel or gpl engine, automatic or manual gearshift, lights), interiors (e.g., seats, manual or automatic air conditioners), and exteriors (e.g., types and sizes of wheels).

Technical configuration is a particular type of design where the general product architecture is defined and its characterization is required according to design specifications. Design activities regard the choice of a component rather than another one, the dimensioning, the verification or the optimization of parts. For what concerns computer aided tools for design, this is a specific problem of Design Automation (DA). DA refers to various tasks of the product development, from the automatic modification of parametric geometric models and automatic definition of parts in the embodiment design to the automatic detailed design of parts or even the generation of new concepts [LS1]. Thus, the technical configuration can be considered as a process that groups activities of the embodiment and detailed design.

In this context, computer aided techniques can be profitably used to support design steps that are "time expensive", e.g., iterations and application of codified methodologies, ensuring in the meantime the best possible solution for the considered applicative domain. Besides, they should provide integrated environments that permit to reduce as much as possible time spent for data exchange, information retrieval, standards consultation, and generation of needed documentation.

This paper discusses meaningful issues related to the development of a Knowledge Based (KB) application to automate a configuration process by using an example related to fired heater for chemical plants. In fact, the fired heater represents a typical example of product technical configuration. We first discuss in detail about product and process configuration concepts. Then, we describe the product and process formalization as well as the most relevant aspects of the implementation activity. Finally, we summarize the main outcomes of the testing phase carried out involving a chemical plant manufacturer.

2- Product & Process Configuration

In the following three main issues are considered: first the

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problem of product configuration, then the characteristics of related process and, finally, the evaluation of a configuration system. Various definitions can be found in literature for product configuration. Sabin and Weigel [SW1] consider it a specific design task characterized by two meaningful aspects: the final product is obtained assembling instances of a fixed set of components and these components interacts each other in a predefined way. This requires two phases: describe the domain knowledge and specify the properties of the desired product. The first represents all possible components and their relationships. Instead, products properties include the requirements a product has to satisfy, its operating environment and, if necessary, optimization rules to search the best solution.

A more significant definition is given by Männistö, Peltonen and Sulonen [MP1]. They propose a classification based on the adopted configuration method. A configuration model is a mechanism, which permits to reconstruct the structure of a product (with different variants) from the same set of data. Such models can be divided in two groups: explicit and implicit depending on how the components of the product structure are identified. The first aims at representing the hierarchical organization of the product with all possible components and how they are assembled. The latter consists in representing the knowledge/rules to identify and choice compatible components and constraints among them. This means that product architecture is not described.

The automatic configuration of a product proposes an integration of both approaches.

Forza and Salvador affirm [FS1] that product configuration consists in permitting the customization of the product without performing task design to satisfy the customer’s requirements. This is not true in our case, since the objective is the product configuration defining its architecture starting from the design process. We think that a configurator should allow a designer to engineer a product satisfying to customer’s requirements and standards of the specific domain, even if the required product has been not yet developed in the past.

Sabin and Weigel [SW1] affirm that the product configuration process consists in providing a complete description of a product variant according to customer’s requirements. Therefore, the configuration process goes from the collection of the information related to the required product variant to the generation of product data necessary to manufacture the variant itself. The configuration moves from the marketing department to the technical one where the customers’ requirements are known and the objective is to choice and size the components composing the assembled product according to standard and design rules defined by the producer. In general, the design rules are represented by mathematical formula that can be easily automated leaving to the designer the task to select those parameters having different values and generating the product variant.

In this context, the offer of customized product can cause various management difficulties, such as data processing and flow that involve various departments of a company.

Traditional solutions to acquire orders are not able to completely satisfy such problem. KBE (Knowledge Based Engineering) systems can profitably help to solve this problem both from a commercial and technical point of view simplifying and automating, at least partially, the process configuration.

The evaluation of a configurator system should be considered with regard to the main production environments/systems. A possible classification, based on the comparison of the time necessary to process an order and time to produce the customized product, groups them in: make to stock, assemble to order, make to order, purchase to order and engineer to order.

In the first four cases, products are already designed and engineered; the customer can make the order selecting the product from a catalogue, in some case with slight modifications that do not require the product redesign.

