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Innovations and Technological Developments in Long Distance Water Transmission Systems

Case Study of Riyadh, Saudi Arabia

By Bernhard Lässer and Alexander Heinz

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SUMMARY: Cities in arid and semi-arid climatic conditions very often depend on reliable and economic water transmission schemes to import water from distant places. With the first Riyadh Water Transmission System, ILF Consulting Engineers had adopted an innovative design approach by applying a closed hydraulic, high pressure system. This design approach was then further developed taking also advantage of the more recent developments in pipe material and equipment design. In order to reduce the investment and operation costs of water pipeline systems, without compromising safety and ease of operation, the design philosophy has been adopted by ILF to numerous water pipeline systems worldwide, providing the optimised solution for each project.

INTRODUCTION

The development of cities in arid and semi-arid climatic conditions with increasing population and industrial activity depend on a reliable and economic potable water supply. Very often the water has to be transported to the consumers from distant locations through water transmission pipeline systems.

Riyadh, the capital of the Kingdom of Saudi Arabia, is characterized by its arid climate location with very low rainfall of only 116 mm average per annum. Due to the energy richness of the country and the associated rise in living standards, the continuous population growth and a rapidly growing industry, the demand for drinking water has steadily increased. In the late 1970s the demand could no longer be covered with supply from ground wells in the wider area of Riyadh. Hence other supply options for the city located at 613 m above sea level and about 400 km from the coast had to be considered. As a result, the construction of a seawater desalination plant at Al-Jubail on the Gulf Coast and the largest long-distance water transport system, the 'Riyadh Water Transmission System' (RWTS) was then completed. This major project was at that time designed and implemented with very innovative approaches. Since its completion in 1983 the system has been expanded and further technical advancements have been applied. ILF Consulting Engineers have been significantly involved as Owner's Engineer for the customer, Saline Water Conversion Corporation (SWCC) in all phases of the projects.

This article provides an outline about the innovations applied for the first project and the further developments implemented in the extension phases.

