# DESIGN AND OPTIMIZE A FLEXIBLE WATER TREATMENT NETWWORKS (CASE STUDY IN AN EGYPTIAN REFINERY)

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***Abstract:***

Sacristies in supply of freshwater, strict regulations on discharging wastewater and the support to encourage the sustainable development by water minimization techniques leads to raise the interest of water reusing, regeneration and recycling. Water is considered as a vital element in chemical industries. In this study, an optimization model will be developed to determine the optimal design of refinery's water network system via source interceptor sink that involves several network alternatives, and then a Mixed-Integer Non-Linear programming (MINLP) was used to obtain the optimal network superstructure based on flow rates, concentration of contaminants, etc. The main objective of the model is to reduce the fixed cost of piping installation interconnections, reducing the operating costs of all streams within the refiner's water networkand to minimize the concentration of pollutants to comply with the environmental regulations. A real case study for one of refineries was studied by GAMS /BARON global optimization platform and the water network had been retrofitted and optimized leading to saving around 195m³/hr. of freshwater with a total reduction reaches to 26 %.

***Keywords**:* Freshwater minimization; Modeling; GAMS; BARON; Water Network Design, wastewater reduction.

## I. INTRODUCTION

The challenges in sustainable progress lead to optimize and utilize water in the chemical processes. This work aims to study all possible retrofit methods for water network in an Egyptian refinery via water minimization strategies and approaches which mainly consists of water reuse, regeneration and recycle. GAMS software which is considered as a user-friendly computation engine had been used to generate the optimum solution. A graphically target approach was implemented firstly for all design alternatives then a mixed- integer nonlinear programming (MINLP) followed to solve the mathematical model using GAMS modeling software. assumptions had been considered during the model developed such as, isothermal operation, isobaric operation, the number of water sources, sinks, interceptors are fixed, the removal ratio for each treatment unit isn't function on the inlet concentration and finally, single contaminant, whichis oil and grease in water network. In this paper, a case study of an Egyptian refinery, is presentedfor minimization both of operating costs and capital costs for its water network by determining theoptimum water flow rate, concentration of pollutants for all possible alternatives, thus the problemcan be stated, a source of freshwater (source), water treatment units (interceptors), water using units (sinks), water supply streams and process unit's outlet.

## II. LITERATURE SURVEY

Freshwater has several uses in chemical industries such as, heat transfer media, cooling, solvents, etc. Traditionally the waste generated from these units was usually sent to a treatment plant for removal of contaminants to meet the wastewater disposal standards. If the amount of freshwater is reduced, the treatment costs will be reduced too. Thus, incentive work to reduce amount of freshwater and waste generated took place. (Smith, 2005). There are three techniques for water network optimization, which are as follows; reuse regeneration and recycling. It was proposed by Wang and Smith (1994a) that the three above aforementioned techniques are considered as an approach for minimizing fresh water. McLaughin& Groff (1992) proposed enhanced water network which is function on inlet water quality or the for the following process unit and contaminants quality in process unit's outlet. A brief description for water reuse, regeneration andrecycle will be discussed as per below.

1. **Water Reuse**: Water is fed to other process where the discharged water contaminant concentration is within the limits of the other unit. It helps in reducing the volume of freshwater and wastewater (Smith, 2005). Figure 1 presents water reuse in a simple network.

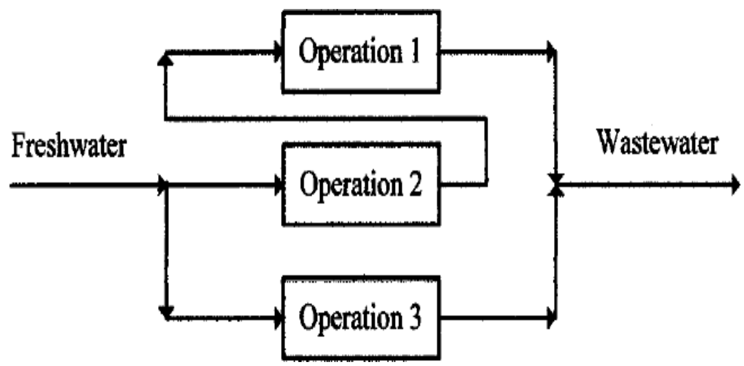


Figure 1: Water Reuse

2. **Water Regeneration:** Feeding used water to a treatment unit for water regeneration by a good quality to be used later on, not only regeneration reduced the volume of freshwater and wastewater. But also it prevents contaminant build up via removing part of effluent load. (Smith, 2005). Figure 2 shows regeneration technique.

