DTRI

Desalination Technologies Research Institute

SWCC

Scale Control in Multi Stage Flash (MSF) Desalination Plants – Lessons Learnt

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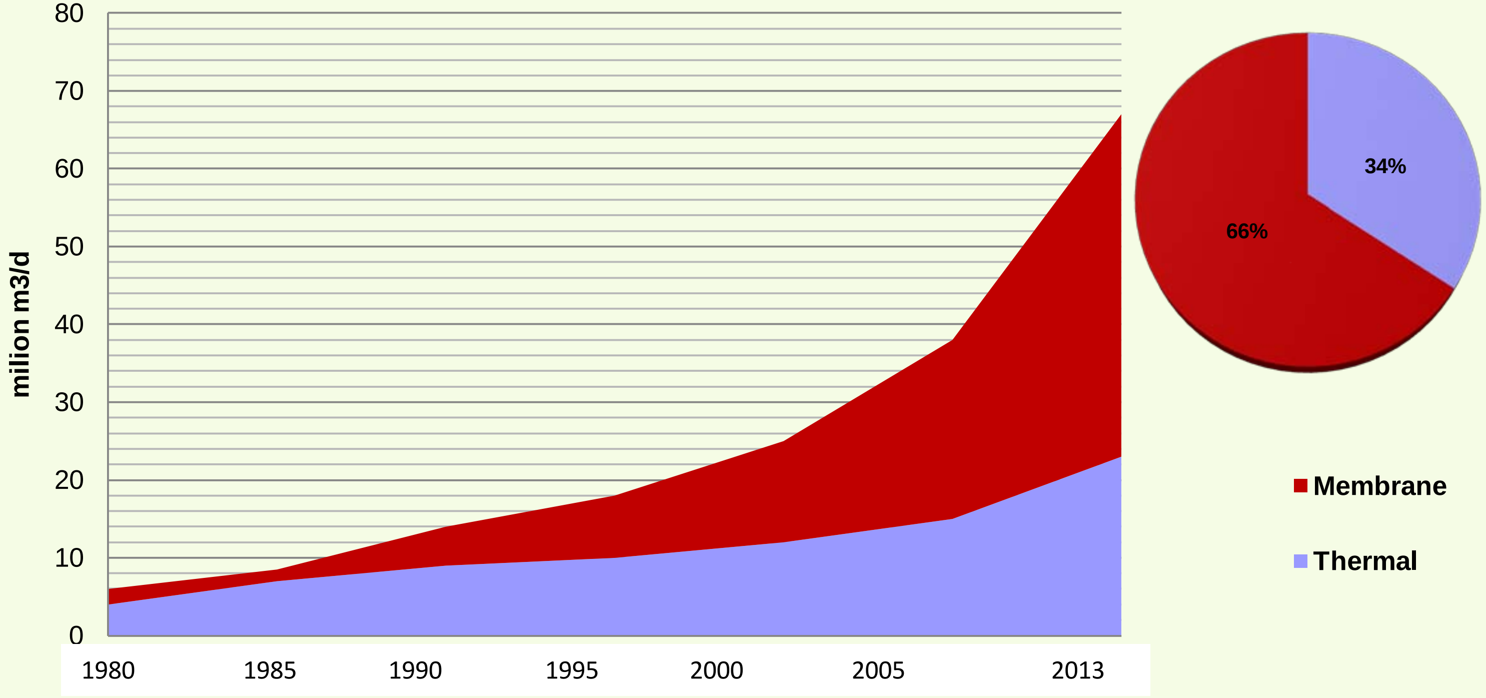
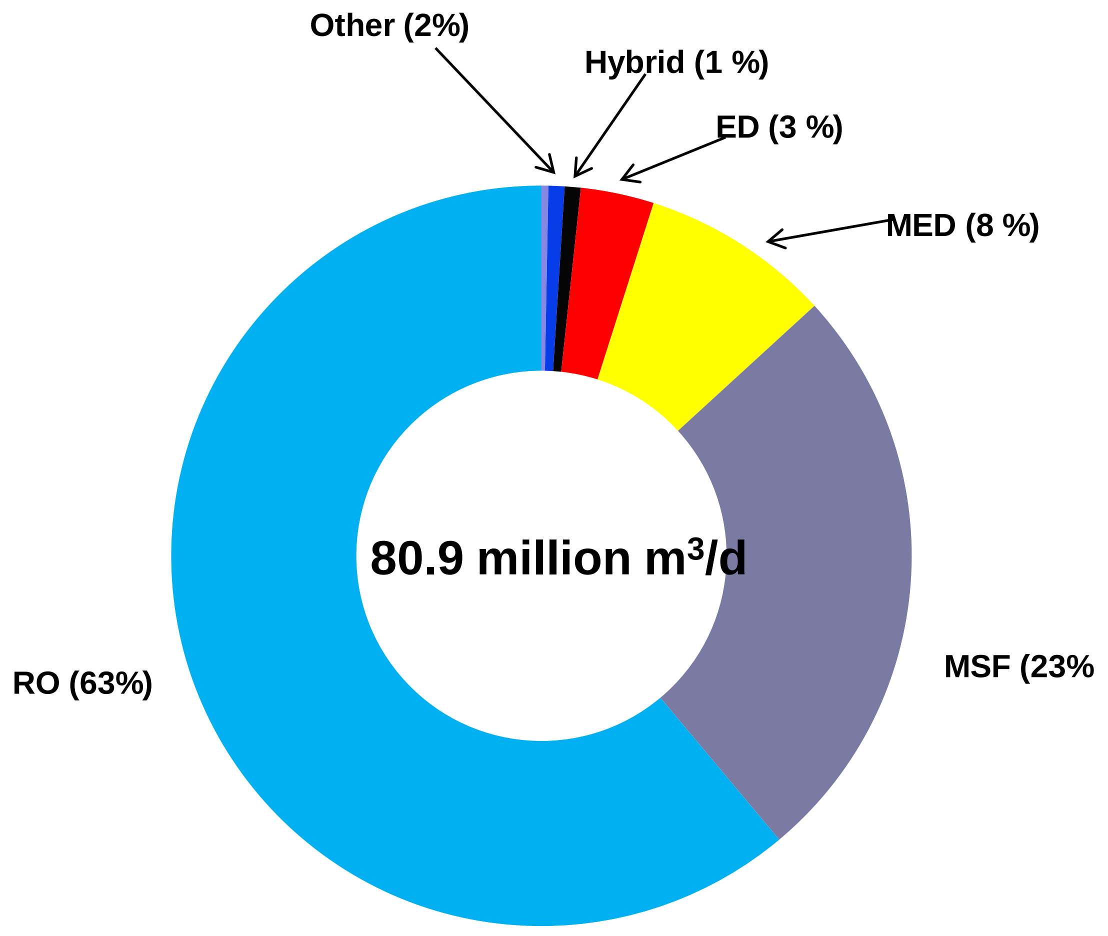
Outline

- Introduction to the desalination industry in the GCC
- The importance of scale control in MSF desalination plants
- Lessons learnt from acid dosed MSF desalination plants.
- Evolution of scale control in threshold chemical additive dosed MSF plants
- Future R&D directions to improve the techno-economic effectiveness of the MSF desalination industry

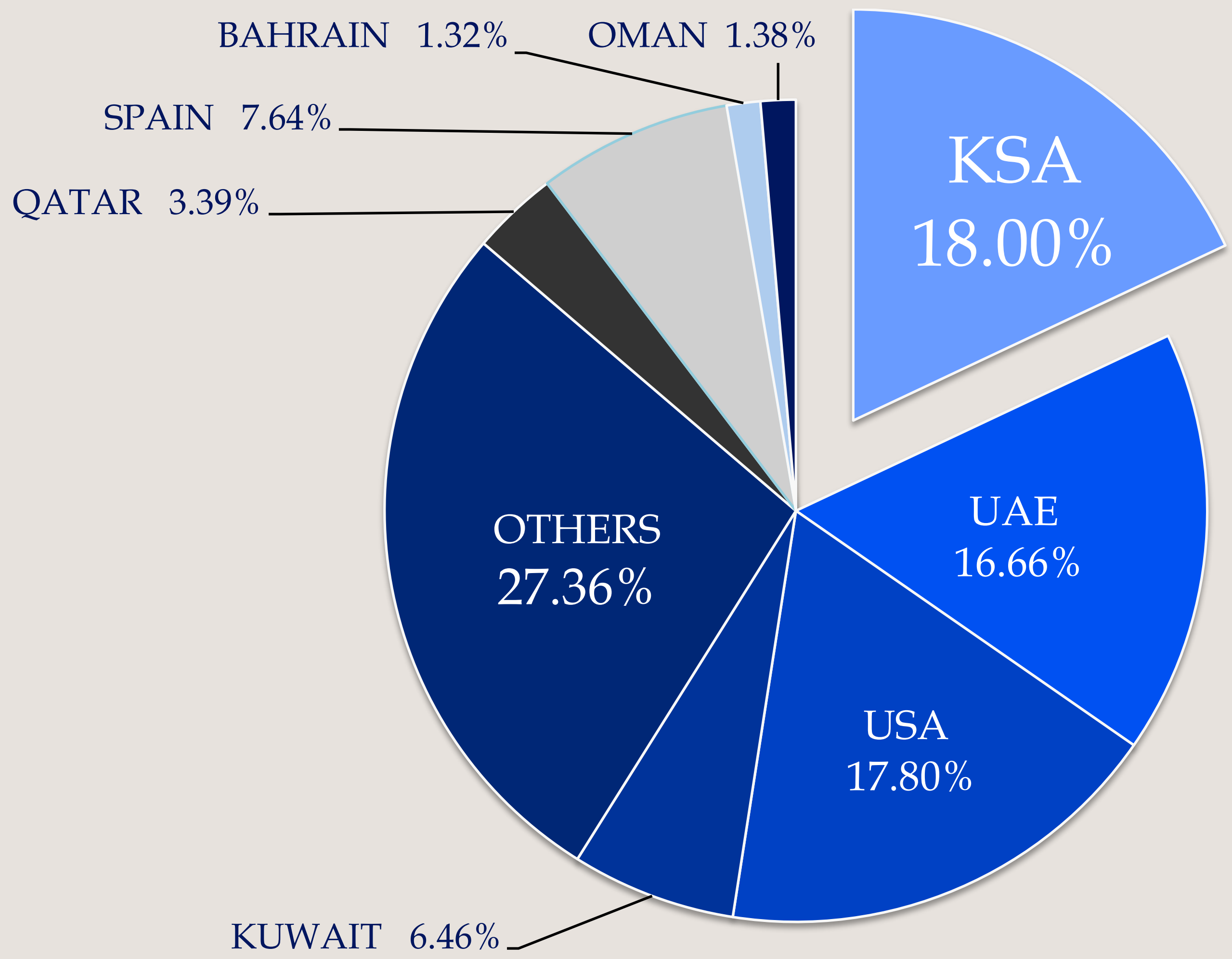


Evolution of the Global installed membrane and thermal capacity,1980-2013 (cumulative)

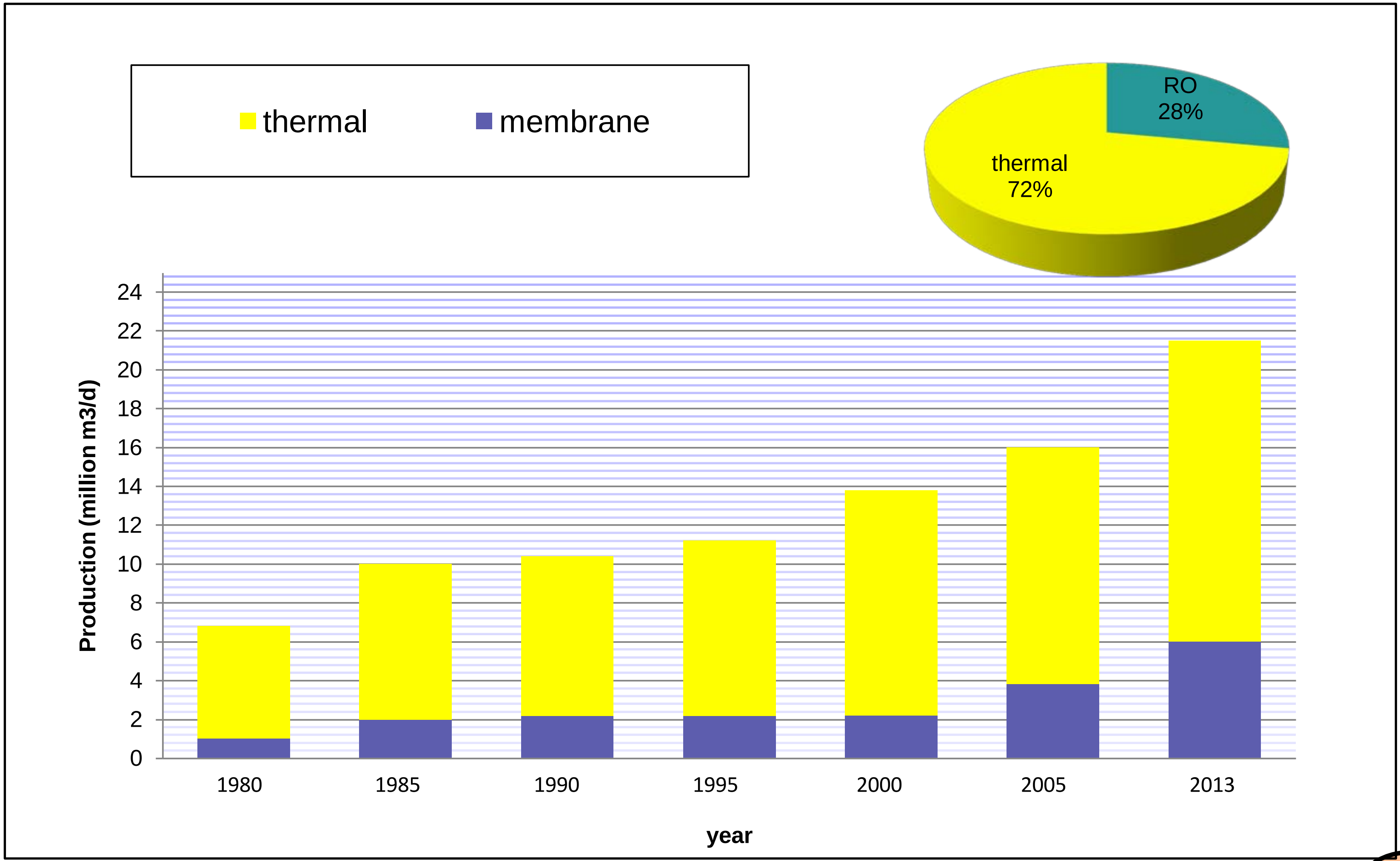
Breakdown of Total Worldwide Installed capacity by technology