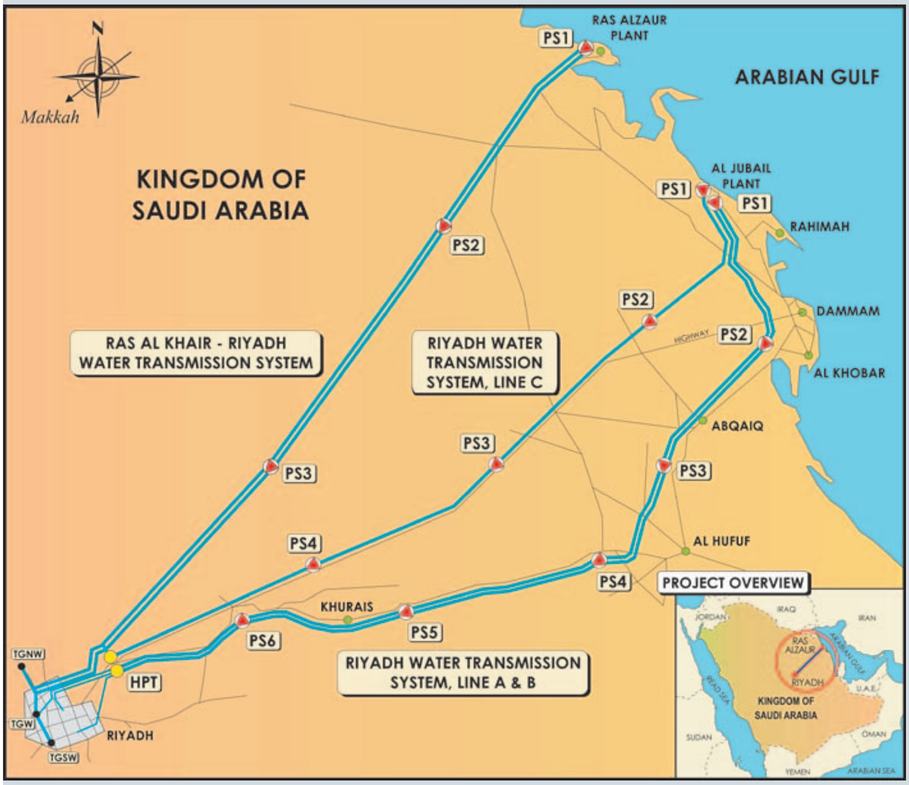

FIGURE 1: **Pipeline routes**

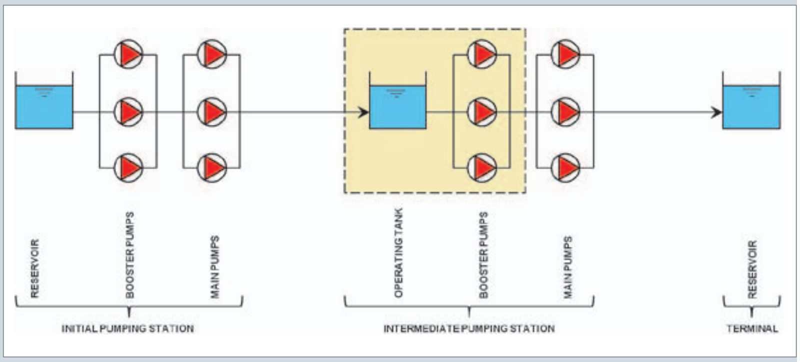

FIGURE 2: **Open pipeline system**

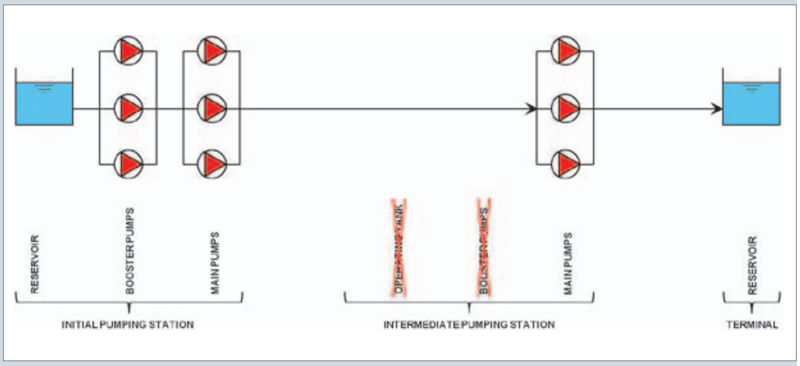

FIGURE 3: **Closed pipeline system**

TECHNICAL INNOVATION

RWTS Line A + B

The first pipeline system to deliver desalinated water from the Arabian Gulf to Riyadh was ‚Line A + B' with 466 km length running from Jubail to Riyadh (see **Figure 1**). The system was designed as a hydraulically closed high pressure system. At this time such an approach was not common since traditionally water pipeline systems had been designed as open systems (for comparison see **Figures 2 and 3**). The closed system design required to develop special hydraulic software tools to study the system behaviour under all normal (steady state) and abnormal (transient) operation conditions as well as the installation of surge protection equipment. At that time recognised university professors predicted that the design will fail.

This innovative and optimised design approach enabled to lower the investment costs as well as specific transportation costs and higher reliability could be achieved compared to conventional systems. By adaption of the closed system approach the number of pumping equipment could be considerably reduced since no intermediate tank capacity and booster pumps are required at the five intermediate pumping stations. In addition the related piping and electro-mechanical equipment associated with these tanks and booster pumps could be eliminated, leading to a more efficient mode of operation and lower energy consumption as well as lower maintenance cost. The system was designed as a 60" twin carbon steel pipeline with cement mortar lining and six pumping stations with a total installed power of 430 MW. Different pipe steel grades along the line, well distributed according the calculated pressure requirements, reaching up to X60 with a minimum pipe wall thickness and a wall thickness / diameter ratio of 1% were selected to mini-

FIGURE 4: **Construction works of RWTS Line A + B**

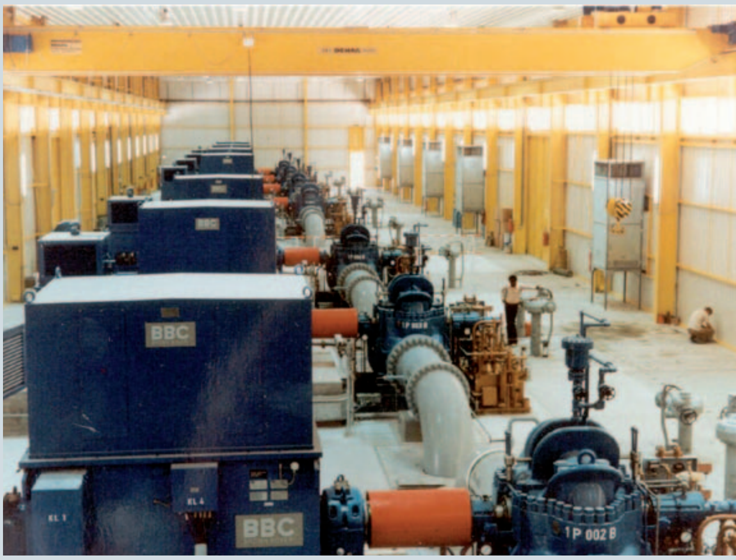

FIGURE 5: **Pumping Station of RWTS Line A + B**

mise the investment. The system was designed for a maximum throughput of 830,000 m³ / day. RWTS Line A + B has been in operation with full capacity since its completion in 1983 without any major shut down. The investment cost was about 1.6 billion US$.

