To: Dr. Dianne McDonnell: PE, PhD

From: Ahmed Alnashwan, Mohammed Alsahali, Kalani De Silva, and Fan Yu-Environmental Engineering Students, CENE 476-Spring 2018

Date: May 9th, 2018

Re: CENE 476-Project Proposal- Conditioning Water Using Template Assisted Crystallization to Prevent Scaling in Boilers

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Dear Dr. McDonnell,

Attached for your review is the project proposal on the topic of Conditioning Water Using Template Assisted Crystallization to Prevent Scaling in Boilers. This memo will provide information on the project understanding, QA/QC, experimental design, scope of work, staffing, scheduling and costing for the entire project. For more information please contact:

- Ahmed Alnashwan: asa267@nau.edu
- Mohammed Alsahali: maa538@nau.edu
- KalaniDe Silva: kd724@nau.edu
- Fan Yu: fy55@nau.edu

Thank you for your time!

NORTHERN ARIZONA UNIVERSITY

Research Plan on Conditioning Water Using Template Assisted Crystallization to Prevent Scaling in Boilers

A. Alnashwan, M. Alsahali, K. De Silva,F. Yu

Northern Arizona University

CENE 476C-Project Proposal

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1.0 Introduction:

1.1Research goal and objectives:

The TAC capstone team will test whether or not Template Assisted Crystallization (TAC) prevent scaling under boiler operating conditions similar to the NAU South boiler plant. The chiller and boiler plant at NAU currently use an ion exchange to soften their water. The team was tasked with testing the ability of an alternative method that could replace the current system.

1.2Stakeholders:

Ellen Vaughn, the manager of the NAU office of sustainability, requested the capstone team to evaluate alternative technologies capable of replacing the ion exchange technology; Ms. Vaughn will act as the client. Dr. Terry Baxter, professor at the Northern Arizona University Department of Civil and Environmental Engineering (NAU-CENE) and Mr. Adam Bringhurst the manager of the environmental labs will provide technical assistance to the TAC Capstone Team.

2.0 Background Research:

2.1 Scaling in plumbing and fixtures:

Hard water scaling of plumbing fixtures occur in the presence of calcium and magnesiumions dissolved in water. These ions form precipitates as calcium carbonate. Water heater elements and heat exchangers are more susceptible to scale build-up, that because of the high temperatures increase the precipitation rates.

This is due to the role that carbon dioxide (CO_2) plays in calcium carbonate formation. In the overall reaction, carbon dioxide falls on the same side of the equation as calcium carbonate. As the temperature increases, the solubility of the carbon dioxide decreases, and the gas leaves the system,resulting in the overall reaction to "go to the right" and produce more calcium carbonate [1&2].

Equation 1: Reaction 01 [2]

$$\boldsymbol{HCO_3^-}(\text{aq}) \leftrightarrow \boldsymbol{OH^-}(\text{aq}) + \boldsymbol{CO_2}(\text{aq})$$

Equation 2: Reaction 02 [2]

$$\boldsymbol{OH^-}(\text{aq}) + \boldsymbol{HCO_3^-(aq)} \leftrightarrow \boldsymbol{CO_3^{2-}}(\text{aq}) + \boldsymbol{H_2O}$$

Equation 3: Reaction 03 [2]

$$\boldsymbol{Ca^{2+}}(\text{aq}) + \boldsymbol{CO_3^{2-}}(\text{aq}) \leftrightarrow \boldsymbol{CaCO_3}(\text{s})$$

Equation 4: Overall reaction [2]

$$\text{Ca}^{2+}(\text{aq}) + 2\text{HCO}_3^-(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + \text{H}_2\text{O} + \text{CO}_2(\text{aq})$$

The final product of this reaction, $CaCO_3$, tends to attach itself onto surfaces due to the electrostatic attraction between the particles and the surface of the heating or pipe element. Once attached to a surface, these particles can act as a nucleation point for more particles to attach. Nucleation is the initial process that occurs in the formation of a crystal from a liquid, or a vapor, in which number of ions, atoms, or molecules become arranged in a pattern characteristic of a crystalline solid [2].

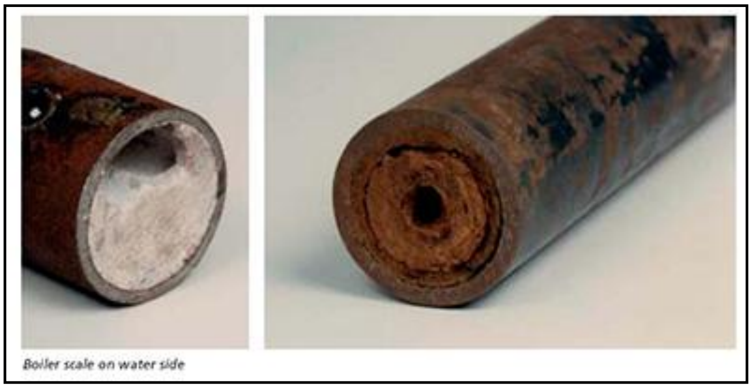

Figure 1: Scaling on pipes [2]

Scaling interferes with heat transfers and may cause hot spots, leading to local overheating. If unchecked, scaling causes progressive lowering of the boiler efficiency by heat retardation, acting as an insulator. Eventually, scale build-up will cause the tube to overheat and rupture. In general, boiler deposits can cut operating efficiency, produce boiler damage, create unscheduled boiler outages, and increase [1&2]

2.2 Alternative Water Softeners:

Ion exchange resin is a common softener which uses ion exchange technology to remove the calcium and magnesium ions in the water. Cation exchange resins can generally retain good efficiency for 5 to 10 years (7 years average), and anion exchange resins for 3 to 5 years (4 years average). However, the efficiency of the resin decreases each year and the cost of the resin has increased over recent years. The raw water supply into the devices has restrictions, the water intake should contain less than 5 ppm turbidity and 0.5 ppm hydrogen sulfide. Additionally, the levels of iron and manganese must be in the dissolved form [5].

Electrically Induced Precipitation method employs the use of currents in the formation of soft precipitates on electrodes. The process needs energy of up to 100W and the length of time that it can be used is limited due to the dangers associated with the use of DC energy. This method requires the use of backwash water which pushes the water backwards into the filters like a cycle to prevent maintenance. It is then reused it again for the cleaning of the electrodes, which needs to be handled manually [6].