Breakdown of Total Worldwide Installed capacity



Historical evolution of total installed capacities of desalination plants in the GCC countries



The majority of sea water desalination plants are employing Multi Stage Flash Process

- **The major problem in operating MSF distillation plants is the formation of scale inside the heat transfer tubes.**

- **Scale deposits in the brine heater and heat recovery section will lead to either high energy consumption or loss of water production**

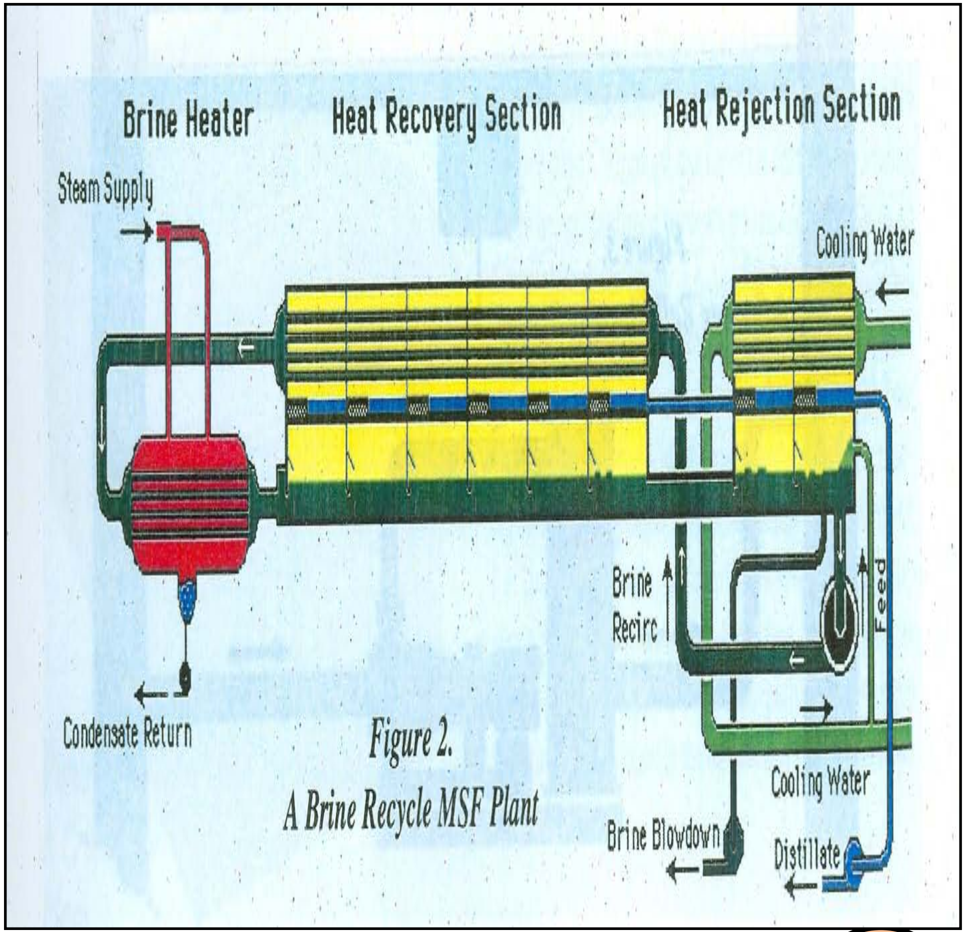
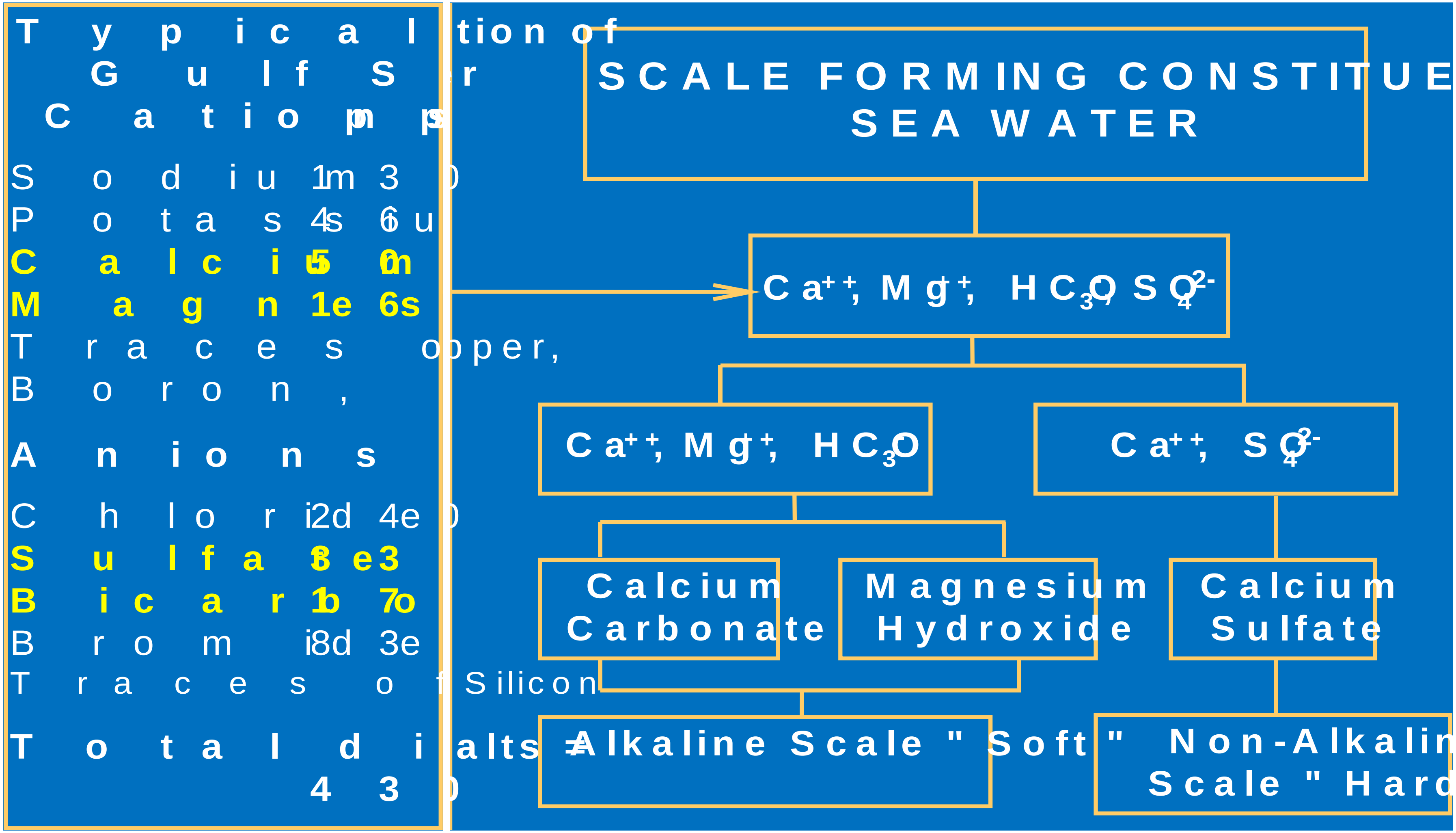


Figure 2.
A Brine Recycle MSF Plant

Scale formation is initiated by some of the dissolved constituents within the seawater



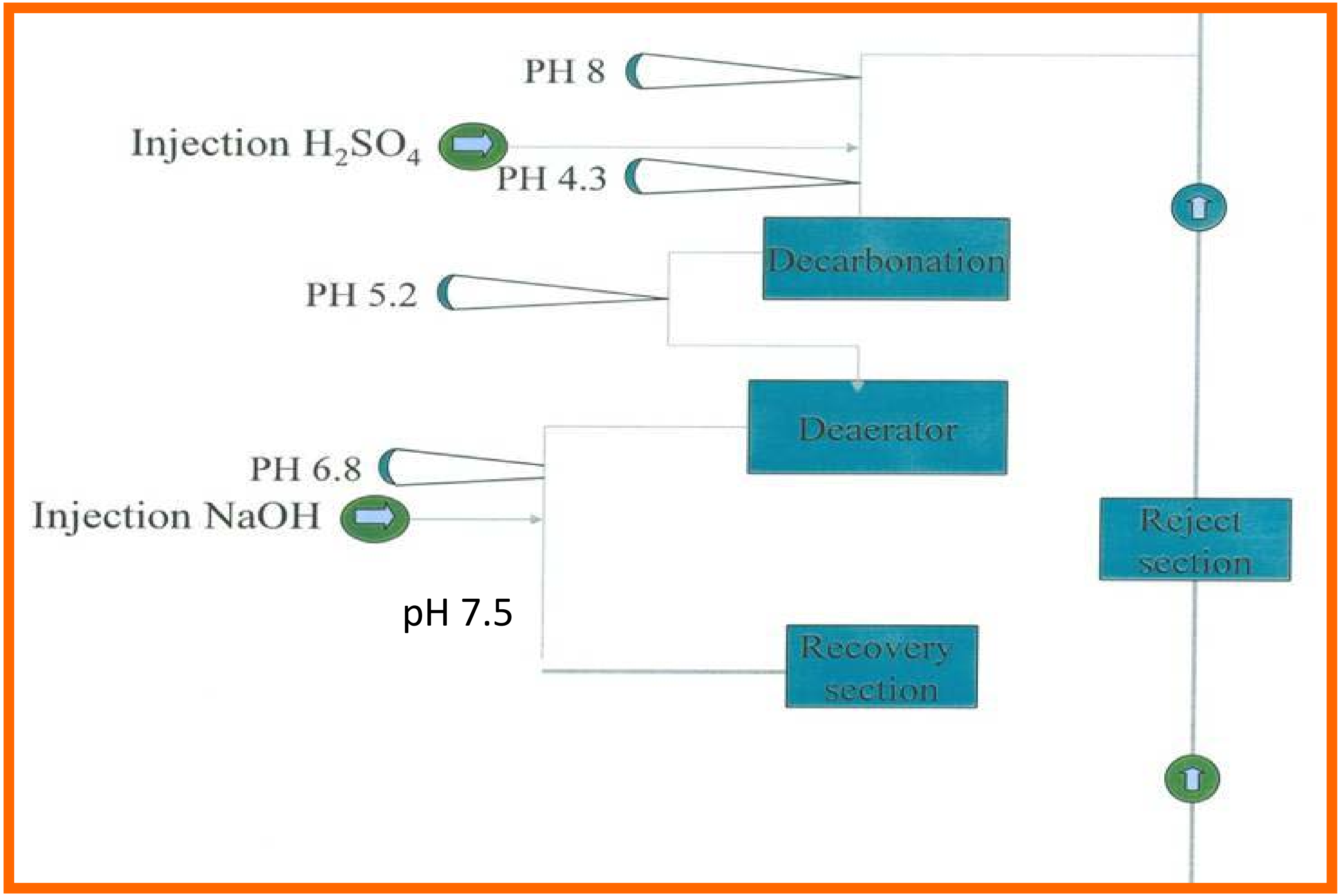
Remove the source of alkaline scale formation.

