Outotec Pressure Oxidation – More out of Sulfide Ore

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ABSTRACT

Outotec is today capable of providing technologies, process equipment and engineering for the construction of pressure oxidation leaching (POX) plants in any location in the world. Outotec works with customers from mine to pure metal, participating in plant design from the process development phase (including test work execution/supervision) to plant commissioning and operations. Either key equipment technology packages with basic engineering or entire POX plants can be supplied.

The addition of pressure oxidation equipment to Outotec's product portfolio adds to and complements already existing significant experience in general hydrometallurgical process and proprietary equipment design and supply.

In addition to providing key pressure vessels, piping and valves to a POX plant, Outotec can offer an enhanced and proven autoclave agitation system that maximises oxygen mass transfer and utilisation. Novel energy and water recovery technology can also be tailored to a customer's specific needs. Importantly Outotec owns and operates extensive test work facilities and can provide test work to ensure the optimum POX flow sheet and materials of construction. Outotec ensures that best available technology (BAT) concepts are used in POX design to improve the availability of the process and minimise unpredicted shutdowns.

INTRODUCTION

Outotec has a long history of developing and supplying process solutions, technologies and services for the mining and metallurgical industries. Outotec can develop a project from conceptual study phase to detailed engineering and Outotec's scope of supply can vary from single equipment to complete plant. With significant metallurgical process experience in two in-house research centres, Outotec continuously develops new process concepts and technologies. Batch testing as well as full continuous pilot testing facilities are available. In addition continuous equipment development and corrosion testing are available to support selected process designs. In many cases this equipment development is supported by computational fluid dynamics (CFD) validation and design.

An Outotec pressure oxidation (POX) technology package can include the whole process chain from ore milling and beneficiation to autoclave oxidation and final gold recovery. In this article, some details of Outotec's innovative approach to pressure oxidation are highlighted, specifically autoclave agitation and gas dispersion as well as a novel energy and water recovery system.

OUTOTEC PRESSURE EQUIPMENT TECHNOLOGY – BACKGROUND

Outokumpu Engineering and now Outotec has extensive experience in autoclave technology and autoclave equipment design and supply mainly for matte leaching in Finland both at Kokkola and Harjavalta plants.

Today Outotec is an independent technology company and is capable of supplying pressure hydrometallurgical equipment and technology into other commodities and outside Finland. Recently Outotec has supplied engineering, process equipment and technology to Petropavlovsk PCL, the second largest gold producer in Russia with assets located in the Far East. Outotec supplied all major equipment for both the Malomir concentrator and Pokrovskiy pressure oxidation plant (Zaytsev *et al*, 2013). Outotec's engineering expertise and proprietary process equipment were combined together with Petropavlovsk's process know-how.

In addition to the Pokrovskiy autoclaves, Outotec has been recently awarded a contract for the supply of two autoclaves for a matte treatment plant in South Korea continuing a long history of matte leaching. A summary of autoclave installations is shown in Table 1.

Historically, Outotec has put substantial effort into improving gas-liquid mass transfer rate in autoclaves in order to maximise both autoclave capacity and utilisation of gaseous reagent. It has been proven by both laboratory-scale measurements and industrial experience (Outokumpu/Outotec) that head space gas reincorporation has significant impact on gas-liquid mass transfer rate in an autoclave. To maximise reincorporation of head space oxygen, Outotec

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TABLE 1

Outotec autoclave technology supply.

Year	No	Location	Application	Autoclave volume (m^3)	T (°C)	P (barg)	Material	Type
1965	1	Kokkola, Finland	Co-plant	20	120	7	Brick	Cont
1965	1	Kokkola, Finland	Co-plant	40	120	7	Brick	Cont
1970	1	Kokkola, Finland	Co-plant	60			Brick	Cont
1980	1	Pori, Finland		5	180	15	Ti	Batch
1981	1	Harjavalta, Finland	Ni-plant	60	120	10	Brick	Cont
1984	1	Harjavalta, Finland	Ni-plant	170	120	10	Ti	Cont
1984	2	Kokkola, Finland	Co-plant	30	150	10	Ti	Batch
1990	2	Kokkola, Finland	Co-plant	125	120	10	Ti	Cont
1994	1	Harjavalta, Finland	Ni-plant	150	150	15	Ti	Cont
1994	1	Harjavalta, Finland	Ni-plant	90	150	15	Ti	Cont
1995	4	Harjavalta, Finland	Ni-reduction	40	230	40	316L	Batch
2012	4	Pokrovskiy, Amursk, Russia	Pressure oxidation of refractory gold	52	230	35	CS + brick lining	Cont
2013	1	South Korea	Ni-plant	20	180	16	Ti	Cont
2013	1	South Korea	Ni-plant	6	130	8	316L	Cont

applies twin impeller combination of OKTOP® agitators. Gas mass transfer performance of OKTOP impellers has been measured to be more efficient compared to standard autoclave solutions (Rushton turbine or Rushton/Pitch blade turbine combination). Outotec has successfully applied modern impeller design with enhanced head space gas reincorporation in many metallurgical processes, mainly in the former Outokumpu plants in Finland.

