Stewardship for Improving Potash Quality Strategic Implementation: “Conversion from Dynamic to Static Fluidized Bed Cooler”

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The Arab Potash Company

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SECTION ONE
Introduction

Company Overview

Arab Potash Company (APC) is the eighth largest potash producer worldwide by volume of production and the sole producer of potash in the Arab World. It also has one of the best track records among Jordanian corporations in the areas of work safety, good governance, sustainable community development, and environmental conservation.

Established in 1956 in the Hashemite Kingdom of Jordan as a pan-Arab venture, APC operates under a concession from the Government of Jordan that grants it exclusive rights to extract, manufacture and market minerals from the Dead Sea until 2058. In addition to its potash operations, APC also invests in several downstream and complementary industries related to Dead Sea salts and minerals, including potassium nitrate, bromine and other derivatives.

As a major national institution and economic contributor, APC employs more than 2,200 workers across its locations in Amman, Aqaba and Ghor Al Safi.Potash production began in 1983 and has since progressed with various schemes aimed at optimizing and expanding this production. The initial plant was built to a capacity of 1.2 million tones of product.

This was expanded in the late eighties to handle 1.4 million tones and key modifications were undertaken with the Solar System to enhance the production of the ore accordingly. A second plant based on different technology and of a capacity of 0.4 million tones was built in 1994 and this brought the total production capacity to 1.8 million tones. Then another cold crystallization plant of 0.45 million tones was built in 2010 and this brought the total production capacity to 2.45 million tones. Further expansion is currently under evaluation to bring the total potash capacity to 3.2 MMTP.

APC management recognizes that Safety, Quality & Environment are crucial for assuring business sustainability, profitability and growth, APC successfully achieved certificates of compliance of the following international and local standards: Occupational Safety and Health Management System Standard –OHSAS -18001, Environmental Management System Standard (EMS) -ISO -14001:2004, Quality Management System Standard (QMS) - ISO -9001:2000, Quality Management System Standard (QMS)- ISO- 9001:2000, General requirements for the competence of testing and calibration laboratories" standard-ISO-17025:2005 and Jordan Quality Mark.

The capital of the Arab Potash Company is 83.3 million Jordanian Dinars. It has a concession from the Jordanian Government to exploit, manufacture, and market the mineral resources of the Dead Sea, until 2058.

The Arab Potash Company employs over 2000 personnel and has offices in Amman, Safi and Aqaba. It owns extensive housing and recreational facilities near its plants, and in addition, it provides the surrounding region with assistance in social, medical, economic and vocational development.

Potash Production Process Description

At the heart of the Ghor El-Safi site are a 112 km^2 solar evaporation ponds system and ore processing plants. The brine from the Dead Sea is pumped at a yearly average rate of 350 million t/a into the solar evaporation system by main intake pumping station, where the initial concentration process is undertaken at the salt ponds where NaCl deposits. The remaining brine is pumped into the Carnallite ponds, to precipitate the raw Carnallite.

The precipitated raw Carnallite is the raw material for producing potash is precipitated as mixture of Carnallite ($KCl.MgCl2.6H2O$) and NaCl. This bed is harvested as a slurry from beneath the brine and delivered to booster pumps on the dikes and then to the refinery through floating pipes.

The Raw Carnallite is harvested and pumped to three refineries. The original plant employs hot leach technology to process the Carnallite to extract potash, but the newer facilities employ cold crystallization.

In the hot leaching unit, the Carnallite slurry is received, dewatered and decomposed in two stages in an agitator tanks. The resulting solids from the decomposition are a mixture of potassium chloride and sodium chloride: this mixture (known as Sylvinite) is dewatered and washed. The resulting cake is conveyed to the Sylvinite processing stage.

In the next Sylvinite processing stage, the Sylvinite cake is leached by heated lean brine to crystallize at draft tube crystallizers. Then the potash slurry from the last-stage crystallizer is directed to dewatering process (cyclones, centrifuges and dryer). In the drying stage, the cake from the centrifuges is conveyed to an oil-fired rotary dryer to remove the last traces of moisture entrained with the crystals. From the dryer, the product is sent to a fluidized bed cooler and then to the screening system, while the dust is collected, using a cluster of high-efficiency cyclones and bag filter system.

Anti-caking agent is added in carefully controlled amounts to minimize the natural tendency of potash to agglomerate during storage and shipment. Free-flowing properties are thus ensured to facilitate handling of these products by the customer.