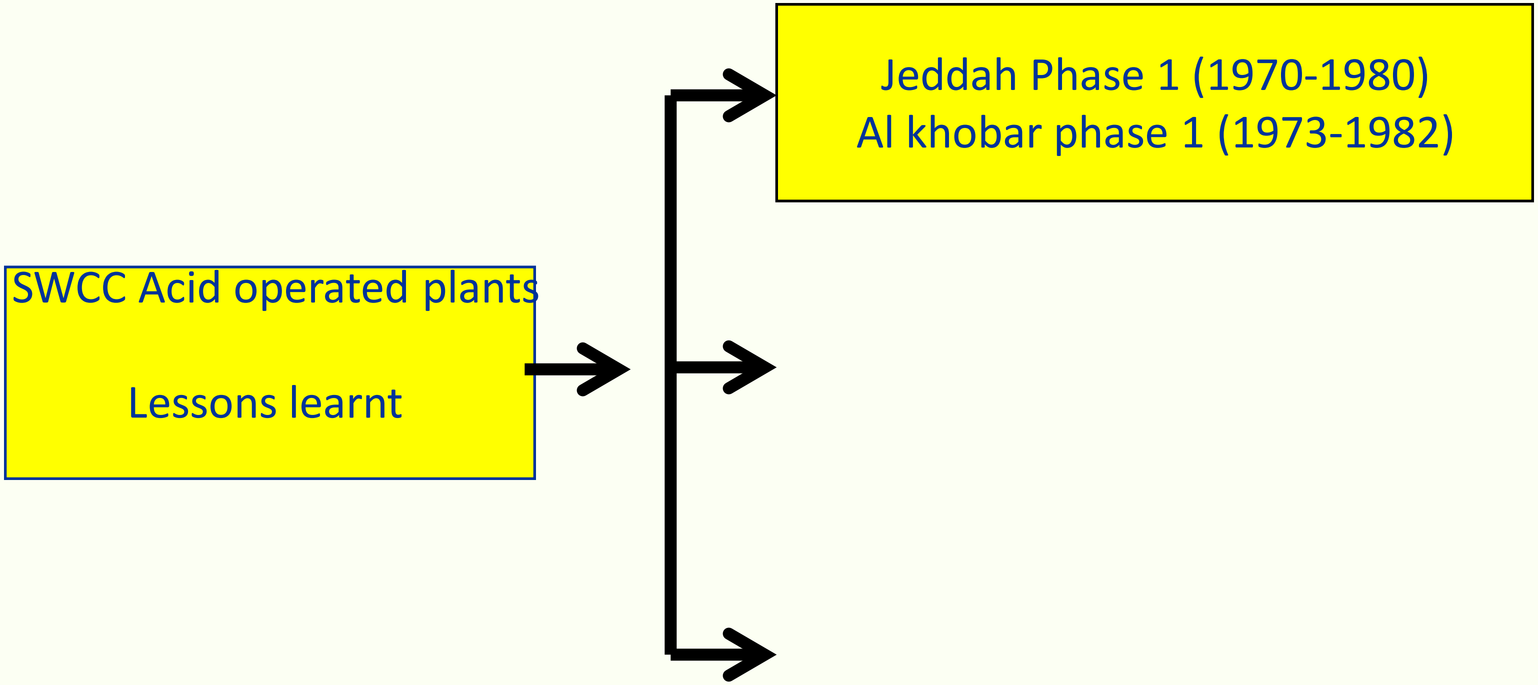
Complete removal or reduction of bicarbonate ions in sea water will eliminate the possibility of $CaCO_3$ or $Mg(OH)_2$ scale formation

Prevention or mitigation of alkaline scale formation

Can be achieved by two different scale control strategies

ALKALINE SCALE CONTROL BY ACID TREATMENT




SWCC Acid operated plants
Lessons learnt
Jeddah Phase 1 (1970-1980)
Al khobar phase 1 (1973-1982)

Jeddah Phase 1 & Al-Khobar Phase-I 1970-1982)

Both plants experienced :
- Undersized decarbonator
- Deaerator overloaded ,

(oxygen content 100-150 ppb)

3. Accelerated corrosion

TBT (design) 121°C,118°C
Operating TBT 115°C
Distiller capacity 2.5 MGD
42,34 stages
No external deaerator
Deaeration:stage 42&34
Shell material:unlined CS
Tube :Cu Ni 90-10

Limited service life
(around 11 years)

Al khobar 2 also was subjected to formation of calcuim sulfate scale because of the seawater high TDS

SWCC
acid operated plants
Lessons learnt

Jeddah Phase 1 (1970-1980)
Al khobar Phase 1 (1973-1982)

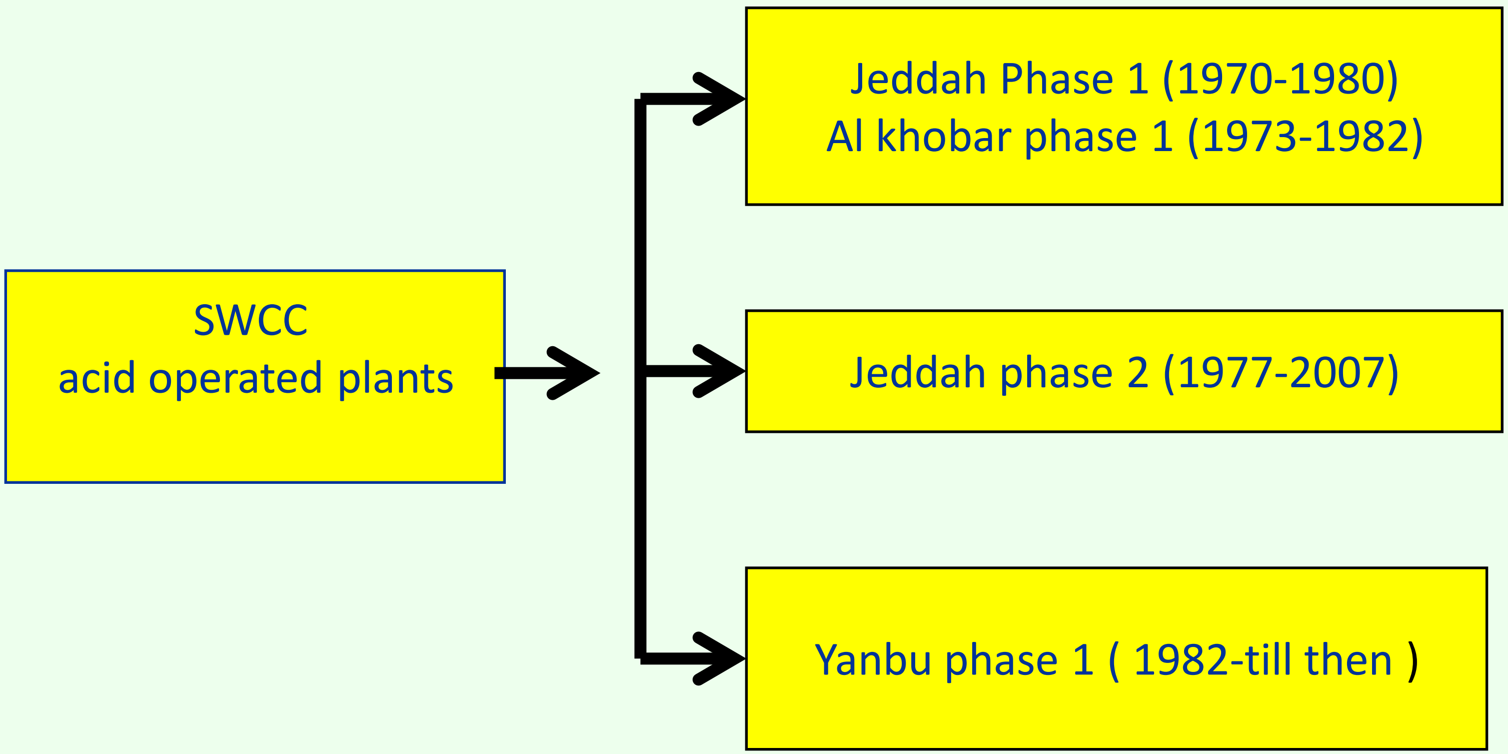
Jeddah Phase 2 (1977-2007)

Jeddah Phase-II
(1977-2007)

- 4 distillers each of production
- capacity of 2.5MIGD
- 34 stages
- TBT (design) 121°C
- TBT (operating) 115°C
- **External deaerator**
- **Ball cleaning once a week**
- Long tube
- **Module#1 lined SS316** ;Tubes 90/10 Cu Ni
- Visual inspection of the plant's physical structure revealed that the plants heat transfer tubes and flash chambers of the high temperature modes are heavily corroded.

Photo #1 Upper parts of the flash chambers

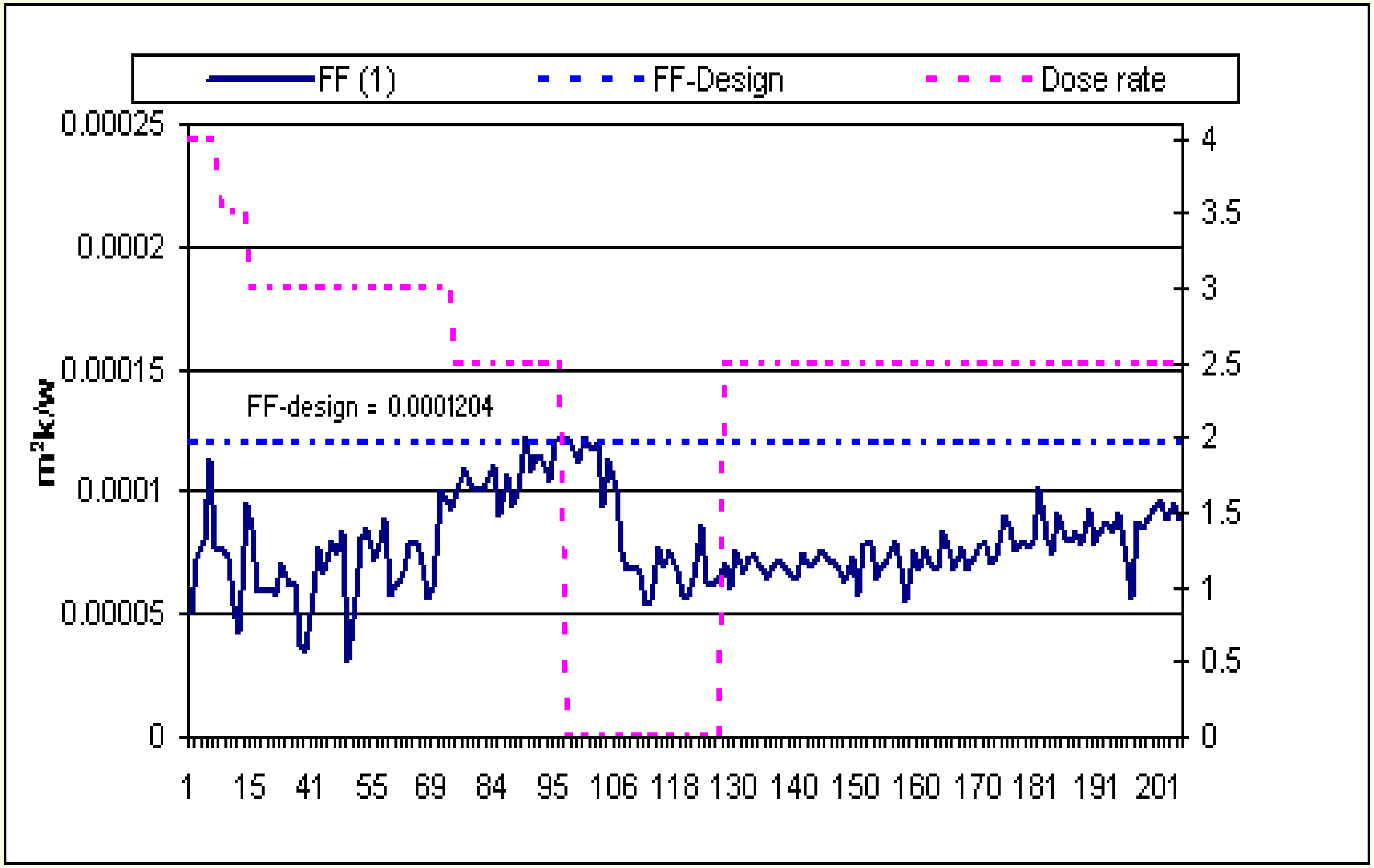
Photo#2 Flash chambers walls


SWCC
acid operated plants
Jeddah Phase 1 (1970-1980)
Al khobar phase 1 (1973-1982)
Jeddah phase 2 (1977-2007)
Yanbu phase 1 (1982-till then)

Yanbu Phase 1

Salient features

1. **4 MSF distillers each with a production capacity of 4.84 MIGD**
2. **24 stages**
3. **TBT (design) 121^{o}C**
4. **TBT operating 115^{o}C**
5. **Originally designed to operate on acid treatment.**
6. **Operating on alternating treatment mode additive/acid treatment**



Variation with time in fouling factor

Remove the source of alkaline scale formation.

Complete removal or reduction of bicarbonate ions in sea water will eliminate the possibility of $CaCO_3$ or $Mg(OH)_2$ scale formation

Prevention or mitigation of alkaline scale formation

Can be achieved by two different scale control strategies

Inhibit the formation and/or deposition of alkaline Scale through addition of proprietary scale inhibiting materials in combination with mechanical on-line cleaning.