PRESSURE OXIDATION OF PYRITE AND ARSENOPYRITE

Pressure oxidation of refractory gold ores and concentrates made its commercial breakthrough in the mid-1980s. In acidic pressure oxidation the sulfide mineral matrix, mainly pyrite and arsenopyrite is destroyed and dissolved at high temperature and pressure using gaseous oxygen. Gold is liberated for leaching and recovery.

Multiphase reaction systems are complex in nature involving several parallel and consecutive reactions occurring at the same time. Also many physical phenomena such as interfacial mass transfer between gas and liquid phases as well as liquid and solid phase diffusion of reactants in the porous media increase the inherent complexity of the reaction system. Main overall chemical reactions occurring in the pressure oxidation autoclave are shown below.

$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,FeSO_4 + 2\,H_2SO_4 \qquad (1)$$

$$FeS_2 + 7\,Fe_2(SO_4)_3 + 8\,H_2O \rightarrow 15\,FeSO_4 + 8\,H_2SO_4 \qquad (2)$$

$$4\,FeAsS + 13\,O_2 + 6\,H_2O \rightarrow 4\,H_3AsO_4 + 4\,FeSO_4 \qquad (3)$$

$$2\,FeAsS + 13\,Fe_2(SO_4)_3 + 16\,H_2O \rightarrow 2\,H_3AsO_4 + 28\,FeSO_4 + 13\,H_2SO_4 \qquad (4)$$

$$2\,H_3AsO_4(a) + Fe_2(SO_4)_3(a) \rightarrow 2\,FeAsO_4(s) + 3\,H_2SO_4(a) \qquad (5)$$

$$Fe_2(SO_4)_3 + 3\,H_2O \rightarrow Fe_2O_3(s) + 3\,H_2SO_4(a) \qquad (6)$$

$$Fe_2(SO_4)_3 + 2\,H_2O \rightarrow 2\,FeOH(SO_4)(s) + H_2SO_4(a) \qquad (7)$$

Only a small amount of elemental sulfur is formed at temperature above 190°C, and the main products are ferric and ferrous sulfate and sulfuric acid.

Ferrous ion formed in the reactions is oxidised by molecular oxygen back to ferric ion, as seen in Reaction 8. Oxidation-reduction of iron plays an important role in the reaction system.

$$4\,FeSO_4(a) + O_2(g) + 2\,H_2SO_4(a) \rightarrow 2\,Fe_2(SO_4)_3(a) + 2\,H_2O \qquad (8)$$

Determining the predominant reaction mechanism and reaction kinetics of such a complex reaction system is not a straightforward task. Aqueous oxidation of pyrite has been reviewed by Lowson (1982), Papangelakis and Demopoulos (1991) and Long (2000). In spite of extensive research activity a unanimous consensus about predominant reaction mechanisms and kinetics of acidic oxidation has not been achieved among researchers.

Long (2000) noted that most of the published research has been carried out at temperatures below 180°C. Only limited data on the kinetics of pyrite and arsenopyrite dissolution in acid pressure oxidation is available at temperatures used in industrial applications, ie 190 - 230°C.

Long (2000) studied the behaviour of pyrite in acidic pressure oxidation at temperature 170 - 230°C and proposed that pyrite is initially oxidised to ferric sulfate by molecular oxygen according to Reaction 9. Formed ferric ion oxidises sulfide in the pyrite according to Reaction 2.

$$4\,FeS_2 + 15\,O_2 + 2\,H_2O \rightarrow 2\,Fe_2(SO_4)_3 + 2\,H_2SO_4 \qquad (9)$$

Long (2000) also reported that ferrous ion oxidation by molecular oxygen (Reaction 8) significantly affects the reaction rate of pyrite oxidation. Long (2000) discovered that the overall initial reaction rate of pyrite dissolution is one half order with respect to oxygen partial pressure, ie dissolved oxygen concentration.

It has been reported by Lowson (1982) that the oxidation rate of ferrous ion to ferric ion in sulfuric acid media is second order with respect to ferrous ion and first order with respect to dissolved oxygen concentration. Copper is also reported to catalyse the oxidation rate of ferrous ion to ferric form.

Generally the reaction rate of pyrite in experiments conducted in small laboratory-scale autoclaves is not limited by interfacial mass transfer rates. However, in industrial-scale applications, interfacial gas-liquid mass transfer rate plays an important role and understanding and improving gas-liquid mass transfer is a primary focus for Outotec agitation design.

AUTOCLAVE AGITATION

Outotec has two in-house R&D centres located in Pori, Finland and Frankfurt, Germany. These centres are specialised in process and equipment technology development for minerals and metals production and are equipped with state-of-the-art laboratories and pilot plants.

Outotec autoclave research activities include fluid dynamic studies and equipment design as well as overall process design. For example, nickel and cobalt reduction, nickel and cobalt sulfide leaching and matte leaching have been extensively studied. Complete technology solutions have been delivered to Kokkola cobalt and Harjavalta nickel plants in Finland. Recently autoclave technology and equipment has been delivered for a matte leaching plant in South Korea and for a refractory gold concentrate POX plant in Russia (Petropavlovsk PLC).

Experimental

Outotec OKTOP impeller configurations have been tested and compared against conventional Rushton impeller systems. Both single and dual impeller combinations were tested. Photographs of tested impeller types are shown in Figure 1 and tested configurations in Table 2. Gas dispersion, gas-liquid mass transfer rate and solid suspension properties were compared in laboratory scale reactors. Tests were done in two reactors with impellers having diameter of 74 mm and 130 - 136 mm.

