

Reuse of the Concrete Mixer Truck Wash Water in the Production of Concrete - A Clean Production Proposal

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Abstract—Concrete is a material used on a large scale in civil construction. In concrete plants, it is manufactured by concrete mixer trucks and this process consumes a large quantity of drinking water. In addition to the production of concrete, the water used to wash the concrete mixer trucks should also be considered, since this also generates a considerable amount of residual water that cannot be disposed of without prior treatment. As such, the objective of this study is to reuse the waste water generated by the washing of the mixer trucks in the production of concrete, thus avoiding the consumption of drinking water, considering that the reuse of this waste water doesn't require chemical treatment. Three compositions were developed: A reference composition produced with drinking water; a composition with 50% drinking water and 50% residual water; and a composition with 100% of residual water. To analyze the concrete, its properties were checked in the fresh and the hardened state, assessing the workability through the slump test and its compressive strength at 14 days and 28 days. In total, 9 test specimens were molded in accordance with age, which meant 3 specimens per composition. The results showed that the concrete produced with the residual water presented the same compression strength as the concrete that used drinking water. It is estimated that a replacement of up to 50% should be used, since the composition containing 50% of residual water showed the greatest gains in strength in relation to the other compositions.

Keywords—Residual Water, Concrete Mixer Truck, Concrete Production, Reuse.

I. INTRODUCTION

Concrete is by far the most often used construction material, considering that more than 10 billion tons are produced worldwide each year. The reasons for this popularity are well known. If properly produced, concrete has excellent mechanical properties and durability, being moldable, adaptable, relatively resistant to fire, and with

the capacity to be designed to meet virtually any set of specifications, more than any other material currently available (Meyer, 2009).

Meyer (2009) also states that because of the large volumes produced each year, concrete has a huge impact on the environment. First, large amounts of natural resources are needed to produce the billions of tons of concrete each year. Second, the cement industry is estimated to be responsible for about 7% of all CO₂ emissions generated. Third, the production of concrete requires large quantities of water, using approximately 1 trillion gallons of water per year throughout the world, not including the wash water for the trucks and the water used to cure the concrete.

Concrete plants make heavy use of water, not only in the production of the concrete itself, but also to wash off the waste from concrete mixer trucks, floors and to sprinkle on the aggregates to reduce dust (Sealey; Phillips; Hill, 2001).

Usually, the washing of mixer trucks occurs twice a day. Considering the use of 15 trucks, a concrete plant is estimated to use approximately 15 thousand liters of water per day. In addition, a plant producing 500 m³ of concrete per day consumes approximately 10 thousand liters of water for this production (Ekolu; Dawneerangen, 2010). The use of residual water can reduce the consumption of drinking water and contribute to a cleaner production of concrete in terms of water (Paula; Ilha, 2014).

Since it contains cementitious material and other impurities, the wash water of concrete mixers cannot be disposed of on construction sites or landfills. The practice of recycling waste water has become essential, and its conservation is pursued as a process necessary for a safe environment. When reused in concrete, waste water from the washed trucks can contribute in an effective and environmentally friendly way, since its reuse does not require chemical treatment (Ekolu; Dawneerangen, 2010). The NBR 15900-1 (ABNT, 2009) defines that waters considered as drinkable are those suitable for concrete, and that they should possess a pH between 5.80 and 8.0 and respect the maximum limits for organic matter (3 mg/L) and solid material (50 000 mg/L).

The chemical properties must meet the following requirements, sulfates (expressed in SO_4^- ions) must not exceed 2 000 mg/L, chlorides (expressed in CL^- ions) must not exceed 500 mg/L for prestressed or grout concrete, 1000 mg/L for reinforced concrete and 4500 mg/L for simple concrete (without reinforcement). Any contamination by harmful substances can affect the setting time and strength of the concrete, and the maximum tolerances must be respected: 100 mg/L for sugar, 100 mg/L for phosphates (expressed as P_2O_5), 500 mg/L for nitrates (expressed as NO_3^-), 100 mg/L for lead (expressed as Pb_2^+) and 100 mg/L for zinc (expressed as Zn_2^+).

