Produced Water Recycle Reuse at the Oman Mukhaizna Oil Field

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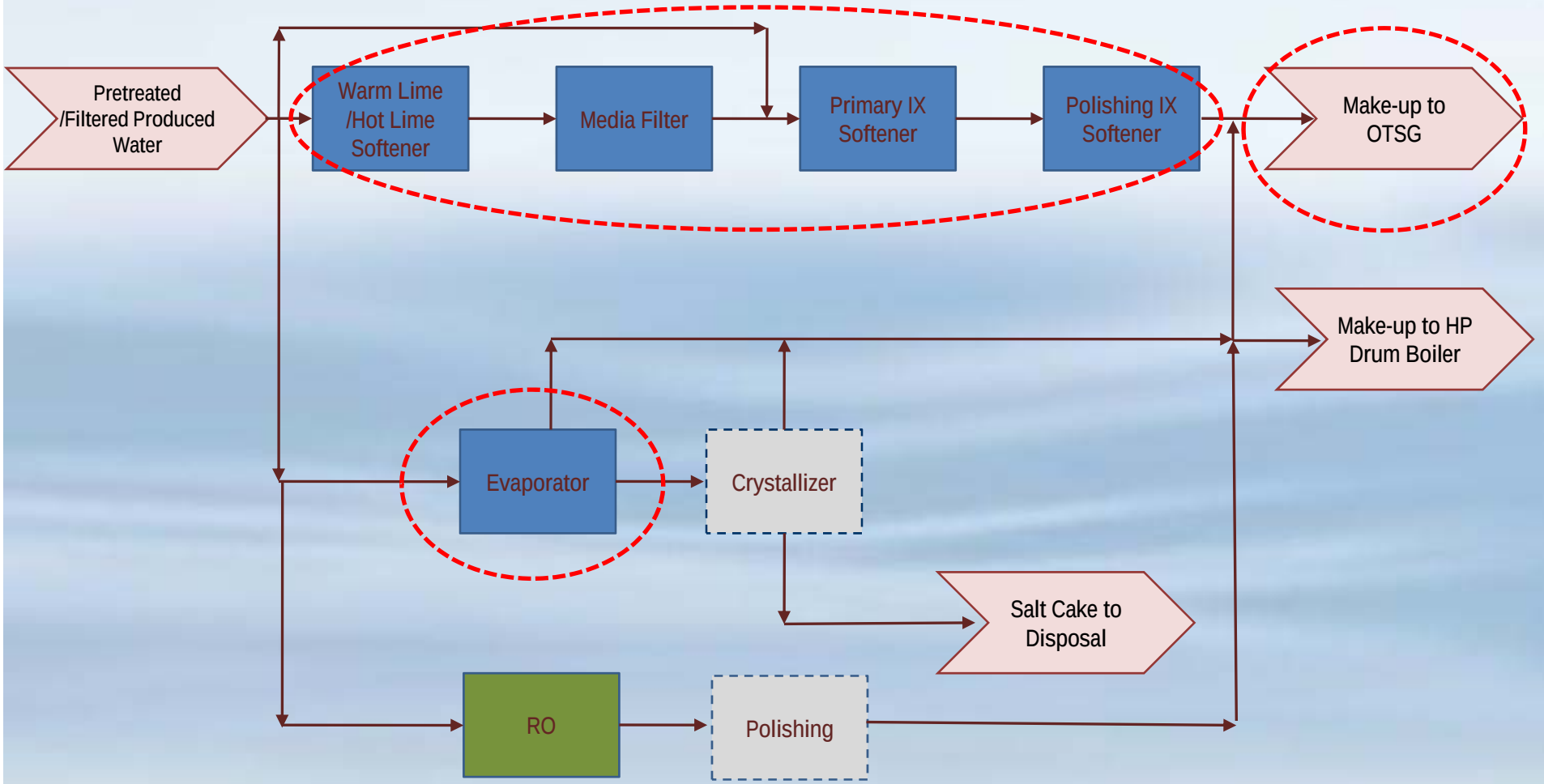
Background