The second processing plant introduced the cold crystallization process. This plant (CCP-1 & CCP2) operates separately from the hot leach refinery and is operated at ambient conditions, with a lower energy requirement. In the process, the carnallite salt is firstly beneficiated by wet screen to obtain coarse carnallite. The process is utilized the flotation technology where fine carnallite is beneficiated in which sodium chloride is floated and pumped to the tailings area. In the crystallization stage, coarse carnallite and fine carnallite are decomposed in crystallizer system in the presence of water. Potassium chloride crystals are formed in the crystallizers. Crystallization unit is being feed to cold leaching stage to remove adhering high $MgCl_2$ brine from the crystallizer product, the product is followed by the dewatering stage. The dryer product is then cooled in a rotary cooler and conveyed to the potash storehouse after adding anti_caking reagent.

In CCP2, a new compaction plant has also been installed to produce more than 250,000 ton per year of high-quality potash. The new compaction plant comprises a post-treatment unit that enhances the quality of granular potash.

Section Two

Background

Potash demand, like most commodities, is cyclical. However aggregate demand graphs indicate an upward trend. For instance, global demand in 2000 was 40 million tons. By 2005 demand increased to 50 million tons before plateauing at 60 million tons in recent years. Analysts project demand to further increase to 70 million tons by 2020. In retrospect, the recent macroeconomic conditions of the market have presented APC with several challenges. To mitigate these risks a strategic decision was implemented to further reduce APC running cost while improving potash product quality through our Fluidized Bed Cooler conversion initiative. This ensured that regardless of potash market prices and demand, we were able to maintain healthy margins offset the cyclical nature of the market.

The unique characteristics of potash can present challenges during processing. Potash is hygroscopic; it easily absorbs and retains moisture from the environment. Consequently, potash is prone to clumping and sticking during processing.

Potash is usually stored in warehouses that have no temperature and humidity control. During storage and transportation, potash may experience large temperature and humidity changes. Moisture accumulation on potash surfaces will penetrate toward the inside of a potash bed over time. For this reason, significant quantities of potash are wasted due to caking.

In general, caked potash is caused by: -

- Improper anti_caking mixing & addition.
- Product Temperature.
- Storage & Transportation Conditions.

Section Three

a. Methodology

Therefore, a systematic and organized process action plant has been developed to reduce the impact of the main causes of potash caking, this include, improve the reliability of equipment, review all downtime incidents, monitor the process parameters and replace major equipment with more reliable efficient such as anti_caking mixing system of standard grade, dedusting system and HLP cooling system..

Standard potash product temperature from the cooler was relatively high (Avg. 99^{o}C) compared with the optimum temperature of anti_caking reagent addition point (82 ^{o}C) to ensure efficient mixing and to avoid amine flashing.

HLP Dynamic Fluidized Bed Cooler Performance

Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Inlet	210	180	182	180	181	186	181	197	185	183	179	180	195	189	186
Outlet	99	99	99	97	95	102	105	103	102	98	99	97	98	97	99

To overcome hot potash product, a complete overhaul had been carried out for the dynamic fluidized bed cooler, nevertheless the performance and the on stream factor quiet low, therefore a decision has been taken to replace the existing dynamic fluidized bed cooler by a modernized high efficient type, consequently a comprehensive study has been carried to select the suitable cooler type.

Four types of coolers were available in the market; column, rotary, dynamic and static fluidized bed. These four coolers presented APC with nine options for installation illustrated below: -

1. Two Rotary Coolers after screens.
2. Two Rotary Coolers before screens.
3. Fluidized bed cooler after screens (The bed contains tube bundles supplied with brine).
4. Fluidized bed cooler after screens (cooling of the product just with ambient air).
5. Fluidized bed cooler after Dryer (cooling of the product with ambient air and liquid media).
6. Column Cooler after screens.
7. Column Cooler before screens.
8. Dryer & Cooler Unit Before screens.

The criteria for selection was Safety, operational reliability, steady control, easily interfaces with newly installed DCS, low maintenance & operating costs and life span. The most crucial criteria for selection were a proven track record for implementation at fertilizer plants.

	Advantages	Disadvantages
Rotary	• Robust and proven equipment	• High capital. • Bad maintenance Conditions. • Heavy – demand complicated steel construction. • High power consumption.

