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WATER MANAGEMENT IN THE AQABA INDUSTRIAL COMPLEX

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ABSTRACT

Jordan has a critical shortage and difficulties in availability of water resources. Thereby, two methods are available for supplying raw water: Desalination and Aqaba waste-water treatment plants. Aqaba Industrial Complex is among the first in the fertilizer industry in the Middle East region to consume some 6,000 m³/day of urban reclaimed water from the treatment plant. Owing to that, the water price has been substantially reduced by 30%. Specific as well as consumption of industrial water during past the 5-year period for different products and material balance of the Acid Cooling Tower process water are given.

A thorough study of the impact of chloride concentration build-up in the process water circuit on the water management of Aqaba Industrial Complex is one of the aims of this article. The study shows the relationship between the Cl⁻ content of ground phosphate rock and Phosphoric Acid Cooling Tower process water. Moreover, the working intervals of their contents have been determined under condition that, Cl⁻ combined aggregate figures should not be higher than the threshold value of 1300 ppm.

Furthermore, it highlighted our experience in reducing the corrosion-erosion problems on specific equipment of phosphoric acid plant. Hence, certain specific aspects of applications of costly construction materials of stainless steels are described. Already, it has been proven that, implementing these materials not only improved reliability but gives a high degree of flexibility in consuming high Cl-containing water. They recently cut maintenance cost and made the operation of the phosphoric acid plant safer.

INTRODUCTION

In the widest sense, the Middle East region with Jordan as well, fresh water is considered a scarce and costly resource. Jordan has a very serious, critical shortage and difficulties in availability of water resources. Its use per capita is among the lowest in the world and as the urban population continues to grow, so does water demand.

The reclamation of water for industrial and irrigation purposes is therefore, in line with Jordan's Water Strategy, formally adopted by the Council of Ministers in May 1997, placing a high priority on the resource value of reclaimed water.

The strategy states unambiguously:

"Waste-water shall not be managed as waste. It shall be collected and treated to standards that allow its reuse unrestricted in agriculture and industry including other non-domestic purposes as well. Thereby, **the water discharge must have zero effluent, without liquid disposal problem.** It is therefore essential to replace the demand for water from natural non-renewable resources to water from renewable ones". In order to put this slogan into practice, the Aqaba Industrial Complex is one of the first in the fertilizer industry in the Middle East region that has planned to consume about 6,000 m³/ day of urban reclaimed water.

This paper reports in detail an updated version that was presented in the March 2003, (AFA Issue No.35). It only focuses on the effect of chlorides on water management.

The need for water especially in Jordan including the Aqaba Special Economic Zone Authority (ASEZA) has increased dramatically over the past three years. Accordingly, two directions of study have been carried out to assess the different methods available for supplying huge quantities of treated raw water. Beside, one of the main objectives of the water projects was to reduce the consumption of high quality drinking water coming from natural non-renewable water resources called Qa-Diss Fare 35 miles from Aqaba town. Treating Red Sea water and Aqaba waste-water are, from the economic and practical point of view, more feasible solution to the existing conditions.

Desalination Plant

Ordinarily, desalination of seawater presents a feasible solution to water shortages specifically, for countries with inexpensive energy sources. It is expensive to build a desalination plant capable of producing 5 million tons per year. Normally, the water is of high quality with total dissolved solids, including chloride, typically below 5 ppm. Andrea Lovato [1] reported, that the heating energy requirement is in the range of 60-360 kWh / m³ fresh water produced. Lisa Connock [2] mentioned that, in the sulphuric acid manufacturing, 90-95 % of the heat could be economically recovered by means of using plate heat exchangers. However, as a consequence, significant economic and environmental benefits can be achieved by recovering the heat from the absorbing and drying towers circulating sulphuric acid, even at temperatures between 80 to 100°C with only minor changes to the existing systems.

For the desalination of Aqaba Gulf water, the sulphuric acid units with capacities of 4500 tons / day, each can produce approximately 4.13 tons of high-pressure steam at 47 bars at 405 °C, thus producing power of around 1 M Kw/hr. The total steam produced is about 119.5 t/hr. From there, 37 tons are consumed for running the turbo-blower and 82.5 tons for export to produce 20 M Kw/hr at the utility plant. The

Desalination project is still under evaluation stage with different private water supply companies.

Aqaba Waste Water Treatment Plant.

On the opposite direction, due to the projected increase in the Aqaba population because of the implementation of the ASEZA Master Plan, there is a corresponding increase of waste-water effluents. Accordingly, the expansion of the treatment facility has become a developmental priority in order to maintain and improve the town's conditions. In consequence, the Water Authority of Jordan (WAJ), with the support of USAID, entered into an agreement with Montgomery Wastson Company to perform final design of the upgrading and expansion of Aqaba Water and Wastewater Facilities Project [3]. From the value engineering analysis, project description, the final design with a total capacity of about 24,000 m³/day are based on the following:

- A natural treatment process, an agricultural reclaimed water system (ARW system),
- A mechanical treatment plant and an urban reclaimed water system (URW system).