- Mukhaizna Oil Field discovered in 1975 by Petroleum Development of Oman (PDO);
- Located in central Oman, approx 660 km from Muscat;
- In 2005 , a Royal Decree was issued by the government approving the development of the Mukhaizna oil field
- Occidental Petroleum is the largest shareholder and also operates the facility;
- In 2011 facility produced 124,000 bpd; designed to produce 150,000 bpd;
- Uses steam flooding EOR technique;
- Estimated reserves of 2 Billion barrels of heavy crude
- Aquatech supplied Phase 1: Evaporators (300K bwpd) and Phase 2 (L1/L2/L3): Conventional (390K bwpd)

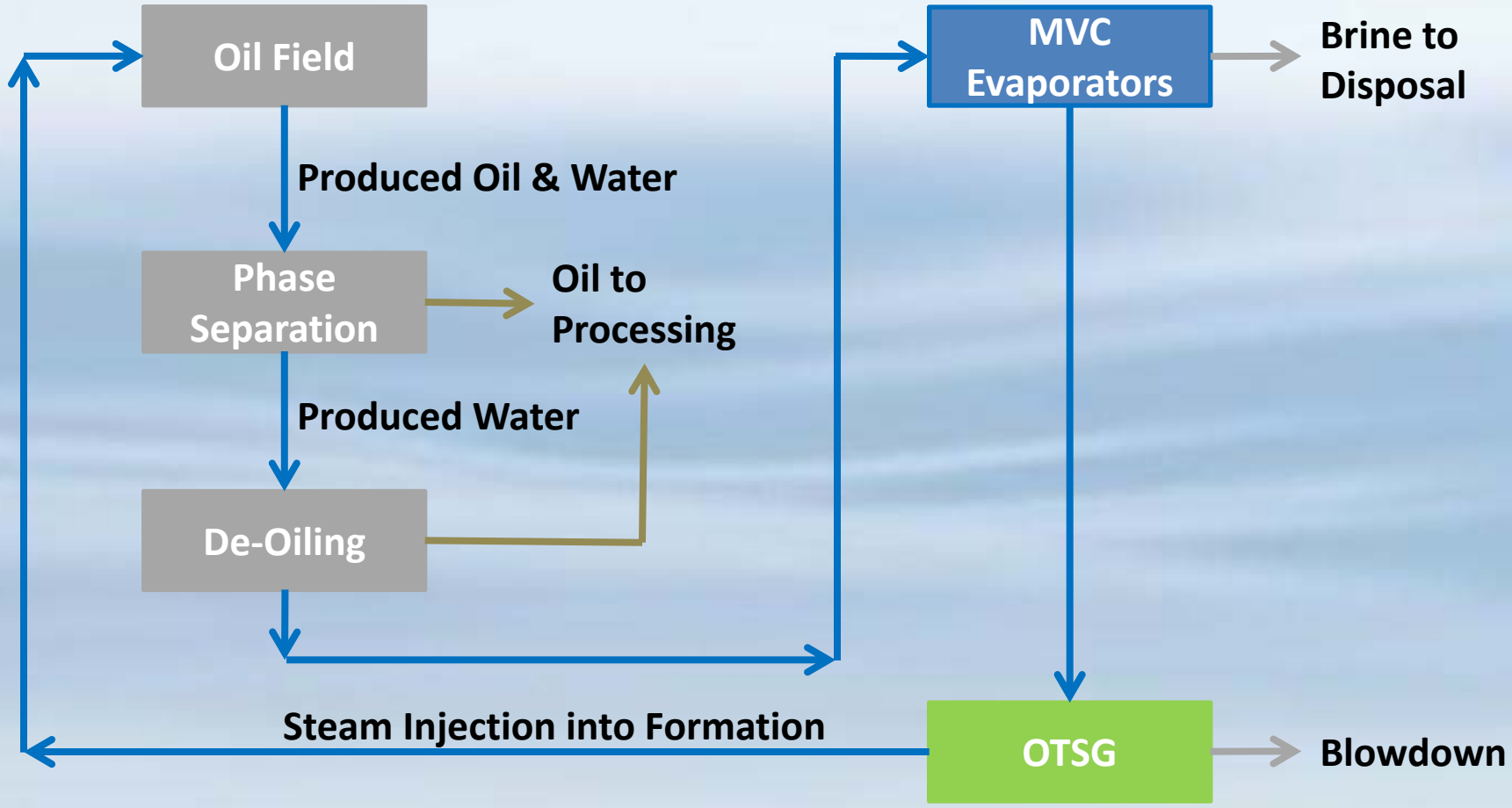
Produced Water for Recycle - PFD



Block Flow Diagram
Produced Water for Recycle – Onshore

What Did We Start With?

Process Scheme – Phase 1



Project Overview – Phase 1

PROJECT: Mukhaizna Phase 1

CUSTOMER: Occidental Mukhaizna LLC
(A subsidiary of Occidental Petroleum Corporation)

SITE/ FACILITY: Mukhaizna Field – 660 km from Muscat, Sultanate of Oman

Aquatech provided following services and scope:

- Design
- Engineering
- Project Management
- Procurement