It is estimated that to produce 1 m³ of concrete, 200 liters of drinking water are needed on average, which may vary in accordance with the composition and the water/cement factor (Ekolu; Dawneerangen, 2010).

The reuse of waste water from the washing of concrete mixer trucks generates large environmental benefits. However, chemicals are used during the washing to assist in the removal of the concrete of the surfaces of the truck mixer, leaving doubts about the reactions that these products may cause on the concrete. Other compounds present in the water are the cement and aggregate residues from the concrete, which can contribute in a positive way to a new concrete mix.

A cleaner production consists in the continuous application of an economic, environmental and technological strategy integrated into the processes and products, which prevents, minimizes or recycles the generation of waste in the productive processes in order to increase the efficiency in the use of raw material, water and energy and to reduce the risks to people and the environment (Terra et al., 2013).

The construction industry demands a large quantity of raw materials at the same time that it generates a considerable volume of waste. The deployment of cleaner production can establish a connection between these two extremes, enabling the transformation of waste into raw materials once again.

Through a focus on the reuse the water, this paper seeks to reuse the waste water generated by the washing of concrete mixer trucks in the production of concrete, avoiding the consumption of drinking water. Test specimens were produced and tested, and the behavior of the concrete made with this water was analyzed, with all assays being performed based on the standards of the Brazilian Association of Technical Standards (ABNT).

II. THE IMPLEMENTATION OF CLEANER PRODUCTION

2.1 Diagnosis of the Production Activity

For the development and application of this study, the steps of the concrete production process in the concrete plant were established, with these steps being made up of following activities, as shown in Figure 1.

The proposed implementation of cleaner production has been applied in a concrete and mortar plant located in the municipality of Chapecó-Santa Catarina - Brazil. A survey of the plant's industrial layout was developed, as shown in Figure 2.

The company has an average daily output of approximately 100 m³ of concrete, with around 50 thousand liters of water being consumed for this production. The largest volume of waste water is generated through the washing of the mixers of the trucks and yards, in addition to the portion of the concrete that returns to the plant after the concreting.

The mixer is an accessory equipment coupled to the chassis of the truck, responsible for receiving and mixing the materials dosed by the dosing equipment.

