# USE OF PROCESS SIMULATION TO CALCULATE THE BENEFITS OF APPLICATION OF ADVANCED PROCESS CONTROL TO DECANTERS IN SERIES[1]

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## Abstract

This paper presents a methodology for the use of numerical simulation and numerical optimization to calculate the potential benefits of applying Advanced Process Control. An example is given where the methodology is applied to a series of decanters for mud washing to recover valuable components in an ore processing facility. The methodology first establishes a Base Case numerical model in a commercial simulator package using historical plant data then uses the Base Case model to calculate benefits resulting from the application of advanced process control. This method provides realistic estimates of benefits taking into account all the primary and secondary effects on the process.

**Key words:** Numerical simulation; Advanced process control; Controlled variables; Economic benefits.

## SIMULAÇÃO DE APLICAÇÕES DE CONTROLE AVANÇADO EM PROCESSOS DE DECANTAÇÃO EM SÉRIE: CÁLCULO DE BENEFÍCIOS

## Resumo

Esse artigo apresenta uma metodologia para utilização de simulação e otimização numérica para calcular os benefícios em potencial da aplicação de Controle de Processos Avançados. É citado um exemplo no qual a metodologia é aplicada á uma série de decantadores de lavagem de polpa para recuperação de componentes de valor no processo de beneficiamento de minério. Essa metodologia estabelece, primeiramente, um modelo numérico “Base Case” em uma ferramenta de simulação de mercado utilizando o histórico da planta e usando esse “Base Case” para calcular os benefícios resultantes na apliacação do processo de controle avançado. Esse método fornece estimativas realistas desses beneficios tendo em vista todos os efeitos primários e secundários do processo.

**Palavras-chave:** Simulação Numérica, Controle Avançado de Processo, Variáveis Controladas, Benefícios Econômicos.

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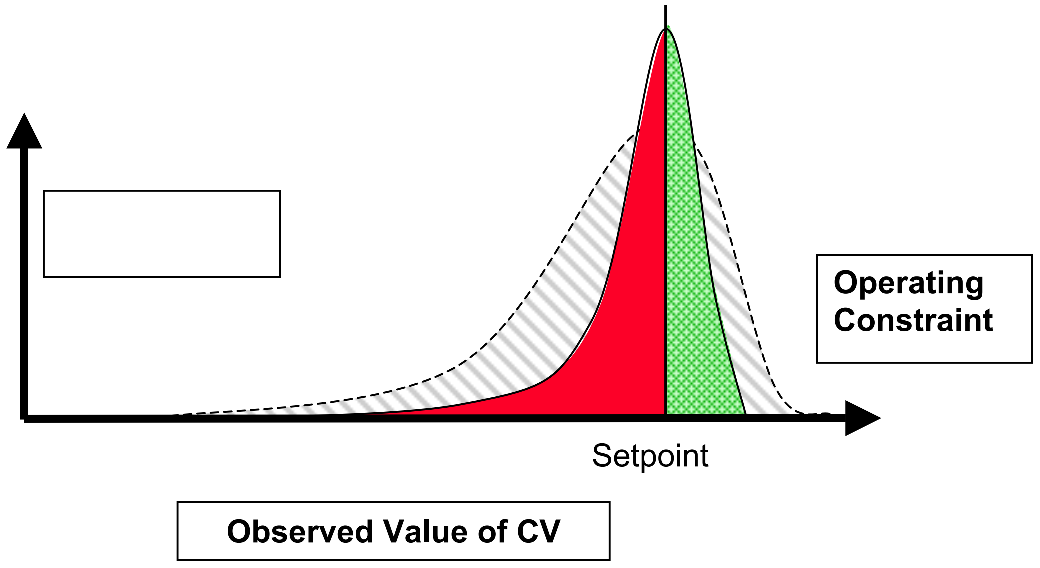
## 1 INTRODUCTION

Starting in the early 1980's, companies in the petroleum refining and petrochemical industries developed and began to implement new process control strategies to improve and optimize the real-time control of industrial facilities. Collectively, these new process control strategies are known in these industries as Advanced Process Control (APC). These strategies are now starting to be accepted in the minerals processing industries such as alumina and copper manufacturing. Fiske(1) reports that in a recent survey of APC Best Practices, 8.25% of respondents were companies in the Metals and Mining industries compared to more than 80% from the Oil and Gas and Petrochemical industries.

