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Modeling and Optimization of Energy Consumption in Multipurpose Batch Plants

Autor	Andrej Szíjjarto
beauftragte Institution	Gruppe für Umwelt- und Sicherheitstechnologie; ETH Zürich
Adresse	ETH Hönggerberg HCI G 138; 8093 Zürich
Telefon, E-mail,	01 / 632 56 66, andrej.szijjarto@chem.ethz.ch,
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Zusammenfassung

Nach Aufstellung des Projektplans und Erstellung eines Literaturüberblicks wurde die Analyse des Fallstudien-Gebäudes begonnen. Nach Gewinnung eines generellen Überblicks über das untersuchte Gebäude wurde als erster Schritt eine Top-Down-Modellierung des Gebäudes durchgeführt. Als Ergebnis dieser Analyse resultierte eine schlechte Korrelation zwischen Energieverbrauch und der Menge der produzierten Chemikalien. Dieses Ergebnis unterstreicht die Notwendigkeit, im Fallstudiengebäude eine Bottom-Up-Modellierung durchzuführen.

Als erster Schritt einer Bottom-Up-Modellierung wurde der 5 bar Dampf für eine Periode von 8 Tagen untersucht. In dieser Zeitspanne wurden 9 verschiedene Chemikalien produziert. Insgesamt wurden für die untersuchte Periode 36 Dampfverbraucher identifiziert, von denen 5 kontinuierlich betrieben wurden. Dieser Dampfverbrauch wurde direkt gemessen und machte ca. 40% des 5 bar Dampfverbrauchs während der untersuchten Periode aus. Der Dampfverbrauch der verbleibenden 31 im Batch-Mode betriebenen Apparate wurde modelliert, wobei empirische Verlustkoeffizienten benutzt wurden, die in einer früheren Studie in einem anderen Gebäude bestimmt wurden (Bieler, 2004).

Obwohl noch keine gebäudespezifischen Verlustkoeffizienten benutzt wurden, resultierte eine gute Übereinstimmung zwischen modelliertem und gemessenem 5 bar Dampfverbrauch – der modellierte Verbrauch machte über die ganze Periode 95.5% des gemessenen Wertes aus. Es muss allerdings berücksichtigt werden, dass der Infrastrukturverbrauch noch nicht in den Berechnungen enthalten ist.

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1 Goals of the project

The main aim of the work performed during the year 2004 was to get the basic overview over the case study plant were the energy consumption analysis will be carried out. As described in a previous report (Szíjjarto, 2004) the top-down approach does not provide the reliable information about the energy utility consumption (see Figure 1) and therefore the next goal was to get more detailed information about particular unit operations using the bottom-up approach. The main idea was to keep the modeling simple (time efficient) and test the models and empirical parameters investigated in previous project in order to specify the transferability of these concepts to another building. The bottom-up modeling can be carried out just after the foregoing data acquisition, which was another goal of the project during year 2004.