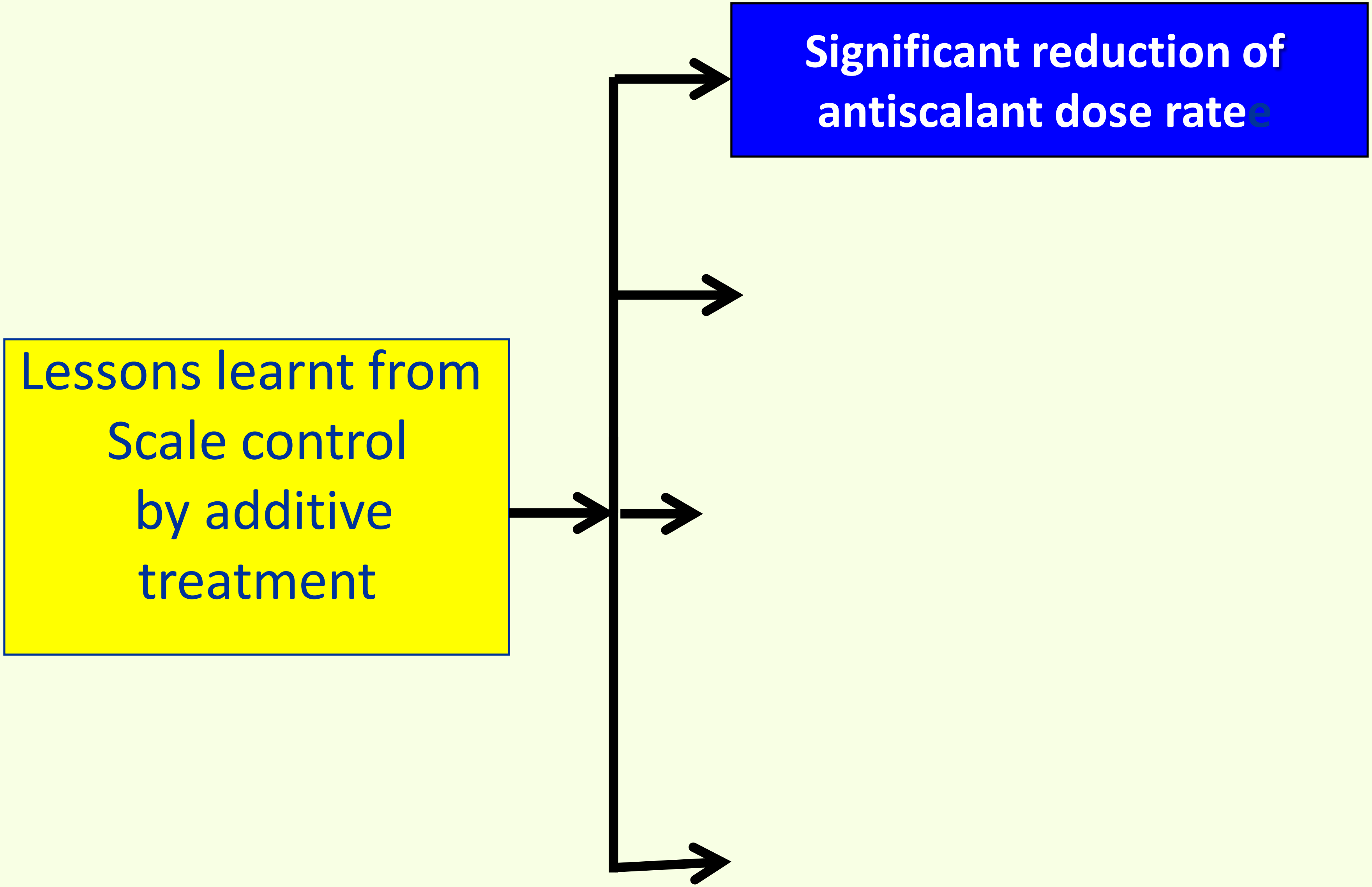
SUPPRESSION OF SCALE PRECIPITATION BY ANTI-SCALANTS

Commonly used antiscalants are derived from three chemical families.

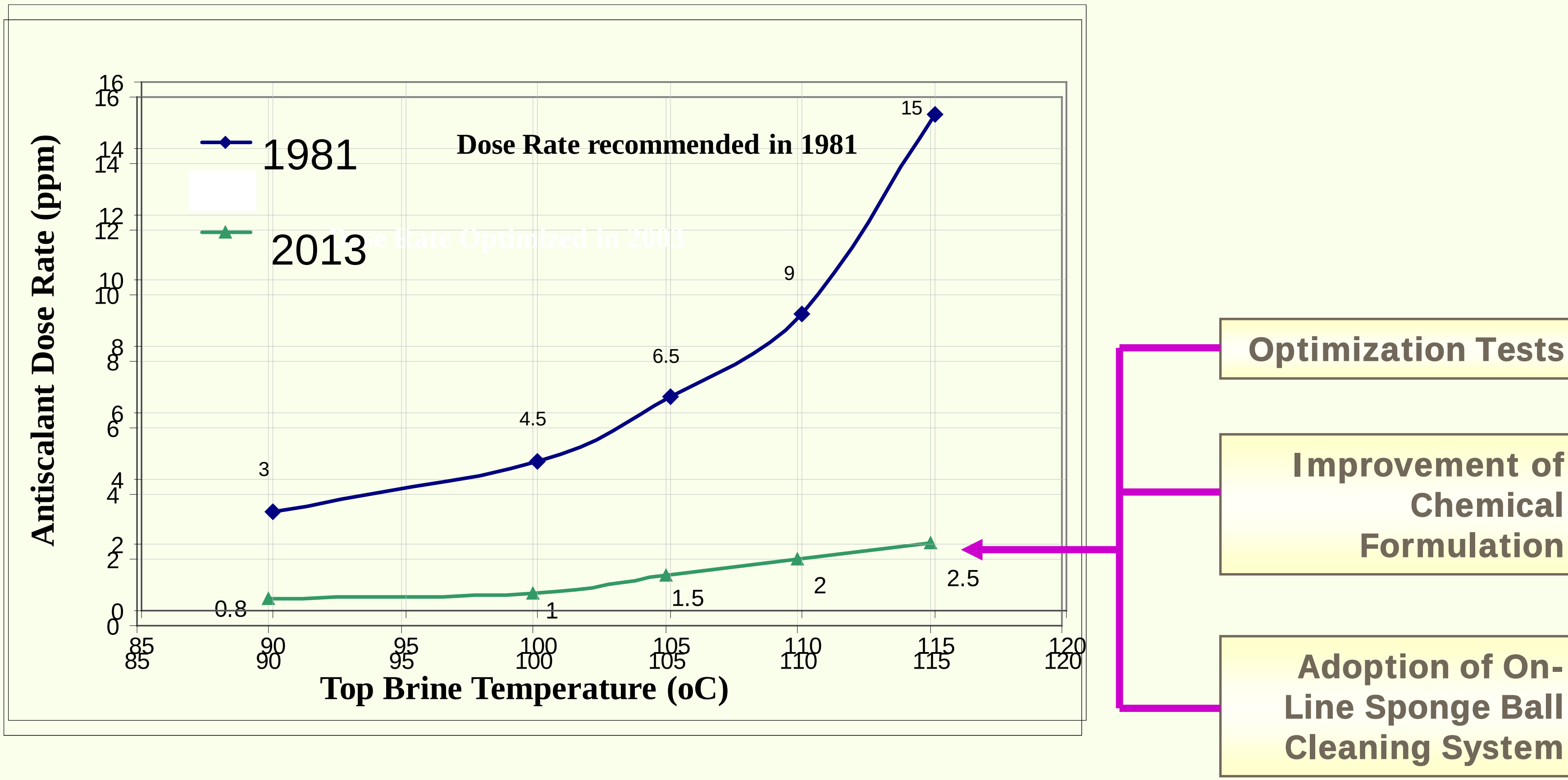
- **Condensed polyphosphates**
- **Phosphonate**
- **Polyelectrolytes (mostly polycarboxylic)**

  1. **Polyacrylic acid**
  2. **Polymethaerylic acid**
  3. **Polymaleic acid**

  (MW 1000 to 5000 DA)


Lessons learnt from
Scale control
by additive
treatment
Significant reduction of
antiscalant dose rate

SWCC's ACHIEVEMENTS IN CONTROLLING ALKALINE SCALE FORMATION



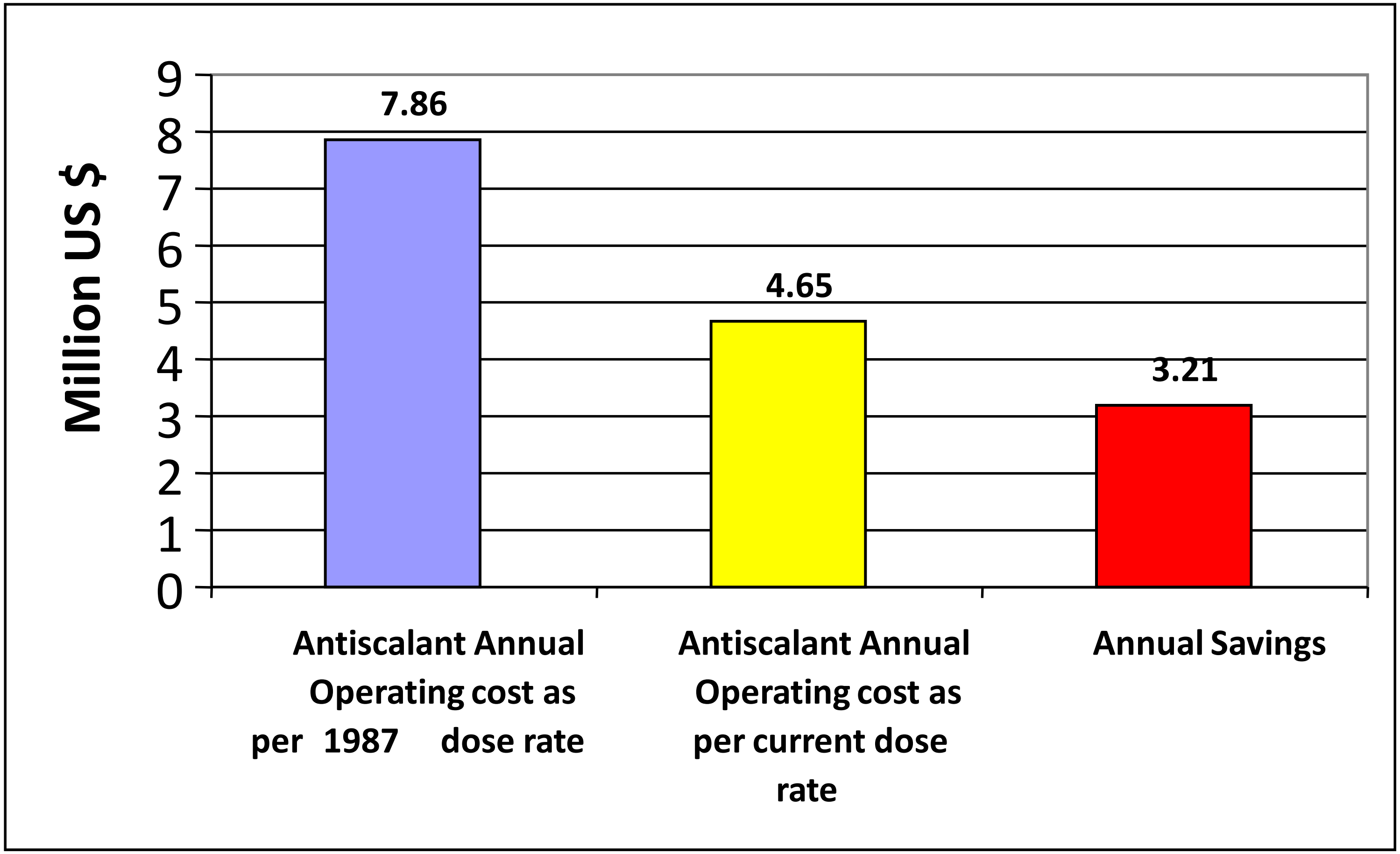
- The most important factor which contributed in the reduction of anti-scalant dose rate is the use of sponge ball cleaning systems.
  - The cleaning balls help to maintain the tubes free from any soft deposit and therefore facilitate the maintenance of low fouling factors for long period of time.Thus extended operational periods between acid cleaning are attained.
  - The sponge balls need not be circulated continuously but for a short period every shift normally 30 minutes three times every 24 hours.

ON-LOAD SPONGE BALL CLEANING

All SWCC MSF plants are equipped with on-line sponge ball cleaning system

Plant		Chemical Treatment	Ball/ Tube Ratio BH	Ball/ Tube Ratio HRC	Frequency of Ball Cleaning Operation	No. of cycles per operation
Jeddah	II	Acid	0.296	0.236	One/week	3 cycle/oper
	III	Antiscalant	0.29	0.665	3 Oper. / Day	4 Cycles / Oper.
	IV	Antiscalant	0.251	0.370	2 Oper./ Week	10 Cycles / Oper.
Jubail	PhI	Antiscalant	0.450	0.427	3 Oper. / Day	8 Cycles / Oper.
	C2 & C3	Antiscalant	0.342	0.324	3 Oper. / Day	8 Cycles / Oper.
	C4	Antiscalant	0.270	0.257	3 Oper. / Day	8 Cycles / Oper.
	C5	Antiscalant	0.300	0.302	3 Oper. / Day	8 Cycles / Oper.
Khobar II		Antiscalant	0.453	0.458	3 Oper. / Day	9 Cycles / Oper.
Yanbu I		Antiscalant	0.243	0.249	3 Oper. / Day	12 Cycles / Oper.
		Acid	0.243	0.249	One Oper./ Week	12 Cycles / Oper.
Al-Shuqaiq		Antiscalant	0.22	0.22	3 Oper/ Day	8 Cycles / Oper. (16 for high TBT)
Al-Shoaiba		Antiscalant	0.251	0.253	3 Oper/ Day	3 Cycles / Oper.
Al-Khafji		Antiscalant	0.351	0.351	One Oper/ Day	9 Cycles / Oper.