However, in some cases, the client provides only the products specs. This can require product engineering and production and, if necessary, its design on the basis of the given specs. This is the case of an Engineer To Order (ETO) approach, where the customer needs highly customized products, such as ships, dedicated machines or industrial plants.

In this context, company staff has to understand and translate the customer’s needs using an engineering configuration system able to generate configurations of the product and of its components that satisfy initial requirements.

To be effective the configurator should be able to collect abstract needs without having a product really described. This work refers to this context where the input to the automatic configuration is the information on the specific product variant provided by customer and the output is the generation of all documentation (drawings, 3D CAD models, data sheet, BOM, etc.).

3- Design automation and knowledge management

The necessity to provide customer with costs estimate and concept design rapidly and as close as possible to the final solution requires the use of proper tools to automate most of design activities and reducing development times. As said, a Design Automation approach can represent a valid solution.

In literature we can find various research works on DA methodologies [FA1] [KL1 [LI1] [PC1] [ST1] and applications [CC1] [HA1] [SM1] [PU1].

Design Automation systems adopt IT tools that integrate domain knowledge and use it to automatically generate a solution to the specific problem. DA is based on the representation of the product and of the design process after having acquired and formalized the associated knowledge. Knowledge embedded in DA systems became sharable among all company departments. The automation consists in substituting design tasks that require the human intervention with procedures and systems that automatically generate the desired solution. The system has in charge the task of almost completely design the customized product and related documentation while the designer has the task to provide input data and, if necessary, functional variables.

Typically, the development of a DA application requires a deep analysis of the design process, i.e., the acquisition and formalization of the knowledge that technical staff uses to design the considered product.

This implies the adoption of a methodology with following requirements:

- Capacity to structure product and process knowledge optimising company’s design processes;

- Maximize the reuse and sharing of company knowledge;
- Integrate systems and documents within an application for product automatic configuration.

Therefore, it is necessary to identify and /or define proper methods and tools able to deal with above mentioned issues and affordable also by people with non specific skills on design automation. Moreover, in traditional design process, some activities are overlapped. For example, in some situations it is not well defined when an engineer works to define product architecture or when s/he executes a step of a procedural process to dimensioning, choosing and so on. In a computer application this fact is not satisfactory; "the design research literature reflects this by exhibiting a dichotomy between process representation and product design" [GG1]. Then, two main topics about knowledge representation within a computer program concern product architecture and design process.
Before describing mentioned issues, acquisition and formalization of knowledge both for product and process we briefly introduce the type of product considered, i.e., fired heater for petroleum refinery plants

3.1 – Fire Heater

The product considered, the fired heater, is a sub-system of petroleum refinery plants used to heat and partially vaporize oil in order to separate it from the hydrocarbons. Fig. 1 shows an image of a chemical plant and of a fired heater.

Figure 1: Petroleum refinery plant.

A fired heater is made up of a *radiant* section whose heat is transmitted to fluid flowing inside the tube coils by radiation, a *convection* section where flue gases leaving the radiant section give up their heat by convection and then released in the environment through the *stack*.
Generally, more common fire heaters can be grouped in (Figure 2): box, cabin and cylindrical.
This classification is based on the amount of heat absorbed by the fluid to be warmed up. This value permits to determine the most convenient solution.
Normally, vertical cylindrical type is adequate up to 20-25 106 kcal/h; while cabin or box for higher values.

3.2 –Knowledge acquisition and formalisation

As mentioned before, knowledge acquisition for both product and process and following formalization are two important phases for the development of a KB application.
Knowledge has been acquired using different sources: interviews with technical staff, technical manual [FW1], standards [AA1] [AA2] and scientific books [GP1]. This permitted to acquire both explicit and tacit knowledge and derive design rules that guide the process development process. For the formalization step, different techniques and models have been adopted. In the following we briefly introduce them and main result.