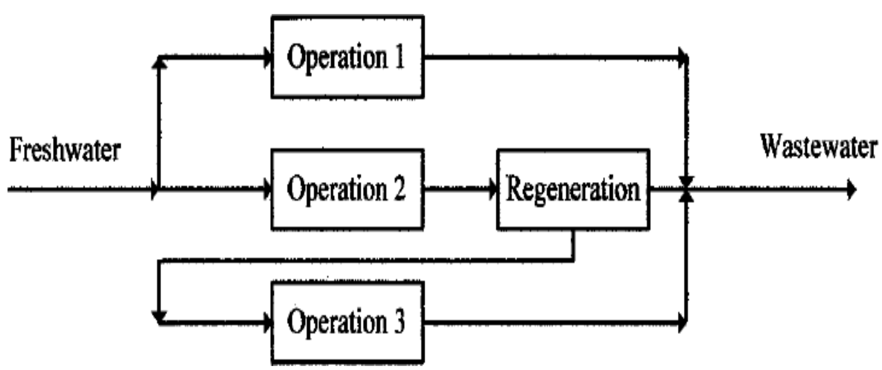


Figure 2: Water Regeneration

3. **Water Regeneration Recycle:** As a result of, high contaminant level, which is usually exceeds the allowable limits the used water is sent to a treatment unit prior recycling or reusing. Figure 3 shows regeneration and recycle scheme.

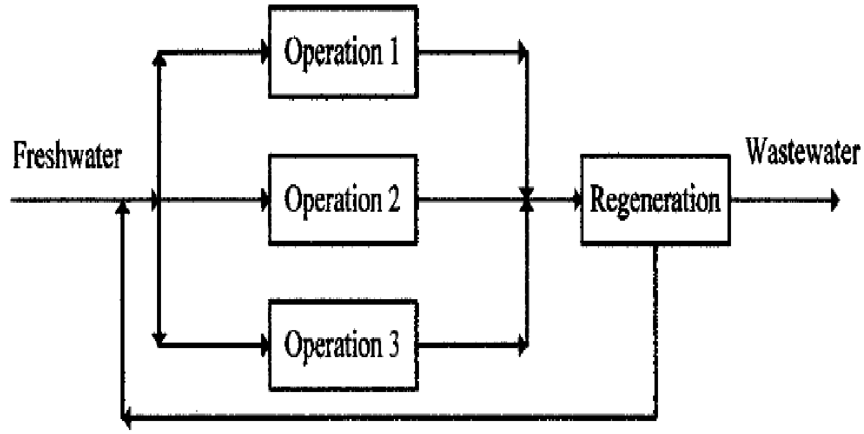


Figure 3: Water Regeneration Recycle

It's illustrated as listed below the literature survey on water network optimizing and retrofitting:

- Wang and Smith (1994): Found the minimum target water consumption by pinch point & limiting water profile, they worked on water networks including single and multiple contaminants. They applied water reuse, regeneration and recycle by a graphical method. The model used assumed a constant contaminant removal ratio (Bagajewicz, 2000).
- Frederico B. Gabriel and El-Halwagi (2005): A super structural representation to find an optimum network based on different alternatives for reusing, recycling using a source- sink-interceptor. After that, a mathematical representation for model development took place and several assumptions were made to linearize the problem.
- Clifford & Christodoulos, (2005): Reformulation- Linearization Technique (RLT) was used for algorithm proposal for finding a global solution; it was applied in pooling systems.
- K.aruppiah and Grossman (2006) : A combination for water using & water treatment unit was made for a superstructure proposal and formulated as NLP problem , but it failed since the produced models aren't convex because of bilinear ties presence , thus it's re-formulated as a MINLP problem.
- Raymond R. Tan, Denny K.S. Ng, Dominic C.Y. Foo and Kathleen (2009): A novel superstructure optimization model for a process with a single contaminant for industrial water networks with regeneration. The optimization model presented in this work is integrates a single, centralized partitioning regenerator with a source-sink superstructure under assumptionof fixed flow rate type processes are within the plant. The global optimal solutions can be found using commercial software.