Economic Impact of Antiscalant Dose Rate Reduction in SWCC MSF Plants



Lessons learnt from
Scale control
by anti-scalants

Significant reduction of antiscalant dose rate

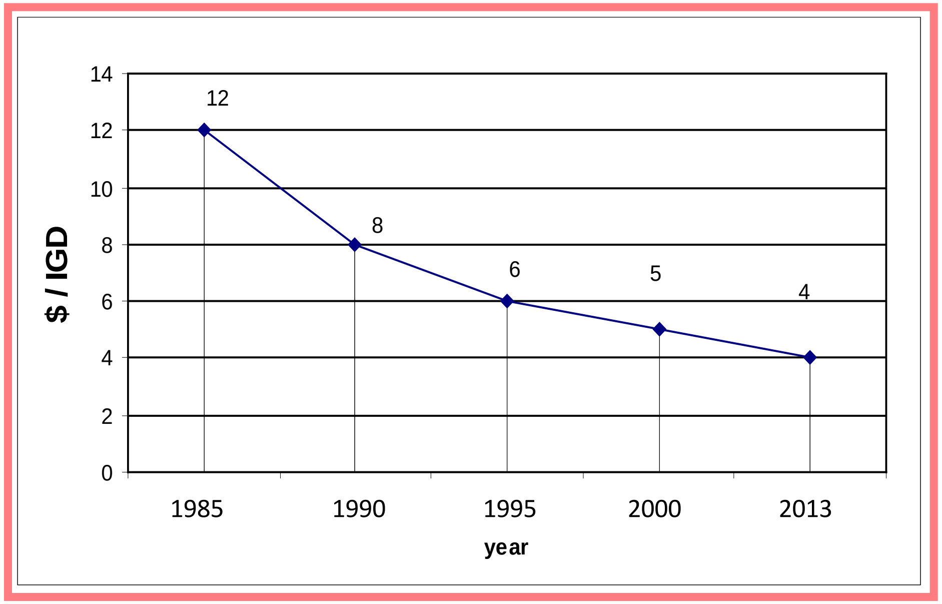
Optimized Thermo-Dynamic Design Parameters

Optimized Thermo-Dynamic Design Parameters

BH Design Fouling Factors

- **Al-Khobar III** 0.264 m^2 °C/kW
- **Shuaiba II** 0.211 m^2 °C/kW
- **Shuaiba I** 0.30 m^2 oC//kW (1982)
- **Al-Jubail II** 0.176 m^2 °C/kW (1983)
- **Jeddah II** 0.086 m^2 °C/kW (1977)
- **Yanbu 1** 0.14 m^2 °C/kW (acid)
- **Tawaleh 'B'** 0.15 m^2 °C/kW
- **Jebel Ali** 0.12 m^2 oC/kW

Price Trend for turn-key complete MSF plants



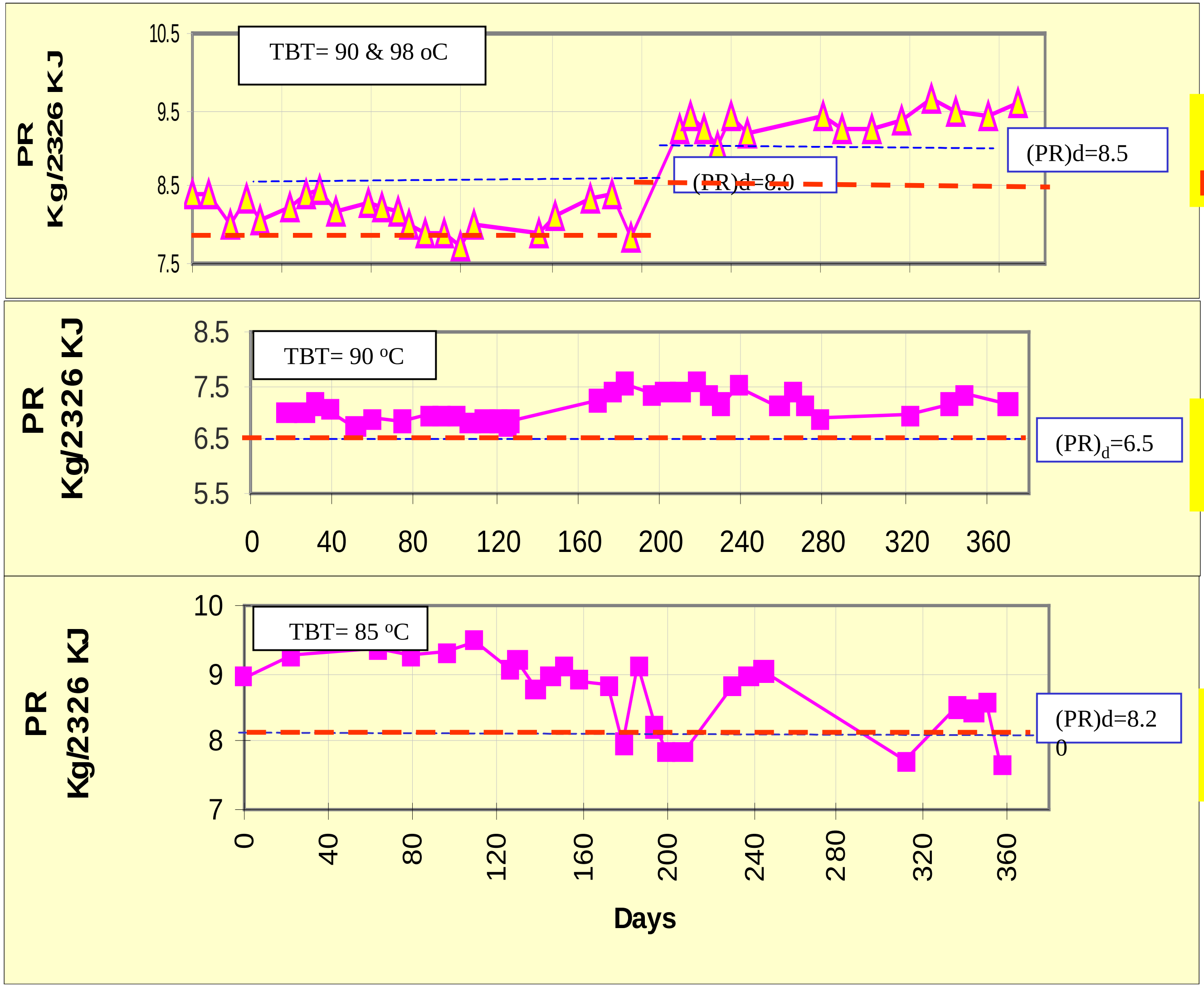
Reasons Constant Reduction of Investment per MIGD

- optimized use of materials of construction.
- Reduction of redundant equipment.
- Optimized mechanical design of evaporator vessel.
- Optimized thermo-dynamic design parameters.

Lessons learnt from Scale control by anti-scalants

- **Significant reduction of anti-scalant dose rate**
- **Optimized Thermo-Dynamic Design Parameters**
- **MSF production capacities and performance ratios are still maintained within or in most cases higher than the design values values.**

PERFORMANCE EVALUATION



Al-Jubail II

TBT = 90– 98 ºC

Prod. = 923–1250 m³/h

Al-Khobar II

TBT = 82– 92 ºC

Prod. = 865– 975 m³/h

Al-Khafji

TBT = 72.7– 88.7 ºC

Prod. = 312– 490 m³/h

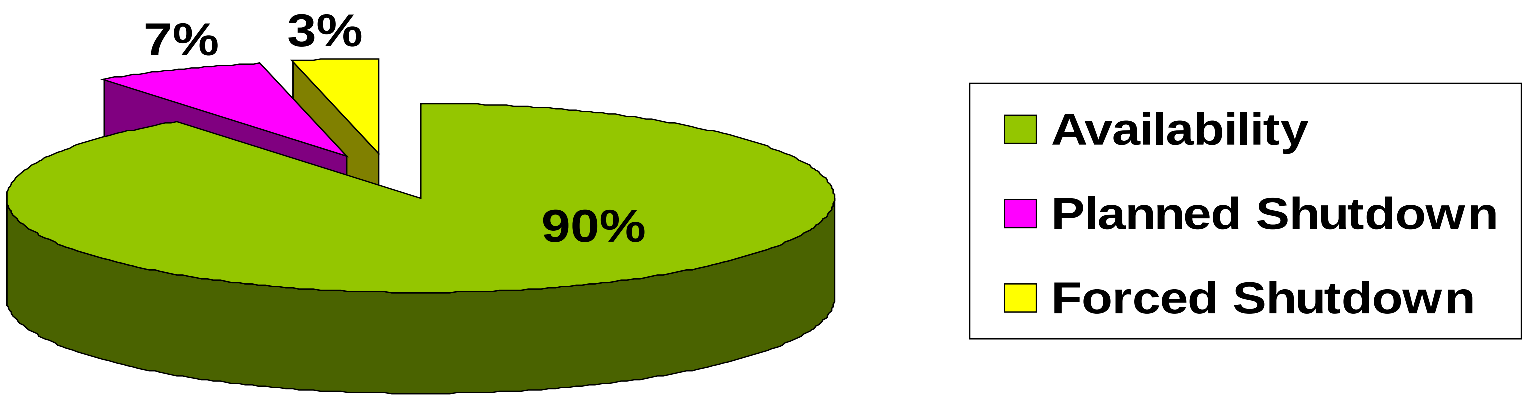
Lessons learnt from Scale control by anti-scalants

Significant reduction of anti-scalant dose rate

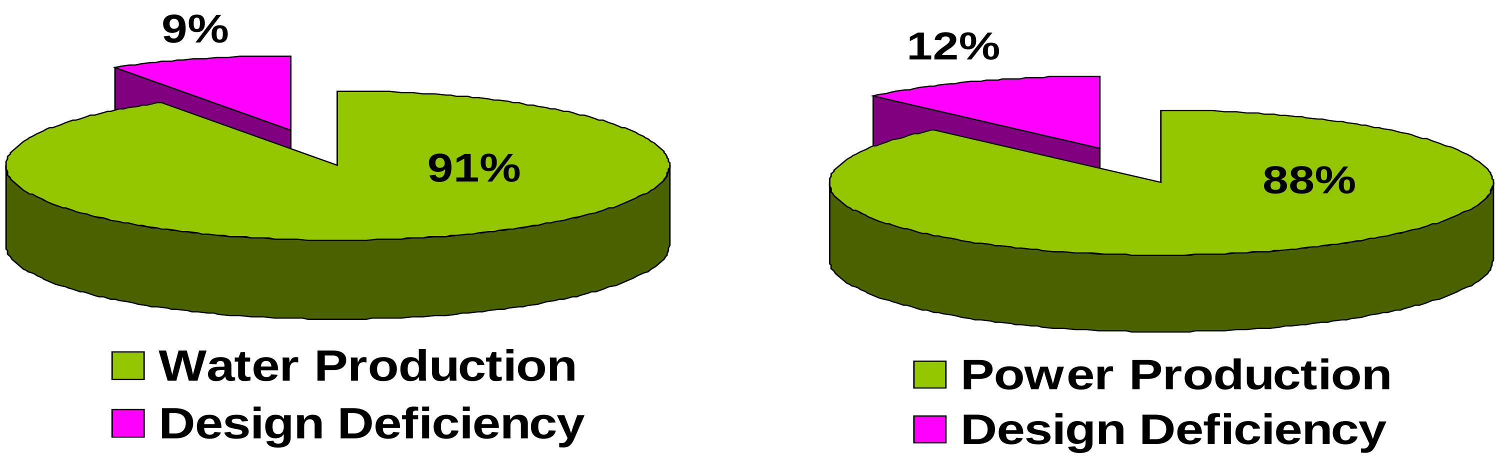
Optimized Thermo-Dynamic Design Parameters

MSF production capacities and performance ratios are still maintained within or in most cases higher than the design values values.

