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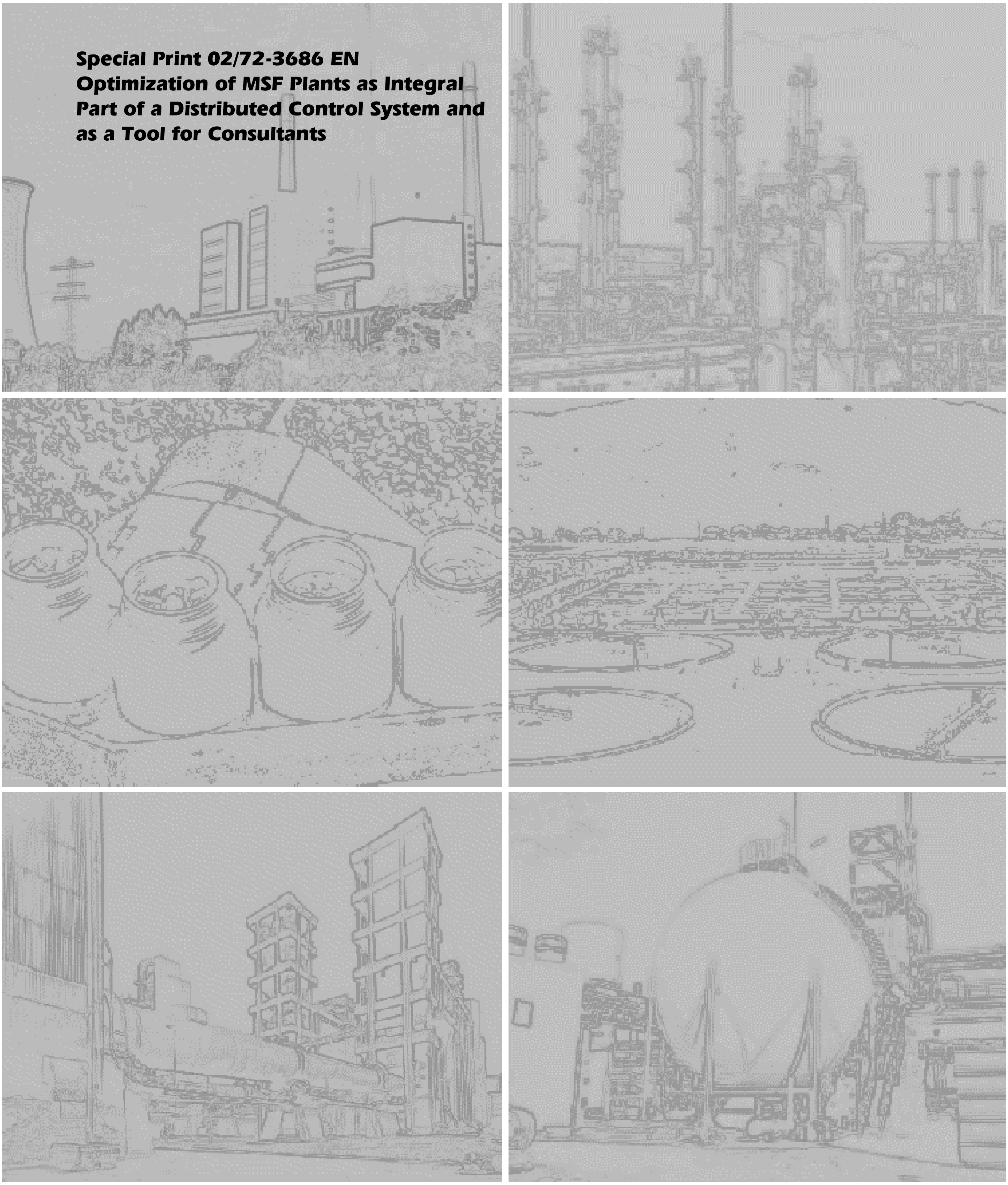

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**Content:**

# Optimization of MSF Plants as Integral Part of a Distributed Control System and as a Tool for Consultants

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## Abstract

Setpoint optimization of MSF plants is used to operate plants in their optimal operating conditions. This can be achieved either by using fixed functional dependencies or by using rigorous models and finding the optimal set of setpoints using an optimization algorithm. As the behavior of the plant is changing with time due to e.g. fouling or changing environmental conditions, the first method has some disadvantages as it can not react on the changing boundary conditions. When using a model, which takes these changes into account, remarkable improvements will be achieved. Another improvement is that the optimization goals may be changed according to the actual needs.