		• Significantly required space.
Column	• Robust equipment. • No moving parts. • Small foot print.	• None proven equipment in potash. • Tube bundles are in direct contact with potash. • Bad maintenance conditions.
Static Fluidized Bed	• Robust and proven equipment • No moving parts.	• High power consumption. • Significantly required space.
Dynamic Fluidized Bed	• Robust and proven equipment0	• High capital. • Bad maintenance Conditions. • Heavy – demand complicated steel construction. • High power consumption. • Moving parts.

Meanwhile, the column has the highest advantages and the lowest disadvantages, the merely concern was its proven technology in potash industry.

b. **Pilot Tests: -**

Based on the above, APC invited the manufacturer companies of column coolers who are leaders in this field to offer comprehensive pilot scale column cooler. Two offers have received to install a column cooler pilot scale.

The objective of carrying out the pilot trial testing using column cooler to cool HLP dryer product discharge to acceptable temperature in order to provide on-site evaluation of the column cooler for cooling potash under typical process conditions. The test will be configured to simulate as closely as possible the conditions and operation of the full size equipment. This pilot test has an intended run period of approximately one work week minimum and will target the following objectives: -

- Demonstrate that the cooling capability and operating parameters confirm APC modeling.
- Evaluate pilot unit operation under typical process conditions

- Confirm that the product will flow at the selected heat exchanger plate spacing and that mass flow is achieved and maintained with the selected discharge device
- Verify that no build-up or scaling forms on heat exchanger surfaces.

Pilot Testing

Test Conditions

Product Flow:	350-700 kg/h	Cooling Medium:	Brine, process water
Plate Spacing:	28mm (centers)	Dry Air Purge:	Testing with purge air

Cooling was achieved at every stage of testing. A variety of scenarios were simulated to give an overview of experimental operation ranges. The following table gives a summary of findings.

Test Results

			Temperature KCl			KCl	Cooling medium						
			in	out	Δ cooling	flow rate	in	out, upper	out, lower	ΔCM upper	ΔCM lower	flow rate upper bank	flow rate lower bank
Run	CM	Run time	[°C]	[°C]	[°C]	[kg/h]	[°C]	[°C]	[°C]	[°C]	[°C]	[m^3/h]	[m^3/h]
1	B 1)	3h	231	50	181	465	28.8	38	31	9.4	1.7	1.7	1.3
2	B 2)	1:30h	203	40	162	508	39	47	39	8.1	1.4	1.5	1.4
3	B 2)	1:30h	222	47	176	422	39	45	42	6	3	1.3	1.2
3 a	B 2)	0:30h	208	44	164	530	38	51	40	13	2	0.9	0.7
4	B 3)	1:45h	223	54	169	515	37	48	42	11	5	0.6	0.6
6	H_2O	3h	230	33	198	409	23	30	26	7	3	1.1	0.6

Based on the above results, the column cooler gives the impression that it is a suitable method for cooling potash, it offering efficient cooling capabilities and convenient operating conditions, the main findings are: -

- The flow of the material was smooth and uniform.
- No stable or semi-stable arches formed anywhere in the unit.
- Mass flow was clearly established.
- Heat exchanger plates were clean and residue free.
- Use of dry purge air prevented scaling on plates

The main challenges during the pilot tests were how to maintain dew point of air in void space below plate temperature to avoid condensation on exchanger plate surfaces. The major output was caking of potash on the plates which leads to: -

- Loss of performance.
- Frequent stoppage for the sake of frequent cleaning.