Capacitive Deionization method absorbs ions from the water onto its electrodes. The ions are attached to the electrodes due to the charge difference, and then released when the electrodes are washed with salt water [6].

Electromagnetic Treatment method uses magnetic fields created by wires wrapped around a pipe. This process creates a soft precipitate by altering the ions. This particular soft precipitate prevents scale from forming on pipes and other appliances [6].

2.3 Template Assisted Crystallization

Template Assisted crystallization technology induces the formation of microscopic calcium and magnesium crystals, which potentially isolate hardness from the water chemistry.

Typical TAC hard water conditioners use a highly specialized media consisting of polymeric beads. These beads provide a preferable nucleation point for the formation of micro-crystals of $CaCO_3$ from the accumulation of Ca^{2+}, Mg^{2+}, and HCO_3^{2-} ions. The crystals grow on the bead until they reach a particular size and then break off. These microscopic crystals are stable and remain suspended in the water flow instead of forming hard mineral scale on the surfaces in your plumbing system [3].

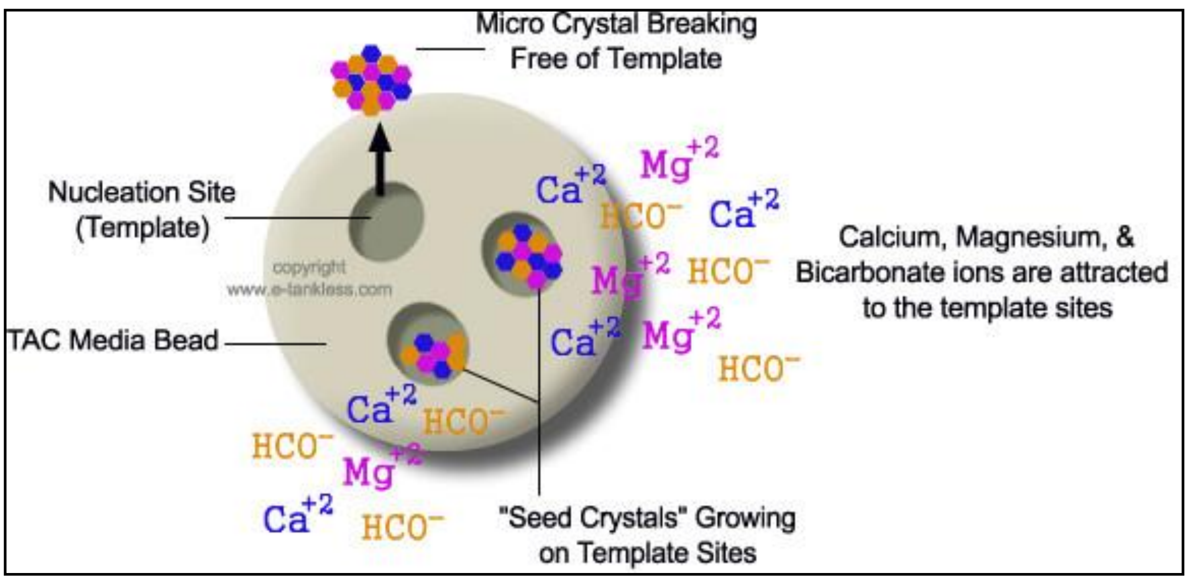

Figure 2: Example of the formation of non-reactive crystals on a nucleation site, How Template Assisted Crystallization (TAC) Filters Work [3]

Several companies manufacture TAC water conditions with proprietary beads that they claim will remove and even eliminate scaling under different conditions (Table 1).

Table 1: Comparison between different TAC technologies [4]

Technology	OneFlow	Next (Scales top)	Pelican Water Systems
Water Pressure	15-100 psi	90 psi	25-80 PSI
Hardness	25 grains	75 grains	75 grains
PH	6.5-8.5	6.5-8.5	7 - 11
Temperature	40 to 110 F	41 to 110 F	36-120 F

2.4Comparison between TAC and other alternatives:

A research project was performed by a team at Arizona State University and engineers from HDR Engineering, Inc. to identify credible alternatives to ion exchange water softeners that would provide consumers with the ability to reduce the impacts of hard water without creating negative salinity impacts on reclaimed water. The research was conducted with water samples from Salt River water, central Arizona project canal water, Scottsdale groundwater, and Santa Clara Valley water district groundwater. The samples collected were tested using five different technologies: electrically induced precipitation (EIP), magnetic water treatment (MAG), capacitive deionization (CDI), template assisted crystallization (TAC),and ion exchange (IX).The water qualities tested for each water source at the start of the testing process and the total calcium scale collected for each technology listed in the following tables [7]:

Table 2: Water Qualities Tested [7]

Parameter	TDS (mg/l)	Hardness (mg/l as CaCo3)
Salt river water (Tempe tap water)	479	180
Central Arizona Project (CAP)canal water	666	150-250
Scottsdale groundwater	1200	450-500
Santa Clara valley water district (SCVWD) groundwater	420	210

Table 3: Scale Totals (g Ca) [7]

Treatment Type	Tempe Tap water	SCVWD	CAP	Scottsdale GW
No treatment	13.36	9.97	20.0	29.75
TAC	0.48	0.33	0.65	3.2
EIP	6.72	5.56	9.84	15.4
MAG	7.56	5.28	10.23	16.7
CDI	0.56	Not tested	Not tested	Not tested
IX	0.79	Not tested	Not tested	Not tested

According to the testing and the results obtained, the research team at ASU concluded that Template assisted crystallization reduced scale formation by greater than 88 percent, and both the electromagnetic and electrically induced precipitation devices reduced scale formation by approximately 50 percent. Overall, water conditioning devices included in the study were capable of reducing scale by 46 to 99 percent, as compared to the untreated case [7]