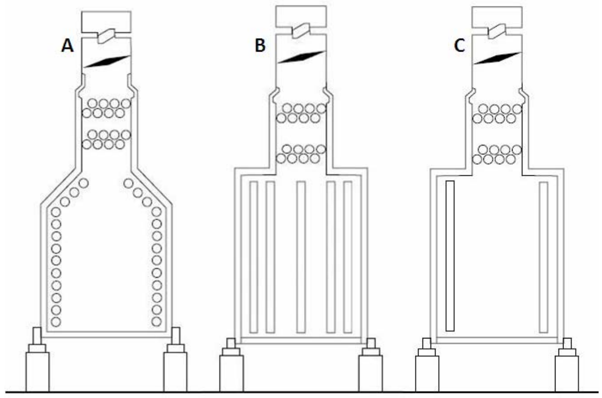

Figure 2: Fired heater: A) Box, B) Cabin and C) Cylindrical.

3.2.1 Product

Several methods and tools are available in literature to represent product knowledge along its life-cycle. We adopted UML Static Class Diagram (http://www.omg.org/uml). This type of diagrams represents the components and functional sub-assembly as O-O classes with associated properties and methods.
First we analyzed the product architecture. A fired heater consists of three main functional subsystems: the radiant, the convection section, and the stack. Figure 3 shows the product structure represented as a tree where it is possible to see the mentioned subsystems and their main sub-components.

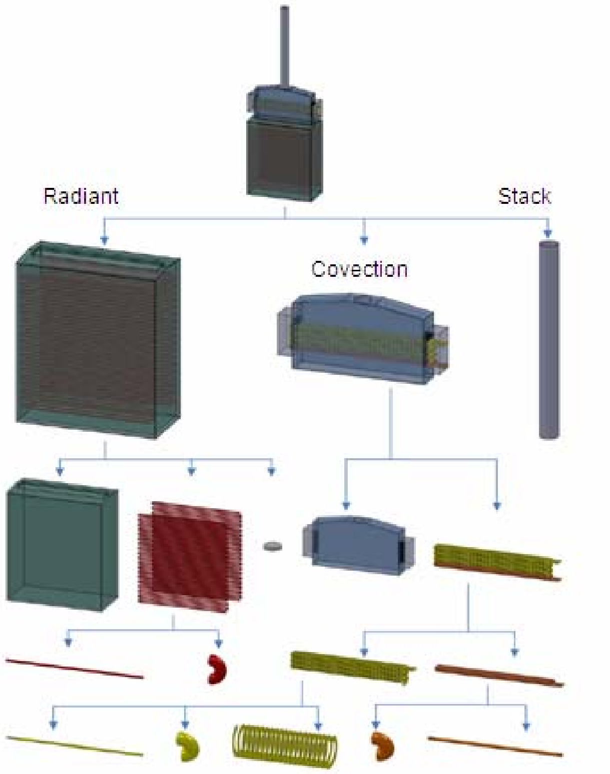

Figure 3: Tree structure of the fired heater.

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Then the tree structure has been translated into UML Static Class Diagrams where subsystems, components, and relationships are properly represented. Figure 4 portrays the main UML diagram where the three mentioned subsystems are represented.

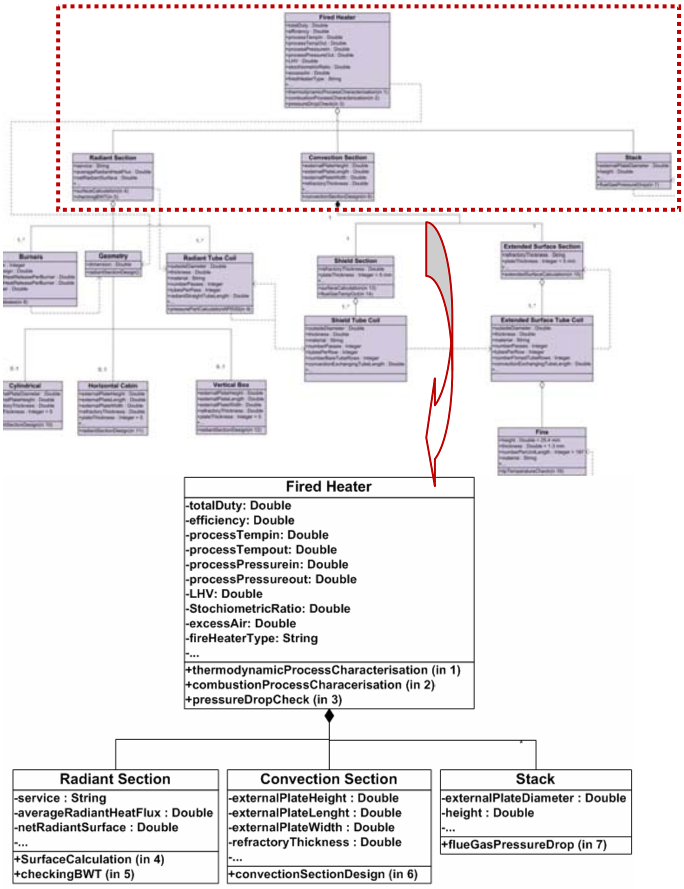

Figure 4: Main UML Class Diagram.