High availability, Load Factor and long life time



Average Availability for Al-Jubail Plant Phase II (1983-2012)



Average Water and Power Load Factors for Al-Jubail Plant Phase II (1983-2012)

S.	Plants	Year	Capacity (migd)	Life Time
1	Jeddah-III	1979	4x5	32
2	Jeddah-IV	1981	10 x 5	32
3	Al-Jubail-I	1982	6 x 6.2	31
4	Al-Khobar-II	1982	10 x 6	31
5	Al-Jubail-II	1983	40 x 5.38	30
6	Al-Khafji-II	1986	2 x 2.6	27
7	Shoaiba-I	1989	10 x 5.06	24
8	Shuqaiq-I	1989	4 x 6.5	24
9	Yanbu-I	1981	5 x 5	32
10	Yanbu-II	1999	4 x 7.94	14
11	Al-Khobar-III	2001	8 x 7.5	12
12	Shoaiba-II	2002	10 x 10	11

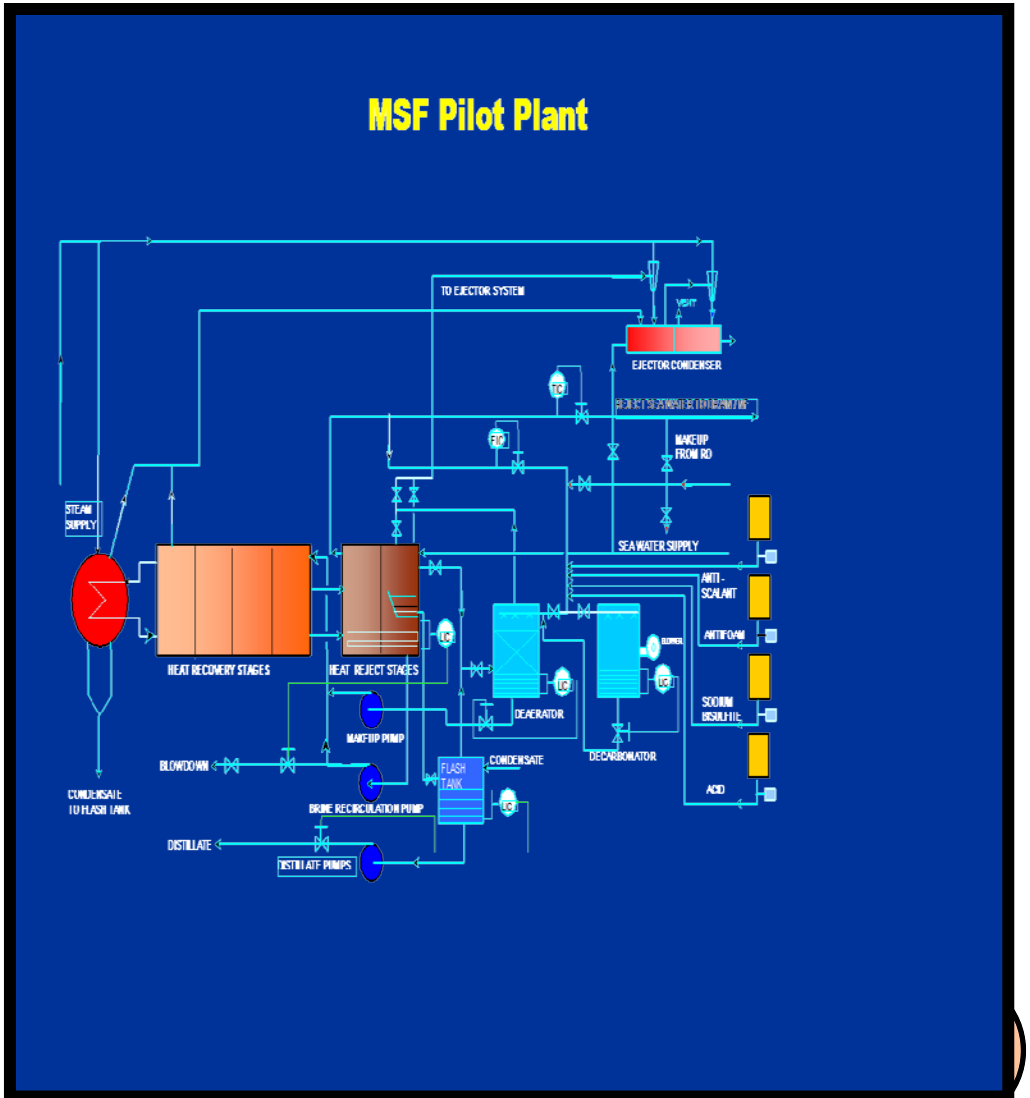
POTENTIAL FOR FURTHER DEVELOPMENT OF SCALE CONTROL IN MSF PLANTS

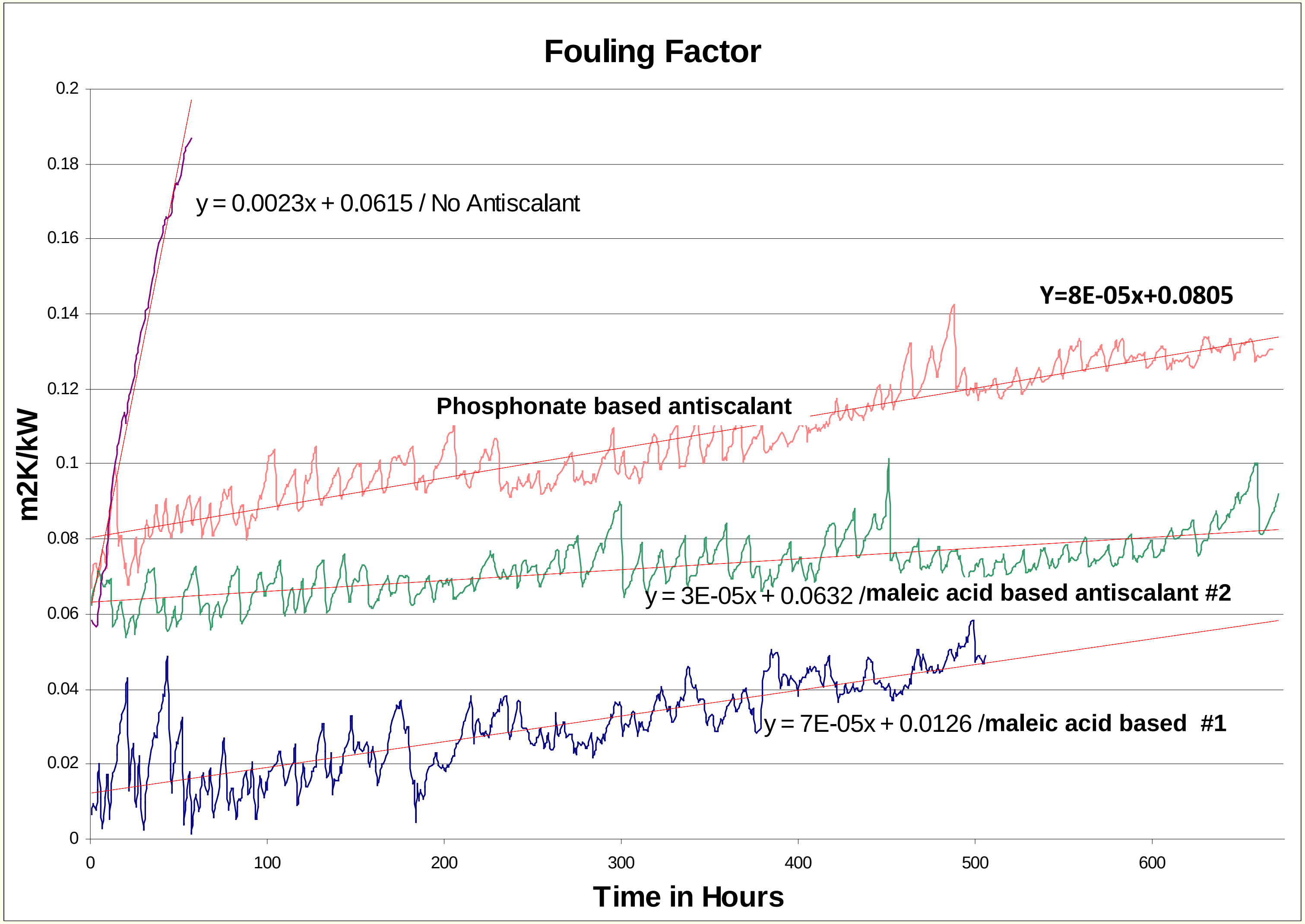
Employ currently available commercial chemical additives to extend the TBT of MSF distillers up to 115ºC

Currently available commercial chemical additives can be employed to operate MSF distillers up to 115°C

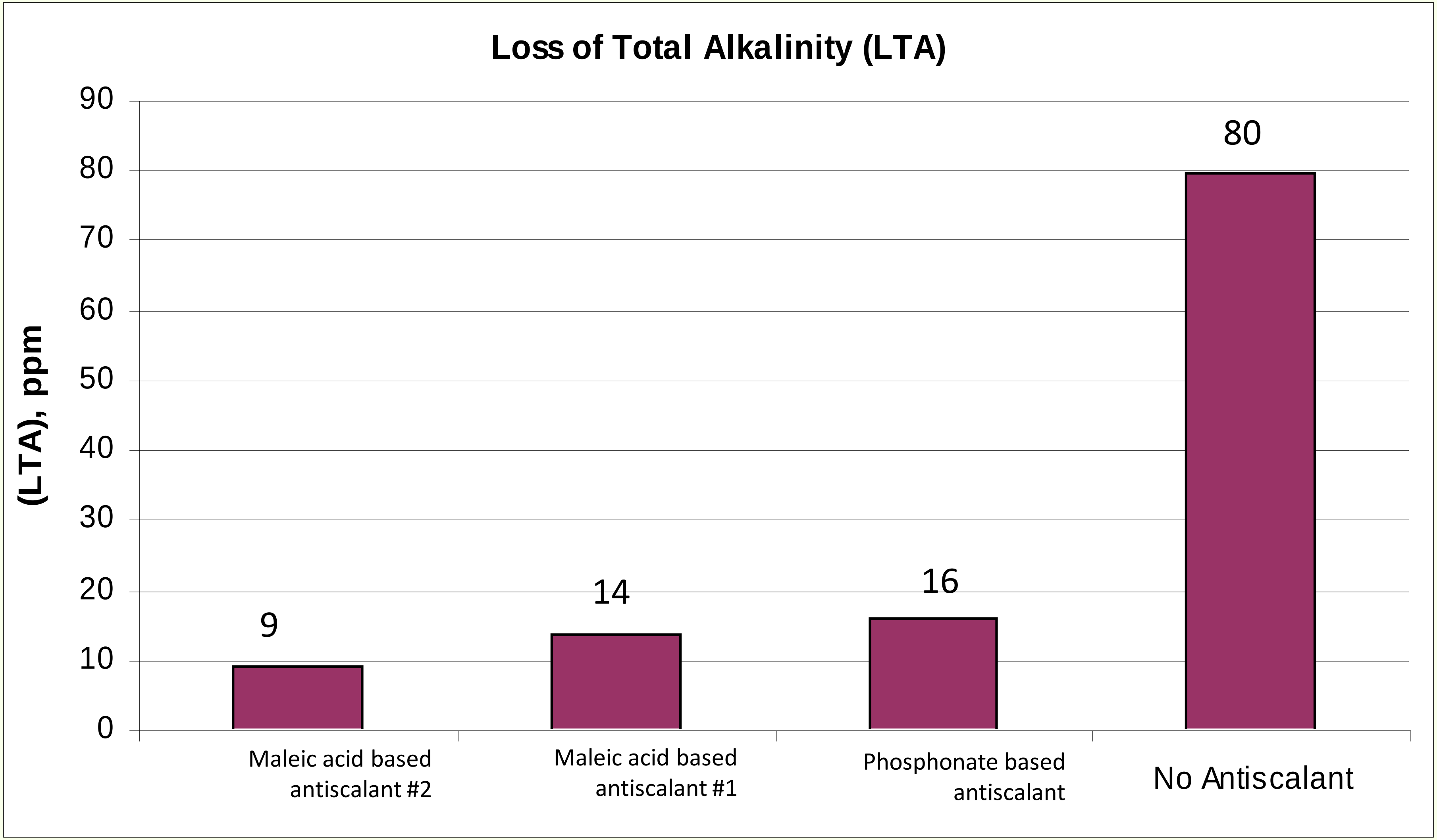
The MSF pilot plant at DTRI, Al-Jubail was used to study the performance of the three commercially available antiscalants which include two different maliec acid based copolymers and phosphonate based antiscalant under very harsh operating conditions

TBT of 119°C,
low dose rate of 1 ppm
and high concentration factor of 1.9 for a one month period.
A baseline test was also conducted without dosing any antiscalant at the same operating conditions





Fouling Factor
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
m2K/kW
y = 0.0023x + 0.0615 / No Antiscalant
Y=8E-05x+0.0805
Phosphonate based antiscalant
y = 3E-05x + 0.0632 /maleic acid based antiscalant #2
y = 7E-05x + 0.0126 /maleic acid based #1
0
100
200
300
400
500
600
Time in Hours

