EXPANDED SUMED SYSTEM: A PIPELINE FOR THE FUTURE

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ABSTRACT
This paper describes the Design, Engineering, Planning and Implementation activities that led up to an advanced, state of the art, optimum and economical solution for expanding an existing system to handle an increase of crude oil throughput from 80 to 117 mta metric tons per year (2.53 Us to 3.71 Us).

The growing demand and reduced net imports of products will increase Western European crude oil requirements to 11 million b/d (barrel per day) equivalent to 20.24 m3/s by year 2000.

SUMED (gulf of Suez - Mediterranean) the Arab Petroleum Pipelines Company has historically secured about 40 % of the market for middle Eastern crude oil movements to Europe.

Given these market shares on incremental volume SUMED should achieve its maximum design throughput of 117 mta by year 2000.

The SUMED pipelines system which is owned and operated by an Arab company having EGYPT, SAUDI ARABIA, KUWAIT, EMIRATES AND QATAR as share holders has been in operation since 1977. An expansion project has started to increase the throughput capacity of the system from 80 to 117 mta. The project completion is expected by mid 1994 with a total expenditure of 120 million dollars.

This paper reviews the evaluation and selection of various electric motor and gas turbines for the main pumping station addition for this pipeline expansion.

I. INTRODUCTION
Traditionally, the Suez Canal provided the only alternative route for tankers transporting oil from the Arabian Gulf to Western Europe, instead of going around the cape.

Fifteen years ago this alternative has been enhanced by the establishment of the SUMED pipelines that goes from Ain Sukhna on the Red sea to Sidi Kerir on the Mediterranean, passing over Egyptian soil. This 320 km pipeline has a major advantage over the Suez Canal. Practically, there is no upper limit imposed on the draft of loaded tankers carrying oil from the Arabian gulf and using the line, as is the case with the Suez Canal. Tankers with dead weight of up to 500 000 tons can be used to transport! oil from the Arabian gulf to Ain Sukhna on the Red sea, 50 km south of Suez. This oil is, then pumped through the pipeline to be loaded, few days later, on smaller tankers waiting at Sidi Kerir on the Mediterranean sea. To get an idea about the savings which can be obtained transporting oil through the SUMED pipeline instead of going around the cape, let us consider Roterdam as a destination port. For this trip the use of the pipeline saves 13 days of the time of the trip.

The use of the line has gradually increased during the past 15 years. On average, 300 tankers discharge oil at Ain Sukhna each year, see Figure 2. These tankers transport about 40 percent of Europe's oil imports from the gulf passes through the line. By 1991, the pipeline was already working at a 104 percent of its capacity.

Engineering, political as well as economical factors had to be considered. The company controlling the pipeline had a fifteen years charter. With the charter up for renewal, it is more beneficial to consider the new expansion. The new expansion was discussed in great details among the share holders and with the Egyptian Government. An extensive study was prepared for that purpose. In the following I outline points of this study.
II ORIGINAL SYSTEM

I Configuration (Figure 3)

The SUMED pipeline system was implemented in 1974 to 1977 to allow the transportation of crude oil of different companies from the Suez gulf to the Mediterranean sea.