Dispersion and suspension tests were performed in a plastic Outotec style horizontal autoclave one compartment model (see Figure 2), which replicates the industrial autoclave compartment design. The horizontal autoclave model was filled with 25.5 - 27.5 L of water. Gas dispersion tests were done with 11 m^3/h air feed at room temperature corresponding to a superficial velocity (J_g) of 2.5 cm/s. The agitation power input was defined with torque measurements during tests.

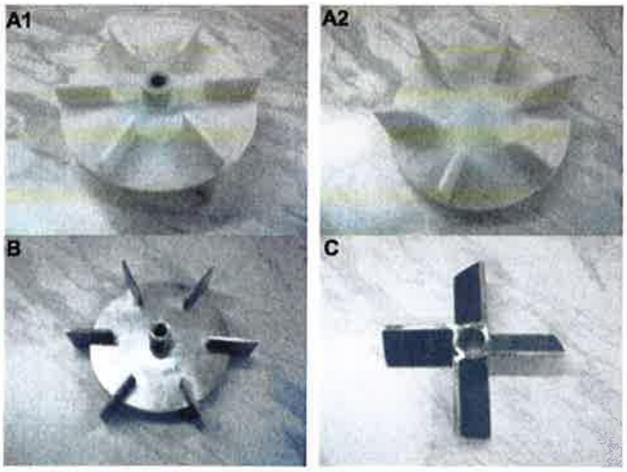

FIG 1 - Impellers used in horizontal autoclave tests: (A1) OKTOP2200 up; (A2) OKTOP2200 down; (B) Rushton turbine; (C) OKTOP1000.

Different parameters were observed during the dispersion tests in the horizontal autoclave model. Gas holdup was measured by comparing the liquid level during agitation to the unagitated condition. Impeller speed required for full dispersion was recorded. Full dispersion occurs when gas is dispersed throughout the entire reactor volume.

During solid suspension tests the just suspended (N_{js}) speed and suspension height at N_{js} were determined with and without air feed. N_{js} is the agitation speed where all particles at the bottom of the tank are moving within one to two second interval. The origin of the N_{js} definition is from Zweitering further explained in Chudacek (1988). Quartz sand at a concentration of 400 g/L and size of 100 - 125 μm was used.

Power input was measured also at ungassed conditions. Ungassed power number was calculated from power input with Equation 10:

$$P = N_p \rho N^3 D^5 \quad (10)$$

where:

P is power input (W)

N_p is power number (-)

ρ is slurry density (kg/m^3)

N is agitation speed (1/s)

D is impeller diameter (m)

Ungassed power numbers were used in power input calculations at different agitation speeds, when ungassed power was compared to gassed power. The number was determined by completely filling the reactor with water with no gas feed. In this way the mixing of gas into solution was minimised. The determined power number values are shown in Table 2.

The mass transfer tests were done at the SRC Hydrometallurgy laboratory in St Petersburg to support the Petropavlovsk autoclave design. Tests were conducted in a vertical autoclave with an effective volume of 4 L and diameter of 176 mm. The reactor had four baffles. A Rushton turbine having eight blades was compared with a twin OKTOP impeller set-up. The impeller diameters were 74 mm. Impeller speed was 500 - 900 rev/min. Tests were done at 2.2 bar and 20°C. Pressure was controlled by oxygen addition. Oxygen flowrate varied between 0.04 and 0.36 m^3/h. Power input was measured during the tests.

The mass transfer tests were based on the well-known sodium sulfite oxidation reaction. A small amount of catalyst such as cobalt or copper is needed to promote the reaction as indicated by Linek, Benes and Sinkule (1990) and Vilaca *et al* (2000). Oxygen mass transfer can be characterised with liquid-side volumetric mass transfer coefficient, k_La. When assuming a well-mixed liquid phase the mass balance of dissolved oxygen can be given in Equation 11:

$$dC/dt = k_La(C^* - C) \quad (11)$$

where:

C^* is the saturation concentration of the gas in liquid (mol/m^3)

TABLE 2

Impeller configurations used in gas dispersion, solid suspension and mass transfer tests.

Test type		Upper impeller			Bottom impeller		
	Power number	Model	Diameter (blades – blade angle) (mm)	Location from surface (mm)	Model	Diameter (mm)	Location from bottom (mm)
Dispersion	8.0				OKTOP2200	130	91
Dispersion	5.2				Rushton	136	91
Dispersion	9.1	OKTOP1000	136 (4 - 45°)	55	OKTOP2200	130	91
Dispersion	6.3	OKTOP1000	136 (4 - 45°)	55	Rushton	136	91
Suspension					OKTOP2200	130	91
Suspension					Rushton	136	95
Suspension		OKTOP1000	136 (4 - 45°)	55	OKTOP2200	130	91
Suspension		OKTOP1000	136 (4 - 45°)	55	Rushton	136	95
Mass transfer		OKTOP1000	74 (4 - 45°)		OKTOP2200	74	
Mass transfer					Rushton	74	