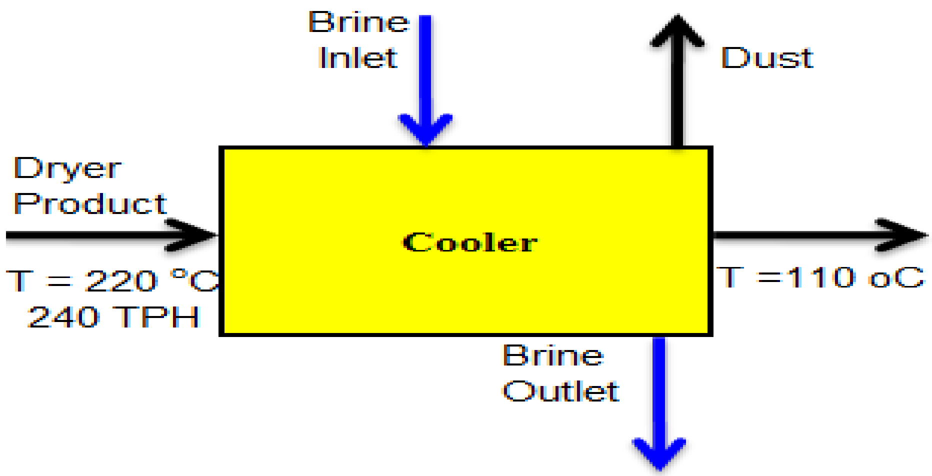
To avoid caking phenomena and afterward analyzing the results, it has been decided that a static fluidized bed was cooler best suited APC needs. The scope of supply included replacement the existing vibrating fluidized bed cooler at the Hot Leach Plant (HLP) with one static fluidized bed cooler in a step to relocate the position of the cooler to cool down all dryer products instead of cooling only standard product. At the same time, the plant shall be expanded by an additional third product screen. However, this issue is not further considered in this paper.

Section Four

Static Fluidized Bed Cooler:

a. Design Criteria

The detailed engineering scope of work has included installation a static fluidized bed cooler in the HLP in order to replace the existing dynamic fluidized bed cooler. The project will essentially include certain modifications in the existing layout of the screening building which embraces the dynamic fluidized bed cooler. The new static fluidized bed cooler shall be designed to handle the entire discharge of the existing rotary dryer at around 220 °C and to cool it down to around 90 °C. The new cooler shall have a capacity of around 240 tons per hour and it shall be equipped with means to produce a cooled product with controlled temperature in the range of 80 – 110 °C to cope with variations in ambient temperature from 5 – 45 °C and dryer product temperature of 170 – 230 °C.



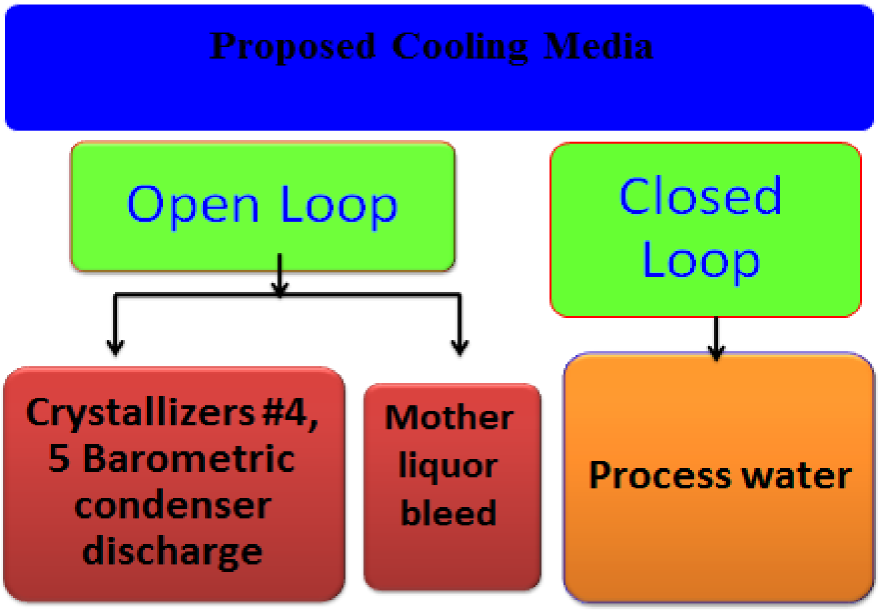
However, the design should take into consideration that no excessive cooling takes place. This requirement is needed to allow for melting the anti-caking reagent added at a downstream stage which typically has a melting point of around 70 ºC. For this purpose, the material (potash) should not be cooled lower than 90oC even in the cold season and even when the production rate falls significantly below 240 tph.

Moreover, the output of the design criteria should consider the following objects during the planning:

- Minimized amount of mechanical conveying equipment.
- Utilization of existing conveying equipment (screw conveyer)
- Utilization of the existing building stock as far as possible to reduce the reconstruction scope for structural engineering.
- Reducing production downtimes during reconstruction.
- Automated operation by using remote-controlled actuators.

Furthermore, the basic engineering design stage of the static fluidized bed cooler included selection of loop type (open or close), cooling media, material selection, de_dusting system selection, Minimized amount of mechanical conveying equipment, utilization of existing conveying equipment, utilization of the existing building stock as far as possible to reduce the reconstruction scope for structural engineering, reducing production downtimes during reconstruction.