The most widely-applied APC applications in the oil refining and petrochemical industries are model-based, predictive control strategies such as Honeywell's Robust Multivariable Predictive Control Technology (RMPCT) that are implemented as supervisory controls on top of base-level regulatory controls. Regulatory controls, for example flow controls, level controls, and temperature controls, in general use the traditional control strategy known as the proportional-integral-derivative (PID) algorithm which is taught in most process engineering curricula at universities. The shortcoming of this traditional control strategy is that it only addresses the control problem based on current observations. This strategy does not take into account the history of control actions or predictions of the future state of the variables we are interested in controlling (known as controlled variables or CVs). APC strategies, especially the model-based, predictive algorithm, do take into account the recent history of control actions, the current observations, and predictions of the future state of the CVs to improve control performance.

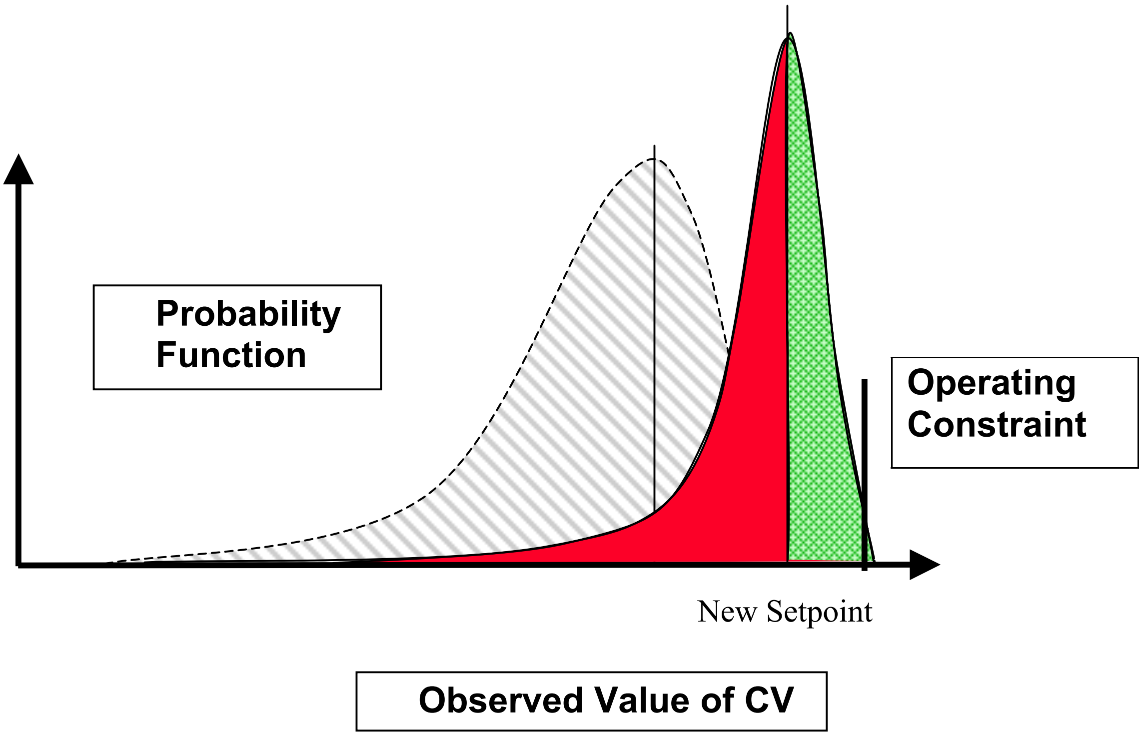
The benefits of applying these advanced strategies are that it results in significant reduction of the variability of the CVs. It is an accepted industry benchmark that advanced control strategies will reduce the variability of CVs, as measured by the standard deviation, by 50% over the performance that can be achieved by traditional regulatory control.(2) The figure below illustrates this concept.