3.2.1 Process

Process knowledge has been formalised adopting IDEF0 and IDEF 3 Process Flow (PF) models (www.idef.com). These techniques are based on graphic languages, simple and easy to be understood and used also by people without a scientific/ technical background.

The design process of a fired heater is based on two interrelated main activities: first, parts are dimensioned applying design rules derived from the thermodynamics and then the designer's choices and calculated parameters values are verified on the base of mechanical and fluid dynamics principles. These two activities are not strictly sequential but are partially carried out in parallel. Once acquired customer's requirements the process is articulated into the following steps:

- Characterize thermodynamic process calculating the heat fired, the fuel mass flow, the gas mass flow and net duty;
- Select burner types: cylindrical, cabin or box;
- Design fired heater subsystems, i.e., the radiant, the convection section and the stack, and the correlated parts;
- Check data especially the bridge wall temperature (BWT), tube size, material, and pressure drop.

We have associated to the IDEF0 diagram and UML sets of design rules that permit to size correctly each component and generate the product configuration. They have been derived both from thermodynamics principles and designers' experience. As an example, consider activity "Characterize thermodynamic process" or UML class Fire heater (Figure 4), associated design rules to calculate heat fired are:

- HFired = Duty Tot /η
  where:
  HFired: = Heat Fired [MW];
  DutyTot = Total Duty [MW].
- H Losses = HFired . ηLosses
  where:
  HLosses = Heat Losses [MW];
  ηLosses = Efficiency Losses.
  It is 2,5% when a preheated system is used otherwise it is 1,5%

- ηtot = η + ηLosses
  where:
  ηtot = Total efficiency;
  η = efficiency.

4- Configurator development

The DA application has been realized using the commercial KBE system, RuleStream. It has been characterized by the following activities.

- Creation of the hierarchic object structure representing all possible configuration of the fired heater;
- Definition of properties of each part, sub-assemblies and complete assembly to the UML diagrams (see Figure 4);
- Rules representation;
- Generation of parts and material databases;
- Creation of the parametric geometric model of each part, using, also in this case, a commercial 3D CAD package;
- Representation of the process creating proper user interfaces for each step;
- Development of the graphical user interface.

The architecture of the fire heater, described in Figure 3, is represented by means of a tree structure ordering the parts in accordance with an assembly and function sub-assembly scheme/logic and the UML diagrams adopted to formalize the product knowledge. Thus, the structure is composed by a set of elements linked by rules. To implement the design process, it has been necessary to define the rules and relationships among the parts and link them to the associated parameters. All ruled related to the design process (formalized with IDEF diagrams) have been implemented linking to each part properties a value derived from an analytical formula or geometric relationship. Figure 5 shows the mapping of UML and IDEF diagrams within the application.

The implemented application is based on two separate models: the first for the plant components while the second for the configuration/design process (Fig. 5). This choice has been done because the design of a fired heater, such as many other products, requires the execution of specific design activities and in parallel the definition of the product architecture.

Therefore, between the two models there is a communication channel to transfer data and information from the process to the product and vice versa (Figure 6). The realised application automatically executes the configuration process, usually performed manually by the designer. It starts with the acquisition of design specs and subsequent steps are performed in accordance with the implemented process.