- Turnkey Installation (Civil, Mechanical & Electrical)
- Inspection & Testing
- Supply FOB site
- Supervision during installation and commissioning, and
- Supervision of Site acceptance test / performance test:

CAPACITY:

- 7 trains of Dual Effect Evaporators
- **Each** train consists of 2 evaporators and produces **284 m^3/h (1250 gpm)** of distillate
- **Total** system distillate production of **1988 m^3/h (8750 gpm) or 300,000 bwpd.**
- Evaporators can be operated in either a seeded or unseeded mode.

Design Considerations – Phase 1

- Starts with the feedwater
- Multiple water sources and cases for design;
- Produced & High Brackish aquifer waters
- Varying blend %s from each
- Maximize recovery rate
- Evaporator technology was selected.
- Ability to handle a vary wide range of feedwater chemistries and provide high recovery rates

Values in mg/l unless otherwise noted	DESIGN
pH (Units)	7.5 - 8.2
Ca	300 - 609
Mg	60 - 296
Total Hardness (as CaCO3)	995 - 2742
Na	7936 - 8555
K	224
Li	0.2
Ba	0.3
Fe	0.02
Sr	6
HCO3	145 - 470
Cl	13,353 - 13,700
SO4	10 - 909
SiO2	23 - 250
B	3
Oil	<20
TDS	22,340 - 23,650
Dissolved H2S	<10
Water Temp (F)	85 - 185