*Original From: Honeywell Process Solutions, internal communications*

**Figure 1** – Variability of Controlled Variable (CV)

In this figure, the hatched area represents the probability function of the value of the CV under only regulatory control. The colored area represents the probability function of the value of the CV under APC control. Since the variability (or standard deviation) is reduced under APC, the probability of exceeding the Operating Constraint is reduced. If we are allowed to maintain the same probability of exceeding the operating constraint as before the application of APC, we can shift the setpoint towards the operating constraint, thus producing tangible benefits. This is illustrated in the following figure.



*Original From: Honeywell Process Solutions, internal communications*

**Figure 2 –**New setpoint value of Controlled Variable

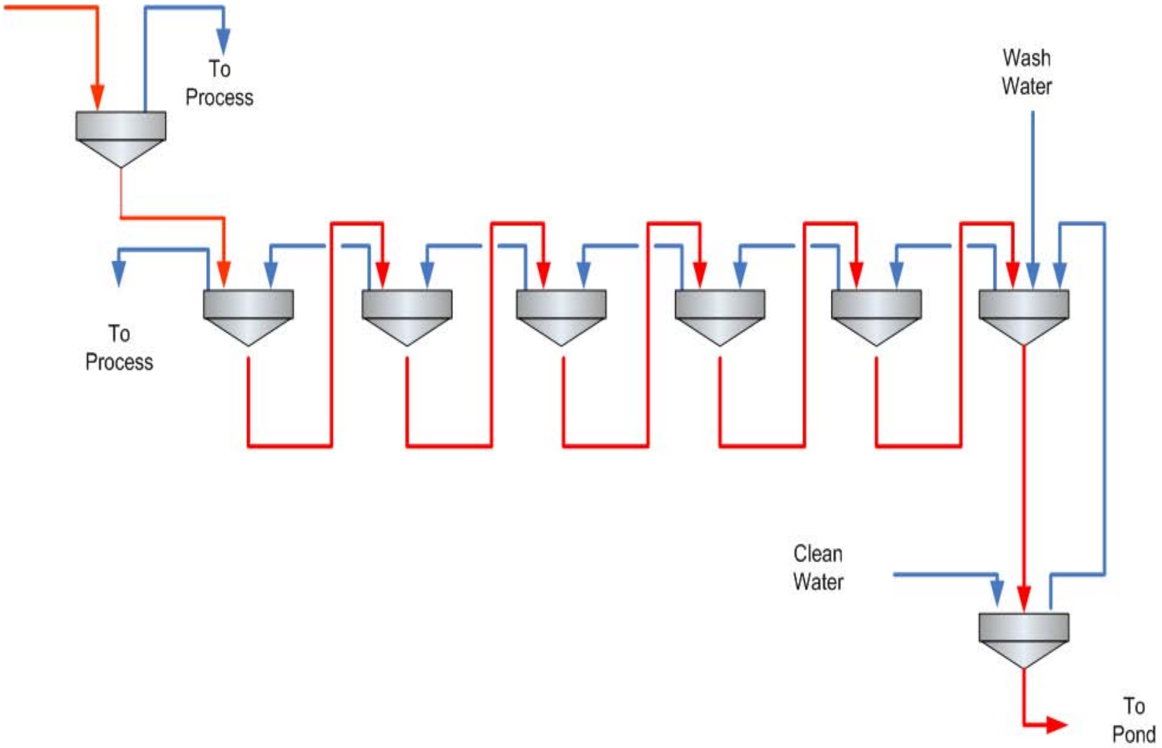
In this figure, we illustrate that with APC, we can move the setpoint of the CV closer to a plant constraint while maintaining the same probability of exceeding it. This, generally, is a more profitable operating point. For example if the CV we are controlling is related to plant feed, and we can operate closer to the plant feed limit, we can produce more product which, in most cases, results in higher profitability. This is the incentive for applying APC to processing facilities.