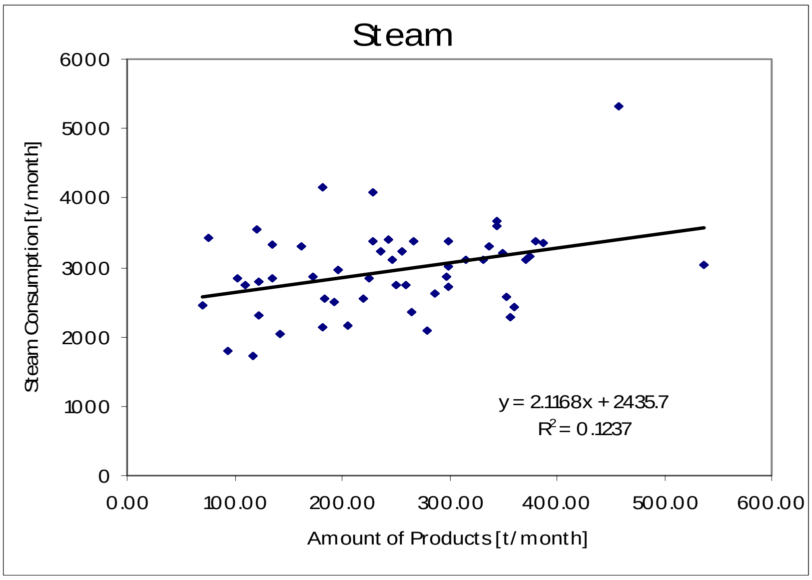

Figure 1: Top-down approach for steam 5 bar

2 Performed work and achieved results

2.1 DETERMINATION OF THE SYSTEM BOUNDARIES

The crucial point considering the energy utility consumption of the case study plant is the definition of the system boundaries. In the case study plant, boundaries of the energy balance are not limited to the production plant, but they have to be extended also to the solvent storage and regeneration building, which contains the continuous rectification columns used for regeneration of solvents stemming from the production building. So the measured overall consumption which is stored in the internal computer database is the consumption of both buildings, as shown in Figure 2. The steam consumption of the continuous rectification columns is measured directly and represents ca. 40% of overall steam consumption for the specified time period[1]. The bottom-up modeling will be focused on the reactors, dryers and Nutsche filters, which are running in batch mode.

[1] The consumption of the rectification columns can varry for different time periods and might be also a big source of uncertainities in the top-down modeling.

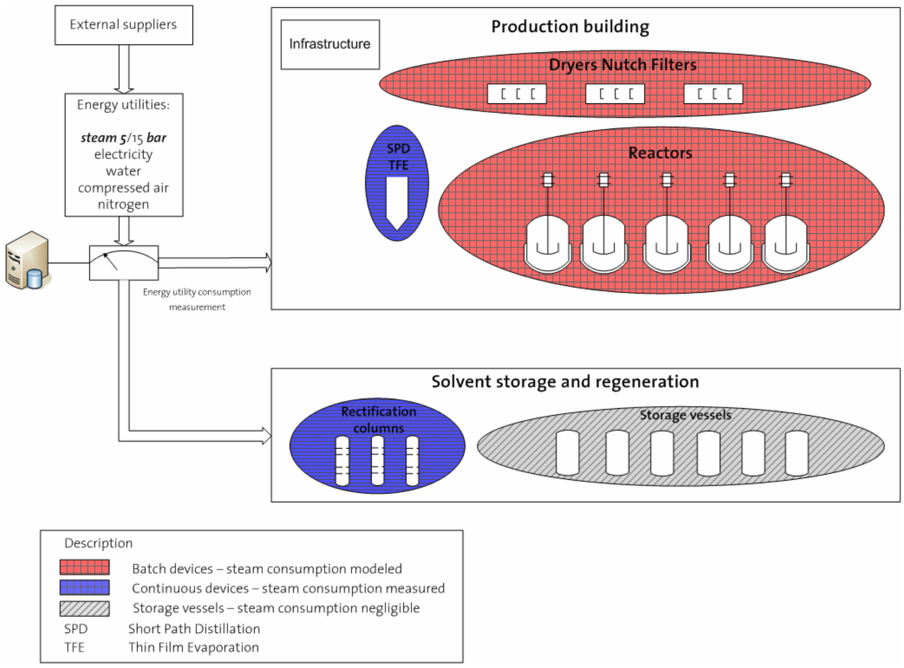

Figure 2: Simplified scheme of the case study plant focusing on 5 bar steam consumers

2.2 DATA ACQUISITION

There is a huge amount of data needed for detailed bottom-up modeling for all energy utilities. As a first step of bottom-up modeling, only one energy utility – 5 bar steam was chosen. The modeling was carried out for 8 days period - 06.06.2004 – 13.06.2004, during this period 9 chemicals were produced.

Choosing the appropriate period was done based on investigation of the production reports, where the number of produced batches of particular chemicals during specified time period is recorded. Candidate periods have to be discussed with the plant chemist in order to eliminate non-standard periods (periods when special operation conditions occurred). After this step, the data acquisition can be performed in following sequence:

- identification of the devices consuming 5 bar steam used for the production of the chemicals during selected period (36 devices were identified) – ***Process Step Procedure (PSP, BVO)***
- gathering the apparatus data for the specified steam consumers (weight and material of device, dimensions, volume of heating/cooling system[2]) – this information is usually stored in ***Computerized Maintenance Management System (CMMS)***, but has to be checked in order to get up-to-date information
- acquisition of the operating conditions of the batch devices for the chosen time period (inside temperature, pressure, weight of reaction mass, average c_p of reaction mass) – the time dependence of T, P, m is stored in the ***internal database of the plant*** and the average c_p can be extracted from ***risk analysis***
- gathering of the steam consumption of the continuous devices – the data from direct measurements of steam consumption are stored in the ***internal database of the plant***
- acquisition of the overall steam consumption for investigated case study plant during selected time period

[2] After discussion with industry experts (Schittek, November 2004)the average weight of 1000 kg for H/C system was chosen as good guess, the detailed values will be used in the future modeling.

