Getting the balance right—some practical design considerations for solvent extraction circuits

by G. Laing*

Synopsis

On scheduled commissioning and effective operation of a solvent extraction circuit relies on getting the design of both the core contact equipment and the peripheral plant right. Experience has shown that poor performance of new plants is frequently a result of 'utility' systems that do not match the requirements of the circuit, rather than the mass transfer equipment itself. Both the operator/owner and designer need to understand the 'complete requirements' for the circuit to get the balance of the design right. This paper reviews generic issues, frequently overlooked or altered during cost-cutting exercises, which have a significant impact on plant performance.

Introduction

The performance of a solvent extraction plant is affected by numerous factors ranging from the fundamental mass transfer characteristics of the system to the layout of the plant. Successful commissioning and operation of a solvent extraction circuit relies on getting all the detail right during the design stage. However, getting the detail right all too often becomes a process of trial and error during the commissioning and early operation of the plant. To satisfy the financial constraints of a project and design the optimum circuit a balanced approach to the plant specification needs to be adopted.

Naturally, the most complex issues receive the greatest attention at the piloting and design phases. However, it is not uncommon that the 'simpler issues' result in poor performance of such plants. Problems are often associated with ancillary equipment required to filter, heat, store, etc., liquors rather than the solvent extraction units themselves. Both the ancillary units and materials of construction tend to be the main focus of cost-cutting exercises in the latter stages of design. Often the case is that the solvent extraction plant is given a higher priority than the utility equipment servicing that plant. This equipment must be considered part of the solvent extraction circuit and allocated the same level of importance as the contact equipment. This paper documents a list of factors, in addition to the extraction, scrubbing, and stripping detail, to be considered for any solvent extraction plant. These issues should be considered both prior to any piloting campaign, to enable a suitable test programme to be established and then again during the detailed design. The discussion is generic, covering a range of issues relevant to conventional mixer settler type circuits.

Evaluating the circuit requirements

Successful inclusion of a solvent extraction circuit in a hydrometallurgical flowsheet requires that the selected process operate under appropriate conditions. Suitable equipment will minimize the risk to both the organic reagents and the surrounding unit operations. The selection of appropriate equipment will depend on numerous factors such as the position of the solvent process in the overall flowsheet, the complexity of the aqueous solutions, likely deviations from normal conditions, solvent sensitivity, solvent cost, etc. Illustrated below is a generic block diagram of a solvent extraction process with some of the peripherals that may be necessary for smooth operation of the plant. Certain of the peripheral units are discussed in some details in the following sections. While the contact equipment is not dealt with *per se*, details of selected issues within each of the extraction, scrub and strip circuits are also addressed.

During the design of the process the risk associated with including a solvent extraction step in the flowsheet should be evaluated and quantified. The following factors should be considered in the evaluation.