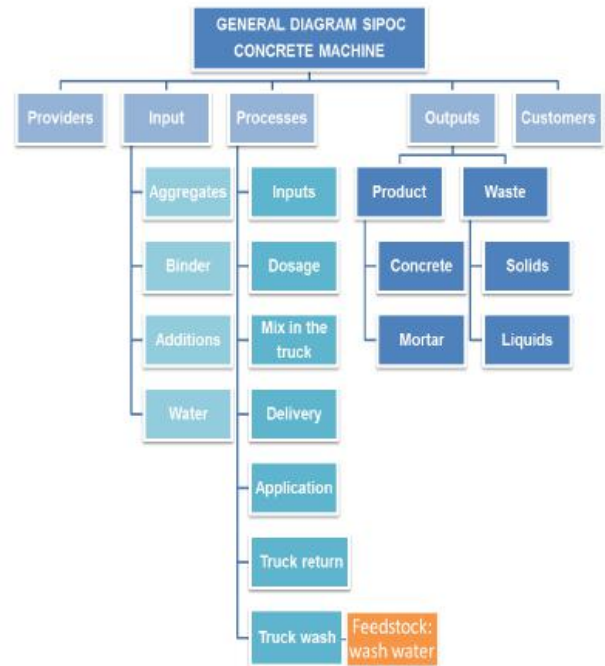


Fig. 1: Flow diagram of the steps of the concrete production process

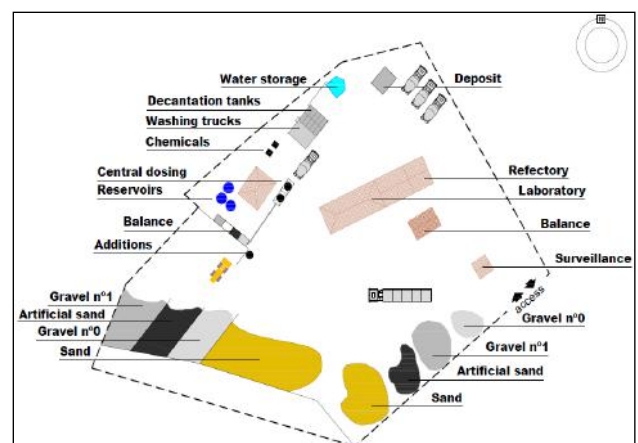


Fig. 2: Industrial Layout of the plant

Based on this information, the main focus for the implementation of cleaner production within this company was to intervene in the water used in the washing of the mixer trucks, as a source of new applications in concrete.

Concrete production demands a huge amount of raw materials, such as aggregates of different particle sizes, binders, additives and water. The company under study acquires its inputs from different production sources.

The fine aggregate (sand) is derived from deposits in the city of Porto União - Santa Catarina - Brazil, the coarse aggregate (gravel) and the artificial sand (stone dust) are obtained from an own mine located in the municipality of Guatambu - Santa Catarina - Brazil. Both are stored in the company's yard. The cement is supplied by the cement company Itambé, is classified as CP II-F-32 and is stored in silos for its conservation.

For the Technological control of the concrete, the company uses specific software for the dosage of materials in order to ensure quality and meet the demands required for each application. As such, it is possible for the products to satisfy the requirements laid down by the consumer, including: strength, workability, curing time, among others.

After the homogenization of the materials in the concrete mixer truck, the concrete or mortar are sent to their application. The truck then returns to the company where it is washed, which is necessary before each new load. This washing generates solid and liquid waste, which is stored in tanks for decanting. After decanting the solid materials, the water is currently reused for the washing of the trucks, yard and equipment.

It is estimated that each production day 30 thousand liters of waste water are generated from the washing of the trucks, and more than 5 m³ of solid waste from the decanting. Part of this water remains in the decanting tanks and is used for subsequent washings, the surplus is sent to third parties who may need water without specific technical specifications, such as for the moisture correction of soils in compression processes.

Because of the large volume of water needed for the company's production process, a new opportunity was identified to incorporate this water from the washing of concrete mixer trucks into the production of concrete or mortar.

It is known that the company uses water from an artesian well, located in the yard of the company, which is graded as drinking water for human consumption. With this in mind, the project in question sought to implement cleaner production within the company, evaluating the volume of water discarded and seeking to replace the use of water from the artesian well by this residual water in the production of concrete, given that the volume generated daily by the washings is relevant in relation to the daily consumption of the company.

In addition to working on the reduction of water consumption, this cleaner production initiative also decreases the quantity of liquid waste disposed of inappropriately in nature or in landfills, since the reuse of wastewater in concrete production may not require chemical treatment.

Another opportunity for cleaner production would be the reuse of the solid waste, because today these materials are disposed of in landfills. As a suggestion for future projects, an analysis of the characteristics of these materials through specific procedures is recommended, classifying their granulometry and applying them again to the concrete, potentially being used in works without structural purposes.

III. INTERVENTION PROPOSALS / OPPORTUNITIES

By evaluating the layout of the concrete plant and studying its entire production process, some opportunities for improvement of this process were identified. Some proposals for intervention are therefore presented with actions in the short (Table 1, 2, 3).

3.1 Prioritization of Identified Opportunities

The priority of the cleaner production initiative was to study the use of water to wash the concrete mixer trucks in the production of concrete in order to achieve results that allow for its applicability, providing a more noble destination for this residual water, reducing the consumption of drinking water and minimizing the inappropriate disposal of this water.

IV. ADOPTED METHODOLOGY

About 20 L of water from washing of the trucks, which was stored in the decanting tanks, was collected and stored for the development of laboratory tests, as shown in Figure 3 (a). The collected water presented a certain degree of turbidity because of the solid particles in suspension. It was therefore necessary to assess the amount of solid material present in the water.