The system mainly consisted of:
- An offshore terminal at Ain Sukhna with two SPM (single point mooring) allowing the mooring of tankers with dead weight up to 250000 tons and one SPM with dead weight of 120000 tons mooring capacity. Each SPM is connected with the ON-SHORE terminal through a sealine 48" (1.219 m) diameter for larger buoys and 42" (1.0668 m) for the smaller one.
- An ON-SHORE terminal at Ain Sukhna including twelve double deck floating roof storage tanks of 103000 m³ capacity each.
- A booster pump station with six vertical centrifugal booster pumps having the dual purpose of:
  a. suction of the crude oil from the tanks to feed the main pumps.
  b. recirculation of the crudes among the different tanks.
- A main pumping station consisting of ten horizontal centrifugal pumps electric motor driven. Each group of five pumps consists of three fixed speed units plus two variable speed units with hydraulic coupling. These units are mainly devoted to one main pipeline with provision, for cross operation.
- An electrical sub-station at Ain Sukhna to power the electric motors and all the utilities with an installed rating of 120 MW.
- An overhead transmission line rated at 220 KV from Helwan to Ain Sukhna.
- Two main parallel pipelines 42" (1.0668 m) diameter connecting Ain Sukhna to Sidi Kerir covering a distance of 320 km each. Both pipelines are equipped with sectionalizing valves and they cross the NILE river, in proximity of Helwan, with two pipeline casings laid under the NILE river bed.
- A relief station with a storage tank and re-injection pumps are installed just upstream the NILE river crossing.
- A Sidi Kerir ON-SHORE terminal including twelve storage tanks of 103000 m³ capacity each.
- A crude oil loading system made of three pumping stations each consisting of three vertical centrifugal booster pumps plus three main horizontal centrifugal pumps. Each pump station is mainly devoted to a group of four storage tanks.
- A turbine metering system downstream of the pumping station for the measurement of the volume of crude delivered to tankers.
- An OFF-SHORE terminal at Sidi Kerir with two SPM with dead weight of 240000 tons mooring capacity and three with dead weight of 120000 tons mooring capacity. Each SPM is connected to the ON-SHORE terminal through sealines 48" (1.219 m) diameter for large buoys and 42" (1.0668 m) diameter for small ones.
- A supervisory control system with the dispatching center located at Ain Sukhna and connected via a microwave telecommunication link.
- A deballast plant at Sidi Kerir terminal consisting of four 30000 m³ cone roof tanks and ten dual tilted plate interceptors leading to a holding basin then to an outfall canal which discharges cleaned water of ten ppm maximum into the Mediterranean.

II Design Conditions

The SUMED pipeline system was originally designed and sized to transport 80 mta of Kuwait crude oil from Suez gulf to the Mediterranean sea.

The Kuwait crude oil was taken as the base for all hydraulic calculations and checks.

The total capacity of 80 mta, corresponding to 93 million meter cube per year was subdivided between the two main pipelines, each one served by a main pump station at Ain Sukhna terminal.

Each pipeline was foreseen to transfer crude oil at a flow rate of 1.619 m³/sec. Even during the first phase of implementation of the system, provisions were made for its future expansion to transfer 117 mta of Kuwait crude.

For this purpose, the preliminary hydraulic calculations were done. The location of the required additional intermediate pump station was identified and two main pipelines were already provided with the necessary mechanical connections.

III NEW EXPANSION

I Configuration (Figure 4)

Based on the results of the studies, the new configuration of the pipeline system for its full design capacity will be similar to the previous one but with the implementation of the new intermediate boosting pump station located at Dahshour west of Cairo.

The station, whose purpose is to boost the flow of crude oil pumped from Ain Sukhna to Sidi Kerir will include two pumping trains each one consisting of three centrifugal horizontal pumps driven by heavy duty gas turbines mainly devoted to one main pipeline but with the possibility to be switched over to the other one. Figure 7 shows the station configuration.

The station shall be complete with all the auxiliary services, buildings, etc. And will be connected, via telecommunication system to both Ain Sukhna and Sidi Kerir terminals.

The new configuration of the Ain Sukhna and Sidi Kerir terminals has been defined as follows:
- Addition of two booster pumps at Ain Sukhna, having the same characteristics as the existing ones.
- Replacement of six impellers of main pumps at Ain Sukhna with high flow ones.
- Provision of a new oil water separator at Ain Sukhna suitable for the new capacity and new environmental restrictions.
- Addition of a new loading pumping station at Sidi Kerir to serve the newly added storage tanks.
- Addition of sealine 52" (1.32 m) diameter and SPM with dead weight of 500000 tons at Ain Sukhna.
- Addition of sealine 48" (1.219 m) diameter and SPM with dead weight of 385000 tons at Sidi Kerir.
- Addition of three storage tanks each of 103000 m³ capacity at each terminal.
- Upgrading of SCADA, metering, automatic sampling and telecommunication systems.
Optimization For Booster Pumping Station

In order to make sure that the latest technological advancements are considered in the study, our relevant experience together with knowledge of the state of the art pipeline technology, equipment, analytical methodologies and computer resources, were put in action.