The optimization strategy based on rigorous models will be used either on-line during operation or off-line by consultants and manufacturers during the planning phase. As the model is based on physical effects it allows to determine the plant behavior from the physical and geometrical data of the plant, thus permitting to modify and optimize the plant layout during the planning phase. During operation the geometrical data of the plant remain constant, but the environmental conditions will change. These, together with the restrictions which are imposed on the process (maximum temperatures, chemical dosing, restricted steam production, etc.), are also taken into account by the model, and the optimal setpoints are calculated accordingly. In order to follow up the real plant behavior, it is necessary to determine the changes imposed by e.g. fouling. This is achieved by calculating the changed heat transfer coefficients. Another module takes care of the measurement errors and tries to minimize their effects.

It will be shown how the above described tasks are implemented in the Distributed Control Systems manufactured by Hartmann & Braun and which tools are available for consultants and manufacturers to support their evaluation work during the planning phase.

**Keywords:** Multistage flash desalination, design, operation, optimization, distributed control system, process information management

## 1 Introduction

Multi stage flash (MSF) plants are todays mostly used processes to produce large quantities of potable water. While in the past it was the most important goal to achieve the highest possible availability of the plants, nowadays the best performance of the plants becomes increasingly important. For that purpose it is no longer sufficient to operate the plants according to the operating manuals of the process manufacturer or following the experience of the operators. It now becomes necessary to use supplementary calculations to determine the optimal setpoints of the individual control loops based on a rigorous process model which allows an improvement of the efficiency under all modes of operation in an unprecedentant quality.

The rigorous plant model may be used in on-line mode for the optimization of the plant under all modes of operation and changing boundary conditions (e.g. summer/winter mode, changing salinity or temperature of the sea water). As it is build using physical laws it may also be used off-line to determine in advance the anticipated behavior of a plant by using the actually designed geometrical and material data including additional heuristic knowledge e.g. to determine the brine level. This helps to examine the construction of the plant and to calculate and evaluate different alternatives. Dynamic simulations allow to examine the transient behavior of the plant and to assure smooth and safe operation during load changes.

During on-line operation of the optimization package, it is very important that the rigorous model used is always tracking the behavior of the real plant. Different measures as e.g. measured data validation and the determination of the effects of fouling and scaling are to be applied to fulfill this task.

## 2 The MSF Process and its Modeling

The MSF Process

The MSF process consists of a series of chambers (stages) which are coupled to each other by a closed flow (see Fig. 1 for a simplified presentation of the process). The sea water to be distillated is circulated through these stages several times (recirculating brine) and is heated in the brine heater. The necessary heat flow is usually provided by a power plant. This cogeneration of electricity and water meets the requirements of arid climates and improves the overall efficiency significantly.

The pressure in the stages is reduced from stage to stage which leads, as the recirculating brine is in thermodynamic equilibrium, to spontaneous evaporation (flashing) of the brine. The evaporated water is condensed at heat exchangers which are simultaneously used to warm-up the recirculating brine on its way to the brine heater (in the heat recovery section) and is collected in the distillate trays. In the heat reject section, the steam is condensed using sea water as cooling medium to establish a predefined temperature and pressure level. Earlier, the cooling water temperature was controlled by recirculating some of the discharged cooling water to achieve a constant temperature profile in the heat reject section during summer and winter mode of operation. Lately this adaption is also achieved via flow control of the cooling water, thus reducing energy consumption [1]. The distillate is discharged from the last stage. The salinity of the brine is controlled through the addition of make-up water and the discharge of the blow-down water.