Hence, a stabilization natural treatment plant (facultative and maturation ponds), with a capacity of 12,000 m³/day would treat waste-water to be reclaimed for agricultural irrigation. Whereas, a mechanical treatment plant with the same capacity is designed to produce reclaimed water suitable for urban landscape irrigation and industrial use.

Because of that, the Ministry of Water, Irrigation, and WAJ entered into two agreements. Therein, one with the ASEZA regarding the management and responsibility of using reclaimed water in a program of landscape irrigation areas in Aqaba Town, the other with JPMC- Aqaba Industrial Complex that will consume 6,000 m³/ day. Therefore, as it currently stands, the envisaged reclaimed water applications are:

9,000 m³/day of ARW for flood irrigation in areas around the treatment plant and to the south of the airport for future expansion.

6,000 m³/day of URW for urban irrigation including urban landscape and park areas.

6,000 m³/day of URW for process purposes in the production units at Aqaba Industrial Complex including a gravity system pipeline and a reservoir with a capacity of about 6,000 m³ [4].

Main characteristics of URW analysis are given in Table 1, on dry basis, ppm.

Table 1. Expected Analyses of Urban Raw Water, on dry basis, ppm.

Parameter	TSS	TDS	PH	NH+4
Minimum	207	713	6.90	55
Maximum	327	944	7.27	70

However, the cost of this type of water is cheaper approximately by 30 % and 50 % than the desalinated and Qa-Dissi waters respectively. Aqaba Industrial Complex has always strived to bring down a cost of production. Owing to that and consequently, the cost of blended water was substantially reduced to one US \$ since September 2002 instead of \$1,4 per cubic meter industrial water. The project is topically under construction

1-CONSUMPTION OF INDUSTRIAL WATER IN AQABA INDUSTRIAL COMPLEX.

The raw industrial water treatment system receives the Qa- Dissi pipeline water at Aqaba Industrial Complex. It is filtered through four sand filters, then, sent by three pumps to a storage tank of 4560 m³ capacity. Hereafter, from this tank, water is distributed to the individual battery limit plants for production operations. Actually, a certain amount of water is consumed in the production of phosphates-containing fertilizers and fluoride salt-in the sections of contaminants absorption from the tail gases. Thereafter, effluents from all plants are re-used without neutralization stage.

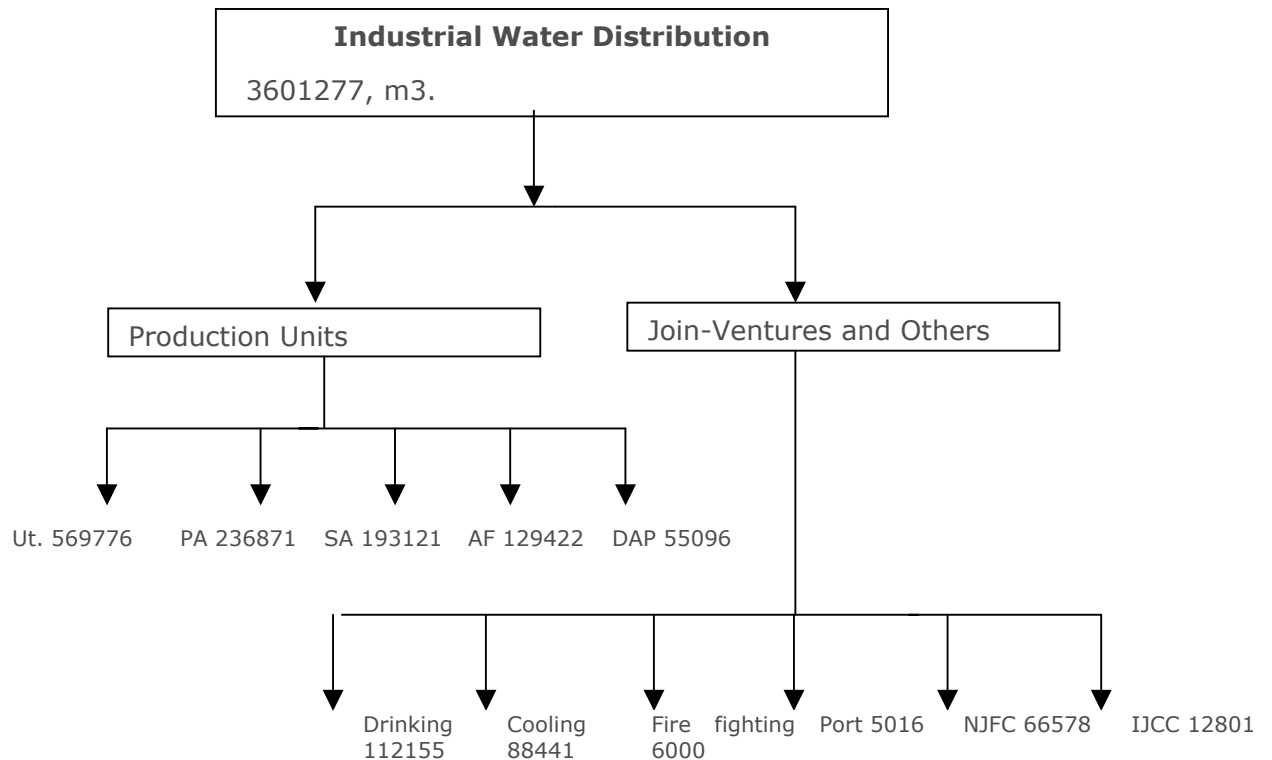
Table-2. Actual Consumption (m³) and Specific Consumption (m³/ t) of Raw Water For Different Products in The Last Five Years.