2.3 DATA ANALYSIS

The bottom-up modeling of the steam consumption is based on the energy balance of particular unit operations. The overall steam consumption of the case plant can be divided into 4 main subgroups[3]:

- steam needed for heating up the reaction media, apparatus and heating/cooling system
- steam needed for evaporation, distillation and reflux
- losses
- steam needed for continuous processes (directly measured)

Steam needed for heating the apparatus, H/C system and reaction mixture was calculated from the energy balance as follows:

$$E_{St,heat} = m_{RM} \cdot c_p \cdot \Delta T \qquad (1)$$

where m_{RM} is the mass of reaction mixture in kg in investigated period and c_p in kJ/(kgK) represents the average heat capacity of the reaction mixture. The temperature and mass of the reaction mixture as a function of time were compared with the corresponding PSP and particular operations in the investigated apparatus were identified as shown in Figure 3.

The loss-term was calculated using the following equation:

$$E_{St,loss} = K \cdot A \cdot \Delta T_{Am} \cdot t \quad (2)$$

where $E_{St,loss}$ represents the amount of the steam-losses in KJ, K is the loss coefficient 2.5 kJ / (min.K) [Bieler, 2004], ΔT_{Am} is the difference between apparatus and ambient temperature in K and t the time in min.

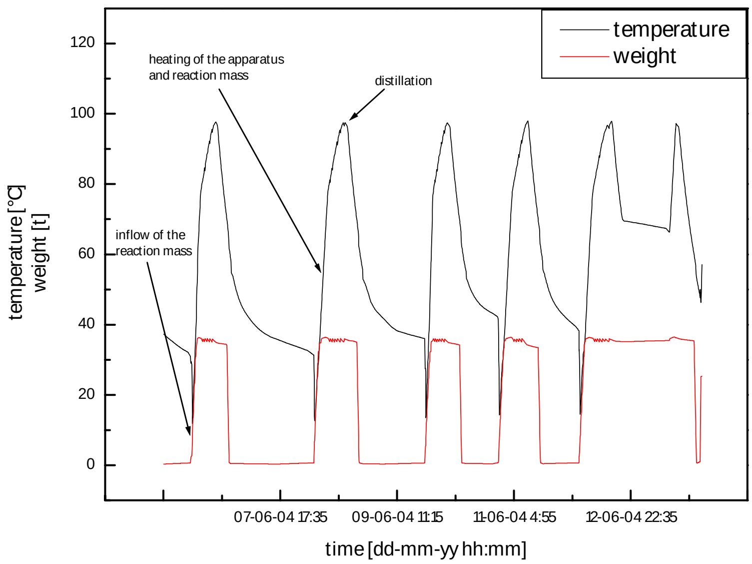

Figure 3: Typical course of temperature and weight of a reactor as a function of time

[3] The heat of reaction stirrer input and infrastructure consumption were neglected at this stage of modeling

2.4 RESULTS OF THE PRELIMINARY BOTTOM-UP MODELING

The allocation of the steam consumption into 4 mentioned subgroups is shown in Figure 4a. As can be seen, the highest portion of the overall steam consumption is used for the continuous regeneration of the solvents. However, the continuous equipment was taken just as a black-box and no further analysis can be performed at the preliminary modeling stage. Therefore only the consumption of the batch apparatus is compared in Figure 4b. Here can be seen that the losses contribute significantly to the overall steam consumption.