For a tabulation of the technical data see **Table 1** and for pictures see **Figures 4 and 5**.

Summarising the following innovations had been implemented in RWTS Line A + B:

- Closed hydraulic system
- High pressure system with operating pressure up to 52 bar
- Wall thickness / diameter ratio of 1 %
- Line pipe diameter 60" spiral welded
- Material grade well distributed

DEVELOPMENTS

RWTS Line C

To expand the capacity of RWTS Line A + B a new system had been implemented, called ‚Line C', which is an independent system. A more direct route of 375 km along the new Dammam - Riyadh highway could be chosen (see Figure 2). The system was implemented as a 60" steel pipeline with cement mortar lining and four pumping stations with total installed power of 150 MW. The maximum throughput is 380,000 m³ / day. Line C was commissioned in 1995 and is in operation to this day. The investment cost was 400 million US$.

Ras Al Khair-Riyadh (Line D + E)

Currently there is a further system Ras Al Khair-Riyadh (Line D + E) under execution, linking the new desalination plant at Ras Al Khair approximately 100 km north of Jubail with a direct route through the desert to Riyadh (see Figure 2). The optimised system configuration chosen consists of a double carbon steel line with 72" diameter and steel grades up to X65 with three pumping stations with a total installed power of 271 MW. A simplified hydraulic profile is displayed as **Figure 6**. The maximum throughput is 947,000 m³ / day. The system shall be put in op-

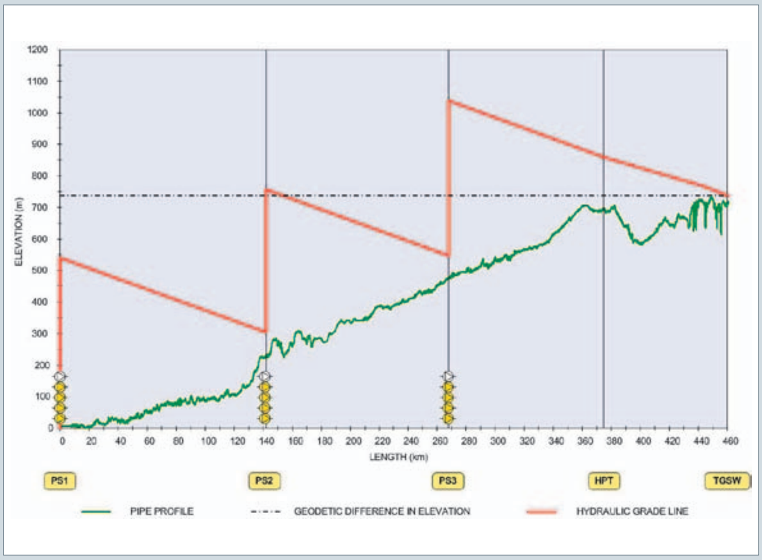

FIGURE 6: **Simplified hydraulic profile of Ras Al Khair - Riyadh**

FIGURE 7: **Pipeline installation works of Ras Al Khair – Riyadh**

eration in 2013 and the investment will be around 2.5 billion US$.

For a tabulation of the technical data see Table 1 and for pictures see **Figure 7**.

Whilst the design of Line A + B can be considered as a real innovation in water pipelines at that time in terms of efficiency and operational security, for the following projects the system layout was further enhanced taking advantage of the more recent development in pipe production and welding technology as well as availability of enhanced mechanical equipment. The following developments were included in the later projects:

- Increase in design pressure for mechanical equipment and pipes
- Wall thickness / diameter ratio of 0.77 %
- Steel grades up to X65 (limited as per availability in KSA)
- Pipe diameter up to 72"
- Reduced number of pumping stations

OPTIMISATION OF WATER PIPELINES

The aim of the optimisation during the design stage of a water pipeline project is to minimize the investment and operating costs for a given operating period of the system while not compromising on safety, reliability and ease of operation of the system. All such requirements are to be considered adequately with the aim to achieve the lowest possible specific transportation costs under the given boundary conditions. The lowest specific transportation costs are a result of the best balance of low investment for material and construction, low energy consumption, low operation and maintenance cost and high availability of the system. It is for this reason that the designer of a water transmission system must be aware of the fact that appropriate decisions can only be taken after thorough financial analysis.