Plants	Specific Consumption, m ³ /t.	Consumption, m ³ .				
		1997	1998	1999	2000	2002
DAP	0.106 - 0.130	66,562	67,881	36,300	53,739	55,096
PA	5.630 - 6.878	209,9110	221,3438	209,3016	228,2837	236,2871
AF	12.640- 13.420	204,535	215,610	190,295	147,061	129,422
SA	0.182 - 0.185	179,949	200,998	209,025	203,019	193,121
NPK		57,633	72,617	94,448	65,692	66,578
Ut		459,146	535,606	610,278	579,251	569,776
Total		3,066,935	3,306,150	3,233,362	3,331,599	3,376,864

The specific and as well as potential annual consumption of industrial water for different products during the past five years period are shown in Table 2. As seen, the highest figures are for phosphoric acid and aluminium fluoride plants. Hence, about 87% of total consumption is distributed among the main water consumers: phosphoric acid, utility plant and sulphuric acid production units. In the ordinary way, industrial water is used in sulphuric acid production for controlling strictly the acid concentration that must be within the range of 98.45-98.65%.

However, the overall water consumption substantially depends on phosphoric acid production. Thanks to that, it had consumed some 3.6 million m³ in 2002 and even though, it can be reached up to a maximum yearly consumption 3.95 million m³ on the basis of the nameplate capacities of the above- mentioned units. Simultaneously, as an illustration, Figure 1, shows the distribution of water on the production units and other joint-ventures companies.

Fig 1. Scheme of Industrial Water Distribution Between The Production Units of Aqaba Industrial Complex and Other Joint-Venture Companies in 2002, m³.



2. MANAGEMENT OF ACIDIC COOLING TOWER PROCESS WATER.

D. Leyshon [5] reported that most recent international phosphoric acid projects have used cooling tower with different approach either to undertake part, or all of effluent water and its quality depends upon the implementing of different process technologies in wet phosphoric acid production. However, there has been a remarkable change in the process technology adopted for the Aqaba Phosphoric Acid plant. Recently, JPMC - Aqaba Industrial Complex has been operating its phosphoric acid plant based on the Prayon Mark –IV conventional Dihydrate Process and Hamon-Sobelco Acid Cooling Tower since 1994 [6]. The acid cooling tower (Photo-1) is forced-draft assisted type (Total outside length x width: 87.18 and 11.2 m), with a capacity approximately 12500 m³, having a thermal capability of 90.756.000 Kcal /hr.

The technical characteristics and operating data show that it consists of 18 cells (6.85x 4.6x 12 m) operating in parallel. Each fan (diameter-3.66m, rpm-340) has air flow rate of 330 000 kg/hr, introduced as counter-flow. Water flow rate is 9075 t/hr to maintain cooling range to within 10°C. Accordingly, from the water balance of the acid cooling tower (Table 3), up to 0.4% of total water quantity is used to compensate the water losses because of evaporation and sweeping by air draft.



Photo 1. Aqaba Acid Cooling Tower

It should be mentioned here, the tower effluent water is a totally closed effluent re-circulation technique resulting effective method of abating pollution. The large effluent rates approximately 1600-2000 m³/day from the various production units: utility, sulphuric acid, phosphoric acid and aluminium fluoride plants are collected and pumped back for consumption at the phosphoric acid plant through the acid cooling tower in order to minimize a fresh industrial water consumption and to bring about zero discharge effluent. The specification of circuit water is highly corrosive, pH below 2, maximum solids in suspension 0.5%, containing fluorine as H₂SiF₆ at around 1%. Others such as sulphuric acid, P₂O₅ and chlorides can reach up to 1.5, 1.2 and 0.1% weight respectively.