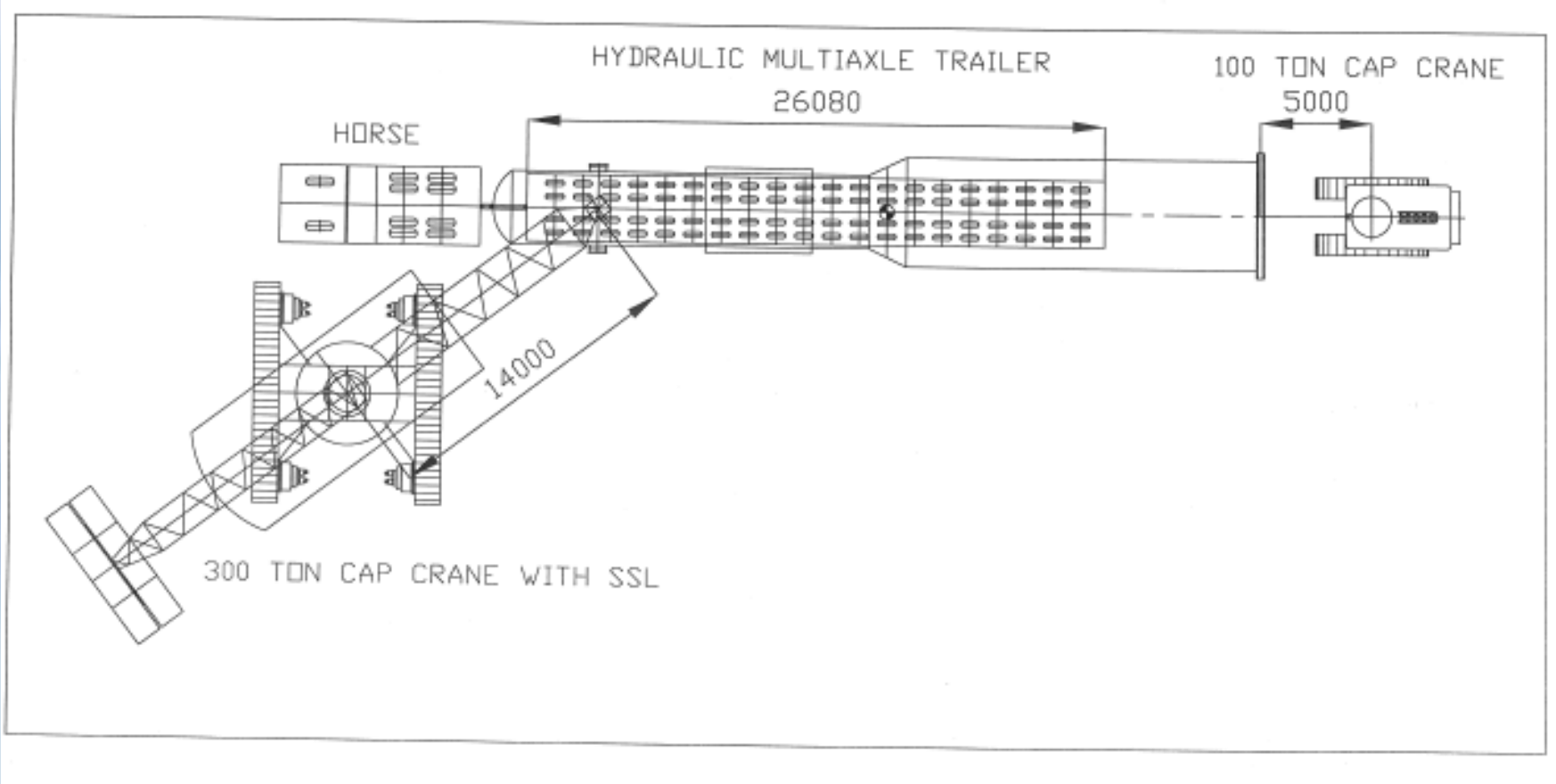
Project Execution – Phase 1

- ✓ **ROUTE MAP**
  - ✓ **Detailed survey**
- ✓ **VEHICLE TRANSPORTATION**
  - ✓ **Distance Covered: 850 Km**
  - ✓ **Avg Speed: 30-45 Km/hr**
  - ✓ **Time (Approx): 5 - 6 days (Mussafeh (UAE) to jobsite**
  - ✓ **Police Escorts/Permits**
  - ✓ **# of stoppages on route**
  - ✓ **Fueling Requirements**
  - ✓ **Vehicle Ingres/Egress**

Project Execution – Phase 1 (cont'd)