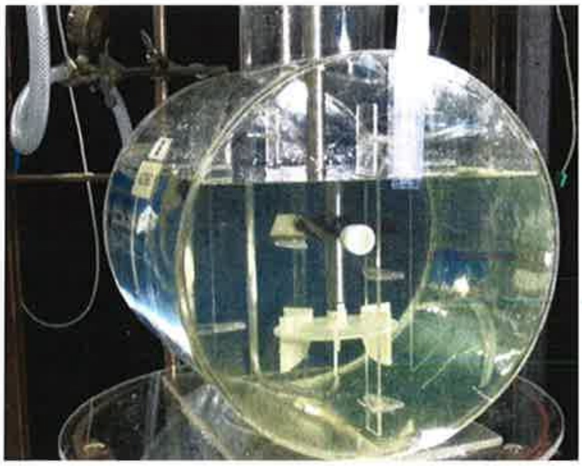

FIG 2 - Horizontal one-compartment autoclave model.

C	is the actual gas concentration at the liquid (mol/m^3)
k_La	is the volumetric mass transfer coefficient (1/s)

The gas mass transfer can be calculated from Equations 12 and 13 with the modified sulfite method as presented by Vilaca *et al* (2000):

$$OTR = \Delta m_{O2} / (V \Delta t) \text{ or } OTR = n_s / (2V \Delta t) \qquad (12)$$

$$k_La = OTR\,H / (P^* - P) \text{ or } k_La = OTR / (C^* - C) \qquad (13)$$

where:

OTR	is oxygen transfer rate [mol/(m^3 s)]
m_{O2}	is oxygen consumption (kg)
n_s	consumed sodium sulfite at zero liquid oxygen level (mol)
V	is liquid volume (m^3)
Δt	is the oxidation time (s)
H	is Henry's constant (atm m^3/mol)
P*	is partial pressure of oxygen in equilibrium in liquid phase (atm)
P	is partial pressure of oxygen in gas phase in bulk (atm)

Experimental results and discussion

OKTOP and Rushton agitator gas dispersion performance was compared and results are shown in Table 3 and Figure 3. Dispersion tests proved that OKTOP agitators out-perform Rushton agitators. Results show that full gas dispersion was achieved at ten to 20 per cent lower tip speed with OKTOP impellers. In an industrial scale autoclave, lower impeller tip speed would result in lower wear rates with lower maintenance cost and increased autoclave uptime.

TABLE 3

Full dispersion agitation limits at air superficial velocity (J_g) of 2.5 cm/s.

Impeller	Agitation (rev/min)	Relative tip speed (%)	Gas hold up[a] (%)	Relative power P(gas) / P(ungas) (%)
OKTOP	450	78	16	56
Rushton	550	100	20	44
Dual OKTOP	450	82/78	18	52
Dual Rushton	500	91	16	43

[a] Compared to un-gassed water volume.

Mass transfer performance was compared for Dual OKTOP and Rushton agitators. Volumetric gas-liquid mass transfer coefficient as a function impeller tip-speed is shown in Figure4. This figure shows that at the same agitation intensity, gas-liquid mass transfer is 24 - 40 per cent more favourable for OKTOP impellers. Conversely for the same k_La power consumption is lower with OKTOP impellers. Part of the difference can be explained by the enhanced head space gas reincorporation performance of the OKTOP design.

OKTOP and Rushton agitator solid suspension performance was compared and results are shown in Table 4. The suspension test results showed strong difference in required power input of just suspended point (N_{js}) between impellers and measured conditions as seen from Table 4. It is clearly seen that OKTOP overcomes Rushton in all cases.

Results show that the point of just suspension can be achieved with 15 - 53 per cent lower agitator speed with OKTOP impeller combinations gassed or ungassed. Also measured power input is respectively 40 - 130 per cent lower with OKTOP impellers. The above results show that higher

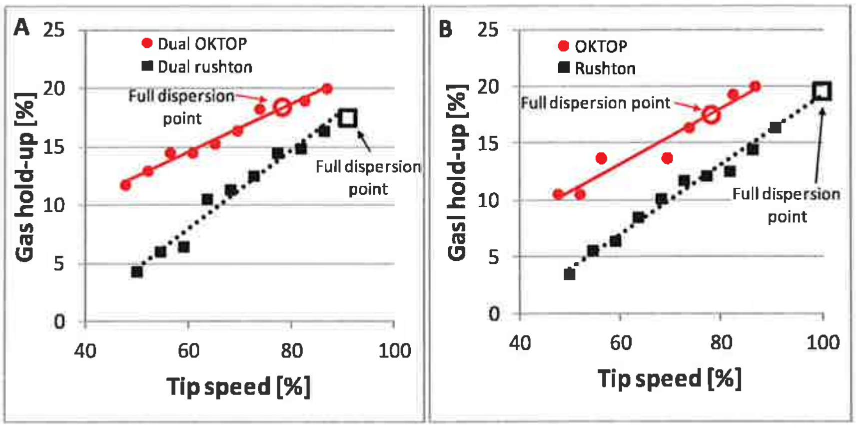

FIG 3 - Gas hold-up as a function of impeller tip speed.

