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Water Conscious Blue Jeans Washing Process: A Case Study of Turkey

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ABSTRACT

Washed denim garments represent a popular field of fashion design and environmental effects of denim washing are being increasingly explored since the process has adverse impacts on the environment due to its chemical discharge and other pollutant emissions that affect water supplies. As being one of the biggest suppliers of denim apparel manufacturing worldwide, Turkey has also faced problems of high water consumption and pollution. To reveal the pressure on the environment caused by the denim washing sub-sector in particular, the water related environmental negative impacts in the industry need to not only be quantified, but also reduced. Accordingly, the study was conducted to develop a sustainable washing process for blue jeans for a medium scaled, commercial denim apparel washing plant. The results showed that the sustainable washing approach displayed superior performance with 36% lower grey water footprint (GWF), lower environmental impact in all categories, 28% lower overall energy demand, 50% lower natural gas and 36% lower direct water resource consumption with similar garment quality and washing effect attained.

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Blue Jean, denim washing, sustainability, water footprint, environmental impact

1. INTRODUCTION

The fashion industry has adverse environmental impacts due to CO_2 emissions, water and chemical consumptions during fibre, yarn and textile production and, distribution and consumption of clothing. Majority of global water usage in the textile sector is associated with cotton cultivation and the wet processes of textile manufacturing. Such processes not only consume but also pollute water resources [1].

Denim, a warp-faced twill fabric which is conventionally produced from indigo-dyed warp and undyed weft cotton yarns, has long become a fashionable representation of the wearers from all ages and still keeps its popularity. Being a popular field of fashion design, intensive effort is spent for developing new concepts and an enhanced trendy look is given to denim garments by washing processes. Besides attaining a fashionable look to denim goods, washing also improves their softness and conformability [2-4]. However, adverse environmental impacts of such processes have led to an increased concern in measuring and reducing environmental burdens.

Basic processing steps for finishing sequence of denim goods are desizing, rinsing, washing (abrasion), rinsing, softening, drying and packing [5]. In order to meet the needs of current denim fashion trends, there are numerous mechanical and/or chemical denim washing techniques used. Each washing technique has its own advantages, but also contains disadvantages and limitations. Stone washing, acid washing, enzyme washing and bleach washing are four of the conventionally used denim washing processes. In order to lessen the effects of these traditional washing processes on the environment and to make sustainable practices possible, studies on developing substitutes for toxic chemicals and inventing resource-saving technologies keep going. Accordingly, recent technologies in denim washing such as biobleaching, use

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of potassium permanganate alternatives, ozone washing, nanobubble e-flow technology, water jet fading, laser technology, plasma treatment, dry ice blasting were developed [6-8].

Water footprint is a way of assessing potential environmental impacts related to water. It is considered as a part of life cycle assessment by which water consumption and water degradation due to the production processes are measured [9]. Direct and indirect water usage calculations are based on green, blue and grey footprints [10, 11]. The green water is the rain water contained in plants and in the root zone of the soil and the green water footprint refers to the rain water volume consumed during the production process. Blue water is sourced from surface or ground water resources and is not returned to the reservoir from which it is drawn or returned to another resource, or returned at a different time. The grey water is defined as the amount of fresh water that is required to assimilate the load of pollutants to meet specific water quality standards. The grey water footprint of a product is an indicator of fresh water pollution that is related with the production of a product over its full supply chain. Life cycle assessment (LCA) is a useful scientific and standardized tool used to analyze environmental impacts, including water footprint, related with life cycle stages, from cradle to grave, throughout the lifetime of products and services. Methodology of the tool allows identifying hot spots throughout the life cycle and helps decision making by enabling the development of processes [12]. According to such a lifecycle assessment study conducted by LS&Co., it was reported that 3,781 liters of water is consumed through the lifecycle of one pair of medium stone washed jeans [13,14]. According to the results of another project conducted to measure the water consumption over the entire lifecycle of a pair of jeans in Brazil, consumption of water to produce a pair of jeans was reported to be 5,196 liters. In the project the components of water consumed was also analysed as given in Table 1 [15].