The Complex has been in operation for over two decades. For Aqaba, it was designed, engineered and constructed in accordance with very stringent effluents criteria. From the initial stage of operation, environmental restrictions on effluents are particularly strict. Besides, the principle of **“Wastewater shall not be managed as Waste”** meant no dumping and discharge of any effluents from production units into the Gulf of Aqaba under any conditions. As an additional guarantee to achieve our goal, proper organization of water consumption at Aqaba Industrial Complex has envisaged maximum possible reduction of fresh industrial water utilization and complete elimination of the effluents dumping into underground water.

However, since 1982 uniform guidelines and standards for liquid effluents have been established hereby to protect against contamination; to record any possible adverse changes in the quality of the ground water, permanent wells were drilled near the gypsum stack for the purpose of sampling and analysis. Furthermore, recently, to ensure safety, any possible changes in the quality of the coastal waters of the Aqaba Industrial Complex, the Marine Science Station is conducting a survey on periodical basis on seawater quality, seabed material and biological survey for monitoring of the environmental conditions.



Photo 2. Sea Water of Aqaba Gulf.

For pollution control, a new Safety & Environmental Department with especially equipped laboratories has been established to routinely monitor and control the Complex's effluents. In addition to that, the labs will ascertain that the pollution control criteria we have set are being observed during production, thus preserving the environment and preventing pollution to the Aqaba Industrial Complex and Aqaba Gulf as well. (Photo 2).

3. WASTES MANAGEMENT

3.1 Waste Solids

Various phosphoric acid industries discharge effluents with preliminary treatment, such as removal, mainly, of gypsum solids. It was necessary in solid management to look for a place far from the Red Sea, hereby; phosphogypsum containing 20 to 35 % free water could be stored safely for many decades to come. Based on a studies and investigations conducted into this problem, it was decided to transport the solid by a conveyor belt, providing stacking system with the aim of storing and distributing the solids into the valley (Photo 3).

The gypsum stack is located approximately two miles east of the Complex. Recently, 1.7 million tons per year of phospho-gypsum on dry basis are produced as a by-product. The most critical variables are the actual cost of gypsum stacking (estimated at more than US\$ 5.5 per ton). Probably, this solution, in spite of the extremely high cost associated with it, was found to be the most suitable for underground water as well as seawater pollution controls.



Photo-3. Aqaba Gypsum Disposal & Stacking System.

3.2-Waste Water and Minimizing Contaminations

In contrast to the solid management, a water management at the Aqaba Industrial Complex operation is complicated by effluent water entering the acid cooling tower that is contaminated mainly by chlorides and fluorides which make it unfit for discharge and uneconomical to remove these impurities by effluent treatment. The effluent contaminated in sulphuric acid can appear in the production process only in emergency leakage from the acid coolers or tanks. These waters are collected in a special pit with subsequent partial neutralization and then sent back to the water cycle.

Hence, the main source of pollution comes from the liquid effluent of the aluminium fluoride process that consists of washing water from the gas scrubbers, mother liquor and plant spillage that are collected and passed through the settling facility by means of a thickener. The capacity of thickener is about 500 m³, which gives an average residence time of about 10 hours. The underflow containing about 15% solids is pumped to a drum filter. Thereafter, this cleans the high chloride effluent water and contains only traces of solid content when it is pumped outside the battery limit and accepted as make-up water in the Phosphoric Acid plant.

In consequence, as concentration of chloride in soluble form gradually increases and build up in circuit water during operation there comes a point where, water is recycled through the acid cooling tower, cannot be completely admitted into the Phosphoric Acid plant. Its concentrations in chloride are significant, ranging from 500 to 1200 ppm, while in the aluminium fluoride the effluent water ranges from 1200 to 1600 ppm. In case of Phosphoric Acid plant under emergency or unscheduled shutdown due to equipment breakdown for a couple of hours and days, the utilization rate of process water is reduced by running the plant at low rate capacities.

To overcome and handle these adverse, critical conditions and restrictions, four rubber lined evaporative ponds with capacities of about 35,000 m³ are available to store the effluent water and to make an emergency management response use

procedures with a view of maintaining other production units continuously running without deterioration of their operating conditions. Even storing it in the evaporative ponds creates a pollution problem, due to lack of space and increase of Cl^- content over an extended time. Therefore, to solve partially this problem, fresh water of about $175 \text{ m}^3/\text{hr}$ used in vacuum pump barometric condenser must be replaced by process effluent water as long as there is reduction in level of these evaporative ponds. One positive feature of water handling into the acid cooling tower is adjusted and controlled at various dumping ratios for use at phosphoric acid plant. Consequently, controlling criteria here are to allow continued operation using high chloride containing water without major upsets and without damage to other equipments.

4-CHLORIDE CONTENT IN THE PHOSPHATE ROCK (PR).

The difficulties of processing wet phosphoric acid production are generally increased by complex nature of the phosphate rocks and presence of impurities; for example, chlorine content is extremely important in the phosphate from the quality point of view. It is an undesirable impurity because of corrosion and environmental impacts.