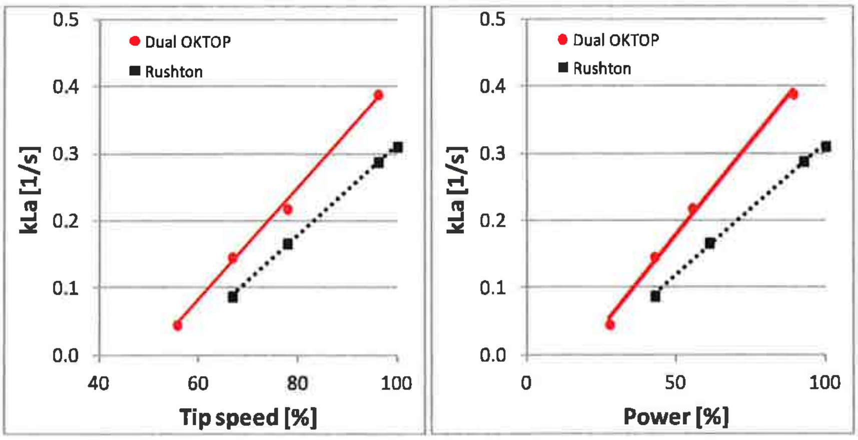

FIG 4 - Volumetric gas-liquid mass transfer coefficient as a function impeller tip-speed.

TABLE 4

Just suspended solids with and without air addition.

Impeller	Air superficial velocity (J_g) (cm/s)	N_{js} (rev/min)	P(meas) (W)
OKTOP	0	220	16
Rushton	0	270	24
Dual OKTOP	0	165	8
Dual Rushton	0	190	11
OKTOP	1.6	300	21
Rushton	1.6	460	48
Dual OKTOP	1.6	310	30
Dual Rushton	1.6	430	48
Dual OKTOP	0.2	230	20
Dual OKTOP	0.7	260	20
Dual OKTOP	1.1	290	25

agitation intensity is required to disperse gas into liquid rather than suspend solids. Conversely solid suspension is critical in systems having low gas feed rates.

Computational fluid dynamics

CFD simulations are extensively utilised to support process development at Outotec. An example is presented below comparing OKTOP and Rushton agitators in an industrial scale autoclave compartment.

The velocity profiles and mixing times of OKTOP2200 and Rushton were simulated in 2.81 m long and 2.44 m diameter horizontal autoclave compartment with a volume of 9.8 m^3. Impeller diameter was 850 mm located 595 mm from the bottom. OKTOP and Rushton impellers were compared with the same power input levels. The rotation speed of OKTOP was 95.5 rev/min and Rushton was 108 rev/min. A schematic picture of the calculation volume is shown in Figure 5.

Turbulence was modelled with realisable k-e-model and agitation rotation with moving reference frame method. Free surface was modelled as a friction less wall. Simulation fluid was water at 20°C. Tracer value is monitored as a function of time at discrete points in the simulation volume. The fully mixed condition was determined by the point when tracer value was at most 0.5 per cent away from theoretical fully mixed value. Mixing times were monitored in six vertical and in seven horizontal level points. The total number of monitoring points was 18.

The velocity profiles seen from compartment head and side for both impellers are shown in Figure 6. Mixing times and flow numbers are shown in Table 5. Simulation results show that with the same power consumption and 12 per cent lower agitation speed the OKTOP impeller gives higher velocity and shorter mixing time than Rushton. The pumping number is 29 per cent higher and average mixing time six per cent shorter with OKTOP impeller than with Rushton.

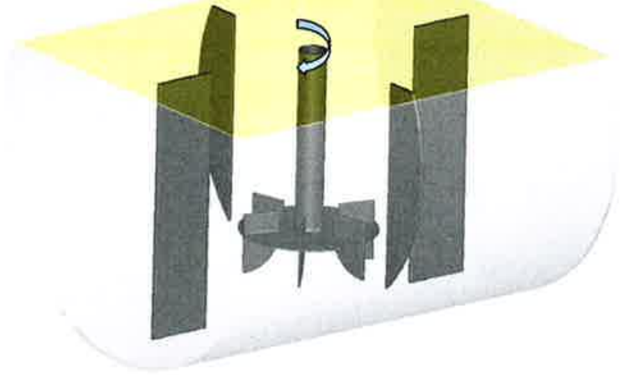

FIG 5 - Schematic figure of autoclave compartment set-up used in computational fluid dynamics simulations.

TABLE 5

Mixing times and pumping numbers of OKTOP and Rushton, based on computational fluid dynamics simulation with equal power input in industrial size autoclave compartment having effective volume of 9.8 m^3.

Name	**OKTOP**	**Rushton**
Agitation (rev/min)	95.5	108
Flow number (N_q)	1.07	0.76
Average mixing time (s)	21.9	23.2
Maximum mixing time (s)	36.0	38.0
Minimum mixing time (s)	14.0	17.0
Standard deviation	5.5	6.3

Agitator scale-up

Scaling up the laboratory and pilot scale results to industrial size solutions is a difficult task. Outotec's in-house developed agitation scale-up rules have been validated at industrial scale at Harjavalta and Kokkola plants ensuring efficient and economical autoclave designs. Based on in-house knowledge and experience Outotec is prepared to offer process guarantees for oxygen utilisation.

