Asian Journal of Physical and Chemical Sciences

Volume 12, Issue 1, Page 10-25, 2024; Article no.AJOPACS.112762
ISSN: 2456-7779

Resizing of Irrigation Pumps Used for Heap Leaching in a Mine: Case of SOMAÏR

Ousmane Mahamadou [a], Souley Harouna [b], Abdourazakou Maman Hassan [b*], Boureima Seibou [a], Illou Issoufa Souleymane [a] and Mamadou Kanta Elh Kassoum [a]

[a] *Department of Electromechanic, School of Mines, Industry and Geology of Niamey (EMIG), Niger.*
[b] *Department of Geosciences, School of Mines, Industry and Geology of Niamey (EMIG), Niger.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJOPACS/2024/v12i1216

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/112762

Original Research Article

Received: 16/12/2023
Accepted: 19/02/2024
Published: 23/02/2024

ABSTRACT

The aim of this study is the analysis and resizing of irrigation pumps used in heap leaching at the Mines de l'Aır company. This company is located in the Arlit department in the Agadez region of Niger. This work essentially consisted of checking the current pumps, integrating the new parameters and choosing the right pumps, either by respecting the current standard or by proposing other types of more efficient pumps. The study revealed that for the 3rd stage pumping circuit, the Total Head (HMT) value of 33.58 m is lower than that of the pumps, which is 34.03 m. This pump sends the fluid to the desired heap height with a pressure of 0.5 bar, whereas the desired pressure for watering is around 2 bar. The result: a drop in uranium juice production. The pump does not exhibit cavitation, as the Net Positive Suction Head (NPSHD) is equal to 4.71 m, a value that far

---

*Corresponding author: E-mail: abdourazakoum@gmail.com;

exceeds the NPSHr , which is equal to 1.44 m. Given that at 1485 rpm the pump is unable to deliver a pressure of 6 bar with the valve closed, we can say that the pump has lost its performance. By the 3rd stage, the HMT of the circuit is equal to that of the pump, so the pump will still be able to deliver the fluid to the piles, but at a very low pressure, and even if both pumps are switched on simultaneously, the flow rate will not exceed 150 m3 /h. This means that irrigation will be very poor, resulting in mediocre uranium juice production. With a pump efficiency of 61.98%, we can say that the pump is operating under optimum conditions and does not suffer from cavitation, as the NPSHD is well above the NPSHr . For the 4th stage circuit, the CPKN 100-404 pump driven at 1650 rpm gives a flow rate of 175 m3 /h and a head of 57.91 M.C.E. The MegaCPK 125-80-380 pump driven at 1750 rpm gives a flow rate of 190 m3 /h and a head of 60.28 M.C.E. The CPKN 150-440 pump, driven at 1450 rpm, operates at 230 m3 /h and 67.55 M.C.E. The MegaCPK 150-125-380 pump, driven at 1750 rpm, delivers 250 m3 /h and a head of 71.71 M.C.E.

Keywords: SOMAÏR; irrigation pumps; heap leaching.

1. INTRODUCTION

In the mining process, removing large quantities of water to maintain production remains a major challenge. These challenges are largely met through the use of pumps during mining operations [1,2]. In addition to water removal operations in mines, pumps are used in the process of irrigating marginal ore to enable proper metal extraction. Currently, in many countries around the world such as the USA, Canada, Australia, Russia, Uzbekistan and Kazakhstan, exactly the same technology is used for uranium extraction, which includes uranium leaching production processes [3-5]. Niger has several uranuim mines. One of the largest and oldest is SOMAIR. At this mine, marginal ores are processed using the heap leaching method. This method requires the use of large quantities of water to extract the metal [6].

Leaching using sulfuric acid solutions is the most widely used process for the extraction of uranium from uraninite ores because of the relatively low cost and wide availability of the acid [7-9]. The leaching process in the study area involves the installation of two rich juice storage basins (each with a capacity of 3,000 m^3), which receive uranium-laden juice (after drainage) via large headers. One of these basins is fed by overflow, followed by an irrigation juice basin (A1 87 11) with a capacity of 6,000 m^3. This tank receives acid-corrected effluent from the solvent workshop. These effluents are used as an irrigation solution on the heaps, and finally, by creating a storm basin (A1 87 13) with a capacity of 14,000 m^3, which in turn receives rainfall over the entire surface of the heap. It is fed by a ditch to collect storm water, which is sent to the rich juice basin. If necessary, effluent from solvent workshop 1 is treated with 98.5% sulfuric acid before being stored in a tank (S1 87 19) with a capacity of 130 m^3. These irrigation juices are then pumped to the irrigation juice tank (A1 87 11). From this basin, the juices are transferred to the leaching heap to feed the drip systems in the sub-cells. After being watered for 90 days, the ore is left to drain for 10 days to reduce its moisture content. The juices are then collected in drains and collectors before feeding the main drain of the drainage network, which carries them to the first pond (which feeds the second pond by overflow).

The irrigation network used in the study area comprises a fixed main collector running to the north-east of the leaching areas, in the ditch between the heap and the slag heap dyke, equipped every 40 m (width of a heap) with a spigot with an isolation valve; a set of sub-collectors perpendicular to the main collector, enabling irrigation juice to be distributed along the heaps in operation, over a length of around 500 m. These sub-collectors are made of a reduced number of flexible plastic pipes, which can be dismantled and "re-installed" using the isolation valves. These sub-collectors are made of a small number of flexible plastic pipes, which can be dismantled and "re-installed" from the main collector's isolation valves. At regular intervals (approximately every 24 m), these sub-collectors are equipped with tees fitted with valves and pressure gauges for supplying and adjusting the pressure of the drip networks, and with a set of drip networks that can be dismantled and "re-installed" from the sub-collector tee isolation valves. These networks are made up of flexible pipes that run along the sub-collectors and distribute the juices into drip pipes installed perpendicularly at regular intervals (approximately every 635 mm). Each drip pipe is around 40 m long (depending on the width of the pile), and includes emitters, spaced at approximately 635 mm intervals. Each emitter delivers a flow rate of around 2 l/h, which can be adjusted by the network pressure. The drip network is extended as the heaps are built up. The part of the drip network that becomes useless after 90 days of watering can be dismantled for reuse on a new heap. From the basins, the rich juices are pumped by the three (3) pumps into a tank (S1 87 16) for buffer storage of rich juices with a capacity of 130 m^3 . From this tank, two pumps (P1 87 17 A/C) convey them to solvent workshop 1, after adding 98.5% sulfuric acid if necessary for pH correction.

Thanks to the processing of marginal ores using the system described above, SOMAÏR has seen remarkable growth in production, and is constantly resizing and optimizing its facilities. With this in mind, it was decided to carry out the present study on the resizing of lixi heap irrigation pumps, integrating the third and fourth stages of heap leaching. The aim here is to check the current pumps, integrate the new parameters and choose the right pumps, either by keeping to the current standard or by proposing other, more efficient types of pump.