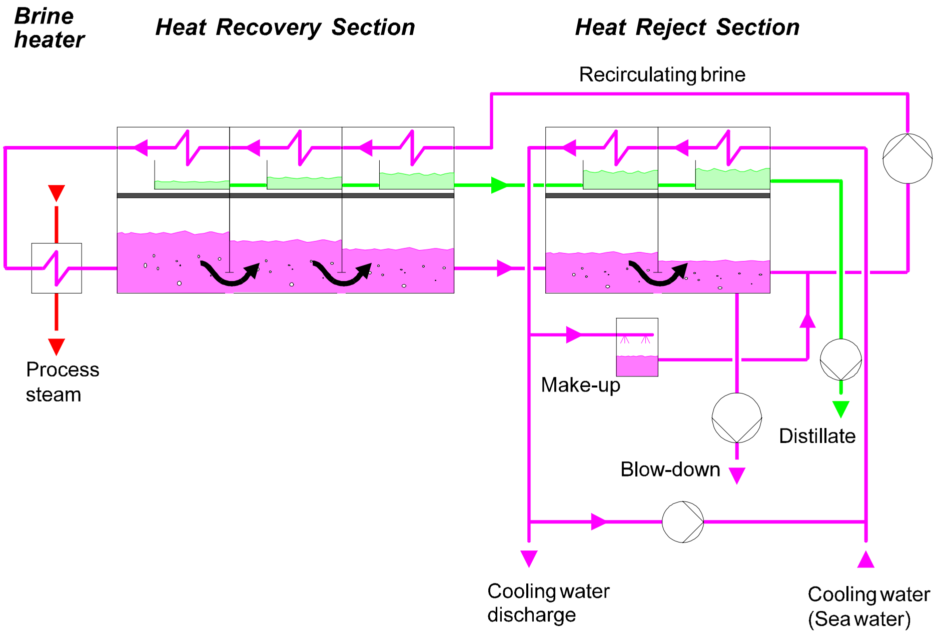


*Fig. 1 Simplified process scheme of a MSF plant*

The output of the process, which is the distillate flow, is not a setpoint which can be set directly. On the contrary, the amount of distillate is the result of the values of the setpoints which are mainly: top brine temperature, recirculating brine flow, make-up flow and cooling water flow. Different sets of setpoints may result in the same distillate flow, but the efficiency of the process will then be changed. That is why an optimization may be executed.

Steady State Modeling of the MSF Plant

Steady-state models for the MSF process can be developed with different grades of accuracy depending on the task of the model. It is a nonlinear model with several hundreds of equations. For on-line setpoint optimization, normally a less rigorous model is required. Simplified models can be achieved by assuming constant physical properties, heat transfer coefficients and temperature drop in all stages, usage of less rigorous equations, etc. Neural nets have lately been used to calculate steady-state models with comparably little computational effort [2]. The disadvantage of this method is that no insight in the process physics is gained and that the neural nets need to be trained with a rather large amount of measured data from already existing plants. Supervisory means have to be provided to determine steady-state and valid plant conditions for the measured values used.

To illustrate the main modules used for the simulation of one stage, see Fig. 2.

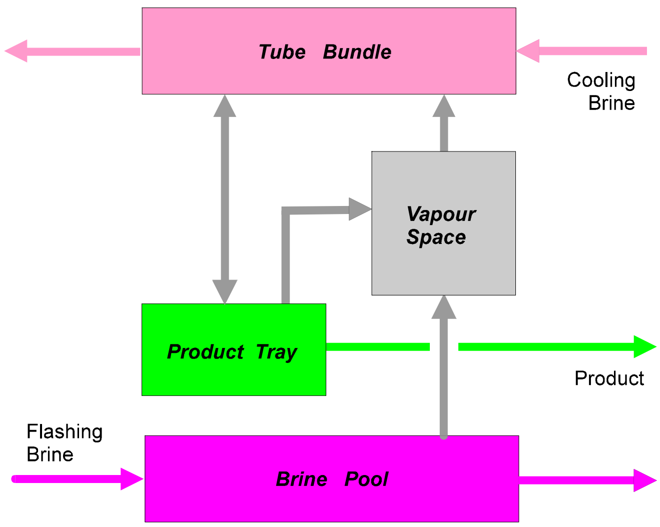


***Fig. 2** Main modules of the stage model*

Since the MSF process is a cycle process, there is a closed information flow. Therefore, solving methods concerning this fact must be used. Two groups of methods have been established for the solution of the model: simultaneous (equation oriented) methods and stage-by-stage (sequential) methods.

The stage-by-stage solution has been widely used because of several advantages:

- The equation system of each unit is calculated separately. Therefore, solving of an equation system with a huge number of equations is avoided.
- Regularly, there is enough experience with stage-by-stage methods. It solves the problems the way the engineer would solve the problem by manual calculation.

On the other hand, stage-by-stage method indicates convergence and stability problems.

According to the simultaneous methods, several hundreds of nonlinear equations describing the MSF process must be solved simultaneously. These equations are interdependent but sparse in nature. The latter fact reduces the calculation efforts considerably and permits the use of special methods. A wide variety of methods for simultaneous solution are presented in the literature. The most important of them for MSF plants are the global Newton-Raphson method and the linearization method used by Helal et al. [3]. The Newton-Raphson method converges very fast when using start values close to the solution, otherwise it does not converge properly, or stability problems are encountered. The method of Helal et al. is based on decomposition of the

