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REDUCTION CELL TECHNOLOGY DEVELOPMENT AT DUBAL THROUGH 20 YEARS

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ABSTRACT

The Dubai Aluminium Company Limited (DUBAL) smelter commenced operations in 1979 with 3 potlines comprising 360 prebaked cells operating at 150 kA and producing 135,000 tonnes of aluminium annually.

By 1990, a series of continuous, innovative improvements to the cell components and operational practices radically transformed the original cell technology to operate at 180 kA. Further, an expansion of 139 cells in Potline 4 resulted in a total of 499 cells with an annual production of ~250,000 tonnes aluminium.

By 1996, having developed and tested, jointly with Comalco of Australia, five prototype reduction cells termed CD-20 at 200 kA, DUBAL installed 240 cells of this design in Potline 5. Total cells thereby increased to 744 and annual production to 375,000 tonnes.

In 1999, another 240 CD20 cells were commissioned in Potline 6 increasing annual production to 536,000 tonnes of high quality aluminium, whilst generating 1400 MW captive power through natural gas-fuelled turbines.

This paper tracks 20 years of DUBAL's continuous advancement in reduction cell technology, both in terms of improvements and development.

INTRODUCTION

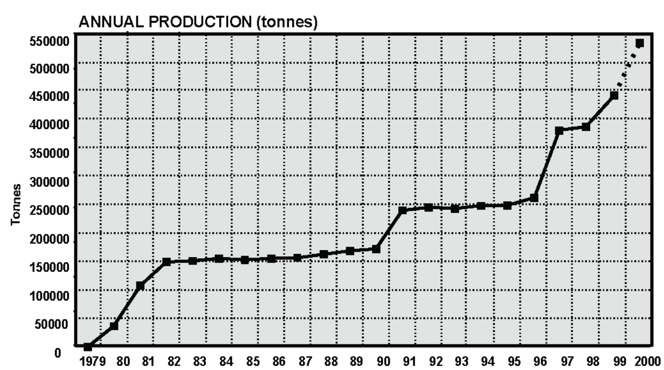
The Dubai Aluminium (DUBAL) smelter in Dubai, United Arab Emirates commenced operations in 1979 with 3 potlines comprising 360 prebaked, centre-break cells operating at 150 kA and rated to produce 135,000 tonnes of aluminium annually. Captive power generation capacity, through natural gas fuelled turbines, was 515 MW and waste heat was channeled to produce potable water from sea water.

The original reduction cell technology, provided by National Southwire Aluminium, U.S.A., was basically a derivative of the Kaiser P-69, side-by-side, end riser design. Since early days, significantly improved productivity was achieved through in-house developments carried out by a dedicated team on small groups of cells. Focus was primarily directed to continuous improvements to the anode manufacturing process, quality, configuration, size and assembly; the cathode design, materials and quality of construction; and various operational practices and process control. The original reduction cells were thus gradually transformed into a unique design capable of operating at >180 kA, resulting in improved productivity, cost effective operations and enhanced cell life.

This improved version of reduction cell, termed the D-18 *, was selected by DUBAL in 1990 to conduct their first expansion of 139 cells in Potline 4. Along with this, DUBAL, jointly with COMALCO of Australia, developed and installed, 5 prototype, magnetically compensated 'CD20' * cells, equipped with point feeders and designed to operate at 200 kA.

Following test operation of the five CD-20 cells for five years, and with full confidence in the design, DUBAL undertook their second expansion by installing 240 CD-20 cells in Potline 5 in 1996. The Potline 5 cells were operated very successfully at 205 kA and the performance results surpassed all design targets. A third expansion of another 240 CD-20 cells in Potline 6 was undertaken in 1998 and commissioning of all cells was completed on 7th October 1999.

In 20 years, DUBAL has grown significantly, not only to a major world aluminium producer, but also as a developer of reduction cell technology. As a result of rapid expansions, DUBAL is now one of the world's largest single site smelters with an annual capacity of 536,000 tonnes aluminium. It also generates 1400 MW of power and produces 30 million gallons of potable water per day for internal consumption and for the city of Dubai. Amidst all this activity, DUBAL's entire smelter, including the power and desalination unit, has been awarded the ISO 9002 and ISO 14001 accreditation since 1993 and 1999 respectively.