2. MATERIALS AND METHODS

2.1 Presentation of the Study Area

SOMAÏR is located around 1,250 km from Niamey and 250 km northwest of Agadez (as the crow flies). Its creation in 1968 gave rise to the mining town of Arlit. Arlit is located in the heart of West Africa, around 2,000 km from the Atlantic Ocean and the Mediterranean, at coordinates 18^o 48' north latitude and 07^o 19' east longitude. Socially, it is a crossroads for all ethnic groups from diverse backgrounds [10,11]. The climate is dry desert with low rainfall. On average, it rains only 40 to 80 mm/year, usually in August. Sandstorms dominate the seasons. Temperatures are very high, often reaching 45^o C during hot spells (e.g. April and May), but can be severely low, reaching 5 to 15^o C (November to March) [12,13]. There are no permanent watercourses, but the fossil hydrographic network still functions well. SOMAÏR's industrial facilities are based around 7 km from the town [14,15].

2.2 Pump Sizing Method

The various steps involved in sizing a pumping system are assessing requirements and selecting components.

Determining your needs enables you to determine the maximum flow rate and total head you require at the inlet. Based on these two parameters and the installation in which the pump is to operate, the pump is selected. Water requirements for irrigation depend on the type of crop, meteorological factors such as temperature, humidity, wind speed, soil evapotranspiration, the season of the year and the irrigation method. However, it is important to rely on local practice and experience.

Depending on the conditions of use, these machines impart to the fluid either mainly potential energy by increasing the pressure downstream, or mainly kinetic energy by setting the fluid in motion. In this way, a pump overcomes the pressure difference, altitude difference and head losses due to the length of the pipe and its various accidents (elbows, valves, turbines, etc.) between the two ends of a circuit. A centrifugal pump must be chosen according to the actual characteristics of the system in which it is to be installed. The data required for correct sizing are : Flow rate and total head.

2.3 Flow Rate

The flow rate Q supplied by a centrifugal pump is the volume delivered per unit of time. It is expressed in cubic meters per second (m3/s) or, more practically, cubic meters per hour (m3/h).

2.4 Manometric Head

A pump's head H is the energy supplied by the pump per unit weight of liquid flowing through it. It is the sum of the geometric heads (suction and discharge) and the (regular) head losses due to friction as the liquid passes through the pipes and hydraulic accessories (singular losses). It is expressed in meters (m).

Head varies with flow rate and is represented by the characteristic curve H = f(Q) for the pump in question (manufacturer's data).

The HMT is determined by applying Bernoulli's theorem between two points in the circuit containing the pump [3], i.e. :

$$\rho W_{1/2} - \Delta P = (P2 - P1) + \rho g(Z2 - Z1) + \frac{1}{2}\rho(V2^2 - V1^2)$$

With : ρ representing the density of the fluid under consideration (kg/m3), W1/2 the useful mass energy of the pump (J/kg),∆ P the sum of all head losses (Pa), P1 = pressure at point 1 (Pa), P2 = pressure at point 2 (Pa), V1 = velocity at point 1 (m/s), V2 = velocity at point 2 (m/s), Z1 = elevation of point 1 (m), Z2 = elevation of point 2 (m) and g = acceleration due to gravity (m/s²).

Dividing the two members of the equation by ρg reveals the HMT :

$$HMT - \frac{\Delta P}{\rho g} = \frac{P2 - P1}{\rho g} + (Z2 - Z1) + \frac{V2^2 - V1^2}{2g}$$

With $\frac{\Delta P}{\rho g} = \Delta H$ (pressure losses in meters).

If we consider the fluid to be perfect and incompressible, and the pipe has the same cross-section upstream and downstream of the pump, then V1 = V2. The relationship then becomes :

$$HMT = \frac{P2 - P1}{\rho g} + (Z2 - Z1) + \Delta H$$

2.5 Hydraulic Power

The hydraulic power imparted to the pumped fluid is related to the two (2) preceding quantities. If Q is the volume flow rate of the fluid, ρ its density and H the pump head, the hydraulic power Phyd is given by :

$$P_{hyd} = \rho . g . HMT . Q$$

With Phyd representing hydraulic power (W), ρ the density of the fluid (kg/m3), g the acceleration of gravity (m/s²), HMT the total head (m) and Q the flow rate (m³ /s).

2.6 Pump Mounting Options

The pump is chosen according to the circuit's characteristics (flow rate and head). There are two types of mounting: suction mounting and pressure mounting.

2.7 A Pump's Operating Point

As the pressure drop ΔH of the hydraulic circuit is proportional to Q², the curve Hr = f(Q) of the hydraulic circuit is parabolic.

The operating point (Fig. 1) is defined by the intersection of the two characteristic curves: resistance Hr = f(Q) of the circuit and duty H = f(Q) of the pump, as specified by the manufacturer.

Manufacturers provide charts showing the H = f(Q) characteristics of different pump models in the same series.

To determine the model corresponding to an operating point, place this point (Q; HMT) on the chart and select the pump whose characteristic lies immediately above this point.

Note that some pumps operate at variable speed. In this case, the manufacturer provides a chart showing the pump's H = f(Q) characteristics for various speeds. We then proceed in the same way, but instead of choosing a pump model, we select an operating speed.

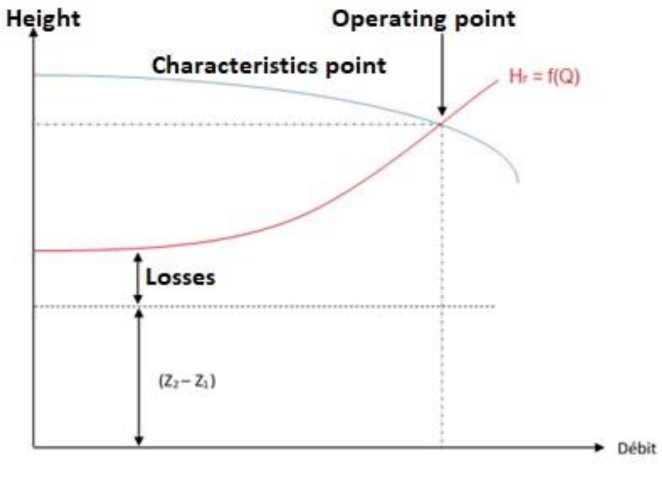

Fig. 1. Pump operating point

2.8 Multiple Pump Use Cases

By placing two (2) pumps in series, the HMT will be equal to the sum of the HMT of the two (2) pumps (Fig.2.) for the same flow rate.

$$HMT = HMT_1 + HMT_2$$

By placing them in parallel, the flow rate will be equal to the sum of the flow rates of the 2 pumps (Fig. 3) for the same head.

$$Qv = Qv1 + Qv2$$

2.9 Irrigation Pump Testing Method P1 8712 A/B/C

2.9.1 Objectives

The P1 8712 A B and C pumps are used to send irrigation juice, i.e. solvent effluent, from the leach storage basin to the heap level, where the ores are sprayed to recover the uraniferous juice. These pumps play a very important role, as their stoppage systematically leads to a drop in sodium uranate production [16].