The most critical point during basic engineering design was the selection of the cooling loop type (open or close) and the cooling media as illustrated below, an intensive study has been carried out to determine the most suitable option, the advantage and disadvantage of each option have been determined: -



1. <u>Close loop</u>: -

- The cooling media will be Water with an approximate quantity of 340 m3/hr. min. @ 38 °C, the calculated return water temperature will be 49°C min. and the estimated make up water will be 5% Max.
- The main concern will be increase the Heat Load on the plant cooling towers which are almost working at their maximum heat load in the Summer time.
- Adding an extra 340 m3/hr with heat load which is about twice the current load will be impossible.
- Thus, a proposal of enlargement of the existing cooling tower and the pumping station has been studied by installing a new cooling tower in the HLP with a capacity of 400 m^3/hr to cool down the return water, the study findings indicate that proposed option is unprofitable due to: -
    1. High capital cost.
    2. High running cost in terms of operation and maintenance.
    3. Approx. double equipment efforts.
    4. High space requirement
    5. Complicated dense measurement devices and control system.

2. Open loop: -

- This option is simpler than closed loop, but the critical point was the selection of the cooling media, two cooling brine options have been studied.

1. Mother liquor brine: -

The mother liquor cooled brine is pumped to barometric condensers of the first four crystallizers in series counter currently with crystallizers' content flow, i.e., overflow and underflow.

The main advantages and disadvantages of using this brine source are: -

Advantage	Disadvantages
• Close Cooling brine source.	• Rich KCl Brine.
• Less Corrosive brine than carnallite brine.	• Higher brine temperature will negatively effect decomposition process.
	• No heat recovery and will negatively affect crystallization yield.
	• More pump head is required.

2. Crystallizers #4, 5 Barometric Condenser Discharge

Clarified carnallite overflow is pumped to the barometric condensers of crystallizers # 4&5 where downstream heat removal takes place then then, to carnallite pan C4. This source is high corrosive (high $MgCl_2$).

The main advantages and disadvantages of using this brine source are: -

Advantage	Disadvantages
• Purge Brine (will not affect plants process)	• Highest brine feed temperature in summer season.
• Closet Cooling brine source.	• High corrosive brine.
• Easy to discharge outlet brine (by gravity to tails tank).	• No heat recovery.
• Simple measurement devices & Control System.	
• Lower space requirement.	

The findings of the loop selection study are summarized in the below table:

	Advantages	Disadvantages

Open Circuit	• Simple. • Fewer measurement devices. • Less control. • One cooling media will be used. • Less Maintenance. • More space.	• High corrosive cooling media. • High requirements for cooler material.
Closed Circuit	• Low corrosive cooling media. • Low requirements for cooler material.	• New Cooling tower required. • More equipment (secondary cooler is a must). • More control technology. • Two cooling media will be used: water & Air. • Controlling product temperature is not easy. • High operating cost due to: - • Losses of makeup (~5%). • Treated water.

Final conclusion: -

- Using open loop technology relative to close loop is better.
- Use Carnallite thickener O/F brine after cooling on the barometric condenser #5.
- Select suitable material of construction as titanium grade 11.