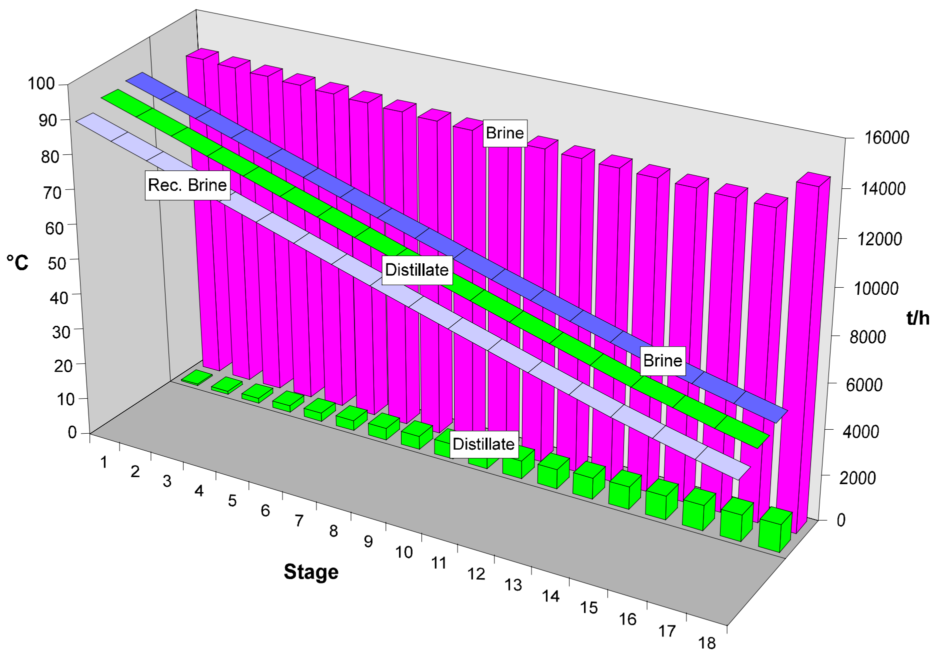


***Fig. 3*** *Calculation results of the MSF steady-state model for Al Taweelah B power and desalination plant*

equations after linearization. The enthalpy balance equations and the heat transfer relations are linearized using data from previous iterations as well as from the present calculations. The equation system is decomposed into subsets by appropriate choosing of the iteration variables. Thereby, the equations are grouped by type rather than by stage. The enthalpy balance equations are formulated into a tridiagonal matrix form, which is solved by the Thomas algorithm. The subsets are solved iteratively in sequence.

The importance of the simultaneous methods has been increased in the last years with the advances in the calculation speed of the computers and the development of sophisticated resolution methods and has been used in the optimization package presented in this paper. The model was extensively validated by comparison of the calculated results with measured data. An example of calculated results for the Al Taweelah B power and desalination plant is shown in Fig. 3.

## 3 Optimization

In the last couple of years several applications of setpoint optimization have been developed for the process industry, such as for economic consumption of energy in chemical and petrochemical plants [4], for an olefin plant with linkage of an economic model with specific parameters of the plant [5] or for fluidized catalytic crackers [6]. Further publications on setpoint optimization for the process industry are [7-10].

For the setpoint optimization, an objective function must be set up and maximized or minimized, respectively. At the same time, the constraints imposed to assure a safe and stable operation of the plant must be satisfied. In cogeneration plants, e.g., it is possible that the availability of steam is restricted due to a predetermined electrical load which has to be produced and has a higher priority than the water generation.

The optimization problem to deal with can be defined as a nonlinear one with a large number of constraints.

### 3.1 Constraints

The most important parameters and variables for optimal operation of the MSF plant are presented in the following list. They are all subject to constraints and may be distinguished in:

Boundary conditions which can not be influenced by the optimization tool:
- Distillate product flow
- Steam flow

Independent variables which are directly influenced by the optimization:
- Top brine temperature
- Brine recirculating flow
- Make-up flow
- Cooling water inlet temperature

Dependent variables calculated by the model using both a/m categories of variables as input:
- Steam temperature
- Cooling water flow
- Last stage level
- Brine level in all stages (except last stage)
- Salinity of brine recirculating flow
- Blow-down flow
- Cooling water recirculation flow
- Antiscale dosing flow

### 3.2 Objective Functions

To deal with different optimization goals it is necessary to provide different objective functions, which are:

Maximization of the distillate flow
The maximization of the distillate flow is aimed at, when shortage of water forces the production of as much water as possible regardless of the product unit cost. In this case, cost will not be considered.

For normal plant operation the quantity for distillate flow depends on the amount of heating steam available. Therefore, under these circumstances the optimization module shall initiate actions to reduce the generation of the electrical power in favor of an increased distillate flow or to start the production of additional heating steam by possibly existing and available auxiliary boilers.