We were asked to bring out the current pump parameters and check whether the pumps are working under optimum conditions.

To do this, we carried out a complete study of one of the pumps (the pumps being identical), using the various data collected directly on the installation.

2.9.1 Procedure

These pumps are connected in parallel, with two of them operating simultaneously, depending on demand, and the third serving as a back-up. In order to verify the rational use of these pumps, we place ourselves in the most unfavorable operating case of the pump and of the plant configuration (i.e. the full load regime and in the most complex configuration) to ensure that the pump characteristics meet the most difficult operating conditions. This will enable us to check whether the pumps studied are really capable of transporting the fluid (irrigation juice) to the heaps at the specific pressure under optimum operating conditions.

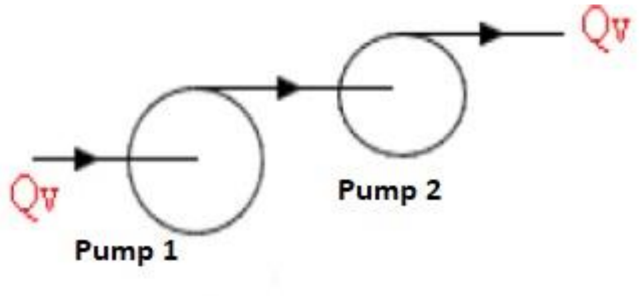

Fig. 2. Pumps in series

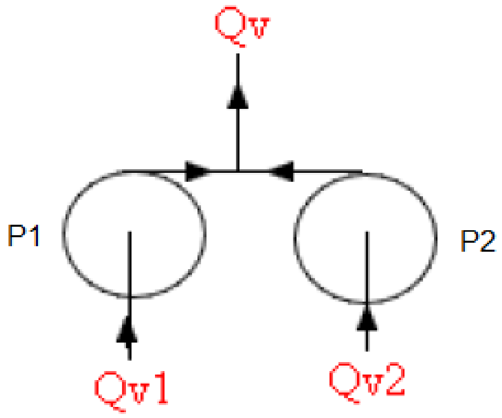

Fig.3. Parallel pump assembly

3. RESULTS AND DISCUSSION

3.1 Initial Pump Circuit Characteristics for 3rd Stage

The Figure below shows the current pumping circuit for the 3rd stage. The following table shows the results of measurements of the circuit's characteristics. Analysis of this table shows that the pump suction diameters are 160 mm for D1 and 150 mm for D2. Discharge diameters are 150 mm for D1, 250 mm for D2 and 200 mm for D3.

3.2 Determination of Fluid Velocity

The fluid velocity is given by the following formula:

$$Q = S \times V \text{ or } S = \frac{\pi D^2}{4} \qquad V = \frac{4Q}{\pi D^2}$$

Q: flow through the pipe (m3/s) ;

D : pipe diameter (m) ;
V: average velocity in the pipe (m/s).

For pipe diameter D = 250 mm, the measured volume flow is Q = 130 m /h^3

$$V = \frac{4*130}{3600*\pi*0{,}25^2} = 0.735 \text{ m/s}$$

3.3 Determination of Fluid Density

The effluent is a mixture of a solution containing uranium ions, sulfuric acid and other impurities. The 1-liter sample is weighed; the mass at 30°C is 1.138 kg.

The density is given by the following formula:

$$\rho = \frac{M}{V}$$

With :

M : mass (Kg) ;
V: Volume (m^3);
ρ: Density (Kg/m).^{3}

$$\rho = \frac{1{,}138}{10^{-3}} = 1138 \text{ Kg/m}^3$$

3.4 Determination of Total Head

$$HMT = H_{geo} + \sum Losses$$

With :

H_{geo} : total geometric height (m) ;
∑pertes = ∆H: singular and regular head losses (m).

The geometrical head is made up of the suction geometrical head H_{geo} A (which is the difference between the pump axis elevation and the lowest liquid level in the suction tank) and the discharge geometrical head H_{geo} R (which is the difference between the discharge port elevation and the pump axis elevation).

In the case of this circuit, the values for H_{geo} Suction and H_{geo} Discharge are 2 m and 27 m respectively. The H_{geo} value would therefore be 29m.

Head losses are of two types: linear or regular head losses and singular head losses.

Linear pressure losses correspond to the loss of pressure in a system due to fluid friction in the piping. Linear pressure losses depend on the type of flow, fluid density, viscosity, fluid velocity, internal pipe diameter and pipe roughness.

3.5 Determining the Regular Pressure Loss Coefficient

Charts are often used to determine the pressure loss coefficient λ. However, there is a formula used in industrial applications. This so-called Blench formula is given by :

$$\lambda = 0{,}79\sqrt{\frac{\varepsilon}{D}}$$

With :
ε Average pipe roughness (m); D Pipe diameter (m).

For the PVC pipe, ε = 0.007 mm and the diameter D_{a1} = 160 mm, which leads to λ_1 = 0.0052.

For stainless steel pipes, ε = 0.015 mm and diameter D_{a2} = 150 mm, giving λ_2 = 0.0079.

For diameter D_{r2} = 250 mm, λ_3 = 0.0061.

For the flexible pipe, ε = 0.01 mm and diameter D_{r3} = 200 mm, giving λ_4 = 0.0055.

The values for ε values are taken from the hydraulic network calculation document [5].

3.6 Determining linear head loss values

Linear head losses per metre of pipe are calculated using Darcy's formula:

$$\Delta H_{linéaire} = \lambda \frac{L}{d} \frac{V^2}{2g}$$

With :
ΔH which corresponds to head losses (m) ; λ which corresponds to the Coefficient of regular (dimensionless) head losses; D which represents the pipe diameter (m); L which represents the pipe length (m); V which corresponds to the average velocity in the pipe under consideration (m/s); and g which represents the acceleration of gravity (m/s²).

$$\Delta H_{linéaire}A = \left(\lambda_1 \frac{L_{a1}}{{D_{a1}}^5} + \lambda_2 \frac{L_{a2}}{{D_{a2}}^5}\right)\frac{8Q^2}{g\pi^2}$$

$$\Delta H_{linéaire}R = \left(\lambda_2 \frac{L_{r1}}{{D_{r1}}^5} + \lambda_3 \frac{L_{r2}}{{D_{r2}}^5} + \lambda_4 \frac{L_{r3}}{16{D_{r3}}^5}\right)\frac{8Q^2}{g\pi^2}$$

$$\Delta H_{linéaire(total)} = \Delta H_{linéaire}A + \Delta H_{linéaire}R$$

The results of the linear pressure loss calculations are shown in the following table.