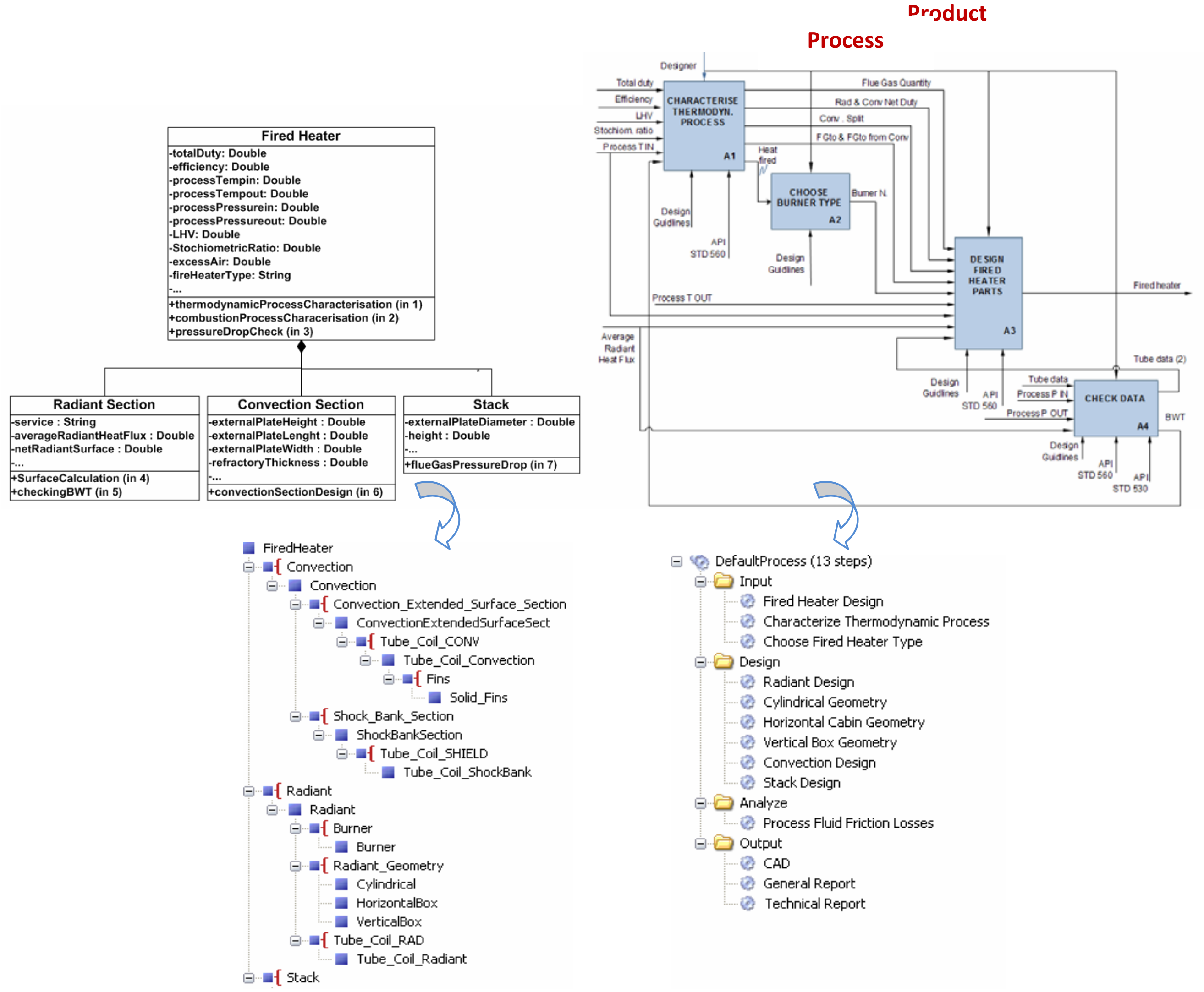

Figure 5: Implemented Product structure and Design process.