Maximization of the performance
The performance ratio shall be used as objective function for the following cases:

- Minimization of product unit energy cost for prefixed distillate product flow,
- Maximization of distillate flow for prefixed steam flow.

In the case of prefixed distillate product flow, the steam cost is normally aimed to be minimized. This case arises, when a certain distillate product flow is required due to limited water consumption and/or high level in the tank buffers.

In the case of prefixed steam flow, the maximization of distillate flow is aimed at.

Minimization of product costs
For the minimization of operation unit cost, two different cases are distinguished:

- Minimization of unit cost with prefixed distillate product flow,
- Minimization of unit cost with prefixed steam flow.

In both cases, the cost consists mainly of
- steam cost for brine heater
- cost of pumping
- cost of pretreatment of seawater (chemicals cost)
- capital cost
- labour cost
- maintenance cost

### 3.3 Optimization Algorithm

For a nonlinear constrained optimization problem, a powerful optimization method is necessary. That is specially important for on-line optimization to satisfy the real time condition. For the selection of the optimization method, two questions should be answered:

- Which optimization methods can be conveniently implemented?
- Which is the optimal method?

To answer the above questions, the mode of set-point optimization (on-line or off-line), the rigorousness of the model, and the number of independent variables and constraints must be considered.

The Successive Quadratic Programming (SQP), which belongs to the iterative quadratic programming methods, has been chosen as optimization algorithm. This method converges very fast [11]. The SQP method solves a sequence of problems with a quadratic objective function and linear constraints. It is suitable for systems with a small number of model equations. When this becomes large, the time taken to solve each quadratic objective function will be large, unless the sparsity of the system is taken into account [9], as it is the case with MSF plants. In the last years, it has often been used for setpoint optimization in the process industry (see e.g. [10]).

## 4 General Prerequisites for the On-Line Optimization of the MSF Plant

During on-line mode of the optimization, the conditions for the optimization are not ideal. Possible disturbances are: deteriorated measurements, changed plant behavior due to fouling or scaling, or transient operating conditions. Countermeasures have to be implemented resulting in a signal flow as shown in Fig. 4.

*Data Acquisition:* This is done in the Distributed Control System (DCS) which provides all necessary tools for data conditioning as are plausibility checks, filtering and monitoring of the transmitters.

*Checking the steady-state condition:* The below mentioned operations can only be performed, when the plant is in steady-state condition. Therefore, the steady-state condition is investigated by checking the changes of the main parameters within a given time range.

*Data reconciliation:* The measured data are investigated on its consistency with the data calculated with a simulation program. In the case of differences, the measured data will be corrected.

*Fouling factor calculation:* Considering that the fouling factor changes with time, it is determined periodically, e.g. once a day. Since it can not be measured directly, it has to be calculated using a model of heat transfer. Thereby, measurements of temperatures of flashing brine, vapour space and recirculating brine as well as the recirculating brine flow are used as input data for the model.

For the on-line optimization mode, this results in the following cycle of tasks:

- The system checks whether the plant is in steady-state condition before starting optimization.
- The already filtered input data are checked by data reconciliation. Incorrect data are either rejected, or adjusted.
- The fouling factors are calculated based on measured data of flows and temperatures.
- The current status of all control loops is detected, so that the degree of freedom available to the process can be determined (manually or automatically).
- The optimization is performed by using the before adjusted objective function and constraints. A new set of setpoints is calculated.
- The optimization solution is sent to the process supervision computer for review by the operator. The operator can interfere to change the targets

and recalculate the setpoints. The operator can also reject the setpoints and adjust them manually.

- Setpoints values accepted by the operator are used for the new operation point. A procedure for time dependent, stepwise changing of the setpoint values is then performed to assure a smooth operation of the plant.