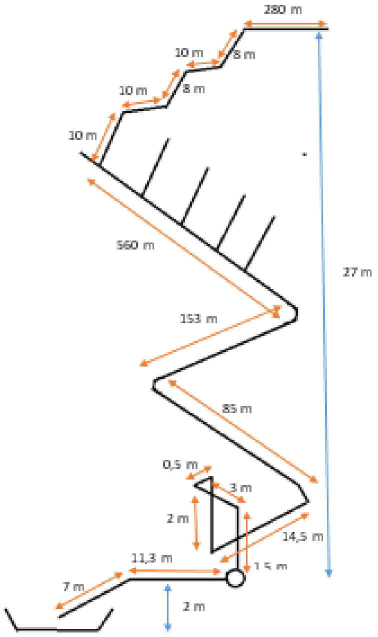

Fig. 4. Current pumping circuit for the 3rd stage. [4]

Measurement results are given in Table 1.

Table 1. Characteristic measurement results

Nº	Designation	Values
1	Suction diameters	D_1 = 160 mm and D_2 = 150 mm
2	Discharge diameters	D_1 = 150 mm; D_2 = 250 mm and D_3 = 200 mm
3	Flow	130 m /h^3
4	temperature	30 to 40 C°
5	Pump outlet pressure	3.8 bar

Table 2. Linear head losses

Parameters	Suction	Backflow
Flow	130 m /h^3	130 m /h^3
G	9.81 m/s2	9.81 m/s2
L_{a1}	10,04 m	
L_{a2}	8,1 m	
L_{r1}		6,72 m
L_{r2}		840,43 m
L_{r3}		309 m
ΔH_{linear}	0,1444 m	0,6763 m
$\Delta H_{\text{linear (Total)}}$	0,8207 m	

3.7 Determining singular pressure Drop Values

Singular head losses are due to sudden widening and narrowing, the presence of elbows, and regulating or measuring devices such as valves and flowmeters. They are proportional to the square of the mean liquid velocity in the element. A singular pressure loss coefficient is dedicated to each element creating singularities in an installation.

This coefficient, ξ, depends on the shape of the bend in the case of an elbow, and on the state of opening in the case of a valve. The coefficients for the system components are taken from the document hydraulic head loss tables and diagrams.

Singular head losses are given by:

$$\Delta H_{singulière} = \Sigma\xi\,\frac{V^2}{2g}$$

With:

V is the velocity in the pipe (m/s), $\Sigma\xi$ which corresponds to the sum of the singularity coefficients, g which represents the acceleration of gravity (m/s²).

The values of ΔHsingular A and ΔHsingular R can be determined using the following formulae:

$$\Delta H_{singulière}A = \left(\frac{\xi_1}{{D_{a1}}^4} + \frac{\sum\xi_{Da2}}{{D_{a2}}^4}\right)\frac{8Q^2}{g\pi^2}$$

$$\Delta H_{singulière}R = \left(\frac{\sum\xi_{Dr1}}{{D_{r1}}^4} + \frac{\sum\xi_{Dr2}}{{D_{r2}}^4} + \frac{\sum\xi_{Dr3}}{16{D_{r3}}^4}\right)\frac{8Q^2}{g\pi^2}$$

Here : $\sum\xi_{Da1}$ represents the sum of the singularity coefficients on the suction pipe with diameter D = 150 mm, $\sum\xi_{Dr1}$ corresponds to the sum of the singularity coefficients on the discharge pipe with diameter D = 150 mm, $\sum\xi_{Dr2}$ represents the sum of the singularity coefficients on the discharge pipe with diameter D = 250 mm; and $\sum\xi_{Dr3}$ represents the sum of the singularity coefficients on the discharge pipe with diameter D = 200 mm. ξ_1 corresponds to the singularity coefficient of the strainer and foot valve.

Total head losses can thus be determined using the following formula

$$\Delta H_{singulière(total)} = \Delta H_{singulière}A + \Delta H_{singulière}R$$

The values of the pressure loss coefficients are given in Table 3.

The total head is determined using the following formula

$$HMT = H_{geo} + \Delta H_{linéaire(total)} + \Delta H_{singulière(total)}$$

According to the calculation, the HMT value is 33.58 m.

Table 3. Singular pressure drop coefficients

	Suction	**Backflow**
Flow Q (m^3 /h)	130	
ξ_1	4	
$\sum\xi_{Da2}$	1,82	
$\sum\xi_{Dr1}$		7,35
$\sum\xi_{Dr2}$		10,33
$\sum\xi_{Dr3}$		5
$\Delta H_{singulière}$ (m)	1,0444	2,1846
$\Delta H_{singulière(total)}$ (m)	3,2295	

Table 4. HMT values as a function of current pump circuit flow

Q (m /h)^3	**0**	**20**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**
H_r (M.C.E)	29	29,12	29,49	30,11	30,97	32,08	33,44	35,05	36,90	39,01	41,35

Table 5. Optimal pump characteristics

Flow Q	**120 m /h^3**
Height H	43 M.C.E
Yield	69,3 %
Speed N	1289 rpm
Power consumption	16.46 kW
NPSH$_r$	1,44 m

3.8 Determination of Hydraulic Power and Mechanical

Hydraulic power characterizes the energy received by the fluid and is given by the following relationship:

$$P_{hyd} = \rho . g . HMT . Q$$

With P_{hyd} corresponding to the hydraulic power (W), ρ which represents the density of the liquid (Kg/m^3), Q which represents the volumetric flow rate (m^3 /s), HMT which represents the Total Head (m) and g which represents the acceleration of gravity (m/s^2).

For $\rho = 1138\, kg/m^3$ g = 9.81 m/s^2, Q = 130 m^3 /h and HMT = 33.58 m, the calculated hydraulic power P_{hyd} = 13,323.74 W.

Mechanical power is the power required at the end of the pump drive shaft, i.e. the power absorbed by the pump. It depends on the pump's overall efficiency; for this centrifugal pump, the efficiency for a flow rate of 130 m^3 /h is 49.34%.

$$P_{abs} = \frac{P_{hyd}}{\eta}$$

The value of the mechanical power deduced is therefore P_{abs} = 27,003.9 W.

A pump's power consumption, real load and efficiency depend on its resistance curve, which is a function of flow rate. Pump manufacturers draw up characteristic curves (head, efficiency, power consumption as a function of flow rate).