* *The CD-20 cells were originally termed "CD-200" to refer to the designed operating amperage of 200 kA. However, these cells are now operated at >200 kA and DUBAL now refers to them as "CD-20' to represent the cell containing 20 anodes. Similarly, the significant retrofit upgrade carried out to the original P-69 cells which has enabled the amperage to be raised from 150 to >180 kA are termed D-18, again referring to the number of anodes in the cell.*

In tracking the achievements of the past 20 years, improvements in the original reduction cell technology are listed apart from development of new technology.

ORIGINAL REDUCTION CELL TECHNOLOGY

Major improvement in the original reduction cell technology, effected through various modifications to cathode and anode design and improved operational practices and process control, has enabled present operation at >180 kA against a designed amperage of 135 – 150 kA [#].

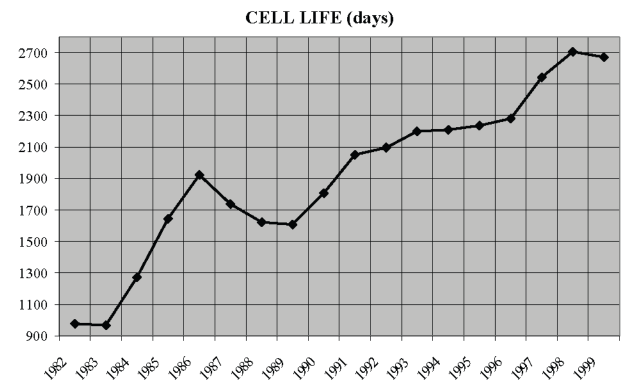
Cathode Design

The original cathode comprised gas / electrically calcined, anthracite based amorphous blocks placed over a bed of alumina insulation and rammed manually with hot paste to form a monolythic carbon sidewall.

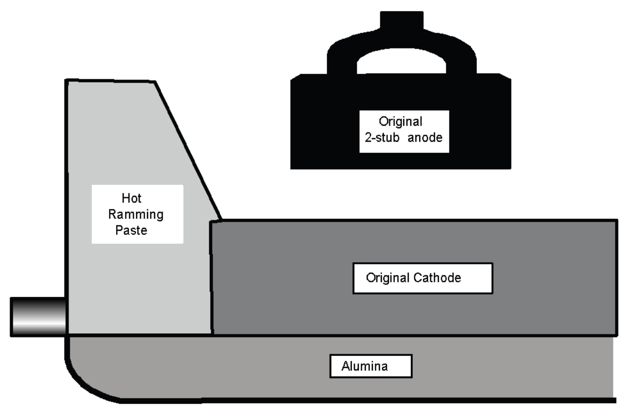
Cathode development through various modifications included:

- Reinforcing the shell cradle structure using I-beams and gusset plates, straightening and repair of old shells at cathode turnaround time.
- Replacing the alumina bottom insulation bed initially with thermally non-degradable and better insulating bricks, and subsequently with calcium silicate and low density vermiculite insulation boards to reduce heat loss through the shell bottom.
- Improving the protection to insulation with low alumina fire slabs and reducing the number of joints.
- Introducing silicon nitride bonded silicon carbide slabs in place of the rammed carbon sidewall to increase heat flow and to accommodate larger anodes.
- Changeover from hot ramming paste, manually rammed to cold ramming paste, machine rammed.
- Increase in cathode block length and standardisation to exclusively electrically calcined, cathode blocks with added graphite.
- Review and on-line control of cast iron elemental composition for cathode – collector bar sealing.
- Enhancement of construction practices and stringent monitoring for quality assurance.
- Selection of quality lining materials following evaluation, through cathode autopsies, and benchmarking of products from various global suppliers.

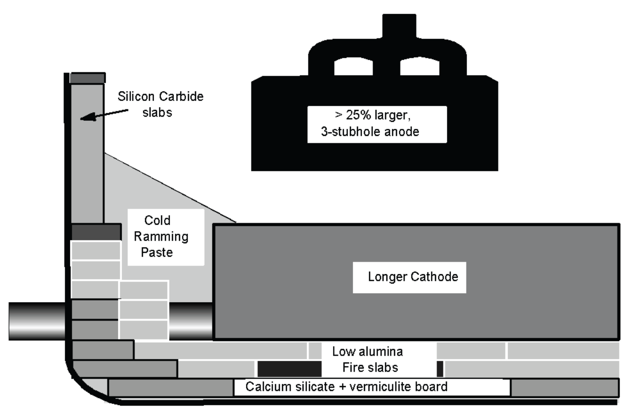
As a result, significant increase in average cathode life was realised through the years.



