

TECHNICAL MODIFICATION OF ALKALI LEACHING CIRCUIT TO IMPROVE SLURRY THROUGHPUT INTO THE AUTOCLAVE

Vipin Kumar Sharma^{1,2,*}, Venkata Rajesh Namboori¹, Chandrasekhar Reddy Tunga¹, Koteswararao Lankalapalli¹, Suman Sarkar¹ and Madala SrinivasaRao¹

Received: May 19, 2023; Revised: July 10, 2023; Accepted: July 17, 2023

Abstract

Tummalapalle Mill represents an alkali-leaching-based uranium processing plant. Alkali leaching occurs inside pressurized autoclaves at controlled temperature and pressure. Although the rated capacity of the Tummalapalle Mill is 3000TPD, only some obstructions were present to achieve the rated capacity. The technical study was done by the process and mechanical engineering team of Tummalapalle Mill for necessary improvements to achieve the rated power, which helped in the overall grinding rate of the processing plant. In the alkali leaching section of the Tummalapalle unit, Autoclaves (pressure vessels) are used for alkali leaching purposes. To run the plant at full rated throughput, i.e., 3000TPD, it is required to push the slurry into autoclaves by double hose-diaphragm pump through spiral heat exchangers with a sufficient flow rate. During the regular course of operation, each double hose-diaphragm pump was able to discharge a limited flow rate with the existing motor-designed parameters. This paper deals with the technical details of double hose-diaphragm pumps, recent technical modifications incorporated and consequent trials taken to increase the pump flow rate and thereby achieve the required throughput into autoclaves

Keywords: Spiral Heat Exchanger, Electric Motor, Double Hose-Diaphragm Pump, Autoclave, Alkali Leaching

Nomenclature

U ₃ O ₈ - Uranium Oxide, TPD - Tons per Day, SELV - Safety Extra Low Voltage, DC - Direct Current, AC - Alternate Current, PELV - Protective Extra Low Voltage, UCIL - Uranium Corporation of India Limited, m ³ /hr- cubic meter per hour, gm/cc - gram per cubic centimeter, mm -	millimeter, min - minute, kW - Kilowatt, Hz - Hertz, V - Voltage, RPM - Rotation per Minute, IP - Ingress Protection, A - Ampere, UL 508 - Standard for Safety for Industrial Control Equipment, LCV - Level Control Valve, NRV - Non-Return Valve, LDV - Let Down Vessel.
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¹ Uranium Corporation of India Limited., Tummalapalle, Kadapa (YSR), Andhra Pradesh, India, Pin Code-516349, India. E-mail: vipinshrm4@gmail.com; ch21d005@iittp.ac.in

² Department of Chemical Engineering, Indian Institute of Technology, Tirupati, Andhra Pradesh, India, Pin Code-517506, India

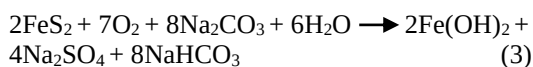
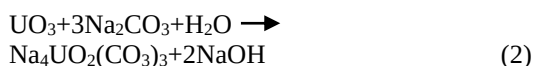
* Corresponding author

DOI: <https://doi.org/10.55766/sujst-2023-04-e0998>

Introduction and literature review

Tummalapalle Mill represents an alkali-leaching-based uranium processing plant. Alkali leaching occurs inside pressurized autoclaves at controlled temperature and pressure. Although the rated capacity of the Tummalapalle Mill is 3000TPD (Suri, 2010), few obstructions were present to achieve the rated capacity i.e., insufficient input flow rate to leaching autoclaves. Uranium Corporation of India Limited is having a continuous contribution toward fulfilling the nuclear fuel need of our nation. It relates to clean and green technological energy production. Presently, UCIL celebrates 50th Golden Jubilee Anniversary. Major ore reserves are situated in Kadapa district, Andhra Pradesh, that rests on alkali leaching (Vipin *et al.*, 2019a).

Chemical reactions of alkali leaching inside autoclaves are as follows (Vipin *et al.*, 2019b);



Chemical reaction (3) is exothermic due to pyrite present in the ore. The temperature may rise to 160°C due to it. Spiral heat exchangers are used for preheating autoclave input. Autoclave discharge slurry temperature helps in preheating; Refer to Figure 1.