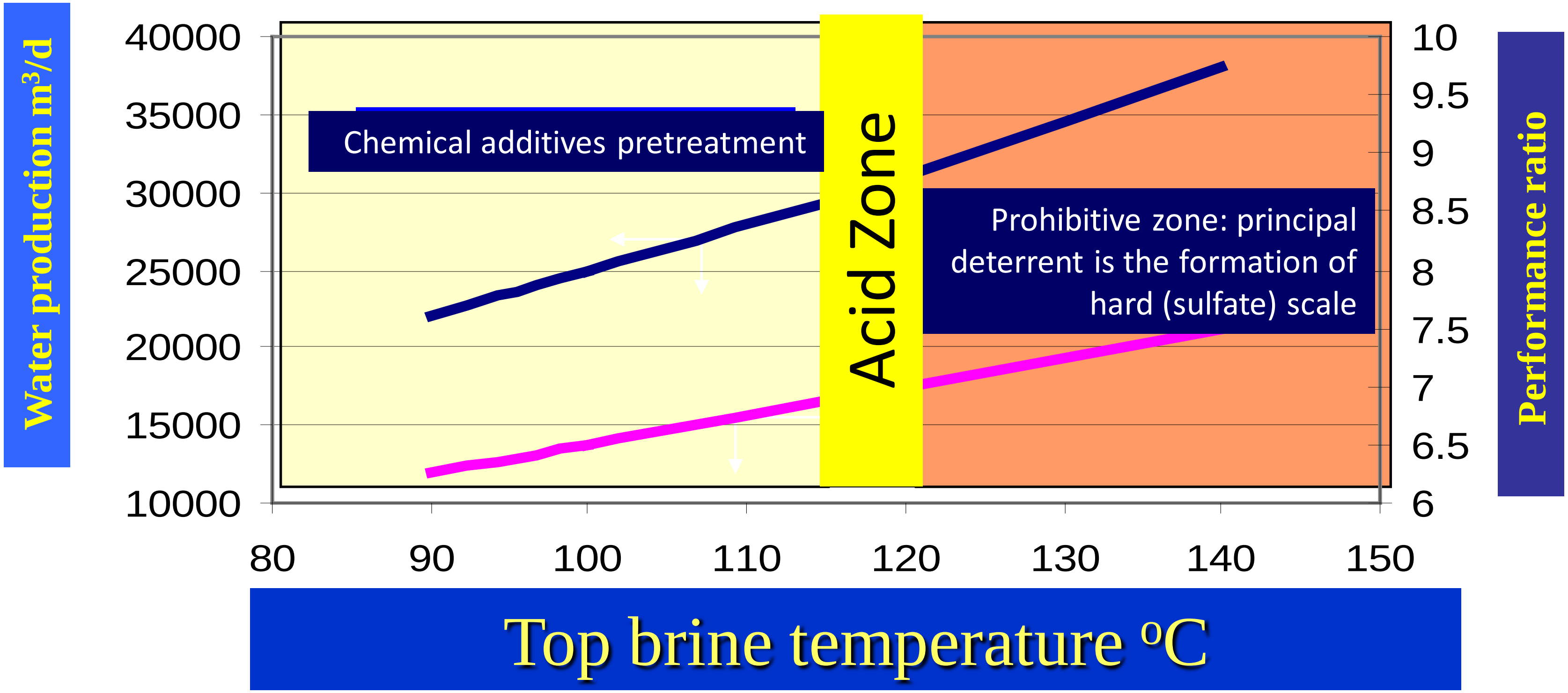


Loss of Total Alkalinity (LTA)
(LTA), ppm
90
80
70
60
50
40
30
20
10
0
9
14
16
80
Maleic acid based antiscalant #2
Maleic acid based antiscalant #1
Phosphonate based antiscalant
No Antiscalant

POTENTIAL FOR FURTHER DEVELOPMENT OF SCALE CONTROL IN MSF PLANTS

- Employ currently available commercial chemical additives to extend the TBT of MSF distillers up to 115°C
- Development of chemical additives that Inhibit calcium sulfate salt precipitation to extend the TBT of MSF distillers to More than 120 °C

PROSPECTS FOR FURTHER DEVELOPMENT OF MSF DESALINATION SYSTEMS



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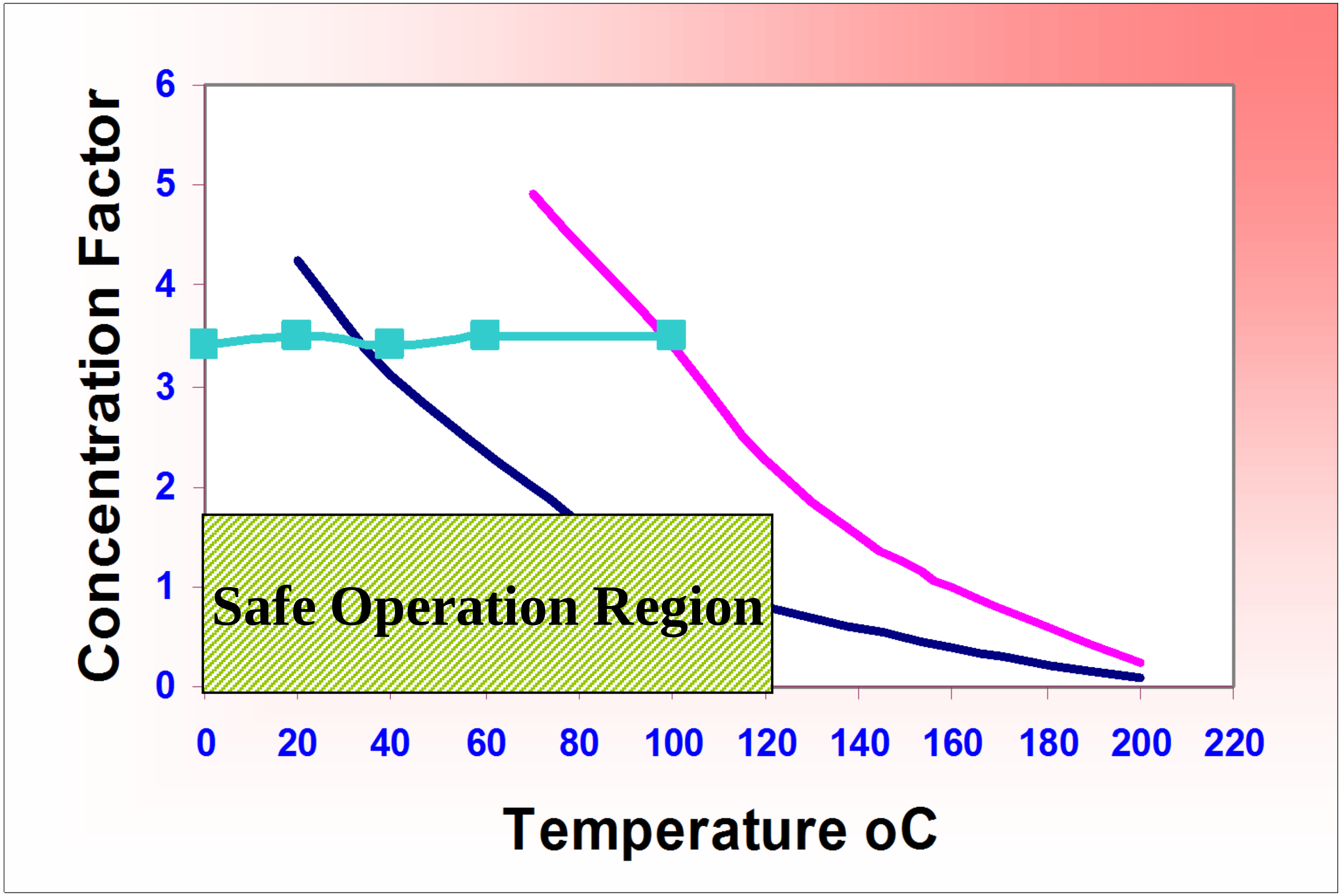
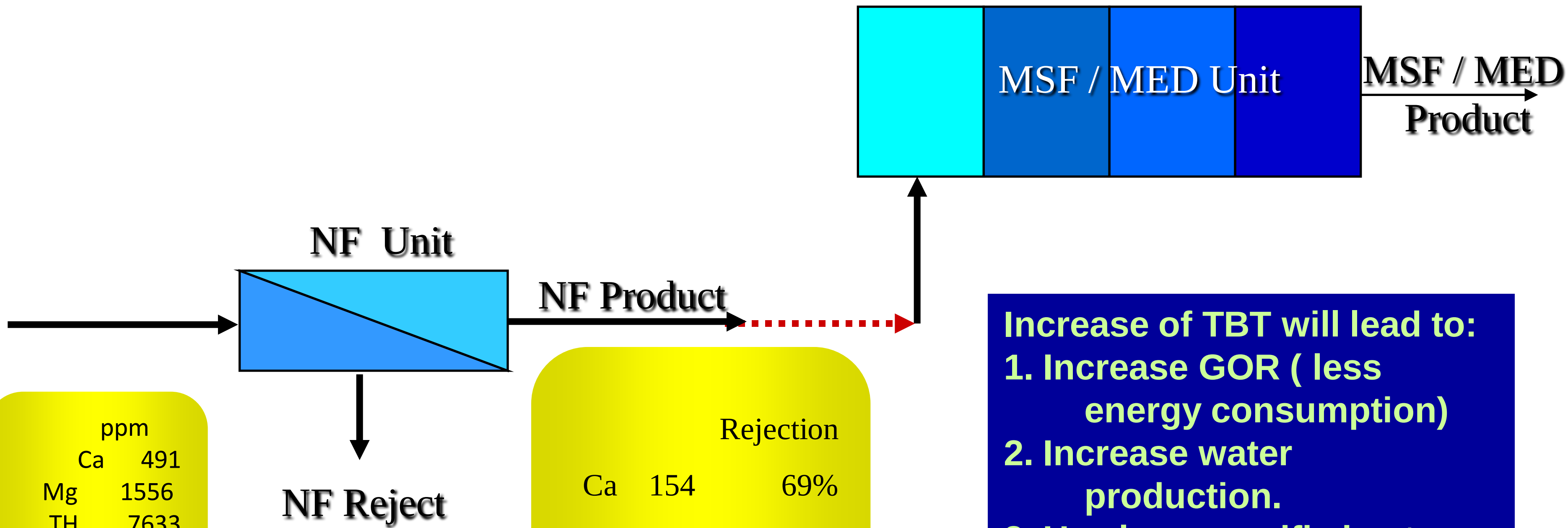
Solubility limits for three forms of calcium sulphate in seawater concentration



CONTROL OF NON-ALKALINE SCALE

- **By operation below 120°C**
  - Operate with low temperature and salt concentration not exceeding the solubility limits
- **By operation above 120°C**
  - Remove Ca^{++} or $SO4^{--}$ by Nanofiltration or Ion Exchange



	ppm
Ca	491
Mg	1556
TH	7633
HCO3	156
SO4	3309
TDS	45550

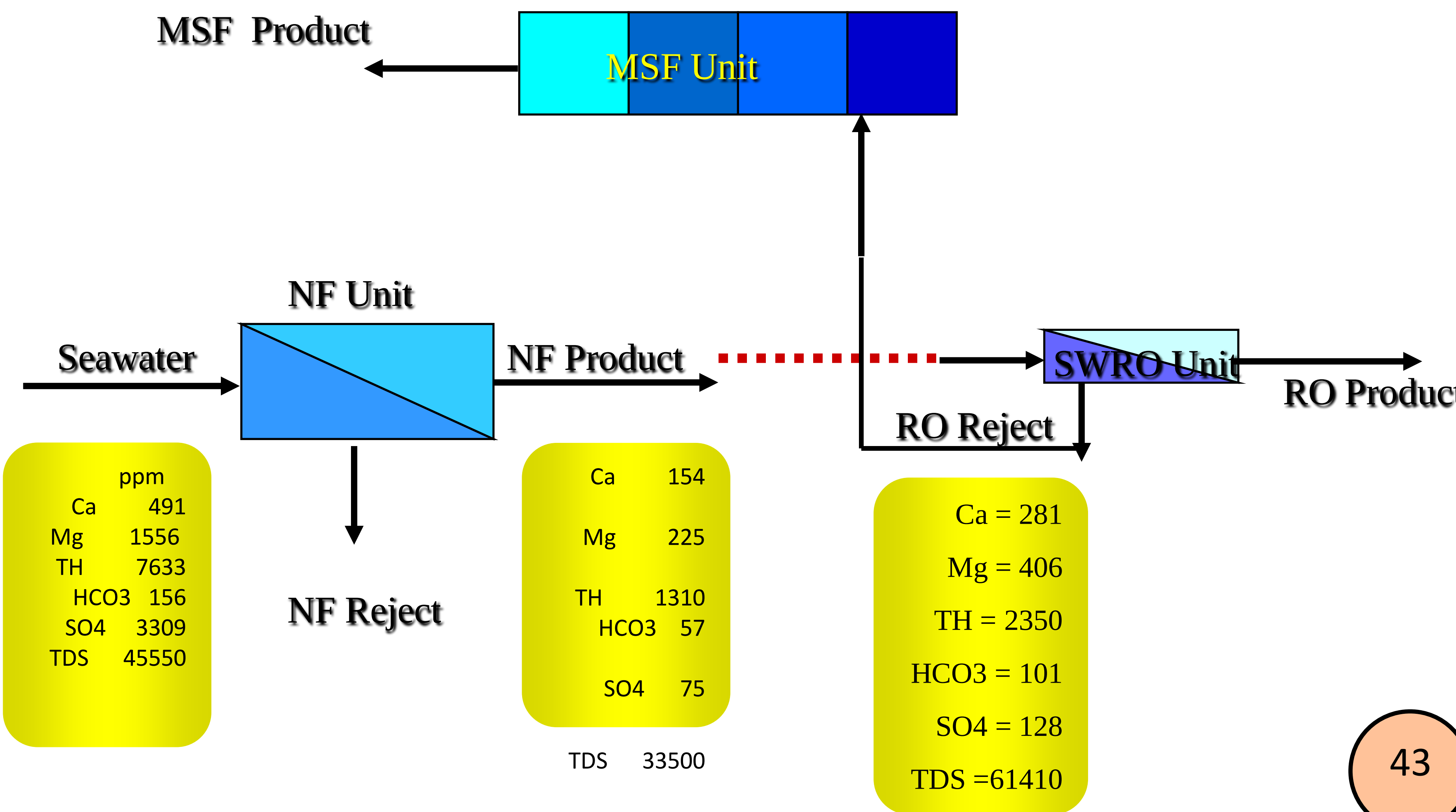
		Rejection
Ca	154	69%
Mg	225	86%
TH	1310	83%
HCO3	57	64%
SO4	75	98%
TDS	33500	26%