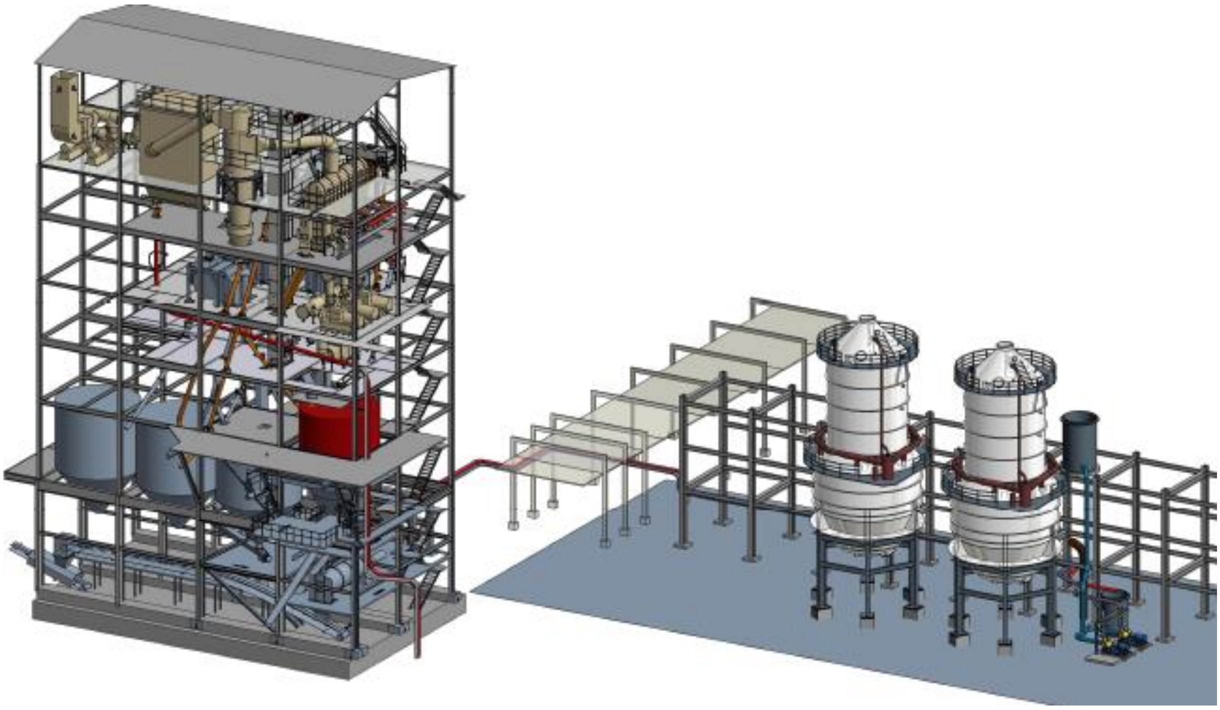
b. Project Components

The basic engineering design has determined the project component with equipment specifications, purchase requisitions have been issued for different international suppliers and based on the technical and commercial evaluation purchase orders have been issued to suppliers as illustrated in the below table:

#	Equipment	Supplier
1.	HLP fluidized bed cooler equipped with dedusting system	Andritz Fliessbett Systeme GmbH
2.	Bucket elevator, Drag conveyor, Slide gate valves - hand wheel and the Slide gate valve – pneumatic	EMDE Industrie - Technik GmbH
3.	Cooling pumps	WEIR SOLUTIONS FZE
4.	Steel structure	Temme-industriebau
5.	Manual valves	IWZ Wolfgang Zierz
6.	Chutes	Hoffmeier Industrieanlagen

		GmbH
7.	Instrumentation & Electrical devices	MATEC Elektro- und Automatisierungsanlagenbau GmbH
8.	Frequency inverter for pumps	Vacon
9.	Fiber glass pipe lines.	STEULER-KCH GmbH
10.	Insulation material	Local supplier/ Negemco

c. **Detailed Engineering Design**



Section Five

Dismantling and Installation Of New Fluidized Cooler With All Accessories

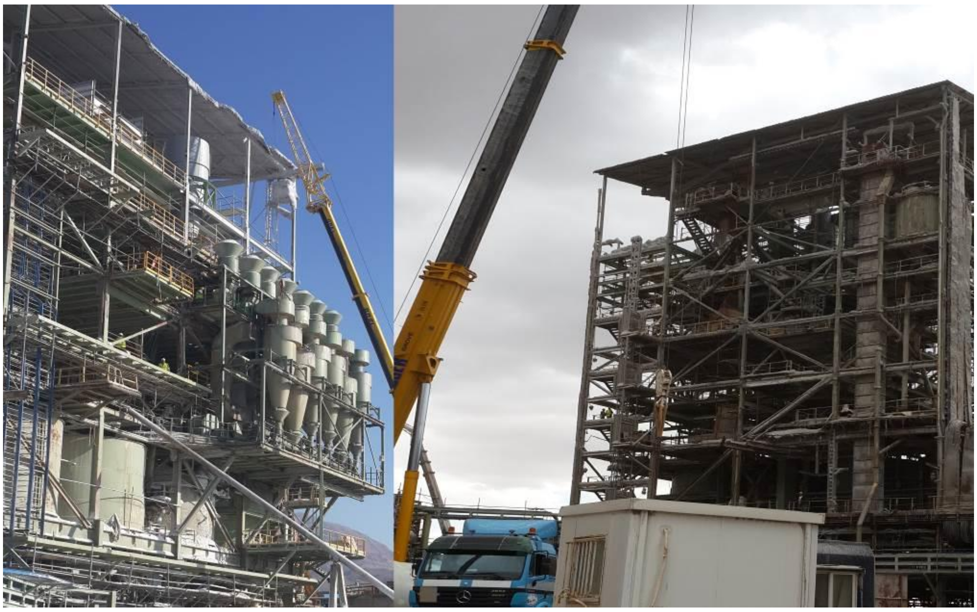
The Arab Potash Company has decided to carry out the installation of the New Fluidized bed Cooler with all related accessories and new steel structure at Hot Leach Plant during the schedule shutdown of Feb. 2016.