The following are key areas for assessment:
- Transient surge analysis and surge protection facilities.
- The most efficient type of pumping unit and prime mover for this application considering the use of variable speed drivers with electronic frequency control as well as the latest gas turbine technology (jet versus heavy duty).
- Design improvements in SPM and both adequacy in light of increased berth occupancy and loading / unloading flow rates as well as tankage constraints and down time.

Consistent with the above, the following studies have been carried out:
- Marine traffic study with computer simulation to define the number of berths and storage facilities.
- Pipeline facilities.
- Dahshour booster pump station.
- Process scheme.
- Cathodic protection schemes.
- SCADA and telecommunications improvements.
- Project implementation.
- Operation philosophy.

According to the scope of the study, an optimization has been carried out to investigate station and pump unit alternatives, and to select the most efficient type of pumping units and prime movers for system operation.

The selection process included an energy study among alternatives of variable speed electric driven horizontal centrifugal pumps with electronic frequency control as well as the latest gas turbine technology (jet versus heavy duty).

The existing pumping station psl configuration consists of two trains each having five pumps operating in series three of which are fixed speed electric driven horizontal centrifugal pumps single stage double suction and two variable speed pumps. each pump has the following characteristics:

<table>
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<tr>
<th>Capacity</th>
<th>KW</th>
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<tr>
<td>First phase</td>
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<td>Second phase</td>
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<tr>
<td>Differential head</td>
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</table>

Figure 8 shows the hydraulic gradient of the pipeline with Arabian-Heavy crude oil for phase one which is already operating at 80 mta and the future phase two of 117 mta.

Figure 5 shows the line characteristic curves for psl-ps2 section (ps2 is the boosting station under consideration ) for each crude oil in summer and winter operating conditions. Also the pump characteristic curves, the achievable flow rate and relevant main pumps differential head for each crude.

Figure 6 shows the line characteristic curves and the required ps-2 main pumps differential head for the the ps2- Sidi Kerir pipeline section. This is only plotted for significant crudes both in winter and summer operating conditions.

Figure 9 shows the differential pressure required at Dahshour pump station during batching operation of the pipeline with Qatar and Arabian-heavy crudes.

As shown on the above figures achievable flow rates are limited by either the maximum allowable discharge pressure (9 MPa) or by maximum absorbed power at Ps-1.

Due to the fact that SUMED pipeline transport by batching operation several different types of crudes, the achievable pipeline flow rate varies continuously both in accordance with the crude characteristics and the volume of the batches.

During the batching operation the differential head varies as follows:

<table>
<thead>
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<th>Max. Differential</th>
<th>Min. Differential</th>
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</thead>
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<tr>
<td>Head in meter</td>
<td>Head in meter</td>
</tr>
<tr>
<td>Ps1 at Ain Sukhna</td>
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</tr>
<tr>
<td>Ps2 at Dahshour</td>
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</table>

The solutions providing both variable speed and fixed speed pumps are not recommended from operability point of view.

In fact these solutions provide control valve on pump station discharge for batching operation. It is to be noted that three or more crudes will be simultaneously present along the pipelines.

On the basis of the above it is to be concluded that Ps2 requires the installation of pumping system having high flexibility.

1. Hydraulic calculations. Hydraulic calculations have been performed taking into consideration the forecasted crude oil distribution (more than 30 types of crudes are handled by the system).

Since pipeline throughput is determined by existing pumping station number one (ps1) having a maximum allowable discharge pressure of 9 Mpa (90 bar). The hydraulic calculations results are presented in Figures 5,6,8 and 9.

2. Annual Throughput Calculations. The calculations are based on the following basic assumptions:

1. Crude oil grades and their forecasted annual distribution based on market forecast.
2. Pipeline utilization factor: 91% i.e. 7972 hours/year.
3. Number of pipelines: two.
4. Hourly flow rates derived from hydraulic study of each crude.
Annual throughput equals to:
Crude percentage X (crude flow rate ton/s summer* 3986 HRS* 3600) + (crude flow rate ton/s winter* 3986 HRS* 3600)*2 pipelines.
Resulting total annual throughput = 119.9 mta based on forecasted crude distribution instead of 117 mta based on design crude.