For this analysis, 101.1023 g of water was placed in a beaker, and this was subsequently put in an oven at a temperature of 105°C for complete evaporation of the liquid so as to quantify the volume of solid material present in the sample. After the necessary time for evaporation had passed, the solid material remaining in the beaker was weighed and this returned a mass of 0.1494 g, which represents less than 0.15% of solid matter present in the water, as shown in Figure 3 (b).

4.1 Concrete Production

Once in possession of all materials, three concrete compositions were developed in order to apply the residual water of the concrete plant. The compositions were established in accordance with the proportion of drinking water replaced by the water from the concrete manufacturer.

A ratio of 1:2:3 was chosen for these compositions, respectively cement, fine aggregate and coarse aggregate, with the water/cement ratio at 0.53. The physical characteristics of the aggregates were ignored, since the focus of analysis in this project was the replacement of the water. Initially, the first experiment contained only drinking water, collected directly from the lab, being named the reference composition. At this stage, 11.31 kg of gravel, 7.54 kg of sand, 3.77 kg of cement and 2 L of water were added to the concrete mixer.

These materials were kept in the concrete mixer's mixing process for about 5 minutes until the mixture was homogeneous. Soon after, a slump test was carried out in accordance with the NBR NM 67 standard (ABNT, 1998). Test specimens were molded in triplicate and then sent for the compression strength trials after 14 days and 28 days of curing.

Table 1: Actions to be undertaken in the short term.

Opportunity	Name of the Action	Description of the Action	Indicators	U/M
1	Concrete with reused water	Use of the concrete mixer truck washing water in concrete production.	Strength	MPa

U/M = Unit of Measurement.

Table 2: Actions to be undertaken in the medium term.

Opportunity	Name of the Action	Description of the Action	Indicators	U/M
1	Concrete with solid waste	Use of the solid waste arising from the concrete mixer truck washing in concrete production.	Strength	MPa

U/M = Unit of Measurement.

Table 3: Actions to be undertaken in the long term.

Opportunity	Name of the Action	Description of the Action	Indicators	U/M
1	Improving the water collection system	Improve the collection system of the water arising from the washing of the concrete mixer trucks, deploying a simple system for the treatment and quality control of this water	Volume of water	m ³
2	Take advantage of the remaining concrete in the trucks to manufacture artifacts	Purchase equipment for the manufacture of concrete artifacts with the concreting leftovers	Quantity of parts	UN

U/M = Unit of Measurement.