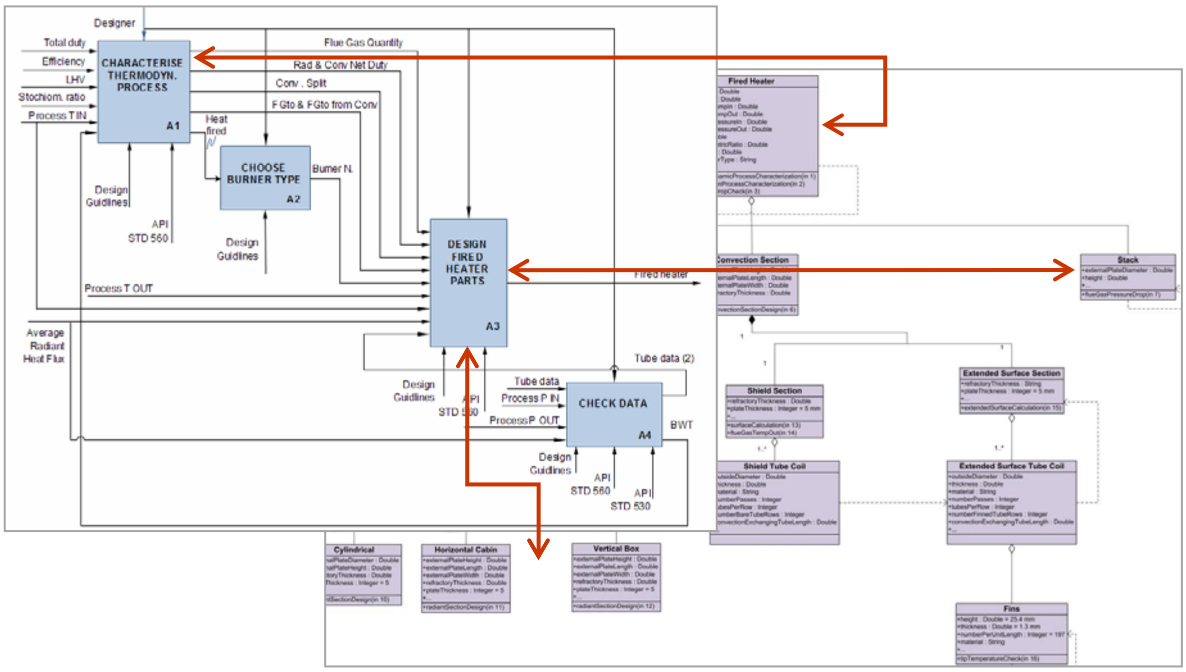

Figure 6: Correlation between the IDEF0 diagram and UML diagram.

5 - Testing

The developed application has been experimented by the technical staff of the involved company with two test cases:

- A cabin fired heater with horizontal tubes already developed by the company;
- A cylindrical and a Box fired heater applying the same data input.

The first test concerns the design of a fired heater suitable to generate a total duty equal to 11.6 MW. The aim of this test has been to demonstrate that the final results generated by the automatic configurator are the same of those obtained following the traditional process within the company.

Figure 7 portrays the acquisition of customer' reqs. All data generated, from the 3D CAD models to the final documentation summarizing fire heater characteristics, were in accordance with those calculated by the company.

The second test concerns the design of fired heater able to generate a total duty equal to 10MW. Entering the same input data (Figure 7), two different configurations have been designed: a cylindrical fire heater (Fig.8a) and a box one both with vertical tubes (Fig. 8b).

This permitted to demonstrate either the accordance of the obtained results with those obtained with the traditional process or the possibility to rapidly generate and compare different design solutions.

The results of the tests confirmed the potential of such type of application also for complex products and the robustness of developed application. Company staff appreciated that the system can be used by people with different levels of expertise and/or skills. In fact, the applications can also used to train new designers. The possibility to follow gradually tasks sequence and the simultaneous control of design parameters and rules allow the junior designers to easily and rapidly acquire the knowledge necessary to work within the specific context.

Company staff considered DA application an optimal tool especially during order acquisition to present the offer to the potential customer and generate technical drawing of the plant, named general arrangements. In this case the introduction within the company could be done in a short time. On the other hand, the introduction of such a technology in the technical departments requires deeper changes and could be done at medium long term.