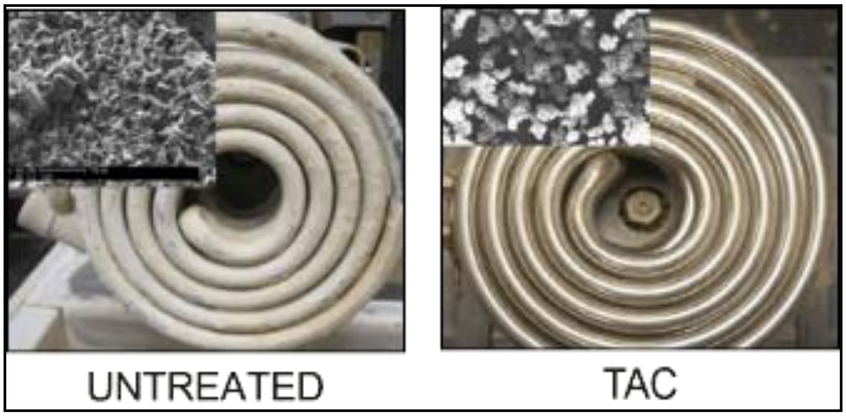

Figure 3: TAC reduced scale formation by 88% [7]

2.5 Site/Location Details:

Northern Arizona University (NAU) constructed the Central Heating Plant building in 1970 and six years later NAU changed the name of the building to Heating Plant Annex. In 2005 the University expanded the plant and added a chiller system to provide air conditioning. It also modernized the architecture by creating a glass exterior wall to allow pedestrians to view the mechanical system. In 2007, the building became the South Heating and Cooling Plant at NAU. The plant uses a system of underground tunnels to circulate hot and cold water throughout the buildings [8].

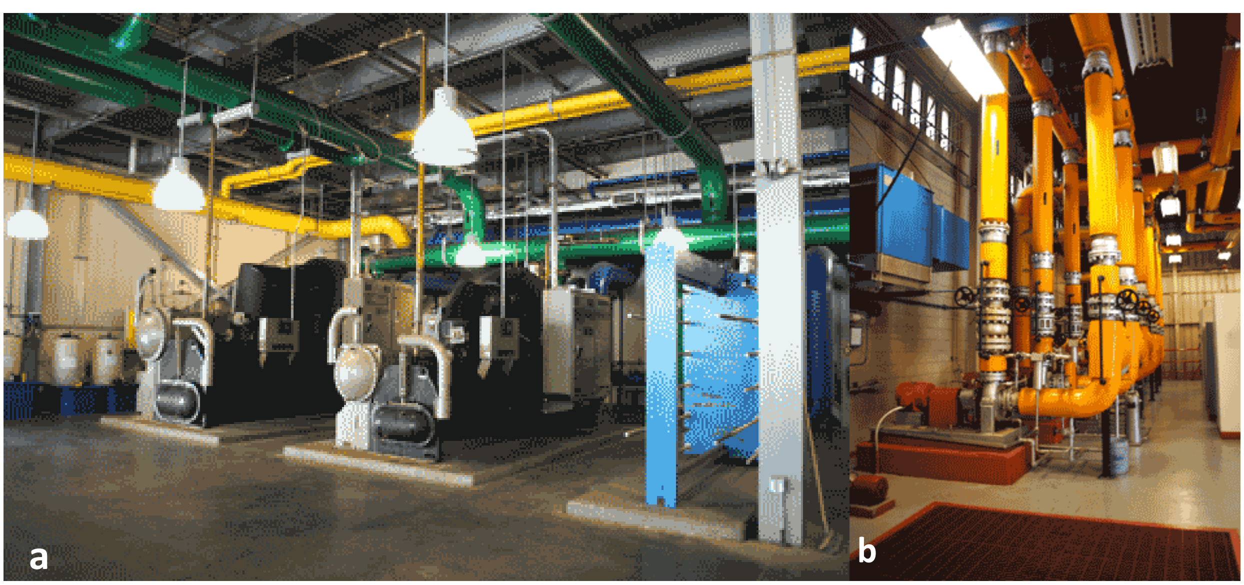

Figure 4: (a) The chillers inside the South Heating and Cooling Plant [8], (b) Part of the boiler system inside the South Heating and Cooling Plant [8]

The following table shows different properties of the water passing through components of the chiller/boiler plant as of 2018:

Table 4: Parameters of water-NAU chiller/boiler plants [9]

Timestamp	Softeners		City Water		Feed Water		
	East	West					
	Hardness	Hardness	Alkalinity	Conductivity	Alkalinity	pH	Conductivity
01-10-18	6	N/A	172	337	16	9	110
01-20-18	4	N/A	162	311	25	9.4	124
01-27-18	N/A	0	174	320	37	9.2	122
02-01-18	N/A	0	170	298	16	9.3	132
02-05-18	0	N/A	96	305	26	9.8	129

3.0 Technical Considerations

3.1 Flow rate testing

Flow rate depends on total quantity and duration of the water in the boiler and chiller. The TAC device creates a turbulent flow within its housing which allows the calcium ions to contact the proprietary blend of metals of the unit's core [11]. Thus, by combining the flowrate and the water hardness the size of the TAC unit can be determined. The followings are the alternatives that could be used to determine the flowrate in the piping system.

- Using the venturi tube on the pipes as a flowmeter.
- Ultrasonic flowmeter.
- Vortex meter

3.2 Hardness testing

The hardness determines the concentration of calcium and magnesium ions in the water. Using a titrant and an indicator the calcium hardness (concentration of $Ca2\ +$), magnesium hardness (concentration of $Mg\ 2+$) and total hardness could be determined. The standard methods used for hardness testing are as follows:

- HACH Water Analysis Handbook: Total Hardness Method 8226 [12]
- HACH Water Analysis Handbook: Calcium Hardness Method 8222 [12]

3.3 Testing performance of the unit

To determine the performance of the unit, several samples will be taken from the chiller/boiler plant input and output water sources. The collected samples will be used to test for the hardness of water, percentage of scale removal and etc. and this data will be used to determine the efficiency of the unit. Some of the methods used for this particular analysis are as follows:

- Word &Excel software used for processing the testing data and performing the results (tables, graphs)
- USGS collection of water sample method [13].

3.4 The standard methods list

The following organizations developed voluntary consensus technical standards for products, processes, services, and systems. They provide professional instructions for any experimental processes and testing during this researching period [14].