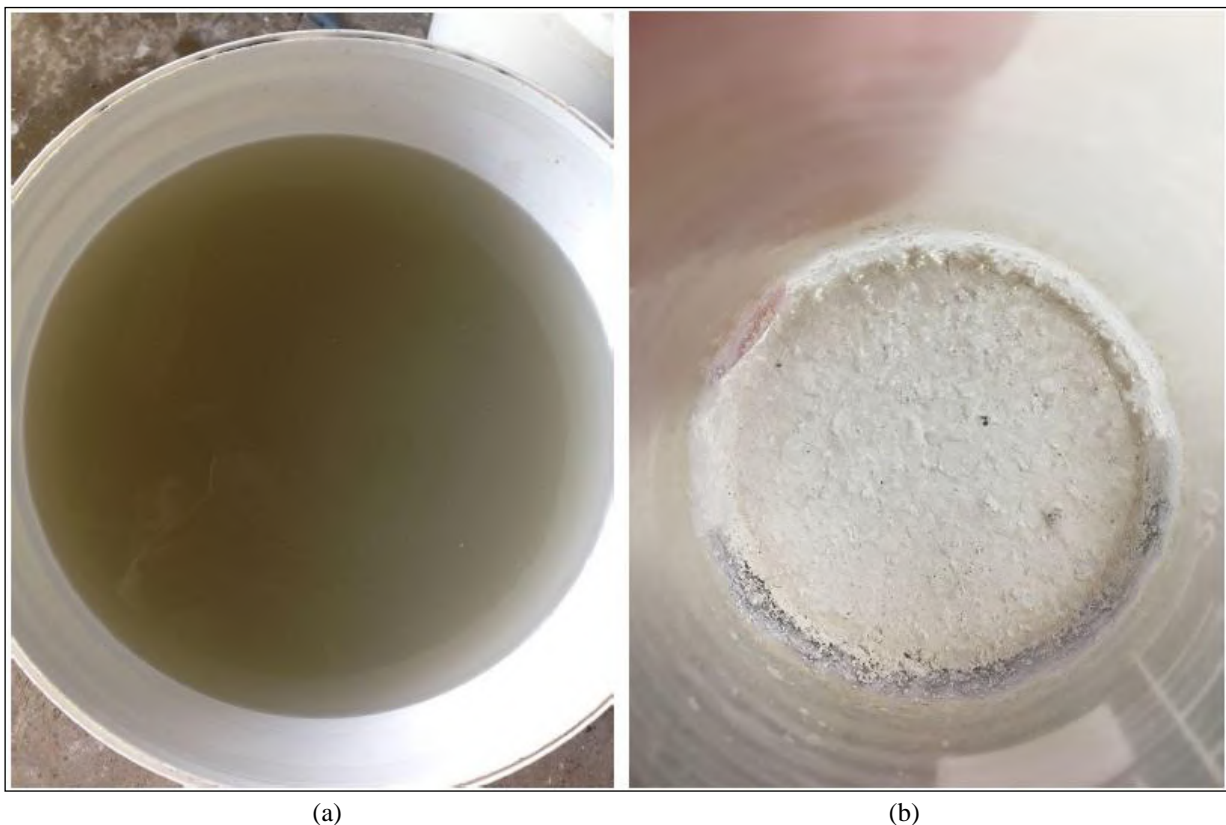


Fig. 3: Water used to wash the concrete mixer trucks (a); solid waste present in the water (b)

On a second moment, the same quantities of materials were added in the concrete mixer, obeying the proportions adopted, but now with 50% of the drinking water replaced by residual water collected at the concrete plant, following the same procedure as described

previously. Test specimens were also produced in triplicate for the compression strength tests at two ages, 14 and 28 days.

Finally, in the third experiment, only the wash water from the concrete mixer trucks was used. The procedure for the

development of this composition followed the same conditions and proportions as the reference experiment. Test specimens were once again produced in triplicate to be subjected to the compression strength test at different curing ages.

The test specimens were demolded 24 h after the production of the concrete, and then put into specific tanks for wet curing until the day of the mechanical tests. In total, 18 test specimens were molded, 6 for each composition divided into two different ages.

At 14 days, three specimens per composition were subjected to the compression test in order to analyze the strength of the material according to the curing period. With this objective, the surface of the specimens were rectified to improve the distribution of the load applied in the test. The specimens were then submitted to the compression test standardized by NBR 5739 (ABNT, 2007). This test consists basically in submitting the cylindrical concrete specimen to an axial force until there is a rupture of the material in order to verify the maximum compression strength of the concrete.

At 28 days, the same procedures were followed to obtain the strength results. Subsequently, the surface of the rupture was examined visually as well as the interaction between the aggregate and the matrix.

The values obtained in the tests were statistically treated with the Tukey method and analyzed in order to validate the proposed objective of cleaner production.

V. RESULTS AND DISCUSSIONS

The compression trials produced strength values for the different concrete curing ages. The values found at 14 and 28 days are shown in, which presents the data for the different compositions used in the methodology (Table 4).

Table 4: Mean compressive strength and standard deviation values

% of waste water used	Ages of mechanical tests (days)	
	14*	28*
0	21.53 ± 0.77a	25.59 ± 1.07a
50	23.34 ± 0.59b	26.59 ± 1.55a
100	20.16 ± 0.34a	24.22 ± 0.59a

* Means followed by the same letter in the column don't differ by Tukey test at 5% probability. The data represent the means ± standard deviation of three replicates of each volume of water.