Being aware of the fact that water scarcity is one of the world's greatest challenges, brands and denim manufacturers aimed to use less water in the finishing stage in order to reduce the environmental impacts. Water<Less® technique from Levi's®, the Conservablue technology from Kipas Denim, Zero Water Blue concept from Soorty Enterprises, D-Clear Technology from Çalık Denim, Springfield's H2Ø denim line, are some of those techniques launched [16-19]. Also, there are ongoing affords spent to determine the environmental burden of denim production and processing by employing water footprint and life cycle assessment approaches in the academia, though these are still in scarcity. In a study by Chico et.al [20], results of water footprint (WF) assessment of jeans from cotton and Lyocell fibres and five corresponding production methods for spinning, dyeing and weaving were reported. The results indicated that the fibre production has the highest water consumption, cotton production being particularly relevant. Vos [21] conducted a WF assessment on a pair of blue jeans, with spatial variation in scarcity taken into consideration. The results showed that raw materials (64%) and consumer washing (32%) were significantly influencial on the blue WF, and compared with the study of Levi Strauss & Co. [13] that was not spatially explicit, it demonstrated less water in fabric mills and more in industrial laundries. Zhao et al. [22] evaluated the virtual carbon and water flows embodied in the global denim product trade using the footprint methods, indicating that the highest carbon emissions and water consumption were denim fabric production and cotton fiber production, respectively. An investigation on the environmental impacts as well as cost and quality of denim products from mechanically recycled and virgin cotton was conducted by Fidan et al. [23]. In the study, eight scenarios using an integrated sustainability assessment approach were identified by using combined heat and power (CHP) plant instead of grid energy. Life cycle assessment approach (LCA) was used for analyzing environmental impacts and according to the results obtained, replacing virgin cotton fibers with recycled one had lower environmental impacts. Finally, the sustainability of an alternative indigo rope dyeing and an existing dying process were evaluated in terms of their environmental and social impacts using the gate-to-gate life cycle assessment (LCA) and social life cycle assessment (S-LCA) approaches. Economic and product quality dimensions were also considered. The results showed that with reduced use of water, chemicals and dyes, denim washing can be transformed to an environmentally friendly process by substituting the chemicals and dyestuff with green alternatives [24].

Table 1. Components of water consumed during the entire lifecycle of a pair of jeans [15].

Process vs Footprint of Water Components	**Green water (liters/pair)**	**Blue water (liters/pair)**	**Grey water (liters/pair)**	**TOTAL (liters/pair)**
Cotton	2108	106	2033	4247
Weaving	-	5	122	127
Manufacturing and - washing		10	352	362
Consumer	-	460	-	460
GRAND TOTAL				5196

As being one of the biggest suppliers of denim apparel manufacturing worldwide, Turkey has faced problems of high water consumption. To reveal the pressure on the environment caused by the denim washing sub-sector in particular, the water related environmental negative impacts in the industry need to not only be quantified, but also reduced. However, the literature survey revealed that there are very limited research, including the national studies, focusing on life cycle assessment based water footprint analysis of denim products. Accordingly, the study under discussion was conducted to develop a sustainable washing process for blue jeans for a medium scaled, commercial denim apparel washing plant in Turkey. In doing so, the Water Footprint methodology defined in ISO 14046 was used as the assessment tool for the comparative study of the developed washing process with the conventional one.

2. MATERIAL AND METHOD

2.1 Material

Blue jeans from 100% cotton, 2/1 twill woven fabric with 340 g/m^2 weight, corresponding to 550 grams for each pair of jeans, were used for the study.

2.2 Method

The raw and washed samples were conditioned (65% RH, 20°C) for 24 hours before testing and then were tested for some of their properties such as weight (ISO 3801), tensile strength (ISO 13934-2), tear strength (ISO 13937-1), seam slippage (ISO13936-1), washing fastness (ISO105-C06), water fastness (ISO 105-E01), APEO (Alkylphenol ethoxylates) (Textile: ISO 18254-1 / Leather: ISO 18218-1) and, heavy metal contents (BS EN 16711-2).

The garments were washed both in accordance with a conventional recipe (as adopted from a commercial denim washing plant) and with a sustainable recipe developed and applied under the commercial conditions in the same plant for the study. 75 pieces of jeans were washed by each of the processes. The basic steps and chemicals involved in both of the processes are given in Table 2 and 3, respectively.