- ASTM: American Society for Testing and Materials
- ANSI: American National Standards Institute
- AWWA: American Water Works Association
- HACH Methods or other manufacturer methods
- Standard Methods: Examination of Water and Wastewater
- Government methods: EPA, routinely defer to above methods

4.0 Potential Challenges

Potential challenges for this project include:

1. Data management: The team will have to take multiple samples in order to test the feasibility of TAC on chiller/boiler plant systems. Managing data related to all the variables involved in the procedure is important as it could affect the final result of the research.The accuracy of self-reported data, without the availability of data for cross-checking, is unknown, which is a challenge in research.
2. Choosing the correct methodology: It is important to choose an efficient and plausible procedure for conducting the research. When choosing the methodology, it is important to plan it out properly while being honest with the resources, and abilities the team has.
3. Choosing the site for setting up the testing unit: It is important that the testing set up is completed with no flaw in order to obtain reliable data. A crucial fact is that the set up location is identified with minimum constraints and ease of use. The NAU chiller boiler plant is the ideal location for the set up. Contacting the utilities services and obtaining a space in the plant is a challenge the team has to overcome.

5.0 Quality Assurance and Quality Control

Quality Assurance in Research comprises all the techniques, systems and resources that are deployed to give assurance about the care and control with which research has been conducted and to ensure transparent project planning [9]. QA for the project will be used to address the following [10]:

- Defining constraints related to the apparatus design

  The main sub task under this is determining the location for the setting up of the apparatus. This allows the team to identify the flow rate tests needed to be conducted, which in return helps the team in obtaining the Fre-Flo unit. This also allows the team to pre design the apparatus set up. The two alternatives for the location considered by the team were as follows:

  1. The south chiller/boiler plant
  2. The hydraulics lab

  Due to complications of setting up the unit in the boiler and obtaining a Fre-Flo unit large enough to handle the flow of the boiler, the hydraulics lab was chosen. The boiler conditions will be simulated in the lab using the necessary equipment and methods.

- Defining sample protocols

  Identifying the appropriate water sample protocols allow the team to accurately represent the environment intended for study and can fulfill the project objectives. The two alternative sample protocols decided by the team are as follows:

  1. Standard method-USGS collection of water sample defining lab standards[13]
  2. EPA surface water sampling method [15]

  The team will acquire water samples before passing through the unit and after the heating of the water. This will allow the team to test pre and post conditions of water. Foe every test, there will be 2 samples collected, i.e. pre and post unit.

  Proper safety precautions must be observed when collecting water samples. Special care must be taken not to contaminate samples. This includes storing samples in a secure location to preclude conditions which could alter the properties of the sample. Samples must be placed into appropriate, labeled containers. All these information should be documented by the team.

- Defining lab work

  This includes identifying the equipment, material, standard methods or any other resources needed to conduct each test. This will also include communicating with Adam Bringhurst, the lab manager, in completing the request forms and chemical hygiene training required to work in a lab. This task also includes identifying the appropriate PPE for each test.

- Documentation of procedures and methods: The documentation of measurements and final results has to be organized and precise as they are a prominent section in research.

Quality control activities should be conducted throughout the course of the project. It ensures that the results are consistent with expectations. The system of technical activities includes [10]:

- Calibrated equipment: Calibration is done by conducting a comparison between a known measurement (the standard) and the measurement using the instruments the team will be using. Typically, the accuracy of the standard should be ten times the accuracy of the measuring device being tested.
- Standard methods used for all testing conducted and the standard reagents, i.e. using specific HACH method for hardness testing.
- The Calculations, estimates, etc. must be checked immediately so that errors are not perpetuated. The checker must have a similar or greater level of experience as the originator, should be a member of the project team familiar with the details of the project, and must be familiar with the type of work proposed for the project [10].
- Label every sheet with the control section, job number, if known, or project location, personal initials, and date. All assumptions and reference materials need to be provided. All materials used need to be labeled and the design manuals and instruction manuals should be used [10].

6.0 Experimental Design:

6.1 Hypothesis:

The team used the manufacturer's claims on TAC units to establish the hypothesis for this research. The manufacturers claim that the TAC conditioners do not reduce water hardness prevents scaling by forming nonreactive crystals with a scaling prevention efficiency of 96%. Thealternative hypothesis that the team came up with is that the water passing through TAC unit does not change or decreases slightly minimal to no scale formed, and for the tap water hardness decreases significantly. To verify this the team will test water quality parameters (specifically hardness) before and after passing through a high temperature. Additionally, the manufacturers claim that the TAC crystals are nonreactive and remain intact and stable over long time period after exposed to high temperature and pressure. Thus, the hypothesis is that the TAC crystals will be visible and remain for long time period. To verify the hypothesis the team will use Scanning Electron Microscopy (SEM) to observe the crystal formation and their stability.

6.2 Design Plan

The experimental design is based on a batch flow reactor. The team will test three different batches under three different detentions times, i.e. batch 1 for one hour detention test, batch 2 for three hours detention test, and batch 3 for six hours detention test. Three different batches will be run multiple times to get a range of results. Since the team is trying to simulate scaling over a long period of time in the boiler, even though the detention time in the boiler seems very short, the exposure time the boiler is longer than a 6-hour batch in the pressure cooker.

The experimental design that the team came up with is shown in the figure below. The control for the system is the tap water getting batched into the pressure cooker 1. Likewise, the tap water goes through the TAC unit then it is batched into the pressure cooker 2. Those two pressure cookers are used to simulate the conditions of the boiler at NAU north boiler plant with a temperature of 240°F and pressure of 160 PSI. The team will be taking 4 samples, i.e. before and after each pressure cooker to test for hardness of water, Alkalinity of water, pH of Water, SEM test, and finally to test the formation of scale.