A profile of the original and current cathode is shown in figure below.



ORIGINAL CATHODE & ANODE DESIGN



CURRENT CATHODE & ANODE DESIGN

Anode Design

The original anode was 1130 mm length x 795 mm width x 635 mm height, and contained 2 stubholes.

[#] *The reduction cell package, which was delivered to DUBAL by National Southwire Aluminium Corp., U.S.A., was for operation between 135 to 150 kA maximum and a rated production capacity of 135,000 t/y, depending on what current efficiency was achieved in operation. DUBAL started operating these cells at ~150 kA and this report compares this against operation at >180 kA today.*

Using these anodes between 1981 and 1984, suitable changes had been made to cell operating variables which enabled an increase in amperage from ~150 kA to 167 kA, thereby increasing production by 15% from 135,000 t/y to 155,000 t/y. However, at this amperage, the cell's metal pad distortion and velocities were very high since the busbar design made no allowance for magnetics. Also, the current density increased from 0.90 to >1.0 A/cm^2 and this caused severe problems of the anodes splitting.

In order to overcome these problems and utilize DUBAL's energy capabilities and increase productivity further, the following changes were made.

Anode Size

The anode size was increased[1] in stages by > 25%. The stubholes were relocated and positioned asymmetrically so as to accommodate the increased anode length towards the sidewalls of the cell.

The anode length primarily increased towards the sidewall of the cell, leaving the anode mounted asymmetrically on the 2-stub rod assembly. The higher stub current density, with the sidewall stubs carrying 54% of the current, caused severe burn-offs.

Following successful pilot trials, all 2-stub anode assemblies were retrofitted to larger diameter 3-stub assemblies with improved mechanical strength and integrity[2]. The total cost of conversion including modifications to handling equipment, thimble press, etc. was approximately US$ 3 million.

With the 3-stub assembly, computer modelling predicted gains in reduction of peak anode temperatures from 740 °C to 580°C, thereby reducing excess oxidation of the anode, better stub current distribution & voltage savings of 100 mV. Actual measured gains are tabled below:

- **Electrical:**

Voltage Drops

Transition joint to:	Unit	2-stub	3-stub
Anode sidewall face	mV	340	230
Anode centre channel face	mV	260	190
Average	mV	300	210

Current Distribution

Sidewall stub	%	54	34
Centre stub	%	-	31
Centre channel stub	%	46	35

- **Thermal:**

Anode Surface Temperature

Between stubs	°C	670	600
Behind sidewall stub	°C	635	510

Anode Quality

Significant improvement to anode quality was achieved through implementation of various changes in the green and baked manufacturing stage.

- **Green Mill**

The various improvements in the manufacturing stage of the green anode included:

✓ Effective coke silo management to achieve coke sizing uniformity across unloading, storage, supply and usage of each coke consignment.

✓ Use of the Blaine apparatus to obtain grain size consistency of the fines fraction.

✓ Channeling two sources of dust to a single source for improving homogeneity of the dust fraction.

✓ Reduce butt contaminants and thus lower anode reactivity by:

- Discarding butt dust from butt crushing operations.
- Retaining the butt undersize fractions in un-ground form.
- Reducing the high ash content 'soaked' butt from anode failures and distributing it uniformly.
- Reducing butt content in anode through smaller butt yield (a result of increased anode shift life).

✓ Enhanced anode properties through:

- Improving the anode aggregate curve.
- Anode recipe formulation by testing iso-density contours of coke supplies using a Y-blender.
- Optimizing binder demand through coke/pitch temperature control and filler density maximization.
- Good binder impregnation during mixing through:
  a. modifications to the kneader gearbox to lower operating torque.
  b. Providing auto-gates at the kneader discharge.
- Modifications to the paste distributor to minimise particle segregation and minimize anode density gradients.
- Optimization of the vibro-compactor parameters.
- Increasing the stubhole flute angle and number of flutes.
- Performance monitoring and selection of quality raw materials through stringent specifications.