3.9 Determination of Resistance and Pump Characteristic Hm (Q)

The operator, with his actual installation, establishes the equation of the resistance curve. The equation of this resistance curve is given by :

$$H_r = H_{geo} + \left[\frac{\lambda_1 L_{a1} + D_{a1}\xi_1}{{D_{a1}}^5} + \frac{\lambda_2 L_{a2} + D_{a2}\sum\xi_{Da2}}{{D_{a2}}^5} + \frac{\lambda_2 L_{r1} + D_{r1}\sum\xi_{Dr1}}{{D_{r1}}^5} + \frac{\lambda_3 L_{r2} + D_{r2}\sum\xi_{Dr2}}{{D_{r2}}^5} + \frac{\lambda_4 L_{r3} + D_{r3}\sum\xi_{Dr3}}{16{D_{r3}}^5}\right]\frac{8Q^2}{g\pi^2}$$

$H_r = 29 + 3518.8165\, Q^2$

With H_r representing the circuit head (m) andQ the flow rate (m /h).^{3}

In general, the flow rate is expressed in m^3 /h on the curves provided by the manufacturer; this leads to a conversion by dividing the flow rate by 3600^2, giving the following formula with the flow rate in m /h.^{3}

$H_r = 29 + 0.000271513\, Q^2$

The H_r values calculated are given in Table 4.

The circuit characteristic or resistance curve is shown in Fig. 5.

The pump characteristic known as head versus flow is given by the pump manufacturer in the form of a curve.

The resistance characteristic Hr(Q) is plotted on the graph Hm(Q) in the manufacturer's documentation; the intersection of the two curves gives the operating point of this pump.

3.10 Cavitation and P1 8712 optimal pump Characteristics

Cavitation is the phenomenon of fluid vapour generation and decondensation due to pressure variations around the fluid's vapour pressure. It produces very violent shocks, leading to rapid and spectacular mechanical corrosion of the pump impeller and diffuser. It does not directly defuse the pump.

The available NPSH (Net Positive Suction Head available) for a suction pump in an open-air basin is given by :

$$NPSH_D = \frac{P_{atm} - P_v}{\rho g} - H_{geo}A - \Delta H_A$$

With : $NPSH_D$ which stands for Net Positive Suction Head available (m), P_{atm} atmospheric pressure (Pa), P_v : absolute vaporization pressure of the fluid (Pa), H_{geo} A : geometric suction height (m), ΔH_A : suction line pressure drop (m).

The NPSH value$_D$ determined is therefore 4.71 m.

The pump specifications supplied by the manufacturer are shown in Table 5.

The results thus obtained in determining the pumping circuit characteristics for the 3rd stage lead us to the following interpretations: Since the HMT (33.58 m) is lower than that of the pumps, which is 34.03 m, this pump sends the fluid to the desired heap height with a pressure of 0.5 bar, whereas the desired pressure for watering is around 2 bar. The result: a drop in uranium juice production.

In the manufacturer's documentation, the maximum efficiency of this pump is 69.3% for a flow rate of 120 m^3 /h between 13 and 155 m^3 /h, which means that for any flow rate below 120 m^3 /h but above 13 m^3 /h, which is the minimum permissible flow rate, the pump's efficiency will decrease, and for any flow rate above 120 m^3 /h but below 155 m^3 /h, which is the maximum permissible flow rate, the pump's efficiency will also decrease. For example, at a flow rate Q = 130 m^3 /h, the pump's efficiency is around 49.3%. In other words, the pump's efficiency is poor.

The pump does not exhibit cavitation, as the $NPSH_D$ is equal to 4.71 m, a value that far exceeds the $NPSH_r$, which is equal to 1.44 m.

Given that at 1485 rpm the pump is unable to deliver a pressure of 6 bar with the valve closed, we can say that the pump has lost its performance.

The consequences of this loss of performance are that the pump is driven at high speed to obtain the characteristics of a low speed. This results in abnormal energy consumption due to the increased power consumption.

3.11 Pump Circuit Parameters Scaled to 3^e^ Stages

Fig. 6**.** shows the pumping circuit up to the end of the 3^e stage.

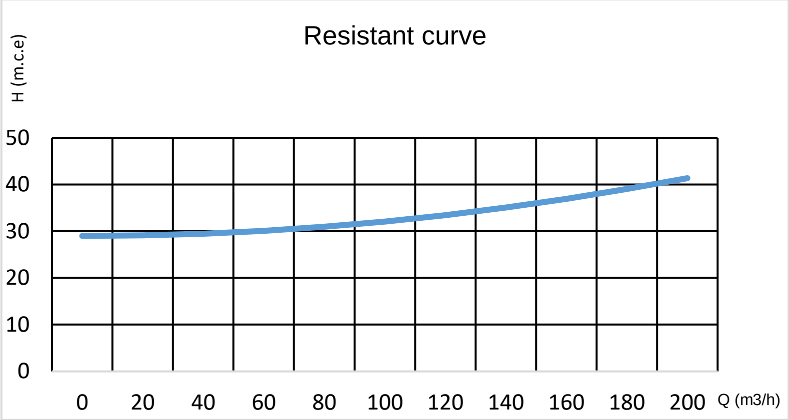

Fig. 5. Circuit characteristic curve

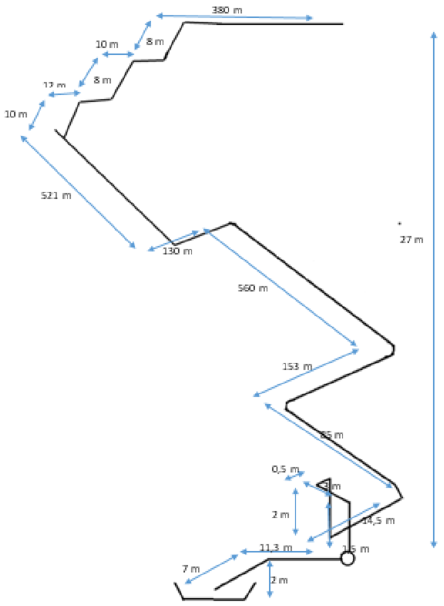

Fig. 6. The pumping circuit to the end of the 3rd stage

3.12 Total head

The suction is still the same, but the discharge has changed (Fig. 6), keeping the same geometric height as with the initial parameters. The new values for the circuit characteristics are given in Table 6 below.

$H_r = 29 + 11.664,2239\ Q^2$

In general, the flow rate is expressed in m^3 /h on the curves provided by the manufacturer; this leads to a conversion by dividing the flow rate by 3600^2, giving the following formula with the flow rate in m /h.^{3}

$H_r = 29 + 0.000900017\ Q^2$

The H_r values calculated are given in Table 7.

Table 6. Circuit characteristic values

L_{a1}	10,04 m
L_{a2}	8,1 m
L_{r1}	6,72 m
L_{r2}	1491,43 m
L_{r3}	428 m
D_{a1}	160 mm
D_{a2}	150 mm
D_{r1}	150 mm
D_{r2}	250 mm
D_{r3}	200 mm
ξ_1	4
$\sum\xi_{Da2}$	1,82
$\sum\xi_{Dr1}$	7,35
$\sum\xi_{Dr2}$	13,51
$\sum\xi_{Dr3}$	5

Table 7. HMT values as a function of circuit flow

Q (m /h)^3	**0**	**20**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**
H_r (M.C.E)	29	29,4	30,63	32,68	35,55	39,24	43,74	49,07	55,21	62,18	69,96

The resistance curve is shown in Fig.7.