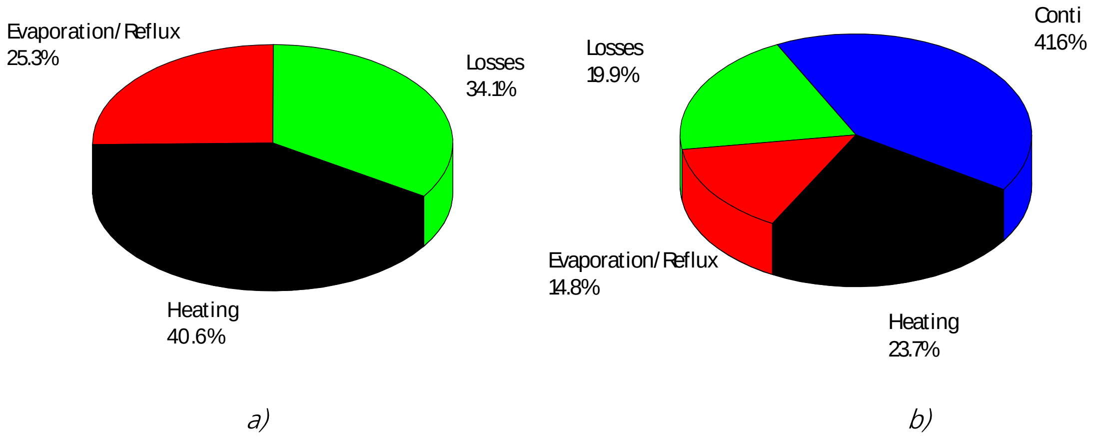

Figure 4: Modeled distribution of overall 5 bar steam consumption during 8-days period

a) with continuous apparatus b) without continuous apparatus

In Figure 5, the overall consumption of the steam is shown. This is strongly influenced by the usage of continuous apparatus for a given product. For products F, H and I, the overall steam consumption is highly above the average value.

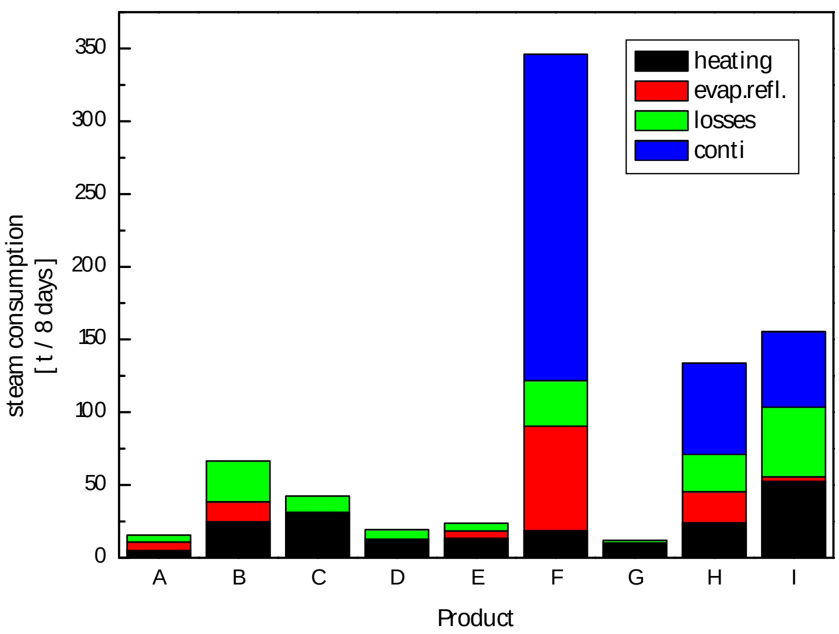

Figure 5: Modeled distribution of overall product-related 5 bar steam consumption during 8-days period

In Figure 6 the specific steam consumption, i.e. the steam consumption per kg of product, for the different chemicals is shown. The specific steam consumption for products F, H and I is considerably higher as compared to the other products. A comparison of Figures 5 and 6 shows that the differences in overall consumption between the different products are mainly due to differences in the specific consumption.