- **Bake Kilns**

  ✓ Increased equivalent bake temperatures and improved calcining homogeneity through:

  - improved firing techniques.
  - Introduction of auto draught control.

  ✓ Increased kiln pit depth in vertical flue furnaces to accommodate larger anodes in a horizontal / vertical packing configuration.

  ✓ Reduced energy consumption through computerised firing and draught control and combustion of tar generated.

  ✓ Conversion from closed to open bake furnaces.

Potroom Equipment

- The ore discharge on the anode change crane was modified for effective covering of anodes.
- The crust breaker bar was redesigned from a toothed, double bar to flat split bar to improve breaking efficiency.
- The siphon pipe of tapping crucibles was redesigned to ease tapping problems.
- The capacity of the tapping crucible was increased.
- Necessary equipment was installed for crushing and recycling of anode top cover material.
- A cavity scoop was attached to the crane for removal of carbon pieces / sludge, if required.

Cell Operation

In view of the changes in line amperage, anode size, lining materials and design, cell operating practices were revised and process parameters optimized.

- Cell energizing practice at full load using sacrificial fuse was introduced.
- A 5-stage preheat practice using split shunts and anode flexibles was adopted as standard practice. This resulted in a smooth step up in amperage with a significantly improved power curve. This contributed to a substantial improvement in cathode preheating.
- Cell operating parameters were adjusted in order to achieve thermal stability and desired freeze profile with the larger anode and redesigned cathode sidewall.
- Bath chemistry was altered by increasing excess AlF_3 and keeping CaF_2 constant ~6%. This reduced liquidus temperature and, then , metal solubility.
- Anode dressing material specification and practice was revised.
- During anode change operations,
  - Introduced the practice of cleaning the bath / alumina crust over the spent anode butt outside the cell cavity instead of into it.
  - Commenced cavity scooping the cathode surface to remove carbon pieces / sludge.
  - This reduced cathode voltage drop and sludge levels in the cells and impacted favourably in improved operational stability and current efficiency.
- The original ‘gang break’ or ‘scheduled feed’ strategy for alumina feed control was replaced by an ‘adaptive feed’ strategy. This resulted in better control of alumina concentration and reduction of sludge in cells.
- Anode shift life was increased from 60 to 76 shifts resulting in reduced disturbance to cell operation.
- Commenced silo management through grain size testing of alumina supplies to ensure equi-distribution of excessive fine-grained ore to all potlines.

Environment

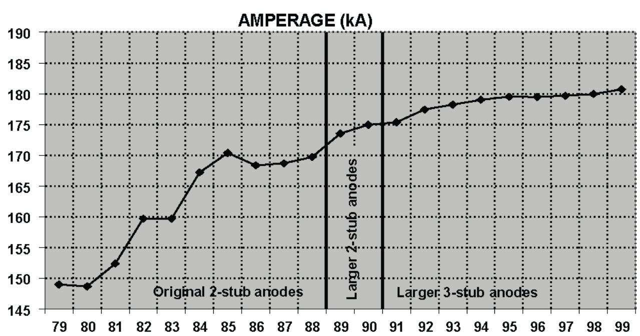
Through the entire development of the D-18 reduction cell technology, thorough attention was paid to environmental protection in all areas of the smelter.

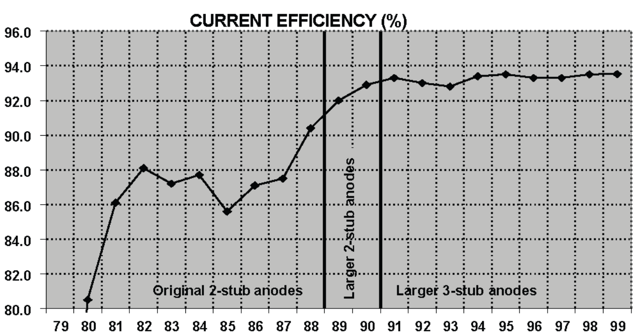
- Use of cold ramming paste for cathode construction.
- Minimising solid, liquid and dust waste generation.
- Combustion of tar generated from the bake furnaces.
- Converting from closed to open bake furnaces.
- Dry scrubbing of pitch fumes and fluorides and recycling of scrubbed materials in the carbon and potrooms.
- Reduction in anode effect frequency.
- Recycling of solid waste from the potrooms.
- Upgrading anode rodding equipment and improving anode butt cleaning facilities.