As per the literature survey, Taner *et al.* 2018a informed that the Cr-C coated SS304 bipolar plates were used in the electrolysis cells and the septic mixture (urea, ammonia, methyl alcohol)

was used in the electrolyzer as a chemical solution to make hydrogen production more efficient and cost-effective. Taner *et al.* 2017a researched that time-dependent voltage and current parameter changes were observed for the performance analysis in the experimental study. Taner *et al.* 2018b aim to improve the performance, efficiency, and development of modeling and simulations of PEM fuel cells by experimental optimization. Taner *et al.* 2021 found the results of the energy efficiency to be 72.4% and exergy efficiency of 85.22% of the PEMFC under 0.5 bar pressure and 0.2 l/min flow rate. Not only on the industrial level, but Taner *et al.* 2019 proved that such a study can be helpful in the field of solar energy-techno economic analysis also, as well as this study related to hydrogen production through alkaline electrolyzers as well as a techno-economic analysis and enviro-economic analysis (Naqvi *et al.*, 2022). A further literature survey was done (Huseyin *et al.* 2017; 2018; Taner *et al.* 2017b; 2018c) for techno-economic analysis considering the additional scope of the study by industry.

Objectives to achieve rate improvement at UCIL, Tummalapalle Mill

- To achieve the maximum output of U_3O_8 production/cost benefits in terms of production enhancement.
- To achieve the rated capacity of Tummalapalle Mill/enhancement in grinding circuit rate.
- Maximum-rated input for autoclave/maximum-rated input and discharge parameters of double hose-diaphragm pump.
- To enhance the upcoming nuclear fuel requirement of the Nation.

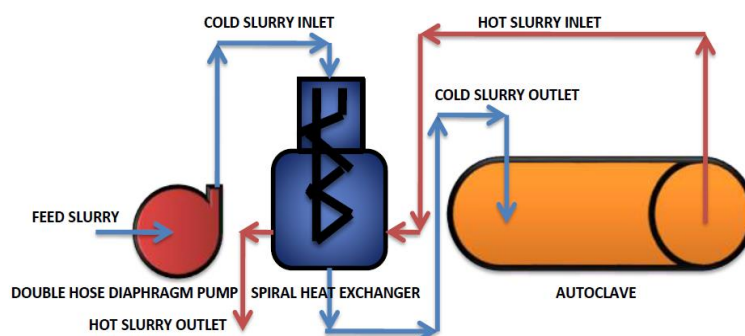


Figure 1. Schematic representation of a present system at UCIL, Tummalapalle Mill (Vipin *et al.*, 2023)

General description of double hose-diaphragm pump

Three numbers of double hose-diaphragm pumps (2 working standby) for pumping the slurry from feed tanks to autoclaves are available at Tummalapalle Mill. The complete pump assembly consists of a base plate box, pump, reduction gearbox, and driving motor, as well as piping and delivery valves. Refer Figure 2. Apart from this, depending on the pump design, special built-in safety components such as leak detectors for hose failure and valve performance monitoring systems are also included. The pump is driven by an electric motor. Due to the reduction of the intermediate gearbox, the motor speed is reduced to the designed driving speed of the pump reduction gearbox. In the reduction gearbox, the rotating movement of the let shaft is converted into an oscillating motion. Concurrently, the rate is reduced to the required number of strokes of the pump with

the intermediate gearbox and with the frequency converter of the motor. Technical details of the double hose-diaphragm pump are mentioned in Table 1.

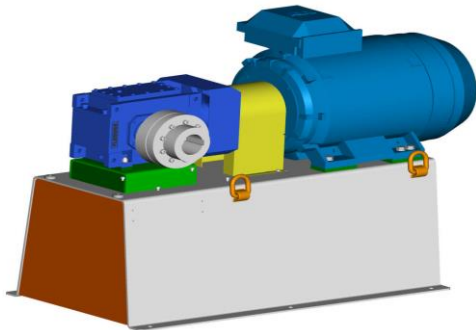


Figure 2. The electric motor of the double hose-diaphragm pump with the intermediate gearbox (Operation and Maintenance, 2023)

Table 1. Technical details of double hose-diaphragm pump

Sl. No.	Technical Characteristics	Parameter Value / Range	Unit
1	Material handled	Alkaline Slurry	-
2	Capacity	30 - 100	m ³ /hr
3	Working Pressure	15	bar
4	Piston Diameter	280	mm
5	Stroke	200	mm
6	Number of Strokes	10 - 50	min ⁻¹

Operation of double hose-diaphragm pump

The reciprocating movement of the plunger displays a defined volume of hydraulic fluid within the pump head. Due to this volume change, both the primary hose-diaphragm and the secondary hose-diaphragm are squeezed together at the same time (like squeezing a vein). Because of the special construction of the double hose diaphragms, they always distort in the same form and direction. An actuation fluid has been used as a direct pressure transmitting element (without causing any efficiency loss) between the primary and the secondary hose-diaphragm, in this case, water/anti-freeze. Technical details of the existing drive motor of the Double Hose-Diaphragm Pump are mentioned in Table 2.