It had been agreed to carry out the works in two phases to reduce the time required for shutdown: -

Phase	Duration	Plant status
One	29/11/2015 to 27/2/2016	During plant operation
Two	28/2/2016 to 7/4/2016	Major shutdown

The Arab Potash Company assigned local contractor to carry out the installation works of the new fluidized bed cooler, the works included safe dismantle existing machinery and steel structure and install a New Fluidized bed Cooler with all accessories and new steel structure at Hot Leach Plant as described below: -

1. **Safe dismantling of Existing machinery and transfer them to APC scrap yard**
    - 7 cyclone and related accessories including fans.
    - 5 screw conveyors.
    - Three supply Fans.
    - 7 Exhaust Fans.
    - Cooler with dimension 9.15mt X 2.70mt at Elevation 20.35 and weight approx. 24 ton and related accessories.
    - Various Chutes at various levels.
    - Safe dismantling of Existing steel structure and transfer them to APC scrap yard.
    - Grating and checkered plates.
    - Roof steel structure and cladding.
    - Handrails.



2. **Installation of steel structure: -**
   - Welding Reinforcement Plates on Existing Columns
   - New steel structure.
   - New Checkered Plates.
   - New Handrails.
   - New stairs.
   - Touchup paint for new steel structure.
   - Reinstallation of Steel Roof.
   - Reinstallation of Roof Cladding.

3. **Installation of new equipment's**
   - Cooler the estimated weight is 14.5 ton - C301
   - Cyclone the estimated weight is 5 ton - F-501 with insulation
   - Bag Filter the estimated weight is 13 ton - F 502 with insulation
   - Trophy chain conveyor at Elevation 34,15 - H401
   - Screw Conveyor starting from level 18.85 up to 20.35
   - Bucket Elevator from elevation 20 up to 39 - H402.
   - Various Chutes at various levels without insulation.
   - Intake Air Filter.
   - Intake air fans (V201 A/B/C).
   - Pumps (P001 A/B).
   - Exhaust air fans(V202 A/B).
   - Valves including rotary valve.
   - Intake Air Silencer X 702, Exhaust Air Silencer X 701, Distribution Bin x 801 and Magnetic Separator FO11,12 & 13.
   - Instrumentation.
   - GRP Pipes including Fittings and lamination works (the material will be loose material).
   - C.S (1" , 2") Pipes and Fittings including supply material.
   - Air compressor.

Section Six

Pre_ commissioning & Commissioning Stage:

The local contractor has carried out the scope of work under the supervision of equipment suppliers and the design engineering company: -