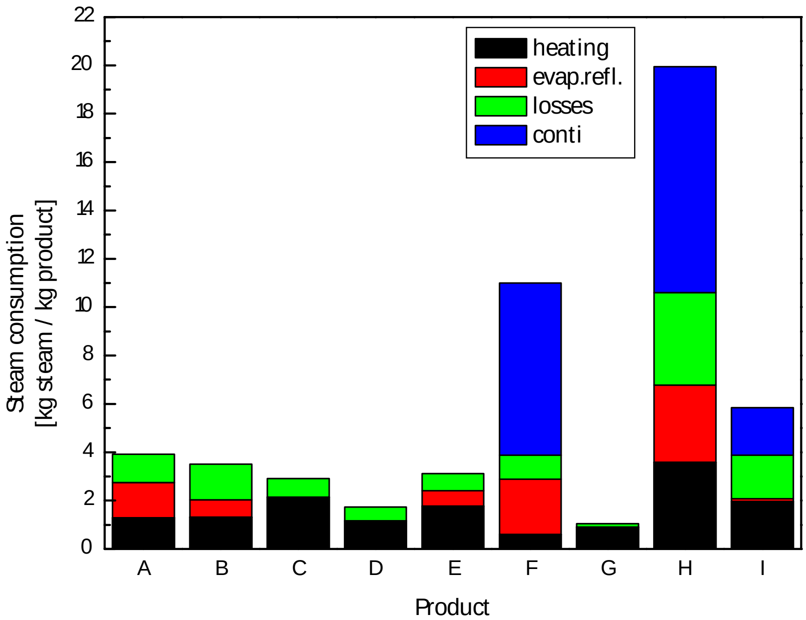

Figure 6: Modeled distribution of specific product-related 5 bar steam consumption during 8-days period

In Figure 7 the calculated overall consumption of 5 bar steam for the eight investigated days is compared to the measurements. The model results are in good agreement with the measurements. However, infrastructure consumption has not been quantified yet and its consideration might lead to higher total values than the actual measurements. This would most probably indicate that the loss coefficients in the investigated building might at least for some equipment units be lower than the value taken from earlier studies. Since some reactors in the investigated building use direct heating they probably have lower loss coefficients than reactors with double-wall heating as investigated in the previous studies from which the loss coefficients was taken. Further investigations are needed to resolve this question.

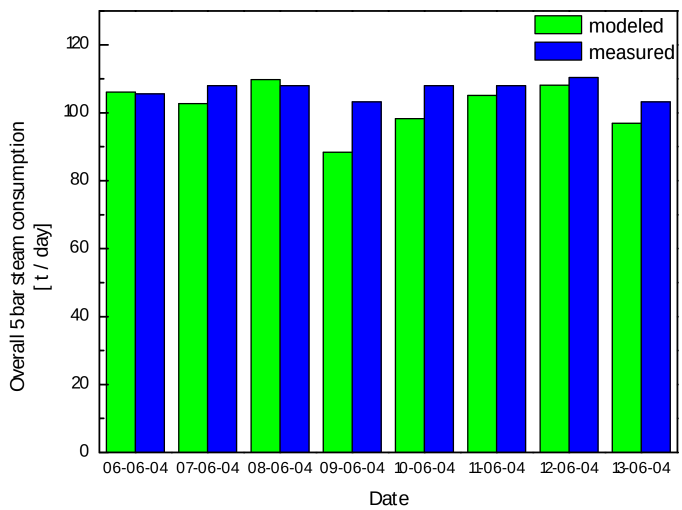

Figure 7: Comparison of modeled and measured 5 bar steam consumption

3 Evaluation 2004, overview 2005

3.1 EVALUATION 2004

The preliminary modeling of the case study building was carried out. The main aim was to set-up the bottom-up model and to test the loss-term measured in the previous project.

The presented model results for 5 bar steam are in good agreement with the measured values, however a more detailed analysis is needed. In particular the infrastructure consumption has to be quantified and the loss coefficients have to be determined. Furthermore, the bottom-up model has to be set-up and tested for the other energy consumption utilities in the investigated building.

3.2 OVERVIEW 2005

The bottom-up model developed during year 2004 will be further developed in order to describe the specific energy consumption for other products and time periods.

The measurement of the loss terms for different reactors will be carried out and the updated values will be used in the bottom-up model.

References:

Bieler, P.S. (2004). "Analysis and Modelling of the Energy Consumption of Chemical Batch Plants," PhD dissertation, Zurich, ETH.

Schittek (2004) Personal communication

Szíjjarto, A. (2004), BfE Status report 'Modeling and Optimization of Energy Consumption in Multipurpose Batch Plants'– August 2004