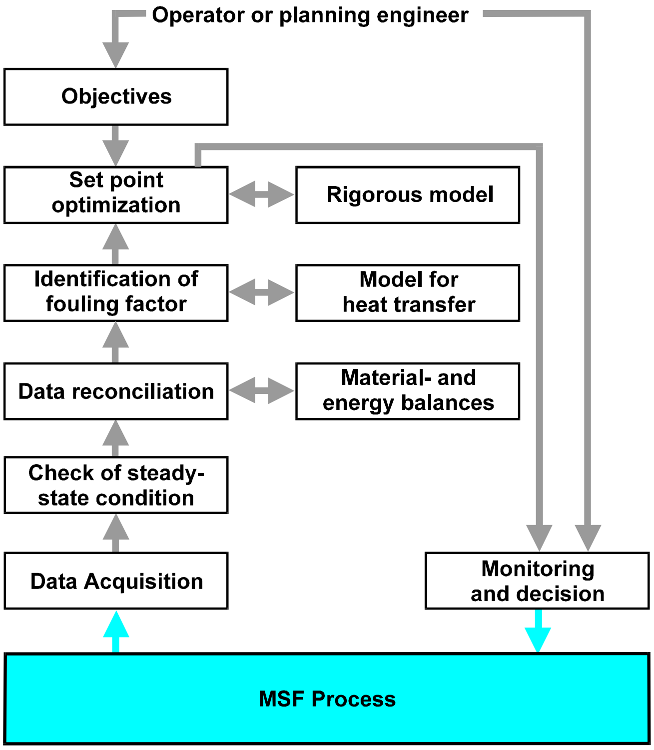


***Fig. 4** Signal flow of on-line optimization*

## 5 Integration of the Optimization Program in the Distributed Control System

The hierarchical structure of modern Distributed Control Systems (DCS) shall be described with the help of the so-called level model (see Fig. 5). While the control loops and standard setpoint guidance are situated in the process control level, other tasks like plant optimization, performance calculations and thermal balancing are situated in the plant management level, which represents the link between the operative tasks of the process control level and the economic tasks of the company management level [12,13].

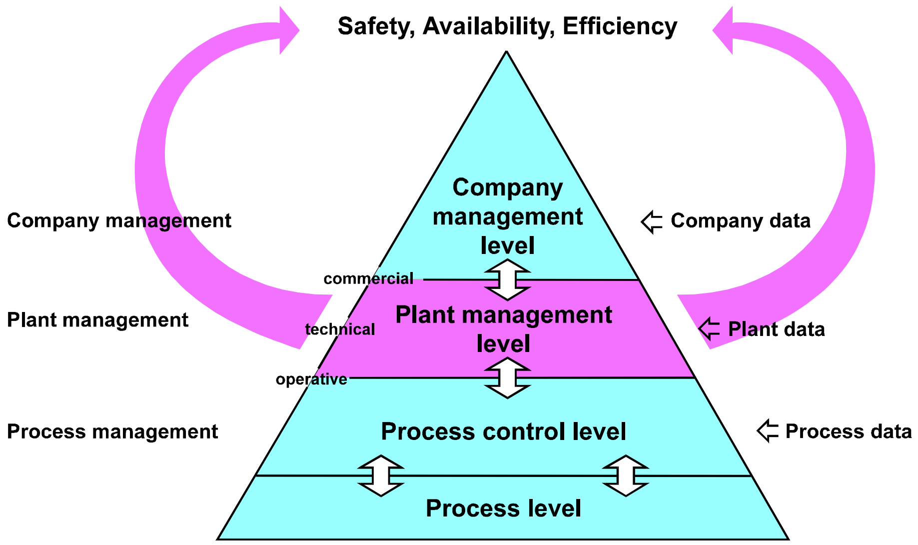


***Fig. 5*** *Level model*

Representative for the various programs for plant management available on the market, the *Performer Series*, the successor of the former *Contronic M* system, is briefly introduced [14]. *Performer* is a product of Hartmann & Braun, a unit of Elsag Bailey Process Automation. It consists of a modular hard- and software structure which allows to tailor solutions according to the current case of application (see Fig. 6).

The *Performer Product "ConDas"* deals with the basic tasks of process information management (like data acquisition, filtering, archiving, logging, etc.) and provides a powerful man machine interface (MMI). The common application programming interface (API) available allows to connect virtually any customer application to *Performer*. A series of available *Performer Solutions* provides additional capabilities like performance calculations, service life calculations, thermal balancing and logging, maintenance management, etc. *ConFlash* is included as a powerful tool to optimize MSF plants, which in itself is organized modularly according to

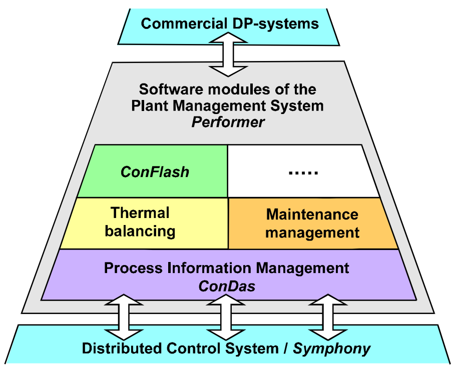


***Fig. 6*** *Modular structure of a plant management system*

the different tasks outlined in Chapt. 4 to allow easy upgrade to new developments.

As an example for the scalable hardware configuration, the Plant Management System (PMS) of the extensive Al Taweelah B plant is outlined in Fig. 7. The relevant data of all six units are collected and condensed in order to allow the plant supervisor - situated in the Central Control Room (CCR) - to monitor the plant status and behavior.