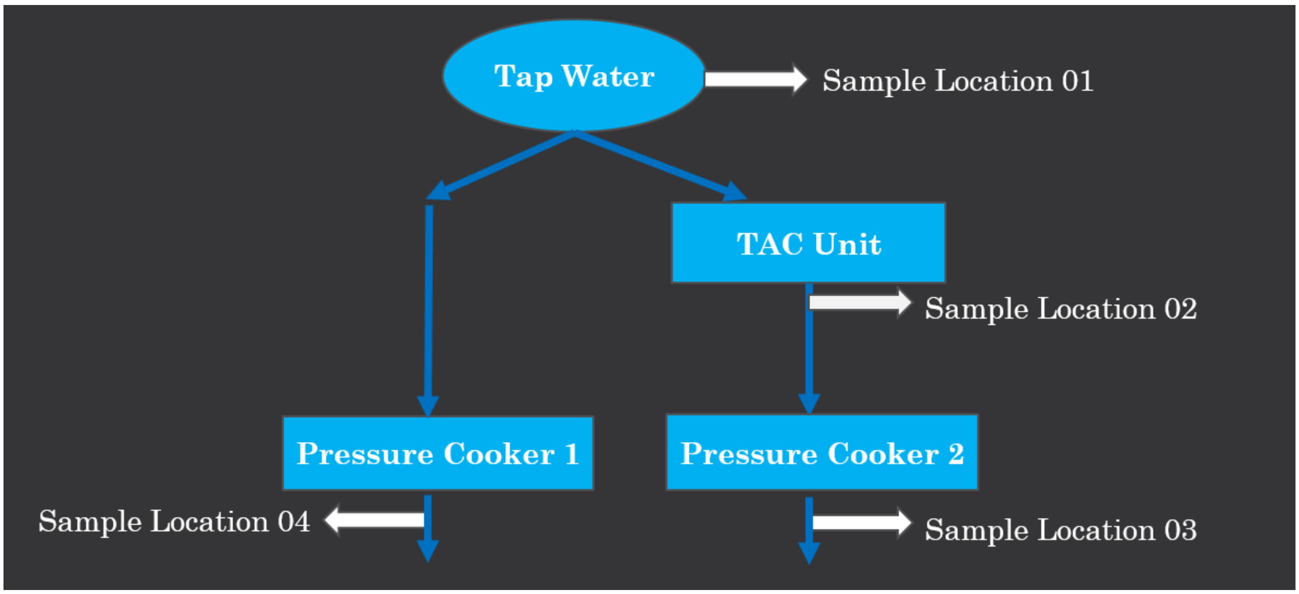

Figure 5: Experimental design set up- Flow chart

7.0 Task 01-Building the Apparatus

7.1 Identifying operating capabilities and obtaining the unit:

The flow rate test is dependent on the location of the apparatus set up. Since the testing unit or apparatus is set up in the hydraulics lab a flowmeter could be used to determine the flowrate and to ensure that the data obtained is accurate a simple volume over time test will be conducted. The following equation will be used to measure the flow:

Equation 5: Flow rate calculation

$$\text{Flowrate} = \text{Volume}/\text{Time}$$

The TAC unit depends on the flow rate of the water. Once the flow rate is determined the team will contact various companies that manufacture TAC unit, i.e.; Fre-Flo, OneFlow and ScaleNet.

7.2 Setting up the unit

Equipment and materials:

- TAC device
- Pressure cooker
- PVC Pipes
- Flow meter
- Timer (min, hours, days)

The TAC unit obtained will be used to finish up setting the apparatus in the identified location (Lab). The team will conduct batch tests using a pressure cooker. This devicewill be used to simulate the conditions of the boiler, i.e. temperature of 240°F and 160 PSI. A pipe will be connected to the water valve or tap in the identified location and the TAC unit will be connected on to the pipe. The water coming out of this pipe will be collected and batched and put into the pressure cookers as a batch and it will be run for different periods of time at a temperature and pressure similar to the boiler on campus. This entire apparatus will be on a movable station, where the apparatus or the system is mounted on. This is to make certain, that the testing equipment and material are not in the way of classes conducted in the lab and also for the ease of use for team members.

8.0 Task 02-Optimization of the apparatus

Optimization will be conducted on the control design (tap water) to ensure that scaling is formed during the selected batch times. This is because the team is still unsure whether it is possible to see scaling in a 1-hr batch, 3-hour batch, or longer. Therefore, the optimization of the design plan will be conducted before the test is run using the TAC device. During this process, the team will determine whether the batch times need to be longer or maybe shorter. If the results conclude that the batch times

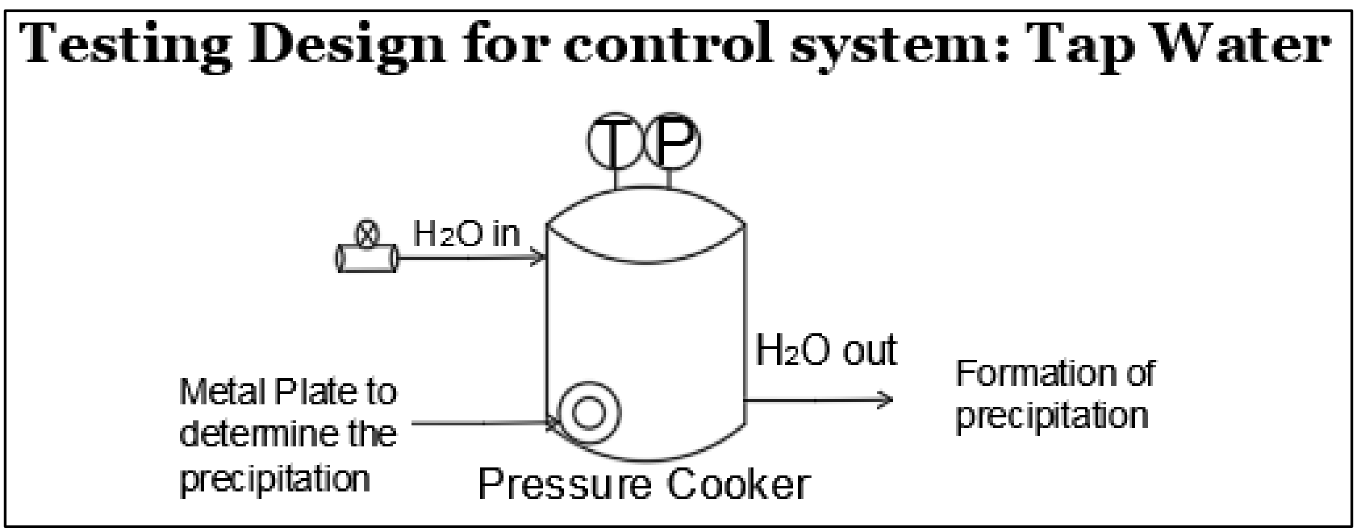

Figure 6: Experimental design control– Hard water (TAP) forms insoluble precipitates (scale) under high temperature (T) and high pressure (P)

need to be longer than 12 hours, the team will consider adding hardness to the water and running the system. The following figure shows the design set up for the optimization process:

9.0 Task 03- Water Quality Testing

After the apparatus is set up and the optimization process is completed the team will begin testing of the water.