## III. DESIGN AND RETROFIT PROCEDURES

For putting a retrofitting design strategy, such as in our study a refinery water network retrofitting data collection is considered to be an important step before optimization model construction for accurate results in GAMS and improving the feasibility of solution, it's listed below the main steps for optimal refinery network retrofits as follows;

- Data collection from the refinery (flow rate, concentration).
- Data Re-conciliation.
- All possible & feasible flow sheets alternatives include material streams and interconnections between process units to be shown in source – interceptor -sink superstructure model.
- Establish the objective function, material balance & constraints for MINLP optimization model.
- A solution strategy to find the optimal network by using GAMS modeling.
- Evaluation & Comparing with the current practices to check its feasibility.

- Frederico B. Gabriel and Mahmoud M. El-Halwagi, (2005) presented a simplified superstructurefor a refinery water network, which is illustrated in figure.4

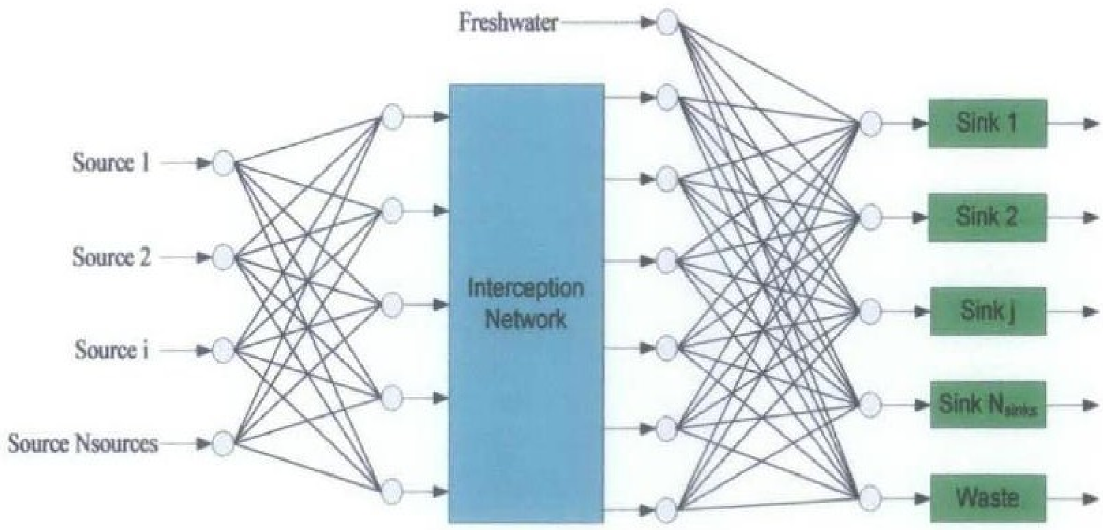


Figure.4. Superstructure Optimization for Water Network

The General Algebraic Modeling System (GAMS) is considered as a high- level modeling system for optimization, its user friendly and can adopt large and complex systems. It can used to solve linear, nonlinear, mixed integer linear, mixed integer nonlinear and complementarily optimization problems. GAMS 23.2.1 / BARON solver is used in the problem that will be listed later on. A superstructure representation is required for all possible configurations for refinery water network optimization. Generally, any refinery water network consists of process & treatment units. Usually, sources, treatment units & sinks are denoted as i, k& j respectively in mapping of superstructure of source –regenerator – sink. There are two common forms for regenerators, which are non- membrane based and membrane based, where in membrane based, the outlet is permeate and reject. The main purpose of the objective function is to minimize both of operating and fixed cost of water network, which can be made by minimizing all costs for operating streams & interconnections of installing pipes. Figure.5 shows a representation for water network in our case study.

## IV. SUPERSTRUCTURE REPRESENATATION AND OBJECTIVE FUNCTION

A superstructure representation is required for all possible configurations for refinery water network optimization. Generally, any refinery water network consists of process & treatment units. Usually, sources, treatment units & sinks are denoted as i, k& j respectively in mapping of superstructure of source –regenerator – sink. There are two common forms for regenerators, which are non-membrane based and membrane based, where in membrane based, the outlet is permeate and reject. The main purpose of the objective function is to minimize both of operating and fixed cost of water network, which can be made by minimizing all costs for operating streams & interconnections of installing pipes. Figure.5 shows a representation for water network in our case study.