For a better understanding of the results, the Tukey test was applied to the experiment, which consists of a means comparison test, serving as a complement to the analysis of variance of the results. This test proves statistically if any of the samples has a significant difference in relation to the other.

Since this study's objective was to apply the residual water, the data found needed to be treated statistically to prove if the results were statistically significant. This way one could observe that, at the younger age, the concrete with the addition of 50% of water from the concrete plant had strength values with a significant increase. At the older ages, however, the different proportions of water used for replacement yielded differences that were no

longer statistically significant. Figure 4 shows the mean values found for each trait at different ages for each sample.

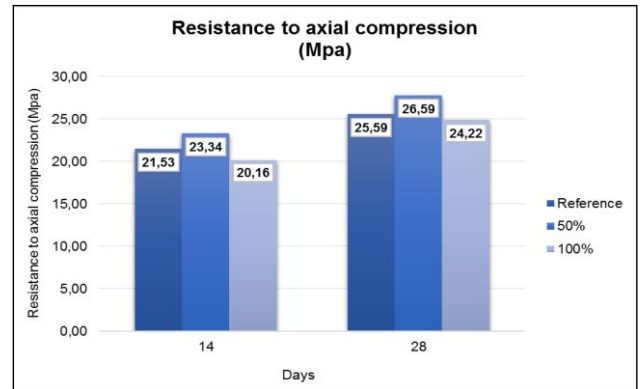


Fig. 4: Compression strength between the different proportions of residual water from the concrete plant.

At 14 days, it is observed that the composition with 50% of residual water had an increase of 8.45% in its compression strength in relation to the reference composition. The composition with 100% of residual water, on the other hand, had a decrease of 6.36% in its compression strength in relation to the reference composition.

At 28 days, it is observed that the composition with 50% of residual water had an increase of 8.63% in its compression strength in relation to the reference composition. The composition with 100% of residual water, on the other hand, had a decrease of 2.77% in its compression strength in relation to the reference composition.

When analyzing the data, an increase in the strength can be seen only in the sample with 50% of residual water, with an improvement at 28 days. It appears that using 100% of residual water tends to decrease the strength.

Although there were no results with statistically significant higher strengths, one can conclude that the residual water from the company can be used in mixtures with a cement basis, since it has the same behavior as those prepared with drinking water.

The conclusion can therefore be drawn that the residual water from the washing can be applied in concrete production, since the results showed that the concrete containing the residual water achieves the same compression strength when compared to the experiment that used only drinking water.

Another relevant factor is the behavior of the concrete with the replacement of the water. The concrete showed typical behavior when subjected to the compression test because conventional Concrete tends to break down in the form of a cone or diagonally. As can be seen in Figure 5, the specimen with 50% water replaced maintained the normal behavior for concrete, breaking diagonally in the transition zone.

When the internal macro-structure of the fractured concrete is analyzed, it is possible to identify that there was a rupture in the transition zone between the aggregate and the matrix. This behavior is explained by the high

water/cement factor used.

Other tests, such as the water's pH and chemical composition, should be performed on the concrete to analyze its behavior and check if there has been any effect of any chemicals that were used in the washing of trucks. This can cause harmful reactions to the concrete that were not identified in this study.



Fig. 5: Fractured test specimens in the compression test with the composition with 50% of residual water.

The application of residual water in the concrete can bring environmental and economic benefits, and it can be used without harming the quality of the concrete. It is therefore estimated that a replacement of up to 50% of drinking water by water from the concrete plant could be used, reducing the volume of water extracted from the groundwater through the artesian well.

The greatest contribution of the deployment of the cleaner production project is linked to the environmental aspect with the reduction in the extraction of natural resources, since from a financial point of view, obtaining water through the artesian well represents negligible costs for the company.

A medium-term action would be linked to the employment of the solid waste in the production of the concrete. Knowing that the daily production of solid waste is approximately 5 cubic meters, this material could be classified according to granulometry and once again used as aggregate, according to its characteristics.