In general, the following criteria provide the basis for a comparison on pipeline system alternatives from the economic point of view:

- Minimum cost for construction and operation
- Minimum energy consumption
- Minimum unit cost per cubic meter of liquid transported
- Maximum reliability of the pipeline system

In addition it has to be emphasised that in practice the time value of money with a view to interest paid for the use of money is a factor which has a great impact on the total cost of a project. The interest rate quite frequently proves to be the predominant factor, especially in projects with low operating costs but high capital requirements.

The comparison of costs is based on the "Net Present Value Method or Discount Method" which is used to obtain comparative costs. The present value of all expenditures in the past and in the future will be determined for one definite point in time (see **Figure 8**).

The objective of a pipeline optimization is to develop the best system (number and sizing of required pumping stations, single or twin pipeline system) and the optimum pipe diameter at which the material and construction cost of the system added to the operating cost (power consumption, maintenance, etc.) will be at a minimum for a definite period of time and throughput scenario (see **Figure 9**).

The following items are used as variables within the possible technical limits and the specific transportation costs are compared for all options:

TAB. 1: **Comparison of technical data**

System	length km	throughput m^3/d	dia. main line	pump stations/ installed power	line pipe material	year of completion	invest in mil. US$
RWTS Line A + B	466	830,000	2 x 60"	6 nos. 430 MW	Grade B to X60	1983	1,600
RWTS Line C	375	380,000	60"	4 nos. 150 MW	Grade B to X60	1995	400
Ras Al Khair-Riyadh (Line D + E)	374 + 92	947,000	2 x 72"	3 nos. 271 MW	Grade B to X65	2013 plan.	2,500

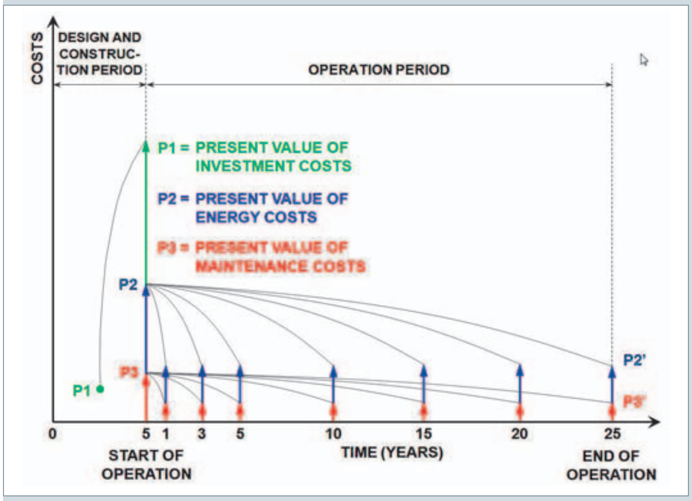

FIGURE 8: **Net present value method**

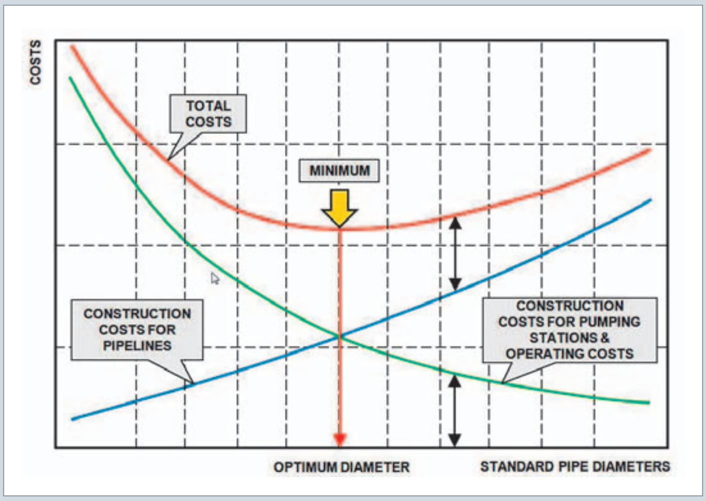

FIGURE 9: **Pipeline diameter optimisation**

- Longitudinal profile of the pipeline (elevation profile, pipeline routes, etc.)
- Pipes (available diameter, wall thickness, steel grades, number of lines, pipe roughness, etc.)
- Throughput rates
- Discount method (time points for investments, optimization period, interest rates, etc.)
- Energy costs
- Maintenance costs
- Other design parameters (safety factors, special design boundaries like fixed locations, etc.)

The results for system configurations with different pipe diameters may be indicated graphically by two curves (CAPEX & OPEX) with varying gradients. The sum of those two curves finally represents the most economic diameter for the pipeline system for the considered time period (see Figure 9).

CONCLUSION

The innovative design approach chosen by ILF Consulting Engineers has proven to be successful and has then been further enhanced over the last thirty years on various projects worldwide. Now with the long term operational experience of the RWTS and several systems in other countries, the used technology proved to be reliable and efficient.

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