One of the challenges that engineers face is the decision whether to apply APC to their process and, if so, what will be a realistic estimate of the benefits to be achieved. This is especially important in today's economic environment, where expenditures must be justified from a financial point of view. Usually, this means that a payback or return on investment must be calculated as a justification of the expenditure. This requires a cost figure and also a quantification of the expected benefit. The cost figure can be determined in a straightforward manner. This paper presents a methodology to calculate the benefits using process simulation.

## 2 EXAMPLE PROCESS

The example used is a train of decanters that are recovering a valuable component from a waste mud stream before the mud is discarded in a tailings pond. This particular example is based on a real plant but the flows and data have been modified to protect the confidentiality of the customer.

The process is a thickener followed by six decanters in series, with the wash water (decantate) flowing counter-current to the mud flow and a final polishing unit that provides a final wash with clean water. The waste mud feed stream is fed to the thickener where the objective is to increase the density of the mud stream by taking out a rough liquid cut. This liquid cut is returned to the process. The underflow from this unit is then fed to the first stage decanter where it is washed by the decantate from the second stage. The decantate from the first decanter is returned to the process as it contains important quantities of the recovered component. The second through fifth stages are identical. The sixth stage is where the primary washing solution is fed. The underflow from this sixth stage undergoes a final polishing with clean water before being discarded. The decantate from the polishing unit is fed to the sixth stage together with the primary washing solution. The figure below shows a simplified process flow diagram.



*Original From: Simplified process flow diagram taken from Honeywell Process Solutions study for Confidential Client*

**Figure 3** – Example process showing decanters in series for recovering valuable components from mud (mud shown in red)

In this process, the content of the valuable component in the mud being fed to the thickener is 1200 – 1300 units and the final content in the waste mud is less than 12 units.

## 3 METHODOLOGY

The methodology to calculate the expected APC benefits using numerical simulation is as follows:

1. Review the process with plant personnel to understand all of the flows within the scope to be considered. Of special importance is the flow topology since the model will require the correct topology in order to replicate the heat and material balance properly.
2. Review all of the operating objectives and constraints with the plant operators to ensure a clear understanding of the operating targets and limitations.
3. Collect historical data for all of the flows, densities, temperatures, pressures and compositions within the scope of interest. In general, it is recommended that one years' worth of one hour averages be used. This granularity of data minimizes the information loss due to averaging, without generating an overwhelming number of points and also provides information as to the impact of seasonal weather variations or of different feedstocks or products on the plant.
4. Using the historical data collected, calculate the average and standard deviations for all of the variables of interest. If there are significantly different operating modes due to seasonal impacts or different feedstocks or products, then the data may have to be segmented and several cases considered. The need to consider several scenarios becomes evident upon visual inspection of the data.
5. Using the known flow topology, and the calculated averages of the variables of interest as model input values, build a representative simulation model of the process. Check that the model's dependent variables match the plant data. This model is known as a tuned plant model since we are using real plant data to "tune" the model and is the Base Case against which we will compare the improved operation that can be expected with the implementation of APC.
6. Once the Base Case model is established, new values for the input variables of the model can be implemented and the model can then solve for all of the unknown or dependent variables. The model solution will take into account all of the effects to each of the operating equipment in the model. This is important because for realistic benefits calculations, you must not only predict all of the primary effects but also the secondary effects on the process.