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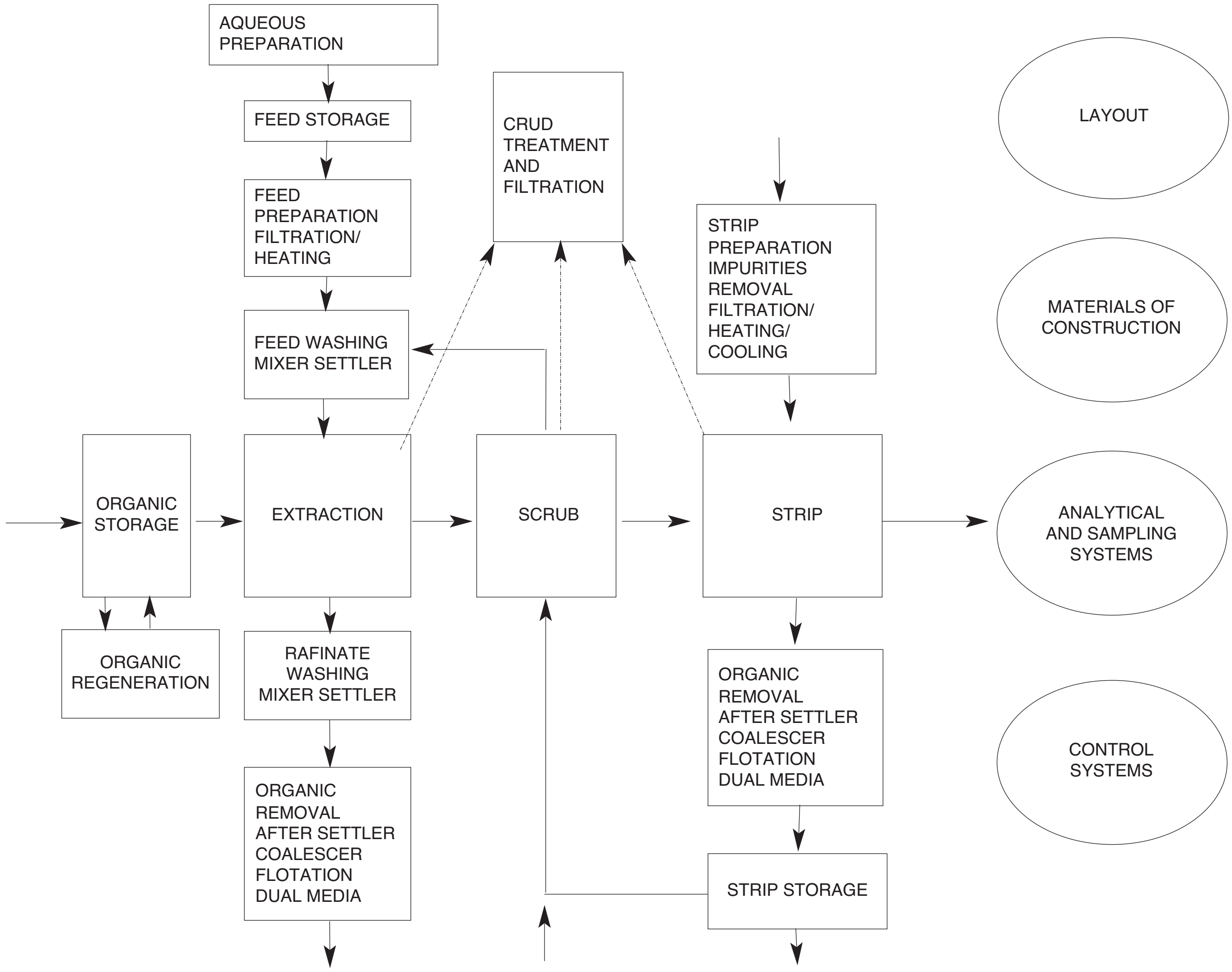

Figure 1—Typical solvent extraction circuit

- *Position of the solvent extraction plant in the process flowsheet*—There are a number of issues to be considered. Firstly, the type of aqueous solution to be contacted with the solvents, this is discussed in more detail in the following point. Secondly, the likelihood of contamination to or from other solvent extraction circuits. Processing using more than one solvent in a series of circuits require careful consideration. Thirdly, the requirement to protect other unit operations linked with the solvent extraction circuit particularly with regard to organic contamination
- *Exposure of the solvent to undesirable components*—The more complex the aqueous feed to a solvent extraction circuit the greater the potential risk. The so-called direct solvent extraction circuits result in high exposure while circuits treating refined (relatively pure) process streams present relatively lower exposure. This is especially true in the case where the aqueous solution may vary considerably in composition particularly with regard to trace elements. A refined process stream having a well-defined composition presents far less risk
- *Resilience of the solvent*—The ranges of available solvents have quite different resistance characteristics to similar conditions and as such may have very different life expectancies. Understand whether solvent replacement will be to make up physical losses or to replace degraded material
- *Cost of the solvent*—Prices range by orders of magnitude, the organic inventory may represent a substantial portion of the plant capital, and replacement, a significant portion of operation.

The example in Table I demonstrates two applications at opposite ends of the spectrum. Risk factors are on a scale of 1 to 5.

The numbers assigned to this example are notional, however, they demonstrate how a circuit may be evaluated in terms of the requirement for ancillary, or protective equipment. The cost of ancillary plant for Case 1 may be similar to the cost of the contact equipment itself while that in Case 2 may be only a small portion of the overall capital cost. Detailed understanding of the circuit requirements and realistic assumptions of operating conditions will minimize the need for retrofits and loss of production.