In Table 4, on the other hand, comparison of both of the processes in terms of water, energy, chemicals and time consumptions for 75 denim jeans are presented.

Table 2. Steps in the conventional and developed processes.

Conventional Process	Developed Process
1.Whiskering	1.Laser treatment for achieving “Whiskering + Emerizing + Potassium permanganate (PP) spraying” effect
2.Emerizing	2.Pre-washing
3.Pre-washing	3.Stoneless enzyme washing
4.Stone washing	4-5.Two stage rinsing
5-6.Two stage rinsing	6.Bleaching with an organic bleacher
7.Hypochloride washing	7.Rinsing
8.Peroxide rinsing	8.Neutralization
9-10.Two stage rinsing	9.Rinsing
11.Centrifuging	10.Washing
12.Drying	11.Rinsing
13.Potassium Permanganate (PP) spraying	12. Washing with acidic dispersant
14.Neutralization	13.Rinsing
15.Rinsing	14.Softening
16. Washing	15.Centrifuging
17.Rinsing	16.Drying
18.Washing with acidic dispersant	-
19.Rinsing	-
20.Softening	-
21.Centrifuging	-
22.Drying	-

Table 3. Chemicals involved in conventional and developed processes.

Chemical Auxiliaries Consumed (g)	Conventional	Developed
Dispersant	2500	2500
Stone enzyme	200	200
Hypocloride	16500	0
Hydrogen Peroxide	3500	1500
Potassium Permanganate (PP)	8,3	0
Permanganate activator	8,3	0
Sulfide	500	1000
Citric acid	1500	1500
Softener	3000	3000
Organic bleacher	0	4000
Soap	500	500
TOTAL	28217	14200

Table 4. Comparison of chemical auxiliaries' consumption for the conventional and developed processes.

	Conventional	Developed
Total water consumption (l)	5300	3370
Total energy consumption (kW)	43,4	58,4
Total chemical consumption (g)	28217	14200
Time for manual treatment (for dry processes - min)	61,5	0
Machine operation duration for dry and wet processes (min)	331	350
Stone amount used (kg)	75	5

In the study, the conventional and sustainable washing processes were compared in accordance with ISO 14046 and ISO 14040/44 standards for water footprint analysis and life cycle assessment (LCA), respectively. The evaluation was made for a pair of jeans, and the system limits were determined as "gate-to-gate" of the washing facility. For water footprint calculations, the "The Water Footprint Assessment Manual: Setting the Global Standard" guide was also used as a source [25]. For LCA, environmental impacts were evaluated in accordance with CML IA Baseline Method, energy consumption calculations were based on Cumulative Energy Demand methodology. The CML-IA baseline is an LCA methodology which is developed by the CML (Center of Environmental Science) of Leiden University, Netherlands. The method provides a list of impact assessment of obligatory impact categories mostly used in LCA. Finally, SimaPro software was used for LCA studies whereas EcoInvent 3.6 database was utilized for modelling electricity, natural gas and chemical consumptions [26,27].

For performing LCA studies, the primary data involved the calculated and measured data for the 75 pairs of jeans during each washing process. The secondary data, on the other hand, came from the most common life cycle inventory (LCI) database Ecoinvent that is embedded into the software and involved the impacts of emissions originating from the supply chain such as the production stages of the chemicals used for washing, electricity and natural gas comsumptions. No environmental impact allocation procedure was applied since neither the conventional nor the proposed washing processes produced any side products.

3. RESULTS AND DISCUSSION

With reference to Tables 2 to 4, the following results can be given:

1. The proposed sustainable washing process has lower number of processing steps with about 6% longer machine operation time. No manual treatment is needed for the process.
2. The amount of water consumed is 36% less than that of the conventional washing process.
3. No hypoclorite, potassium permanganate and permanganate activator were used in the sustainable washing process proposed. Instead, an organic bleaching agent was employed.
4. The stone amount used for the conventional process is 93% higher than that of the developed one.
5. The conventional process has almost twice as much chemical auxiliary consumption than the proposed one.
6. The developed process has higher energy consumption (about 34%).

3.1 Comparison of the conventional and sustainable washing processes

3.1.1. Comparison in terms of water footprint

The analysis on the water footprint of two denim washing processes showed that the water amount consumed very much depended on the specific denim look required.