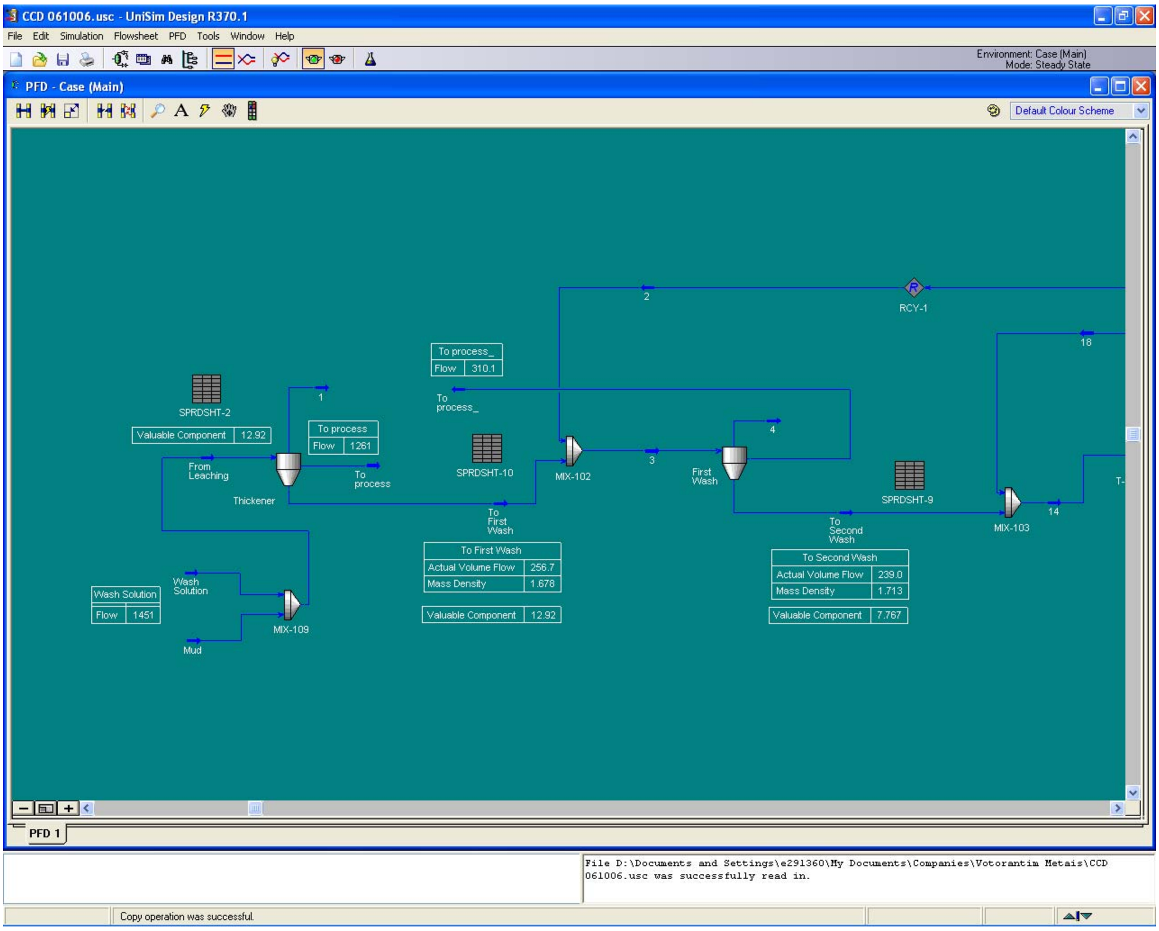
## 4 DISCUSSION

The benefits analysis indicates that application of Advanced Process Control (APC) and Advanced Regulatory Control (ARC) applications to the train of Counter Current Decanters will result in significant benefits in reduced valuable component losses in the underflow of the Polishing unit. This can be achieved by a combination of Improved Control and operating the decanters at Maximum Underflow Densities.