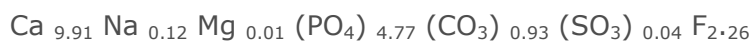
A group of researchers [7,8], studies by I.Jallad and others, have shown that the composition analysis of P_2O_5 , CaO , F , CO_3 , Na_2O , MgO and SO_3 contents of Jordanian sedimentary rock for EL-Hassa and Eshidiya of the three productive beds in ($\text{A}_1, \text{A}_2, \text{A}_3$) can be expressed by the generalized structural formulas of francolites :



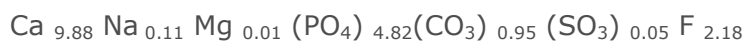
For bed A_1 ;



for bed A_2 ;



Whereas, phosphate deposits from bed A_3 has the other formula



The presence of Na_2O has a strong positive correlation with Cl and this might be attributed to its presence in mostly clay minerals and less percentage within francolite minerals structure. However, chlorine content within these types of raw material can be highly variable.

Methods and a choice of process technology that can be implemented for removing chlorines from phosphate rocks depend mostly on their chemical and mineralogical structures within the phosphate ores. Therefore, for obvious reason, two ways based on radically different processes are technically possible: by beneficiation and calcination. The first mentioned is by far the most popular process adopted for the Jordan sedimentary rock deposits.

Sodium chloride in Jordan phosphate rock is relatively soluble, formed in the acid from chloride ions. It is easy to remove by means of washing, consuming reasonable amount of flushing water that ranges from 1.75 to 3 m³ per ton of rock and recycling 1.25 m³. From practical experience the quantity of water depends upon the extent to which the chlorine content has to be reduced. Actually, implementing beneficiation process has double effect on rock quality; removes both chlorine and silica fines called (slime), upgrades its quality, and improves filtration and plant condition. On the other hand, reducing the Cl⁻ content to minimum means that a high quality ore has to be washed out thoroughly along with other useful impurities especially Al₂O₃ and some reactive SiO₂. Principally, from international practical experiences, studies and research show the presence of these oxides at an extremely low level have adverse impact on the plant load and performance of phosphoric acid manufacturing [9] besides the deteriorating effects on physico-mechanical properties of downstream fertilizers products [10].

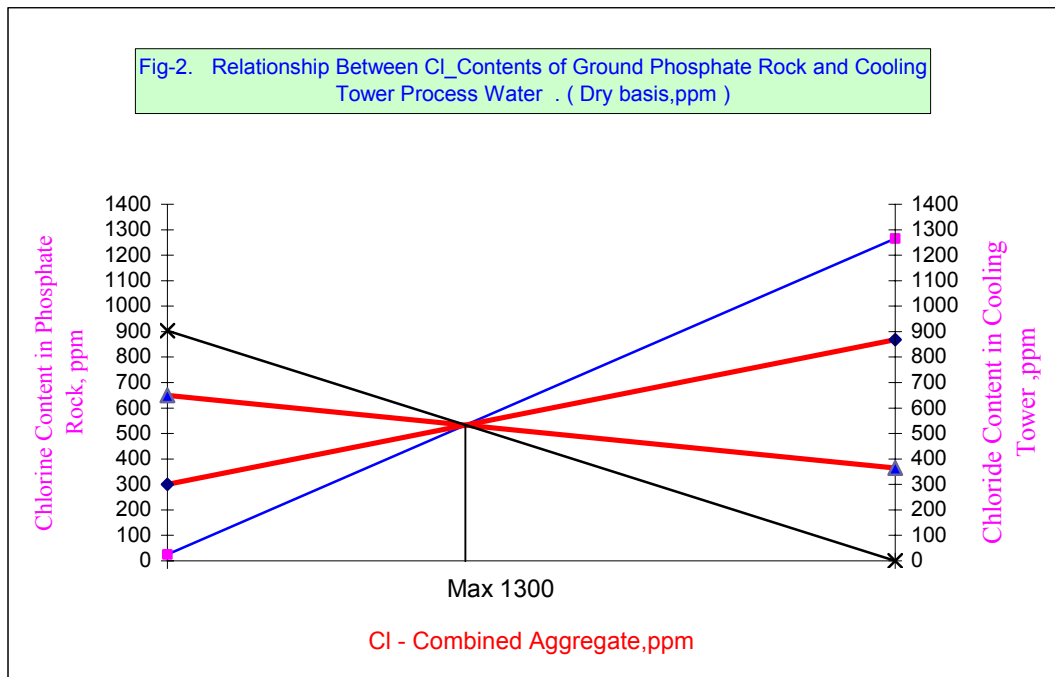
The principal factors to optimize chlorine concentration are: the chlorides can be adjusted in a phosphate in such a way as not to be very low for the purpose of avoiding washout completely the useful impurities and consuming considerable amount of industrial water. It should not be rather high due to the corrosiveness of the produced acid level and to avoid environmental problems. In spite of these facts, this a subject of phosphate management at mines.