Green water footprint was not considered in the study since no rainwater was consumed for the washing processes. Blue water consumed, which refers to the amount of water utilized during the washing processes in liters, was 36% lower for the proposed method. As an indicator of pollution, the grey water footprint (GWF) was calculated using the formulae given by [25, 28].

$$GWF = \frac{L}{\text{cmax - cnat}} \; [volume/time] \tag{1}$$

In Equation (1), L is the pollutant load entering a water body (L, in mass/time), cmax is the maximum acceptable concentration in mass/volume refering to the ambient water quality standard of the pollutant and, cnat is the natural background concentration in the receiving water body in mass/volume.

In order to compare the two processes in terms of wastewater pollution, the grey water footprint calculations were made using the values obtained both at the end of the relevant washing process and at the exit of the water treatment facility (Figure 1).

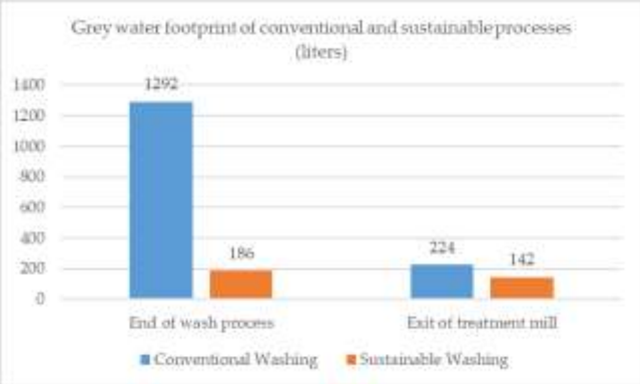

Figure 1. Grey water footprint of the conventional and sustainable processes

For one pair of jeans, the conventional washing process consumed 71 liters of blue water having pollutant loads, and the amount of water needed to raise the process effluent water to a quality that will not burden the discharge medium, i.e. the grey water footprint, was 1292 liters. In the case of the developed sustainable washing, the blue water footprint corresponded to 45 liters and the grey water footprint was 186 liters, representing an improvement of 86%, when compared to the conventional one. The polluted water was discharged to a wastewater treatment plant at the end of each washing process so that the pollution level was reduced to a certain discharge standard as required by the Turkish Water Pollution Control Regulation [29]. In accordance with the specifications in the Regulation, the grey water footprint of water leaving the water treatment plant was calculated as 224 liters and 142 liters for the conventional and sustainable processes, respectively. The calculated values revealed an improvement of approximately 36% (in parallel with the consumption of blue water) for the sustainable washing process in terms of GWF at the exit of the water treatment facility.

As may also be seen from Figure 1, the water treatment facility reduced the pollution burden of waste water produced by the conventional process as much as six (6) times. Although the contamination load of the effluent water at the end of the sustainable washing process is much lower, the level of water contamination loads resulting from both of the processes approached to each other after the water treatment, which means that a lower treatment load is imposed onto the mill.

As a final note, the water stress, which refers to the impact of high water use relative to water availability [30], of the sustainable washing process was 33% lower than that of the conventional one.

3.1.2. Comparison of resource consumption

The comparative study of the resource consumption was based on the data obtained from both of the washing processes performed in the denim washing plant. And the results are given in terms of percentages (%) in the figure in order to eliminate unit differences of the impact categories (Figure 2).

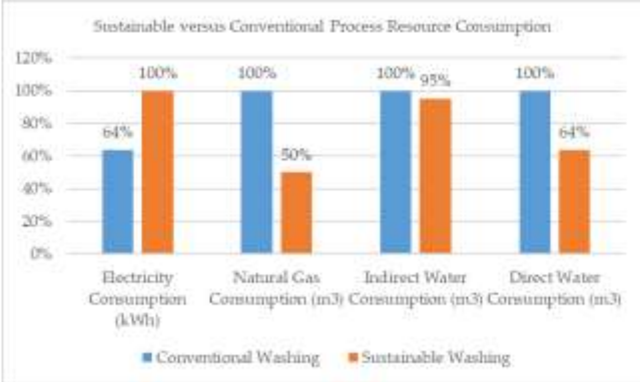

Figure 2. Resource consumption of the conventional and sustainable processes

As may seen from Figure 2, the highest natural gas and “direct and indirect water consumption” was related to the conventional process. However, the electricity consumption of the sustainable process is higher by 46%. It appears that the significant decrease in water and natural gas consumption through the developed process was compromised by the high electricity consumption.