Table 2. Technical details of the existing drive motor of the Double Hose-Diaphragm Pump

Sl. No.	Technical Characteristics	Parameter Value	Unit
1	Energy	75	kW
2	Rotational Speed	1000	min ⁻¹
3	Frequency	50	Hz
4	Switch Fuse	415	V
5	Enclosure	IP55	-

When the plunger moves forward, the fluid handled inside the primary hose-diaphragm is pressed through the discharge valve into the discharge line due to the exerted pressure and the resulting volume change. The suction valve is closed. When the plunger moves backward (towards the reduction gearbox), the hose diaphragms, which are distorted during the discharge stroke, get back to their original cylindrical shape again. In the pump head, a vacuum arises, enabling the suction valve to open. The fluid handled then flows through the opened ball valve into the primary hose-diaphragm. Due to the oscillating movement of the plunger, a new discharge stroke begins.

The task of the secondary hose-diaphragm is to separate the actuation fluid between the primary and secondary hose-diaphragm from the hydraulic fluid between the plunger and secondary hose-diaphragm.

Power supply (power) for the drive motor of the double hose-diaphragm pump

Terminal 1: L (AC unit) / L+ (DC unit) and Terminal 2: N (AC unit) / L- (DC unit).

For DC units, the provided voltage ought to be protected superficially (max.2A). The terminals of the DC supply are directly linked with the terminals of the sensor supply. Due to this, the SELV criteria should be adhered to for DC provisions (shielded low voltage, circuit galvanically split from other circuits, not earthed). If the DC circuit is to be earthed (e.g., because of nationalized policy), the PELV criteria should be adhered to (shielded low voltage, circuit galvanically split from other circuits). The device is supplied from an isolating source and protected by an overcurrent device such that the limited voltage circuit requirements per UL 508 are met. If the unit has abounded with AC voltage, the low voltage provision for the sensors meets the SELV provision.

Connection of sensors for double hose-diaphragm pump

Adherence to the SELV criteria is important for the sensor connection so that there is no dangerous contact voltage at the sensor that can enter the unit. In the case of relay outputs, the voltage between the different output circuits (terminals 4, 5, 6 - terminals 7, 8, 9 - terminals 10, 11, 12; Refer to Figure 3) does not exceed the permissible maximum value of 300V AC. A miniature fuse is inserted (≤ 5 A fast-acting).

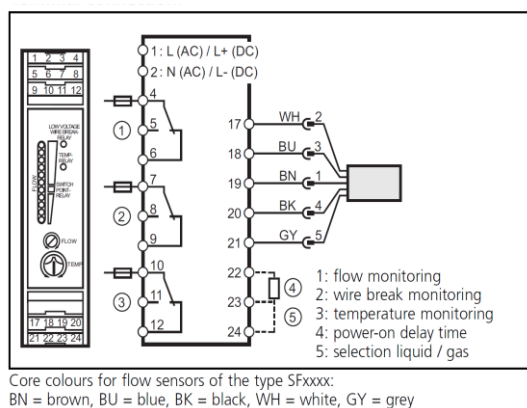


Figure 3. Terminal connection of Double Hose-Diaphragm Pump (if muk)

Measuring principle of double hose-diaphragm pump

Leaks in the valves of oscillating positive displacement pumps are flows in which cavitations occur. This generates sound waves. The resonance waves are transferred to the regulator board. The acoustic emission sensor of the acoustic diagnostics unit detects these sound waves on the

exterior of the valve housing. The sound pressure level L generated by the leak depends on the hydraulic power P_{hyd} as follows:

$$L = 10 \log \frac{\eta * P_{hyd}}{P_o} \quad (4)$$

L - Sound pressure level

η - Energy conversion coefficient, from hydraulic to acoustic

P_{hyd} - Hydraulic power

P_o - Reference power

The hydraulic power at a valve depends on the pressure differential Δp and the flow rate follows:

$$P_{hyd} = \Delta p * Q \quad (5)$$

P_{hyd} - Hydraulic power

Δp - Pressure differential

Q - Flow rate

The valves of an oscillating displacement pump open and close periodically. The sound pressure level of an intact valve is low. The sound pressure level of a defective valve depends on the valve's position. A pumpworking normally changes the valve position periodically between open and closed. The sound pressure level, therefore, fluctuates periodically.