Solvent extraction plant feed liquor

The feed solution to the solvent extraction (SX) plant must

Table I

Risk ratings of two hypothetical solvent extraction plants

	Case 1	Risk	Case 2	Risk
Aqueous feed composition	Complex solution direct from a leach circuit	4	Refined solution containing well defined components	2
Downstream unit operations	Raffinate to second SX circuit in series. EW on strip circuit	5	Raffinate to effluent. Precipitation on strip circuit	2
Stability of solvent	Organic molecules susceptible to oxidation and poisoning by trace elements	4	Stable non-oxidizing solvent composition easily regenerated	1
Cost of solvent	High cost, low availability solvent	4	Low cost solvent	1
Skill of potential operators and analytical staff	Poor skill, long-term training required	5	Skilled staff from similar type operation	2
Overall risk	**Very high**	**22/25**	**Low**	**8/25**

be compatible with the solvents and suitable for the selected equipment. This requires that potential solvent poisons, scaling compounds and solids be reduced to levels such that continuous, long-term operation of the plant is achieved. Removal of poisons and scale-forming components will require suitable specialized processes. While it is beyond the scope of this paper to discuss such operations, design of the SX circuit should make provision for 'slippage' from such circuits. This may involve developing a suitable operating strategy for such an event or provision of sufficient feed storage capacity to isolate the SX plant until the excursion has been rectified. Removal of solids requires some form of filtration system. Suitable filtration capacity for the unsteady state condition should be provided for. Designing to average expected solids loading may result in substantial plant downtime from crud formation because of solids breakthrough to the SX circuit.

Control systems—flow and interface level

Flow measurement and control within the solvent extraction circuit is critical to maintaining a stable and efficient operation. All instruments should be such that they may be removed for inspection and cleaning with the plant operational. The type of instrument should also be carefully reviewed in terms of suitability to the liquor being measured and constituents (e.g., dissolved solids, suspended solids, organics) that may be present in such liquors. Control valves should provide very smooth changes in flow, thus minimizing the likelihood of setting up cyclical patterns. As most solvent extraction applications rely on either gravity or inefficient pump mixers for liquor transfer, reduction in line size for flow measurement and control valves must be carefully reviewed. Cost savings realized by reducing valve sizes may be very attractive, however, they may cause long-term problems for the operator.

Interface level control in settlers may be affected in a number of ways. While the weir type system is most commonly utilized a level control loop acting on the aqueous discharge from the settler may also vary the interface. The interface is measured by float type instrument. The preferred method of operation will depend on the process as each system has both advantages and disadvantages. The factors governing the choice of level control should include not only steady state operation but how the system will react dynamically and under shutdown conditions. Overflow systems do not normally seal completely, and as a result, settler levels may change under reduced or zero flow conditions. The consequence of a settler level dropping may be severe as the separation of organic and aqueous may be lost and organic may be drawn into the aqueous system. The ability to 'freeze a circuit' on as shutting down has very significant advantages. The ability to see an interface may be useful as a 'manual check' of instrumentation measurements. Sight glasses are obviously the most simple and efficient way to check an interface and should be considered where practical. They should also be accessible for *in situ* cleaning. Automatic level control may be advantageous particularly in the situation where minimizing organic inventory is critical based on the high cost of the extractant. Once the method of level control has been selected, the task of engineering a fail-safe system needs considerable attention. Redundant valves, instruments and storage tanks should be allocated to ensure that slugs of organic are not lost from the system.

Measurement of process data

As temperatures and pressures in SX systems are typically benign, measurement of process data is relatively simple. However, this is complicated by the fact that instruments need to be resistant and may even need to operate in both aqueous and organic media. The equipment must be both robust and located in a suitable position for the required duty. As the processes are atmospheric, care should be taken to ensure that instruments can be withdrawn from tanks during operation for calibration and maintenance purposes.

Materials of construction

While this is an area that normally gets significant attention during the design of the plant, the materials of construction are frequently subject to change when the cost containment phase of a project arrives. Experience has demonstrated that compromising on materials of construction particularly in terms of settlers seldom pays off. Substitution of steels, fibreglass and polyconcrete with cheaper plastic materials may reduce the life expectancy of the plant to unacceptable levels. The effects of solvents on rubbers, plastics and the glues used to hold them together may not be adequately demonstrated in piloting trials! Prudent design will allow for some mechanical type cleaning of all surfaces in the plant.