3.1.3. Comparison of the environmental ımpact categories

Figure 3 demonstrates that the overall environmental impact of the sustainable process developed is lower than that of the conventional one.

The results of the life cycle assessment (LCA) calculations in Figure 3 revealed that the global warming potential decreased by 35% when the jeans were washed by the sustainable process. The highest energy demand of the conventional washing (section 3.1.4) as well as the presence of sodium hypochlorite in the process are mainly responsible for higher GWP of the conventional process.

The impact on depletion of both natural and fossil fuel resources decreased by 51% and 28%, respectively when the sustainable washing process was employed. This is due to the absence of sodium hypochlorite in the alternative process. In the conventional washing, 54,7% of this effect comes from the production stage of sodium hypochlorite. Increased natural gas consumption of the conventional process also contributed to this impact category.

The ozone depletion impact of the sustainable washing process dropped as much as 79% (Figure 3). The contribution of the production phase of sodium hypochlorite used in the conventional process to this category was 75%.

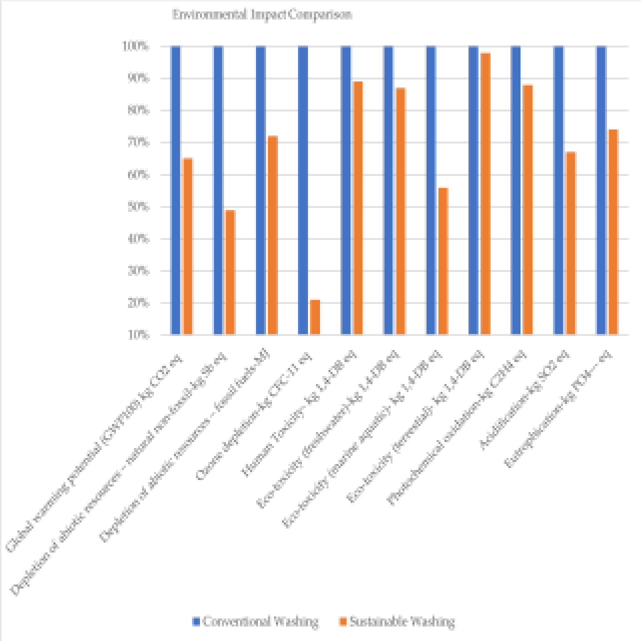

Figure 3. Environmental impact comparison of the processes

The production phase of the chemicals and electricity consumption are also influencial parameters for fresh water, marine aquatic and terrestial ecotoxicity. In terms of this impact category, the least improvement occurred in terrestial ecotoxicity (2%) for the alternative washing process developed. This might be due to the use of the same amount of dispersing agent and softener in both of the processes. Generally speaking, these chemicals are highly responsible for the environmental impact, and the biggest contribution (90%) to this category comes from their production phases. For the human toxicity and photochemical oxidation impacts, the production phases of the chemicals such as dispersing agent, softener and sodium hypochlorite are responsible. Supply of electricity energy also has a significant impact on photochemical oxidation.

For both of the washing processes, the environmental impacts in terms of acidification and eutrophication originated from similar sources, but the lack of sodium hypoclorite in the sustainable washing process resulted in a drop for acidification (33%) and eutrophication (26%).

According to the given results of LCA, the use of sodium hypochlorite appears to be of particular importance for all of the impact categories examined. From a holistic point of view, it is evident that the proposed denim washing process is environmentally advantageous compared with the conventional one.

3.1.4. Comparison of energy demand

Characterization factors for the energy resources are divided into the following impact categories [27].

1. Non renewable, fossil
2. Non renewable, nuclear
3. Non renewable, biomass
4. Renewable, biomass
5. Renewable, wind, solar, geothermal
6. Renewable, water

In Figure 4, the energy demand comparison for the processes is presented.