Figure 4. The bottom short piece of the suction accumulator (highlighted) of the double hose-diaphragm pump at the autoclave area of UCIL, Tummalapalle Mill

Technical modifications at alkali leaching circuit to improve slurry throughput into autoclave

Upon taking trials with several modifications and consultation with the supplier of the double hose-diaphragm pump, we observed whether the

following implementations could lead to an increase in the flow rate in the pump.

a) Increase the suction line size (with which the pump can get maximum suction at all times).

b) Increase the RPM of the motor (such that the number of strokes per minute can increase, and it may help in an increase of the flow rate).

Later on, it was observed that an increase in the suction line size is not advisable because it may cause settling of particles in the suction side. It was decided to change the bottom short piece of the suction accumulator, as mentioned in Figure 4. The function diagram for flow monitoring of the Double Hose-Diaphragm Pump is mentioned in Figure 5.

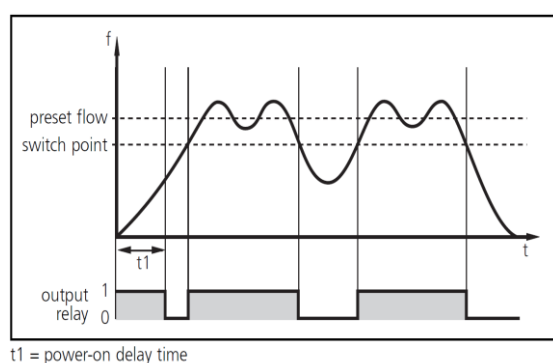


Figure 5. Function diagram for flows monitoring of Double-Hose Diaphragm Pumps (IFM UK, 2021)

Modifications were done in one pump, and trials were taken, but the flow was not increased satisfactorily. Then, in consultation with the pump supplier, it was decided to increase the RPM of the pump by increasing the drive motor RPM. The existing motor itself, at 73 Hz frequency, was able to provide the speed of 1500 RPM, with which it was possible to achieve the required flow rate. Motor frequency was analyzed as a collaborative study of the concerned section to achieve a suitable solution. The existing motor was replaced (a 996 RPM drive motor, which was originally supplied by the supplier) with another motor of 1480 RPM. After the replacement of the motor, trial runs were taken, and found that at 1200 RPM of, the motor double hose-diaphragm pump (the number of strokes per minute increased) was able to discharge sufficient slurry. We continued the operations on a particular double hose-diaphragm pump for about a few hours with that flow rate and found no abnormalities. The pump was able to discharge sufficient

slurry through an existing spiral heat exchanger, and there were no vibrations in the circuit. In addition to this, slight modifications near the LCV pipeline were made before the letdown vessel or autoclave discharge tanks to control sufficient input/output and to maintain proper levels. Online flow transmitters are available at the ore processing plant. Regular monitoring is done for the evaluation of the effectiveness of the modifications.

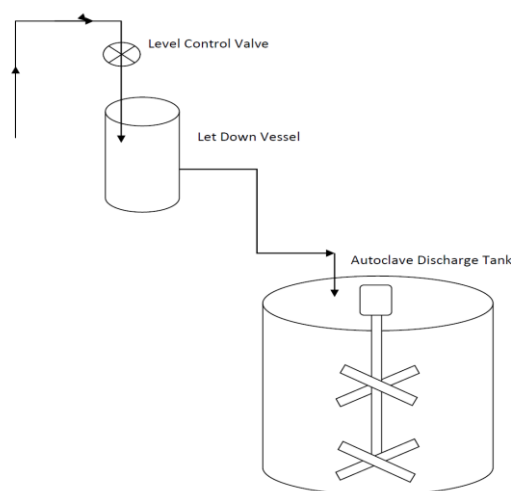


Figure 6(a). The existing system at the autoclave discharge into LDV and further to the autoclave discharge tank

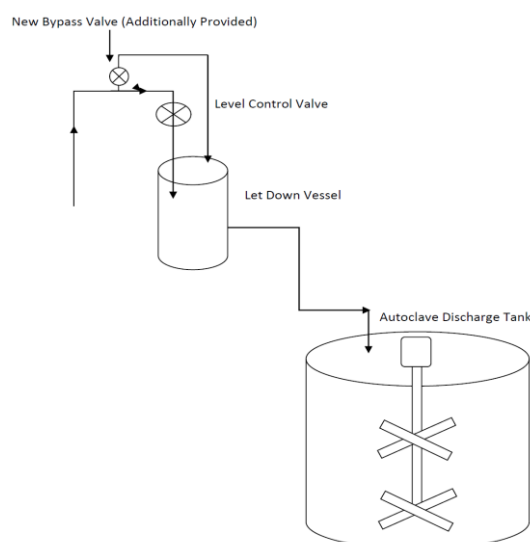


Figure 6(b). Modified system for autoclave discharge into LDV and further to autoclave discharge tank, to allow desired discharge

Additional scope of technical modification in alkali leaching circuit and resolution of problems

As input to the autoclave increased from limited to sufficient flow rate when autoclave pressure was maintained at 7 bar pressure. It was observed that the autoclave level variation was insufficient, even at the full opening of the autoclave LCV. It indicates that there was some obstacle to the sufficient discharge of slurry from the autoclave.