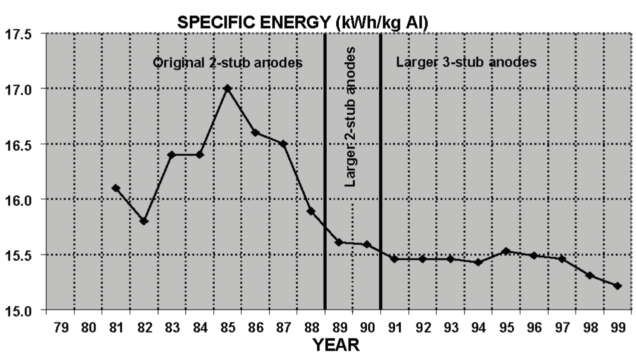
Results

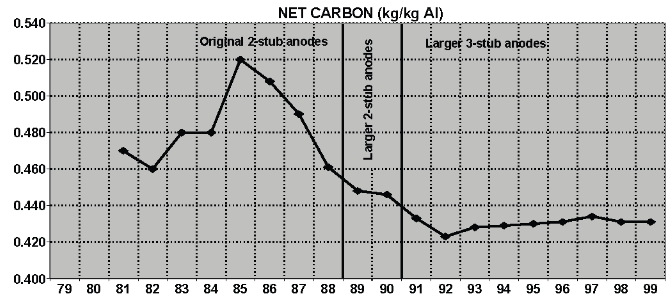
A comparison of the overall performance improvements through the various modifications to design and operating techniques of the D-18 cell technology (499 cells, Potlines 1-4) is shown in table below and the graphs that follow illustrate the historical trend improvement of the various operating parameters.

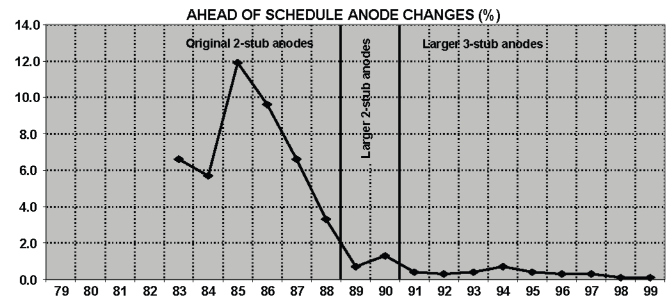
		Unit	From 1984	To 1999
Butt	Ash	%	1.02	0.39
	F	%	0.20	0.05
Anode	**Baked** density	g/cc	1.542	1.571
	Air permeability	nPm	0.76	0.48
	Flexural strength	daN/cm^2	117.0	142.6
	CO_2 reactivity	%	21.3	13.6
	Dusting index	%	4.4	1.1
	Ash content	%	0.45	0.23
	Performance: Top Oxidation	mm	34	20
	Reduction in area	%	8.8	6.7
	Ahead of schedule changes	%	3.3	0.2
	Anode failure rate	%	5.8	0.3
	Net carbon	kg/kg Al	0.461	0.428
Cell	Amperage	kA	150	180
	C.E.	%	87.5	93.5
	Specific Energy	kWh/kg Al	16.5	15.3
	Metal pad hump	cm	10	7
	Anode Effects	no/cell/day	1.70	0.46
	Average cathode Life	days	1,650	> 2,500