HEAVY CRANE CONCEPT

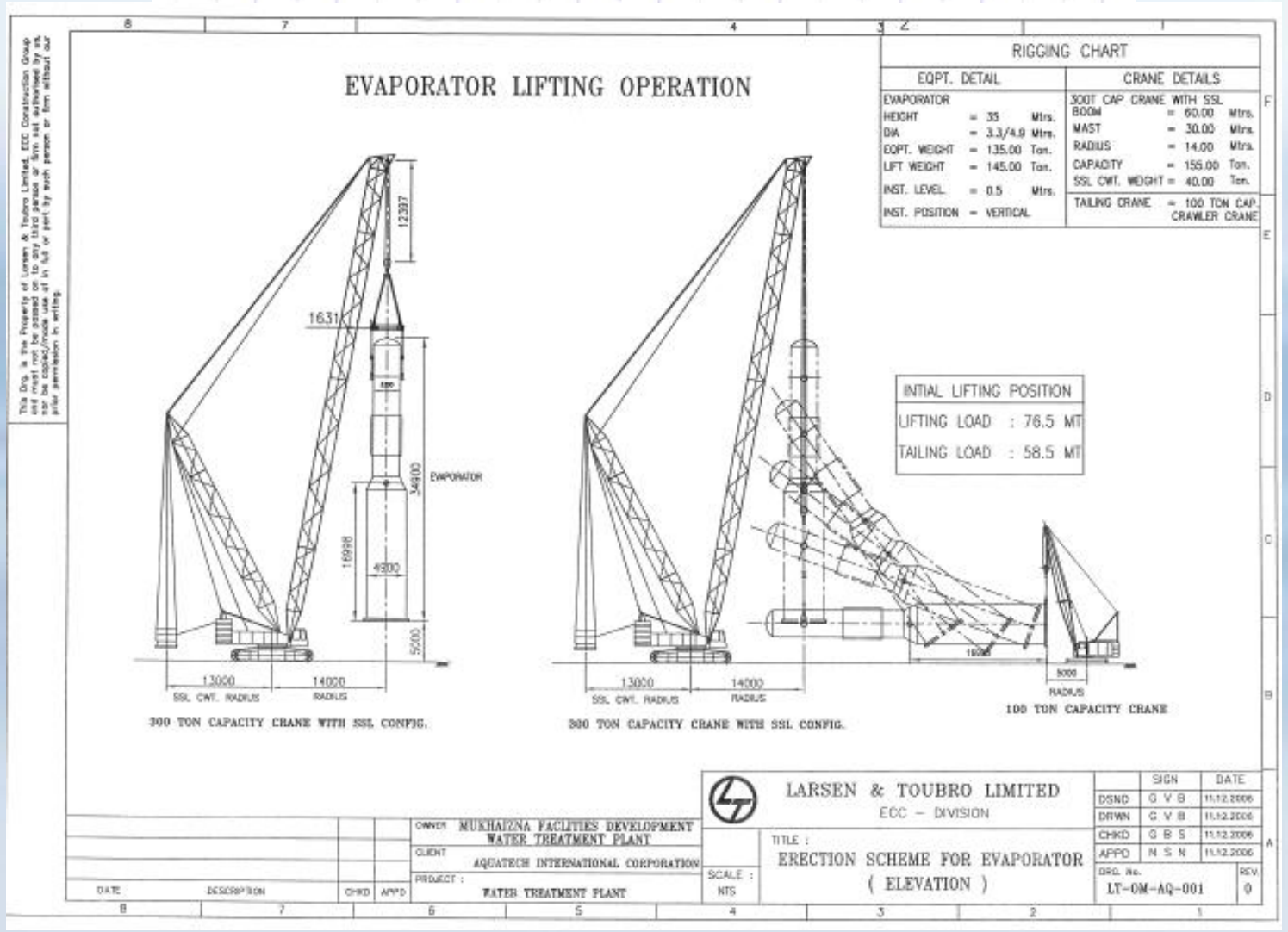
FALLING FILM EVAPORATOR UNLOADING AT SITE



Project Execution – Phase 1 (cont'd)

HEAVY CRANE CONCEPT

METHODOLOGY FOR FALLING FILM EVAPORATOR INSTALLATION



Project Execution – Phase 1 (cont'd)

ERECTION & INSTALLATION

Project Execution – Phase 1 (cont'd)