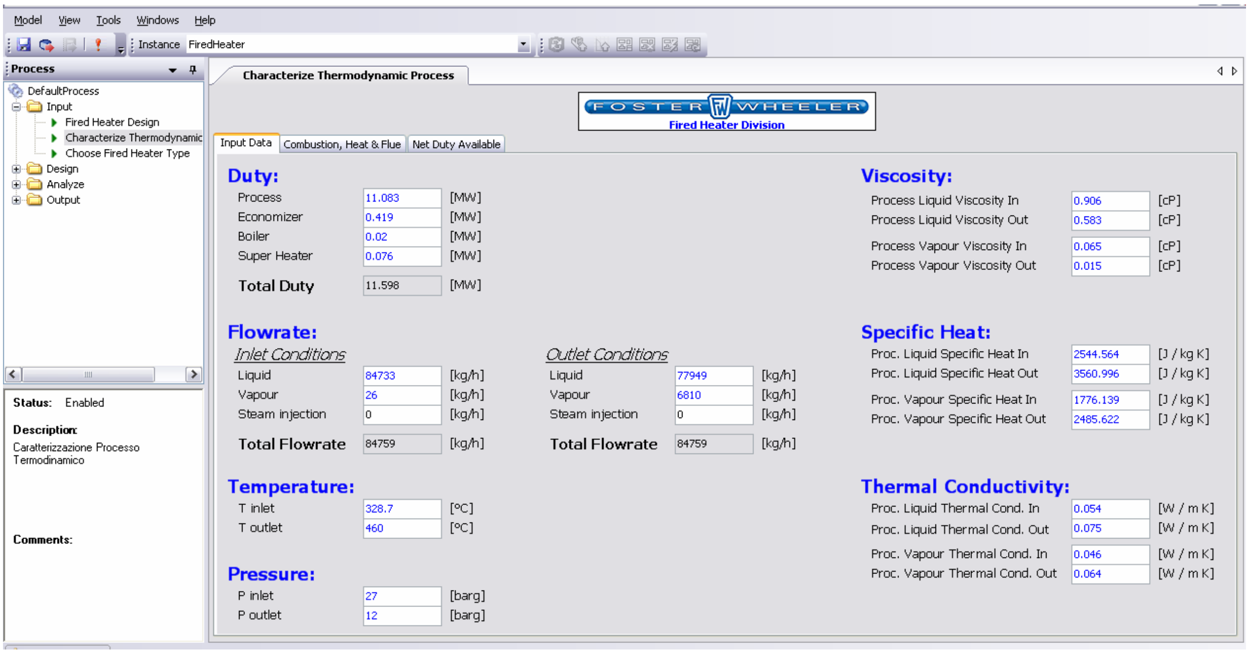

Figure 7: The KB application: entering design specs for thermodynamic characterization.

6- Conclusions

This paper presents a DA application specifically developed for automatic fired heater configuration that has been validated with technical staff of the involved company.

The application permits to simplify the designer's effort in designing the considered product reducing the tasks s/he usually performs manually. The configurator can be used both by designers and by commercial technicians. In fact, also a non expert person is able to configure a particular kind of fired heater simply entering the value of few parameters corresponding to customer's reqs. For example, a company seller can satisfy rapidly the customer's need showing rapidly the product configuration or possible alternative solutions.

Moreover, the product and process knowledge, properly acquired and formalized, can be used to disseminate best practices within company departments making people aware of company intellectual property.

The authors have foreseen future developments along three directions. First, the application can be integrated with CAE tools, e.g., for FEA; then the extension to other kinds of fire heater. In fact, the application has been implemented with and object-oriented logic and the product components can be re-used to create new families, such cylindrical fired heater with helicoidal tube coil, box heater with double radiant or even other kind of products, such as heat exchangers.

Finally, an enhancement regarding the detailed design of the components can be realized since the prototype of the application is focused on embodiment design.

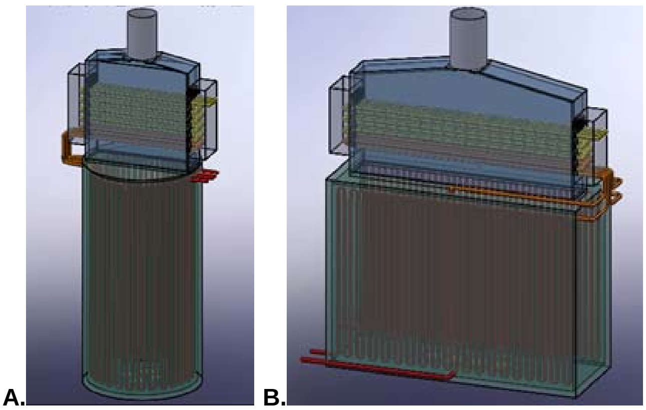

Figure 8: A) Cylindrical fired heater; B). Box Fired heater.

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