Via Wide Area Network (WAN) it is possible to communicate with the commercial data processing facilities or with a Load Dispatch Center (LDC) to have the production setpoints set centrally.

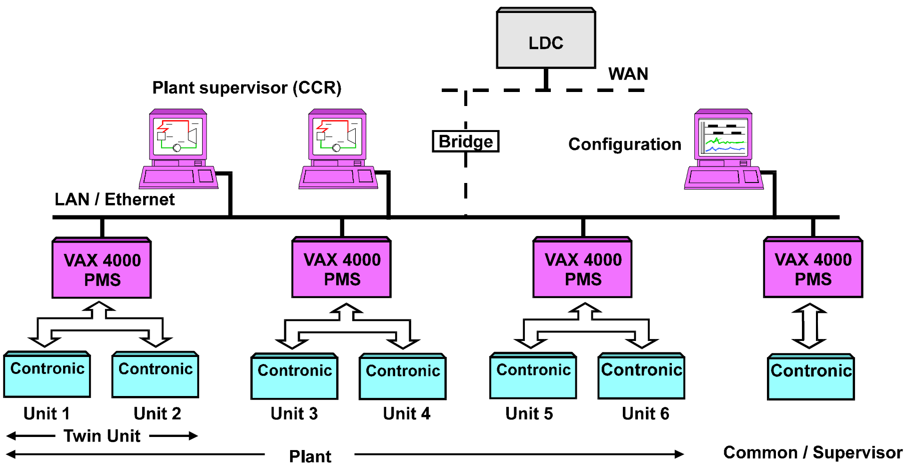


***Fig.** 7 Performer Network Configuration of the Al Taweelah B plant*

<u>ConFlash - The implementation of the optimization module</u>

The optimization objectives are selected via an appropriate faceplate on the operator console (see Fig. 8). The constraints are partially calculated in the background (as e.g. the available heating steam, depending on the necessary electricity generation) or entered manually (see Fig. 9). Data reconciliation is performed in the background and is only checked on request. The optimization is started either manually or cyclically.