ERECTION & INSTALLATION

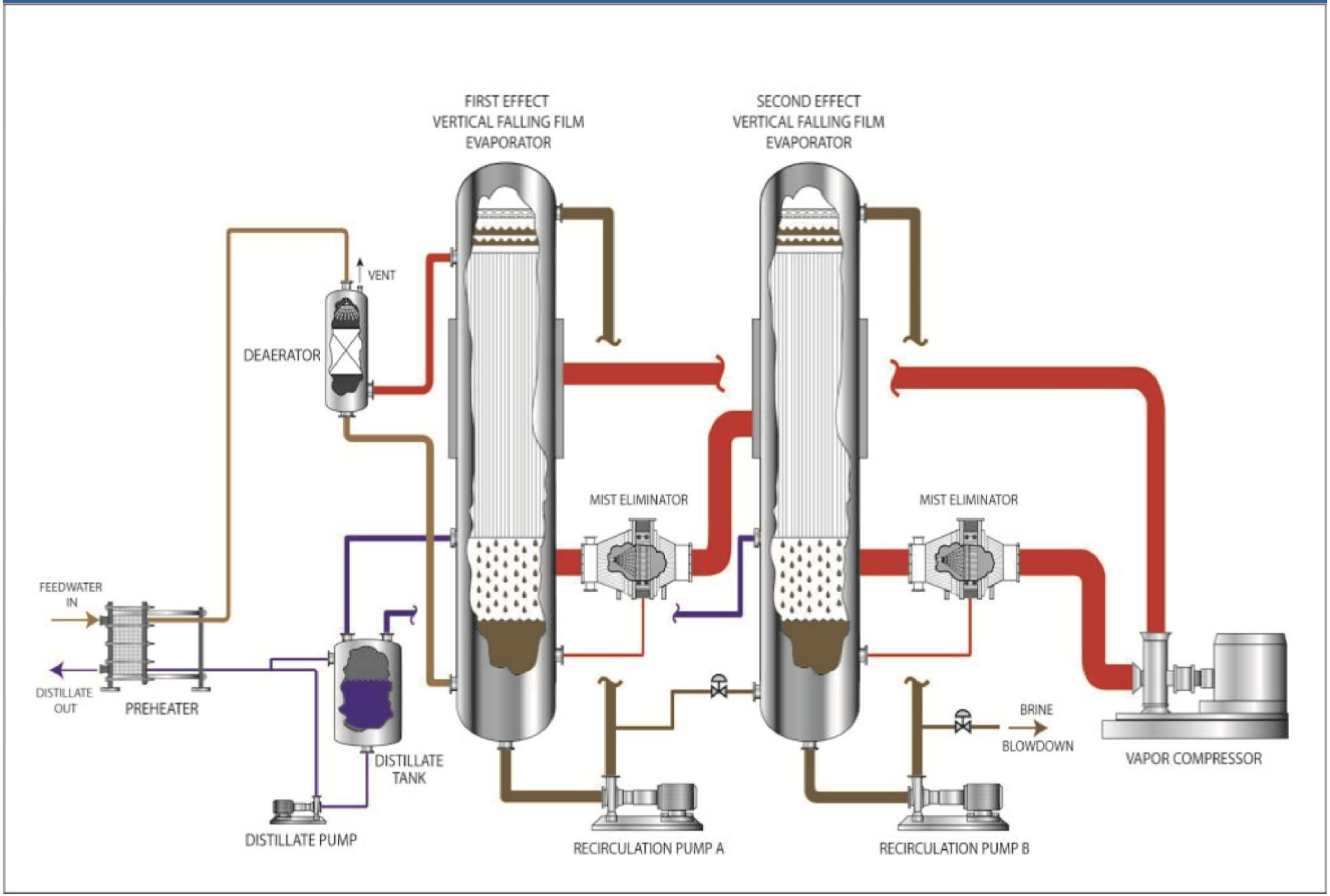
Project Execution – Phase 1 (cont'd)

ERECTION & INSTALLATION

Design Highlights – Phase 1

- ✓ 7 trains x 42,860 bwpd distillate capacity each for total of 300,000 bwpd (8750 gpm) of distillate
- ✓ Each train is arranged as 2 effect vertical tube falling film evaporators driven by a single compressor
- ✓ High efficiency external mist eliminators
- ✓ Dual plate brine distribution
- ✓ Operation in Seeded slurry ($CaSO_4$)and Unseeded scale control modes
- ✓ $CaCl_2$/Na_2SO_4 to balance chemistry for seeded operation; pH adj, antiscalant & anti-foam
- ✓ Power consumption over 10% less than a single train configuration
- ✓ 1st effect has a low scaling rate and essentially the number of tubes requiring cleaning is reduced by 50%
- ✓ System produces:
  - ✓ < 5 mg/l TDS;
  - ✓ < 0.5 mg/l TH
  - ✓ < 0.05 mg/l SiO_2