PR being the main raw material consumption with rate 4000 to 5000 tons per day is often mixed with PR from different mines to obtain grade 68-70 BPL. Adjusting their contents , including chlorine is of paramount importance [10].

Recently, operating experience has proved that, the main method for controlling the water quality of the Aqaba Industrial Complex is routine laboratory analysis and controlling the range of deviation by adjusting daily their content in RP. The normal frequency of phosphate analysis is increased immediately if results are found to veer off spec. Presently, in order to have the lowest possible levels of environmental impact, Aqaba Industrial Complex has adopted the highest standards of operation.

5- EFFECT ON ACID QUALITY

Furthermore, another important factor that should be taken into consideration is that, the Phosphoric Acid plant was designed and constructed on the basis that, Cl in 30% Phosphoric Acid product and Cl- combined aggregate of the PR used and process water should not be higher threshold values. Generally less than a maximum of 800 and 1300- ppm respectively are extremely important to keep operating costs realistic.



$$C_t = C_w + C_R + < 1300 \text{ -----(1)}$$

$$C_w = \text{Cl}^- \text{ content in water} \times 0.75 \times 6 \times \text{P}_2\text{O}_5 \text{ in rock} / 100 \text{ -----(2)}$$

Where: - C_R : Cl^- content in ground phosphate rock used, C_t : Total Cl^- content.

The combined aggregate value is a fictitious number and calculated according to equations (1) and (2).

As an illustration, Fig 2 clearly shows how these two parameters should be controlled within the allowable working shadows areas (350-650-ppm). Thereby, when Cl^- content in PR is below the limit of 350 ppm, then at the acid cooling tower, water can reach as high as 900, where phosphate can be processed with the object of getting combined aggregate of 1300 as maximum, although the average concentration of the chlorides in acidi cooling tower is always maintained below the threshold limit.

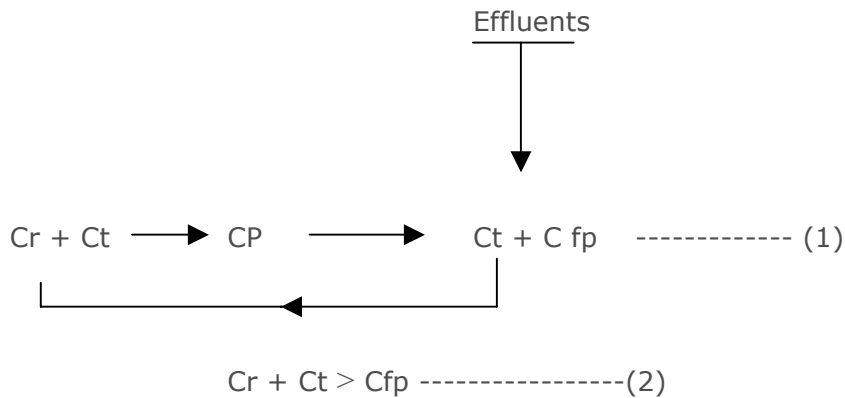
Table 3. Analysis Data of Cl⁻ Contents of Ground Phosphate Rock, 30% Phosphoric Acid, Process Water, FSA and Results of Combined Aggregate, on dry basis, ppm.

Cl Content on dry basis, ppm					
Phosphate Rock		30% Acid	Process Water	FSA	Combined
P2O5	Cl			(H ₂ SiF ₆)	Aggregate
31.34	750	862	463		1400
31.5	657	940	445		1268
31.43	710	856	450		1346
31.83	765	890	421	9180	1368
32.11	716	859	491		1425
31.89	540	870	710		1559
31.27	703	844	555		1484
31.4	586	945	713	7900	1593
30.8	600	858	597		1427
32.02	488	807	650		1424
32.29	466	903	753		1560
31.83	500	914	780	9215	1617
31.95	755	842	409		1343
32.7	746	855	471		1439
32.3	630	1033	501		1600
32.42	681	921	443		1327

Moreover, a broad analysis of the chloride composition and the calculated data of combined aggregate as the base of employed daily analysis results are representative in Table 3 and indicates that, all samples have high chloride content, some of them are much over the standard value. Also a relatively high variation is seen in the Cl⁻ combined aggregate values which ranges from 1268 to 1617 ppm and in the PR is between 466 to 765, and generally higher this limit. Whilst, in the acid cooling tower, acid figures in somewhat higher at 1033-ppm during operation. Therefore, the maximum limit actually causes increase in corrosion on generally all equipment coming into contact with the reaction medium, then the construction materials of equipment become a significant factor in design of the phosphoric acid equipment in view of the content limits that have been established.

By way of illustration, Fig. 3 shows a simple material balance and circuit of Cl⁻ content in PR distributed in different proportion between final products and by-products. Besides, the exhaust gas as HCl in a negligible percentage depends on operating conditions.

Fig.-3. Scheme of Cl⁻ circuit of Raw Materials, Process Water and By -Products and Final Products.