In view of the different applications of concrete, it is necessary for the company to develop an appropriate procedure for the collection and storage of water and also to evaluate the dosages for the achievement of the best performance of the concrete.

In the long term, two opportunities for intervention were identified. In a first analysis, the deployment of a water quality control system is recommended in order to make it similar to the water from the artesian well. This process can be accomplished through the deployment of filter systems that are capable of retaining the particles in suspension.

The chemical characteristics of the water in question

should also be analyzed to avoid the presence of harmful agents or those that can modify the properties of the concrete. This measure will require technological and financial investments, contributing to the validation of the initial proposal.

The second opportunity in the long term is linked to the possibility of exploiting the percentages of concrete that return from works inside the mixers. This occurs because of the excess volume of concrete with respect to the request by the customer.

Often, the volume requested ends up being higher than what is actually used in the concreting. This excess material returns to the concrete plant still with the capacity of being applied. To avoid it being disposed in landfills or other types of inappropriate disposal, this material should therefore be given a more noble purpose.

To take advantage of this opportunity, equipment could be purchased for the manufacture of concrete artifacts, adding commercial value and contributing even more with the reduction of environmental impacts. In addition, this proposal would lead to the reduction of solid and liquid waste already at the beginning of the process, since the remaining concrete returning from works inside the mixer is washed, transformed into a compound volume of waste and deposited in the decanters. Otherwise, these materials wouldn't even be included in the waste decantation and filtration cycle.

However, the possibility of adopting this last measure would impact the previously proposed actions, both in the short and medium term, considerably reducing the opportunities for exploiting the solid waste as aggregates and also the water for use in the production of machined concrete.

VI. MONITORING AND EVALUATION

To put the cleaner production proposal into practice, it is necessary to implement a plan to monitor and evaluate the actions so as to maintain the improvement of the program. Fundamental steps for the proper functioning of the project will include: monitoring the collection of wash water, preventing the entry of contaminants; studying dosages for the optimization of the concrete's strength; continuously evaluating the concrete produced through this method; and assessing the purpose of the application of the concrete.

VII. IDENTIFICATION OF BARRIERS

There are factors that interfere with the possibility of deploying the technique described in this project, because chemical products are used in the washing of the mixer trucks and this can cause abnormalities in the concrete if this water is applied. In addition, other impurities can be harmful, such as oils and greases from the truck.

Since there is no treatment of this water to ensure its quality, this leaves some doubts as to the reactions that these chemicals can cause in the concrete. The company will therefore restrict itself in the deployment of this cleaner production technique, given that any abnormality generated in the concrete can be detrimental to the progress of a work and disqualify the product of the concrete plant.

VIII. CONCLUDING REMARKS

When dealing with civil construction, it is essential to develop new techniques and to improve already existing ones, since this segment causes significant impacts to the environment, more than any other.

The greatest contribution of the deployment of the cleaner production project is linked to replacing the drinking water by the residual water in the production of concrete, bringing major environmental and social benefits, reducing the consumption of drinking water and decreasing the amount of waste disposed of inappropriately in nature or in landfills.

According to the Tukey test performed on the samples at 14 days of curing, there was a statistical significance between the 50% composition and the reference composition, as well as between the 100% and 50% composition, showing that replacing 50% of residual water in the mix yielded the best compression strength results in relation to the reference composition and the composition with 100% of residual water. At 28 days of curing, on the other hand, no statistically significant difference was found for any of the comparisons because of the chemical reactions in the concrete's curing process. It is estimated that a replacement of up to 50% of drinking water by water from the concrete plant should be used, since the composition containing 50% of residual water showed the greatest gains in strength in relation to the other compositions.

Based on the results, the conclusion can be drawn that the residual water from the washing can be applied in concrete production, since they showed that the concrete containing the residual water achieves the same compression strength when compared to the experiment that used only drinking water.

As a continuation of this research, it is suggested that the effects of any chemicals used in the washing of concrete mixer trucks on the concrete's behavior are analyzed, since these may cause pathologies in the concrete.

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