The benefits were estimated by calculating the reduction in valuable component losses in the underflow mud from the polishing unit by use of a numerical simulation. The valuable component losses can be reduced by: a) increasing the primary wash solution flow rate, b) reducing the valuable component content of the washing solution or c) increasing the underflow density of each decanter such that the washing efficiency of the whole washing train is improved. Since the operators currently try to maximize the underflow densities, subject to various operating constraints, it is reasonable to apply advanced control strategies that mimic the operator's strategy.

The calculation of the economic benefits of application of APC resulting in improved control requires knowledge of the relationship between the improved underflow densities and the valuable component content in the underflow of the Polishing unit. Any valuable component contained in the mud from the last decanter is lost from the process. Any reduction in the valuable component content of the mud will, by material balance, provide additional valuable component production.

The relationship between underflow densities and valuable component losses was established by use of a simulation model of the washing train. Honeywell's UniSim Design rigorous simulation software was utilized for this numerical model. The model utilizes a simplified representation of the dissolved valuable component in the washing train but it does include the hydraulic mixing effects in each decanter and decanter split factors. The model was tuned to the plant data and was found to represent the process well-enough to provide an estimate of the relationship between the underflow densities and the valuable component losses.



Valuable Component 12.92

To process
Flow 1261

To process_
Flow 310.1

To First Wash
Actual Volume Flow 256.7
Mass Density 1.678

Valuable Component 12.92

To Second Wash
Actual Volume Flow 239.0
Mass Density 1.713

Valuable Component 7.767

Wash Solution
Flow 1451

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*Original From: Honeywell Process Solutions UniSim Design simulation program, case developed for Confidential Client.*

**Figure 4** – Graphical User Interface (GUI) of commercial simulation package

The figure above shows the graphical user interface (GUI) in Honeywell's UniSim Design simulation package. This screen capture shows the representation of front part of the example process, the Thickener and First Wash stage. A full view of the simulated process is not possible due to space limitation of this paper. However, the tables showing some of the variables of interest are evident in this screen shot. Detailed information on any stream is available by double-clicking on its respective icon.

The procedure used in matching the plant data was to let the model converge on the calculated average underflow densities in each decanter, by varying the split factors in each decanter and also letting the wash solution to the sixth decanter, and all flows in between the decanters to vary. An optimization function in UniSim Design was used for this purpose. The predicted valuable component losses in the underflow from Polishing unit were in good agreement with the values observed in the plant data. All of the flows predicted were also within the ranges specified by plant personnel. Thus, the use of the model to calculate changes in valuable component losses was acceptable for the purpose of this study.

## 5 CONTROL BENEFITS

The following chart illustrates the results of the data analysis and the estimated improvements due to improved control. As indicated, the first row is the calculated average underflow density in each of the decanters over the period covered by the data. The second row is the standard deviation of the data. The third row is one half of the standard deviation, and the fourth row is the improved underflow densities after implementation of APC to the decanters.

**Table 1:** Results of data analysis and estimated improvements

| | Thickener | 1 | 2 | 3 | 4 | 5 | 6 | Polishing |
|---|---|---|---|---|---|---|---|---|
| **Average Density** | 1678 | 1713 | 1648 | 1618 | 1645 | 1640 | 1645 | 1657 |
| **Std. Dev.** | 6.26 | 24.9 | 11.7 | 32.1 | 22.5 | 9.67 | 6.94 | 30.3 |
| **1/2 SD** | 3.13 | 12.5 | 5.85 | 16.1 | 11.3 | 4.84 | 3.47 | 15.2 |
| **Improved Average Density** | 1681 | 1726 | 1653 | 1634 | 1656 | 1645 | 1649 | 1673 |

*Original From: Honeywell process Solutions Study Report for Confidential Client*

The calculation of the improved average density is based on standard industry practice that application of APC will permit a reduction in variability of one-half of the standard deviation. The average can then be moved towards operating constraints by that one-half standard deviation while maintaining the same probability of exceeding the constraints. Thus, our conservative expectation is that application of APC will permit the underflows to operate at a higher density by one half of the standard deviation of current operation, as shown on the fourth row of the table above.