Where:

C_r^- :total Cl⁻ in raw materials; C_t^- Cl⁻ in the acid cooling tower process water; C_p^- the total Cl⁻ passing inter-mediate product such as 30% phosphoric acid and FSA; C_{fp}^- total Cl⁻ in final products and by-products.

The industrial calculation results have indicated, that the input of chlorides in the process is considerably higher, than the output in final products at the rate of 0.1703 t / hr.

Currently most of the chlorides ranging from 1.75 to 3.40 kg per ton of P₂O₅ produced with evolved fluorides in the concentration stage are absorbed by the liquid FSA ranging in quantity from 50 to 100 tons per day. Usually, by-product clear FSA containing less than 50 ppm P₂O₅ is to be re-used at aluminium fluoride plant in a 50 tons / day a high quality product produced [11,12,13], while, in case the aluminium fluoride plant is shut down for longer periods of time the excess quantity FSA either can be introduced into the granulation units or neutralized. The major drawback of using FSA in diammonium phosphate plant is accumulation of white salts formed during operation inside the scrubbing system. Hence, recently the acid has mixed with concentrated phosphoric acid prior admitting to diammonium phosphate reactor.

Several directions have been adopted to minimize the build up of Cl⁻ in the circuit water of the acid cooling tower. The phosphate rock used should be adjusted within tolerance limits to between 350 and 650 ppm as a maximum **from the economical point of view**. The second is, to increase the Cl⁻ content output by means of reducing the P₂O₅ concentration acid produced to diammonium phosphate granulation units as much as possible according to the equation of P₂O₅ material balance on dry basis (%) without affecting the fertilizer product specifications.

Wet P₂O₅ (%).

$$\text{Dry Basis} = \left\{ \frac{\text{Wet P}_2\text{O}_5 (\%) \times 98 / 71 + \text{H}_2\text{SO}_4 (\%) + \text{solid} (\%)}{\text{Wet P}_2\text{O}_5 (\%) \times 98 / 71 + \text{H}_2\text{SO}_4 (\%) + \text{solid} (\%)} \right\} * 100 = 65.5\% \text{ Design Figure}$$

Beside, it has been established by operating experience and acid cooling tower material balance that, the utilization rate of process water can be increased by the increase of monthly production rate of higher than 34 000 tons of P_2O_5 . Since the make up industrial water flow increases proportionately, the running at the nameplate capacity of one of the important acid cooling towers significantly affect the consumption of process water within the acceptable concentration levels of the impurities.

6-MATERIAL OF CONSTRUCTION

The corrosiveness of wet phosphoric acid is quite complex, and depends on the physical properties of phosphoric acid slurry solids and process operating parameters. Corrosion of metals in this industry is strongly influenced by combination chlorides and free sulphates. Becker [14] mentioned that, higher operating levels of 3% free sulphuric acid dramatically activates corrosion by a factor 10. Also other impurities and interacting factors such as HF, FSA and fluoride complex ratio [15], chlorine content 0.1% as maximum allowable concentration that would be acceptable, are most corrosive towards stainless steel. Becker [16] mentioned, the two major type of corrosion, which takes place during phosphoric acid production, is a combination of abrasion–corrosion and pitting because of the presence of chlorides. However, from the materials point of view, it is very well known that the chlorine content highly affects the choice of the construction materials of stainless steel employed. Although, as far as possible, standard materials are used in phosphoric acid plant, those of the austenitic types 317L and 904L have been used extensively over the years in piping systems, pumps and agitators.

A technically workable solution to the problem of chloride corrosion has been found in the more resistant alloys suitable as at least 904 L alloy steels. Encival's general recommendations [17], that chloride content in acid between 500 to 900 ppm austenitic alloys like UB-6 and super austenitic Sanicro-28 [18]are most corrosion resistant and normally the first choice. Under high amount of chloride, 900-ppm, resulting in noticeably high rates of localized and general corrossions [14,19], Duplex steels, Alloy-31 and Hastelloy can be used. P Plateus [17] reported that new austenitic alloys named UB-6P containing higher level of Cu and tungsten, is available with 40% higher abrasion- corrosion resistance than well-known UB-6.P.

J Audouard reported [20] recently, that certain cases Duplex like UR-52N+ alloys, also to be candidates even for construction of phosphoric acid storage tanks, in spite of high unit costs. However, Table 5 shows the chemical composition of different specific steel grades, which are commonly used in phosphoric acid manufacture

Table-5. Chemical Composition of Different Stainless Steels Grades and Cast-Iron - -30% Cr Employed In Phosphoric Acid Production.