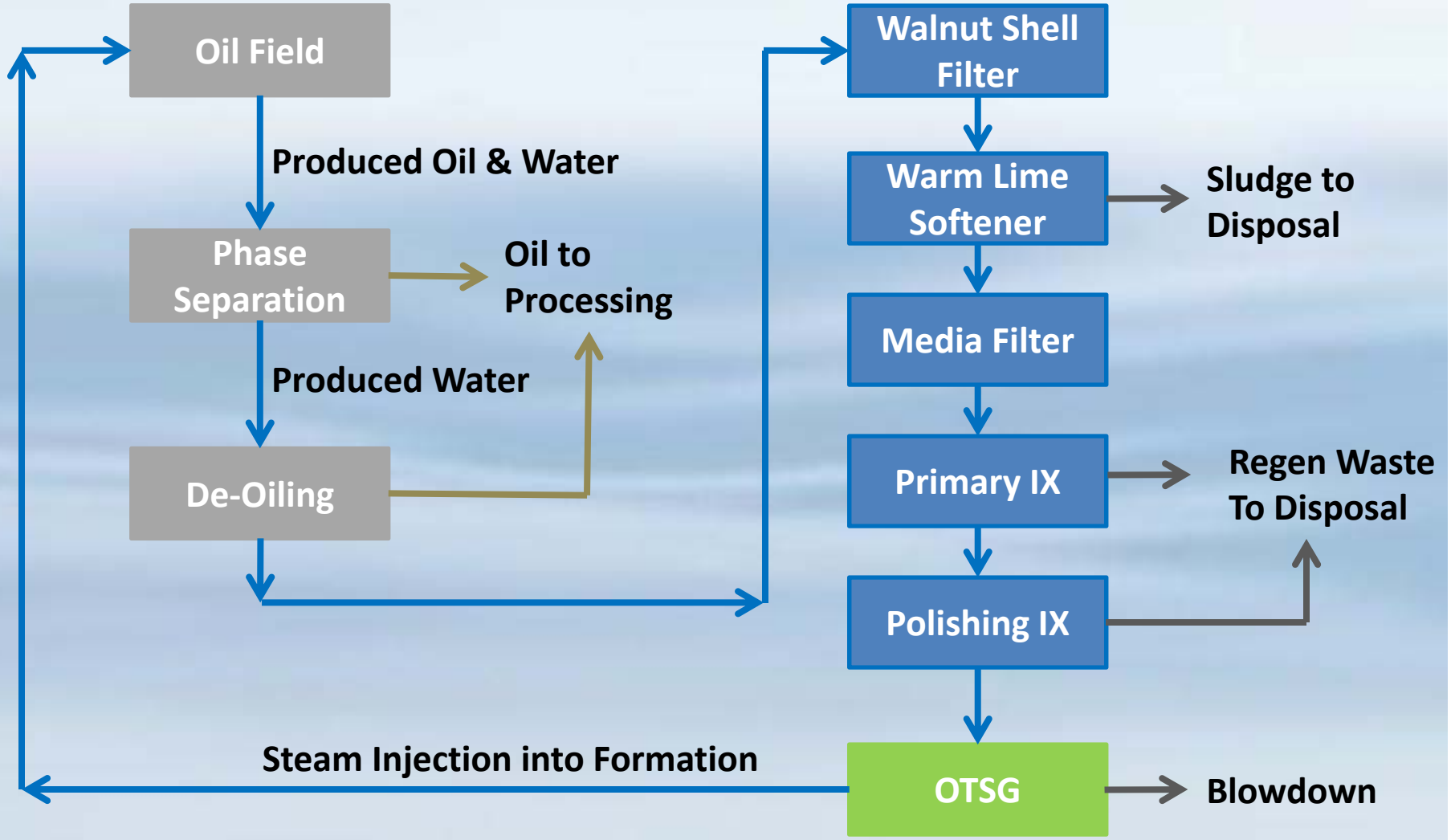
Two Effect Single Train



Project Highlights – Phase 1

- ✓ Overall Schedule: 36 months (approx) from PO to overall facility commissioned & performance tested
- ✓ At 18 months from PO, first evap tower was delivered….On average it took 6-8 wks for the installation of a train with some activities overlapping each other from train to train.
- ✓ 6-8 weeks per train for start-up/commissioning activities with some activities overlapping each other and the total time it took between the 1st and 7th train being commissioned/start-up was approximately 9-10 months calendar wise.
- ✓ First train was placed into commercial operation in August 2008
- ✓ All trains passed performance testing for power consumption, production capacity and distillate quality
- ✓ During peak construction, over 2000 workers with various skills at the jobsite
- ✓ Multiple safety awards earned

Process Scheme – Phase 2



Project Overview – Phase 2

PROJECT: Mukhaizna Phase 2

CUSTOMER: Occidental Mukhaizna LLC
(A subsidiary of Occidental Petroleum Corporation)

SITE/ FACILITY: Mukhaizna Field – 660 km from Muscat, Sultanate of Oman

Aquatech provided following services and scope:

- Design
- Engineering
- Project Management
- Procurement
- Inspection & Testing
- Supply FOB site
- Supervision during installation and commissioning, and
- Supervision of Site acceptance test / performance test:

CAPACITY:

Lot 1: 130,000 bwpd (861 m^3/h; 3789 gpm)

Lot 2: 140,000 bwpd (927 m^3/h; 4080 gpm)

Lot 3: 120,000 bwpd (795 m^3/h; 3497 gpm)

Total: 390,000 bwpd (2583 m^3/h; 11,366 gpm)

Each lot of water treatment facilities in Phase 2 comprised of the following general process steps

- Walnut Shell Filters
- Warm Lime Softening Clarification
- After Filters
- Ion Exchange Softening – Primary & Polishing
- Chemical storage & handling

Design Considerations – Phase 2

- Produced water existed as the main feedwater source;