3. Alternatives Considered. The new boosting station was analysed and different solutions were compared from the technical and economical points of view see (Table 1). A total of 15 different configurations were considered and thoroughly studied by varying the number of units, their configuration as well as the prime movers (electric motors and gas turbines).

As far as the electric motor alternatives are concerned, the different configurations are related to the number of units per pumping station (five or four) in addition to either using fixed speed motors with hydraulic variator or variable speed motors.

As far as the gas turbines alternatives are concerned, the different configurations are related to the number of units per pumping station based on the available gas turbines on the market, hence for different configurations. The gas turbines types as shown in Table 1 can be classified into three categories:
- A- Heavy duty with ISO powers 10900 and 26120 KW
- B- Jet Derivative with ISO powers 14000, 15690 and 22000 KW
- C- Industrial with ISO powers 10500 and 17330 KW

The heavy duty gas turbines are characterized by a low pressure ratio, low efficiency, easy accessibility for maintenance on sites, high reliability and strong design.

The jet derivative are an industrial application of the aircraft with high efficiency light weight and overhaul maintenance must be done at manufacture shop.

The industrial gas turbines have been designed to combine the high efficiency of the jet derivative with a mechanical design close to the heavy duty

4. Economical Study. The economical comparison among the different solutions were carried out considering the investment costs, operating costs and down time impact according to the following main topics:
- a. Basis of Evaluation
  - Initial investment cost
  - Maintenance cost including spare gas generators
  - Operating cost for certain consideration (fuel gas/electric)
  - Gas/Diesel generators for electrical power generation for the plant since some heavy duty gas turbines have on-board generator.
  - Loss of production cost
  - Reliability = (8760-forced outage power)/8760
  - Availability = yearly operating Hours/8760
  - One spare unit to be considered per pumping station
- b. Investment costs include:
  - Machinery and other equipment
  - Fuel and starting gas system
  - Electric power feeding
- c. Operating costs
  - c.1 Maintenance costs as an annual percentage of investment cost derived by:
    * time between overhauls as suggested by manufacturers and users.
    * firing hour maintenance costs from same sources
  - Annual percentage of investment costs
    Electric motor driven units 1%
    Heavy duty gas turbines 3%
    Industrial gas turbines 3.5%
    Jet derivative gas turbines 5%
  - * Lubricant oil cost
  - * Area cost impact from our experience in operation, maintenance and spare parts policies
- c.2 Energy costs for fuel and electric power
- c.3 Down-time parameter due to overhaul maintenance and scheduled inspection (loss of production).
- d. Net present value:
  - Optimization has been made on net present value basis, with different sensitivities by taking into consideration the sum of all outflows mainly (1) the amount of investment depreciation cost and (2) the amount of operating costs to be born during the system working life (assumed to be 15 years). Discounting on a fixed rate of 10% which is the minimum acceptable rate of return.
  - Examples of different considered sensitivities are:
    Life time, fuel gas, electric power prices and different forecasts, local and international different escalation rates.

5. Results. The results of economical calculations relevant to all examined solutions for the base case are shown in Table 1 as investment cost and net present value indexes.

On the basis of economical calculation results and keeping into account the technical aspects of the different examined solutions it results that the recommended arrangement for Dahshour pump stations is solution 13 which provides the installation of three main pumps driven by heavy duty gas turbines for each station.

In fact by summarizing, this solution has the main following advantages:
- Lowest net present value
- Good operability (all pumps are variable speed)
- High reliability (heavy duty gas turbines type are world wide used)
- Lowest number of operating units (two) and one unit stand by for each station.