	Standard UNS	C	Mn	Cr	Ni	Mo	N	Cu	P	Si	S	Fe
317L		0.02	1.6	19.0	14.0	3.0			0.002	0.4		Bal.
UR45N	S31803			22.0	5.3	2.8	0.16					
904L	N08904	0.02	1.49	20.0	27.0	4.3	-----	1.5	0.022	0.36	0.001	Bal.
Sanicro-28	N08028	0.02	2.0	27.0	31.0	3.5	----	1.0	0.025	0.6	0.015	Bal.
Nicrofer-3127hMo	Alloy-31	0.015	2.0	27.0	31.0	6.5	0.2	1.3	0.02	0.30	0.01	Bal.
Cast-Iron- -30% Cr		0.01	0.08	26.7	0.18	3.91	0.00	---	0.002	0.02	0.003	Bal.
UR52N	S32550	0.02	-----	25.0	6.5	2.8	0.16	1.6				
UR52N+	S32520	0.02		25.0	6.0	3.5	0.025	1.5				

Obviously, the increase in chromium (Cr), molybdenum (Mo), nickel (Ni) copper (Cu) and nitrogen (N) content of stainless steel generally improved corrosion resistance and mechanical strength. According to D. Leyshon's [17] report, very small changes in the original design of construction materials can have a substantial impact on the maintenance cost.

Referring to the Aqaba Phosphoric Acid plant, experience has shown that the major difficulty in operating acid cooling tower is caused by the high chloride present in process water, which calls for special steels. Unfortunately, the plant, which was designed based on 317 and 317L and 904L stainless steel materials, had not accepted as such for its existing equipment materials of construction.



Photo-4. Circulation Axial pump impeller- UB-6 material.

Consequently, the main material of equipment construction of Attack- Filtration and Concentration sections have to be changed to increase the resistance against corrosion-erosion. Moreover, in particular, the Ucego-Filter No.-12, filtrate pipes material 904-L SS, which had suffered vapour-phase attack by chloride in the phosphoric acid are replaced by highly resistant Nicrofer 3127 h Mo in spite of high material cost. Furthermore, Low-Level Flash Cooler (LLFC) circulating axial pump for circulating the slurry (Photo-4) is subject to very corrosive and erosive conditions; consequently, its impeller had been replaced by Sanicro-28. Besides, 30% and 54%

phosphoric acid settling tanks rekers were replaced by Sanicro-28 instead of carbon steel rubber-lined rekers (RLCS).

Rhone-Poulenc reactor service coolers and acid mixers materials were also changed from 904 L -8mm to cast-iron 30 % Cr -2 % Mo with thickness of 16mm. Also the 30 % phosphoric acid pumps impellers material had changed to cast-iron 30 %Cr-2 % Mo. When, filter-cloth washing system including pipes and nozzles were replaced by the Duplexes grade UR52N+ (UNS 32520) they have shown to have superior overall performance relating to corrosion and abrasion and with the best performance to investment cost ratio [20,21].



Photo-5. Phosphoric Acid Circulating Axial Pump Discharge Duct.

Experience with rubber-lined equipment particularly for attack-digesters tanks and concentration units has been rather mixed. Recently, the discharge of axial pump ducts (Photo-5) in the concentration lines where the areas are suffering from high vertex and turbulent phenomenon had resulted in extensively high erosion problems on the rubber- lining. Furthermore, we were unsuccessful in using CSRL elements in gas demister of concentration units, because of difficulties in repairing, handling and cleaning as well.



Photo-6. Phosphoric Acid Circulating Axial Pump Discharge Duct.

Owing to that, the first time the ducts and demister elements (Photo-6 & 7). have been changed from RLCS to Super Stainless Steel Sanicro-28 and Austenitic 904L there was trouble-free cleaning. The application of Sanicro-28 for demister elements are successfully operating since 1998 solving completely contamination of P_2O_5 in FSA [11]. At high vertex areas located in the slurry LLFC inlet deflector, the lining of carbon brick are subjected to high erosion and caused great difficulties in plant operation and in prolonged shutdowns. Providing a 6mm, UB-6 anchored sheet lining over the bricks has helped in extending the life of bricks. Similar modifications have been also implemented in the phosphoric acid sludge pits under high-speed agitators. These have been found to be helpful in improving the life of lining.



Photo-7. Gas Demister Element of Concentration Units.

Recent designed construction material of equipment has achieved a reduction in corrosion erosion affording greater protection to plant load. Typically, it takes several years to reach satisfactory results for corrosion-erosion on the plant equipment. In considering the plant equipment there are systematic and effective communications channels among equipment suppliers and manufacturers of material - who aim to provide product to fulfill the desired service function with Aqaba Phosphoric Acid engineers, who face the actual consequence of equipment's failure.

CONCLUSION

- 1-The build-up of chloride content in the acid cooling tower water circuit is the main problem of water management in the Aqaba Industrial Complex.
- 2- The chlorine content in the phosphate rock fed into the phosphoric acid reactors should be adjusted within the range of 350 to 650 ppm.
- 3- Implementing new stainless steels as material of construction have been found to be helpful in improving reliability for phosphoric acid plant's performance and output.

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