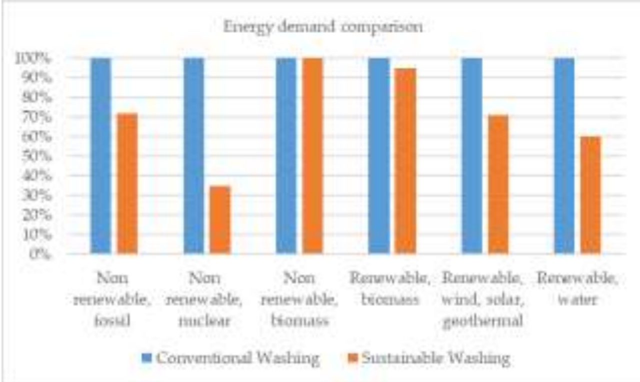

Figure 4. Energy demand comparison

Energy footprint is an important parameter that should be evaluated together with carbon emissions. Total amount of the energy consumed, together with the determination of the sources it is obtained, is a valuable guide for establishing the potential gains. For the sustainable washing process, the overall energy demand decreased by 28%. In Table 5, on the other hand, it can be seen that 79% of the energy consumed by both of the washing processes comes from non-renewable, fossil fuels. The minor differences observed in the energy demand between the conventional and sustainable washing processes might be attributed to the energy consumed during the production stage of the raw materials used. In other words, the differences may have resulted from the indirect effects coming from the supply chain.

3.2. Quality assessment of the washed blue jeans

The washed samples were tested for some of their physical and color fastness properties. Furthermore, the washing effect attained for each pair of blue jeans was also compared visually with the help of a focus group since it is indispensable for a trendy look in jeans (Figure 5). Table 6 shows the results for the unwashed and washed samples.

Finally, no azo dyes, heavy metal particles and alkylphenols/alkylphenol ethoxylates (APEO) were detected on the samples under consideration. Accordingly, it may be concluded that the sustainable approach developed for denim washing yielded not only acceptable jeans quality characteristics but also an agreeable washing effect, similar to those provided by the conventional process.

CONCLUSION

Creating a lucrative denim outlook via traditional washing processes arises sustainability concerns since these washing methods host enormous health and environmental risks. New denim washing approaches that can provide sustainable solutions are being sought for in order to support the environment and consumer. In that respect, this work focused on transforming a conventional denim washing process to a water conscious one. Regarding that, the process was redesigned by replacing harmful chemicals with an organic one, and by shortening the wash process route. Some important findings of the study are as follows:

- Grey water footprint of the sustainable process was lower than that of the conventional one at the end of the washing process and at the exit of the water treatment mill.
- So far as the the environmental impact was concerned the proposed washing process has a lower impact in all selected categories than the conventional one. Energy demand of the new process was also lower for all categories.
- The electricity consumption of the developed method was higher whereas the conventional process gave the highest natural gas and "direct and indirect water consumption".

Table 5. Energy taxonomy for the total consumed energy

	Conventional process (%)	Sustainable process (%)
Non renewable, fossil	79	79
Non renewable, nuclear	6	3
Non renewable, biomass	1	1
Renewable, biomass	10	13
Renewable, wind, solar, geothermal	1	1
Renewable, water	3	3

Conventionally washed pair   Sustainably washed pair   Conventionally washed pair   Sustainably washed pair

Figure 5. Blue Jean samples washed with the conventional and the sustainable process

Table 6. Properties of the Unwashed and washed samples.

	Unwashed samples	Washed (conventional)	Samples washed samples (sustainable)
Weight (g/m^2)	339.6	335.9	336.3
Tensile strength (Warp/**Weft**- kgf)	55.01/**29.70**	44.94/**29.57**	55.73/**33.48**
Seam slippage -Seam opening 6mm (Warp/**Weft**- kgf)	19.08/>**20.39**	19.71/>**20.39**	20.39/>**20.39**
Wash fastness- Colour change	4	4	4
Water fastness- Colour change	4/5	4/5	4/5
Rubbing fastness -dry	Front: 2/3 Back: 3	Front: 4 Back: 4	Front: 4/5 Back: 3

And thereby it may be concluded that the sustainable washing approach displayed superior performance in terms of water footprint, environmental impact, energy demand, natural gas and water resource consumption with similar garment quality and washing effect attained. Also, it is believed that the study offers an insight for denim producers and researchers for developing further sustainable denim washing solutions.

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