9.1Testing the hardness of the Water

The first lab work is to test the hardness of water. The degree of hardness in the water determines the capacity and performance of the TAC system. The hardness test will be conducted on water samples collected before and after each pressure cooker.

The standard methods used for hardness testing are as follows:

3.3.1.1. HACH Water Analysis Handbook: Total Hardness Method 8226 [12]

3.3.1.2. HACH Water Analysis Handbook: Calcium Hardness Method 8222 [12]

The total hardness Lab requires ManVer color indicator, the titrant used is EDTA. The only difference for the calcium hardness is using CalVer color indicator. Once the titration isstopped and relevant data is recorded and the following calculations will be conducted:

Equation 6: Hardness

$$Hardness = Titrant\ (ml) \times Normality \times 50{,}000 mlofsample$$

Equation 7: Magnesium Hardness

$$CH = CaHardness + MgHardness.$$

Equation 8: Total Hardness

$$TotalHardness = CH + NCH$$

These values will be used to identify the degree of hardness, i.e. soft, moderately hard, hard or very hard.

9.2 Testing the Alkalinity of the Water

The secondsub task under water quality testing is the alkalinity test. Alkalinity of water is related to the existing basic salt ions in the solution. In this project, the carbonate ions that cause scaling in pipes/pumps. The standard methods used in the lab are as follows:

3.3.2.1. HACH Water Analysis Handbook: HACH method 8203 [12]

3.3.2.2. Standard Methods (SM): Alkalinity Method 8221 [12]

After all the relevant data is recorded, the alkalinity calculations will be conducted using the following equations:

Equation 9: Phenolphthalein Alkalinity

$$PALK = Titrant\ (ml) \times Normality \times 50{,}000 mlofsample$$

Equation 10: Total Alkalinity

$$TALK = Titrant\ (ml) \times Normality \times 50{,}000 mlofsample$$

Equation 11: Alkalinity

$$\text{Alkalinity-}Alk = PALK + TALK$$

9.3 Testing the pH of water

The team will be conducting a pH test on the water samples collected before and after each pressure cooker. The standard method used is ASTM D1293-18. The pH is an important parameter in the design plan as the precipitation of calcium carbonate precipitation increases with higher pH.The test determines the pH through the electrometric measurement. The lab uses glass electrode as the sensor of pH meter. The water tested should have conductivity above 5 µS/cm, and no buffer will be required for this lab.

9.4Electron Microscopy Test

The team will conduct an electron Microscopy test to analyze the crystal formed by the TAC procedure. The sample will be sent to the NAU Electron Microanalysis Core Facility located in room 104 of Wettaw Hall. This particular facility on campus uses a cameca SX-50 electron microprobe (EMP). The water samples will be filtered through a micro filter and this micro filter will be sent to the lab to be tested.

9.5Testing the Scale Formation

The final test conducted will be on the scale formation. There are no standard methods that are available for the testing of the scale formation. The team will follow following procedure to determine the scale formation: solid scale willbe removed from the heating element by scraping with a stainless steel tool, combined with any loose scale from the bath, and weighed. A 10-mg sample of the solid scale will be dissolved using hydrochloric acid (HCl) and diluted in 100-mL of deionized water. Raise the pH to approximately pH 7 using potassium hydroxide. The solution will then be tested for calcium and hardness content using the EDTA method described above and this percentage of calcium content will be applied to the total weight of scale collected. The remaining scale in the bath and on the heating element can be dissolved using a 1N HCl solution which was neutralized with potassium hydroxide and then this will be used for the measure of calcium and hardness content using the EDTA method. By summing the total mass of scale collected with the calculated mass of scale that was dissolved in acid, the total scale formed during each test can be determined [2].

10.0 Task 04: Analysis of Results

10.1 Scale comparison

Using the data obtained from the scale formation test for the TAC system and the data obtained from the tap water or the control system, a comparison of scale formation will be conducted. Since, there's a chance of total scale forming in the design control is significantly greater thanthat for the TAC system, the results for each water test will be normalized to the design controls to show the relative reduction in scale formation. This would be presented in a graphical format.

10.2 Hardness comparison

A graphical comparison similar to scale comparison will be conducted for the hardness of the water obtained from the two pressure cookers. This will help us prove that the scale formed on the control design is greater than what is formed on the water boiled using the TAC conditioned water. The following figure shows a theoretical graph that the team has come up with the use of the hypothesis predicted.