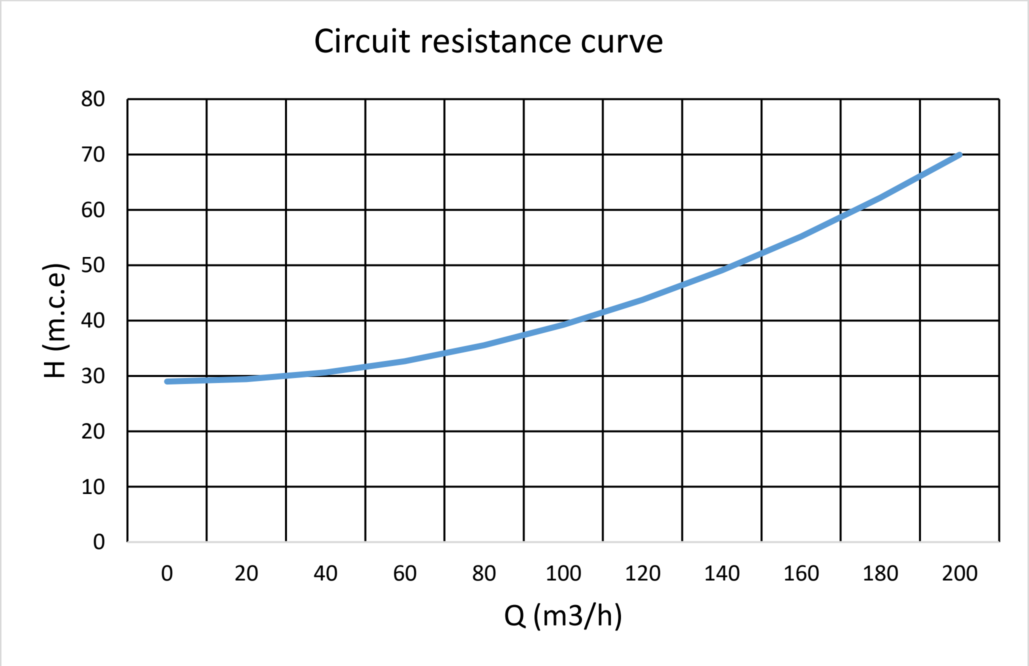

Fig. 7. Circuit characteristic curve

3.13 Pump Characteristics

This characteristic is given by the manufacturer. We plot the resistance curve on the same graph, and the intersection gives us the operating point.

This gives us the following operating point: Flow rate Q = 120 m^3 /h, Height H = 43.74 M.C.E, Efficiency η = 61.98%, Power input P = 26.26 kW and $NPSH_r$ = 1.35 m.

Available NPSH is determined using the following formula:

$$NPSH_D = \frac{P_{atm} - P_v}{\rho g} - H_{geo}A - \Delta H_A$$

P_{atm} = 0.955 bar; P_v = 0.07375 bar; H_{geo} A = 2 m ;

ΔH_A= 1,16 m ; ρ = 1138 kg/m^3 and g = 9.81 m/s^2.

$NPSH_D$ = 4.73 m

$NPSH_D$ > $NPSH_r$ +1 m. 1 m here represents the safety margin.

The HMT of the circuit is equal to that of the pump, so the pump will still be able to deliver the fluid to the piles, but at a very low pressure, and even if both pumps are switched on simultaneously, the flow rate will not exceed 150 m^3 /h. This means that irrigation will be very poor, and uranium juice production mediocre. With a pump efficiency of 61.98%, we can say that the pump is operating under optimum conditions and does not suffer from cavitation, as the $NPSH_D$ is well above the $NPSH_r$.

3.14 4th stage pump circuit parameters Speed

The fluid velocity is given by the following formula:

Q = S x V or $S = \frac{\pi D^2}{4}$ $V = \frac{4Q}{\pi D^2}$

Where Q represents the flow rate in the pipe (m^3 /s), D the pipe diameter (m) and V the average velocity in the pipe (m/s).

For pipe diameter D = 250 mm and measured volume flow Q = 240 m^3 /h; V = 1.35 m/s.

3.15 Total Head

$$HMT = \frac{P_2 - P_1}{\rho g} + H_{geo} + \Delta H$$

Where P_2 represents the pressure at the drip pipe inlet, which must be 2 bar, P_1 the suction pressure, which is the atmospheric pressure, H_{geo} the geometric height;

ΔH: sum of pressure drop.

The geometrical suction height remains equal to 2 m, but the discharge height changes as we move to the fourth floor and the pile height is 6 m, which gives us the values Hgeo R = 32 m and H_{geo} = 34 m.

The values for linear and singular pressure losses are given in the following Tables 8 and 9:

Table 8. Linear pressure loss results

	Suction	Backflow
Q (m /h)^3	240	
L_{a1} (m)	10,04	
L_{a2} (m)	8,1	
L_{r1} (m)		6,72
L_{r2} (m)		1491,43
L_{r3} (m)		428
$\Delta H_{linéaire}$ (m)	0,4922	6,3793
$\Delta H_{linéaire(total)}$ (m)	6,8715	

Table 9. Singular pressure loss results

	Suction	Backflow
Q (m /h)^3	240	
ξ_1	4	
$\sum\xi_{Da2}$	1,82	
$\sum\xi_{Dr1}$		7,35
$\sum\xi_{Dr2}$		13,51
$\sum\xi_{Dr3}$		6
ΔH_{sing}	3,56	7,9788
$\Delta H_{sing(total)}$	11,5388	

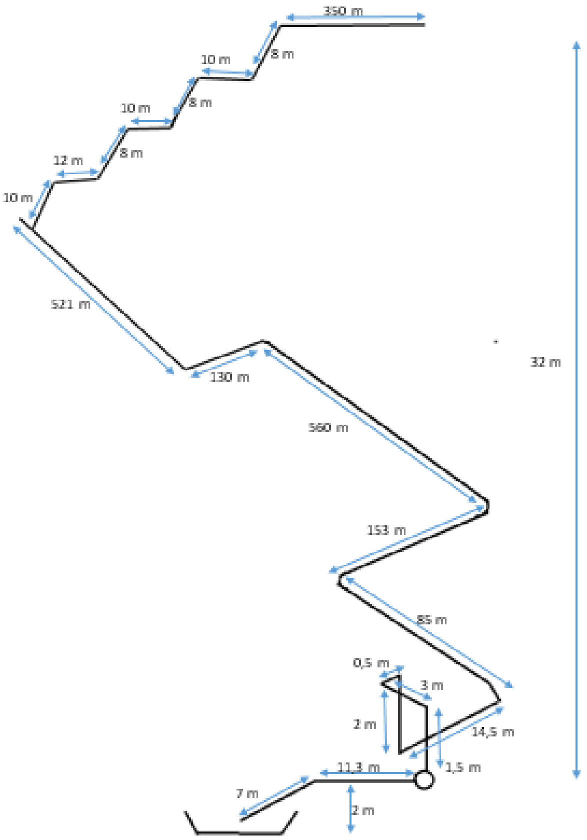

Fig. 8 The pumping circuit for the 4^e stage

The circuit used is shown in Fig. 8.