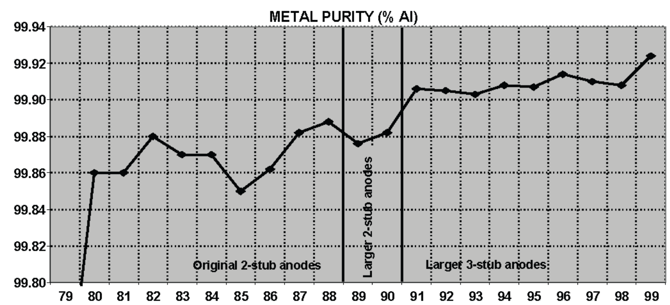


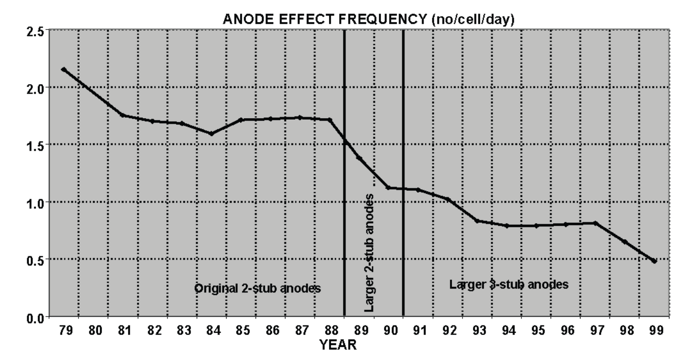












NEW REDUCTION CELL TECHNOLOGY

In 1990, through collaboration with COMALCO of Australia, DUBAL developed a new reduction cell design termed CD-20 and installed 5 prototype cells during construction of Potline 4. The cell technology focussed an alumina feeding system, a cathode / anode design and a busbar system, the latter two developed using computer modeling. The superstructure was incorporated with a tap hole breaker, as well as a dedicated AlF_3 feeder for better control and automation.

The prototype cells were connected to booster rectifiers and tested for five years during which time appropriate changes were made to the cathode design, busbar design, process control systems and operating practices. Towards the latter part of the project, the computer hardware and software were optimized for controlling the cells, thereby moving away from the traditional centralized computer system to a decentralized system.

In 1996, having achieved full confidence in the design, DUBAL installed and commissioned 240 CD-20 cells in Potline 5. These cells were controlled by 120 pot control units (PCU's), each controlling 2 cells. The control software for the PCU's were fully developed in-house. All 240 cells are currently operating satisfactorily at 205 kA, achieving the material and thermal balance, as well as magnetic stability predicted by the model, and surpassing the design targets for current and energy efficiency.

In 1999, having made design modifications to the first generation CD-20 cells to permit further increase in amperage, another 240 CD-20 cells were installed and commissioned in Potline 6.

REAL TIME CELL SIMULATOR

In the course of DUBAL's technological development, a computer simulator of an electrolytic cell has been constructed. In order to enable the "Soft cell" to better approach the behaviour of the live one, the cell simulator was adapted in both static and dynamic modes, using detailed plant measurements and then controlled by real algorithms [6].

An adequate software-hardware environment has been developed to receive the line current signal from the plant data network and to establish a reliable data exchange between the Pot Control Unit (PCU) and the 'soft cell'[7].

The real time simulator can help in the following aspects of the reduction activity:

- ✓ process analysis and process parameter sensitivity,
- ✓ off-line training of operational personnel,
- ✓ developing and fine tuning cell control strategies and their related algorithms, and
- ✓ testing the functioning of the hardware-software system.

SUMMARY

Through 20 years of operation, DUBAL has not only made significant improvements to the original reduction cells through various in-house innovations, but has also developed its own reduction cell technology. Currently, two technologies are in operation, salient features of which are tabled alongside.

Today, DUBAL continues on the path of continuous improvement and maintains a policy to be self-reliant in reduction cell technology for all future expansions. In a current position of being a reduction cell technology developer in the region, a third generation, energy efficient reduction cell for higher productivity is already in testing.

Reduction Cell Technology	Unit	D-18	CD-20
Cells in operation	nos	499	485
Anodes / Cell	nos	18	20
Anode Rod configuration	no of stubs	3	3
Anode Current Density	A/cm^2	0.89	0.90
Alumina Feeding		Centre Break	Point Feed
Busbar configuration		End riser	Side riser
Amperage	kA	180	205
Current Efficiency	%	93.5	94.7
Specific Energy (DC)	kWh/kg Al	15.3	13.6
Cell Voltage	V	4.8	4.3
Anode Effects	nos/cell/day	0.46	0.12
Metal Purity	% Al	99.92	99.90
Net Carbon	kg/kg Al	0.428	0.416
Excess AlF_3	%	8.5	11.0
Ave cathode life	days	> 2,500	*

* *Average operating age: Potline 5 - 1054 days, Potline 6 - 101 days*

ACKNOWLEDGEMENTS

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