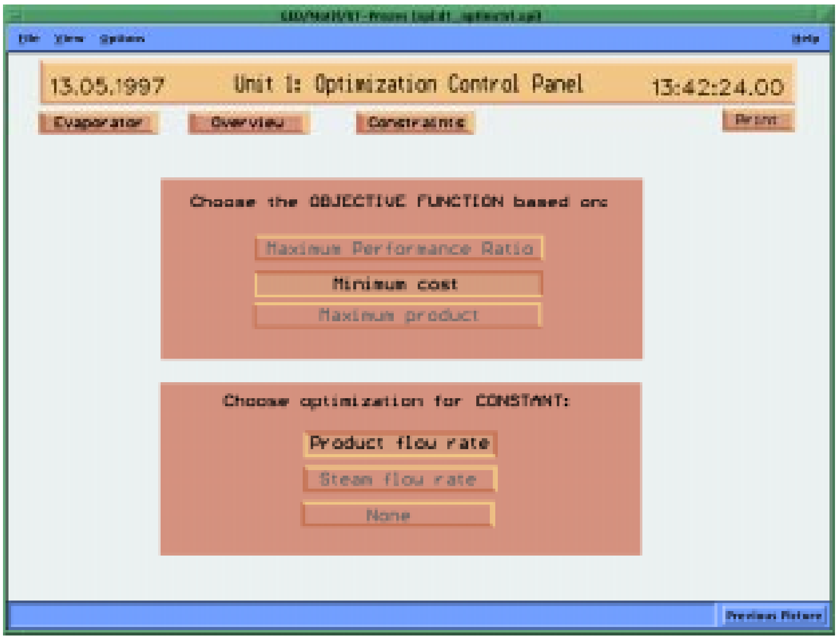


*Fig. 8 Faceplate for the selection of optimization objectives*

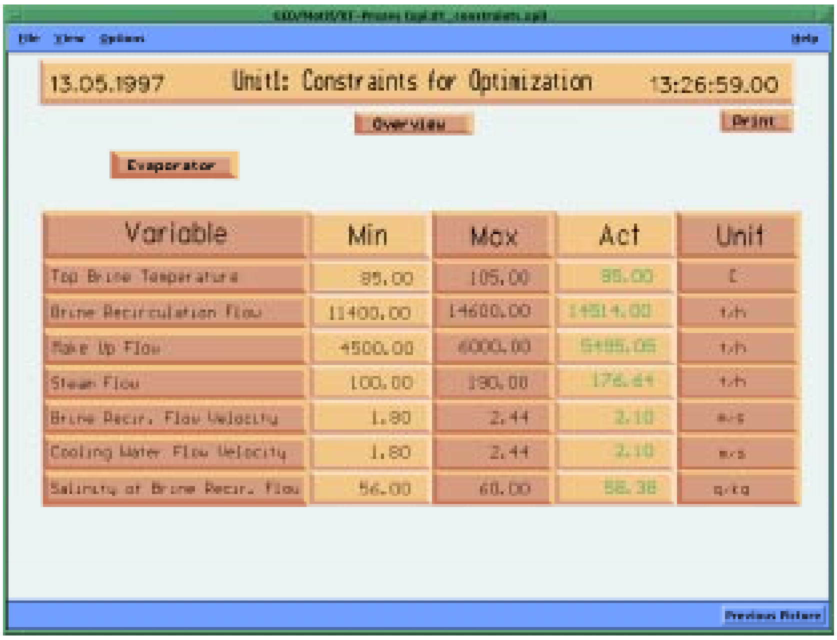


*Fig. 9 Faceplate for manually entered constraints*

The calculated setpoints are shown to the operator so that he can decide to sent them to the DCS or to recalculate them (see Fig. 10).
If the reliability of the optimization system has been approved, the setpoints

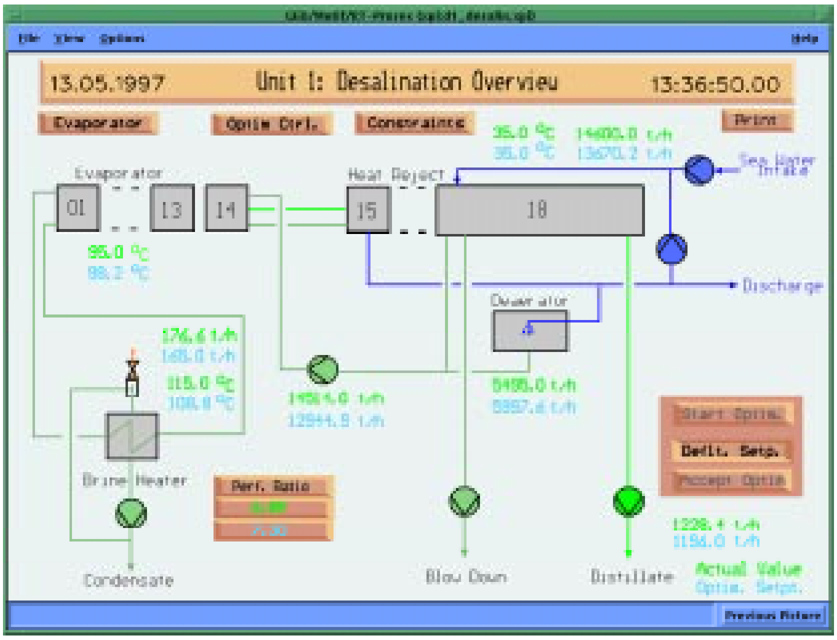


*Fig. 10 Display of calculated setpoints*

may be sent to the DCS fully automatically. However, sophisticated supervisory tasks are included, which will stop this automatic approach for safety reasons if, e.g. the data reconciliation module detects too large deviations of the measured values.

## 6 Off-line Version for Consultants and Manufacturers

The optimization program is also available as an off-line version based on PC. The modules necessary for the on-line optimization are not included. Instead, a sophisticated MMI for the configuration of the plant model is included together with enhanced facilities to visualize the simulation results. This allows consultants and manufacturers to simulate the behavior of plants to be constructed, or of modifications to be implemented in existing plants. Effects of the layout of the plant on the performance characteristic may be studied for all possible operating conditions.

Additionally, besides the comprehensively presented steady-state model, a dynamic model of the MSF plant is also available. This model uses nearly the same design data as the steady-state one and, therefore, allows to examine easily the behavior of the plant to be investigated under transient conditions. All control loops are included and may be configured or changed according to the needs of the plant. This is a great help for the design of a stable, safe and smooth operation of the plant even during load changes.

## 7 Conclusion

It has been shown how the steady-state simulation of a MSF plant is implemented and how the program may be incorporated in a Distributed Control System to perform on-line optimization. Other benefits in the area of plant design are:

- Simulation and evaluation of different design parameters for new plants during the design phase.
- Prediction of the performance of planned and existing plants under a wide range of possible conditions.
- Investigation of the operational stability e.g. due to blow-through or liquid pileup.

This demonstrates that the presented optimization program will be used with great benefits by consultants or manufacturers, and owners of MSF desalination plants.

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