3.16 The Pressure Difference

P_1 is the pressure at basin level, which is equal to atmospheric pressure, and P_2 is the watering pressure of the lixi heaps, which is equal to 2 bar. $P_2 - P_1 = 1.045$ bar.

As the calculation was made with new pipes, we have to add 20% for ageing and scaling, so the total loss ΔH is about 22.08 m. The total head to be reached by the pump is therefore HMT = 65.44 m

3.17 Pump Selection

To choose the right pumps, we calculated the system's total head HMT, evaluated the desired flow Q and placed the point (HMT; Q/2) for the choice of two (2) in parallel and the point (HMT; Q) for the choice of a single pump on the selection grid also known as the KSB pump characteristic curve network [17].

Within the framework of this study, the choice of pumps was made according to two (2) scenarios:

The first scenario was based on the current pump family, with two pumps to meet the needs. The CPKN 100-400 pump (CPKN 100-404) running at 1650 rpm and the MegaCPK 125-80-380 pump running at 1750 rpm were chosen.

The second scenario is based on the current pump family, with a single pump to meet all requirements. In this case, the CPKN 150-440 pump running at 1450 rpm and the MegaCPK 150-125-380 pump running at 1750 rpm are chosen.

3.18 The Operating Point

This is the intersection of the resistance curve and the pump characteristic curve.
The H_r values calculated are given in Table 10. The resistance curve is shown in Fig. 7.

3.19 Pump Characteristics

These head versus flow characteristics are given by pump manufacturers in the form of a curve [7]. The operating points are given in Table 11.

3.20 Hydraulic Power and Mechanics

The hydraulic power values for each pump are given in Table 12.

The power required at the end of the pump drive shaft depends on the pump's efficiency and hydraulic power.

The mechanical power values for each pump are given in Table 13.

3.21 Cavitation

The NPSH$_D$ expresses the characteristics of the fluid and the geometric arrangements of the installation. The residual pressure at the pump inlet must always be higher than the vapour pressure of the pumped fluid P_v to avoid fluid vaporization or cavitation.

To achieve this, the available NPSH must be greater than the required NPSH by a margin of 0.5 to 1 m.

NPSH$_D$ > NPSH$_R$ +1 m

The NPSH values$_D$ for each pump are given in Table 14.

Table 10. HMT values as a function of flow .

Q (m /h)^3	**0**	**20**	**40**	**60**	**80**	**100**	**120**	**140**
H_r (M.C.E)	43,36	44,82	45,34	46,21	47,42	48,98	50,88	53,13
Q (m /h)^3	160	180	200	220	240	260	280	300
H_r (M.C.E)	55,73	58,68	61,97	65,61	69,59	73,92	78,6	83,62

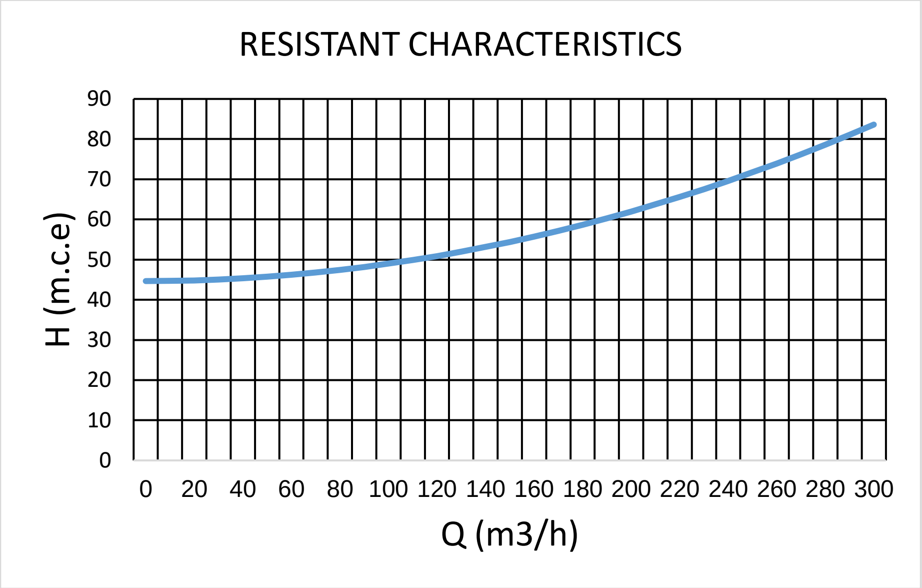

Fig. 9 Resistance characteristic curve

Table 11. Operating points of the selected pumps

	CPKN 100-404 1650 rpm	**MegaCPK 125-80-380 1750 rpm**	**CPKN 150-440 1450 rpm**	**MegaCPK 150-125-380 1750 rpm**
Q (m /h)^3	175	190	230	250
H (M.C.E)	57,91	60,28	67,55	71,71
NPSH$_r$ (m)	2,6	4	1,5	2,5
η (%)	64,22	70,9	70	77
P_a (kW)	43	44	60	63

Table 12. Hydraulic power of each pump .

	CPKN 100-404 1650 rpm	**MegaCPK 125-80-380 1750 rpm**	**CPKN 150-440 1450 rpm**	**MegaCPK 150-125-380 1750 rpm**
P_{hyd} (W)	27 585,72	31 209,97	42 336,96	48 852,43

Table 13. Mechanical power consumption.

	CPKN 100-404 1650 rpm	**MegaCPK 125-80-380 1750 rpm**	**CPKN 150-440 1450 rpm**	**MegaCPK 150-125-380 1750 rpm**
P_a (W)	43 035,44	44 019,7	60 481,37	63 444,71

Table 14. Available NPSH values for each pump

	CPKN 100-404 1650 rpm	**MegaCPK 125-80-380 1750 rpm**	**CPKN 150-440 1450 rpm**	**MegaCPK 150-125-380 1750 rpm**
$NPSH_D$ (m)	5,17	4,73	3,38	2,62

The parameters of the 4th stage pumping circuit thus determined allow us to make the following interpretation: The CPKN 100-404 pump, driven at 1650 rpm, gives us a flow rate of 175 m^3 /h and a head of 57.91 M.C.E., enabling us to achieve the desired flow rate and head, i.e. 240 m^3 /h and 70 M.C.E., using the two pumps in parallel. It satisfies leaching requirements, and therefore enables higher production. It operates with an efficiency of 64.22%, a power consumption of 43,035.44 W and a required NPSH of 2.6 m. The pump is highly efficient and will not cavitate, as the available NPSH ($NPSH_D$ = 5.17 m) is greater than the required NPSH ($NPSH_r$ = 2.6 m) plus 1 m, which we have considered as a safety margin.