IV. IMPLEMENTATION PLAN (Figure 10)
SUMED has provided planning, economic market-study, operation, engineering, maintenance and project management activities for pipeline business for a long time. The experience gained on these diversified activities, has developed not only efficient project implementation methods but also a cadre of effective project managers and engineers within SUMED.
Since the application of the latest technology to the pipeline industry is our goal, SUMED has developed the latest state of the art technologies and computer programmes as well as latest technologies in materials and equipment. For examples:

- SCADA system for pipeline operation
- CADD INTERGRAPH workstation system (microstation 4.0)
- IBM mainframe and PCs for running the following: Feasibility studies, Project management V.M. application system, Pipeline simulation system, Cathodic Protection
- Computerised maintenance assurance program
- COMPASS software for linking maintenance with purchase inventory control and financial packages
- Millennium latest financial package

In addition to all the above SUMED has a pioneering experience in the following aspects:

- Offshore single point mooring systems regarding large diameter marine hoses 0.6m diameter x 13.7m long (24' x 45ft long), mooring hoses for tankers with dead weight of up to 500,000 tons tankers.
- Computerised turbine flow meters
- Tankage
- Automatic samplers
- CUSTODY transfer operations between two offshore terminals
- Personnel training and development

V. CONTRACTING STRATEGY

The usual practice for SUMED in carrying out similar projects is based on lump sum turn-key contracts in which the contractor is given well defined starting and finishing points and undertakes responsibility to perform the whole work at a fixed cost. This strategy was not possible in the present case, simply because a parliment act is required to initiate the whole process. To gain time, the company started to work on the detailed engineering work and to prepare for bid invitation for the procurement of the main turbo units while the act was in the works. The lead time required for the procurement of the main turbo pumping units put this activity onto the critical path. By the time the act was ratified, contracts for the procurement of the gas turbine pumping units were awarded. This saved more than six months and was possible only through the initiative taken by the company to form a multidisciplinary team to prepare a detailed engineering study for the project while the act was being discussed in the parliment. It has been estimated that a turn-key approach would have resulted in about 15% reduction in the cost of this project. Procurement phase started after the contract has been signed and a construction bid package is being prepared. Periodic meetings are being held to assure total quality for the project.

Remaining activities for project completion are:
- Completion of remaining procurement activities.
- Construction activities.
- Commissioning startup and guarantee tests.
- Personnel recruiting and training in operation and maintenance of equipments.
- Coordination with all other activities relating to the housing, power, water supply, sewage, communications, roads and all other activities for the new boosting stations.
- Integration with company 5 years plan projects.
- Marketing for the throughput increase with company's users.

VI. CONCLUSIONS

The following generic conclusions are made, and can be applied for similar future projects:

1. Selected solution of using three pumping units driven by heavy duty frame 5 gas turbines is preferable, both economically and technically. This selection was based on the particular considerations discussed above. The study shows that:
   - The solutions based on pumps driven by electric motors are generally more expensive than those based on pumps driven by gas turbines.
   - Fewer number of pumping units are more economical and give higher operational simplicity.
   - Heavy duty gas turbine driven pumps are more economical than jet type.
   - Flat rating is not technically accepted.
   - From operability point of view all pumps should be variable speed.

2. The decision taken by company management to form a multidisciplinary team for the preparation of the required studies, rather than go for the traditional turn-key contracting approach, proved to be wise. Not only a top quality piece of work has been accomplished but greater savings were achieved as well. Replacing an Inspect-in quality program by Design-in, Build-in quality programs reduced implementation errors as well as inspection time. Moreover, it improved the cross functional communications between different departements represented in the multidisciplinary team. Delegating responsibility and authority to the level that could best realize innovative and cost reducing solutions proved to be a useful strategy.

VII. REFERENCES

SUMED internal studies.
LOYDS information centers.
OECD quarterly oil statistics.
WESTINGHOUSE CANADA report.
### TABLE 1

#### ELECTRIC DRIVEN PUMPS

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#### GAS TURBINE DRIVEN PUMPS

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**LEGEND:** F = fixed speed, V = variable speed, S = stand by, H.C. = hydraulic coupling, V.S.M. = variable speed motor, H.D. = heavy duty, IND. = industrial, ABS. = absorbed, CONS. = consumption, RPM = revolutions per minute, ALT. = alternative

### ALTERNATIVE NUMBER

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