Crud handling systems

From the outset, the crud handling system should be considered an integral part of a solvent extraction circuit, having equal importance to the contact equipment. Depending on the anticipated severity of the crud problem the system may be designed to operate continuously or in a batch-wise fashion. As the formation of crud may occur rapidly and extensively the system should have sufficient capacity to store significant quantities of crud which may then be treated at a reasonable rate. Filtration systems should be sized conservatively providing for the poorest fluxes, as the types of crud formed may vary during the course of operation. Removal of crud from settlers may be achieved by a number of methods. In most cases, access to the settler, by the operator, is necessary to identify the location of the crud and in some instances physically remove the crud with a 'vacuum cleaner' type system.

The treatment system should include sufficient tankage to perform the necessary steps for separation of the crud from the organic and aqueous phases. This normally includes 'washing in diluent' followed by settling and filtration through an absorbent clay. There may be special requirements for acid treatment, etc.

Tankage and storage capacity

Solvent extraction circuits are normally coupled to a number of other unit operations that may operate quite independently of the circuit. Volumetric balance around the circuit may only be achieved by the inclusion of significant storage buffer around the plant. Dynamic scenarios should be considered when specifying storage capacity. The storage facilities should not be designed to accommodate two opposing requirements, that of the solvent extraction plant and that of the down/upstream unit operation. Generally, solvent extraction plants respond poorly to stop start situations and may take considerable time to settle down to steady state. Operating errors are for more likely to occur during start-up or shutdown of the plant. Adequate storage will in many cases provide the necessary buffer to prevent having to go through frequent start-up or shutdowns.

Design of tankage around a solvent extraction circuit should allow for the possibility of both aqueous, organic or both ending up in the vessel. Materials of vessels should be suitable for all liquors in the circuit and tanks should be designed in such a way that operators can easily determine the quantities of each phase in a particular tank. Pump discharge arrangements should be carefully designed to facilitate decanting of either phase from any tank without affecting the operation. While storage tanks should not be expected to perform the duties of after settlers, suitable design of feed systems may assist in facilitating significant phase separation in the vessel by minimizing the amount of agitation that occurs within the vessel.

Organic recovery from aqueous and strip liquors

The system of organic removal should include stages that remove organic within the SX circuit (such as a pH adjustment step) followed by recovery of 'bulk' organic (for upset conditions) followed by recovery of normal arisings from steady state operation. The equipment for example would include a mixer settler for pH adjustment, followed by an after settler to recover slugs of material, followed by coalescers, dual media filters and carbon columns. Suitable instrumentation should be included on the final settler or after settler to warn operators of organic in the aqueous stream. The plant should also be designed to operate organic continuous in the final stages (of extraction or stripping) to minimize organic entrainments in the aqueous stream. An organic wash stage in which aqueous is contacted only with diluent to reduce losses of extractant or to clean up the aqueous feed stream may be necessary.

Organic entrainments tend to be consistently high during a plant startup and having the facility to put the plant onto recycle may be an effective method of controlling entrainments until the plant 'settles down'. When the organic removal requirements have been specified, the media usage in the various units may be predicted. Time should be taken to design user-friendly systems for change-out of media and in the case of high consumption there may be justification to look at regeneration methods for carbon and cleaning of media.

Piping systems

Piping systems in solvent extraction plants need to be carefully designed as in many instances, the process relies on gravity or inefficient pump mixers to transport the liquors. The process engineer responsible for the design of the plant must be actively involved in the piping design and plant layout. Plant layouts should obviously allow for efficient operation of the equipment. Compressing of plant footprints to save on piping costs is a practice that should be avoided. Pipe sizing should be done on the basis that there will be some degree of scale formation on the surfaces—scale even adheres to plastic pipes. Restrictions in piping runs should be kept to a minimum and reduction in line diameters for installation of valves and instrumentation should be avoided.