HEAT RECOVERY SYSTEM

Outotec energy and water recovery system

In the POX of sulfidic ores and concentrates autoclaves are often used thereby allowing high operating temperature and high oxygen partial pressure. The oxidation of these ores and concentrates is often highly exothermic and large amounts of excess energy can be generated.

Once leached the discharge of the autoclaves is commonly reduced in temperature and pressure by allowing the autoclave discharge slurry to flash, that is, to convert the sensible heat of the slurry at high temperature into a flash steam thereby cooling the leach slurry. Unfortunately the flash steam generated is dirty and contains often considerable 'carryover' slurry as explained in Nakai *et al* (2006).

The energy of sulfur oxidation can provide all the energy required to operate an autoclave at temperature with no additional energy input required. This point, often described as autothermal operation typically occurs with >5 per cent (w/w) sulfur in feed solids. In some applications, particularly for low sulfur ores, autothermal operation is not possible and fresh steam or recycled flash steam is contacted with incoming fresh feed slurry to preheat slurry, Mason and Gulyas (1999).

However in applications where there is an excess of sulfur (eg sulfide concentrates) above the autothermal limit, typically >8 per cent (w/w) sulfur, recycling of flash steam is not required and the autoclave must be cooled to maintain operating temperature. In these cases flash steam and the contained energy and water is wasted to atmosphere.

Outotec has developed process equipment and technology (Finnish Patent application no 20126354) to allow recovery of usable energy and water from autoclave flash steam. A flow sheet showing a typical application of the Outotec EWRS system is shown below in Figure 7. Importantly the individual equipment components that make up the Outotec EWRS are well-known technologies eg direct contact condensers, heat

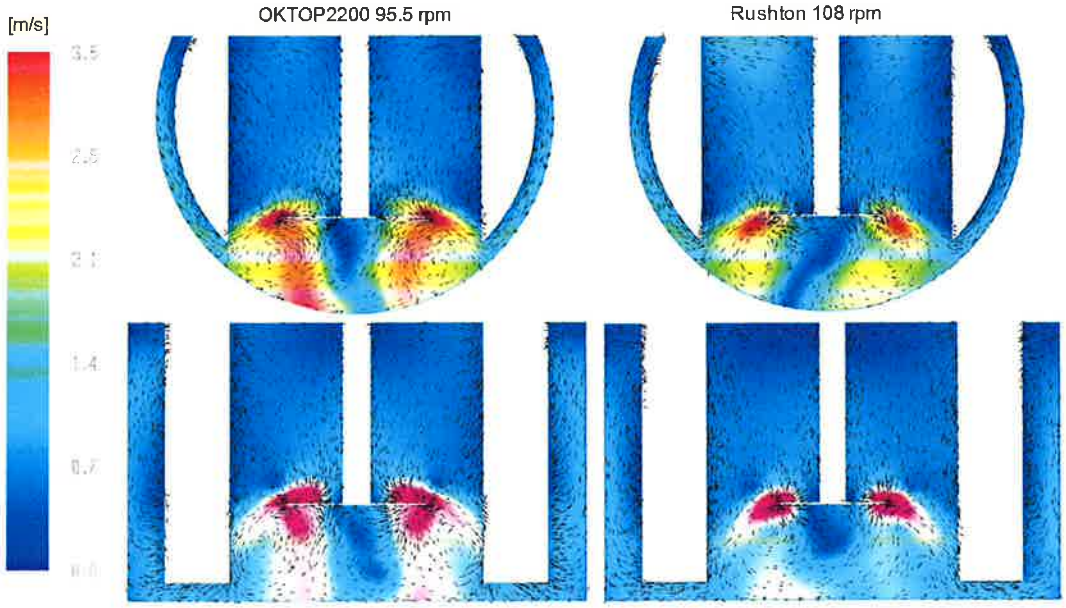

FIG 6 - Velocity profiles of OKTOP and Rushton in computational fluid dynamics simulation. Upper row is from compartment end and bottom row from compartment side. Empty spaces in pictures represent baffles and shaft.