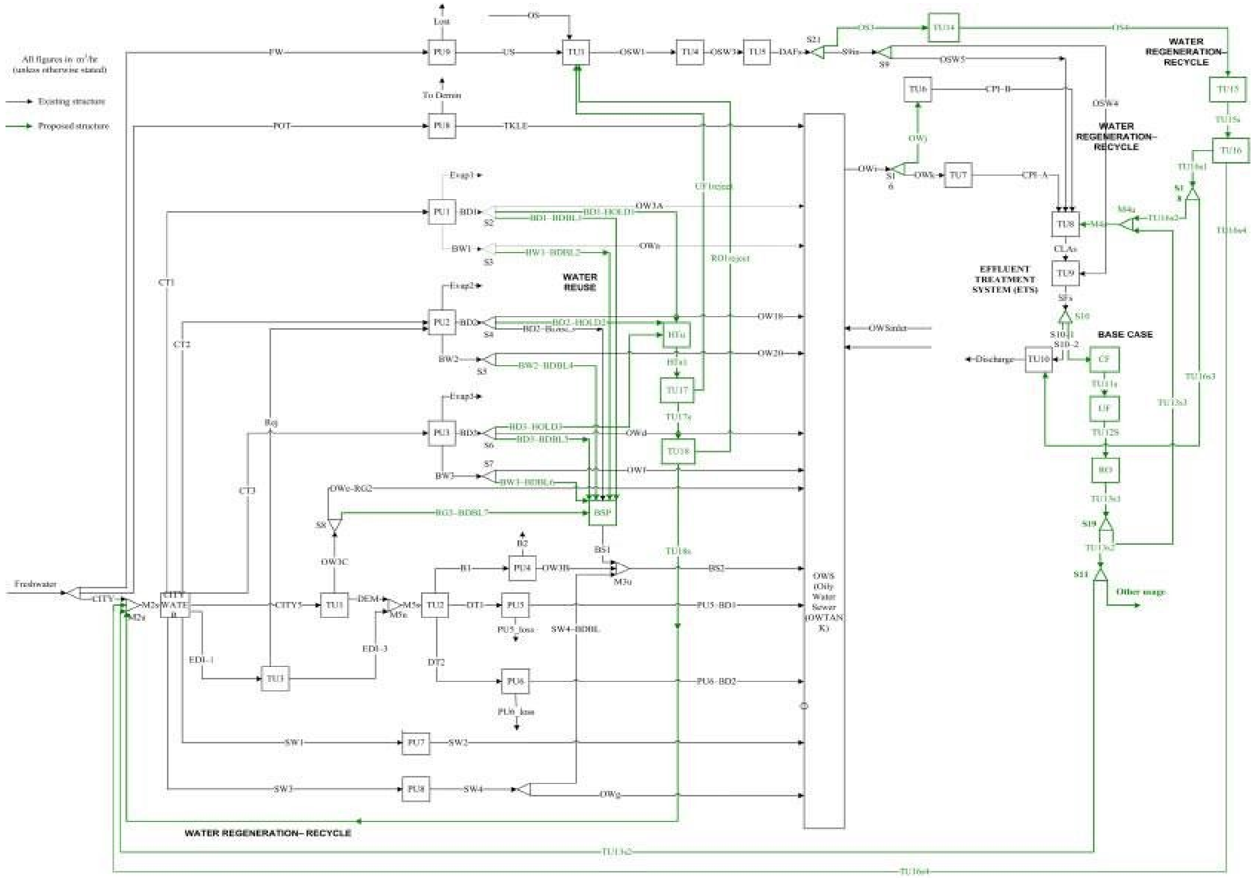


Figure.5: water network in our case study

## V. CASE STUDY

In order the proposed model a case study from an Egyptian refinery had been studies based on actual operating data. Refinery's water network consists of 24 sources, 13 interceptors and 11 sinks. Oil & grease is the contaminants studied in this paper. As per the refinery's operating data,the flow rate & concentration of contaminants for sources and sinks, etc. are listed as below tables.It's required to find the optimal refinery network based on reducing freshwater consumption. Table 1shows Source's flow rate and contaminant concentration and Table 2. shows the flow rate and concentration of contaminant.