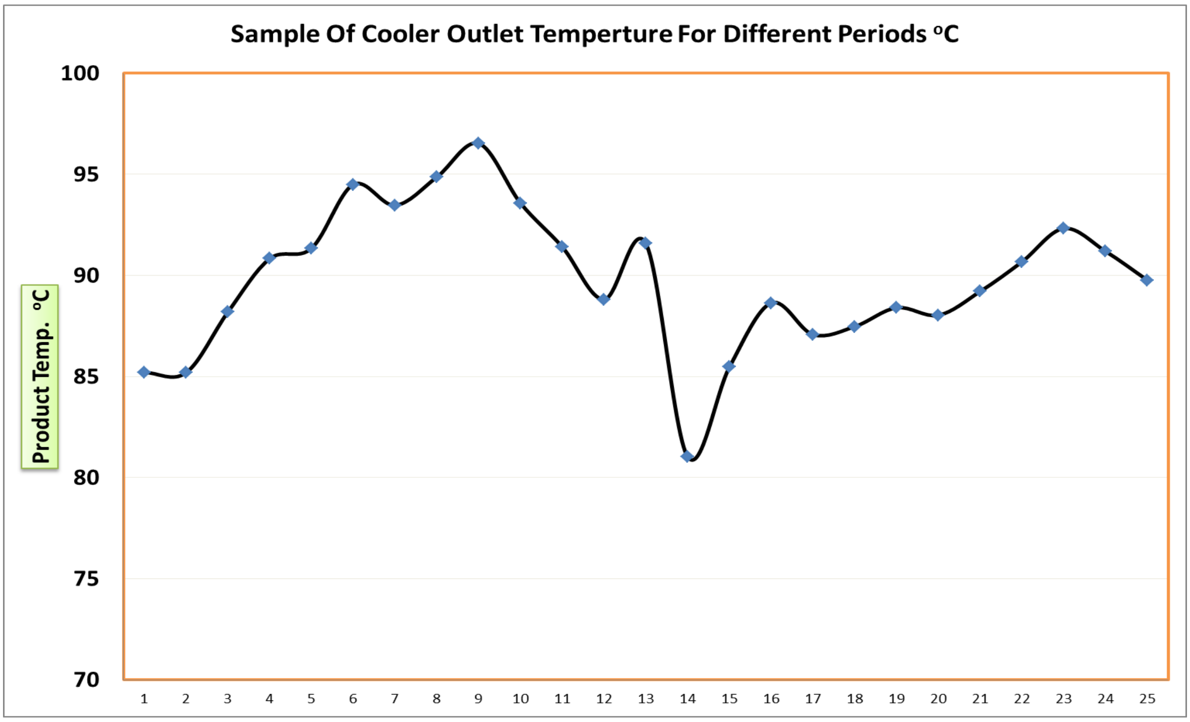
- Andritz/ cooler with all ancillaries.
- EMDE/ drag conveyer and bucket elevator.
- E&I: Matec.
- Ercosplan.

- During installation works, APC, equipment suppliers and the design engineering companies issued snag lists to ensure save and proper installation works.
- APC commissioning team had issued the takeover snag list to contractor on April 10th, 2016.
- Contractor had completed the commissioning snag list on May 10th, 2016.
- The wet commissioning of the cooler has been started on May 16th, 2016.
- The cooler system performance is satisfactory; it's working smoothly, there is not any major failure of the cooler system.

Performance Test Results

DESCRIPTION	Tag No.	UNIT	Run 1	Run 2	Run 3	Run 4	Run 5
Dryer Feed Rate	WI-4960	tph	184	185	193	193.5	176.1
Dryer Product Temp.	TI-6406	°C	202	204	205	207.5	206.9
Cooler Feed Temp.	TI-8420	°C	180	181	183	184.1	183.5
Cooler Inlet Brine Temp.	TI-8313	°C	56	55	55	53.07	52.34
Cooler Inlet Brine Flow Rate	FI-8312	m^3/h	272	276	284	284.6	290
Cooler Chamber 1 Outlet Brine Temp.	TI-8322	°C	76	75	76	74.68	72.87
Cooler Chamber 2 Outlet Brine Temp.	TI-8328	°C	68	67	67	66.05	64.85
Cooler Chamber 3 Outlet Brine Temp.	TI-8325	°C	63	62	62	60.43	59.43
Cooler Chamber 4 Outlet Brine Temp.	TI-8331	°C	60	59	59	57.41	56.51
Cooler Chamber 1 Outlet Product Temp.	TI-8419	°C	136	138	139	138	137.3
Cooler Chamber 2 Outlet Product Temp.	TI-8418	°C	0	0	0	0	0
Cooler Chamber 3 Outlet Product Temp.	TI-8417	°C	86	86	87	84.91	84.07
Cooler Chamber 4 Outlet Product Temp.	TI-8112	°C	77	77	77	74.78	73.68
Cooler Product Outlet Temp.	TI-8427	°C	74	74	74	71.75	70.67
Cooler Exhaust Gas Temp.	TI-8423	°C	123	124	125	125	123.4

- During start up, cooler product outlet temperature was relatively low, therefore two brine chambers have been closed to control the product temperature.



Conclusion & recommendations:

The project is successfully installed and commissioned during May 2016: -

- The new cooler has been operated based on best practices to cool HLP dryer product from 220°C to 100°C.
- The overall Equipment Effectiveness (OEE) has increased and thus less production losses.
- Dust content with end product and emissions of dust are also eliminated.
- Higher overall heat transfer coefficient.