Organic regeneration

A side stream that allows for treatment of the solvent externally to the main circuit may be necessary. This, for example, may include a high concentration acid strip to remove components that are not stripped under the normal stripping conditions. In the assessment of whether such a circuit is necessary prediction of likely excursions from steady state in up-stream processes will be important.

Where there are two or more solvent extraction processes in series, solvent, slipped from the primary circuit may need to be recovered from the secondary circuit in a side stream. This should be considered a last resort option, as fail-safe mechanisms should be included in the primary circuit to prevent the occurrence of organic slippage.

Neutralizing or pH adjustment reagent addition

The mechanism of introducing the base to the process liquors is important and will result in operational problems if not properly designed. There are many options available ranging from injection of an aqueous solution of the base into the primary mixers to pre-equilibration of a pure organic stream by ammonia gas. Individual options are beyond the scope of this paper, however, in general terms the followng should not be overlooked.

The use of strong and concentrated bases may result in the formation of an emulsion with certain extractants (notably Cyanex 272). Strong bases may also cause precipitation of metal species in localized high pH regions that may lead to the formation of cruds. Therefore, consider the strength of the reagent used and the mixing available (which tends to be mild and kept to a minimum) to introduce the material to the process. The neutralizing reagent may be added to the process based on the pH of the aqueous phase. In organic continuous systems it may not be possible to measure the pH in the mixer requiring some phase separation to take place before a measurement may be obtained. The location of the pH instrument is important, as lag time in the control loop should be minimized.

Sampling and analytical

Like other hydrometallurgical processes, the successful operation of a solvent extraction plant is dependent on accurate and efficient analyses of representative samples. The multi-component systems in solvent extraction plants make the sampling and analysis more challenging. Detailed design of plants should include allocation of the required sample points to effectively achieve the above. In certain configurations the aqueous phase may not be accessible to operators, for example when level control valves are used for interface control, in which case sample points in transfer lines may be necessary. Multiple sample points in mixer tanks and storage tanks should also be considered, as mixtures may not be homogeneous.

The analytcal requirements will depend on the selected process and particularly the requirement to monitor organic composition, quality and entrainment values. Typically, the aqueous analytical requirements will fit in with the remainder of the process. In general terms the determination of entrainments and monitoring of solvent condition and quality, is non-trival and may require special techniques or assistance from external organizations. The sample composition may also be time dependent requiring immediate attention. The requirements to accomplish the above should be quantified as early as possible and provision made for the associated equipment and training of relevant staff prior to commissioning of the circuit.

Conclusions

Solvent extraction circuits are a combination of mass transfer equipment and appropriate process plant to maintain the specified conditions in the feed, discharge and within the circuit. Provision of a successful plant requires that the entire circuit be considered throughout flowsheet development, plant design and construction. Operators/owners and designers must avoid the trap of committing the majority of the resources to the mass transfer problems at the expense of potentially fatal 'side issues'. A balanced approach will ensure that the peripheral equipment services the solvent extraction equipment as required.

Acknowledgements

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Richards Bay to become birding mecca*

Bird lovers will soon have a new destination to add to their list of birding venues, as the city of Richards Bay in northern Zululand is set to become a birding paradise with the establishment of an avitourism route.

The project has come about through a R2-million donation to BirdLife South Africa from global mining group Rio Tinto and its local subsidiary Richards Bay Minerals.

Dr Aldo Berruti, director of Birdlife South Africa, said that the donation would enable Richards Bay to be placed firmly on the lucrative international birding map and become a birding jewel in South Africa.

'Many people do not realize the diverse array of birding that can be found in the city. On my last visit I saw as many Lesser Jacanas in this region as I have throughout South Africa over the previous 15 years!

'Currently birding in South Africa is worth about R300-million a year, so the opportunities this programme can create in Richards Bay is tremendous. We also hope to make Richards Bay the centre-point of birding outings for the BirdLife International World Congress, which will be held in Durban in February 2004' said Berruti.

In addition to the establishment of the route, the funds will be used to train and equip local community members as birding guides.

RBM managing director George Deyzel said that this ensured the sustainability of the project, 'By providing the local community with opportunities for direct employment they are able to reap the benefits of conservation management and ecotourism, which is vital for the sustainability of the route.