Table.1. shows Source's flow rate and contaminant concentration

| # | SOURCE | FLOWRATE (M³/Hr.) | O& G (MG /L) |
|---|---|---|---|
| 1 | ROCESS UNIT 1 | 19 | 2.2 |
| 2 | ROCESS UNIT 2 | 21 | 2.2 |
| 3 | ROCESS UNIT 3 | 17 | 3 |
| 4 | ROCESS UNIT 4 | 10 | 1.5 |
| 5 | ROCESS UNIT 5 | 5 | 1.7 |
| 6 | FLARE KO DRUM | 19 | 0 |
| 7 | CONDENSATE TANK | 1.5 | 600000 |
| 8 | 1st CRUDE TANK DRUM | 1 | 4 |
| 9 | 2nd CRUDE TANK DRUM | 7 | 2 |

| | | | |
|---|---|---|---|
| 10 | 3rd CRUDE TANK DRUM | 3 | 300 |
| 11 | USERS | 29 | 0 |
| 12 | 1st DESALTER | 28 | 1200 |
| 13 | 2nd DESALTER | 27 | 1400 |
| 14 | COKE DRUM | 4 | 2 |
| 15 | SULPHUR RUNOFF | 18 | 0 |
| 16 | ADMINISTRATIVE USERS | 18 | 0 |
| 17 | COOLING WATER | 4 | 1 |
| 18 | COOLING WATER | 11 | 7 |
| 19 | BOILER BLOW DOWN | 55 | 35 |
| 20 | COOLING TOWER UNIT | 1.5 | 1 |
| 21 | COOLING TOWER UNIT | 2 | 2 |
| 22 | SERVICE WATER | 70 | 1 |
| 23 | OILY SURFACE WATER | 2.5 | 3.9 |
| 24 | FRESH WATER | DECISION VARIABLE | 0 |

Table .2. Flow rate and concentration of contaminant.

| # | SINK | FLOWRATE ($M^3$/Hr.) | O& G (MG /L) |
|---|---|---|---|
| 1 | FIRE WATER | 2.5 | 85 |
| 2 | COOLING TOWER1 | 23 | 46 |
| 3 | COOLING TOWER | 51 | 50 |
| 4 | BOILER | 179 | 10 |
| 5 | BOILER BLOWDOWN | 44 | 85 |
| 6 | POTABLE WATER | 18 | 65 |
| 7 | HEADER 1 | 3 | 69 |
| 8 | HEADER 2 | 33 | 69 |
| 9 | OILY WATER | 23 | 74 |
| 10 | BOILER BLOWDOWN | 50 | 80 |
| 11 | DISCHARGE | 375 | 10 |

## VI. RESULTS AND DISCUSSIONS

GAMS / BARON modeling platform was used to optimize the water network. Table.3. Shows model size and time taken in modeling.

| TYPE | MINLP |
|---|---|
| SOLVER | GAMS /BARON |
| CONTINOUS VARIABLE | 4,715 |
| DISCRETE VARIABLE | 2,136 |
| BILINEAR VARIABLE | 32,985 |
| CONSTRAINTS | 4,332 |
| ITERATIONS | 412 |
| TIME (SEC.) | 3,675 |

Based on refinery's data, the current freshwater consumption is 750 m³/ hr. A reduction of freshwater consumption around 26 % can be achieved by the new proposed water network after integrating the formulated model with source, sink and interceptor. Consequently, the optimized network doesn't require using some of treatment units, which will in turns will leads to reductionin fixed costs especially in any refiner's water network during the design phase.

## VII. CONCLUSION

The study concentrated on forming a mathematical model for a refinery water network, which consists of twenty-four sources, eleven sinks and thirteen interceptors and having a single contaminant, which is oil & grease. GAMS / BARON modeling platform was used for network optimization. Several feasible networks are configured by usingMINLP. The model can reduce 195 m³/ hr from freshwater consumption, which will decrease the operating cost, generated wastewater too within the environmental acceptable limits for contaminants discharging.

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