We increased the autoclave pressure from 7 to 9 bar under controlled conditions, and trials were taken for higher discharge. However, the autoclave level variation was insufficient at the full opening of the autoclave LCV also. Even after, the objective of sufficient slurry discharge from the autoclave is not achieved.

After a detailed inspection, it was noticed that the LCV pipeline size was reduced to 3 inches from 6 inches to accommodate a 3-inch LCV. It was observed that this reduction in pipeline size to 3 inches was the reason for the obstacle to meeting rated autoclave discharge Figure 6(a). It was decided to lay one bypass line before the LCV such that an additional quantity of slurry could be discharged into the LDV and then to the autoclave discharge tank. Accordingly, a new line is drawn, and a trial run was taken. It was observed that the autoclave level is being maintained constantly after technical modifications Figure 6(b). This confirmed that rated discharge was achieved from autoclaves.

Observations to be followed in support of technical modifications

- a) Suction for double hose-diaphragm pumps should always be available.
- b) The strainer at the suction end is to be checked/cleaned regularly for sufficient suction during operations.
- c) All NRVs in the double hose-diaphragm pumps should be healthy and perform their operation.
- d) At the discharge of the double hose-diaphragm pump, we have an accumulator for absorbing vibrations and maintaining the constant discharge pressure generated by the pump at different strokes. The charging pressure of nitrogen should always be 80% of the pump discharge pressure (with which the accumulator observes vibrations).
- e) Differential pressure between autoclave and double hose-diaphragm pump discharge pressure should not be more than 3-4 bar always. Which sufficient flushing of spiral heat exchangers is required regularly to remove settled slurry, trash, etc.

f) Interim storage of gearbox oil, hydraulic oil, and actuation fluid should remain in the pump always.

g) The last and most important one is the entrance of foreign/trash particles into pump suction should be avoided.

Electrical safety devices

According to electronic regulations, only skilled electricians are allowed to work on electrical equipment. Precautions are taken as specified by the electronic regulations. The rotation direction of the motor is rechecked regularly. The control panel is provided with protective devices, which are set to the actual situation on-site to ensure proper operation. By using a frequency converter, it is confirmed that the parameter for the nominal output torque is set to the 1, 1 fold of the needed torque at the point of maximum pressure and flow.

Conclusion

Leaching studies on different ores having chemical refractory uranium minerals (betafite, liandratite) and an ore where the uranium phases are in very-fine to ultrafine dissemination in the host matrix have indicated the scope of recovering uranium very efficiently by using an autoclave reactor (Sreenivas *et al*, 2010). This is to conclude that, after implementing our suggested modifications, the number of strokes per minute increased at the pump and thereby increased the flow rate. The slurry flow rate was increased by 25% (if required, we can increase the slurry flow rate further), which will be sufficient to operate the plant with a throughput capacity. It can help in achieving additional improvements from the Tummalapalle unit for the organization in terms of production. By doing these modifications in the autoclave area, we can control the plant to operate at full capacity because the alkali leaching circuit is the main heart of the ore processing unit, and the double hose diaphragm pump is responsible for passing the required throughput into the circuit.

Acknowledgment

We thank the management of Uranium Corporation of India Limited. We also thank Dr. C.K. Asnani (C&MD), Shri Rajesh Kumar, D(T), and Shri. K. Sharma, GM(I/P&IRs/CP), for their valuable suggestions towards improvement and CR&D activities at Tummalapalle Mill. I also thank Dr. T.

Sunil Kumar, HOD, and Professors from the Department of Chemical Engineering, Indian Institute of Technology Tirupati for providing valuable guidance in my academic and research work. We thank the organizers of the International Conference on Advances in Chemical & Materials Sciences (ACMS)-2022 for selecting our research work as the Best Technical Paper Award in the 75th Platinum Jubilee Celebration of the Indian Institute of Chemical Engineers (IICChE).

Funding

This work was supported by Uranium Corporation of India Limited Management.

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