'The project is also an opportunity to create a new industry which is sure to be highly successful given our city's close proximity to other world-class natural attractions,' said Deyzel. ◆

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Winners of catalyst innovation competition announced*

Winners of the Catalyst Innovation Competition, run by Catalyst Innovation Incubator, Acorn Technologies and Deloitte & Touche, were announced at an awards ceremony held at Deliotte & Touche premises in Woodmead.

Winner of the R35 000 first prize is Wernich de Villiers of Stellenbosch University who developed a new method to measure the change in the average height of phase conductors above the ground plane of high-voltage (HV) Overhead Transmission Lines (OHTLs). The innovation will result in more effective and reliable ampacity control systems. This will enable accurate calculations to be made to gauge additional voltages to be transmitted which will have far-reaching consequences for provision of electricity, especially to outlying, rural areas.

The second prize of R25 000 was awarded to Andre Venter of the University of Pretoria for an analytical technique allowing chemical information obtained from complex chemical mixtures to increase or decrease analysis times considerably. The innovation is a leading edge development in the field of analytical chemistry which can be used across a broad spectrum of industries and is protected by a provisional patent.

Willem Opperman of the University of Stellenbosch won the third prize of R15 000 for a device which generates sulphur dioxide gas, a vital preservative in exporting deciduous fruit, especially grapes. A pilot production project is already generating income.

Representing the Department of Science and Technology, Deputy Director-General, Dr Adi Paterson expressed the deep admiration of the Department for the extensive resources Deloitte & Touche dedicated to promoting innovation. 'I am not only stunned by the quality of the submissions,' he professed, 'but extremely excited to see that our exceptional intellectual capital wants to showcase not academic papers, but products and services which will change the quality of life of thousands of people.'

He added that the government was actively promoting the creation of an environment which would favour innovation and entrepreneurship and mentioned the National Research & Development Strategy which has cabinet approval. 'The three pillars of the strategy are the promotion of innovation without which no economy can grow, the development of our human capital, without whom no ideas can blossom and the building of a new mutually reinforcing partnership in government which will create resources and infrastructure to favour innovation.'

Introducing the speakers and finalists, Gavin Goldblatt, CEO of Catalyst Innovation Incubator, praised the growing interest of students at tertiary level in investigating the business potential of products and services and not focusing merely on pure research.

The theme was continued by Vassi Naidoo, Chief executive of Deloitte & Touche who stressed the important role business had to play in stimulating the entrepreneurial and innovative spirit of our youth. 'We can be immensely proud of the intellectual capital we possess in South Africa,' he said. 'Closer links between tertiary institutions and business and industry, together with a more proactive role by financial institutions and venture capital organizations must ensure that we develop this pool of talent. In this way we can not only put a stop to the brain drain, but develop our economy further to enable us to compete globally.'

Before presenting the prizes with Naidoo, Peter Breitenbach, CEO of Acorn Technologies which commercializes life science innovations, provided an overview of the judging process. 'Innovation, business aspects and presentation were the main elements towards marks,' he explained.

The seven runners-up all received an award of R2 000. 'Like the winners,' added Breitenbach, 'their submissions demonstrate significant business potential. Last year, the competition resulted in one start-up business, one new business unit within a large corporate and two potential businesses currently in the stage of royalty and commission negotiation. I am confident that this year even more will result in commercializable products and services.' ◆

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The Geological Society of South Africa (GSSA) Honours Award for 2001*

The Geological Society of South Africa has awarded their Honours Awards for 2001 to Dr Ferdi Camisani-Calzolari, Fellow of the South African Institute of Mining and Metallurgy.

The Honours Award is conferred from time to time on a member or group of members of GSSA who in the opinion of the Council, has made a particularly meritorious contribution to The Geological Society of South Africa or to the geological fraternity of southern Africa.

The Society has honoured Dr Camisani-Calzolari in recognition of his valuable leadership skills and guidance that saw the SAMREC Code to completion in 2001 and then clearly and unambiguously incorporated into the Johannesburg Securities Exchange requirements. The GSSA also appreciate the continuing efforts, made by Dr Camisani-Calzolari towards promoting competence in the field of mineral resource management among the geological fraternity of southern Africa. ◆

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