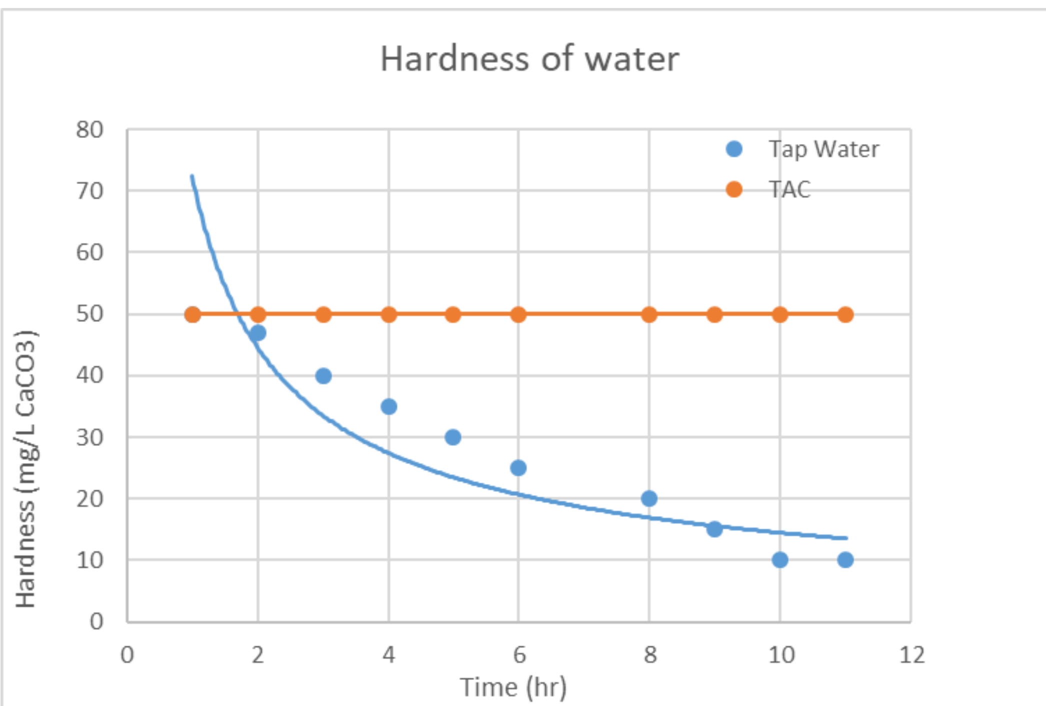

Figure 7: Theoretical comparison of hardness

11.0 Task 04: Project Management:

11.1 Meetings:

- Technical Advisor Meetings

The team has decided to meet every week with the technical advisor, Dr. Terry Baxter. This is to ensure that the team is on track and also he will be the main assistance the team has in completing all the tasks related to the research. These meeting times will be used to get feedback and discuss questions or information related to the project.

- Grading Instructor

The team will be meeting up with the grading instructor, Dr. Dianne McDonnell, every week to get feedback on the deliverables due. This time will be utilized to identify any mistakes in team deliverables and what can be done to fix those mistakes. The team will use this time to update the grading instructor on the progress of the research.

- Team Meetings

The team will hold 2 team meetings per week. This is to ensure that everybody is on track and the work is done smoothly without any bumps along the way. Attendance of each team member is compulsory, and the team members will take turns in being the leader and the note taker at each meeting.

- Client Meetings

The client meetings will be conducted once a month. This is mainly to inform or report to the client on the progress of the research and keep them updated on the tasks the team will be conducting and to get their feedback on it as well.

11.2Deliverables

- 30% Deliverable

The first draft of the research plan

- 60% Deliverable

The second draft of the research plan

- Final Report

The final research plan, which will be created using the feedback given on the first two drafts (30% and 60%)

- Web page

The webpage will include all the information related to the research.

- Final Presentation

The final presentation will include all the information related to the research.

12.0 Project Limitations

Project limitations include challenges and exclusions related to the project.

12.1 Project challenges

- Simulation of chiller/boiler conditions in the lab: if the lab is the location of the apparatus set up
- Coordination with the facilities: to make sure that they are on board with our research proposal

12.2 Project exclusions

- Not testing anything other than what is described throughout the scope, i.e. hardness, TSS, etc.
- Testing the TAC unit only on the South chiller/boiler plant

13.0 Project Scheduling

Effective project scheduling plays a crucial role in ensuring project success. Therefore to keep this project on track and to manage quality to decrease product errors, the team has set realistic time frames and assigned resources appropriately to come up with the overall project schedule.

Table 5: Overall project schedule

Task Name	Start Date	End Date
Set up apparatus	5/30/18	6/07/18
Testing (batching)	6/08/18	8/30/18
Water quality testing	6/08/18	8/30/18
Analysis of results	6/29/18	9/18/18
30% proposal	10/1/18	10/1/18
60% proposal	11/12/18	11/12/18
Webpage	11/12/18	11/12/18
Final proposal	12/12/18	12/12/18
Final presentation	12/14/18	12/14/18
Project Management	5/30/18	12/14/18
Meetings	5/30/18	12/14/18

The following table represents the major tasks and milestones for the project. The time is allocated for each task by taking into account the sub tasks under each major task. The project will start at the start of the summer and it will be finished at the end of the fall semester. The team will utilize Gantt charts thatare commonly used for tracking project schedules. For this the team showed additional information about the various tasks or phases of the project, for example howthe tasks relate to each other, how far each task has progressed, what resources are being used for each task and so on.

Task Name	Duration	Start	Finish
Setting and Running Appratus	**10 days**	**Wed 5/30/18**	**Tue 6/12/18**
Identify operating Capacity	4 days	Wed 5/30/18	Mon 6/4/18
Obtain the Unit	1 day	Mon 6/4/18	Mon 6/4/18
Install the system and optimization	6 days	Tue 6/5/18	Tue 6/12/18
Fnish Optimization	0 days	Tue 6/12/18	Tue 6/12/18
Testing (Batching)	**61 days**	**Wed 6/13/18**	**Wed 9/5/18**
Batch 1: one hour testing	10 days	Wed 6/13/18	Tue 6/26/18
Lab Analysis	**15 days**	**Wed 6/13/18**	**Tue 7/3/18**
Electron Microscope Test	15 days	Wed 6/13/18	Tue 7/3/18
Hardness Test	15 days	Wed 6/13/18	Tue 7/3/18
Scale Formation Test	15 days	Wed 6/13/18	Tue 7/3/18
Batch 2: three hours testing	20 days	Wed 6/27/18	Tue 7/24/18
Lab analysis	**30 days**	**Wed 6/27/18**	**Tue 8/7/18**
Electron Microscope Test	30 days	Wed 6/27/18	Tue 8/7/18
Hardness Test	30 days	Wed 6/27/18	Tue 8/7/18
Scale Formation Test	30 days	Wed 6/27/18	Tue 8/7/18
Batch 3: six hours tesig	31 days	Wed 7/25/18	Wed 9/5/18
Lab analysis	**30 days**	**Wed 7/25/18**	**Tue 9/4/18**
Electron Microscope Test	30 days	Wed 7/25/18	Tue 9/4/18
Hardness Test	30 days	Wed 7/25/18	Tue 9/4/18
Scale Formation Test	30 days	Wed 7/25/18	Tue 9/4/18
Complete Testing	0 days	Wed 9/5/18	Wed 9/5/18
Analysis	**58 days**	**Wed 7/4/18**	**Fri 9/21/18**
Lab data analysis Scale analysis	58 days	Wed 7/4/18	Fri 9/21/18
30% proposal	0 days	Mon 10/1/18	Mon 10/1/18
60% Proposal	0 days	Mon 11/12/18	Mon 11/12/18
Final Presentation	0 days	Wed 12/12/18	Wed 12/12/18
Final Proposal	0 days	Fri 12/14/18	Fri 12/14/18
Project Mangement	**137 days**	**Thu 6/7/18**	**Fri 12/14/18**
Group Meeting	136 days	Thu 6/7/18	Thu 12/13/18
TA Meeting	136 days	Thu 6/7/18	Thu 12/13/18
GI Meeting	136 days	Thu 6/7/18	Thu 12/13/18
Clent Meeting	137 days	Thu 6/7/18	Fri 12/14/18