This results in a reduction of average losses of valuable component from 23.4 units per hour to 21.9 units per hour resulting in a significant economic benefit.

## 6 MAXIMUM UNDERFLOW DENSITIES

Plant personnel indicated that the underflow pumps could handle underflow densities as high as 1750 before experiencing problems. With improved control, additional benefits can be achieved by increasing the underflow densities target to operate at higher levels than current operation without concern for exceeding the 1750 density upper limit. The potential benefits associated with this mode of operation were arrived at by letting the model calculate the operating conditions if all the decanters were allowed to run with a 1700 underflow density target which still leaves a safety margin of 50 units of density. In this mode of operation, the average valuable component losses would be further reduced to 15.8 units per hour, resulting in a greater economic benefit per year compared to the Base case. This is results in an incremental benefit over the benefits associated with just improved control. The feasibility of this type of operation is dependent on other constraints, such a rake torque, capacity of flocculant pumps, etc. The controller would maximize the underflow densities subject to these constraints on a real-time basis as the algorithm takes into consideration constraints in real-time.

The manner in which this would be implemented is to configure the underflow densities as targets for the APC strategy. The controller would then seek to increase the underflow density of each decanter, up to its limit, whenever there are no constraints active. The controller has a predictive model that will predict values for all of the important CVs as a function of the past control moves, as well as the current state of the variables. The controller is designed to accept hard targets or ranges both for the CVs as well as the constraint variables.

## 7 ADDITIONAL BENEFITS: MAXIMIZE PRIMARY WASHING SOLUTION

One of the insights provided by the model was that significant additional benefits can be achieved by maximizing the flow of the primary Wash Water to the sixth decanter. Maximization of the primary Wash water is an example of an APC strategy known as a **constraint pushing** application. Constraint Pushing is a mode of operation in a multivariable application wherein the controller monitors all of the relevant constraints within its scope and, if no constraints are active, maximizes a flow until all of the constraints are met. Typically, this type of application results in significant increases in throughput and, thus, increased revenue.

A rough estimate of the benefits that could potentially be achieved by a constraint pushing APC application on the primary Wash Water loop was arrived at by allowing the model maximize this flow subject to constraints. Plant personnel indicated that the maximum achievable flow of Primary Solution is 460 units per hour. By operating at the maximum underflow densities of 1700 in each decanter with a maximum primary Wash Water flow of 460 units per hour results in valuable component losses of only 1.53 units per hour in the underflow of Polishing unit. So, APC in a constraint pushing mode could reduce the valuable component losses by a factor of ten.

## 8 SUMMARY OF ESTIMATED BENEFITS

The table below is a summary of the estimated benefits under the conditions described above. The figures shown are each compared to the base case therefore the benefits are not cumulative. The incremental benefits can be calculated by the difference between them.

**Table 2**: Estimated benefits

| | Units of Measure | Base case | Improved Control | Max U/F Densities | Maximize Wash Water |
|---|---|---|---|---|---|
| **Polishing unit valuable component content in U/F** | Composition units | 12.64 | 12.22 | 9.32 | 0.9 |
| **Volumetric U/F from Polishing Unit** | Flow units per hour | 252.4 | 246.5 | 237 | 237.1 |
| **Mass density U/F from Polishing Unit** | Density units | 1657 | 1673 | 1700 | 1700 |
| **Liquid Volume Fraction in Mud from Polishing Unit** | Fraction | 0.733 | 0.727 | 0.716 | 0.716 |
| **Valuable component Loss from Polishing Unit** | Mass units per hour | 23.4 | 21.9 | 15.8 | 1.53 |
| **Economic Incentive compared to Base Case (Base Case = 1)** | | **1** | **2.94** | **10.89** | **29.56** |

*Original From: Honeywell Process Solutions Study Report for Confidential Client*
*NOTE: These data have been modified but are correct relative to each other*

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