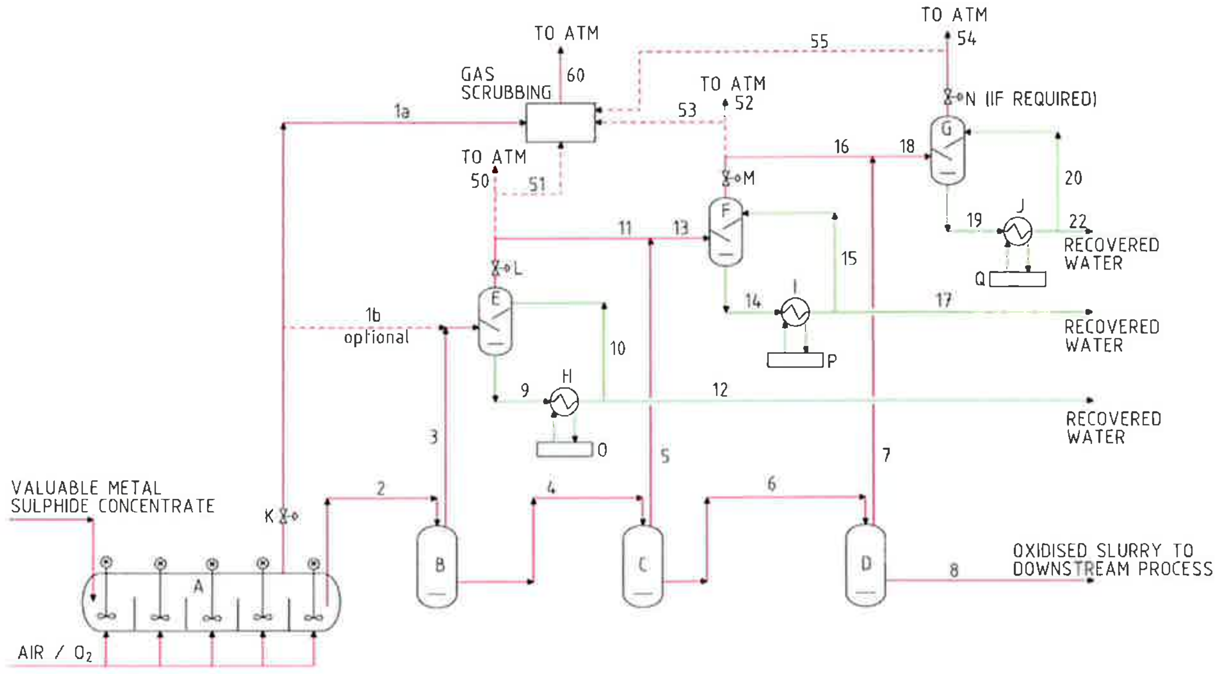

FIG 7 - Example of Outotec energy and water recovery system.

exchangers, pressure control valves, etc. The combination of these technologies allows efficient and flexible heat recovery tailored to the needs of the end-user.

The key features of the Outotec EWRS systems are:

- Direct contact tray-type condensers (eg E, F and G in Figure 7) are used to contact dirty flash steam with recirculating cooled condensate/slurry. Indirect condenser heat exchangers like shell and tube exchangers are avoided due to the potential of scaling and blockages.
- The condenser is fully integrated into the autoclave flash system with the corresponding flash vessel and condenser operating as one isobaric unit with pressure controlled on the outlet of each condenser. Fluctuations in autoclave operation can be readily accommodated with direct pressure control thereby minimising the impact on autoclave operations. Cool condensate flowrate can also be controlled to allow energy recovery to match the throughput of the autoclave.
- The direct contact condenser is a proven and highly efficient heat exchanger which operates counter-currently and can achieve very low approach temperatures enabling high temperature condensates to be produced.
- Non-condensables, if present, are continuously vented with the excess flash steam.
- By re-circulating condensate which already contains solids then nucleation sites for precipitation are provided which will help minimise scale on condenser trays and walls. However, even if scale formation occurs, then the internal trays are known to operate effectively even in a heavily scaled condition.
- Energy in hot condensate is transferred via indirect heat exchangers (eg H, I and J in Figure 7).
- These heat exchangers could be open plate type or spiral and they are designed for easy cleaning if and as required.
- Spare heat exchangers can also be provided enabling continued operation while off-line exchangers are cleaned.
- Using a condenser-heat exchanger combination allows the energy recovery to be decoupled from the direct pressure control required to maintain stable autoclave flash vessel operation.
- Transfer of energy from recirculating condensate allows broad possibilities for the utilisation of recovered energy and recirculation of the condensate to the condenser. For example high-grade energy recovered from the high temperature stage (eg condenser E and heat exchanger H in Figure 7) could be used for generating clean, low- to medium-pressure steam in a boiler. Medium-grade energy (eg condenser F and heat exchanger I in Figure 7) could be used for example in district heating of buildings in cold climates, water desalination or could possibly be used internally within the metal recovery process plant itself.
- Importantly the pressure and hence temperature of each stage in the EWRS can be tailored and configured to the grade of energy required by varying the flash vessel-condenser design pressure.
- Also with appropriate pressure control (using pressure control valves eg L, M and N in Figure 7) the amount of energy transferred to the heat exchangers eg H, I and J can be varied within a predetermined range.
- Since steam is condensed some water is recovered and this water could be used within an existing process thus offsetting the use of additional fresh water.

Example of energy and water recovery system

Outotec has designed and is supplying equipment for an EWRS installation in far eastern Russia as presented in Zaytsev *et al* (2013). Commissioning of the plant at the Pokrovskiy site of Petropavlovsk Gold is expected in early 2014 and a flow sheet is shown in Figure 8. The description of the system follows.

Partial energy recovery from the oxidation of sulfide sulfur from gold concentrates will be installed with approximately 24 MW of energy recovered into a district heating system. This will reduce the significant cost of building heating during cold winter months.