Figure 8: Gantt chart-part 01

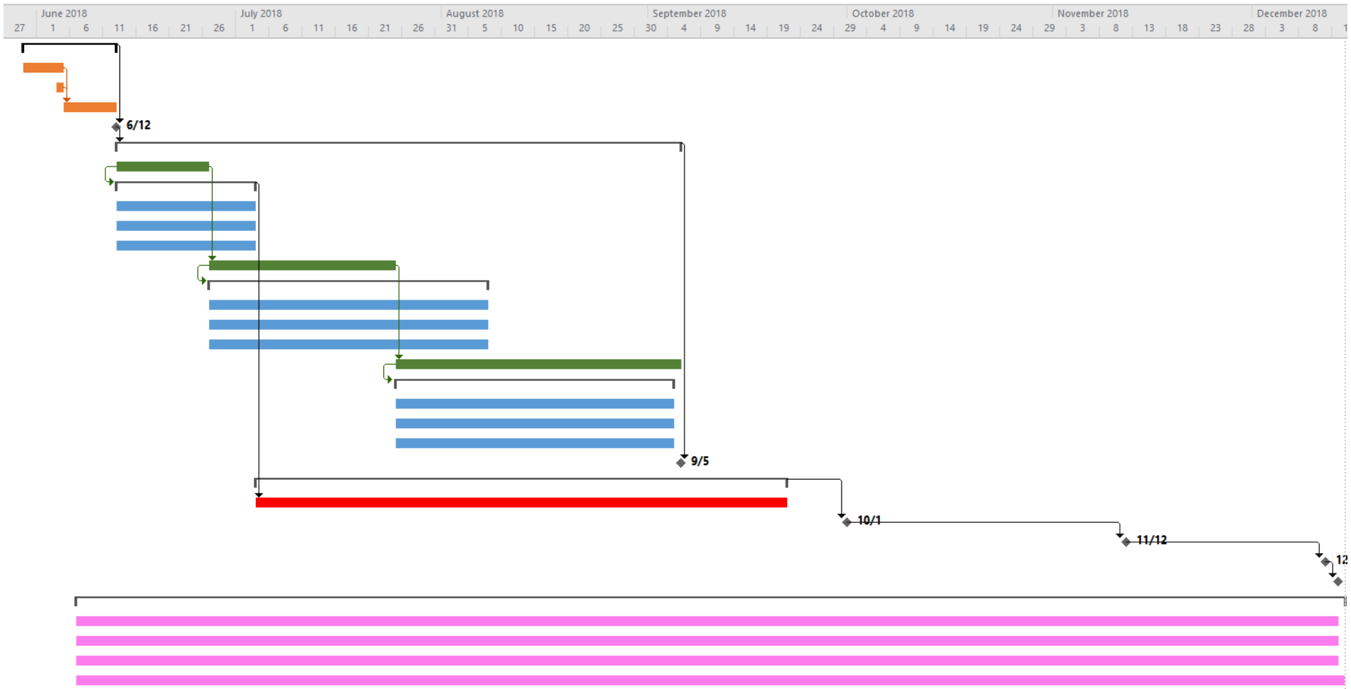

Figure 9: Gantt chart- part 02

The arrows on the chart represent the critical path for the project and the milestones are represented by the diamond. Each task is color coded for ease of use and most of the tasks are dependent on each other. The meetings and project management will be conducted throughout the project time period.

14.0 Project Staffing

The team decided to have four main personnel for this research project. The following table shows the project personnel and their hourly rates:

Table 6: Project personnel

Personnel	Code	Rate $/hr
Senior Engineer	SENG	255
Junior Engineer	JENG	175
Lab Technician	LT	103
Research Analyst	RA	135

For each personnel, the amount of hours that need to be contributed for each project task was determined.

Table 7: Staffing plan for the project

	SENG	JENG	LT	RA
Task Name	**Hours**			
Setting up the apparatus	2	8	4	5
Testing (batching)	15	80	80	30
Water quality testing	12	90	105	45
Analysis of results	6	15	5	60
30% proposal	10	10	2	2
60% proposal	10	10	2	2
Final proposal	30	20	5	5
Webpage	5	5	2	2
Final presentation	10	10	3	3
Total task hours	100	248	208	154
Total engineering hours	710			

The following table shows the staffing need for each major task. The hours are accounted for the sub tasks under each major task as well. The SENG overlooks the entire project, JENG will be conducting and available for all the tasks that need to be completed, LT will be taking over the water quality testing or lab work and the RA will be handling the analysis conducted for the research. The total engineering hours for this research project came up to be 710.

15.0 Cost Analysis

The following table represent the total material cost that the team has come up with [17]:

Table 8: Total material cost

Materials	Quantity	Unit Cost $/hr	Total Cost $
TAC unit	01	600.0	600.0
PVC pipes	03	6.95	20.85
Pressure cooker	02	1050.0	2100.0
pH meter	01	600.0	600.0
Sampling containers	12	12.5	150.0
Hose	02	10.99	21.98
Bucket 5 gal	01	6.21	6.21

Timer	01	10.67	10.67
Flow meter	01	45.0	45.0
Total materials cost			3554.71

The following table represents the total labor costs and the total engineering billing cost including the material and labor costs.

Table 9: Labor costs and the total billing cost of engineering services

Personnel	Total Hours	Rate $/hr	Multiplier	Total Cost $
SENG	100	255	2.43	61965.00
JENG	248	175	2.03	88102.00
LT	208	103	2.18	46704.32
RA	154	135	2.30	47817.00
Total labor cost				244588.32
Total engineering billing cost				248143.03

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