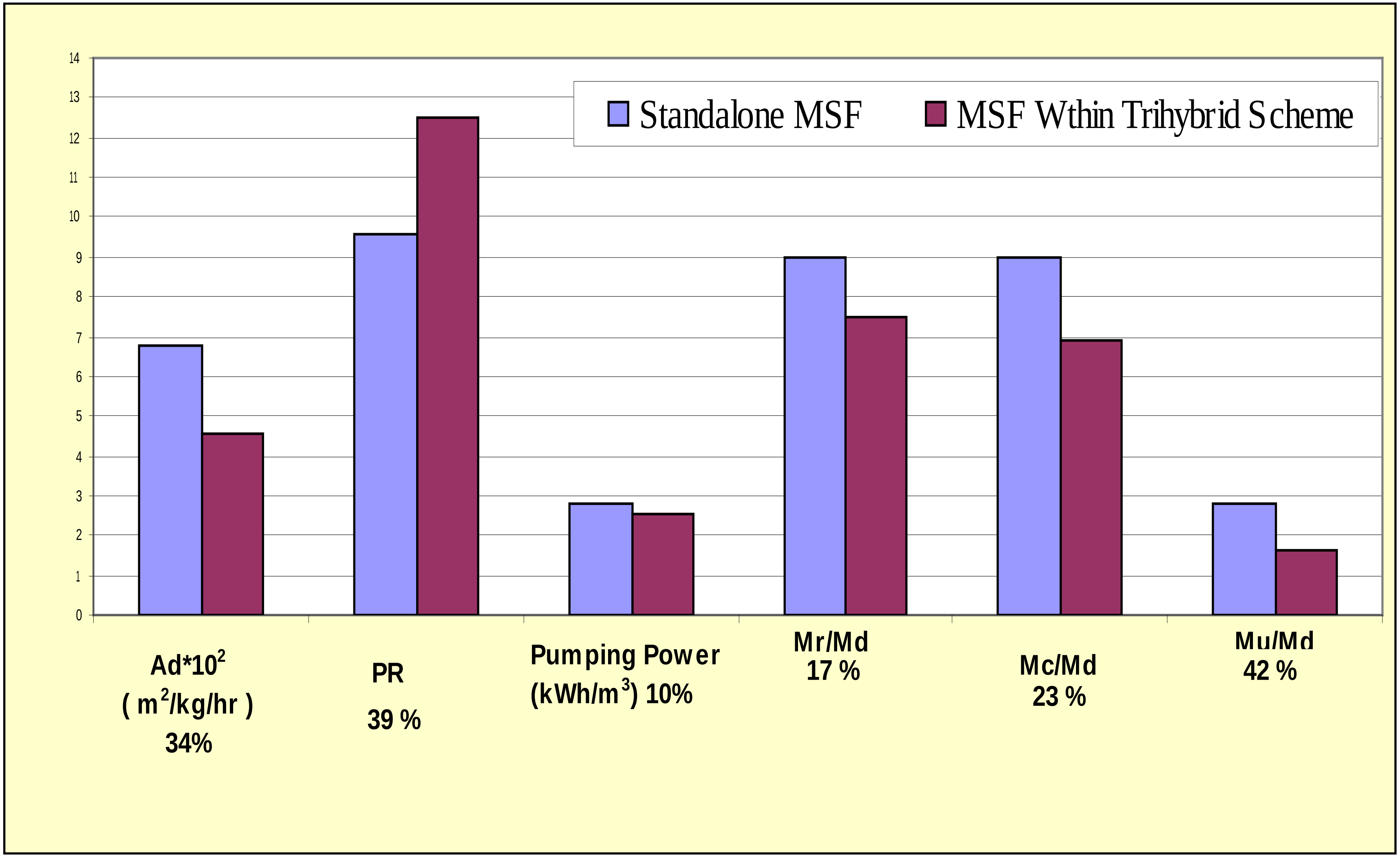
Increase of TBT will lead to:

1. Increase GOR (less energy consumption)
2. Increase water production.
3. Use less specific heat transfer area
4. Low vacuum duty
5. Less pumping energy
6. Decrease in demister size

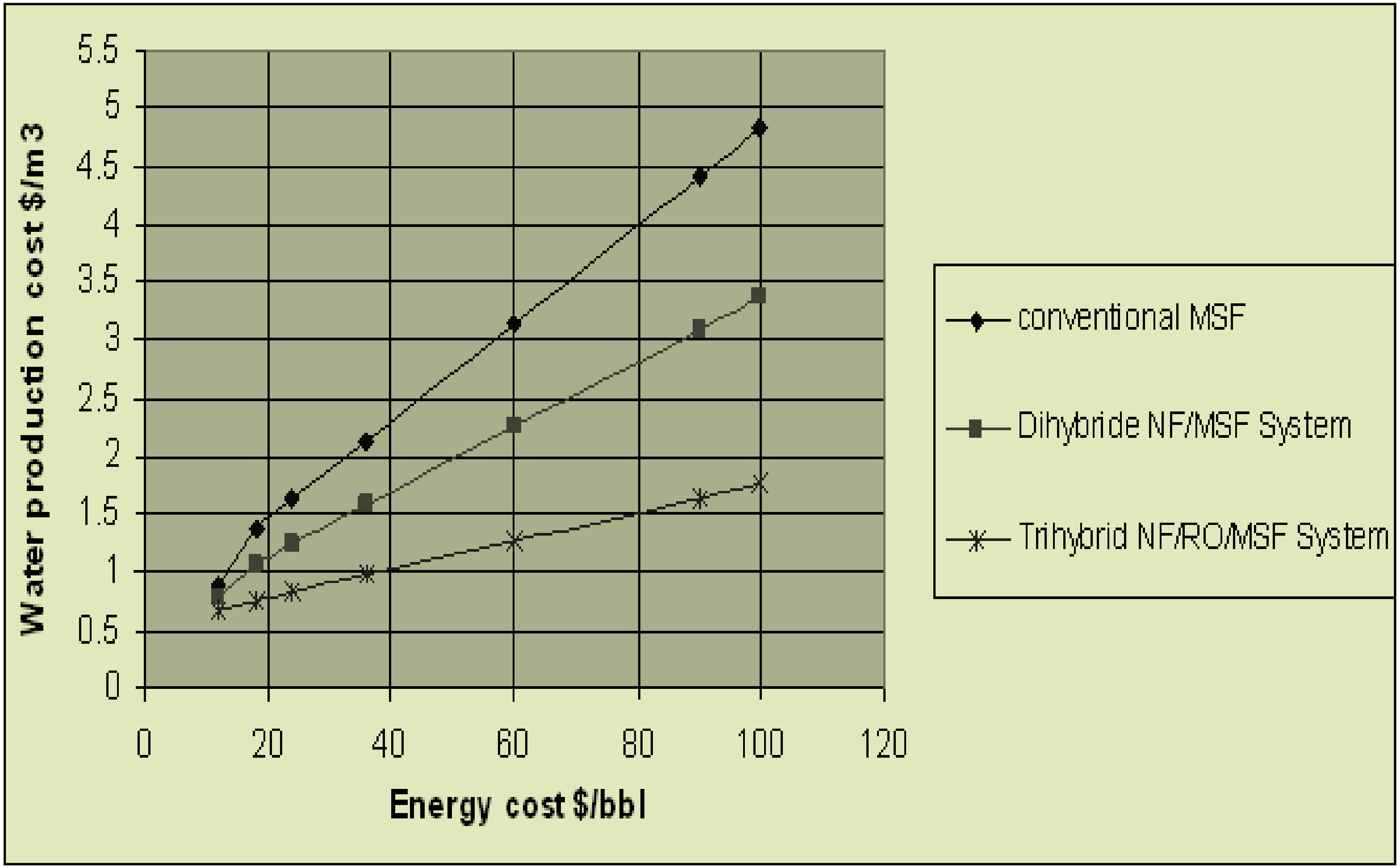
Removing calcium, magnesium, bicarbonate and sulphate ions in the raw seawater by NF membranes opened the possibility to be hybridized with either MSF, MED or RO processes

NF/RO/MSF Tri-hybird System



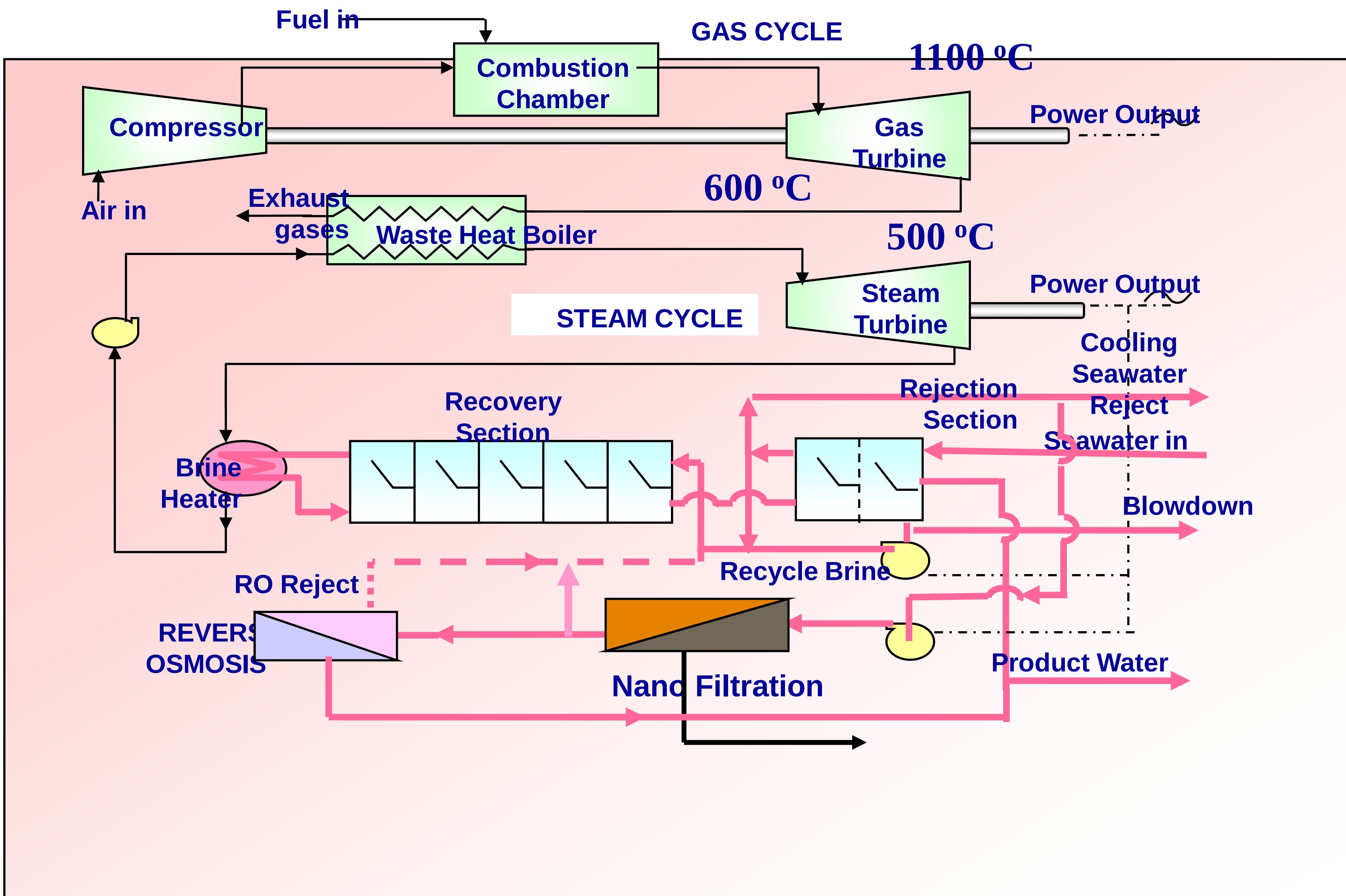


Comparison between the standalone MSF and MSF combined with NF/RO configuration



Impact of energy cost on water production cost

Conceptual design of an Improved Power/Water Cogeneration Cycle



LESSON LEARNT

- SWCC embarked upon a highly ambitious research program to optimize dose rate of chemicals which are frequently used in MSF distillers. Recommended antiscalant dose rates to SWCC in 1981 were 12.5 and 4.5 for top brine temperature (TBT) of 110 and 90^{o}C, respectively and are currently reduced to only 2.0 and 0.8 ppm for the respective temperatures.

LESSON LEARNT

- As the result of satisfactorily performance of scale control chemical additives, MSF distillers which are over 30 years old, instead of being derated due to ageing, actually maintained production and performance ratios that equaled or, in most cases, surpassed the original design specifications.. This in turn, enhances the cost effectiveness of MSF process.

LESSON LEARNT Continued……

- As a result of successful approach to control alkaline scale formation, design fouling factors less than 0.15 m^2K/kW can be safely employed in new additive MSF designs.

LESSON LEARNT

Continued……

- Employing on-line ball tube cleaning with a ball to tube ratio in the range of 0.22 to 0.45 proved to be a successful mean to augment the role of chemical additives to inhibit scale formation.

Thank You