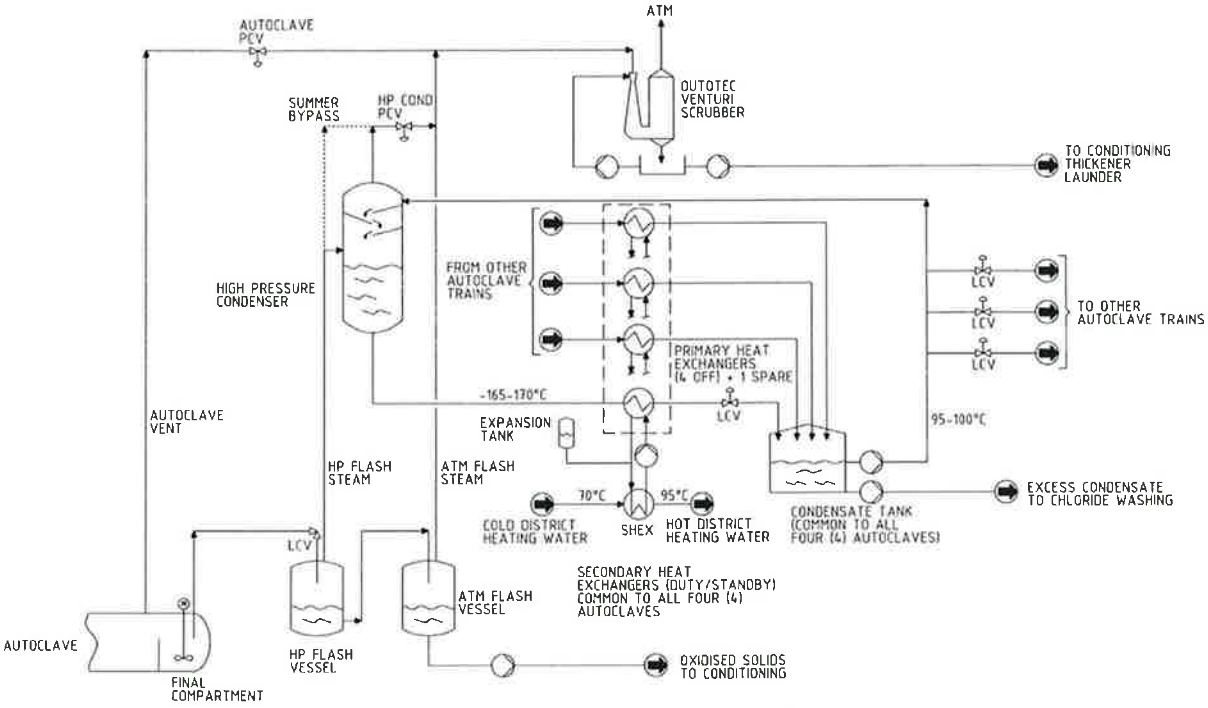

FIG 8 - Energy and water recovery system for Petropavlovsk Gold.

At Pokrovskiy high temperature slurry (at 225 - 230°C) from each autoclave will be flashed in two stages.

The energy from high-pressure (HP) flash steam will be converted into useful energy for district heating purposes. HP flash steam is at high temperature and provides a large driving force for energy transfer.

Flash steam generated from each HP flash vessel on each autoclave 'train' is directed to direct contact tray type HP condenser. There will be four autoclave trains and each train has a dedicated HP condenser associated with each HP flash vessel.

Recirculating low temperature condensate is pumped to the top of each condenser to partially condense flash steam. Excess flash steam is vented and pressure is controlled in both the HP flash vessel and in the HP condenser via a pressure control valve on the vent line exit the condenser.

Since flash steam is partially condensed, water is recovered and recycled to a chloride washing circuit hence minimising fresh water usage for chloride removal. Chloride removal is critical to maximise gold recovery in POX circuits especially in the presence of organic carbon as explained in more details in Zaytsev *et al* (2013).

Excess vent steam from each condenser is combined with the autoclave vent and atmospheric flash vessel steam and directed to a dedicated Outotec Venturi gas scrubber. There are separate scrubbers for each autoclave. Final steam and non-condensable gases discharged to the environment from the scrubber will be clean and essentially acid and solids free. During summer the heating system can be bypassed and all flash steam will be directed to the Venturi Scrubber.

Recovered high temperature condensate from the bottom of the condenser is directed to a primary heat exchanger (PHEX). There will be separate PHEXs for each condenser for each autoclave. Discharge from each PHEX is directed to a common condensate tank for all four autoclaves. This tank will be at atmospheric pressure and approximately 85 - 90°C in normal operation.

On the other (clean) side of the PHEX is a pressurised closed circuit circulating clean water operating on the hydronic principle using a separate expansion tank. By operating as a pressurised closed loop the electrical energy for pumping circulating water is minimised. The system is designed to prevent acidic contamination of the closed circuit circulating water system by operating at a higher pressure to the HP condenser-PHEX loop.

Heated recirculating water from the PHEX is then directed to a Secondary Heat Exchanger (SHEX). On the other side of the SHEX is pressurised cool water from a district heating system, which is heated from 70°C to 95°C. With this design the district heating water is isolated from acidic slurry/water.

CONCLUSIONS

With in-house research capabilities and engineering expertise Outotec can develop a project from conceptual study phase to detailed engineering and Outotec's scope of supply can vary from single equipment to complete plant.

In addition to supplying key equipment, Outotec can design, supply, install and commission entire POX plants; this adds to and complements already existing significant experience in other hydrometallurgical process and proprietary equipment.

Outotec can offer enhanced and proven autoclave agitation systems that maximises oxygen mass transfer and utilisation while minimising wear.

Outotec can provide tailor-made solution to specific client needs. As an example an innovative energy and water recovery process technology was developed and supplied for Petropavlovsk.

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