- Significantly lower TDS design water
- Faster system delivery schedule was required
- Conventional process was selected
- Client selected IX SAC polishing (in lieu of recommended WAC) considering “expectation” of further lowered TDS to 4500 mg/l

Values in mg/l unless otherwise noted	DESIGN
pH (Units)	6.5 - 8.5
Ca	140
Mg	30
Total Hardness (as CaCO3)	322 - 483
Na	2402
Ba	1
Fe	0.1
Sr	12 - 20
HCO3	348
Cl	3829
SO4	248 - 372
SiO2	233
Oil	<20
TDS	6500
Dissolved H2S	4 - 10
Water Temp (F)	95 - 203

Project Execution – Phase 2

Project Execution – Phase 2 (cont'd)

Design Highlights – Phase 2

- ✓ 3 Lots of varying capacity providing a total of 390,000 bwpd (11,366 gpm) of product water
- ✓ 4 x 33% Walnut shell filters;
- ✓ 1 x 100% Warm Lime Softening Clarifier
- ✓ 4 x 33% Afterfilters
- ✓ 4 x 33% Primary SAC (co-current); 4 x 33% Polishing SACs (split flow counter-current)
- ✓ Recommended polishing WAC
- ✓ System produces:
  - ✓ < 50 mg/l SiO_2
  - ✓ < 1 mg/l TH at elevated TDS level of 6500 mg/l and
  - ✓ < 2 mg/l TH at elevated TDS level of 8500 mg/l

Lessons Learned

- Consider produced water and make-up water chemistry as separate stand-alone in addition to % blends;
- Ensure client follows O&M procedures….issues with trains being operated longer than recommended which resulted in tube pluggage, very difficult scale to remove;
- N+1 system design. Original Phase 1 design was “N+1” but being operated as “N”;
- Increase modularization;
- Secure O&M maintenance contract…….Ensures proper operation, ability to train local staff and results in a happier customer;
- Local suppliers/fabricators were an important part of the project success;
- Secure shop capacity for major fabricated components early;
- Increase focus on transport and logistics planning and cross border movement of major shipments;
- Understanding the business culture. Hiring Oman locals was key.

Summary & Conclusions


Thank you!
Aquatech