The MegaCPK 125-80-380 pump, driven at 1750 rpm, gives a flow rate of 190 m^3 /h and a head of 60.28 M.C.E. so the two pumps in parallel give a flow rate of 245 m^3 /h and a head of 70.64 M.C.E. We can confirm that this pump also satisfies the conditions for irrigating lixi heaps, with an efficiency of 70.9% and a required NPSH of 4 m. Here, there is a risk of cavitation, as the available NPSH (4.73 m) exceeds the pump's required NPSH by only 0.73 m.

The CPKN 150-440 pump, driven at 1450 rpm, operates at 230 m^3 /h and 67.55 M.C.E. This pump meets irrigation needs on its own, so there's no need for parallel installation. It has an efficiency of 70% and a required NPSH of 1.5 m. With this pump, there's no risk of cavitation, as the available NPSH ($NPSH_D$ = 3.38 m) is greater than the required NPSH + 1 m.

The MegaCPK 150-125-380 pump, driven at 1750 rpm, delivers a flow rate of 250 m^3 /h and a head of 71.71 M.C.E. It also satisfies leaching conditions on its own, with an efficiency of 77% and a required NPSH of 2.5 m. The pump is highly efficient, but unfortunately presents risks of cavitation, as the available NPSH is 2.6 m. The CPKN 150-440 pump is the most efficient: all you have to do is install two pumps in parallel, one for leaching operation and the other on stand-by.

4. CONCLUSION

The study revealed that for the 3rd stage pumping circuit, the HMT value of 33.58 m is lower than that of the pumps, which is 34.03 m. This pump sends the fluid to the desired heap height with a pressure of 0.5 bar, whereas the desired pressure for watering is around 2 bar. The result: a drop in uranium juice production. The pump does not exhibit cavitation, as the $NPSH_D$ is equal to 4.71 m, a value that far exceeds the $NPSH_r$, which is equal to 1.44 m. Given that at 1485 rpm the pump is unable to deliver a pressure of 6 bar with the valve closed, we can say that the pump has lost its performance. By the 3rd stage, the HMT of the circuit is equal to that of the pump, so the pump will still be able to deliver the fluid to the piles, but at a very low pressure, and even if the two pumps are switched on simultaneously, the flow rate will not exceed 150 m^3 /h. This means that irrigation will be very poor, resulting in mediocre uranium juice production. With a pump efficiency of 61.98%, we can say that the pump is operating under optimum conditions and does not suffer from cavitation, as the $NPSH_D$ is well above the $NPSH_r$. For the 4th stage circuit, the CPKN 100-404 pump driven at 1650 rpm delivers a flow rate of 175 m^3 /h and a head of 57.91

M.C.E. . The MegaCPK 125-80-380 pump driven at 1750 rpm delivers a flow rate of 190 m^3 /h and a head of 60.28 M.C.E. The CPKN 150-440 pump driven at 1450 rpm operates at 230 m^3 /h and 67.55 M.C.E. The MegaCPK 150-125-380 pump driven at 1750 rpm delivers a flow rate of 250 m^3 /h and a head of 71.71 M.C.E.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Qazizada ME, Pivarčiová E. Reliability of parallel and serial centrifugal pumps for dewatering in mining process. Acta Montanistica Slovaca. 2018;23(2).
2. Bridgwood EW, Singh RN, Atkins AS. Selection and optimization of mine pumping systems. International Journal of Mine Water. 1983;2:1-19.
3. Altaev Sh A, Chernetsov GE, Oryngozhin Ye S. Development technology of hydrogenic uranium deposits in Kazakhstan. Almaty. 2003;294.
4. Krupnik LA, Bitimbayev M Zh, Shaposhnik SN , Shaposhnik YN et al N et al. Validation of rational backfill technology for Sekisovskoe deposit. Journal of Mining Science. 2015;51(3):522-528.
5. Oryngozhin ES, Fedorov EV, Alisheva ZN, Mitishova NA. In-situ leaching technology for uranium deposits. Eurasian Mining. 2021;2:31-35.
6. Feng Q, Li T, Qian B, Zhou L, Gao B, Yuan T. Chemical characteristics and utilization of coal mine drainage in China. Mine Water and the Environment. 2014; 33(3):276.
7. Bhargava SK, Ram R, Pownceby M, Grocott S, Ring B, Tardio J, Jones L. A review of acid leaching of uraninite. Hydrometallurgy. 2015;151:10-24.
8. Hoummady E, Golfier F, Cathelineau M, Truche L, Durupt N, Blanvillain JJ, Lefevre E. A multi-analytical approach to the study of uranium-ore agglomerate structure and porosity during heap leaching. Hydrometallurgy. 2017;171:33-43.
9. Morrison K, Filas F. Conventional heap leaching of uranium ore in the western United States. In Tailings and Mine Waste; 2014.
10. Sidi-Tanko OK. Dynamics of vegetation in mining area in the urban commune of Arlit" Master's Thesis, Abdou Moumouni University of Niamey Niger; 2012.
11. AMAN" Status report on the quality of the Tarat and Izegouande water tables Summary of analyzes chemical and radiometric available in December. 2010;1-98.
12. SRK “Environmental and Social Impact Study Report on the Madaouéla West project, Arlit, Niger final version. 2015;2.
13. Yaou Korgom F. Hydrogeological and hydrogeochemical characterization of the groundwater in the Arlit Mining Zone in Niger Final year work ; 2019.
14. Tadewal A, Farida BD, Moussa K, Ousmane B. Hydrogeological characterization of the Izegouande Permian aquifer (Tim Mersoï Basin, North Niger) American Journal of Sciences and Engineering Research. 2021;4(5):12-23.
15. Daou IE, Harouna S, Hassan AM, Charzynski P, Switoniak M, Badjo ATD. Assisted Radiological Stabilization and Monitoring of Radon Fluxes and Gamma Irradiations of Residues from the Processing of Uranium Ore of Arlit Mines (Northern Niger) Using Multivariate Statistical Methods and the Geotechnical Approach. Journal of Materials and Environmental Science. 2022;13(12):1354-1369.
16. Mr. Mamadou Kanta Elh Kassoum; Resizing the lixi heap irrigation pumps by integrating the third and fourth floor, heap leaching-SOMAÏR.School of Mines, Industry and Geology, End of cycle dissertation with a view to obtaining a Diploma of 'Engineer (DI). Mechanical Engineering Department. 2016;72.
17. Ghorbani Y, Franzidis JP, Petersen J. Heap teaching technology—current state, innovations, and future directions: A review. Mineral Processing and Extractive Metallurgy Review. 2016;37(2):73-119

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/112762